Final Report
930-389

COLLECTION AND ANALYSIS OF QC/QA DATA FOR SUPERPAVE MIXES

Sponsored by

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JULY 2001

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EXECUTIVE SUMMARY

Asphalt content, voids and mat density QC/QA data were collected for selected Marshall and Superpave mixes during 1997 to determine if accuracy and variability of the measured properties were similar or different for the two types of mixes. Analyses indicated accuracy and variability of asphalt content measurements for Marshall and Superpave mixes were comparable. Analyses also indicated accuracy and variability of voids and mat density measurements were not comparable. However, no changes to pay adjustment criteria were recommended for Superpave mix voids or mat density.

Additional data for Superpave mixes were collected during 1998, 1999, and 2000 to determine if accuracy and variability would improve and stabilize as contractors accumulated experience with Superpave mixes. Analyses indicated accuracy and variability of asphalt content measurements for Superpave mixes remained consistent and comparable to Marshall mixes. Variability of voids for Superpave mixes stabilized but remained higher than variability of voids for Marshall mixes. The accuracy in achieving target voids for Superpave mixes deteriorated and stabilized at values poorer than achieved for Marshall mixes. Variability of mat density measurements for Superpave mixes decreased and stabilized at values comparable to Marshall mixes. The accuracy of mat density measurements for Superpave mixes improved but stabilized at values poorer than achieved for Marshall Mixes.

Since pay adjustment criteria are set based on historical variability measures, no changes (from criteria based on Marshall mixes) are recommended for asphalt content and mat density. Pay adjustment criteria for voids of Superpave mixes should be based on a standard deviation of 0.9%. This is larger than the approximately 0.6% standard deviation for Marshall mixes and reflects the larger variability associated with the gyrator compactor compared to the Marshall hammer. No consideration for maximum aggregate size or design ESAL range is recommended when setting pay adjustment criteria for Superpave mixes.

Accuracy of mix property measurements are not considered when setting limits for pay adjustment criteria. The assumption is made that there is no bias in measurements and, "on average", target values are achieved. Historical data for Marshall mixes validated this assumption for asphalt content and voids, but indicated mat density measurements were consistently about 0.5% lower than the 94% TMD target. Analysis of data for Superpave mixes indicate that, "on average", target asphalt contents are achieved, but voids and mat density measurements are consistently lower than target. From a construction QC/QA perspective, lack of accuracy should be controlled by reduced pay, if pay adjustment limits are reasonably set. However, this seems not to be the case for ALDOT specifications, since bonus payments are the norm for Superpave, as well as Marshall mixes.

The consistently low voids content (approximately 3.6%) and mat density (approximately 93.2% TMD) measurements are of greater concern, from a pavement performance perspective, than the high bonus payments from a construction QC/QA perspective. Numerous factors, many of which are non technical, are considered when setting criteria for determining pay adjustments. The value of pay adjustments achieved are not important as long as the desired level of construction quality control is achieved. However, low voids and mat density achieved during construction may eventually adversely affect the performance of pavements constructed with Superpave mixes.

INTRODUCTION

The Alabama Department of Transportation (ALDOT) implemented a statistically based quality control/quality assurance (QC/QA) procedure for managing hot mix asphalt (HMA) construction in 1992. The three HMA properties selected for quality assurance were asphalt content, voids of laboratory compacted samples and mat density as a percentage of theoretical maximum density (TMD). Limits for pay adjustments were set based on historical data collected during construction of HMA designed and controlled with Marshall procedures. These historical data, and verification data collected during the 1993 construction season, are summarized in Table 1. The data illustrate improvement and stabilization of the variability of asphalt content, voids and mat density. The data also indicate that after implementation of the QC/QA specification in 1992, target values for asphalt content and voids were consistently achieved. A final observation from Table 1 is the consistent inability to achieve target 94% TMD mat compaction. The average deviations from target in1992 and 1993 indicate only about 93.4% TMD is reasonably achieved.

Table 1. Summary of Historical Marshall Mix Statistics

Year	Projects	Standard Deviation of Mesaurements			Average Deviation from Target ($\Delta = X - X_T$)		
		AC (%)	Voids (%)	Mat Density (%TMD)	AC (%)	Voids (%)	Mat Density (%TMD)
1990	4	0.43	1.05	1.69	0.14	0.19	-1.09
1991	11	0.22	0.60	1.91*	0.01	0.13	-1.14*
1992	113	0.20	0.65	1.45	-0.03	0.04	-0.65
1993	107	0.18	0.60	1.19	-0.01	0.00	-0.56

*3 of 11 projects had extremely high variability.

ALDOT began implementation of Superpave procedures for design and control of HMA construction in 1997. There are two differences in Marshall and Superpave procedures that may result in differences in the variability and accuracy of asphalt content, voids and mat density measurements. The differences are the use of gyratory rather than impact hammers for sample compaction and the introduction of multiple compaction energy levels, based on traffic, for laboratory sample preparation. Marshall designs are based on either 50 or 75 blow compaction levels, whereas, Superpave designs are based on six compaction levels (ESAL ranges A-F), controlled by the number of gyrations for sample preparation. As a result, limits for pay adjustments in QC/QA specifications, based on historical Marshall data, may not be applicable for controlling construction of Superpave mixes.

There are some indications, evidence presented later, that asphalt contents for Superpave mixes, particularly for high ESAL ranges, are lower than asphalt contents for comparable

Marshall mixes. The obvious reason is increased Superpave compaction energy. However, there are no reasons the variability and accuracy of asphalt contents of Marshall and Superpave mixes should be different. The mix production process, as well as sampling and testing procedures, are the same.

There are reasons for differences in measured air voids of construction control specimens compacted with Marshall and Superpave procedures. These reasons include the following:

1. Sample size,
2. Compactor to compactor consistency, and
3. Location of compactor and reheating of mix.

Compacted Marshall samples are 4 in. diameter and Superpave samples are 6 in. diameter. Therefore, considerably more mix is tested with Superpave samples. There are no reasons to think that sample size will cause differences in the accuracy of measured voids, but variability may be affected.

Marshall compaction hammers are rather simple devices and the several available brands operate the same. Superpave gyratory compactors are more complicated devices and available brands have different operating procedures for controlling applied pressure and gyration angle. There seems a significant potential for small differences in gyratory compactor performance to influence accuracy and variability of voids measured on compacted samples.

Initially, gyratory compactors were not available at asphalt plants for use by both contractors and ALDOT. This required, in some situations, that mix be transported to ALDOT division laboratories for compaction. The additional handling and required reheating has the potential to influence accuracy and precision of measured voids.

Sampling and/or testing for mat density is the same for Marshall and Superpave mixes. However, differences in accuracy (achieving target density) and variability may result because asphalt contents are different; which influences compactability. Asphalt contents for Superpave mixes are generally lower than Marshall mixes and, thus, achieving target density may be more difficult for Superpave mixes. In addition, because there are six compaction energy levels, a wider range of asphalt contents are likely in the Superpave system. This could lead to more variability in mat density.

During the first two years (1997 and 1998) Superpave procedures were implemented for design and control of HMA construction, no pay adjustments were applied. Beginning in 1999, procedures were added to specifications for adjusting pay based on measured asphalt content, voids and mat density. For the 1999 construction season, pay adjustments to bid prices were applied at one half the computed rate. For the 2000 construction season computed pay adjustments were fully applied. It is postulated that the application of pay adjustments, combined with increased experience with Superpave procedures and mixes, may influence the accuracy and variability of asphalt content, voids and mat density.

OBJECTIVES

Accuracy and variability of asphalt content, voids and mat density measurements for HMA designed and controlled with Superpave procedures may be different from HMA designed and controlled with Marshall procedures. Initial objectives of this study were to:

- Collect asphalt content, voids and mat density during production and placement of Marshall and Superpave mixes,
- Compare variability and accuracy in achieving target values for Marshall and Superpave mixes, and
- Recommend modifications to criteria for determining pay adjustments for Superpave mixes, as appropriate.

Based on analyses of initial data, the project was extended and additional data for Superpave mixes collected and analyzed. Additional objectives of this study were to:

- Determine if accuracy and variability of asphalt content, voids and mat density measurements improved and stabilized as contractors accumulated experience with Superpave mixes and as pay adjustments were applied, and
- Recommend modifications to criteria for determining pay adjustments for Superpave mixes, as appropriate.

SCOPE

To accomplish initial project objectives, QC/QA data for HMA was collected during the 1997 and 1998 construction seasons. During 1997, data was collected from 9 projects with Marshall mix and 9 projects with Superpave mix. One comparable sized project with each mix type of was selected in each ALDOT division. During 1998, data was collected from 20 projects with Superpave mix. At least one project was located in each division, except Division 5. Seventeen of the projects were on state routes and three projects were on the interstate system. An interim report, based on analyses of 1997 and 1998 data and dated June 1999, was prepared to address initial objectives. To accomplish additional objectives, QC/QA data was collected from 27 projects in 1999 and 30 projects in 2000 with Superpave mix.

DATA SYNTHESIS AND ANALYSIS

SYNTHESIS

Data were provided by ALDOT division personnel in various formats. These data were synthesized into databases for statistical analysis. Data for 1997 Marshall mixes and for 1997, 1998, 1999, and 2000 Superpave mixes were compiled. Because of the large database sizes, hard copies are not provided with this report. Digital/electronic copies are available and will be provided upon request.

Table 2 is an example of the data with some synthesis which illustrates format. Column 1, except for the last row, lists the counties in which projects were located. Column 2 contains design ESAL ranges and column 3 lists maximum aggregate size. Columns 4-8 contain, respectively, number of measurements, means, standard deviations, minimum and maximum measurements. For example, the data in row 2 is for mix from a project in Baldwin county with 25 mm size maximum aggregate that was designed for ESAL range D. The last row contains statistics for combined data for all mixes.

Table 3 is an example of data required only for asphalt content. Since job mix formula for asphalt contents are variable, means of differences between target and measured asphalt contents provide a more meaningful measure of accuracy than means of asphalt content. In addition, the standard deviations of combined data are different and the standard deviation of differences between target and measured values provides the more meaningful measure of variability. Standard deviations for voids and mat density are consistent, since target values are constant, i.e., 4% for voids and 94% TMD for mat density.

ANALYSIS

Comparison of Marshall and Initial (1997-98) Superpave Mix Data. Summary statistics for asphalt content, voids and mat density are listed in Tables 4-6, respectively. Summary statistics for Marshall mix data collected in 1990 through 1993 are also listed for comparison. Analysis of standard deviations and means of differences between measured and target values reveal the following relative to Marshall and Superpave mixes:

1. Variability and accuracy of asphalt content and voids measurements for 1997 Marshall projects are comparable to variability and accuracy of similar measurements for 1992 and 1993 Marshall projects. The variability of 1997 asphalt contents is somewhat higher but, from an engineering perspective, the difference is not considered significant.

2. Variability and accuracy of mat density measurements for 1997 Marshall projects are somewhat better than variability and accuracy of similar measurements for 1992 and 1993 Marshall projects.

3. Variability and accuracy of asphalt content measurements for 1997/1998 Superpave projects and 1997 Marshall projects are comparable.

4. Variability and accuracy of voids measurements for 1997/1998 Superpave projects are not as good as variability and accuracy of 1997 Marshall projects.

5. Variability and accuracy of mat density measurements for 1997/1998 Superpave projects are not as good as variability and accuracy of 1997 Marshall projects.

Based on the above comparisons the following were initially concluded relative to criteria for determining pay adjustments:

1. There have been no significant changes in variability and accuracy of asphalt content, voids and mat density for Marshall mixes and no changes to criteria for pay adjustments are needed.

2. The continued inability to consistently achieve target 94% TMD mat compaction for Marshall mixes means that pay reductions, based on mat density, will be greater than pay reductions for asphalt content and voids.

3. No changes to criteria for asphalt content pay factors are warranted for Superpave mixes.

4. The increased variability of voids and mat density for Superpave mixes are sufficient to warrant changes in pay adjustment criteria.

5. The inability to achieve target 94% TMD compaction for Superpave mixes and the relatively large mean deviation $(\overline{\Delta} = -0.24\%)$ from target 4% voids for 1998 Superpave projects indicates a fundamental deficiency that should not and cannot be addressed with pay adjustment criteria.

One of the possible reasons why variability and accuracy of voids and mat density measurements for Superpave mixes are different from Marshall mixes is decreased asphalt content for Superpave mixes. Compaction energy levels for preparing specimens to select asphalt contents is known to be greater for Superpave than Marshall procedures. Table 7 confirms that asphalt contents for Superpave mixes are lower than asphalt contents for comparable Marshall mixes. The difference of about 0.4% will likely make it more difficult to achieve target mat density for Superpave mixes, but should not influence variability or accuracy of voids measurements, or variability of mat density measurements.

Table 2. Asphalt Content (Contractor Data)

COUNTY	ESAL Range	Maximum Aggregate Size, mm	No. of Measurements	Mean	Standard Deviation	Minimum	Maximum
BALDWIN	D	12.5	25	4.91	0.42	3.17	5.75
		25.0	34	4.07	0.20	5.38	6.30
BLOUNT	E	12.5	24	5.77	0.23	5.38	6.30
		37.5	233	4.37	0.23	3.56	5.04
HOUSTON	E	19.0	17	4.40	0.14	4.24	4.90
		25.0	20	4.00	0.18	3.67	4.28
MADISON	D	12.5	14	5.44	0.18	5.22	5.80
		25.0	18	4.30	0.15	3.98	4.57
MONTGOMERY	D	19.0	20	5.31	0.21	4.60	5.63
		25.0	19	3.87	0.18	3.60	4.23
SUMTER	D	19.0	12	5.52	0.14	5.28	5.86
		25.0	18	4.47	0.17	4.17	4.73
TALLADEGA	D	12.5	22	5.72	0.12	5.49	5.92
		25.0	48	4.14	0.20	3.74	4.54
TUSCALOOSA	C	12.0	16	6.06	0.23	5.76	6.43
		25.0	30	4.91	0.17	4.53	5.16
WALKER	E	19.0	8	4.60	0.20	4.38	4.96
		25.0	23	4.08	0.25	3.51	4.47
		37.5	4	4.11	0.14	3.96	4.30
ALL	-	-	605	4.58	0.60	3.17	6.43

Table 3. Arithmetic Deviation from Target Asphalt Content (Contractor Data)

COUNTY	ESAL Range	Maximum Aggregate Size, mm	No. of Measurements	Mean	Standard Deviation	Minimum	Maximum
BALDWIN	D	12.5	25	-0.09	0.42	-1.83	0.75
		25.0	34	-0.08	0.20	-0.49	0.55
BLOUNT	E	12.5	24	-0.03	0.23	-0.42	0.50
		37.5	233	-0.03	0.23	-0.84	0.64
HOUSTON	E	19.0	17	-0.40	0.14	-0.56	0.10
		25.0	20	-0.15	0.18	-0.48	0.13
MADISON	D	12.5	14	-0.11	0.18	-0.33	0.25
		25.0	18	-0.20	0.15	-0.52	0.07
MONTGOMERY	D	19.0	20	0.01	0.21	-0.70	0.33
		25.0	19	-0.03	0.18	-0.30	0.33
SUMTER	D	19.0	12	-0.08	0.14	-0.32	0.26
		25.0	18	-0.13	0.17	-0.43	0.13
TALLADEGA	D	12.5	22	0.02	0.12	-0.21	0.22
		25.0	48	-0.06	0.20	-0.46	0.34
TUSCALOOSA	C	12.5	16	-0.04	0.23	-0.34	0.33
		25.0	30	-0.29	0.17	-0.67	-0.04
WALKER	E	19.0	8	-0.10	0.20	-0.32	0.26
		25.0	23	-0.22	0.25	-0.79	0.17
		37.5	4	-0.20	0.14	-0.34	0.00
ALL	-	-	605	-0.08	0.24	-1.83	0.75

$\Delta = X_{mea} - X_{jmf}$

Table 4. Summary Statistics for Asphalt Content

Year	Projects	MARSHALL			SUPERPAVE		
		n	σ(%)	$\overline{\Delta}$ (%)	n	σ(%)	$\overline{\Delta}$ (%)
1990	4	1607	0.43	0.14	—	—	—
1991	11	797	0.22	0.01	—	—	—
1992	113	3068	0.20	-0.03	—	—	—
1993	107	3818	0.18	-0.01	—	—	—
1997	9	557	0.24	-0.02	930	0.25	-0.10
1998	20	—	—	—	1425	0.21	-0.02
1999	27	—	—	—	2124	0.26	-0.06
2000	30	—	—	—	1465	0.25	0.00
1997-2000 Superpave	86	—	—	—	5944	0.25	-0.04

$\Delta = X_{mea} - X_{jmf}$

Table 5. Summary Statistics for Voids Content

Year	Projects	MARSHALL			SUPERPAVE		
		n	σ(%)	$\overline{\Delta}$ (%)	n	σ(%)	$\overline{\Delta}$ (%)
1990	4	905	1.05	0.19	—	—	—
1991	11	797	0.60	0.13	—	—	—
1992	113	3068	0.65	0.04	—	—	—
1993	107	3818	0.60	0.00	—	—	—
1997	9	557	0.57	-0.07	930	1.01	-0.07
1998	20	—	—	—	1425	0.88	-0.24
1999	27	—	—	—	2124	0.92	-0.40
2000	30	—	—	—	1465	0.90	-0.40
1997-2000 Superpave	86	—	—	—	5944	0.93	-0.31

$\Delta = X_{mea} - X_{imf}$

Table 6. Summary Statistics for Mat Density

Year	Projects	MARSHALL			SUPERPAVE®		
		n	σ(%)	$\overline{\Delta}$ (%)	n	σ(%)	$\overline{\Delta}$ (%)
1990	4	8958	1.69	-1.09	—	—	—
1991	11	2219	1.91	-1.14	—	—	—
1992	113	12,149	1.45	-0.65	—	—	—
1993	107	11,119	1.19	-0.56	—	—	—
1997	9	1877	1.01	-0.39	1272	1.48	-1.77
1998	17	—	—	—	4873	1.53	-1.52
1999	27	—	—	—	8804	1.10	-0.95
2000	30	—	—	—	6282	1.13	-0.78
1997-2000 Superpave	83	—	—	—	21,231	1.29	-1.08

$\Delta = X_{mea} - X_{imf}$

Table 7. Comparison of Asphalt Contents for 1997 Marshall and Superpave Mixes

MIX TYPE	MEAN % AC SUPERPAVE	MEAN % AC MARSHALL	DIFFERENCE
SURFACE	5.32	5.74	0.42
BINDER	4.28	4.65	0.37

Three factors were noted earlier that potentially could affect voids of Superpave mixes. To see if compactor to compactor consistency, transportation and reheating of mix might be factors, a survey was conducted of compactor usage during 1997. Results from this survey are tabulated in Table 8. The survey generally indicated the following:

- Contractors used the same compactor for mix design and construction control.
- Contractors and the DOT used different compactors for construction control.
- DOT compactors, except for Division 9, were located at division laboratories and required transport and more mix reheating.

Table 8. Results of Gyratory Compactor Survey for 1997 Superpave Projects

	CONTRACTOR		DOT
DIVISION	DESIGN	CONTROL	CONTROL
1	Troxler	Troxler*	Troxler*
2	–	–	–
3	Pine	Pine	Pine
4	*No Response*		
5	Troxler	Troxler	Troxler
6	Troxler	Troxler	Troxler
7	Troxler	Troxler	Troxler
8	Troxler**	Pine**	Troxler
9	Troxler	Troxler	Troxler***

* *ALDOT and contractor used different compactors for control (except Division 1).*
** *Contractor used same compactor for design and control (except Division 8).*
*** *DOT compactors located at division labs (except Division 9).*

Based on the survey, variability and accuracy of contractor and DOT voids measurements should probably have been different. However, averages in Table 9 indicate little difference. Certainly more direct comparisons would be needed to definitively determine the influence of compactors and reheating, but the statistics in Table 9 indicate other factors likely had a greater influence on voids of Superpave mixes.

Table 9. Comparisons of Contraction and ALDOT Voids for 1997 Superpave Projects

AGENCY	NO. OF MEASUREMENTS	MEAN VOIDS %	STANDARD DEVIATION %
CONTRACTOR	605	3.92	0.99
ALDOT	325	3.93	1.05

Superpave Mix Data. Means and standard deviations for asphalt content, voids and mat density for Superpave mixes from Tables 4, 5 and 6 are plotted as time trend graphs in Figures 1-6. Figure 1 indicates the ability to achieve target asphalt content has improved from 1997, and has stabilized at values only slightly lower than target. Figure 2 indicates asphalt content variability has been relatively consistent at a standard deviation of about 0.25%.

Figure 3 illustrates a troublesome trend for voids. Inability to achieve target 4% voids decreased from 1997 and appears to have stabilized at about 0.4% low. It is speculated that this may be a result of attempts to improve mix compactability (this need will be demonstrated later), but Figure 1 does not confirm expected higher asphalt contents. Indeed Figure 1 indicates asphalt contents only slightly lower than target. Figure 4 indicates variability of voids has stabilized at a standard deviation of about 0.9%.

Figure 5 indicates the ability to achieve target 94% TMD has steadily increased since implementation of Superpave design in 1997. The biggest improvement occurred between 1998 and 1999 and corresponds with initiation of pay adjustment application (one half computed rate). Application of full pay adjustments in 2000 resulted in a smaller increase in density which may mean a limit of about 93.2% TMD is being approached for mixes, as currently designed, with prevailing compaction processes. This persistent inability to achieve target mat compaction is apparently not causing unacceptably large pay reductions for contractors. It does, however, raise concerns that pavement performance may be adversely affected or that the 94% TMD target may be unnecessarily restrictive. Only detailed observation and comparison of performance of pavements constructed with Superpave designed asphalt concrete will be able to determine which concern is valid. Figure 6 indicates variability of mat density measurements improved significantly between 1998 and 1999 and appears to have stabilized at a standard deviation of about 1.1%.

Design ESAL Range and Maximum Aggregate Size Effects. To determine if design ESAL range or maximum aggregate size influenced measured properties of Superpave mixes, data was sorted and statistics computed. Sorts were carried out and statistics computed for the combined (1997-2000) database and for the 2000 database. The statistics from this exercise are tabulated in a series of tables appended to this report. Trends in the statistics for combined (1997-2000) data are illustrated in a series of plots.

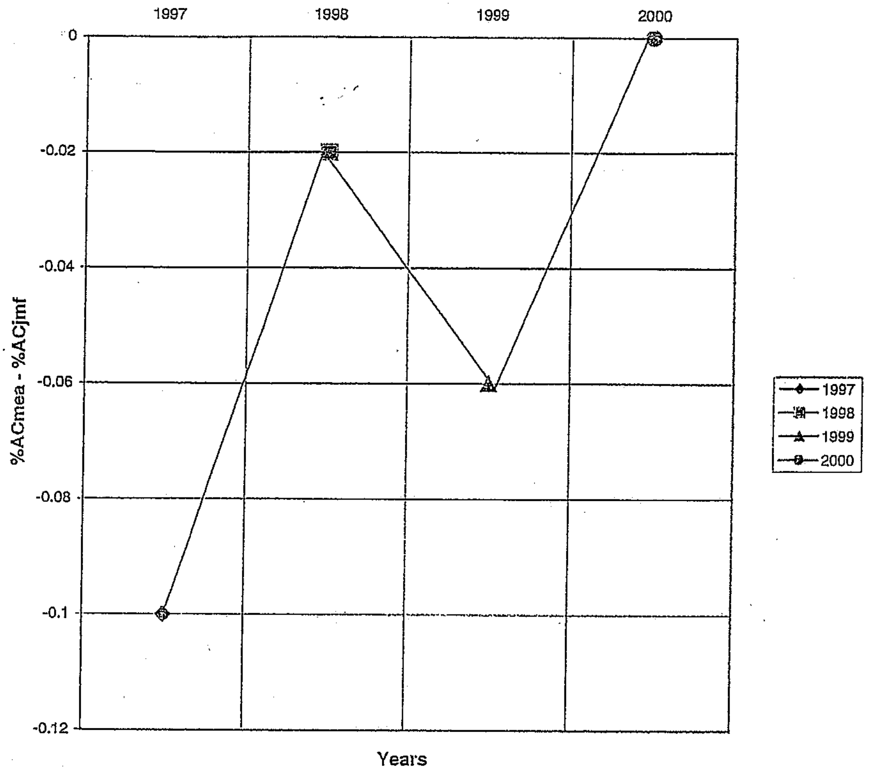


Figure 1. Time Trend for Difference Between Measured and JMF % AC for Superpave Mixes

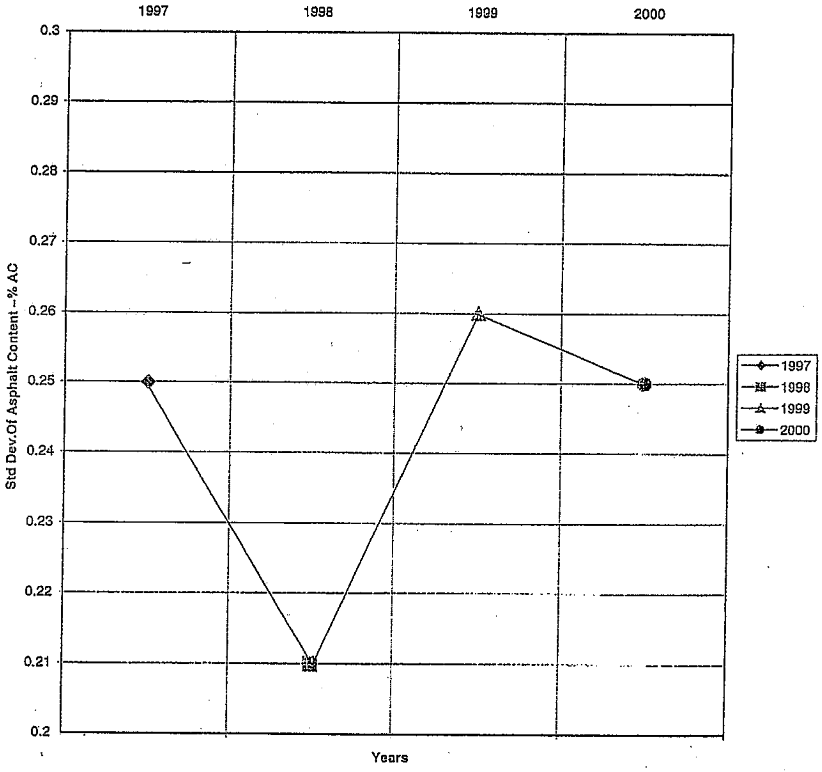


Figure 2. Time Trend for Standard Deviation of Asphalt Content Measurements for Superpave Mixes

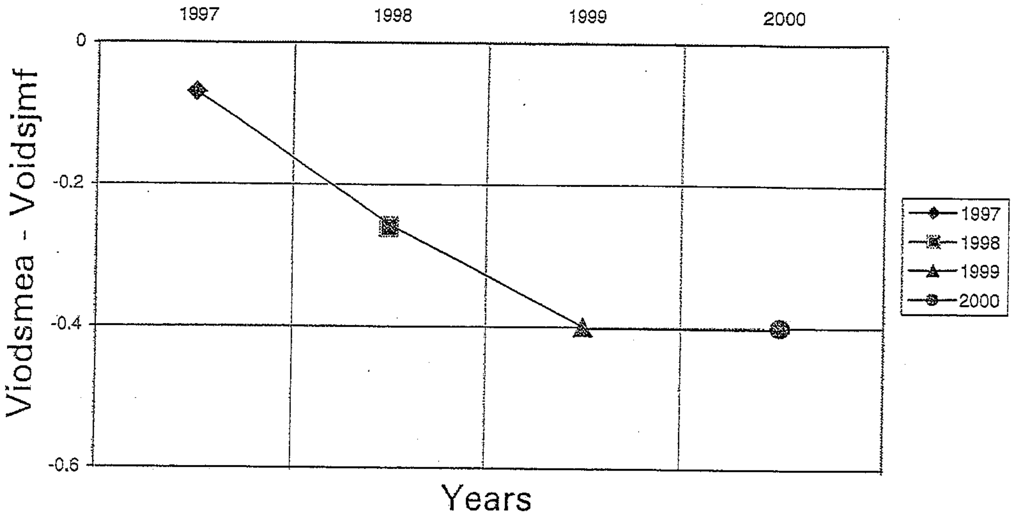


Figure 3. Time Trend for Difference Between Measured and Target (4%) Voids for Superpave Mixes

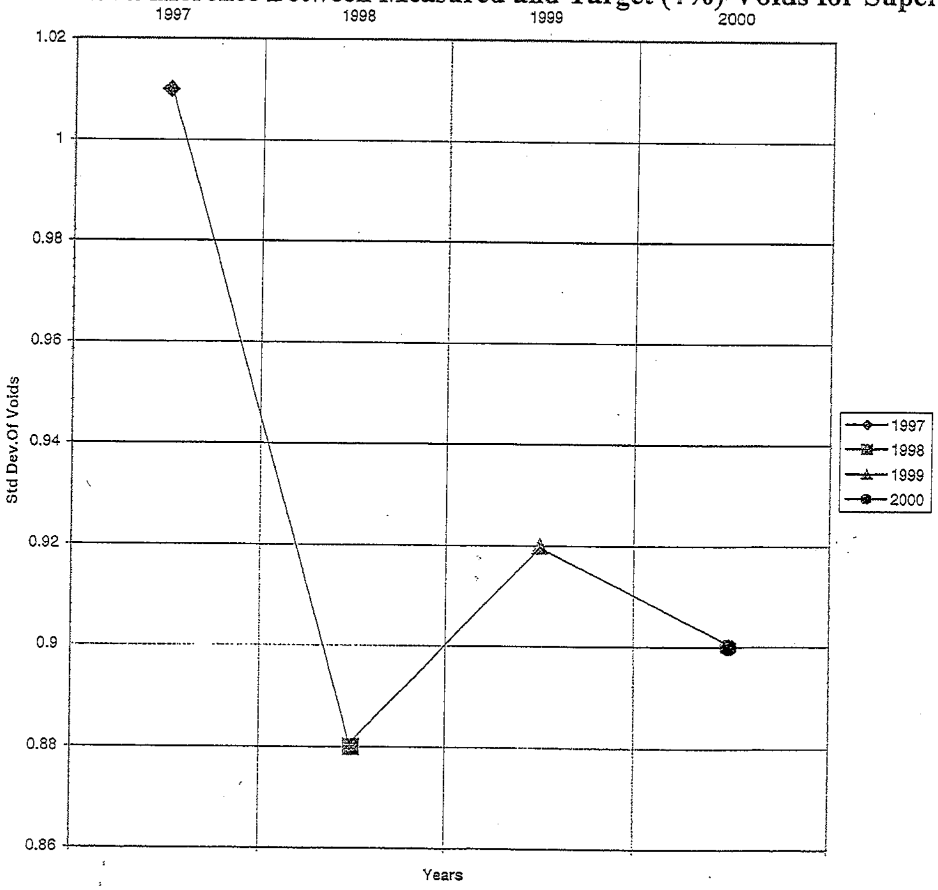


Figure 4. Time Trend for Standard Deviation of Voids for Superpave Mixes

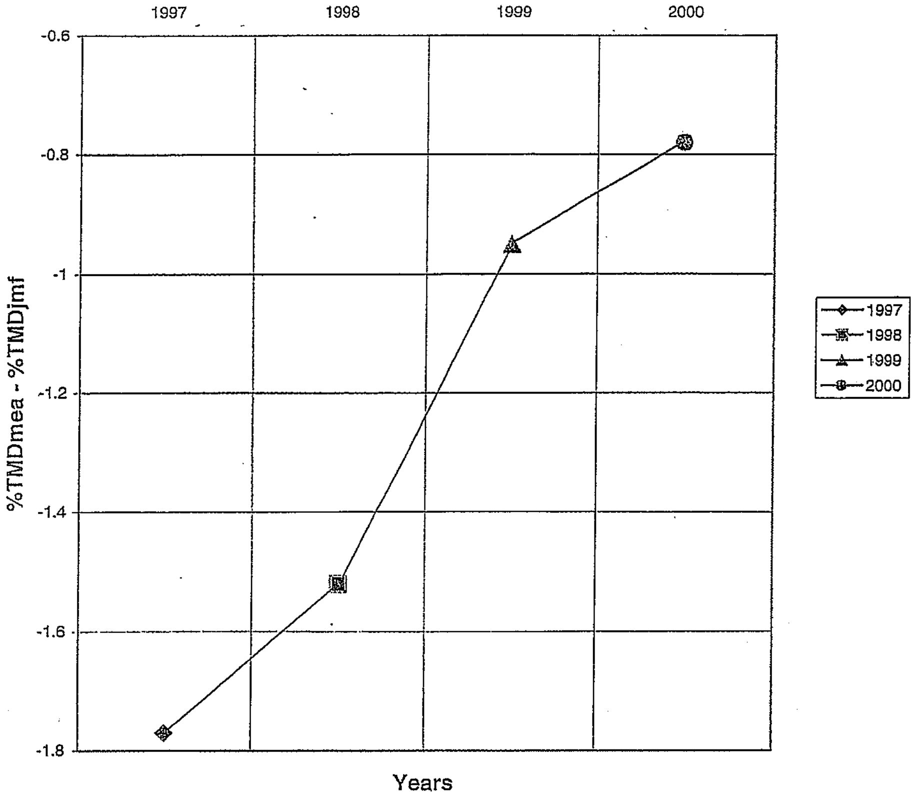


Figure 5. Time Trend for Difference Between Measured and Target (94% TMD) Mat Density

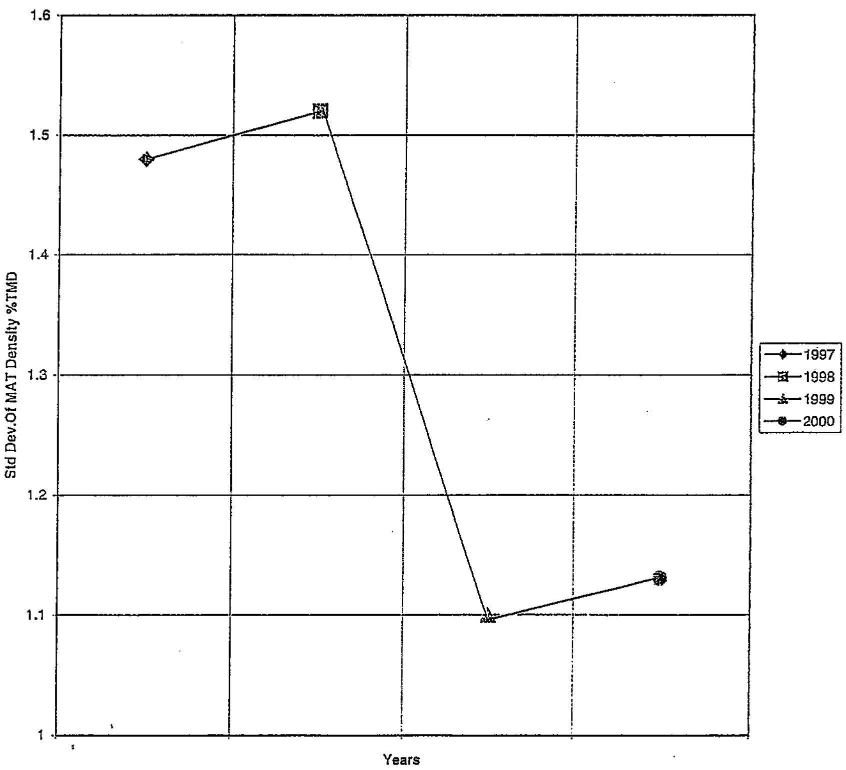


Figure 6. Time Trend for Standard Deviation of Mat Density Measurements for Superpave Mixes

Figure 7. is a plot of asphalt content versus maximum aggregate size that shows, as expected, asphalt content generally decreases as maximum aggregated size increases. Figure 8 contains plots that show maximum aggregate size has no appreciable effect on accuracy or variability of asphalt content measurements.

Figure 9. contains a plot that shows void content increasing as maximum aggregate size increases. The large numbers of measurements involved in computing the means of the voids provides a high level of confidence that the observed trend is real, but no plausible explanation can be offered. The second plot in Figure 9 shows no clear trend or an appreciable effect of maximum aggregate size on variability of void measurements.

Figure 10. contains a plot that shows mat compaction, measured as percent theoretical maximum density, increases as maximum aggregate size increases. Mat thickness is directly related to maximum aggregate size and the observed trend is thought to be a result of improved compactability for thicker mats. The second plot in Figure10 shows that variability of mat compaction decreases as maximum aggregate size increases. This is again thought due to mat thickness, with thicker mats cooling slower and more uniformly.

Figures 11-14 are plots that show the effects of design ESAL range on asphalt content, voids and mat compaction for Superpave mixes. The number of data points for design ESAL ranges C, D and E are about ten times greater than the number of data points for design ESAL ranges B and F (see Table A4). This large difference in database size suggests greatest confidence is warranted for trends indicated by statistics for design ESAL ranges C, D, and E, and contradictions indicated by statistics for ESAL ranges B and F can be safely disregarded.

Figure 11 indicates a decrease in asphalt content as gyrations for design increases. The data suggests limiting compaction may be reached at about 100 gyrations. Figure 12 suggests accuracy and variability of asphalt content measurements are relatively affected by design ESAL range.

Figures 13 indicates little difference in accuracy and variability of void and measurements for design ESAL ranges C-E. The nonconformance for ESAL ranges B and F are likely due to their relatively smaller numbers of measurements as noted above.

Figure 14 indicates the ability to achieve target mat compaction decreases (0.4% TMD) and standard deviation increases (0.16% TMD) from design ESAL range C to E. These trends may indeed result from differences in mix compactability. However, they, nor the trend in asphalt content, illustrated in Figure 11, can be entirely explained by differences in design compaction level since 100 gyrations are specified for both ESAL ranges D and E. Again inconsistencies for design ESAL ranges A and F can be safely discounted.

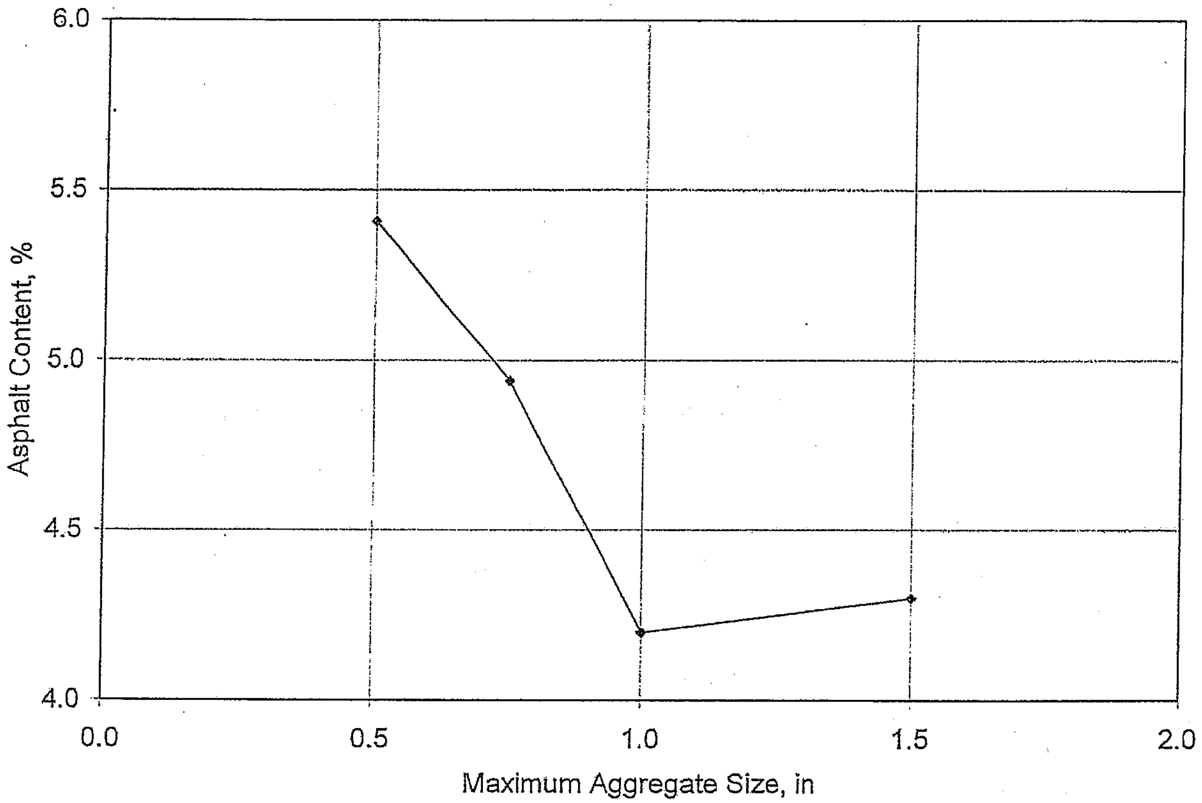
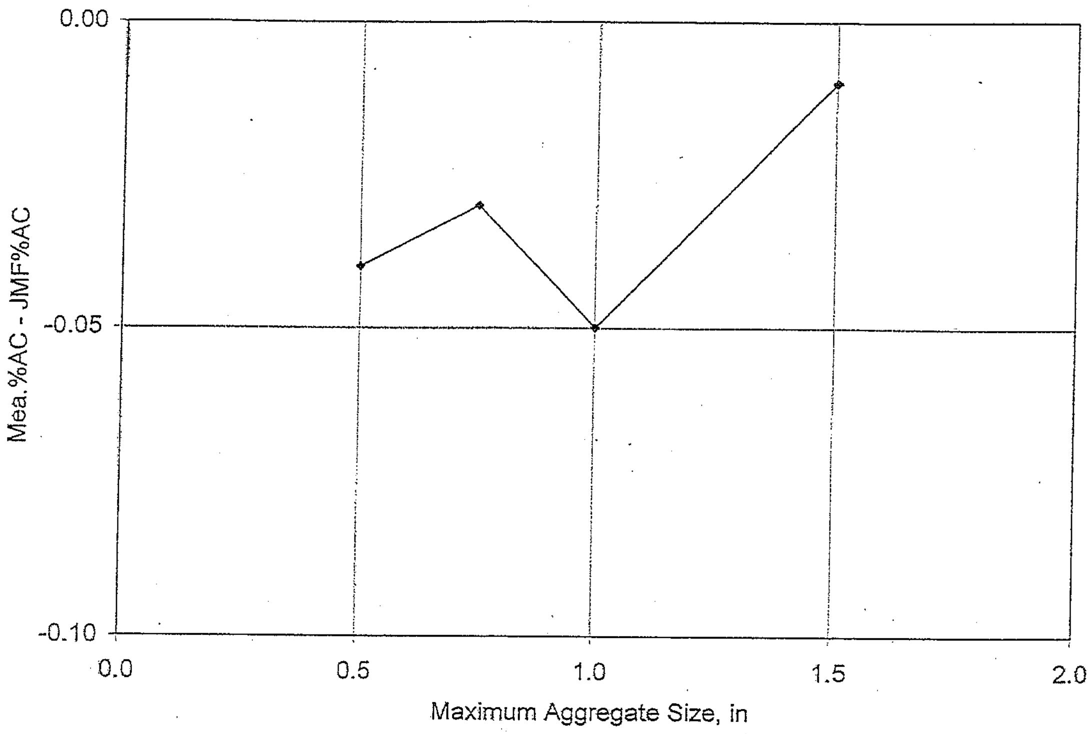


Figure 7. Asphalt Content Versus Maximum Aggregate Size



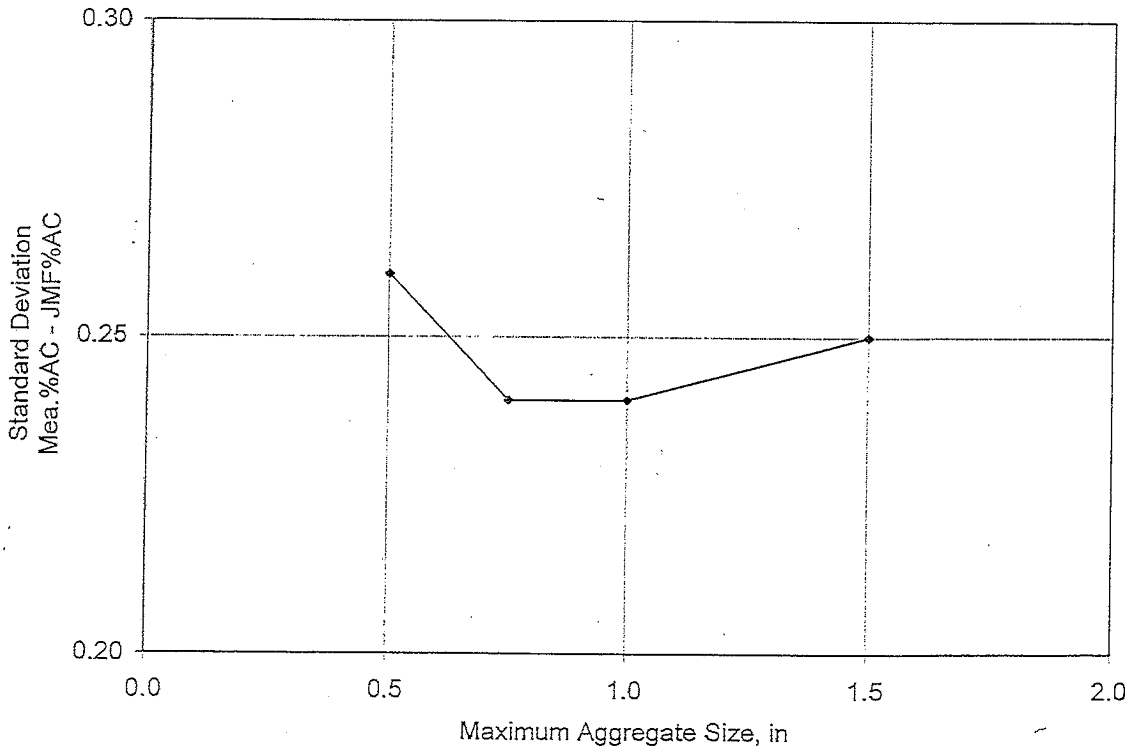
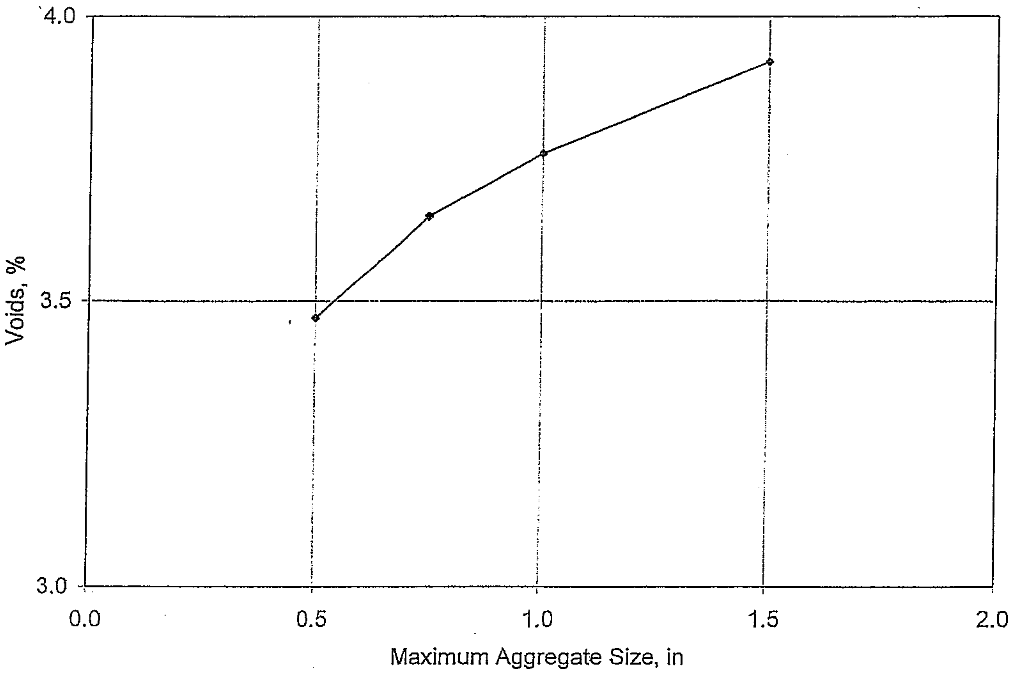


Figure 8. Accuracy and Variability of Asphalt Content Versus Maximum Aggregate Size



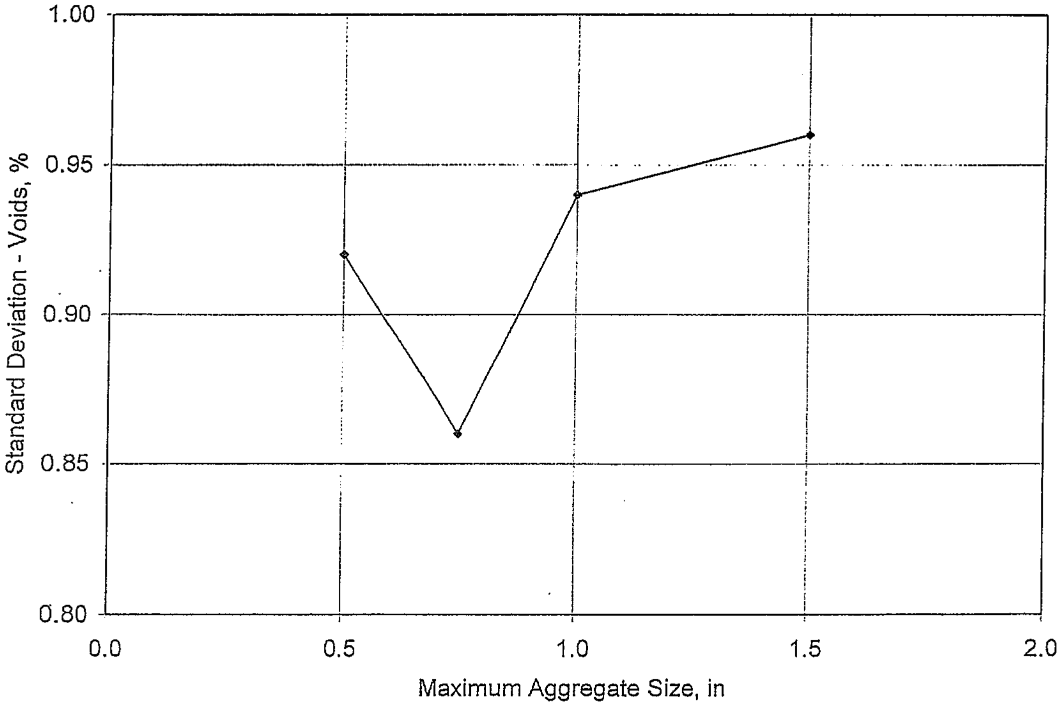


Figure 9. Accuracy and Variability of Voids Versus Maximum Aggregate Size

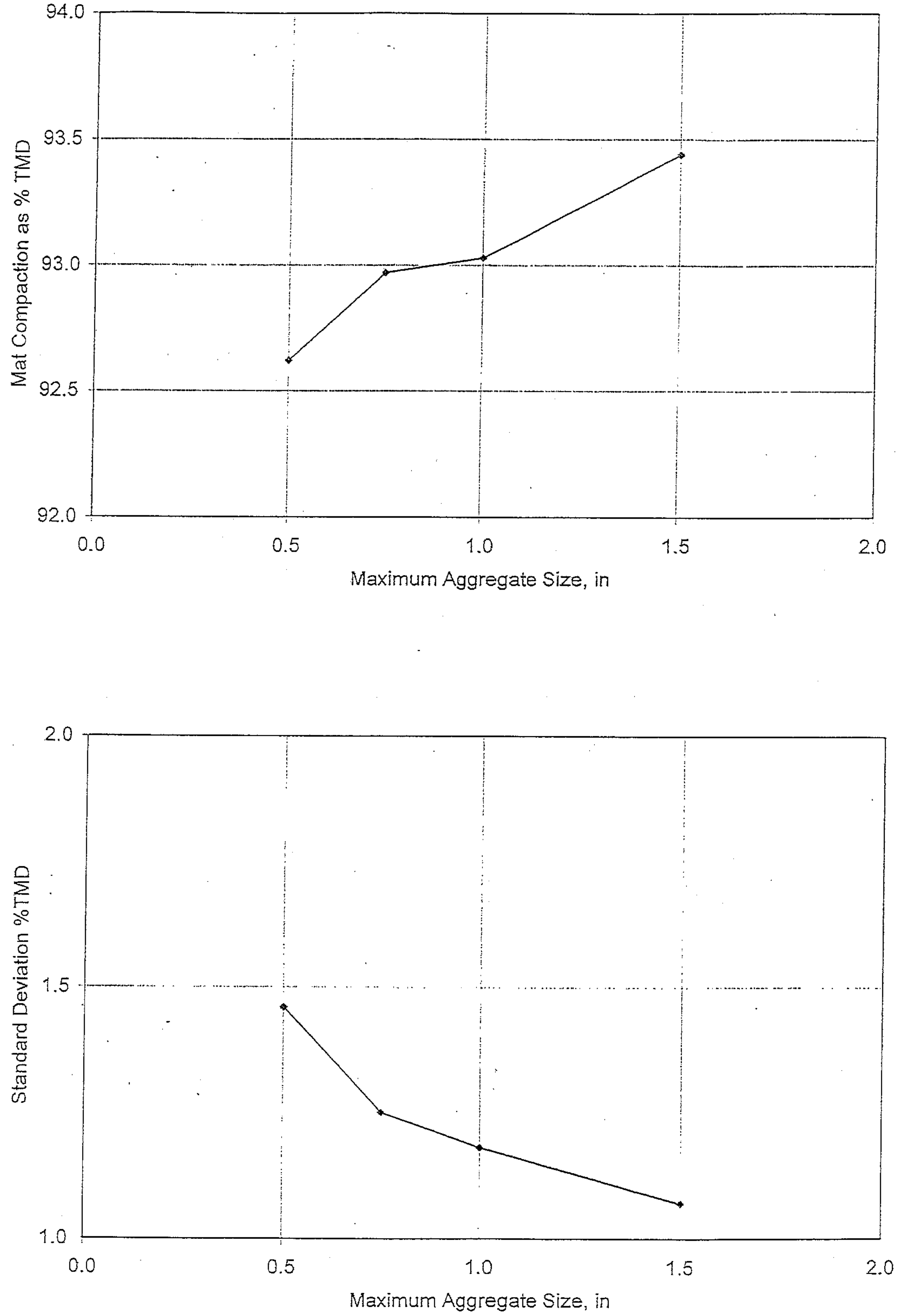


Figure 10. Accuracy and Variability of Mat Compaction Versus Maximum Aggregate Size

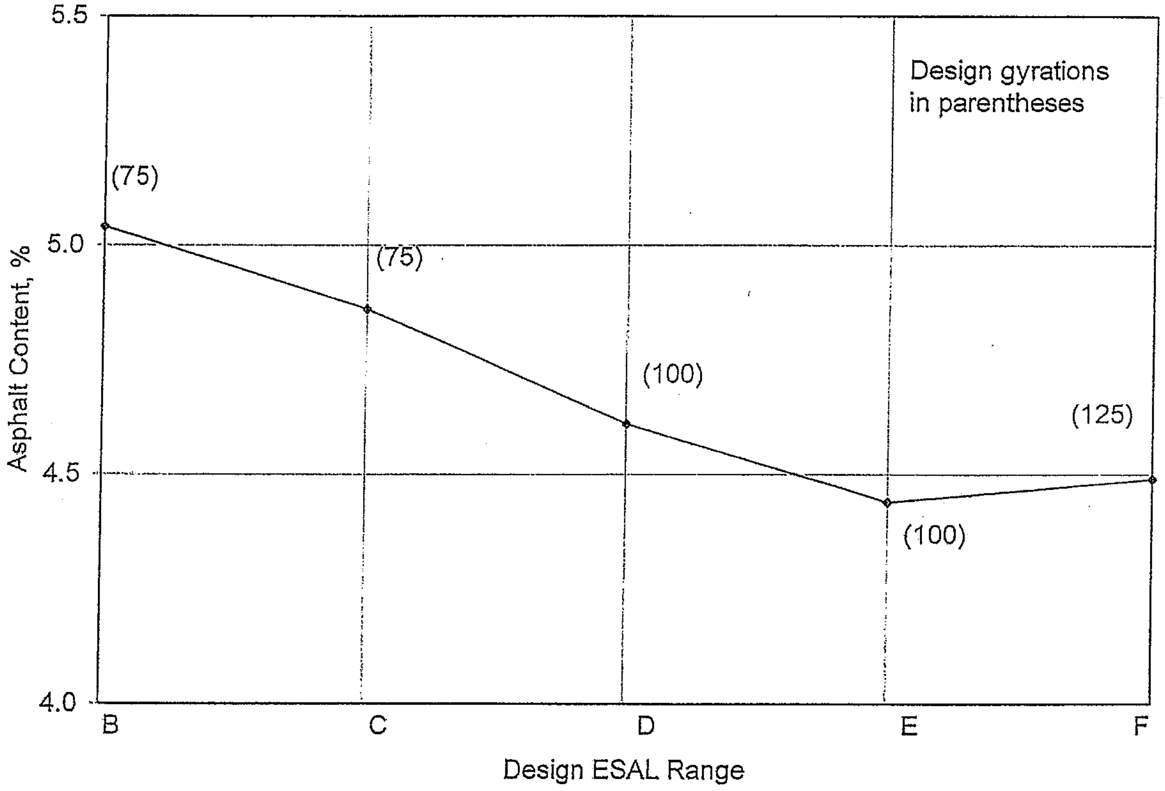


Figure 11. Asphalt Content Versus Design ESAL Range

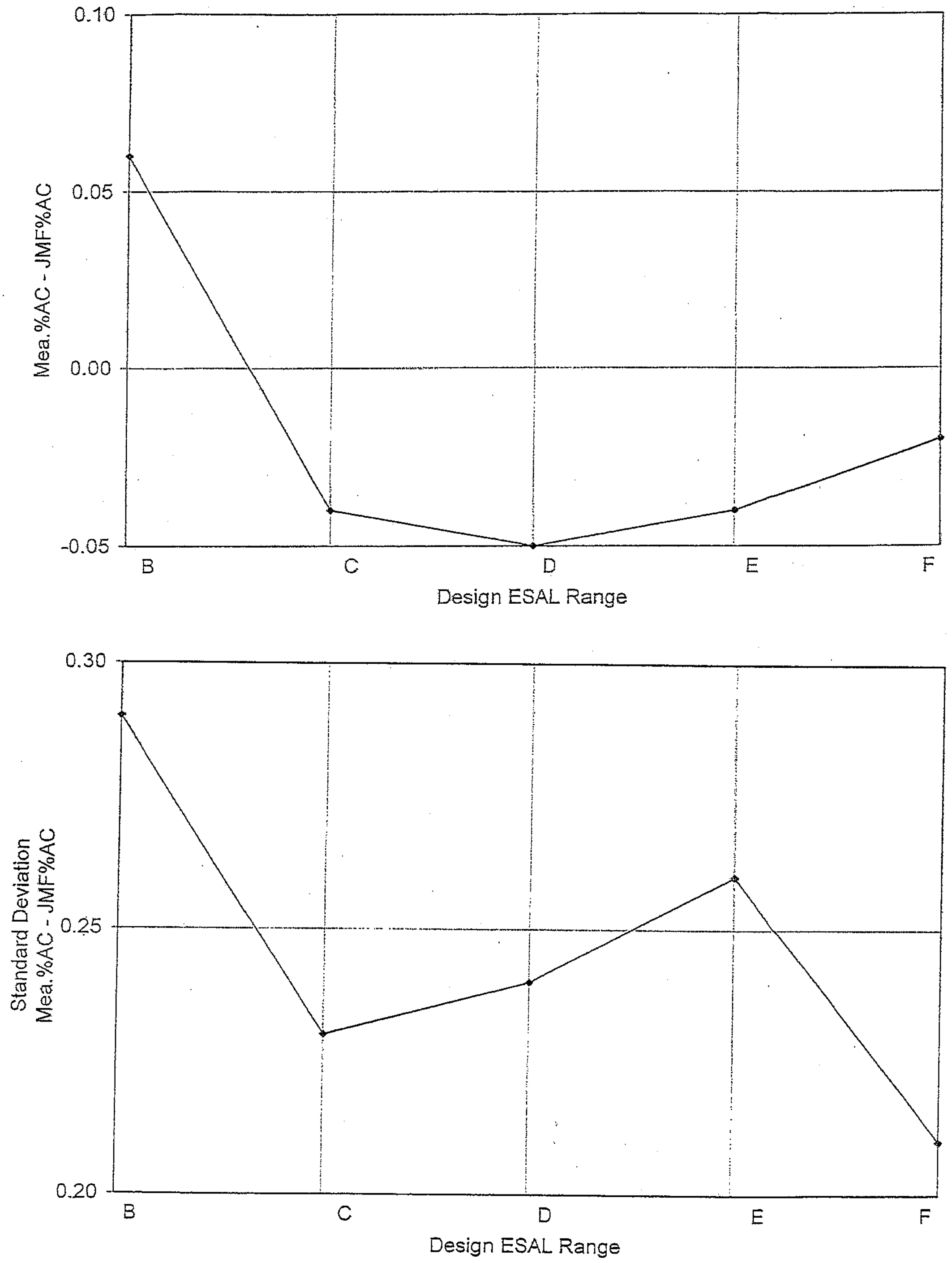


Figure 12. Accuracy and Variability of Asphalt Content Versus Design ESAL Range

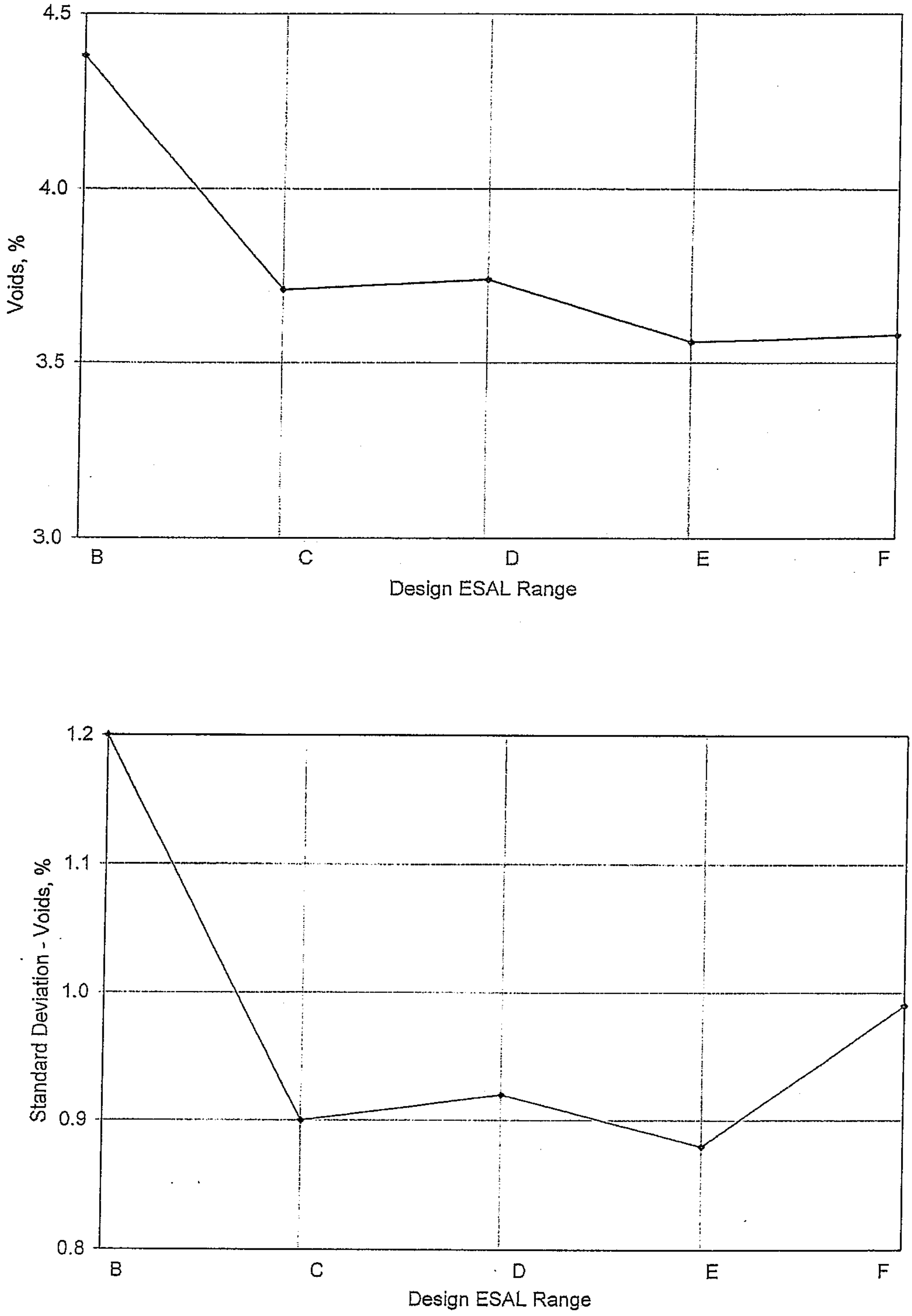
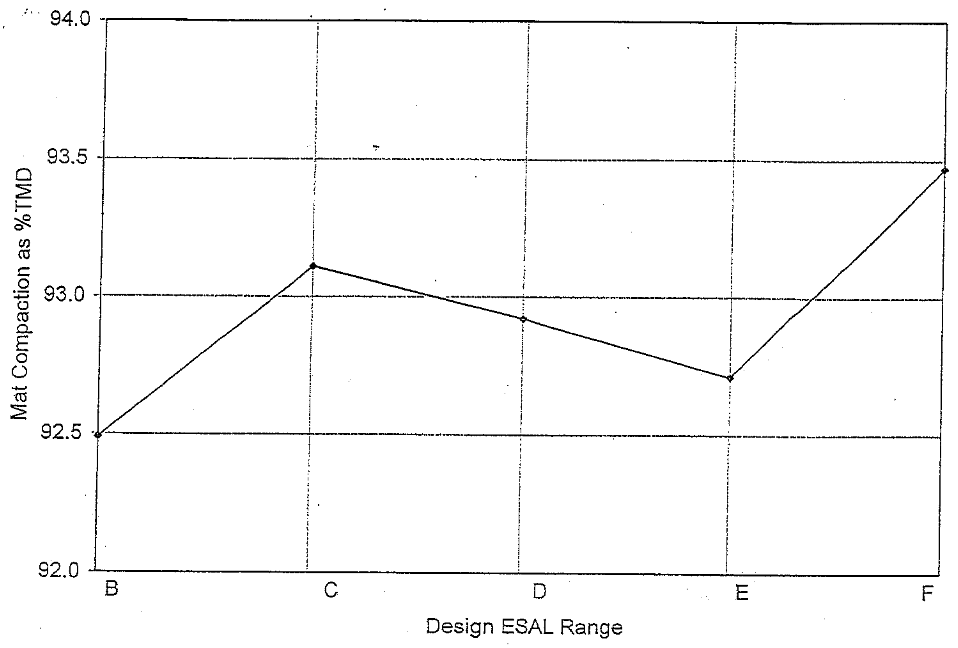


Figure 13. Accuracy and Variability of Voids Versus Design ESAL Range



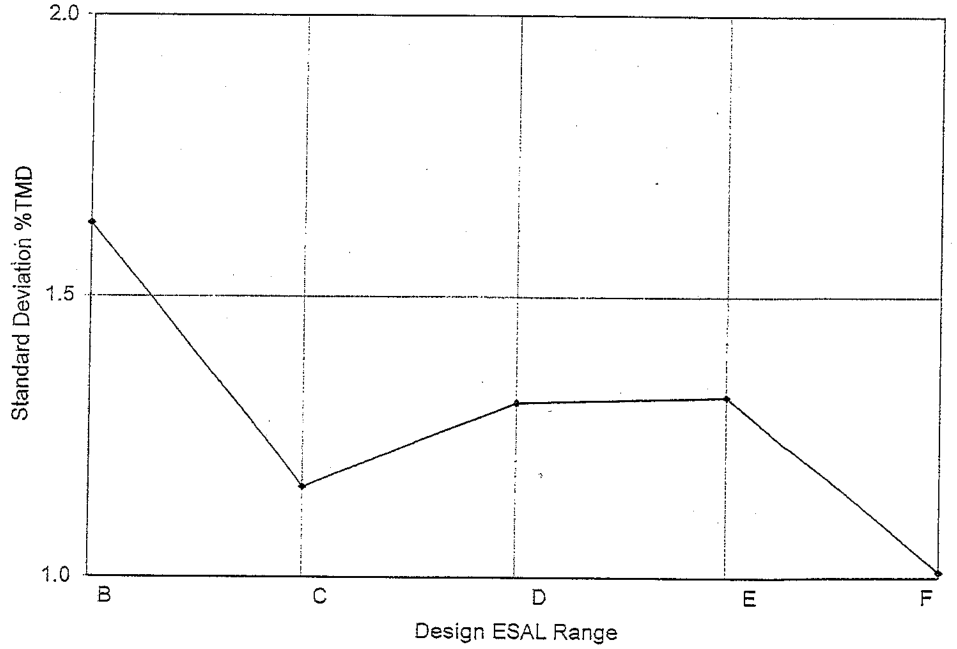


Figure 14. Accuracy and Variability of Mat Compaction Versus Design ESAL Range

Comparison of Contractor and ALDOT Superpave Mix Data. Table 10 contains summary statistics from contractor and ALDOT data for 1997 through 2000. Except for asphalt content, contractor measurements are always closer to target values than ALDOT measurements. Contractor measurements, for all three parameters, are always less variable than ALDOT measurements. The magnitude of the differences in accuracy and variability may seem small but, considering the large sample sizes; indicate, to a high probability, real differences in sampling and testing that cannot be attributed to chance.

Table 10. Comparisons of Statistics for Contractor and ALDOT Superpave Data

ASPHALT CONTENT						
	CONTRACTOR			*ALDOT*		
Year	n	$\overline{\Delta}$, (%)	σ, %	n	$\overline{\Delta}$, (%)	σ, %
1997	605	-0.08	0.24	325	-0.13	0.26
1998	919	-0.03	0.20	506	-0.01	0.24
1999	1313	-0.05	0.25	811	-0.07	0.27
2000	887	0.01	0.22	578	0.00	0.29
VOIDS						
1997	605	-0.08	0.99	325	-0.07	1.05
1998	919	-0.23	0.79	506	-0.26	1.02
1999	1313	-0.35	0.85	811	-0.48	1.01
2000	887	-0.37	0.84	578	-0.44	0.99
MAT DENSITY						
1997	798	-1.76	1.48	474	-1.77	1.49
1998	3272	-1.43	1.41	1601	-1.70	1.74
1999	5857	-0.88	0.99	2947	-1.10	1.28
2000	4232	-0.69	0.98	2050	-0.98	1.38

CONCLUSIONS AND RECOMMENDATIONS

Means and standard deviations indicate accuracy and variability of asphalt content measurements for Superpave mixes are comparable to accuracy and variability of asphalt content measurements for Marshall mixes.

Means and standard deviations indicate accuracy and variability of void measurements for Superpave mixes are not comparable to accuracy and variability of void measurements for Marshall mixes; deviation from target (4%) and variability for Superpave mixes are larger.

Means indicate accuracy of mat density measurements for Superpave mixes are not comparable to accuracy of Marshall mixes; deviation from target (94% TMD) is larger for Superpave mixes. Standard deviations indicate variability of mat density measurements for Superpave mixes are comparable to variability of mat density measurements for Marshall mixes.

Voids and mat density measurements consistently lower than targets have the potential to adversely affect the performance of pavements constructed with Superpave mixes.

Expected relationships between asphalt content and maximum aggregate size and between asphalt content and design ESAL range were observed; asphalt content decreased as maximum aggregate size increased and as the number of design gyratons, corresponding to design ESAL range, increased. Accuracy and variability of asphalt content measurements appear to be relatively unaffected by maximum aggregate size or design ESAL range.

Void content appears to be unaffected by design ESAL range, but appears to increase as maximum aggregate size increases. This cannot be explained and should not be considered when setting pay adjustment criteria. The variability of void measurements seems insensitive to maximum aggregate size or design ESAL range.

Mat density increases and variability decreases as maximum aggregate size increases. These trends are thought to be related to mat thickness and it is not recommended that the influence of maximum aggregate be considered when setting pay adjustment criteria for mat density. Mean mat density nor variability of mat density measurements appear to be affected by design ESAL range.

Accuracy and variability of contractor measurements for asphalt content, voids and mat density for Superpave mixes are consistently better than accuracy and variability of ALDOT measurements.

No changes to pay adjustment criteria for asphalt content and mat density of Superpave mixes are recommended as standard deviations are comparable to Marshall mixes. Target values are not being consistently achieved for mat density but this should not be considered when setting criteria for pay adjustments.

Pay adjustment criteria for voids of Superpave mixes should be developed based on a standard deviation of 0.9% (0.6% used for Marshall mixes).

An effort should be made to determine if pavement performance is being adversely affected by lower than target voids and mat density that are consistently achieved for Superpave mixes. Consideration of changing target values should also be a part of this process.

APPENDIX

STATISTICS FOR DATA SORTED ACCORDING TO MAXIMUM AGGREGATE SIZE AND DESIGN ESAL RANGE

Table A1. 2000 Superpave Mix Statistics Sorted According to Maximum Aggregate Size

MAX AGGREGATE SIZE (mm)	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
ASPHALT CONTENT					
12.5	372	5.51	0.55	-0.02	0.26
19.0	407	5.01	0.55	-0.01	0.24
25.0	528	4.22	0.32	0.00	0.25
37.5	158	4.37	0.22	0.12	0.21
VOIDS					
12.5	372	3.55	0.84	-0.45	0.84
19.0	407	3.66	0.87	-0.34	0.87
25.0	528	3.65	0.99	-0.35	0.99
37.5	158	3.41	0.79	-0.59	0.79
MAT DENSITY					
12.5	1672	93.21	1.18	-0.79	1.18
19.0	1818	93.29	1.08	-0.71	1.08
25.0	2551	93.17	1.13	-0.83	1.13
37.5	241	93.25	1.23	-0.75	1.23

$\Delta = x_{mea} - x_{jmf}$

Table A2. Combined Mix Statistics Sorted According to Maximum Aggregate Size

MAX AGGREGATE SIZE (mm)	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
ASPHALT CONTENT					
12.5	1283	5.41	0.49	-0.04	0.26
19.0	1369	4.94	0.52	-0.03	0.24
25.0	2740	4.20	0.36	-0.05	0.24
37.5	552	4.30	0.30	-0.01	0.25
VOIDS					
12.5	1283	3.47	0.92	-0.53	0.92
19.0	1369	3.65	0.86	-0.35	0.86
25.0	2740	3.76	0.94	-0.24	0.94
37.5	552	3.92	0.96	-0.08	0.96
MAT DENSITY					
12.5	5289	92.62	1.46	-1.38	1.46
19.0	5876	92.97	1.25	-1.03	1.25
25.0	9632	93.03	1.18	-0.97	1.18
37.5	373	93.44	1.07	-0.56	1.07

$\Delta = x_{mea} - x_{jmf}$

Table A3. 2000 Suprepave Mix Statistics Sorted According to Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
ASPHALT CONTENT					
B	110	4.94	0.76	0.06	0.33
C	619	4.94	0.68	-0.06	0.24
D	428	4.76	0.80	0.01	0.23
E	217	4.50	0.32	0.13	0.21
F	91	4.30	0.31	0.03	0.19
VOIDS					
B	110	4.40	1.23	0.40	1.23
C	619	3.56	0.87	-0.44	0.87
D	428	3.60	0.70	-0.40	0.70
E	217	3.22	0.78	-0.78	0.78
F	91	3.84	1.13	-0.16	1.13
MAT DENSITY					
B	349	92.62	1.54	-1.38	1.54
C	2498	93.32	0.90	-0.68	0.90
D	2324	93.09	1.23	-0.91	1.23
E	530	93.39	1.25	-0.61	1.25
F	581	93.47	1.01	-0.53	1.01

$\Delta = x_{mea} - x_{jmf}$

Table A4. Combined Superpave Mix Statistics Sorted According to Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
ASPHALT CONTENT					
B	173	5.04	0.79	0.06	0.29
C	1763	4.86	0.65	-0.04	0.23
D	2057	4.61	0.68	-0.05	0.24
E	1761	4.44	0.53	-0.04	0.26
F	190	4.49	0.58	-0.02	0.21
VOIDS					
B	173	4.38	1.20	0.38	1.20
C	1763	3.71	0.90	-0.29	0.90
D	2057	3.74	0.92	-0.26	0.92
E	1761	3.56	0.88	-0.44	0.88
F	190	3.58	0.99	-0.42	0.99
MAT DENSITY					
B	555	92.49	1.63	-1.51	1.63
C	5659	93.11	1.16	-0.89	1.16
D	8955	92.92	1.31	-1.08	1.31
E	5420	92.71	1.32	-1.29	1.32
F	581	93.47	1.01	-0.53	1.01

$\Delta = x_{mea} - x_{jmf}$

Table A5. Asphalt Content Statistics for 2000 Superpave Mix Statistics Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	40	5.83	0.25	0.09	0.17
C	199	5.50	0.41	-0.08	0.22
D	133	5.44	0.73	0.05	0.30
19.0 mm Maximum Aggregate					
C	169	5.21	0.57	-0.03	0.28
D	115	5.03	0.62	-0.03	0.19
E	78	4.80	0.19	0.10	0.19
F	45	4.55	0.22	-0.05	0.22
25.0 mm Maximum Aggregate					
B	64	4.50	0.35	0.07	0.41
C	217	4.28	0.33	-0.06	0.22
D	170	4.10	0.24	0.02	0.20
E	31	4.09	0.23	-0.04	0.24
F	46	4.05	0.12	0.10	0.12
37.5 mm Maximum Aggregate					
B	6	3.72	0.03	-0.18	0.03
C	34	4.41	0.14	-0.07	0.13
D	10	4.17	0.19	0.02	0.19
E	108	4.41	0.18	0.21	0.18

$\Delta = x_{mea} - x_{jmf}$

Table A6. Asphalt Content Statistics for Combined Superpave Mix Statistics Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	68	5.93	0.26	0.09	0.18
C	370	5.47	0.45	-0.07	0.23
D	573	5.37	0.53	-0.05	0.27
E	272	5.30	0.39	0.00	0.28
19.0 mm Maximum Aggregate					
C	519	5.24	0.49	0.01	0.24
D	374	4.86	0.48	-0.04	0.21
E	375	4.60	0.34	-0.05	0.27
F	101	4.94	0.42	-0.09	0.23
25.0 mm Maximum Aggregate					
B	99	4.51	0.31	0.05	0.35
C	834	4.37	0.40	-0.06	0.22
D	1061	4.15	0.28	-0.06	0.24
E	657	4.06	0.35	-0.07	0.24
F	89	3.98	0.16	0.06	0.15
37.5 mm Maximum Aggregate					
B	6	3.72	0.03	-0.18	0.03
C	40	4.43	0.15	-0.04	0.16
D	49	3.74	0.28	-0.05	0.19
E	457	4.35	0.23	0.00	0.26

$\Delta = x_{mea} - x_{jmf}$

Table A7. Voids Statistics for 2000 Superpave Mixes Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	40	3.62	0.93	-0.38	0.93
C	199	3.25	0.81	-0.75	0.81
D	133	3.97	0.64	-0.03	0.64
19.0 mm Maximum Aggregate					
C	169	3.81	0.80	-0.19	0.80
D	115	3.34	0.59	-0.66	0.59
E	78	3.20	0.79	-0.80	0.79
F	45	4.73	0.83	0.73	0.83
25.0 mm Maximum Aggregate					
B	64	4.91	1.19	0.91	1.19
C	217	3.62	0.85	-0.38	0.85
D	170	3.51	0.71	-0.49	0.71
E	31	3.03	1.07	-0.97	1.07
F	46	2.98	0.55	-1.02	0.55
37.5 mm Maximum Aggregate					
B	6	4.16	0.10	0.16	0.10
C	34	3.72	1.11	-0.28	1.11
D	10	3.30	0.41	-0.70	0.41
E	108	3.28	0.65	-0.72	0.65

$\Delta = x_{mea} - x_{jmf}$

Table A8. Voids Statistics for Combined Superpave Mixes Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	68	3.82	0.93	-0.18	0.93
C	370	3.41	0.93	-0.59	0.93
D	573	3.63	0.96	-0.37	0.96
E	272	3.13	0.65	-0.87	0.65
19.0 mm Maximum Aggregate					
C	519	3.86	0.75	-0.14	0.75
D	374	3.44	0.75	-0.56	0.75
E	375	3.54	0.95	-0.46	0.95
F	101	3.80	1.15	-0.20	1.15
25.0 mm Maximum Aggregate					
B	99	4.78	1.25	0.78	1.25
C	834	3.73	0.90	-0.27	0.90
D	1061	3.89	0.92	-0.11	0.92
E	657	3.51	0.82	-0.49	0.82
F	89	3.33	0.71	-0.67	0.71
37.5 mm Maximum Aggregate					
B	6	4.16	0.10	0.16	0.10
C	40	4.05	1.43	0.05	1.43
D	49	4.03	0.94	0.03	0.94
E	457	3.90	0.91	-0.10	0.91

$\Delta = x_{mea} - x_{jmf}$

Table A9. Mat Density Statistics for 2000 Superpave Mixes Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	56	94.24	0.79	0.24	0.79
C	754	93.48	0.85	-0.52	0.85
D	862	92.90	1.33	-1.10	1.33
19.0 mm Maximum Aggregate					
C	545	93.06	1.23	-0.94	1.23
D	682	93.41	0.85	-0.59	0.85
E	241	93.53	1.28	-0.47	1.28
F	350	93.23	1.04	-0.77	1.04
25.0 mm Maximum Aggregate					
B	293	92.31	1.45	-1.69	1.45
C	1199	93.35	0.71	-0.65	0.71
D	780	93.01	1.34	-0.99	1.34
E	48	93.47	1.09	-0.53	1.09
F	231	93.83	0.86	-0.17	0.86
37.5 mm Maximum Aggregate					
E	241	93.25	1.23	-0.75	1.23

$\Delta = x_{mea} - x_{jmf}$

Table A10. Mat Density Statistics for Combined Superpave Mixes Sorted According to Maximum Aggregate Size and Design ESAL Range

MIX DESIGN ESAL RANGE	n	$\overline{x}$ (%)	σ_x (%)	$\overline{\Delta}$ (%)	σ_Δ (%)
12.5 mm Maximum Aggregate					
B	137	92.57	2.09	-1.43	2.09
C	919	93.39	0.88	-0.61	0.88
D	2787	92.64	1.46	-1.36	1.46
E	1446	92.12	1.47	-1.88	1.47
19.0 mm Maximum Aggregate					
C	1926	92.89	1.30	-1.11	1.30
D	2108	93.07	1.20	-0.97	1.20
E	1492	92.88	1.29	-1.12	1.29
F	350	93.23	1.04	-0.77	1.04
25.0 mm Maximum Aggregate					
B	418	92.46	1.45	-1.54	1.45
C	2814	93.16	1.10	-0.84	1.10
D	3928	93.01	1.22	-0.99	1.22
E	2241	92.91	1.12	-1.09	1.12
F	231	93.83	0.86	-0.17	0.80
37.5 mm Maximum Aggregate					
D	132	93.80	0.52	-0.20	0.52
E	241	93.25	1.23	-0.75	1.23

$\Delta = x_{mea} - x_{jmf}$

Table 10. Comparisons of Statistics for Contractor and ALDOT Superpave Data

ASPHALT CONTENT						
	CONTRACTOR			*ALDOT*		
Year	n	$\overline{\Delta}$, (%)	σ, %	n	$\overline{\Delta}$, (%)	σ, %
1997	605	-0.08	0.24	325	-0.13	0.26
1998	919	-0.03	0.20	506	-0.01	0.24
1999	1313	-0.05	0.25	811	-0.07	0.27
2000	887	0.01	0.22	578	0.00	0.29
VOIDS						
1997	605	-0.08	0.99	325	-0.07	1.05
1998	919	-0.23	0.79	506	-0.26	1.02
1999	1313	-0.35	0.85	811	-0.48	1.01
2000	887	-0.37	0.84	578	-0.44	0.99
MAT DENSITY						
1997	798	-1.76	1.48	474	-1.77	1.49
1998	3272	-1.43	1.41	1601	-1.70	1.74
1999	5857	-0.88	0.99	2947	-1.10	1.28
2000	4232	-0.69	0.98	2050	-0.98	1.38