A Statistical Study of Asphaltic-Concrete

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A typical New Jersey State Department of Transportation construction project was selected to establish average values and variability parameters for asphaltic pavement material characteristics, such as asphalt content and gradation, presently used as measures of quality. The effect of variations in material or the material production process, sampling, and field and laboratory testing on the measured variability parameters are discussed. A comparison is made between present field and laboratory testing to determine the possibility of reducing the number of tests normally run on a construction project. The validity of the Department's present sampling and testing processes, and the adequacy of its present asphaltic-concrete specifications are studied.

A FORTRAN computer program was used to perform the analysis.

Findings indicate that for New Jersey, field testing alone cannot as yet supplant laboratory testing as the basis for final judgment on material compliance. For the asphaltic content determination, it was established that the Department's present sampling and laboratory testing processes are as valid (in uniformity) as those typical of the highway field today. It was found that in general the asphaltic-concrete specifications, for the construction project studied, dealt fairly with the material supplier allowing sufficiently for the natural variabilities encountered. However, a few important exceptions were noted which occurred in the critical areas of the asphaltic-concrete test. In these instances the specifications were found to be overly restrictive for the present capabilities of the production, sampling, and testing processes.

•THE NEW JERSEY State Department of Transportation has recently completed its initial research project in the area of statistical quality control. One phase of this project dealt with a statistical investigation of asphaltic paving materials. The purposes of this investigation were as follows.

1. To establish, for the asphaltic paving materials of a normal construction job, average values and variability parameters for the material characteristics currently used as measures of quality (asphalt content, gradation, etc.).
2. To determine, through analysis of variance, the effect on measured variability parameters of variations in the material, the material production processes, sampling, and testing.
3. To compare, through the use of the specialized sampling and testing plan required for the analysis of variance, the present field and laboratory testing processes.
4. To use the statistical data from this and similar studies to determine the validity of the Department's present sampling and laboratory testing processes and to provide information on the adequacy of its present specifications.

This project was performed in conjunction with the quality control research program established by the U. S. Bureau of Public Roads. The purpose is essentially to gather,

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from the various state highway agencies, statistical parameters that can be used to establish statistical quality control procedures for highway construction. It was intended that the statistical data established in New Jersey's investigation be provided to the Bureau to augment its information on asphaltic-concrete.

The procedure used in the Department's investigation was outlined in the Bureau of Public Roads' research guide, The Statistical Approach to Quality Control in Highway Construction (1). Random sampling and testing plans were employed which provided test data in an appropriate form for the desired statistical analysis. The actual analysis was done with a FORTRAN computer program given in the Bureau's research guide.

A comparison of field, or at-the-plant testing, with laboratory testing was made to determine the possibility of reducing the number of tests now being performed on any one job. At the present time, daily production control is handled through mixture samples taken and tested by Department inspectors at the asphaltic or bituminous concrete plant. Duplicates of the plant-tested samples are also sent to the Department's main laboratory in Trenton to verify the field results. In addition, for the wearing course and the stabilized base components of a pavement, samples of the actual pavement are obtained for laboratory testing, to establish a final record of material compliance. This testing program results in the same material being tested two or occasionally three times.

For obvious economic reasons, the Department wishes to eliminate laboratory testing, either totally or in part, and to rely primarily on field test results to establish material compliance. It is willing to make this change, however, only if field testing can be shown to measure compliance, throughout the state, in as nearly uniform a manner as that currently provided by the main laboratory. In the investigation described, a within-laboratory testing variance was first established for the main laboratory. This was then compared to a combined within-and-between-plant testing variance for the field, to ascertain the practicability of making the desired testing changes.

SCOPE

The construction job selected called for the resurfacing of a previously constructed route. Two types of bituminous materials were specified: FABC-top (wearing course), and FABC-bottom (binder course). On mixture samples from each of these materials, determinations of asphalt content and aggregate gradation were made. The statistical parameters evaluated for each of the foregoing characteristics were the mean ($\bar{x}$), the overall variance, standard deviation (square root of overall variance), and the components of variance for testing, for sampling, and for the material production process.

MATERIALS AND BATCHING EQUIPMENT

The construction job studied used some 26,000 tons of FABC-top and approximately 27,000 tons of FABC-bottom. A 5,450-ton portion of each material was selected for the in-depth sampling. The "lot volume" was in accordance with the 50 sampling units suggested by the Bureau of Public Roads, at a ratio of one sample unit per each 90 to 110 tons of mix.

In both materials, crushed trap rock and bituminous sand were combined with a 60 to 70 asphalt-cement to achieve the desired mixtures. For the top or wearing course material, a filler of dolomite dust was also used. The two types of mixtures were required to meet the specifications given in Table 1.

The binder course material sampled was mixed in 4-ton batches at a Batch-O-Matic plant having a twin shaft pugmill mixer. Five hot bins were used for aggregate storage with their batch quantities and the amount of asphalt all being controlled automatically. The mixing time employed for each batch was 5 sec dry and 30 sec wet. The specified mixture temperature was 300±15 F.

A continuous-mix plant with an output of 200 tons/hr was used for production of the FABC-top material. Aggregate storage was accommodated in 4 hot bins, with mixing

TABLE 1

SPECIFICATIONS FOR TOP AND BOTTOM COURSE ASPHALTIC-CONCRETE[a]

Item	Top Course	Bottom Course
Percent asphalt content	6.2±0.3	4.7±0.3
Percent stone content (retained on No. 10)	40±4	70±5
Percent pass. 1½ in. and retained on 1 in.	–	0-35
Percent pass. 1 in. and retained on ½ in.	0-10	25-70
Percent pass. ½ in. and retained on ¼ in.	12-40	0-20
Percent pass. ¼ in. and retained on No. 10	8-30	0-15
Percent pass. No. 10 and retained on No. 30	2-17	1-11
Percent pass. No. 30 and retained on No. 50	4-24	2-15
Percent pass. No. 50 and retained on No. 80	6-22	2-14
Percent pass. No. 80 and retained on No. 200	3-20	2-13
Percent pass. No. 200	4-8	0-5

[a] The New Jersey Department of Transportation utilizes target values only for asphalt and stone contents. The Department's present method of test for sieve analysis specifies the use of both perforated plate screens and wire cloth sieves. The screen sizes employed are 1½, 1, ½ and ¼ in.; the sieve sizes are numbers 10, 30, 50, 80, and 200.

performed by a twin shaft pugmill. All processed material was subjected to a mixing time of 47.5 sec. The mixing time was given by the following formula:

$$\text{Mixing time (sec)} = \frac{\text{pugmill dead capacity (lb)}}{\text{pugmill output (lb/sec)}}$$

The mixture temperature specified for the binder course material was the same as that of the top: 300±15 F.

SAMPLING

At each plant 227 trucks were required to achieve a material lot volume of 5450 tons. Only 50 were subjected to sampling. The trucks sampled were chosen with a

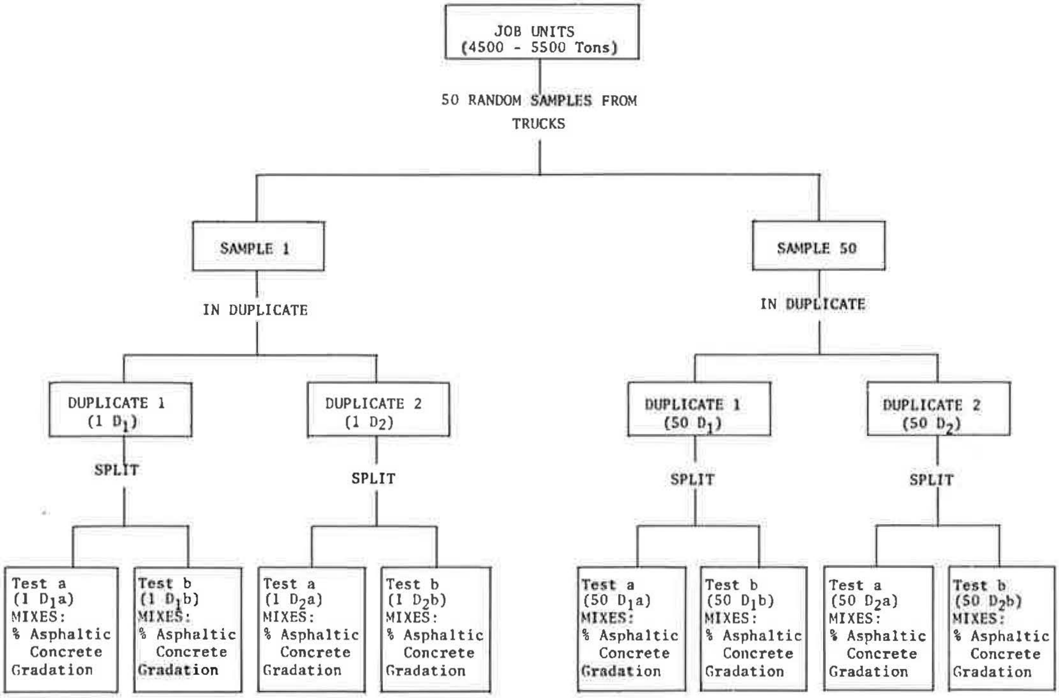

Figure 1. Sampling plan.

table of random numbers. For each truck, two 1-ft deep furrows were dug in the conical pile of asphaltic material extending from apex to base. One furrow was in the rear of the truck; the other in the front. In each furrow, three approximately equal-volumed scoops of material were taken—one at the apex, one at center, and one at the base of the pile. The three scoops were thoroughly mixed together to form one sample volume of approximately 11 lb. The sample volume from one furrow was labeled duplicate sample no. 1 and that from the other, duplicate sample no. 2.

When all sampling was completed, duplicates were sent to the Department's Trenton laboratory to be divided into test portions. Each duplicate was cut into quarters, and the diagonally opposite quarters were combined to form two test portions per duplicate sample.

The samples taken in accordance with this plan (Fig. 1) were in addition to those obtained by the plant inspectors for their normal plant control work.

It was originally intended to take temperature measurements in each of the furrows of a sampled truck. But the time required for the thermometers to reach a temperature equilibrium with the bituminous concrete was so long that the special sampling operation began to interfere with the flow of material out of the plants. To avoid excessive disruptions in normal plant activities, the temperature measurements were discontinued.

TESTING

To obtain variability values for both field and laboratory testing processes, testing was divided equally between the two testing areas: for each of the two material types (top and bottom) 25 of the 50 lot samples (including four test portions per sample) were tested in the main laboratory and 25 in the field.

The field testing was performed at five different bituminous-concrete plants, using available plant testing equipment. At each plant, only one set of testing apparatus was used. Thirteen experienced Departmental plant inspectors performed the actual testing. The bituminous material for field analysis was distributed so that the four test portions of any one sample were each analyzed at a different plant. This mode of distribution was selected so that a measure of the total testing variability, both within and between typical field testing plants, could be obtained.

Laboratory testing was performed by five experienced technicians utilizing all the normally employed equipment which included: four different sets of sieves, two shakers, three balances, and two centrifuges. ASTM Method D 2172-63T Method A(2) was used for asphalt content determinations in both the laboratory and the field. Sieve analysis of extracted aggregate was performed in accordance with AASHO Method T 30 (3). These methods are currently standard testing methods for the Department.

DATA ANALYSIS

As samples were obtained in a manner conforming to the experimental design suggested by the U.S. Bureau of Public Roads (BPR), test results were suitable for analysis with the computer program provided in the BPR's research guide.* This program was used to determine all the statistical parameters desired in the study. The procedure of the program for analysis of variance is based on the assumption that the variances considered are additive and that overall variance is the sum of three components: process variance, sampling variance, and testing variance. This assumption is given by

$$\sigma'^2 = \sigma_p^2 + \sigma_s^2 + \sigma_t^2$$

where

σ'^2 = overall variance of measurements,

σ_p^2 = process or material variance,

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*Copies of the program are available from the author upon request.

σ_s^2 = variance due to random errors of sampling, and

σ_t^2 = variance due to random errors of testing.

The initial step in the analysis was to determine the separate variability values for the two types of testing used. For each material, the laboratory testing variability was evaluated by first analyzing, with the BPR program, only the laboratory data (100 test results per material, 25 samples at four tests per sample). The testing variances calculated were then taken as measures of the variability of testing within the main laboratory. The same approach was used with the field data, analyzing them separately to establish a set of testing variances for the field testing process. These latter variances, however, had a different meaning from those for the main laboratory. The field testing variances, in reality, were measures of the combined testing variability within and between the plants (field testing laboratories) used.

The remaining statistical parameters required were determined by combining the field and laboratory results for each material and running the combined data a second time through the Bureau's program.

DISCUSSION OF FINDINGS

Normality Check

For the purpose of determining the adaptability of the test data to standard statistical treatment, several checks were made to ascertain how well the data distribution for each test characteristic agreed with the theoretical normal distribution. The first approach consisted of plotting frequency histograms and looking for signs of pronounced skewness or multimodal tendencies. Plots of cumulative frequencies were made on normal probability paper, and the resulting curves were compared to the diagonal straight line of the normal curve. The last technique employed consisted of comparing areas under the normal curve within specified limits of the mean with those areas under the test distribution defined by the same limits (Table 2).

The use of the foregoing techniques revealed only one excessive deviation from the normal curve. Test data for the 1-in. screen on the top material had an extremely skewed distribution. Figure 2 shows the frequency histogram and cumulative frequency plot of the 1-in. screen data. The skewness is to be expected and is caused by the material having an average passing percentage very close to the zero percent limit.

Except for a few instances of slight peakedness, the remainder of the data conformed fairly well to the theoretical normal curve and appeared suitable for use with standard statistical methods.

TABLE 2

COMPARISON OF AREAS OF TEST DISTRIBUTIONS WITHIN SPECIFIED LIMITS WITH THOSE OF THEORETICAL NORMAL CURVE

Test Property	Percentages Within Given Limits					
	Top Material			Bottom Material		
	$\bar{x}$ $\pm 0.675\sigma$	$\bar{x}$ $\pm\sigma$	$\bar{x}$ $\pm 2\sigma$	$\bar{x}$ $\pm 0.675\sigma$	$\bar{x}$ $\pm\sigma$	$\bar{x}$ $\pm 2\sigma$
Normal curve	50.0	68.3	95.5	50.0	68.3	95.5
AC	53.0	72.5	97.0	53.0	67.5	95.0
SC	51.0	75.5	95.5	55.0	70.5	94.5
Passing 1½ in. and retained on 1 in.	—	—	—	57.0	75.5	97.0
Passing 1 in. and retained on ½ in.	61.0	82.5	96.1	52.0	74.0	96.0
Passing ½ in. and retained on ¼ in.	47.5	70.5	95.5	52.5	67.5	94.5
Passing ¼ in. and retained on No. 10	56.0	70.5	95.0	58.0	76.0	92.0
Passing No. 10 and retained on No. 30	53.5	72.5	96.5	49.0	69.0	91.0
Passing No. 30 and retained on No. 50	53.0	72.5	98.5	50.5	68.0	95.0
Passing No. 50 and retained on No. 80	48.0	63.0	97.0	50.0	67.5	95.0
Passing No. 80 and retained on No. 200	50.5	70.5	96.0	46.0	66.5	95.0
Passing No. 200	63.0	80.5	93.0	46.0	65.0	94.5

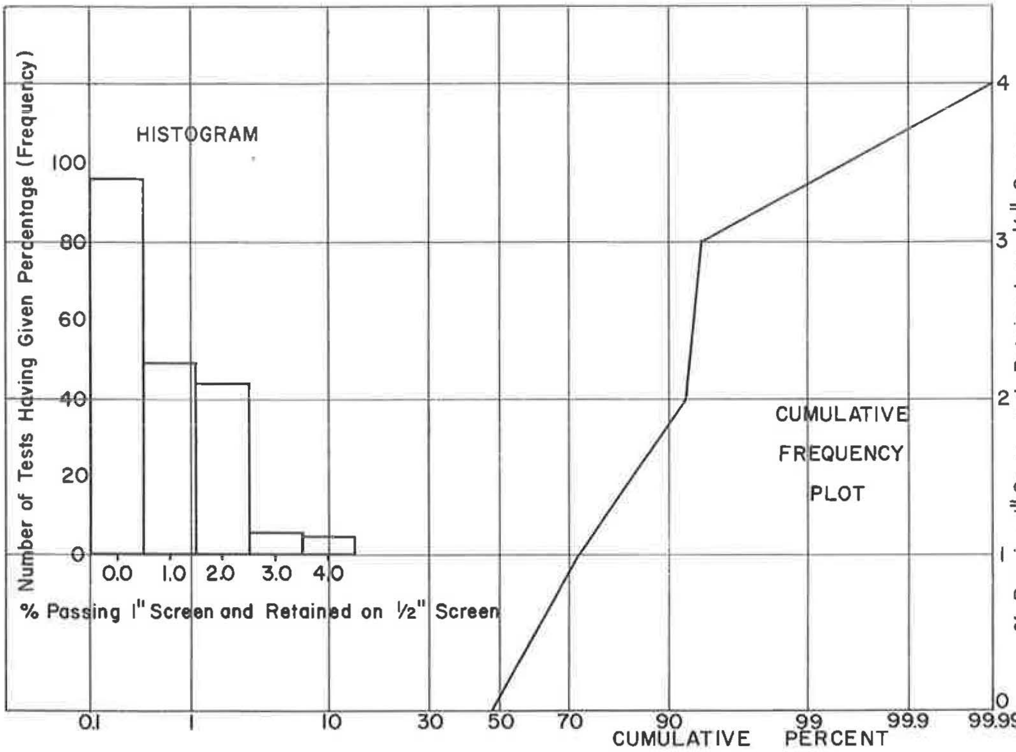

Figure 2. Normality checks of test data on percent passing 1-in. screen and retained on $\frac{1}{2}$-in. screen for top material.

Differences in Laboratory and Field Testing

The results of the separate analysis of testing variabilities are given in Table 3. For each test property, a testing variance for both the laboratory and the field is provided. In a majority of the cases the field testing variance (within and between field laboratory testing variance) exceeds the laboratory value (within main laboratory testing variance); for 15 out of the 21 test properties the field variance is largest.

A statistical F test at the 5 percent level was made to determine how many of the observed variance differences were actually significant. The results (Table 3) showed that only 10 of the 21 was significantly different. However, in 7 significant cases the field variance was the largest. Of greater importance, 5 of the 7 occurred in the critical areas of the bituminous test: the determinations of asphalt content, stone content, and passing the No. 200 sieve.

Field testing variance was significantly larger for all 3 critical properties on the top material and for 2 of the 3 on the bottom material. The excessiveness of the field variability was particularly striking for the asphalt content determination. With variabilities expressed as variances, field testing for asphalt content was nearly 20 times more variable than laboratory testing on top material, and 15 times more variable on bottom material.

The large field testing variances appear to be primarily due to differences between testing plants. If no difference in test method existed between field testing locations, the mean of the test results for each field testing plant should have been approximately the same. In the instances of large field testing variance, these means were strikingly

TABLE 3

TESTS FOR SIGNIFICANCE OF VARIANCE DIFFERENCE BETWEEN FIELD AND LABORATORY TESTING (5% Level)

Test Property	Testing Variance		Largest Variance	Computed F Ratio	Critical F Ratio	Significant Difference
	Laboratory Value	Field Value				
(a) Top						
Percent asphalt content	0.0088	0.1734	Field	19.70	1.75	Yes
Percent stone content	1.5500	2.9040	Field	1.87	1.75	Yes
Sieve analysis						
Percent passing 1 in. and retained on ½ in.	0.7200	1.0358	Field	1.44	1.75	No
Percent passing ½ in. and retained on ¼ in.	2.6100	6.2827	Field	2.41	1.75	Yes
Percent passing ¼ in. and retained on No. 10	0.9200	0.7246	Lab	1.27	1.75	No
Percent passing No. 10 and retained on No. 30	0.9000	0.3591	Lab	2.51	1.75	Yes
Percent passing No. 30 and retained on No. 50	1.6400	1.8232	Field	1.11	1.75	No
Percent passing No. 50 and retained on No. 80	1.1700	0.9429	Lab	1.24	1.75	No
Percent passing No. 80 and retained on No. 200	0.7600	3.0043	Field	3.95	1.75	Yes
Percent passing No. 200	0.2900	0.5121	Field	1.76	1.75	Yes
(b) Bottom						
Percent asphalt content	0.0111	0.1658	Field	14.94	1.75	Yes
Percent stone content	2.9700	7.9839	Field	2.69	1.75	Yes
Sieve analysis						
Percent passing 1½ in. and retained on 1 in.	13.8400	19.7247	Field	1.42	1.75	No
Percent passing 1 in. and retained on ½ in.	17.1100	23.1702	Field	1.35	1.75	No
Percent passing ½ in. and retained on ¼ in.	8.0100	9.3947	Field	1.17	1.75	No
Percent passing ¼ in. and retained on No. 10	3.0000	1.4930	Lab	2.01	1.75	Yes
Percent passing No. 10 and retained on No. 30	0.6200	0.3234	Lab	1.92	1.75	Yes
Percent passing No. 30 and retained on No. 50	0.5400	0.8708	Field	1.61	1.75	No
Percent passing No. 50 and retained on No. 80	0.4600	0.4776	Field	1.04	1.75	No
Percent passing No. 80 and retained on No. 200	0.8700	0.9584	Field	1.10	1.75	No
Percent passing No. 200	0.3000	0.2867	Lab	1.05	1.75	No

different. With the asphalt content determination, mean differences were almost as large as the entire specification range. This suggests that an extremely significant disparity existed in either equipment, procedure, or testing technique from one plant to another during this study.

These findings indicate that in the more important areas of the bituminous concrete test, for top and bottom material, there is a lack of uniformity in the field in relation to the laboratory. This discrepancy appears to be the result of a deficiency in the standardization of the field testing method.

Individual Test Results

Table 4 summarizes all test results and includes the mean and standard deviations for each tested property. It also indicates the percentage of tests that fell within and outside the specification limits. For more than half of the test characteristics or properties, all samples tested were within the desired limits. Furthermore, for the passing 1½ in., 1 in., ½ in., ¼ in., and No. 200 properties on bottom material, failures were recorded on only one end of the specification. For the ½-in. data, a comparison of the mean and standard deviation with the specification center value and tolerance (in parentheses above the mix specification Table 4b) shows that the failures resulted primarily because the material's average was too far above the middle of the specification range. For the other four sieves this same effect, combined with the occurrence of a few extreme values, seems to account for the small failing percentages reported.

The remaining failures occur in the three critical areas of the bituminous test (asphalt content, stone content), and passing No. 200 for top course and asphalt content and stone content for bottom course. These properties have failures at both ends of the specification. The failure of material at both the upper and lower limits is an in-

TABLE 4

SUMMARY OF EXTRACTION TEST RESULTS

Test Property	Mix Specification	No. of Tests	Mean	Std. Dev.	Percent of Tests		
					Within Spec.	Below Spec.	Above Spec.
(a) Top Mixture							
Percent asphalt content	6.2±0.3	200	6.40	0.335	64.0	4.0	32.0
Percent stone content (retained on No. 10)	40±4	200	41.51	2.904	83.0	1.0	16.0
Percent passing 1 in. and retained on ½ in.	(5±5) 0-10	200	0.875	1.019	100.0	0.0	0.0
Percent passing ½ in. and retained on ¼ in.	(21±9) 12-40	200	26.35	2.980	100.0	0.0	0.0
Percent passing ¼ in. and retained on No. 10	(19±11) 8-30	200	14.27	1.987	100.0	0.0	0.0
Percent passing No. 10 and retained on No. 30	(9.5±7.5) 2-17	200	9.07	1.623	100.0	0.0	0.0
Percent passing No. 30 and retained on No. 50	(14±10) 4-24	200	12.32	1.520	100.0	0.0	0.0
Percent passing No. 50 and retained on No. 80	(14±8) 6-22	200	12.68	1.516	100.0	0.0	0.0
Percent passing No. 80 and retained on No. 200	(11.5±8.5) 3-20	200	12.22	1.637	100.0	0.0	0.0
Percent passing No. 200	(6±2) 4-8	200	5.49	1.141	92.5	5.0	2.5
(b) Bottom Mixture							
Percent asphalt content	4.7±0.3	200	4.83	0.433	58.5	13.5	28.0
Percent stone (retained on No. 10)	70±5	200	68.38	3.169	87.0	10.5	2.5
Percent passing 1½ in. and retained on 1 in.	(17.5±17.5) 0-35	200	9.57	5.313	99.5	0.0	0.5
Percent passing 1 in. and retained on ½ in.	(47.5±22.5) 25-70	200	34.84	5.136	97.5	2.5	0.0
Percent passing ½ in. and retained on ¼ in.	(10±10) 0-20	200	16.56	4.596	82.0	0.0	18.0
Percent passing ¼ in. and retained on No. 10	(7.5±7.5) 0-15	200	7.37	2.638	99.0	0.0	1.0
Percent passing No. 10 and retained on No. 30	(6±5) 1-11	200	4.39	0.941	100.0	0.0	0.0
Percent passing No. 30 and retained on No. 50	(8.5±6.5) 2-15	200	6.20	1.011	100.0	0.0	0.0
Percent passing No. 50 and retained on No. 80	(8±6) 2-14	200	6.60	1.029	100.0	0.0	0.0
Percent passing No. 80 and retained on No. 200	(7.5±5.5) 2-13	200	6.93	1.340	100.0	0.0	0.0
Percent passing No. 200	(2.5±2.5) 0-5	200	2.54	0.653	99.5	0.0	0.5

dication that the variability of test data is in excess of that allowed by the specification. This is confirmed by the fact that, in all five cases cited, four times the standard deviation (for data normally distributed this would encompass 95.5% of the test results around their mean) is in excess of the specification range. This excessive variability of the data does not necessarily indicate that the material itself is too variable; it may be the result of undue testing or sampling variability. The exact cause of the excessive overall variations can be ascertained from the analysis of variance.

Analysis of Variance

Table 5 gives the results of the analysis of variance performed on the test data from the two plants. For each property tested, the table gives the overall variance of the data, the standard deviation, and the three components of the total variance: the process, sampling, and testing variances. Inasmuch as the laboratory and the field test

TABLE 5

ANALYSIS OF VARIANCE—EXTRACTION TEST RESULTS

Test Property	Variance				Std. Dev.
	Process	Sampling	Testing	Total	
(a) Top Mixture					
Percent asphalt content	0.0216	0.000	(0.0088) 0.0911	0.1127	0.335
Percent stone content (retained on No. 10)	5.0439	1.1623	(1.5500) 2.2270	8.4331	2.904
Percent passing 1 in. and retained on ½ in.	0.1405	0.0000	(0.7200) 0.8779	1.0384	1.019
Percent passing ½ in. and retained on ¼ in.	3.3819	1.0503	(2.6100) 4.4463	8.8785	2.980
Percent passing ¼ in. and retained on No. 10	2.8679	0.2586	(0.9200) 0.8223	3.9488	1.987
Percent passing No. 10 and retained on No. 30	1.7195	0.2837	(0.9000) 0.6295	2.6328	1.623
Percent passing No. 30 and retained on No. 50	0.5774	0.0000	(1.6400) 1.7316	2.3090	1.520
Percent passing No. 50 and retained on No. 80	0.8620	0.3803	(1.1700) 1.0565	2.2993	1.516
Percent passing No. 80 and retained on No. 200	0.0000	0.7961	(0.7600) 1.8821	2.6782	1.637
Percent passing No. 200	0.4927	0.4085	(0.2900) 0.4011	1.3022	1.637
(b) Bottom Mixture					
Percent asphalt content	0.0421	0.0573	(0.0111) 0.0885	0.1878	0.433
Percent stone content (retained on No. 10)	2.4201	2.1425	(2.9700) 5.4770	10.0395	3.169
Percent passing 1½ in. and retained on 1 in.	5.1919	6.2548	(13.8400) 16.7823	28.2291	5.313
Percent passing 1 in. and retained on ½ in.	0.8170	5.4197	(17.1100) 20.1401	26.3768	5.136
Percent passing ½ in. and retained on ¼ in.	10.8057	1.6141	(8.0100) 8.7023	21.1221	4.596
Percent passing ¼ in. and retained on No. 10	3.2970	1.4145	(3.0000) 2.2465	6.9580	2.638
Percent passing No. 10 and retained on No. 30	0.2597	0.1541	(0.6200) 0.4717	0.8855	0.941
Percent passing No. 30 and retained on No. 50	0.1062	0.2097	(0.5400) 0.7054	1.0212	1.011
Percent passing No. 50 and retained on No. 80	0.1637	0.4267	(0.4600) 0.4688	1.0592	1.029
Percent passing No. 80 and retained on No. 200	0.3408	0.5396	(0.8700) 0.9142	1.7946	1.340
Percent passing No. 200	0.1327	0.0000	(0.3000) 0.2933	0.4260	0.653

results were combined for this portion of the analysis, the testing variances are actually averages of the individual variances for the two testing processes. The mathematics of the analysis of variance are such that these are straight arithmetic averages. For purposes of comparison, the laboratory testing variances are included (in parentheses above the averaged testing variance values).

To determine the cause of the excessive variability of test results in the five instances previously cited, a comparison was made of the variance components for the test properties involved. Examination of the components of the asphalt content determination for top material clearly shows that the testing variance is by far the largest factor indicating that most of the recorded variability was caused by testing. This averaged testing variance compared with that of the laboratory alone reveals that laboratory testing could not have been responsible for the excessive testing variability. The laboratory value is less than one-tenth of the averaged figure. The field testing,

TABLE 6

COMPARISON OF SPECIFICATION TOLERANCES WITH OVERALL VARIABILITIES ASSUMING LABORATORY TESTING

Test Property	Top Material				Bottom Material			
	Spec. Tolerance	σ'^{a}	$2\sigma'$	$3\sigma'$	Spec. Tolerance	σ'^{a}	$2\sigma'$	$3\sigma'$
Asphalt content	±0.30	0.174	0.35	0.52	±0.30	0.332	0.66	1.00
Stone content	±4.0	2.78	5.6	8.3	±5.0	2.74	5.5	8.2
Passing 1½ in. and retained on 1 in.	—	—	—	—	±17.5	5.04	10.1	15.1
Passing 1 in. and retained on ½ in.	±5.0	0.93	1.9	2.8	±22.5	4.84	9.7	14.5
Passing ½ in. and retained on ¼ in.	±9.0	2.65	5.3	8.0	±10.0	4.51	9.0	13.5
Passing ¼ in. and retained on No. 10	±11.0	2.01	4.0	6.0	±7.5	2.78	5.6	8.3
Passing No. 10 and retained on No. 30	±7.5	1.70	3.4	5.1	±5.0	1.02	2.0	3.1
Passing No. 30 and retained on No. 50	±10.0	1.49	3.0	4.5	±6.5	0.93	1.9	2.8
Passing No. 50 and retained on No. 80	±8.0	1.55	3.1	4.7	±6.0	1.02	2.0	3.1
Passing No. 80 and retained on No. 200	±8.5	1.16	2.3	3.5	±5.5	1.32	2.6	4.0
Passing No. 200	±2.0	1.06	2.1	3.2	±2.5	0.66	1.3	2.0

$^{a}\sigma' = \sqrt{\sigma_p^2 + \sigma_s^2 + \sigma_t^2}$ laboratory

therefore, had to be the primary causal factor for the high combined or averaged testing variance recorded. This same effect, to a lesser extent, also occurred in the other four cases of concern.

The influence of field testing, although significant, does not explain all the excessiveness in the questionable overall variabilities. After adjusting these parameters to account for the field testing effect, they still fail to be compatible with the governing specification limits. With an equitable specification and well-controlled production, sampling, and testing processes, the plus-or-minus tolerance should probably fall between ±2σ and ±3σ. The ±2σ allowance would provide for the acceptance of 95.5 percent of the production output; ±3σ would result in an output acceptance of 99.7 percent. Table 6 compares overall variabilities, assuming the use of only laboratory testing, with specification tolerances. There is an obvious inconsistency with this approach for the five test properties of concern. With these properties (asphalt content, stone content, and passing No. 200 sieve—top material, asphalt content and stone content—bottom material), the tolerances correspond to something less than ±2σ. This means that either a lack of control existed in the contributing variability factors (the production process, sampling, and laboratory testing) or that the specifications cannot be satisfied under existing standard controls. The actual situation can be established by comparing the variability parameters recorded here with those typical of the bituminous concrete field in general.

For the test properties shown previously to have no failing results, or failures at only one end of the specification (passing 1½-in. screen through No. 80 sieve on both materials, and passing the No. 200 sieve on bottom material), Table 6 indicates a different type of disparity with the ±2σ to ±3σ approach. For these properties, with the exception of the items passing ½ and ¼-in. screens on bottom material, the specification tolerances exceed ±3σ. In this instance, the specifications seem to have provided more allowance than was actually required for the existing variation. It appears that a target value approach, similar to that used with asphalt content and stone content properties, employing tolerance limits smaller than the present specification ranges, could have been used without additional burden on the supplier.

Comparison of Present Variability Parameters with Bureau of Public Roads Data

To check the validity of the Department's present sampling and laboratory testing processes, and to determine a reason for the five instances of inordinate overall variability, a comparison was made of the variability parameters of this study with those established by other state highway agencies. The data were extracted from a compilation of statistical parameters provided by the quality control task force of the Bureau of Public Roads (4) as a summary of its research findings to date. The sampling and testing variabilities for the asphalt content determination obtained by other states and those in this study are given in Table 7 in the form of variances. The corresponding

TABLE 7

COMPARISON OF VARIANCE COMPONENTS FOR ASPHALT CONTENT DETERMINATION

Data Source	Number of Tests	Variance Components		
		Process	Sampling	Testing
		(a) Top Material		
Present study	200	0.0216	0.0000	0.0088
U. S. Bureau of Public Roads				
State				
No. 14	200	0.066	0.006	0.002
No. 17	—	—	—	0.256
No. 17	—	—	—	0.256
No. 21	40	0.084	0.000	0.043
No. 21	24	0.06	0.00	0.05
No. 21	128	0.04	0.00	0.04
		(b) Bottom Material		
Present study	200	0.0421	0.0573	0.0111
U. S. Bureau of Public Roads				
State				
No. 17	—	—	—	0.0961
No. 17	—	—	—	0.0729
No. 21	284	0.04	0.04	0.06
No. 21	68	0.17	0.05	0.08
No. 21	380	0.09	0.06	0.06

process variances in each case are also included. Variability of our laboratory testing compares favorably with that of other states; most of the sources reporting have higher variability for both top and binder materials. The same is true of our sampling variability, except that for binder material ours is among the highest values reported. The process variances for this particular study are the lowest of all sources reporting. This may reflect the fact that the two plants involved in this investigation were automatically controlled systems reputed to have a high degree of uniformity in production.

Analysis of variance data was not available in the Bureau's tabulations for the other asphaltic-concrete test properties included in this study. However, data were provided on overall variability for the No. 10 (stone content) and No. 200 sieve characteristics. This information is given in Table 8 along with the overall variability values (standard deviations assuming the use of only laboratory testing) determined in the present study. Our measured variabilities, again, compare favorably, being below the weighted average of other states in all instances, with the exception of the No. 200 sieve property for top material. For this characteristic, however, the overall standard deviation is still within the range of values recorded by other states.

It can be inferred from the latter comparisons that our sampling and laboratory testing processes for the No. 10 and No. 200 sieves are also on a par with those typical of the highway field today. This is only an inference, however. The overall variabilities compared are a function of material variability, in addition to the sampling and testing factors. It is possible that small material variances produced the small overall variabilities obtained. A more comprehensive check of the validity of sampling and testing for these and the remaining properties of the asphaltic-concrete test cannot be accomplished until additional variance component data are provided by the Bureau of Public Roads.

From the preceding discussion it is evident that in the five instances of indicated excessive overall variability, the variability parameters were actually not inordinate by present standards. Therefore, the specification limits for these test properties (asphalt content, stone content, No. 200—top material; asphalt content, stone content—bottom material) were unrealistically restrictive in the control of materials at the two plants studied. Their narrow allowance for variations was incompatible with the present capabilities of asphaltic-concrete production, sampling, and testing. Whether or not this is the case on other construction projects for the state can only be conjectured. Further investigation is obviously necessary.

TABLE 8

COMPARISON OF OVERALL STANDARD DEVIATIONS ON PASSING NO. 10 AND NO. 200 SIEVES

Sieve	Present Study	Range of BPR Report	Weighted Average
		(a) Top	
No. 10	2.78	2.0-5.0	3.14
No. 200	1.06	0.27-1.27	0.86
		(b) Bottom	
No. 10	2.74	2.67-3.9	3.67
No. 200	0.66	0.55-1.5	0.67

SUMMARY AND CONCLUSIONS

For FABC top and bottom in the critical areas of the asphaltic-concrete test, field testing is significantly more variable than main laboratory testing; this difference was extremely pronounced in the case of the asphalt content determination. The discrepancy appears to be primarily due to differences in field test method from one plant to another.

Testing variances were found in the variance analysis to contribute substantially to the overall variability of test results. This fact, combined with the observation that significant differences in test method exist between field testing locations, indicates that the replacement of laboratory testing by field testing, as the final means for measuring material compliance, would result in a marked decrease in the uniformity of the compliance-measuring process. Therefore, for FABC-top and FABC-bottom, it is concluded that field testing cannot as yet replace laboratory testing as the basis for final judgment of material compliance. A greater standardization of the field method (equipment, procedure, testing technique) is required before this change would be practicable.

For the two asphaltic-concrete plants included in this study, present specifications on top and binder asphaltic-concrete generally dealt fairly with the materials supplier. As specifications on individual test results, for the most part they made sufficient allowance for the natural variabilities encountered. There was also an indication that in the less critical areas of asphaltic testing a decrease in the specification ranges was possible if a target value approach were used. However, there were several important exceptions to these general observations. In the three critical areas of the asphaltic-concrete test, five of the six governing specifications were overly restrictive for the present capabilities of the production, sampling, and testing processes. In these instances a loosening of the limits appears required to provide an equitable specification.

A comparison with data supplied by the U. S. Bureau of Public Roads showed that the uniformity of the sampling procedures and laboratory testing process for the asphalt content determination is on a par with and, perhaps, even superior to that of other highway agencies. For this test property, therefore, the Department's present sampling and laboratory testing processes are at least as valid (in uniformity) as those typical of the highway field today.

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