Hot-Mix Asphalt Mix Properties Measured for Construction Quality Control and Assurance

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The Alabama Highway Department (AHD) developed and implemented a quality control/quality assurance (QC/QA) program for hot-mix asphalt (HMA) construction from 1990 to 1992. Several HMA properties were measured for construction quality control and assurance. The effects of statistically based QC/QA specification implementation on construction quality are discussed. Measurements of asphalt content and air voids were made by AHD and various contractors for base/binder mix, surface mix, and surface mix with latex. Statistical analyses were performed to assess differences between agency measurements and among measurements for the different mix types. The accuracy and precision of measurements increased from 1990 to 1992, indicating improved construction quality, improved technician sampling and testing skills, or both. No statistically significant differences occurred between AHD and contractor measurements, but numerically AHD measurements tended to have higher variability and mean deviation from target values, especially in 1992 when contractor measurements were used for computing pay adjustments. No statistically significant differences occurred among the three mix types for asphalt or air void content, but there are some indications that the use of latex modifier decreased asphalt content variability.

Providing a quality product to meet performance requirements has always been a goal of the highway industry. Current high-capacity facilities require innovative quality management techniques to ensure that high performance requirements are met.

Hot-mix asphalt (HMA) production and placement are a significant part of highway construction and maintenance activities. Under the traditional owner-dominated construction management approach, construction quality was ensured through the experience-based skills and judgment of technicians and engineers. Satisfactory quality achievement depended on the experience and skill level of individuals involved. However, engineering duties have expanded to the extent that many quality assurance activities have been delegated to those whose skills and experience are often inadequate for on-the-spot judgments (*1*). To reduce the need for engineering judgment, the highway construction industry is moving toward statistically based quality control/quality assurance (QC/QA) programs to monitor, evaluate, and control work.

A statistical QC/QA procedure is implemented by setting limiting acceptance criteria to ensure desired product quality. For the construction of HMA, several properties may be considered. Asphalt content, air voids, aggregate gradation, and mat density are commonly used control properties. The Alabama Highway Department (AHD) uses asphalt content, air voids of laboratory-compacted (Marshall) samples, and mat density for quality assurance and contractor quality control. Aggregate gradation, Marshall stability, and retained tensile strength are also quality control properties. Only observations of asphalt content and air voids are considered in this paper.

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Because of the speed of construction, an effective quality control program requires rapid determination of HMA properties. Nuclear gauges provide this capability for asphalt cement content (*2*). Stroup-Gardiner et al. (*3*) developed a precision statement for the nuclear asphalt content gauge. Wu (*4*) compared the nuclear gauge with the extraction method and automatic recordation and found it as precise as extraction and that it compared better with recordation than extraction.

To develop realistic and valid quality requirements, acceptance limits should be based on a statistical analysis of variations in materials, processes, sampling, and testing (*1*). Since acceptance limits are based on variability and assume mean values equal target values, accurate (unbiased) and precise sampling and test procedures are essential for QA application (*5*).

The Western Association of State Highway & Transportation Officials (WASHTO) QA Task Force (*6*) suggested that achievable quality levels should be based on a historical data base. However, if historical data are collected from construction controlled with traditional specifications, it may be biased. WASHTO recommends model QC/QA specifications be used to develop data bases. *NCHRP Synthesis of Highway Practice 38* (*2*) suggested the use of a sufficient number of unbiased test results to develop acceptance limits. AHD developed a historical data base by gradually implementing statistically based QC/QA specifications over three construction seasons (1990 to 1992).

With statistically based QC/QA specifications, quality control responsibility is transferred to the contractor, but quality assurance responsibility is retained by the owner (*6*). However, some state highway agencies have chosen to use contractor QC data for QA purposes with periodic duplicate testing to verify test results. AHD began using contractor QC data for computing pay factors in 1992. Therefore, differences in measurements need analysis to set criteria for ascertaining consistency.

Acceptance limits for one type of HMA mix may not be valid for other types (*2*). McMahon et al. (*1*) showed that in highway construction a substantial portion of variability comes from the material variation or the construction process itself. Most specifications use the same acceptance limits for all types of mixes: base, binder, and surface. Base/binder mixes are coarser, have lower asphalt contents, and are placed in thicker lifts than surface mixes. In addition, the use of modified binders is increasing and may possibly affect test results. Since material variability, sampling and testing variability, or both may be different for different types of mixes, possible differences should be investigated to ensure validity of established acceptance limits.

DATA COLLECTION AND RESEARCH PROGRAM

Data for this research were collected during the implementation of a QC/QA program for HMA construction by AHD. Data were collected on projects constructed from 1990 through 1992 and include measurements by AHD and various contractors. Data were collected for base (AHD 327 designation), binder (AHD 414 designation), surface (AHD 416 designation), and surface with latex modified binder (AHD 417 designation) mixes. Due to similarities, base (327) and binder (414) mixes were grouped and given the designation 414.

During 1990 a model QC/QA specification was applied to collect data from four construction projects with 12 different mixes. The projects were managed with existing specifications, but contractors were apprised of the consequences had QC/QA specifications been enforced. The model QC/QA specification was modified using 1990 data and a new trial specification was partially implemented to control HMA construction on 11 projects during 1991. Partial implementation meant that pay adjustments were applied at one-half the computed rate (i.e., if a pay reduction of 2 percent was computed, only a 1 percent reduction was applied). Data were collected for 21 different mixes on the 11 trial projects.

After evaluations of 1990 and 1991 data, further modifications were made to the specifications and they were applied to all HMA construction projects during 1992. This study includes data collected from 46 projects with 48 mixes constructed during 1992.

Properties used for QA include asphalt content measured with a nuclear gauge, air voids in total mix for Marshall compacted samples, and mat density measured with both nuclear gauge and field cores. However, this analysis includes data for asphalt content and air voids only. Asphalt content and air voids are expressed as a percentage of total mixture. Available data are summarized in Table 1.

Sampling and testing were conducted according to schedules in the specifications. Samples for AC and air voids were taken from loaded trucks at production plants and quartered. The contractor took one-quarter for testing, AHD took one-quarter but did not test samples every time, and two-quarters were set aside for referee testing, as required. This resulted in unequal testing frequencies for AHD and the contractor. In addition, specified frequencies varied from year to year, so inconsistencies occurred in available numbers of test results.

TABLE 1 Summary of Available Data

		Number of Mixes	
Year	Mix Type	Asphalt Content	Air Void Content
1992	414	3	3
	416	40	40
	417	5	5
1991	414	7	7
	416	14	14
	417	1	1
1990	414	6	4
	416	3	3
	417	3	3

Pay adjustments depend on the deviation of measured properties from target values. Table 2 presents the limiting criteria used from 1990 through 1992. The limiting values are for single tests and are based on deviation from target value. Target values are the job mix formula (JMF) asphalt content and 4 percent air void. The JMF asphalt content is different for different projects and the deviations from target values were used as the variable (i.e., Deviation, Δ = measured value − JMF). The target value for voids was always 4 percent, but, for consistency, the differences between measured voids and 4 percent were also used as the variable. Because JMF is a constant for any particular project, the standard deviation (SD) of Δ will be the same as SD of actual measurements. In addition means of Δ will provide a consistent measure of accuracy, relative to target value, for asphalt content as well as for voids.

The following two symbols will be used as variables: Δ_{AC} is measured asphalt content (percent) – JMF (percent) and Δ_V is measured air voids (percent) – 4 percent.

There was no statistically planned experiment for collecting data. Therefore, the data were collected in an uncontrolled environment. An important limitation is the unequal amount of data for comparison. Precise determination of actual effects of any factor requires a controlled experiment based on statistical procedures. Despite these limitations, the comparisons provide valuable insight into the accuracy and precision of HMA construction control and assurance measurements.

TABLE 2 Acceptance Limits

	1990		1991		1992	
Pay Factor	AC	Voids	AC	Voids	AC	Voids
1.00 (from)	0.00	-1.0	0.00	0.0	0.00	0.00
(to)	0.50	+1.0	0.70	1.0	0.45	1.20
0.98 (from)	0.00	-1.1	...	...	0.46	1.21
(to)	0.55	+1.3			0.49	1.30
0.95 (from)	0.00	-1.2	0.71	1.1	0.50	1.31
(to)	0.60	+2.0	0.80	2.0	0.54	1.44
0.90 (from)	0.00	-1.5	0.81	2.1	0.55	1.45
(to)	0.70	+2.5	0.90	3.0	0.63	1.68
0.80 (from)	0.00	-2.0	0.91	3.1	0.64	1.69
(to)	0.80	+3.0	above	above	above	above

Note: All the limit values are for the average of absolute deviations from the target (JMF) value except 1990 air void content. For 1990 air voids, the unsymmetrical acceptance limits are for the average of the arithmetic deviations from the target. For more than one test the limits given in the table are divided by $\sqrt{n}$, where n is the number of tests.

Dbase III Plus was used for synthesizing and sorting data and PC SAS (Statistical Analysis System) (*7*) was used for the statistical analysis. The *t*-test was used to compare means and the F-test to compare variances. A 5 percent level of significance or 95 percent level of confidence was used for all hypothesis testing. Hypothesis for mean was $H_o: \bar{x}_1 = \bar{x}_2$ and $H_a: \bar{x}_1 \neq \bar{x}_2$. Hypothesis for variability was $H_o: \sigma_1^2 = \sigma_2^2$ and $H_a: \sigma_1^2 \neq \sigma_2^2$.

RESULTS OF ANALYSIS

Comparison Between AHD and Contractor Asphalt Content

Analyses of AHD and contractor asphalt content measurements were made by comparing data for individual mixes. The results of these analyses are summarized in Table 3. The results in Table 3 are demonstrated by examining the 1992 416 mix row. Forty individual 416 mixes were examined in 1992. The number of measurements for individual mixes varied from 3 to 18 for AHD and 5 to 43 for contractors. When AHD and contractor asphalt content measurements were compared, only 4 of 40 were found to have significantly different variability. Of these four, AHD variabilities were larger in all cases. AHD and contractor mean deviations were significantly different for 16 of 40 individual mixes. Of the 16, AHD mean deviations were higher for 14 mixes.

A second way of comparing AHD and contractor asphalt content measurements was to combine data for each mix collected during 1 year and then to combine the data for all mixes. The results of these analyses are summarized in Table 4. The results in Table 4 are demonstrated by again examining the 1992 416 mix row. The AHD and contractor data for the 40 individual mixes were combined into two data sets, and the variances and mean deviations of these data sets compared. Table 4 indicates that the variances of the AHD and contractor 416 mix asphalt content measurements were significantly different and that AHD variability was higher. Table 4 also indicates that the mean deviations from target asphalt contents were significantly different and that mean AHD deviations were higher.

Numerical comparisons between AHD and contractor variances and deviations from target values were also made. Values for combined data are summarized in Table 5. Again using 1992 416 mix data for illustration, the standard deviation of AHD measurements for the 40 individual mixes was 0.244 percent compared to 0.175 percent for contractor measurements. These numbers indicate AHD measurement were not as precise as contractor measurements. Mean deviations from target values were −0.086 percent for AHD and −0.029 percent for contractors. These numbers indicate, on average, both AHD and contractor measurements smaller than JMF values and greater deviation from target values for AHD measurements.

Standard deviations and mean deviations from target values for combined mix data (Table 5) and individual mix data are plotted in Figures 1 and 2, respectively. The concentration of points below the line of equality in Figure 1 depicts the trend of greater AHD measurements variability indicated by the data in Tables 3–5. No such consistent trend is obvious for mean deviations in Figure 2.

On the basis of an analysis of the results in Tables 3–5 and Figure 1, the following inferences were drawn regarding the variability of AC measurements:

- AHD and contractor variabilities are not likely to be significantly different. Table 3 shows that only 6 individual mixes of 48 in 1992 and 3 of 12 in 1990 were significantly different. For 1991 none were significantly different. Results for combined group data shown in Table 4 indicate significantly different variability for only 5 of 12 cases.
- In cases in which AHD and contractor variabilities are significantly different, AHD variabilities are more likely to be higher.

TABLE 3 Summary of Statistical Analyses of Differences Between AHD and Contractor Asphalt Content Measurements for Individual Mixes

Year	Mix Type	Total no. of Mixes	Mixes With Significantly Different Variability	Mixes With Higher Variability	Mixes With Significantly Different Mean Deviation	Mixes With Higher Mean Deviation
1992	414	3	1	1A[a]& 0C[b]	0	...
	416	40	4	4A & 0C	16	14A & 2C
	417	5	1	1A & 0C	1	1A & 0C
	All	48	6	6A & 0C	17	15A & 2C
1991	414	7	0	...	1	1A & 0C
	416	14	0	...	5	2A & 3C
	417	1	0	...	0	...
	All	22	0	...	6	3A & 3C
1990	414	6	1	1A & 0C	2	1A & 1C
	416	3	2	0A & 2C	1	1A & 0C
	417	3	0	...	1	0A & 1C
	All	12	3	1A & 2C	4	2A & 2C

[a] A = AHD.
[b] C = Contractor.

TABLE 4 Summary of Statistical Analyses of Differences Between AHD and Contractor Asphalt Content for Combined Mix Data

Year	Mix Type	Significantly Different Variability	Higher Variability	Significantly Different Mean Deviation	Higher Mean Deviation
1992	414	yes	AHD	no	...
	416	yes	AHD	yes	AHD
	417	no	...	no	...
	Combined	yes	AHD	yes	AHD
1991	414	no	...	yes	Contractor
	416	no	...	yes	AHD
	417	no	...	no	...
	Combined	no	...	yes	Contractor
1990	414	yes	AHD	no	...
	416	no	...	no	...
	417	no	...	yes	Contractor
	Combined	yes	AHD	yes	AHD

- In general AHD variability is higher than contractor variability. This observation is true for mixes with and without significant differences. Differences were larger in 1992 than in 1990 or 1991.
- There was a general decrease in variability from 1990 to 1992.

On the basis of an analysis of the results in Tables 3–5 and Figure 2, the following inferences were drawn regarding the accuracy of AC measurements:

- AHD and contractor mean deviations from JMF asphalt content are not likely to be significantly different. Table 3 shows that about one-third of the mixes have significantly different mean deviations from JMF.
- In cases in which AHD and contractor mean deviations were significantly different, neither was consistently larger for 1990 and 1991 data.
- For 1992 data AHD results are consistently larger. In 1992 17 mixes had significantly different mean deviations, and AHD mean deviations were larger for 15 mixes.

The AC data indicate that variability decreased and accuracy increased from 1990 to 1992 and that AHD variabilities and mean

TABLE 5 Average Δ_{AC} and Standard Deviation σ_{AC} for Combined Mix Data

Year	Mix Type	Standard Deviation, σ_{AC}		Mean Deviation, Δ_{AC}	
		AHD	CON	AHD	CON
1992	414	0.226	0.175	0.042	-0.014
	416	0.244	0.175	-0.086	-0.029
	417	0.173	0.143	0.013	-0.013
	Combined	0.239	0.170	-0.060	-0.025
1991	414	0.267	0.232	-0.020	0.064
	416	0.208	0.212	-0.036	0.010
	417	0.179	0.173	0.109	0.154
	Combined	0.226	0.218	-0.023	0.033
1990	414	0.443	0.390	0.150	0.124
	416	0.561	0.547	0.464	0.319
	417	0.251	0.242	-0.004	-0.087
	Combined	0.452	0.406	0.163	0.111

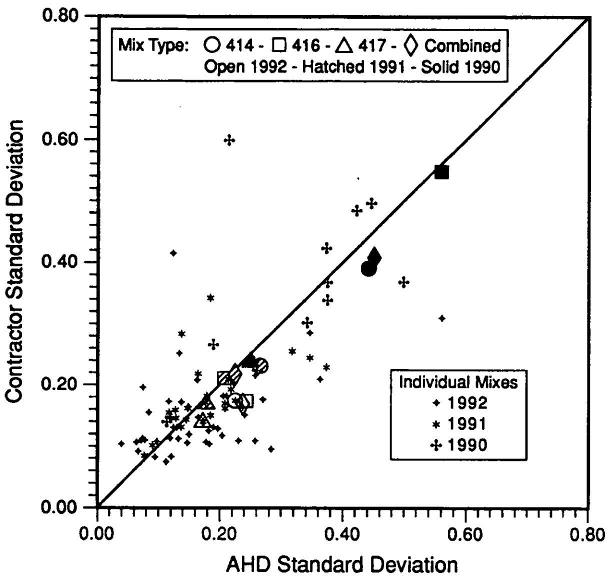

FIGURE 1 Summary of AHD and contractor asphalt content standard deviation.

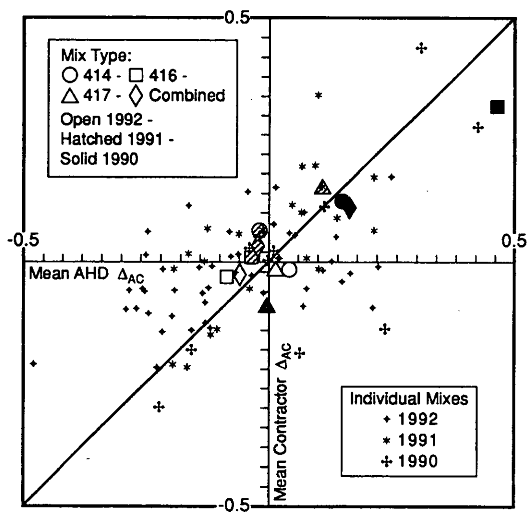

FIGURE 2 Summary of AHD and contractor asphalt content mean deviation.

deviations tend to be higher than those for contractors. Possible reasons for these trends are (*a*) improved technician training and experience, (*b*) implementation of a QC/QA program with application of price adjustments based on contractor test data, and (*c*) real improvements in the quality of HMA construction.

Stroup-Gardiner et al. (*3*) found that standard deviations of nuclear asphalt content gauge varied from 0.16 percent to 0.23 percent. These values were accepted by ASTM for development of ASTM D4125 precision statements. According to ASTM D2172, the extraction method single-laboratory standard deviation range to be used in precision statements is 0.19 percent to 0.21 percent and the recommended multilaboratory standard deviation range is 0.22 percent to 0.23 percent. The standard deviation for 1992 nuclear asphalt content gauge data for Alabama projects varied from 0.14 percent to 0.24 percent and is comparable to data reported by Stroup-Gardiner et al. and standard deviations used to develop ASTM precision statements.

Comparison Between AHD and Contractor Air Voids

Tables 6–8 and Figures 3 and 4 summarize the analysis of air void content data. The layout of the tables and the interpretation of data are the same as for asphalt content. As an example, the 1992 416 mix row in Table 6 contains comparisons of data from 40 individual mixes. AHD and contractor variabilities were different for only six mixes, and AHD variabilities were higher for four of these. AHD and contractor mean deviations from 4 percent voids were significantly different for only 2 of 40 individual mixes, and in both cases AHD mean deviations were larger.

Table 7 contains the results for combined mix data. When data for the 40 1992 individual 416 mixes were combined, the AHD variability was significantly higher, but AHD and contractor mean deviations from 4 percent voids were not significantly different.

Table 8 contains numerical values for the combined data. AHD and contractor standard deviations for combined 1992 416 mix data were 0.693 percent and 0.578 percent, respectively. Mean deviations from 4 percent voids for this data were −0.052 percent and −0.041 percent, respectively.

Individual and combined mix data are plotted in Figures 3 and 4. No consistent differences between AHD and contractor results are apparent.

From the analysis of the data in Tables 6–8 and Figures 3 and 4, the following inferences can be made regarding the variability of air void content measurements:

- Individual mixes show no appreciable difference between AHD and contractor variability. Only 6 mixes of 48 in 1992, 3 of 22 in 1991, and 2 of 10 in 1990 were significantly different. However, when data are combined, 7 of 12 cases have significantly different variability.
- In cases in which AHD and contractor variabilities are significantly different, AHD variabilities are more likely to be higher. Eight of 11 individual mixes and six of seven combined mixes with significantly different variability had higher AHD variability.
- As shown in Figure 3, 1991–1992 variabilities are less than 1990 variabilities and 1991–1992 AHD variabilities are consistently less than comparable contractor variabilities.

From the analysis the following inferences can be made regarding the accuracy of air void content measurements:

- AHD and contractor mean deviations from 4 percent air void content are not likely to be significantly different. Tables 6 and 7 show that few individual and combined mixes had significantly different mean deviations.
- The general trend indicated in Table 8 and Figure 4 is that the mean deviation from 4 percent target air voids gradually decreased over the years (1990 to 1992).
- Table 8 and Figure 4 provide no consistent indication that measured air voids were higher or lower than the target 4 percent.

The analysis indicates that variability decreased and accuracy increased from 1990 to 1992. This is the same trend observed for

TABLE 6 Summary of Statistical Analyses of Differences Between AHD and Contractor Air Void Content Measurements for Individual Mixes

Year	Mix Type	Total no. of Mixes	Mixes With Significantly Different Variability	Mixes With Higher Variability	Mixes With Significantly Different Mean Deviation	Mixes With Higher Mean Deviation
1992	414	3	0	...	0	...
	416	40	6	4A[a] & 2C[b]	2	2A & 0C
	417	5	0	...	1	1A & 0C
	All	48	6	4A & 2C	3	3A & 0C
1991	414	7	1	1A & 0C	0	...
	416	14	2	2A & 0C	1	1A & 0C
	417	1	0	...	0	...
	All	22	3	3A & 0C	1	1A & 0C
1990	414	4	1	1A & 0C	0	...
	416	3	1	0A & 1C	0	...
	417	3	0	...	2	1A & 1C
	All	10	2	1A & 1C	2	1A & 1C

[a] A = AHD.
[b] C = Contractor.

TABLE 7 Summary of Statistical Analyses of Differences Between AHD and Contractor Air Void Content for Combined Mix Data

Year	Mix Type	Significantly Different Variability	Higher Variability	Significantly Different Mean Deviation	Higher Mean Deviation
1992	414	no	...	no	...
	416	yes	AHD	no	...
	417	no	...	no	...
	Combined	yes	AHD	no	...
1991	414	yes	AHD	no	...
	416	yes	AHD	no	...
	417	no	...	no	...
	Combined	yes	AHD	no	...
1990	414	yes	AHD	no	...
	416	no	...	no	...
	417	yes	Contractor	yes	AHD
	Combined	no	...	no	...

asphalt content and possible reasons are the same as previously discussed.

Adettiwar (*8*) conducted a study to gather data for preparing precision statements for different HMA property tests. He reported air voids standard deviation of 0.62 percent for single-laboratory and 0.97 percent for multilaboratory testing. According to ASTM D3203, single-laboratory standard deviation is 0.51 percent and multilaboratory standard deviation is 1.09 percent for nonporous aggregates. The standard deviations for 1992 data varied from 0.50 percent to 0.69 percent and from 0.40 percent to 1.13 percent for 1990 through 1991 data. These values are comparable with both ASTM standard values and Adettiwar's study.

Comparison of Asphalt Content Among Mix Types

Table 9 summarizes the comparisons among asphalt contents of the three mixes considered. No strong indication of differences or sim-

TABLE 8 Average Δ_V and Standard Deviation σ_V for Combined Mix Data

Year	Mix Type	Standard Deviation, σ_V AHD	Standard Deviation, σ_V CON	Mean Deviation, Δ_V AHD	Mean Deviation, Δ_V CON
1992	414	0.504	0.522	0.005	0.107
	416	0.693	0.578	-0.052	-0.041
	417	0.552	0.517	0.059	0.114
	Combined	0.660	0.567	-0.033	-0.001
1991	414	0.656	0.517	0.032	0.034
	416	0.703	0.595	0.229	0.100
	417	0.552	0.397	0.430	0.202
	Combined	0.688	0.565	0.188	0.090
1990	414	1.130	0.996	0.358	0.370
	416	0.884	0.982	-0.413	-0.386
	417	0.660	0.881	-0.269	0.002
	Combined	1.085	1.007	0.160	0.225

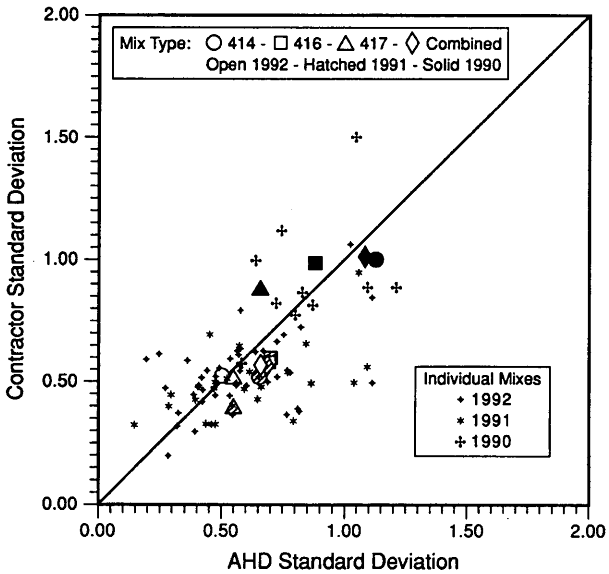

FIGURE 3 Summary of AHD and contractor air void content standard deviation.

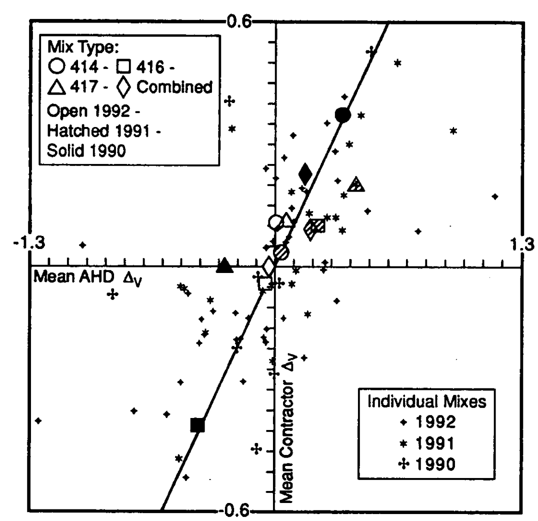

FIGURE 4 Summary of AHD and contractor air void content mean deviation.

ilarities in variability or accuracy are apparent between 414 and 416 mix or 414 and 417 mix. Comparison of 416 mix and 417 mix reveals significantly different variability four of six times and significantly different mean deviation five of six times. The 1991 data do not follow this trend, but there was only one project with 417 mix in 1991 and the number of measurements was small. In addition, the variability and mean deviation from target JMF are generally greater for 416 mix than for 417 mix. The only difference between 416 and 417 mixes is the addition of latex to 417 mixes, and there are no obvious reasons why this should improve the precision and accuracy of asphalt content measurements. The opposite effect might be expected considering that the nuclear gauge measures only the presence of hydrogen atoms. However, this will not be an effect if actual modified or unmodified asphalt cements are used during calibration. Even if unmodified asphalt cement were used in the calibration, the effects of latex should be minimal since the hydrogen content of latex and asphalt cement are both about 10 percent (*9,10*).

Comparison of Air Voids Among Mix Types

Comparisons among air void contents of the three mixes considered are summarized in Table 10. There are no strong indications that the

TABLE 9 Summary of Comparison of Mixes for Asphalt Content

Comparison Between Mixes	Year	Agency	Significantly Different Variability	Higher Variability	Significantly Different Mean Deviation	Higher Mean Deviation
414 & 416	1992	AHD	no	...	yes	416
414 & 416	1992	CON	no	...	no	...
414 & 416	1991	AHD	yes	414	no	...
414 & 416	1991	CON	no	...	yes	414
414 & 416	1990	AHD	yes	416	yes	416
414 & 416	1990	CON	yes	416	yes	416
414 & 417	1992	AHD	no	...	no	...
414 & 417	1992	CON	yes	414	no	...
414 & 417	1991	AHD	no	...	no	...
414 & 417	1991	CON	no	...	yes	417
414 & 417	1990	AHD	yes	414	yes	414
414 & 417	1990	CON	yes	414	yes	414
416 & 417	1992	AHD	yes	416	yes	416
416 & 417	1992	CON	yes	416	no	...
416 & 417	1991	AHD	no	...	yes	417
416 & 417	1991	CON	no	...	yes	417
416 & 417	1990	AHD	yes	416	yes	416
416 & 417	1990	CON	yes	416	yes	416

mixes are significantly different in terms of mean deviation or variability. In addition, numerical comparison did not show any particular trend.

CONCLUSIONS AND RECOMMENDATIONS

The historical data base obtained during implementation of the AHD QC/QA program for HMA was analyzed and the following conclusions and recommendations were developed.

Conclusions

- The mean deviations from target values and variabilities of measured asphalt content and air voids decreased from 1990 to 1992. This decrease indicates improved construction quality, improved sampling and testing by better trained and experienced technicians, or both. This observation emphasizes the need to check periodically the validity of the historical data base used to set acceptance criteria.
- There are no strong indications of statistically significant effects of the measuring agency on mean deviations from JMF or variabilities of asphalt content or air voids. However, AHD mean deviations and variabilities tended to be consistently higher than those of contractors.
- Use of latex as a modifier in surface mix has a significant effect on the determination of asphalt content by nuclear gauge. Latex reduces the variability and increases the accuracy relative to target value of asphalt content measurements.
- Measured variabilities for asphalt content and air voids compare well with those of other researchers.

TABLE 10 Summary of Comparison of Mixes for Air Void Content

Comparison Between Mixes	Year	Agency	Significantly Different Variability	Higher Variability	Significantly Different Mean Deviation	Higher Mean Deviation
414 & 416	1992	AHD	yes	416	no	...
414 & 416	1992	CON	no	...	yes	414
414 & 416	1991	AHD	no	...	no	...
414 & 416	1991	CON	no	...	no	...
414 & 416	1990	AHD	yes	414	yes	416
414 & 416	1990	CON	no	...	yes	416
414 & 417	1992	AHD	no	...	no	...
414 & 417	1992	CON	no	...	no	...
414 & 417	1991	AHD	no	...	yes	417
414 & 417	1991	CON	no	...	no	...
414 & 417	1990	AHD	yes	414	yes	414
414 & 417	1990	CON	no	...	yes	414
416 & 417	1992	AHD	no	...	no	...
416 & 417	1992	CON	no	...	yes	417
416 & 417	1991	AHD	no	...	no	...
416 & 417	1991	CON	yes	416	no	...
416 & 417	1990	AHD	yes	416	no	...
416 & 417	1990	CON	no	...	yes	416

Recommendations

- Reasons for consistently higher AHD variability.and deviation from JMF should be investigated with a series of carefully controlled experiments.
- The effect of latex modifier on the nuclear method for asphalt content measurement should be investigated further.

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