STATE OF FLORIDA

Precision Statements for Maximum and Bulk Specific Gravity of Plant Produced Asphalt Mixtures

Research Report
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ABSTRACT

With the Florida Department of Transportation's adoption of the Superpave mixture design system in 1997 and Contractor Quality Control (CQC) specifications in 2002, a need existed to conduct variability studies for all of the test procedures used in the mixture acceptance and payment process. This research report documents the studies conducted to determine the allowable testing variability for the determination of maximum specific gravity (G_{mm}) of plant produced asphalt mixtures and bulk specific gravity (G_{mb}) for plant produced laboratory fabricated specimens and for roadway cores. For G_{mm}, the within-lab precision is 0.013 and the between-lab precision is 0.016. With respect to G_{mb}, for laboratory fabricated specimens, the within-lab precision is 0.011 and the between-lab precision is 0.022. For roadway cores, the allowable difference between the QC and VT G_{mb} test results is 0.015 for fine graded mixtures and 0.018 for coarse graded mixtures.

INTRODUCTION

The Florida Department of Transportation, herein referred to as the Department, started using the Superpave mixture design system in 1997 and adopted Contractor Quality Control (CQC) specifications in 2002. With the implementation of both of these systems, the Department substantially changed the means in which hot-mix asphalt (HMA) is sampled and tested. Furthermore, the nature of the mixtures changed substantially from what had been used in the previously used Marshall mixture design system. With the Superpave mixture design system, less reclaimed asphalt and natural sands were used. Additionally, coarse graded mixtures were used for the first time by the Department and became common place for high traffic level roadways.

With these changes came a need to develop test method precision statements specific to the mixture types and testing procedures used by the Department. Additionally, it was desired to use plant produced HMA in order to encompass all of the sources of variability that exist when sampling and testing Department mixtures. These sources of variability include: 1) differences in an asphalt mixture within the truck bed, 2) sampling the truck, 3) splitting the mixture into sample size, 4) differences in testing equipment, and 5) variability associated with the operator.

Research report FL/DOT/SMO/01-445 documented the development of precision statements for asphalt binder content and aggregate gradation after extraction via the ignition oven. This report will document the development of the precision statements for the maximum specific gravity test (G_{mm}) and the bulk specific gravity of laboratory compacted HMA specimens and roadway cores. With the completion of these precision statements, all of the test procedures used in the CQC system for HMA acceptance and payment will utilize precision statements developed from plant produced HMA and specific to the mixture types and testing procedures used by the Department.

This report will be divided into two sections. The first section will discuss the development of the G_{mm} precision statements and the second section will discuss the development of the G_{mb} precision statements.

G_{mm} PRECISION STATEMENT

Experimental Plan

The experimental plan was established per the guidelines of ASTM E 691-92 and ASTM C 802-94. These practices establish the minimum number of laboratories, materials, replicates, etc. and provide the framework for the statistical analysis necessary to determine the within and between-laboratory precision values.

Thirteen laboratories participated in the round robin study; six FDOT district laboratories, the FDOT State Materials Office and six contractor laboratories. Six different Superpave mixtures were sampled from six different asphalt contractors at six different asphalt plants. Table 1 lists the six mixtures and their characteristics.

Table 1 – Mixtures Tested for G_{mm} Precision Study

Mixture Number	Nominal Maximum Aggregate Size	Coarse or Fine Gradation	Aggregate Types	Asphalt Binder Type
1	12.5	Fine	Georgia granite, sand, RAP	PG 64-22
2	9.5	Fine	South Florida limestone, sand, RAP	PG 64-22
3	19.0	Coarse	Nova Scotia granite, RAP	PG 64-22
4	12.5	Coarse	South Florida limestone, RAP	PG 64-22
5	12.5	Fine	Central Florida limestone, New Brunswick granite, sand, RAP	PG 64-22
6	12.5	Fine	Alabama limestone, sand, RAP	PG 64-22

Each individual mixture was sampled at the asphalt plant from the truck bed by a different technician. One Department person from the State Materials Office was present at each sampling to verify that proper Department sampling methods were adhered to and to take possession of the sample boxes. Mixtures were not sampled from either the beginning or end of a production run. Fifteen boxes were filled at each sampling. Thirteen of the boxes were then randomly distributed to the participating laboratories and two boxes were kept as spares. Instructions and worksheets were given to all of the laboratories to detail the splitting and testing procedures and for reporting the data. Participating laboratories were not given any information about the mixture type, aggregate gradation, asphalt binder content, etc.

For each mixture, four replicate samples were split out to the appropriate weight and tested for maximum specific gravity per FM 1-T 209. The laboratories were instructed to have a single operator perform all testing for a particular mixture using the same equipment, preferably on the same day. However, it was encouraged to have different mixtures tested by different operators using different equipment, if available. This practice is encouraged in ASTM E 691 to better capture the true variability of the procedure. However, most of the laboratories used only one set of G_{mm} testing equipment since that was all that was available.

The total number of samples tested was 312 (13 laboratories x 6 mixtures x 4 replicates). All of the data was sent to the SMO for analysis. The actual number of samples used in the precision calculations was slightly less than 312 due to outliers, which will be discussed in subsequent sections.

One step in the procedure for determining the G_{mm} of a mixture is to perform a “dryback” of the mixture to determine its saturated surface dry (SSD) weight. This is a critical step, especially with absorptive limestone mixtures; however, it takes approximately one hour to perform this portion of the procedure. A shortcut procedure has been developed that utilizes a dryback correction factor, which is determined by calculating the G_{mm} of the mixture in two ways: 1) using the SSD weight and 2) using the original dry weight in place of the SSD weight. The difference in these two values is the correction factor. During production, this correction factor is then added to the G_{mm} value calculated using the shortcut procedure to determine the "true" G_{mm}, as if the SSD portion of the procedure had been performed. The determination of the correction factor is described in FM 1-T 209. For this precision study, the within-lab and between-lab precision values were determined in two ways: using both the SSD method and the correction factor method of determining the G_{mm}. The SSD method will be discussed first, followed by the correction factor method.

Data Analysis

ASTM E 691 thoroughly details the layout, analysis, and interpretation of the data in order to determine the within-lab and between-lab precision values. The procedure is the same whether examining G_{mm}, % asphalt binder content, or any other test parameter. One important aspect of the procedure is the calculation of the consistency "k" and "h" statistics for the determination of data that may be deemed outliers.

The k statistic is a measure of one laboratory's within-lab variability compared to all of the laboratories combined. k values are positive numbers with the value of "1.0" representing the average within-lab variability. A k value greater than "1.0" indicates higher within-lab variability compared to all of the laboratories combined, whereas a k value less than "1.0" indicates less within-lab variability compared to all of the laboratories combined. An alternative approach to examining high within-lab variances is presented in ASTM C 802. The ratio of the largest within-lab variance for a particular mixture to the sum of the variances of all of the laboratories for that mixture is compared to a critical value.

The h statistic is an indicator of how one laboratory's test average, for a given mixture, compares with the average of all the other laboratories. h values can be either positive or negative values with zero representing a laboratory average equal to the overall multi-laboratory average. A positive h value for a particular laboratory represents a higher average than the overall average and a negative value represents a lower average than the overall average. Critical values for both k and h statistics are provided in ASTM E 691 at the 0.5% two-tailed significance level and are a function of the number of laboratories and number of replicates.

Tables 2-7 present the test data for all of the laboratories for each mixture and include the calculated statistical values needed to determine the presence of outliers. Values in bold red font exceed the critical values.

Table 2 - G_{mm} Precision; Mixture #1 Data

Largest Variance/Sum of Variances: **0.4366** Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.545	2.548	2.546	2.540	2.545	0.0037	0.00	0.000013	-1.1922	0.6525
2	2.549	2.554	2.555	2.540	2.549	0.0070	0.00	0.000049	0.0128	1.2511
3	2.546	2.548	2.547	2.544	2.546	0.0017	0.00	0.000003	-0.8606	0.2966
4	2.563	2.547	2.558	2.551	2.555	0.0072	0.01	0.000051	1.3812	1.2771
5	2.559	2.553	2.550	2.555	2.554	0.0038	0.00	0.000015	1.2078	0.6843
6	2.566	2.550	2.536	2.542	2.548	0.0134	0.00	**0.000179**	-0.2500	**2.3824**
7	2.539	2.546	2.542	2.550	2.544	0.0052	-0.01	0.000027	-1.3263	0.9211
8	2.549	2.552	2.555	2.550	2.551	0.0024	0.00	0.000006	0.5266	0.4345
9	2.542	2.550	2.547	2.539	2.545	0.0050	0.00	0.000025	-1.2407	0.8952
10	2.549	2.551	2.549	2.555	2.551	0.0030	0.00	0.000009	0.4275	0.5335
11	2.549	2.545	2.549	2.544	2.547	0.0024	0.00	0.000006	-0.6414	0.4199
12	2.547	2.553	2.550	2.556	2.552	0.0037	0.00	0.000014	0.5730	0.6588
13	2.556	2.550	2.555	2.558	2.555	0.0036	0.01	0.000013	1.3823	0.6423
				Average	2.549			0.000409		
				$s_{x\ bar}$	0.003907					

s_r = 0.005612

$(s_R)^*$ = 0.006236

s_R = 0.006236

$2.8 * s_r$ = 0.016

$2.8 * s_R$ = 0.017

Table 3 - G_{mm} Precision; Mixture #2 Data

Largest Variance/Sum of Variances: **0.4329** Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.374	2.376	2.376	2.373	2.375	0.0016	0.02	0.000003	**3.0814**	0.4173
2	2.332	2.350	2.352	2.352	2.346	0.0093	0.00	**0.000087**	-0.4607	**2.3722**
3	2.345	2.349	2.350	2.348	2.348	0.0022	0.00	0.000005	-0.2348	0.5647
4	2.345	2.345	2.353	2.354	2.349	0.0049	0.00	0.000024	-0.1029	1.2397
5	2.345	2.349	2.347	2.345	2.346	0.0018	0.00	0.000003	-0.4714	0.4558
6	2.338	2.343	2.344	2.338	2.341	0.0031	-0.01	0.000010	-1.1406	0.7910
7	2.350	2.354	2.346	2.349	2.350	0.0031	0.00	0.000010	-0.0461	0.7985
8	2.347	2.351	2.350	2.349	2.349	0.0021	0.00	0.000004	-0.1103	0.5254
9	2.344	2.345	2.342	2.345	2.344	0.0015	-0.01	0.000002	-0.7668	0.3734
10	2.352	2.353	2.345	2.346	2.349	0.0041	0.00	0.000017	-0.1189	1.0351
11	2.355	2.354	2.348	2.344	2.350	0.0050	0.00	0.000025	0.0160	1.2794
12	2.351	2.352	2.353	2.346	2.351	0.0031	0.00	0.000009	0.0675	0.7745
13	2.351	2.353	2.351	2.354	2.352	0.0015	0.00	0.000002	0.2877	0.3851
				Average	2.350			0.000202		
				$s_{x\ bar}$	0.007963					

s_r = 0.00394

$(s_R)^*$ = 0.008663

s_R = 0.008663

$2.8*s_r$ = 0.011

$2.8*s_R$ = 0.024

Table 4 - G_{mm} Precision; Mixture #3 Data

Largest Variance/Sum of Variances: **0.5753** Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.454	2.458	2.457	2.456	2.456	0.0016	0.00	0.000003	-0.2865	0.1638
2	2.455	2.456	2.453	2.455	2.455	0.0014	0.00	0.000002	-0.4122	0.1380
3	2.460	2.468	2.466	2.467	2.465	0.0040	0.01	0.000016	0.4743	0.4059
4	2.464	2.461	2.469	2.469	2.466	0.0038	0.01	0.000015	0.5210	0.3901
5	2.475	2.470	2.473	2.469	2.472	0.0029	0.01	0.000008	1.0077	0.2943
6	2.386	2.437	2.444	2.437	2.426	0.0269	-0.03	**0.000723**	**-2.7997**	**2.7349**
7	2.473	2.454	2.452	2.485	2.466	0.0155	0.01	0.000240	0.5302	1.5772
8	2.459	2.449	2.457	2.457	2.455	0.0042	0.00	0.000018	-0.3584	0.4296
9	2.457	2.471	2.465	2.478	2.468	0.0089	0.01	0.000079	0.6741	0.9060
10	2.452	2.462	2.466	2.464	2.461	0.0064	0.00	0.000041	0.0957	0.6542
11	2.475	2.474	2.457	2.468	2.469	0.0083	0.01	0.000068	0.7383	0.8416
12	2.445	2.448	2.458	2.450	2.450	0.0055	-0.01	0.000030	-0.7860	0.5587
13	2.466	2.471	2.468	2.462	2.467	0.0035	0.01	0.000013	0.6015	0.3603
				Average	2.460			0.001256		
				$s_{x\ bar}$	0.011986					

s_r = 0.00983

$(s_R)^*$ = 0.014701

s_R = 0.014701

$2.8*s_r$ = 0.028

$2.8*s_R$ = 0.041

Table 5 - G_{mm} Precision; Mixture #4 Data

Largest Variance/Sum of Variances: 0.1589 Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.376	2.376	2.372	2.373	2.374	0.0023	0.00	0.000005	0.7444	0.6619
2	2.377	2.373	2.369	2.375	2.373	0.0034	0.00	1.14E-05	0.5464	0.9736
3	2.362	2.370	2.370	2.371	2.368	0.0039	0.00	1.56E-05	-0.4127	1.1373
4	2.376	2.376	2.380	2.378	2.377	0.0022	0.01	4.98E-06	1.3671	0.6434
5	2.366	2.368	2.360	2.363	2.364	0.0034	-0.01	1.19E-05	-1.2013	0.9934
6	2.373	2.367	2.369	2.363	2.368	0.0044	0.00	1.96E-05	-0.4650	1.2768
7	2.359	2.355	2.361	2.367	2.360	0.0050	-0.01	2.49E-05	-1.9539	1.4371
8	2.373	2.371	2.374	2.372	2.373	0.0012	0.00	1.55E-06	0.4546	0.3588
9	2.374	2.380	2.369	2.372	2.374	0.0045	0.00	2.01E-05	0.6787	1.2914
10	2.373	2.367	2.365	2.362	2.367	0.0046	0.00	2.09E-05	-0.7442	1.3172
11	2.373	2.377	2.376	2.372	2.375	0.0026	0.00	6.76E-06	0.8345	0.7496
12	2.363	2.367	2.368	2.366	2.366	0.0025	0.00	6.14E-06	-0.8469	0.7142
13	2.372	2.378	2.377	2.375	2.375	0.0027	0.01	7.47E-06	0.9982	0.7881
				Average	2.370			0.00016		
				$s_{x\ bar}$	0.00516					

s_r = 0.003469

$(s_R)^*$ = 0.005971

s_R = 0.005971

$2.8 * s_r$ = 0.010

$2.8 * s_R$ = 0.017

Table 6 - G_{mm} Precision; Mixture #5 Data

Largest Variance/Sum of Variances: 0.2933 Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.344	2.349	2.347	2.351	2.348	0.0031	0.00	0.000010	0.9379	0.6913
2	2.344	2.345	2.348	2.344	2.345	0.0021	0.00	4.33E-06	0.2570	0.4637
3	2.338	2.346	2.345	2.346	2.344	0.0035	0.00	1.21E-05	-0.1736	0.7749
4	2.329	2.335	2.341	2.345	2.337	0.0071	-0.01	5.07E-05	-1.8127	1.5870
5	2.337	2.332	2.340	2.333	2.336	0.0039	-0.01	1.53E-05	-2.2704	0.8732
6	2.349	2.344	2.346	2.347	2.347	0.0023	0.00	5.22E-06	0.6324	0.5094
7	2.336	2.343	2.335	2.354	2.342	0.0088	0.00	7.67E-05	-0.5597	1.9527
8	2.344	2.351	2.343	2.348	2.347	0.0035	0.00	1.19E-05	0.6206	0.7706
9	2.341	2.344	2.344	2.349	2.345	0.0033	0.00	1.08E-05	0.1019	0.7322
10	2.343	2.347	2.345	2.347	2.346	0.0020	0.00	4.02E-06	0.3700	0.4472
11	2.349	2.342	2.353	2.342	2.347	0.0055	0.00	3.05E-05	0.5841	1.2322
12	2.344	2.347	2.349	2.344	2.346	0.0022	0.00	4.99E-06	0.3965	0.4981
13	2.345	2.344	2.355	2.347	2.348	0.0050	0.00	2.53E-05	0.9161	1.1210
				Average	2.344			0.00026		
				$s_{x\ bar}$	0.003846					

s_r = 0.004485

$(s_R)^*$ = 0.005466

s_R = 0.005466

$2.8 * s_r$ = 0.013

$2.8 * s_R$ = 0.015

Table 7 - G_{mm} Precision; Mixture #6 Data

Largest Variance/Sum of Variances: 0.1946 Critical: 0.3080

Critical h value = 2.41 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.538	2.539	2.541	2.542	2.540	0.0020	0.00	0.000004	0.4727	0.5222
2	2.547	2.543	2.544	2.541	2.544	0.0026	0.01	6.57E-06	0.9732	0.6594
3	2.531	2.537	2.530	2.538	2.534	0.0044	0.00	1.9E-05	-0.3465	1.1198
4	2.543	2.536	2.543	2.543	2.541	0.0036	0.00	1.33E-05	0.6502	0.9373
5	2.528	2.519	2.526	2.530	2.526	0.0044	-0.01	1.96E-05	-1.4196	1.1382
6	2.525	2.525	2.513	2.527	2.523	0.0062	-0.01	3.82E-05	-1.8345	1.5907
7	2.530	2.529	2.536	2.528	2.531	0.0035	-0.01	1.23E-05	-0.7832	0.9023
8	2.540	2.540	2.540	2.544	2.541	0.0022	0.00	4.74E-06	0.5875	0.5600
9	2.542	2.546	2.539	2.542	2.542	0.0026	0.01	6.53E-06	0.7341	0.6572
10	2.529	2.530	2.524	2.524	2.527	0.0030	-0.01	9.1E-06	-1.2960	0.7759
11	2.542	2.537	2.549	2.540	2.542	0.0050	0.01	2.51E-05	0.7181	1.2886
12	2.535	2.544	2.546	2.541	2.542	0.0047	0.01	2.19E-05	0.6692	1.2039
13	2.549	2.543	2.539	2.542	2.543	0.0040	0.01	1.61E-05	0.8748	1.0306
				Average	2.536			0.00020		
				$s_{x\ bar}$	0.007595					

s_r = 0.003888

$(s_R)^*$ = 0.008307

s_R = 0.008307

$2.8 * s_r$ = 0.011

$2.8 * s_R$ = 0.023

Removal of Outliers

As shown by the bold, red values in Tables 2-4, mixtures 1-3 contained outliers. Data for lab #6 was removed from the data set for mixture #1 and the statistics were recalculated (see Table 8). Data for labs #1 and 2 were removed from the data set for mixture #2 and the statistics were recalculated (see Table 9). Data for lab #6 was removed from the data set for mixture #3 and the statistics were recalculated (see Table 10). Note that after the data for lab #6 was removed from the data set for mixture #3, lab #7 was then identified as failing the k statistic. However, it is stated in ASTM E 691, that data that was not determined to be an outlier in the first round of statistical calculations should not be excluded, if that data then becomes an outlier in the second round of statistical calculations after other outlier data has been removed after the first round of statistical calculations. Therefore, the data for lab #7 remained in the calculations for mixture #3.

Table 8 - G_{mm} Precision; Recalculated Mixture #1 Data after Removal of Lab #6

Largest Variance/Sum of Variances: 0.2227 Critical: 0.3264

Critical h value = 2.38 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.545	2.548	2.546	2.540	2.545	0.0037	-0.005	0.000013	-1.1647	0.8352
2	2.549	2.554	2.555	2.540	2.549	0.0070	0.000	0.000049	-0.0078	1.6014
3	2.546	2.548	2.547	2.544	2.546	0.0017	-0.003	0.000003	-0.8463	0.3797
4	2.563	2.547	2.558	2.551	2.555	0.0072	0.005	0.000051	1.3062	1.6347
5	2.559	2.553	2.550	2.555	2.554	0.0038	0.005	0.000015	1.1396	0.8760
7	2.539	2.546	2.542	2.550	2.544	0.0052	-0.005	0.000027	-1.2934	1.1790
8	2.549	2.552	2.555	2.550	2.551	0.0024	0.002	0.000006	0.4856	0.5561
9	2.542	2.550	2.547	2.539	2.545	0.0050	-0.005	0.000025	-1.2113	1.1459
10	2.549	2.551	2.549	2.555	2.551	0.0030	0.002	0.000009	0.3905	0.6828
11	2.549	2.545	2.549	2.544	2.547	0.0024	-0.003	0.000006	-0.6358	0.5374
12	2.547	2.553	2.550	2.556	2.552	0.0037	0.002	0.000014	0.5301	0.8432
13	2.556	2.550	2.555	2.558	2.555	0.0036	0.005	0.000013	1.3072	0.8221
				Average	2.549			0.000231		
				$s_{x\ bar}$	0.00407					

$s_r =$ 0.004384

$(s_R)^* =$ 0.005566

$s_R =$ 0.005566

$2.8*s_r =$ 0.012

$2.8*s_R =$ 0.016

Table 9 - G_{mm} Precision; Recalculated Mixture #2 Data after Removal of Labs #1 and 2

Largest Variance/Sum of Variances: 0.2274 Critical: 0.3480

Critical h value = 2.34 Critical k value= 1.94

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
3	2.345	2.349	2.350	2.348	2.348	0.0022	0.000	0.000005	0.0084	0.6980
4	2.345	2.345	2.353	2.354	2.349	0.0049	0.001	0.000024	0.3313	1.5324
5	2.345	2.349	2.347	2.345	2.346	0.0018	-0.002	0.000003	-0.5708	0.5635
6	2.338	2.343	2.344	2.338	2.341	0.0031	-0.007	0.000010	-2.2091	0.9777
7	2.350	2.354	2.346	2.349	2.350	0.0031	0.002	0.000010	0.4704	0.9870
8	2.347	2.351	2.350	2.349	2.349	0.0021	0.001	0.000004	0.3131	0.6494
9	2.344	2.345	2.342	2.345	2.344	0.0015	-0.004	0.000002	-1.2939	0.4616
10	2.352	2.353	2.345	2.346	2.349	0.0041	0.001	0.000017	0.2922	1.2796
11	2.355	2.354	2.348	2.344	2.350	0.0050	0.002	0.000025	0.6223	1.5816
12	2.351	2.352	2.353	2.346	2.351	0.0031	0.002	0.000009	0.7485	0.9574
13	2.351	2.353	2.351	2.354	2.352	0.0015	0.004	0.000002	1.2876	0.4761
				Average	2.348			0.000112		
				$s_{x\ bar}$	0.003253					

$s_r =$ 0.003187

$(s_R)^* =$ 0.004266

$s_R =$ 0.004266

$2.8*s_r =$ 0.009

$2.8*s_R =$ 0.012

Table 10 - G_{mm} Precision; Recalculated Mixture #3 Data after Removal of Lab #6

Largest Variance/Sum of Variances: **0.4506** Critical: 0.3264

Critical h value = 2.38 Critical k value= 1.96

Laboratory Number	Test Results, x 1	2	3	4	Average	s	d	s^2	h	k
1	2.454	2.458	2.457	2.456	2.456	0.0016	-0.006	0.000003	-0.9204	0.2414
2	2.455	2.456	2.453	2.455	2.455	0.0014	-0.008	0.000002	-1.1431	0.2035
3	2.460	2.468	2.466	2.467	2.465	0.0040	0.003	0.000016	0.4268	0.5985
4	2.464	2.461	2.469	2.469	2.466	0.0038	0.003	0.000015	0.5094	0.5751
5	2.475	2.470	2.473	2.469	2.472	0.0029	0.009	0.000008	1.3712	0.4338
7	2.473	2.454	2.452	2.485	2.466	0.0155	0.004	0.000240	0.5256	**2.3253**
8	2.459	2.449	2.457	2.457	2.455	0.0042	-0.007	0.000018	-1.0477	0.6334
9	2.457	2.471	2.465	2.478	2.468	0.0089	0.005	0.000079	0.7805	1.3357
10	2.452	2.462	2.466	2.464	2.461	0.0064	-0.002	0.000041	-0.2436	0.9646
11	2.475	2.474	2.457	2.468	2.469	0.0083	0.006	0.000068	0.8941	1.2408
12	2.445	2.448	2.458	2.450	2.450	0.0055	-0.012	0.000030	-1.8049	0.8238
13	2.466	2.471	2.468	2.462	2.467	0.0035	0.004	0.000013	0.6519	0.5313
				Average	2.462			0.000533		
				$s_{x\ bar}$	0.006769					

s_r = 0.006667

$(s_R)^*$ = 0.008897

s_R = 0.008897

$2.8 * s_r$ = 0.019

$2.8 * s_R$ = 0.025

Determination of Precision Values

Table 11 shows the necessary variances and standard deviations for determining the precision statement. Because a final test result is reported as the average value of two tests, i.e. two flasks, the between-lab average variance value, which was calculated using single tests, is divided by √2 to obtain the between-lab average variance for test results that are reported as the average value of two tests.

Table 11 - G_{mm} Precision; Variance and Standard Deviation Summary Table for Dryback Procedure

Mixture Number	Average Gmm	Components of Variance		Variance		Standard Deviation		Coefficient of Variation	
		Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab
1	2.549	0.000019	0.000012	0.000019	0.000031	0.004384	0.005566	0.172	0.218
2	2.348	0.000010	0.000008	0.000010	0.000018	0.003187	0.004266	0.136	0.182
3	2.462	0.000044	0.000035	0.000044	0.000079	0.006667	0.008897	0.271	0.361
4	2.370	0.000012	0.000024	0.000012	0.000036	0.003469	0.005971	0.146	0.252
5	2.344	0.000020	0.000010	0.000020	0.000030	0.004485	0.005466	0.191	0.233
6	2.536	0.000015	0.000054	0.000015	0.000069	0.003888	0.008307	0.153	0.328
			Average Variances:	0.000020	0.000044				
			Avg. Variance (using avg. of 2 flasks):	n/a	3.09802E-05				
			Standard Deviations:	0.00449	0.00557				

The precision values are then calculated by multiplying the within-lab and between-lab standard deviations by $2\sqrt{2}$ to determine the acceptable range between two test results. Table 12 summarizes the standard deviations and acceptable precision values for G_{mm} using the dryback procedure. The within-lab precision is 0.013. This defines the maximum allowable difference between two samples, where a sample is considered “one flask.” The between-lab precision is 0.016. This defines the maximum allowable difference between two test results, where a test result is defined as the average G_{mm} of two samples, i.e., “two flasks.”

Table 12 - G_{mm} Precision for Dryback Procedure

Test Method	Standard Deviation (1S)		Acceptable Range of Two Test Results (D2S)	
	Within-lab	Between-lab	Within-lab	Between-lab
Gmm using dryback procedure (plant produced mix)	0.00449	0.00557	0.013	0.016

Determination of G_{mm} Precision for Non-Dryback Procedure

As mentioned previously, a shortcut procedure has been developed that utilizes a dryback correction factor, which is determined by calculating the G_{mm} of the mixture in two ways: 1) using the SSD weight and 2) using the original dry weight in place of the SSD weight. An analysis of the data used to determine the precision values using the dryback procedure was performed using the original dry weight in place of the SSD weight for each sample in the calculation of G_{mm}. This was undertaken to see how much of an effect the dryback procedure had on the variability of the test method and if a separate precision statement would be needed if this form of the test method is followed. The resultant variance and standard deviation summary is shown in Table 13 and the resultant precision values are shown in Table 14.

Table 13 - G_{mm} Precision; Variance and Standard Deviation Summary Table for Non-Dryback Procedure

Mixture Number	Average Gmm	Components of Variance		Variance		Standard Deviation		Coefficient of Variation	
		Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab
1	2.551	0.000019	0.000009	0.000019	0.000028	0.004407	0.005315	0.173	0.208
2	2.365	0.000010	0.000034	0.000010	0.000043	0.003147	0.006593	0.133	0.279
3	2.463	0.000041	0.000033	0.000041	0.000074	0.006441	0.008625	0.261	0.350
4	2.381	0.000011	0.000025	0.000011	0.000036	0.003319	0.006022	0.139	0.253
5	2.362	0.000022	0.000012	0.000022	0.000033	0.004672	0.005779	0.198	0.245
6	2.540	0.000012	0.000016	0.000012	0.000029	0.003526	0.005348	0.139	0.211
			Average Variances:	0.000019	0.000041				
			Avg. Variance (using avg. of 2 flasks):	n/a	2.88007E-05				
			Standard Deviations:	0.00440	0.00537				

Table 14 - G_{mm} Precision for Non-Dryback Procedure

Test Method	Standard Deviation (1S)		Acceptable Range of Two Test Results (D2S)	
	Within-lab	Between-lab	Within-lab	Between-lab
Gmm using non-dryback procedure (plant produced mix)	0.00440	0.00537	0.012	0.015

As shown in Table 14, the within-lab and between-lab precision values are each improved by 0.001 by not using the dryback procedure. A slight improvement was expected, however the difference is not sufficient enough to warrant a separate precision statement for the non-dryback procedure. Therefore, the precision values presented in Table 12 are the values that are to be used for the G_{mm} test when conducted with either the dryback or non-dryback approach. FM 1-T 209 has been revised to include these values.

G_{mb} PRECISION STATEMENT

As with the variability study for the G_{mm} test method, the experimental plan for the G_{mb} test method was established per the guidelines of ASTM E 691-92 and ASTM C 802-94. Separate studies and analyses were conducted for the two different sample types that utilize this test method. The first analysis is for laboratory samples compacted with the Superpave gyratory compactor and the second analysis is for roadway cores.

Experimental Plan - Laboratory Compacted Specimens

Fourteen laboratories participated in the round robin study; seven FDOT district laboratories, the FDOT State Materials Office and six contractor laboratories. Three different gyratory compactor models were used in the fourteen laboratories and represent the majority of compactor types used in Florida. Six different Superpave mixtures were sampled from four different asphalt contractors at six different asphalt plants. Table 1 lists the six mixtures and their characteristics.

Table 15 – Mixtures Tested for G_{mb} Precision Study

Mixture Number	Mix Type	Coarse or Fine Gradation	Design Gyrations	Aggregate Types	Asphalt Binder Type
1	SP-12.5	Fine	100	Georgia granite, sand, RAP	PG 76-22
2	FC-9.5	Fine	75	Southeast Florida limestone	ARB-5
3	SP-12.5	Fine	75	Southwest Florida limestone, RAP	PG 64-22
4	FC-12.5	Fine	75	Nova Scotia granite, Central Florida limestone, sand	ARB-5
5	FC-12.5	Fine	75	Georgia granite, Nova Scotia granite, sand	PG 76-22
6	SP-12.5	Coarse	100	Georgia granite, RAP	PG 76-22

Each individual mixture was sampled at the asphalt plant from the truck bed by a different technician. One Department person from the State Materials Office was present at each sampling to verify that proper Department sampling methods were adhered to and to take possession of the sample boxes. Mixtures were not sampled from either the beginning or end of a production run. Mix was sampled from three locations within the truck. A shovelful of mixture was obtained from each location and placed in a separate, well labeled box. A total of forty five boxes were filled at each sampling. A total of three boxes per mixture type were distributed to each participating laboratory. Boxes were randomly selected from each of the three sample locations in the truck bed. Instructions and worksheets were provided to all of the laboratories to detail the heating, splitting, testing, and reporting procedures. For each mixture, participating laboratories were provided with the sample weight, compaction temperature, and number of gyrations for compaction.

For each mixture, the three boxes were heated at the compaction temperature for 1.5 hours and then combined into one pile. Per the technique described in FM 1-T 168, three replicate samples were split out to the appropriate weight and conditioned in an oven for one hour at the compaction temperature. Each sample was then compacted and tested for bulk specific gravity per FM 1-T 166. The laboratories were instructed to have a single operator perform all testing for a particular mixture using the same equipment, preferably on the same day. However, it was encouraged to have different mixes tested by different operators using different equipment, if available. This practice is encouraged in ASTM E 691 to better capture the true variability of the procedure. However, most of the laboratories used only one set of G_{mb} testing equipment since that was all that was available.

The total number of samples tested was 252 (14 laboratories x 6 mixtures x 3 replicates). All of the data was sent to the SMO for analysis. The actual number of samples used in the precision calculations was slightly less than 252 due to outliers, which will be discussed in subsequent sections.

Data Analysis

As with the variability study for the G_{mm} test method, the data analysis for the G_{mb} variability study was conducted per the procedures detailed in ASTM E 691 and ASTM C 802. Tables 16-21 present the test data for all of the laboratories for each mixture and include the calculated statistical values needed to determine the presence of outliers. Values in bold red font exceed the critical values.

Table 16 - G_{mb} Precision; Mixture #1 Data

Largest Variance/Sum of Variances: 0.2958 Critical: 0.3450

Critical h values = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.494	2.495	2.500	2.496	0.0032	0.00	0.000010	0.5167	0.8421
2	2.493	2.501	2.498	2.497	0.0040	0.01	0.000016	0.6242	1.0587
3	2.488	2.492	2.484	2.488	0.0040	0.00	0.000016	-0.3786	1.0479
4	2.498	2.503	2.507	2.503	0.0045	0.01	0.000020	1.1972	1.1813
5	2.492	2.491	2.489	2.491	0.0015	0.00	0.000002	-0.0921	0.4002
6	2.504	2.506	2.505	2.505	0.0010	0.01	0.000001	1.4479	0.2620
7	2.493	2.494	2.492	2.493	0.0010	0.00	0.000001	0.1586	0.2620
8	2.478	2.491	2.479	2.483	0.0072	-0.01	0.000052	-0.9516	1.8951
9	2.493	2.492	2.494	2.493	0.0010	0.00	0.000001	0.1586	0.2620
10	2.486	2.486		2.486	0.0000	-0.01	0.000000	-0.5935	0.0000
11	2.473	2.474	2.472	2.473	0.0010	-0.02	0.000001	-1.9902	0.2620
12	2.484	2.480	2.469	2.478	0.0078	-0.01	0.000060	-1.4888	2.0348
13	2.494	2.496	2.495	2.495	0.0010	0.00	0.000001	0.3735	0.2620
14	2.500	2.506	2.497	2.501	0.0046	0.01	0.000021	1.0181	1.2005
			Average	2.492			0.000204		
			$s_{x\ bar}$	0.009307					

s_r = 0.003817

$(s_R)^*$ = 0.009815

s_R = 0.009815

$2.8*s_r$ = 0.011

$2.8*s_R$ = 0.027

Table 17 - G_{mb} Precision; Mixture #2 Data

Largest Variance/Sum of Variances: 0.2369 Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.276	2.279	2.281	2.279	0.0025	0.00	0.000006	0.4429	0.8931
2	2.275	2.282	2.282	2.280	0.0040	0.01	0.000016	0.5507	1.4342
3	2.274	2.273	2.270	2.272	0.0021	0.00	0.000004	-0.2400	0.7387
4	2.288	2.291	2.288	2.289	0.0017	0.01	0.000003	1.5571	0.6147
5	2.268	2.268	2.271	2.269	0.0017	-0.01	0.000003	-0.5995	0.6147
6	2.285	2.291	2.291	2.289	0.0035	0.01	0.000012	1.5571	1.2293
7	2.264	2.264	2.267	2.265	0.0017	-0.01	0.000003	-1.0308	0.6147
8	2.269	2.262	2.272	2.268	0.0051	-0.01	0.000026	-0.7432	1.8211
9	2.275	2.278		2.277	0.0021	0.00	0.000005	0.2092	0.7528
10	2.261	2.264	2.263	2.263	0.0015	-0.01	0.000002	-1.2824	0.5421
11	2.260	2.263	2.262	2.262	0.0015	-0.01	0.000002	-1.3902	0.5421
12	2.272	2.269	2.263	2.268	0.0046	-0.01	0.000021	-0.7073	1.6262
13	2.282	2.285	2.286	2.284	0.0021	0.01	0.000004	1.0539	0.7387
14	2.279	2.282	2.280	2.280	0.0015	0.01	0.000002	0.6226	0.5421
			Average	2.275			0.000111		
			$s_{x\ bar}$	0.009274					

s_r = 0.002818

$(s_R)^*$ = 0.009555

s_R = 0.009555

$2.8*s_r$ = 0.008

$2.8*s_R$ = 0.027

Table 18 - G_{mb} Precision; Mixture #3 Data

Largest Variance/Sum of Variances: **0.5282** Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.265	2.261	2.261	2.262	0.0023	0.00	0.000005	0.5185	0.5418
2	2.259	2.256	2.265	2.260	0.0046	0.00	0.000021	0.2482	1.0752
3	2.246	2.251	2.247	2.248	0.0026	-0.01	0.000007	-1.1418	0.6207
4	2.256	2.275	2.277	2.269	0.0116	0.01	**0.000134**	1.3294	**2.7193**
5	2.249	2.249	2.251	2.250	0.0012	-0.01	0.000001	-0.9488	0.2709
6	2.270	2.270	2.268	2.269	0.0012	0.01	0.000001	1.3294	0.2709
7	2.254	2.258	2.262	2.258	0.0040	0.00	0.000016	0.0165	0.9385
8	2.249	2.254	2.248	2.250	0.0032	-0.01	0.000010	-0.8715	0.7542
9	2.260	2.264	2.263	2.262	0.0021	0.00	0.000004	0.5185	0.4884
10	2.242	2.249	2.240	2.244	0.0047	-0.01	0.000022	-1.6438	1.1088
11	2.251	2.245	2.248	2.248	0.0030	-0.01	0.000009	-1.1418	0.7039
12	2.264	2.264	2.264	2.264	0.0000	0.01	0.000000	0.7116	0.0000
13	2.253	2.260	2.258	2.257	0.0036	0.00	0.000013	-0.0993	0.8459
14	2.271	2.268	2.265	2.268	0.0030	0.01	0.000009	1.1749	0.7039
			Average	2.258			0.000254		
			$s_{x\ bar}$	0.008633					

s_r = 0.004262

$(s_R)^*$ = 0.009308

s_R = 0.009308

$2.8*s_r$ = 0.012

$2.8*s_R$ = 0.026

Table 19 - G_{mb} Precision; Mixture #4 Data

Largest Variance/Sum of Variances: **0.4067** Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.269	2.269	2.282	2.273	0.0075	0.00	0.000056	0.0306	1.1128
2	2.295	2.294	2.296	2.295	0.0010	0.02	0.000001	1.3239	0.1483
3	2.282	2.282	2.282	2.282	0.0000	0.01	0.000000	0.5479	0.0000
4	2.266	2.269	2.270	2.268	0.0021	0.00	0.000004	-0.2679	0.3086
5	2.256	2.260	2.261	2.259	0.0026	-0.01	0.000007	-0.8251	0.3923
6	2.308	2.304	2.314	2.309	0.0050	0.04	0.000025	2.1397	0.7463
7	2.258	2.264	2.272	2.265	0.0070	-0.01	0.000049	-0.4868	1.0414
8	2.257	2.234	2.265	2.252	0.0161	-0.02	**0.000259**	-1.2429	**2.3862**
9	2.291	2.298		2.295	0.0049	0.02	0.000025	1.2941	0.7339
10	2.255	2.259	2.254	2.256	0.0026	-0.02	0.000007	-1.0041	0.3923
11	2.258	2.277	2.253	2.263	0.0127	-0.01	0.000160	-0.6062	1.8774
12	2.258	2.256	2.260	2.258	0.0020	-0.01	0.000004	-0.8847	0.2965
13	2.271	2.268	2.279	2.273	0.0057	0.00	0.000032	-0.0092	0.8431
14	2.270	2.275	2.273	2.273	0.0025	0.00	0.000006	-0.0092	0.3731
			Average	2.273			0.000637		
			$s_{x\ bar}$	0.016752					

$s_r =$ 0.006744

$(s_R)^* =$ 0.017634

$s_R =$ 0.017634

$2.8 * s_r =$ 0.019

$2.8 * s_R =$ 0.049

Table 20 - G_{mb} Precision; Mixture #5 Data

Largest Variance/Sum of Variances: 0.1723 Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.406	2.409	2.409	2.408	0.0017	0.01	0.000003	0.9925	0.5966
2	2.407	2.412	2.403	2.407	0.0045	0.01	0.000020	0.8950	1.5532
3	2.395	2.395	2.396	2.395	0.0006	-0.01	0.000000	-0.8602	0.1989
4	2.411	2.418	2.410	2.413	0.0044	0.01	0.000019	1.7238	1.5014
5	2.402	2.399	2.394	2.398	0.0040	0.00	0.000016	-0.4214	1.3921
6	2.413	2.414	2.411	2.413	0.0015	0.01	0.000002	1.6750	0.5262
7	2.394	2.395	2.396	2.395	0.0010	-0.01	0.000001	-0.9089	0.3444
8	2.400	2.393	2.397	2.397	0.0035	0.00	0.000012	-0.6651	1.2097
9	2.398	2.399	2.402	2.400	0.0021	0.00	0.000004	-0.2264	0.7170
10	2.396	2.401	2.396	2.398	0.0029	0.00	0.000008	-0.5189	0.9943
11	2.392	2.387	2.391	2.390	0.0026	-0.01	0.000007	-1.6402	0.9113
12	2.403	2.401	2.398	2.401	0.0025	0.00	0.000006	-0.0801	0.8668
13	2.396	2.398	2.403	2.399	0.0036	0.00	0.000013	-0.3239	1.2419
14	2.402	2.403	2.406	2.404	0.0021	0.00	0.000004	0.3587	0.7170
			Average	2.401			0.000118		
			$s_{x\ bar}$	0.006837					

$s_r =$ 0.002903

$(s_R)^* =$ 0.007236

$s_R =$ 0.007236

$2.8 * s_r =$ 0.008

$2.8 * s_R =$ 0.020

Table 21 - G_{mb} Precision; Mixture #6 Data

Largest Variance/Sum of Variances: 0.3333 Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.397	2.404	2.404	2.402	0.0040	0.00	0.000016	-0.0019	0.8250
2	2.410	2.415	2.408	2.411	0.0036	0.01	0.000013	0.7328	0.7360
3	2.394	2.402	2.396	2.397	0.0042	0.00	0.000017	-0.3430	0.8498
4	2.420	2.428	2.420	2.423	0.0046	0.02	0.000021	1.6511	0.9428
5	2.393	2.400	2.399	2.397	0.0038	0.00	0.000014	-0.3430	0.7728
6	2.411	2.419	2.422	2.417	0.0057	0.02	0.000032	1.2313	1.1607
7	2.403	2.397	2.396	2.399	0.0038	0.00	0.000014	-0.2380	0.7728
8	2.387	2.396	2.381	2.388	0.0075	-0.01	0.000057	-1.0776	1.5411
9	2.399	2.408	2.403	2.403	0.0045	0.00	0.000020	0.1293	0.9204
10	2.390	2.388	2.388	2.389	0.0012	-0.01	0.000001	-1.0251	0.2357
11	2.390	2.387	2.392	2.390	0.0025	-0.01	0.000006	-0.9464	0.5137
12	2.392	2.372	2.376	2.380	0.0106	-0.02	**0.000112**	-1.7073	**2.1602**
13	2.413	2.416	2.416	2.415	0.0017	0.01	0.000003	1.0476	0.3536
14	2.416	2.411	2.412	2.413	0.0026	0.01	0.000007	0.8902	0.5401
			Average	2.402			0.000336		
			$s_{x\ bar}$	0.012705					

$s_r =$ 0.004899

$(s_R)^* =$ 0.01332

$s_R =$ 0.01332

$2.8 * s_r =$ 0.014

$2.8 * s_R =$ 0.037

Removal of Outliers

As shown by the bold, red values in Tables 18, 19, and 21, mixtures 3, 4, and 6 contained outliers. Data for lab #4 was removed from the data set for mixture #3 and the statistics were recalculated (see Table 22). Data for lab #8 was removed from the data set for mixture #4 and the statistics were recalculated (see Table 23). Data for lab #12 was removed from the data set for mixture #6 and the statistics were recalculated (see Table 24). Note that after the data for lab #8 was removed from the data set for mixture #4, lab #11 was then identified as failing the k statistic. However, it is stated in ASTM E 691, that data that was not determined to be an outlier in the first round of statistical calculations should not be excluded, if that data then becomes an outlier in the second round of statistical calculations after other outlier data has been removed after the first round of statistical calculations. Therefore, the data for lab #11 remained in the calculations for mixture #4.

Table 22 - G_{mb} Precision; Recalculated Mixture #3 Data after Removal of Lab #4

Largest Variance/Sum of Variances: 0.1861 Critical: 0.3630

Critical h value = 2.41 Critical k value= 2.15

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.265	2.261	2.261	2.262	0.0023	0.01	0.000005	0.6455	0.7601
2	2.259	2.256	2.265	2.260	0.0046	0.00	0.000021	0.3645	1.5083
3	2.246	2.251	2.247	2.248	0.0026	-0.01	0.000007	-1.0810	0.8708
5	2.249	2.249	2.251	2.250	0.0012	-0.01	0.000001	-0.8803	0.3801
6	2.270	2.270	2.268	2.269	0.0012	0.01	0.000001	1.4888	0.3801
7	2.254	2.258	2.262	2.258	0.0040	0.00	0.000016	0.1235	1.3166
8	2.249	2.254	2.248	2.250	0.0032	-0.01	0.000010	-0.8000	1.0580
9	2.260	2.264	2.263	2.262	0.0021	0.01	0.000004	0.6455	0.6852
10	2.242	2.249	2.240	2.244	0.0047	-0.01	0.000022	-1.6030	1.5555
11	2.251	2.245	2.248	2.248	0.0030	-0.01	0.000009	-1.0810	0.9874
12	2.264	2.264	2.264	2.264	0.0000	0.01	0.000000	0.8463	0.0000
13	2.253	2.260	2.258	2.257	0.0036	0.00	0.000013	0.0031	1.1867
14	2.271	2.268	2.265	2.268	0.0030	0.01	0.000009	1.3281	0.9874
			Average	2.257			0.000120		
			$s_{x\ bar}$	0.008302					

s_r = 0.003038

$(s_R)^*$ = 0.008664

s_R = 0.008664

$2.8 * s_r$ = 0.009

$2.8 * s_R$ = 0.024

Table 23 - G_{mb} Precision; Recalculated Mixture #4 Data after Removal of Lab #8

Largest Variance/Sum of Variances: **0.4243** Critical: 0.3630

Critical h value = 2.41 Critical k value= 2.15

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.269	2.269	2.282	2.273	0.0075	0.00	0.000056	-0.0669	1.3922
2	2.295	2.294	2.296	2.295	0.0010	0.02	0.000001	1.2638	0.1855
3	2.282	2.282	2.282	2.282	0.0000	0.01	0.000000	0.4653	0.0000
4	2.266	2.269	2.270	2.268	0.0021	-0.01	0.000004	-0.3740	0.3861
5	2.256	2.260	2.261	2.259	0.0026	-0.02	0.000007	-0.9472	0.4908
6	2.308	2.304	2.314	2.309	0.0050	0.03	0.000025	2.1031	0.9336
7	2.258	2.264	2.272	2.265	0.0070	-0.01	0.000049	-0.5992	1.3028
9	2.291	2.298		2.295	0.0049	0.02	0.000025	1.2331	0.9181
10	2.255	2.259	2.254	2.256	0.0026	-0.02	0.000007	-1.1315	0.4908
11	2.258	2.277	2.253	2.263	0.0127	-0.01	0.000160	-0.7220	**2.3487**
12	2.258	2.256	2.260	2.258	0.0020	-0.02	0.000004	-1.0086	0.3710
13	2.271	2.268	2.279	2.273	0.0057	0.00	0.000032	-0.1079	1.0547
14	2.270	2.275	2.273	2.273	0.0025	0.00	0.000006	-0.1079	0.4668
			Average	2.274			0.000378		
			$s_{x\ bar}$	0.016282					

s_r = 0.005391

$(s_R)^*$ = 0.016867

s_R = 0.016867

$2.8 * s_r$ = 0.015

$2.8 * s_R$ = 0.047

Table 24 - G_{mb} Precision; Recalculated Mixture #6 Data after Removal of Lab #12

Largest Variance/Sum of Variances: 0.2545 Critical: 0.3450

Critical h value = 2.44 Critical k value= 2.16

Laboratory Number	Test Results, x 1	2	3	Average	s	d	s^2	h	k
1	2.397	2.404	2.404	2.402	0.0040	0.00	0.000016	-0.1469	0.9736
2	2.410	2.415	2.408	2.411	0.0036	0.01	0.000013	0.6635	0.8686
3	2.394	2.402	2.396	2.397	0.0042	-0.01	0.000017	-0.5232	1.0030
4	2.420	2.428	2.420	2.423	0.0046	0.02	0.000021	1.6765	1.1127
5	2.393	2.400	2.399	2.397	0.0038	-0.01	0.000014	-0.5232	0.9121
6	2.411	2.419	2.422	2.417	0.0057	0.01	0.000032	1.2134	1.3698
7	2.403	2.397	2.396	2.399	0.0038	0.00	0.000014	-0.4074	0.9121
8	2.387	2.396	2.381	2.388	0.0075	-0.02	0.000057	-1.3336	1.8188
9	2.399	2.408	2.403	2.403	0.0045	0.00	0.000020	-0.0022	1.0863
10	2.390	2.388	2.388	2.389	0.0012	-0.01	0.000001	-1.2757	0.2782
11	2.390	2.387	2.392	2.390	0.0025	-0.01	0.000006	-1.1889	0.6063
13	2.413	2.416	2.416	2.415	0.0017	0.01	0.000003	1.0108	0.4173
14	2.416	2.411	2.412	2.413	0.0026	0.01	0.000007	0.8371	0.6374
			Average	2.403			0.000224		
			$s_{x\ bar}$	0.011517					

$s_r =$ 0.004151

$(s_R)^* =$ 0.012005

$s_R =$ 0.012005

$2.8*s_r =$ 0.012

$2.8*s_R =$ 0.034

Determination of Precision Values

Table 25 shows the necessary variances and standard deviations for determining the precision statement.

Table 25 - G_{mb} Precision; Variance and Standard Deviation Summary Table for Laboratory Compacted Specimens

Mixture Number	Average Gmb	Components of Variance		Variance		Standard Deviation		Coefficient of Variation	
		Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab	Within-Lab	Between-Lab
1	2.492	0.000015	0.000082	0.000015	0.000096	0.003817	0.009815	0.153	0.394
2	2.275	0.000008	0.000083	0.000008	0.000091	0.002818	0.009555	0.124	0.420
3	2.257	0.000009	0.000066	0.000009	0.000075	0.003038	0.008664	0.135	0.384
4	2.274	0.000029	0.000255	0.000029	0.000284	0.005391	0.016867	0.237	0.742
5	2.401	0.000008	0.000044	0.000008	0.000052	0.002903	0.007236	0.121	0.301
6	2.403	0.000017	0.000127	0.000017	0.000144	0.004151	0.012005	0.173	0.500
			Average Variances:	0.000014	0.000124				
			Average Standard Deviations:	0.00380	0.01113				
			Precision:	0.011	0.031				
			For averages of two samples:	n/a	0.022				

The precision values are then calculated by multiplying the within-lab and between-lab standard deviations by $2\sqrt{2}$ to determine the acceptable range between two test results. Department specifications require that G_{mb} values for two laboratory compacted specimens be averaged and reported as one test result when comparing values obtained between two laboratories. Therefore, the precision value for between-lab single specimens must be divided by $\sqrt{2}$ to obtain the between-lab precision for test results that are reported as the average value of two specimens. This is in accordance with ASTM C 670. Table 26 summarizes the standard deviations and acceptable precision values for G_{mb}. The within-lab precision is 0.011. This defines the maximum allowable difference between two specimens. The between-lab precision is 0.022. This defines the maximum allowable difference between two test results, where a test result is defined as the average G_{mb} of two specimens.

Table 26 - G_{mb} Precision for Laboratory Compacted Specimens

Test Method	Standard Deviation (1S)		Acceptable Range of Two Test Results (D2S)	
	Within-lab	Between-lab	Within-lab	Between-lab
Gmb (laboratory compacted specimens using plant produced mix)	0.00380	0.01113	0.011	0.022

Experimental Plan - Roadway Cores

The Department's specifications require that roadway cores be obtained on a stratified random basis at a frequency of five cores per sublot, where a sublot is typically defined as 1000 tons of asphalt mixture. One core is randomly located and obtained within every 200 tons of mixture, as placed on the roadway. The Quality Control (QC) technician then tests these five cores to determine the average G_{mb} for that sublot. This process occurs for each of the four sublots that comprise a LOT of asphalt mixture. The Department's Verification Technician (VT) then randomly selects one of the four sublots and tests the same cores that the QC technician tested for that sublot. In this entire process, the QC technician does not test the same core more than one time nor does the QC technician test multiple cores from the same location. Furthermore, the VT technician does not test an independent core, but instead tests the same core as the QC technician. The Department specifies a maximum allowable tolerance between the QC and VT test results. Historically, this value has been 0.022, which is the same as that for the between-lab tolerance for laboratory compacted specimens. Due to the nature of the Department's system for measuring roadway density, it is difficult to conduct a variability study in the conventional method outlined per the guidelines of ASTM E 691 and ASTM C 802. Within the Department's system, there is no within-lab or between-lab tolerance in the conventional sense. Therefore, it was determined that the best method to define an allowable tolerance between QC and VT test results was to analyze significant historical data and determine the 95% confidence interval for the difference between QC and VT tests. From this information, a suitable tolerance could be developed. Furthermore, the data for fine graded and coarse graded mixtures would be analyzed separately to see if a difference existed between the mixture types.

Data for coarse and fine graded mixtures was obtained from the Department's Laboratory Information Management System (LIMS) database. G_{mb} results, as well as the individual weights needed to calculate the G_{mb} results, were obtained. Data was obtained for the QC and corresponding VT test results for the same core. A total of 979 pairs of data were obtained for fine graded mixtures and 235 pairs of data for coarse graded mixtures. The 95% confidence intervals are shown in Table 27.

Table 27 - 95% Confidence Intervals for G_{mb} of Fine and Coarse Graded Roadway Cores

	QC Gmb - VT Gmb	
	Fine Graded Mixtures	Coarse Graded Mixtures
95% Confidence Interval	-0.009 to 0.015	-0.008 to 0.018

Note that for each mixture type, the interval is not symmetric about zero, but instead greater on the positive side of zero. Since the VT G_{mb} result was subtracted from the QC G_{mb} result for all of the data pairs, this indicates that the QC G_{mb} result was greater than the VT G_{mb} result on average.

The calculation for G_{mb} is as follows:

$$G_{mb} = A / (B-C)$$

Where: A = dry weight
B = saturated surface dry (SSD) weight
C = weight submerged in water

In addition to the G_{mb} test results, the three individual weights that comprise each G_{mb} value were also obtained from LIMS (see Table 28).

Table 28 - Average Difference Values for QC and VT Weights Used in G_{mb} Calculation for Roadway Cores

Mixture Type	QC Gmb - VT Gmb		
	Dry Weight	SSD Weight	Weight Submerged in Water
Fine Graded Mixtures	0.9	1.3	1.7
Coarse Graded Mixtures	2.8	1.8	2.3

Further examination into these three individual weights indicates that the dry weight was higher on average for the QC result than the VT result and is the main factor in the higher QC G_{mb} test results. The SSD weight and the weight submerged in water also show differences but a large majority of the difference is cancelled out since the weight submerged in water is subtracted from the SSD weight. However, note that the difference for the weight submerged in water is slightly larger than the difference for the SSD weight. This results in a smaller calculated volume of the sample for the QC result, hence contributes partially to a higher QC G_{mb} value.

The desired form of the precision statement is to have one allowable difference value when subtracting the QC and VT results. It is not desirable to have an asymmetrical range. For fine graded mixtures, the range of the 95% confidence interval is: [0.015 - (-0.009) = 0.024]. The allowable difference would be one half the range; i.e. 0.024 / 2 = 0.012. However, due to the asymmetry of the confidence interval, legitimate differences > 0.012 or ≤ 0.015 would be excluded. Therefore, it was decided to be conservative and use a precision value of ± 0.015 for fine graded mixtures. For the same reasons, the precision value for coarse graded mixtures was set at ±0.018. Note that in both situations, these values are less than the 0.022 value that has been used historically. See Table 29 for a summary of the precision values for G_{mb} of roadway cores.

Table 29 - Precision Values for G_{mb} of Roadway Cores

Mixture Type	Multi-laboratory Precision
	Acceptable Range of Two Test Results
Fine Graded Mixtures	0.015
Coarse Graded Mixtures	0.018

In an effort to address the differences in dry weight values between QC and VT test results, the test procedure (FM 1-T 166) has been modified to standardize the order that the three weights (dry, submerged in water, and SSD) are obtained. It was determined that QC and VT technicians do not typically perform the steps in the same sequence. QC technicians typically perform the dry weight as the final step after drying the wet core in front of a fan for a short time. VT technicians typically measure the dry weight first after the core has been stored for multiple days or weeks. It is believed that this is the cause of the difference in dry weights, i.e. the QC dry weight is greater on average than the VT dry weight. The order of steps has been standardized as follows: 1. weight submerged in water, 2. saturated surface dry weight, and 3. dry weight. It is likely that implementation of this change will result in improved precision of this test method. At a future date, another analysis will be conducted to determine if the precision value should be modified.

CONCLUSIONS

With the Department's adoption of the Superpave mixture design system in 1997 and Contractor Quality Control (CQC) specifications in 2002, a need existed to develop test method precision statements specific to the mixture types and testing procedures used in the mixture acceptance and payment process. This research report documents the studies conducted to determine the allowable testing variability for the determination of maximum specific gravity (G_{mm}) of plant produced asphalt mixtures and bulk specific gravity (G_{mb}) for plant produced laboratory fabricated specimens and for roadway cores. It was necessary to use plant produced asphalt mixtures in order to encompass all of the sources of variability that exist when sampling and testing mixtures. These sources of variability include: 1) differences in an asphalt mixture within the truck bed, 2) sampling the truck, 3) splitting the mixture into sample size, 4) differences in testing equipment, and 5) variability associated with the operator. The experimental plans were established per the guidelines of ASTM E 691 and ASTM C 802.

For G_{mm}, the within-lab precision is 0.013 and the between-lab precision is 0.016. With respect to G_{mb}, for laboratory fabricated specimens, the within-lab precision is 0.011 and the between-lab precision is 0.022. For roadway cores, the allowable difference between the QC and VT test results is 0.015 for fine graded mixtures and 0.018 for coarse graded mixtures.

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