

# STATISTICAL SPECIFICATION FOR THE ACCEPTANCE OF PUG MILL-MIXED BASE AND SUBBASE MATERIALS

M. C. Anday, Virginia Highway Research Council

This paper discusses the system currently used in Virginia for accepting pug mill-mixed base and subbase materials and a proposed system based on a job-mix band and a process tolerance concept. In developing the proposed system, we used a random sampling plan to collect samples from 14 plants in Virginia that produce subbase and base materials. The samples were tested to determine their gradation and liquid and plastic limits. From the results, average standard deviations for each property were determined and used for the selection of the job-mix band and the process tolerances. The proposed specifications, which permit acceptance or rejection of 2,000-ton lots, are believed to have the following advantages: The use of a job-mix band should result in more uniformly graded materials; job-mix bands developed by use of average standard deviations will allow flexibility in the operations of the plants; and the process tolerances developed, which are based on the averages of 4 samples, will allow for day-to-day variations in materials.

•OFFICIALS of the Virginia Department of Highways have long realized the need for statistical specifications in highway construction and maintenance operations and have encouraged the Virginia Highway Research Council's efforts to develop such specifications. As a result, the council has developed several specifications that have been adopted by the department, and the study reported here is an extension of this developmental work.

## PURPOSE AND SCOPE

The purpose of the study was to develop statistically based specifications for pug mill-mixed materials. In short, the study attempted to accomplish the following:

1. Develop, on the basis of an analysis of the present system, a sampling, testing, and acceptance procedure that would lend itself to statistical analyses and yet require as few disruptions as possible in current procedures;
2. Determine the variabilities in the gradation, water content, and liquid and plastic limits of pug mill-mixed materials; and
3. Suggest a package procedure for sampling, testing, and accepting the materials, and offer recommendations regarding factors such as the point of sampling and process tolerances.

Though it was originally planned that the study would include all types of aggregate pug mill-mixed materials used in Virginia, only materials 21A and 21 were produced during the sampling period.

## PROCEDURE

### Analysis of the Present System

At present the Virginia Department of Highways requires that all aggregate base and subbase materials be pug mill-mixed (1). The properties of the pug mill-mixed

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materials are determined at the plant by the plant inspector. The rate of sampling is a minimum of 1 test sample per 1,000 tons of material, taken from the pug mill chute or from the truck. Also, at least 2 tests per day are required.

The samples taken are "representative" in the sense that the inspector looks for a portion of the material that he thinks is representative of the whole. The samples are split to provide the amounts of materials needed for testing; usually they are quartered. One quarter is used for a gradation test; another is slowly air-dried and used for determining the liquid and plastic limits; and the remainder is discarded. Each 1,000 tons of material is accepted or rejected on the basis of 1 test and, in a sense, is bought at the plant as far as the mix constituents are concerned.

The present specification is a product of many years of experience and numerous modifications. It seems to provide the highway department with the materials desired, but in the author's opinion it could be improved in the following areas:

1. Representative sampling—A great fallacy in representative sampling is that it assumes that a person can visually select a portion of the material that represents the whole. Though in some cases this is possible, one cannot safely assume that every plant inspector can do it day after day. An unbiased method such as random sampling or stratified random sampling would relieve the inspector of the burden of selecting the sample and thus would be a great improvement.

2. Checking for compliance on the basis of individual test values—That the present system of accepting or rejecting materials on the basis of individual test values can be misleading is demonstrated by the distributions shown in Figure 1. An individual test value (Fig. 1a) may pass, be recorded, and, because acceptance or rejection is based on an individual test, then be forgotten. If, however, data are accumulated, including occasional failing test values, they may plot as shown in Figure 1b. If the population of the data is then plotted in the form of a normal curve, as in Figure 1c, one can see that there is a great deal of material that actually does not meet the specification. Limited sampling will not disclose most of these failing values because of the laws of probability. They are, however, there. Failing test values do not necessarily indicate the presence of bad materials because "failing" is determined by comparing a value to the specification limits. Thousands of miles of roads have been built in Virginia with

very few failures. One, therefore, cannot help concluding that the unnoticed failing values were obtained from material that was actually good. The questions that then arise are, Why does not the specification encompass these materials? Why does not the compliance system show that they are actually there? Unless these questions are answered, the legal defensibility of the system is not very sound. The author believes that a compliance checking system based on the means of several samples is much sounder. An acceptance or rejection system based on a specified lot size of material and the average of several samples can give the tester a much better insight as to where the mean of the population of that material is located.

3. Use of a master band—The present Virginia specification for the gradation of pug mill-mixed materials consists of a master band within which all test values must fall to be classified as "passing." This master band is formed around Fuller's curve, and the mean as well as the limits have evolved from many years of experience. However, because compliance is based on individual samples, the gradation of the materials

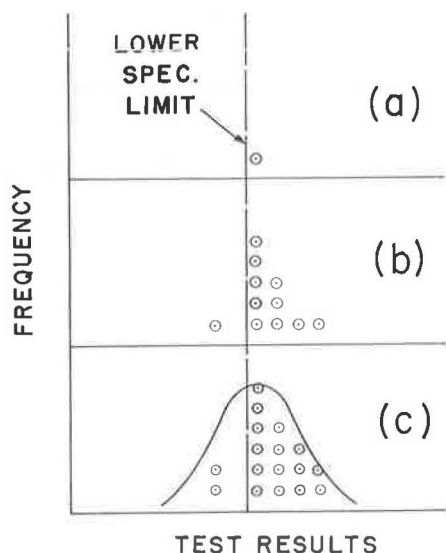


Figure 1. Accumulation of individual test values.

can meander as shown in Figure 2. Technically this meandering of the gradation within the master band is considered undesirable, but with the present specification there is no way to avoid it. It is believed that a compliance check based on means with set limits can lessen this meandering and result in improved materials.

### The New Approach

From the analysis of the present system, it is apparent that a statistical approach will be helpful; this is discussed in the following subsections.

**Random Sampling**—The new approach is based on statistical concepts. The sampling, therefore, has to be of a random nature and based on a definite lot size. Implementation of this concept probably will be very difficult because the present system has been in effect for such a long time and inspection personnel have become accustomed to representative sampling. It is believed, however, that random sampling will relieve the inspectors of the task of selecting the sample and will eliminate a great deal of confusion. Tests for compliance of pug mill-mixed materials are time consuming. Ordinarily by the time the tests are completed the material is already in the road. The present system, based on penalty points, allows some below-specification materials up to a certain number of accumulated penalty points (1). If the accumulated penalty points are above the limit set, then the material is to be removed from the road. In enforcing this specification, the project inspectors keep a record of where each truck load of material is placed. To permit location of the material in case removal is necessary, the new approach will use a stratified random sampling procedure. That is, the lot size will be divided by the number of samples and one random sample will be taken from each subplot.

**Testing Based on Means**—As explained earlier, acceptance and rejection will be based on the mean of several samples rather than on individual values.

### Job-Mix Band and Process Tolerances

A new concept, the job mix, will be included in the specifications for pug mill-mixed materials. The purpose will be to try to keep the means of properties in the middle of a job-mix band. Each producer will be required to submit a job mix that will fall in this band. Once the job mix is approved, the job-mix band will be removed from consideration and the producer will be allowed process tolerances around the job mix. This is shown in Figure 3. Figure 3a shows the job-mix band for a property. From this band the producer will be allowed to choose the location of the property involved, such as location 1 or 2 (Fig. 3b). Once the location of this property as submitted by the producer is approved, he will be given the process tolerances (Fig. 3c). The allowance of process tolerances is also thought to be an improvement to the system because it recognizes that the same test values cannot be attained day after day because of the variabilities inherent in the process.

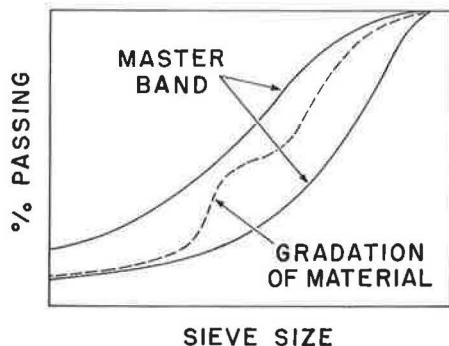


Figure 2. Possible gradation based on individual samples and a master band.

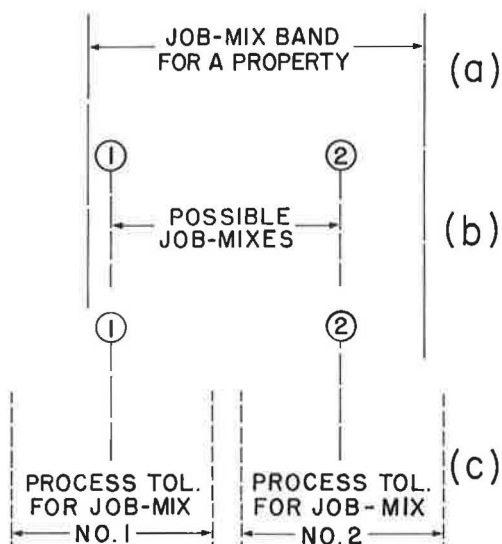


Figure 3. Job mix and process tolerances.

TABLE 1  
MEANS AND STANDARD DEVIATIONS OF MATERIAL 21A

Property	Mean						Standard Deviation					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Percent passing												
2-in. sieve <sup>a</sup>	99.0	99.9	92.3	100.0	99.9	99.9	0.8	0.3	3.5	0.0	0.3	0.3
1-in. sieve	65.2	68.4	65.2	77.6	75.2	69.8	4.9	6.3	3.8	8.5	4.7	5.2
3/8-in. sieve	40.2	29.9	42.1	34.4	34.4	39.4	4.9	4.5	3.7	4.3	4.5	5.2
No. 10 sieve	25.0	15.9	25.8	17.4	14.3	23.0	3.9	2.4	2.7	2.5	2.4	2.7
No. 40 sieve	12.5	10.7	8.7	9.1	7.5	10.9	2.0	1.8	1.2	1.6	1.4	1.3
No. 200 sieve												
Liquid limit, percent	22.1	15.7	17.8	19.4	13.7	21.1	1.5	0.9	1.0	1.3	0.9	2.2
Plasticity index, percent	0.5	0.0	0.0	0.0	0.0	0.8	1.3	0.0	0.0	0.0	0.2	1.9
Water content, percent	6.4	6.4	5.4	5.5	4.9	6.0	1.0	1.8	0.8	0.9	0.8	1.1

<sup>a</sup>Top size for all plants.

**Field Work**—To develop the new approach required that the variabilities of the gradation, as determined by different sieve sizes, and liquid and plastic limits be determined. In Virginia water content is not a pay item; that is, no penalty is imposed if the water content is too high or too low. It was included in this study, however, for purposes of information. With the cooperation of the materials engineers from the 8 construction districts in the Virginia Department of Highways, the author chose major plants in each district for study. At each plant written instructions on the new testing procedures were provided the plant inspector and the district materials technician in charge of pug mill mixes and discussed with them. In accordance with the instructions, the samples were taken by the inspectors in a random fashion by using a table of random numbers and were identified by the use of index cards. The samples were then sent to the district laboratories for testing, and the test data obtained were sent to the author for analysis. The inspectors were asked to take 30 or more samples from all aggregate materials produced by each plant. However, the Virginia Department of Highways generally uses materials designated as 21A and 21, and these were the only materials produced during the study period.

## ANALYSIS OF RESULTS

### The Data

The data obtained from the district laboratories were analyzed by the use of a computer. In the analysis the mean,  $\bar{x}$ , and the standard deviation,  $\sigma$ , for each property—that is, the gradation on each sieve, liquid limit, plasticity index, and water content—were determined. These are given in Tables 1 and 2. Data given in the tables are

TABLE 2  
MEANS AND STANDARD DEVIATIONS OF MATERIAL 21

Property	Mean								Standard Deviation							
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
Percent passing																
2-in. sieve <sup>a</sup>	83.9	91.0	90.6	94.7	90.6	97.5	85.4	92.0	5.7	4.2	3.8	2.5	2.7	4.0	5.3	3.1
1-in. sieve	58.6	60.0	58.5	70.2	70.2	62.0	69.1	57.2	5.5	7.3	6.6	5.1	6.6	9.0	6.7	6.3
3/8-in. sieve	41.6	38.2	35.6	41.3	30.8	30.4	36.7	27.2	4.4	6.1	5.2	4.5	4.1	5.6	4.8	4.5
No. 10 sieve	25.3	22.7	20.9	25.6	16.3	14.0	16.5	12.0	3.4	3.9	3.4	3.6	2.1	3.2	2.8	1.9
No. 40 sieve	14.0	8.0	5.0	11.3	10.0	7.7	9.3	6.7	1.7	2.5	1.6	1.5	1.5	2.5	2.3	1.2
No. 200 sieve																
Liquid limit, percent	20.0	17.6	18.2	20.5	16.5	14.7	15.0	14.9	1.0	0.7	1.4	1.5	0.9	1.3	0.9	1.6
Plasticity index, percent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water content, percent	4.6	5.9	5.1	6.0	6.3	5.6	4.5	4.3	1.1	0.8	0.8	1.2	1.1	1.5	0.9	0.7

<sup>a</sup>Top size for all plants.

TABLE 3

AVERAGES AND RANGES FOR MEANS AND STANDARD DEVIATIONS FOR MATERIALS 21A AND 21

Property	Material 21A				Material 21			
	Mean		Standard Deviation		Mean		Standard Deviation	
	Average	Range	Average	Range	Average	Range	Average	Range
Percent passing								
2-in. sieve	100	0	0	0	100	0	0	0
1-in. sieve	98.5	92.3 to 100	0.9	0 to 3.5	89.9	83.9 to 94.7	3.9	2.5 to 5.7
3/4-in. sieve	70.2	65.2 to 77.6	5.6	3.8 to 8.5	63.0	56.5 to 70.2	6.6	5.1 to 9.0
No. 10 sieve	36.7	29.9 to 42.1	4.5	3.7 to 5.2	35.2	30.4 to 41.6	4.9	4.1 to 6.1
No. 40 sieve	20.2	14.3 to 25.8	2.8	2.4 to 3.9	19.2	12.0 to 25.6	3.2	1.9 to 3.9
No. 200 sieve	9.9	7.5 to 12.5	1.6	1.2 to 2.0	9.2	5.0 to 14.0	1.9	1.2 to 2.5
Liquid limit, percent	18.3	13.7 to 22.1	1.3	0.9 to 2.2	17.2	14.7 to 20.5	1.2	0.7 to 1.6
Plasticity index, percent	0.2	0 to 0.8	0.6	0 to 1.9	0	0	0	0
Water content, percent	5.8	4.9 to 6.4	1.1	0.8 to 1.8	5.3	4.3 to 6.3	1.0	0.7 to 1.5

sufficiently uniform to enable one to assume average mean and standard deviation values for each property. One exception is the plasticity index values. Because most of the test results for this property were zero, good measures of the mean and standard deviation values were not obtained.

Average mean and standard deviation values for each property were obtained by tabulating the averages and ranges of each property of each material. These are given in Table 3. Based on the averages and ranges of the mean and standard deviation values given in Table 3 and the distribution of the data given in Tables 1 and 2, average standard deviation values were selected for each property of the materials. These are given in Table 4. Water content values are not included in Table 4 because, as was mentioned earlier, it is not a pay item and was determined only for information purposes. The standard deviation values for the plasticity index are based on only a very few samples.

#### Development of the Job-Mix Band

The current specifications for materials 21A and 21 are given in Table 5. In order for the materials to pass, all test values are required to be within the ranges given. Statistically, this would imply that the mean of the population of the material produced has to be 3 standard deviations from both the upper and lower limits. An extreme case is shown in Figure 4. It is apparent from the data shown in Figure 4 that it would be impossible to produce material that would fall within the specification limits if the variability or standard deviation is 6.5 percent. Yet from the study it was found that the average standard deviation is around 6.5 percent for the 3/8-in. sieve.

One should not lose sight of the fact that the sources of the standard deviations obtained in this study—that is, the materials sampled—were all accepted materials. They were "good" and technically desirable materials apparently representative of those with which the Virginia Department of Highways has built excellent roads with very few failures.

At this stage of the study it was concluded that with the current specifications, which are based on individual samples, one has very little idea of where the population mean and extremes are located. From this fact, it was in turn concluded that some "good" but "out of specification" materials can be accepted under the present system.

The next step then was to determine, for each property, the lower and upper limits that actually could exist in today's production.

TABLE 4

SELECTED AVERAGE STANDARD DEVIATIONS FOR MATERIALS 21A AND 21

Property	Material 21A	Material 21
Percent passing		
2-in. sieve	Top size	Top size
1-in. sieve	2	4
3/4-in. sieve	5.5	6.5
No. 10 sieve	4.5	5.0
No. 40 sieve	2.8	3.0
No. 200 sieve	1.6	2.0
Liquid limit, percent	1.3	1.0
Plasticity index, percent	0.6	—

TABLE 5

CURRENT SPECIFICATIONS, JOB-MIX BANDS, AND PROCESS TOLERANCES FOR MATERIALS 21A AND 21

Property	Current Specifications		Job-Mix Bands		Process Tolerances <sup>a</sup>	
	Material 21A	Material 21	Material 21A	Material 21	Material 21A	Material 21
Percent passing						
2-in. sieve	100	100	100	100	Top size	Top size
1-in. sieve	90 to 100	71 to 95	94 to 100	79 to 87	±3	±6
3/4-in. sieve	50 to 85	50 to 80	63 to 72	61 to 69	±9	±10
No. 10 sieve	25 to 50	25 to 50	34 to 41	34 to 41	±7	±7
No. 40 sieve	12 to 30	12 to 30	18 to 24	18 to 24	±4	±4
No. 200 sieve	5 to 15	5 to 15	8 to 12	8 to 12	±2	±2
Liquid limit, percent	Max. 25	Max. 25	Max. 23	Max. 23	+2	+2
Plasticity index, percent	Max. 3	Max. 3	Max. 2	Max. 2	+1	+1
Water content, percent	6 ± 2	6 ± 2	—	—	—	—

<sup>a</sup>For the average of 4 samples.

This was accomplished by taking each mean of each property and adding to it (or subtracting from it) its variability, that is, 3 standard deviations. By plotting all the populations in this manner, the statistically existing lower and upper limits were obtained.

An attempt was made to locate the job-mix band by moving in from the statistically existing lower and upper limits a value corresponding to three times the assumed average standard deviation for each property. As this was done, it was noticed in many instances that the current specifications will be at a 1 standard deviation (using an average standard deviation) distance from the statistically existing high or low values. Therefore, it was decided to use this method, as shown in Figure 5, to calculate job-mix bands for all properties. It is admitted that the calculations in some cases were tempered with engineering judgment. This was necessary, for example, in the gradation calculations where materials 21A and 21 had the same limits but not necessarily the exact same average standard deviations (Tables 4 and 5). The job-mix bands calculated and adjusted with engineering judgment are also shown in Table 5. It should be noted that the liquid limit and plasticity index bands are one-sided.

### Development of Process Tolerances

As was mentioned earlier, the author endorses the concept that the same test values cannot be obtained day after day. For this reason process tolerances have to be allowed. It is noted that they are directly related to the number of samples tested. If a single sample is used for the acceptance or rejection of materials, then the entire population limits, that is, ±3 standard deviations, should be used as process tolerances. Because the use of a single sample is not desirable, then process tolerances should be adjusted by using the standard error concept. The relation between the standard error and the standard deviation is as follows:

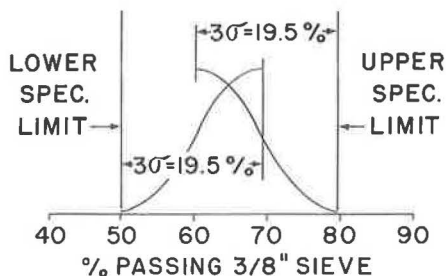


Figure 4. Location of the mean of the 3/8-in. material produced as it relates to specification limits.

$$\sigma_{\bar{x}} = \sigma / \sqrt{N}$$

where

$\sigma_{\bar{x}}$  = standard error,  
 $\sigma$  = standard deviation, and  
 $N$  = number of samples averaged.

Another point that one has to consider in determining process tolerances concerns the acceptance of material that is outside the specification. This is, if no material outside the specification is to be accepted, then process tolerances can be set at ±3 standard errors. If



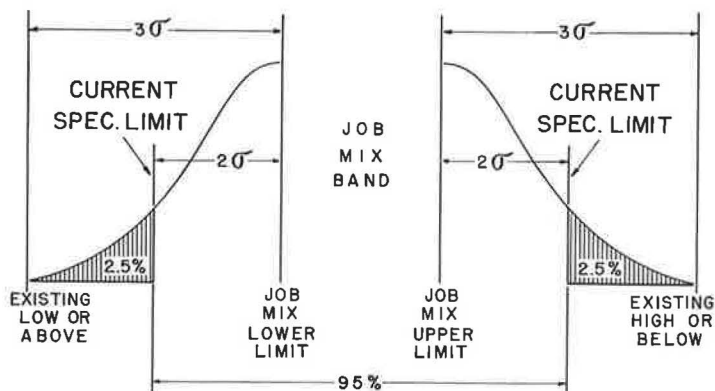


Figure 5. Job-mix band versus existing population, using average standard deviations.

5 percent can be allowed to fall outside specifications, then the limits can be set at  $\pm 2$  standard errors. Any other percentage, of course, can be chosen.

On the basis of experience and for purposes of simplicity, the author decided to use  $\pm 3$  standard error limits and a sample size of four for the acceptance or rejection of a lot size. The process tolerances are, therefore, calculated from the following formula:

$$\text{Process tolerance} = \pm 3\sigma_{\bar{X}} = \pm (3\sigma/\sqrt{N}) = \pm (3\sigma/\sqrt{4}) = \pm 1.5\sigma$$

In the case of the liquid limit and the plasticity index, a one-sided process tolerance of 1.5 standard deviations was used. The process tolerances calculated with this formula are also given in Table 5. They are based on the averages of 4 samples.

#### Lot Size

As mentioned in other parts of this report, in the proposed system the acceptance or rejection of material will be based on an average of 4 samples to be taken in a stratified random manner from a lot. The size of the lot to be sampled is generally established on the basis of practicality. It depends on how much one can spend on testing and the degree of certainty desired.

At present the Virginia Department of Highways requires a rate of testing of a minimum of 1 test per 1,000 tons of material. Therefore, if a lot size of 4,000 tons is chosen and 4 samples are taken, then the number of tests required by the proposed system will result in the same amount of testing. For practicality and economy this is desirable. However, it was learned from interviews with the district materials engineers that, although the specifications require a minimum of 1 test per 1,000 tons of material, many plant inspectors run more than this number and the rate of testing is closer to 1 test per 500 tons. It was, therefore, decided to propose a lot size of 2,000 tons.

#### DISCUSSION OF RESULTS

During the development of the proposed system, several assumptions were made. These are summarized as follows:

1. Because of the system currently in use, the Virginia Department of Highways accepts materials that are actually out of specification. These materials are assumed to be good road-building materials because the system has been accepting them for many years and the construction that includes these materials has performed satisfactorily.

2. The study sampled 14 major plants in the 8 construction districts of the Virginia Department of Highways. This constitutes about 10 to 15 percent of all plants in Virginia and might be considered a small sample. From the uniformity of the data collected, however, the author believes that more sampling will not change the results significantly.

3. It was also assumed that the chosen average standard deviations can be achieved by all plants that produce materials 21A and 21. This might not be possible in all cases, and some plants might have to improve their methods of operation. For example, for material 21, an average standard deviation of 6.5 percent was used for the variability of the  $\frac{3}{8}$ -in. sieve. Data given in Table 2 show plants 2 and 6 have a variability much above this value and will experience difficulty in meeting the proposed specification. The other plants, however, will not have any difficulty. This requirement is believed to be desirable because it will encourage the producers to upgrade their operations.

### CONCLUSIONS AND RECOMMENDATIONS

Based on the data collected on materials 21A and 21 for this study the following conclusions were drawn:

1. Although the current specification is doing a fair job, it can be improved so as to make the system more defensible from legal and technical standpoints.
2. The current specification, because of the system, accepts a certain amount of material that is outside of the specification limits. This material is, however, good material and should be encompassed in the specification.
3. The variabilities determined are fairly uniform, and the use of average standard deviations seems warranted (Table 4).
4. The use of a job-mix band should result in more uniformly graded materials.
5. Job-mix bands developed by use of average standard deviations will allow flexibility for each plant (Table 5).
6. The process tolerances developed, which are based on the averages of 4 samples, will allow for day-to-day variations in material (Table 5).
7. A lot size of 2,000 tons seems to be adequate for plants in Virginia.

It was, therefore, recommended that the proposed specification, which is based on a job-mix band and process tolerances, be tried on a pilot study basis in Virginia.

### RECENT DEVELOPMENTS

Before the report on this study was written, the data and the findings were submitted to the Virginia Department of Highways with recommendations for the adoption of the proposed statistical specification on a trial basis. The materials engineer in charge of statistical specifications translated the recommended method into standard specification form. The recommended specification was then reviewed by the Materials Division, and as a result of 2 discussion meetings several modifications were made to permit more practical application. Because the recommended specification is not a part of but a result of this study, the final version of it is included in the Appendix. No interpretations of this specification and no comments on the modifications made are offered. It should be sufficient to say that the modifications are very minor and will aid the implementation of the recommendations made.

### ACKNOWLEDGMENTS

The author thanks all the district materials engineers, their assistants in charge of pug mill mixing, and the plant inspectors for their excellent cooperation in providing the data for this study. Thanks are also extended to S. N. Runkle, head of the Data Systems and Analysis Section of the Virginia Highway Research Council, for his help with the computer analysis of the data; and special thanks go to J. H. Dillard, state highway research engineer, for offering the benefits of the experience he gained in developing statistical bituminous specifications. The study was financed under HPR funds administered through the Federal Highway Administration. The opinions, findings, and



conclusions expressed are those of the author and not necessarily those of the sponsoring agencies.

## REFERENCE

1. Central Mix Aggregate Reference Guide, 1969-1970. Virginia Department of Highways.

## Appendix

VIRGINIA DEPARTMENT OF HIGHWAYS  
SPECIAL PROVISIONS FOR  
SUBBASE AND AGGREGATE BASE COURSES  
(STATISTICAL QUALITY CONTROL SPECIFICATIONS) 4-1-70

Material for subbase and aggregate base courses on this contract shall be furnished in accordance with the applicable requirements of the 1966 edition of the Road and Bridge Specifications as amended herein below.

Sections 209 and 210 of the Specifications are completely replaced by the following:

Description -- Material for subbase course shall consist of natural or artificial mixtures of natural or crushed gravel, crushed stone, slag, natural or crushed sand, with or without soil mortar.

Aggregate base course will be designated as Type I or Type II Aggregate Base Material.

Type I aggregate base material shall consist of crushed stone, crushed slag, or crushed gravel combined with soil mortar, with or without other admixtures. Gravel shall consist of particles of which a minimum of 90 percent, by weight of the material retained on the No. 10 sieve, shall have at least one fractured face by artificial crushing.

Type II aggregate base material shall consist of sand-clay mixtures; gravel, stone, or slag screenings; sand and crushed coarse aggregate; or any combination of these materials combined with soil mortar, with or without other admixtures.

### Detail Requirements --

Aggregate subbase course shall conform to the following requirements:

- (a) Grading shall conform to Table VI (attached) for Size 21, 21A or 22. Aggregate size to be used will be specified in the contract.
- (b) Atterburg Limits: Liquid limit shall not be more than 21; plasticity index shall be not more than 4.
- (c) Soundness shall conform to Table IV, Section 203.

TABLE VI  
DESIGN RANGE

Size No.	Amount finer than each laboratory sieve (Square Openings*), Percentage by Weight					
	2	1	3/8	No. 10	No. 40	No. 200
21	100	79 - 89	61 - 69	32 - 41	16 - 24	8 - 12
21A	100	94 - 100	63 - 72	32 - 41	16 - 24	8 - 12
22		100	62 - 78	39 - 56	26 - 34	8 - 12

\* In inches, except where otherwise indicated. Numbered sieves are those of the U. S. Standard Sieve Series.

Aggregate base course shall conform to the following requirements:

- (a) Grading shall conform to Table VI (attached) for Size 21, 21A or 22. Aggregate size to be used will be specified in the contract.
- (b) Atterburg Limits: Liquid limit shall not be more than 21; plasticity index shall be not more than 1 for Type I and not more than 4 for Type II.
- (c) Soundness shall conform to Table IV, Section 203.
- (d) Abrasion Loss shall be not more than 45 percent.

Admixtures — Chemicals or other admixtures to be used with subbase or aggregate base course shall meet the requirements of the current specifications. Chemicals or other admixtures not covered by current specifications may be used on written approval of the Engineer.

Job-Mix Formula — The Contractor shall submit, for the Engineer's approval, a job-mix formula for each mixture to be supplied for the project, prior to starting work. The job-mix formula shall be within the design range specified in Table VI, Design Range (see attached) for the particular size number specified. The job-mix formula shall establish a single percentage of aggregate passing each required sieve size, and shall be in effect until modified in writing by the Engineer. When unsatisfactory results or other conditions make it necessary, the Contractor shall prepare and submit a new job-mix formula for approval. Approximately one week may be required for the evaluation of a new job-mix formula.

Mixing — The materials for subbase or aggregate base course shall be mixed in an approved central mixing plant of the pug mill or other mechanical type, unless otherwise specified. The materials shall be blended prior to or during mechanical mixing in such a manner that will insure conformance with the specified requirements. In the production of these materials, optimum moisture, plus or minus two (2) percentage points, will be required.

Plant Inspection — The preparation of subbase and aggregate base course material shall be subject to inspection at the plant. For this purpose, the Contractor shall provide a suitable building to be used as a field laboratory in accordance with the requirements of Supplemental Specifications for Section 539. The Contractor shall furnish, maintain, and replace as condition necessitates, the following equipment:

- 1 Motorized screen shaker for coarse and fine aggregate gradation analysis.

- 1 Set of sieves for the motorized shaker. The screen sizes shall include those necessary for testing the material being produced.
- 1 Sample splitter capable of handling material from sand up to 6 inch particles.
- 1 Motorized soil grinder, bench or floor model. The grinder shall be constructed using a 15 to 20 inch bench or floor model drill press.  
The press shall be equipped as follows: Hand fed type with 6-inch stroke; variable shaft speed of 300 rpm (plus or minus 100 rpm); powered by an electric motor of  $\frac{1}{2}$  hp or larger; machined steel adapter tapered on one end to fit drill and threaded on the opposite end for proper length to receive rubber mall attachment.

The above mentioned equipment shall be installed and ready for operation in the specified field laboratory.

**Note:** Cast iron grinding pots and rubber malls will be furnished by the Department.

The Department's representative shall have ready access to all parts of the plant for checking the accuracy of the equipment in use, inspecting the condition and operation of the plant, and for any purpose in connection with the materials and their processing.

**Acceptance** — Sampling for determination of gradation, liquid limit, and plasticity index will be performed at the plant, and no further sampling will be performed for these properties. However, should visual examination reveal that the material in any load is obviously contaminated or segregated, that load will be rejected without additional sampling or testing of the lot. In the event it is necessary to determine, quantitatively, the quality of the material in an individual load, one sample (taken from the load) will be tested and the results compared to the "process tolerance for one test" as described herein. The results obtained in the testing of a specific individual load will apply only to the load in question. Gradation, liquid limit, and plasticity index determinations will be performed in the plant laboratory furnished by the Contractor; however, the Department reserves the right to discontinue the use of the plant laboratory for acceptance testing in the event of mechanical malfunctions in the laboratory equipment and in cases of emergency involving plant inspection personnel. In the event of such malfunctions or emergencies, acceptance testing will be performed at the District or Central Office laboratory until the malfunctions or emergency has been satisfactorily corrected or resolved.

Acceptance for gradation, liquid limit, and plasticity index will be based upon a mean of the results of four tests performed on samples taken in a stratified random manner from each 2000 ton lot. A lot will be considered to be acceptable for gradation if the mean of the results obtained from the four tests fall within the following process tolerances allowed for deviation from the job-mix formula:

Sieve	Process Tolerance, % Passing	
Top Size	±	0.0
1"		5.0
3/8"		9.5
#10		7.0
#40		4.0
#200		2.0

A lot will be considered to be acceptable for liquid limit and plasticity index if the mean of the results obtained from the four tests fall within the following process tolerances allowed for deviation from the values given in Detail Requirements Section:

Atterburg Tests	Process Tolerance,
	<u>%</u>
Liquid Limit	+ 2.0
Plasticity Index	+ 1.0

Should the liquid limit exceed 30 or the plasticity index exceed 6 for Type I base material or 9 for Type II base material or subbase material on any individual sample, the 500 ton portion of material from which the sample was taken will be considered a separate part of the lot and shall be removed from the road, unless otherwise directed by the Engineer.

In the event that the job requires less than 2,000 tons of material; or that the amount of material necessary to complete the job is less than 2,000 tons; or that the job-mix formula is modified within a lot, or a portion of the lot is rejected for excessive liquid limit or plasticity index, the mean results of samples taken will be compared to a new process tolerance, computed as follows:

Process tolerance for one test =  $\frac{\text{Process tolerance for mean of four tests}}{0.5}$

Process tolerance for mean of two tests =  $\frac{\text{Process tolerance for mean of four tests}}{0.7}$

Process tolerance for mean of three tests =  $\frac{\text{Process tolerance for mean of four tests}}{0.9}$

Individual test results and lot averages obtained from acceptance testing will be plotted on control charts as the information is obtained. Standard deviations, when computed, will be made available to the Contractor. However, the Inspector will in no way attempt to interpret test results, lot averages or standard deviations for the Contractor in terms of needful plant or process adjustments.

Adjustment System — An adjustment of the unit bid price will not be made for the value of one test result or the mean value of two or three test results, unless circumstances as stated in Acceptance Section above require that the lot size be less than 2,000 tons. Should the value of one test result or the mean value of two or more test results, as required by Acceptance Section above, fall outside the allowable process tolerance, an adjustment will be applied to the unit bid price as follows:

Sieves	Adjustment points for each one (1) % that the gradation is out of process tolerance
<u>2"</u>	<u>1</u>
1"	1
3/8"	1
#10	1
#40	3
#200	5
Atterburg Limits	Adjustment points for each point that the Atterburg limits are out of process tolerance
<u>Liquid Limit</u>	<u>3</u>
Plasticity Index	7

In the event the total adjustment for a 2,000 ton lot is greater than twenty-five points, the failing material shall be removed from the road. In the event the total adjustment is twenty-five points or less and the Contractor does not elect to remove and replace the material, the unit price paid for the material will be reduced 1% of the unit price bid, for each adjustment point. The adjustment will be applied to the tonnage represented by the sample or samples.

The Contractor shall control the variability of his product in order to furnish the project with a uniform mix. When the contract item is greater than 1,000 tons and an adjustment is necessary as indicated in the following table, it shall be for the entire quantity of that type material on the project based upon its variability as measured by the standard deviation.

Sieve Size	Standard Deviation		
	1 adjustment point for each sieve size	2 adjustment points for each sieve size	3 adjustment points for each sieve size
2"	0.6 - 1.5	1.6 - 2.5	2.6 - 3.5
1"	4.6 - 5.5	5.6 - 6.5	6.6 - 7.5
3/8"	7.1 - 8.0	8.1 - 9.0	9.1 - 10.0
#10	5.6 - 6.5	6.6 - 7.5	7.6 - 8.5
#40	3.6 - 4.5	4.6 - 5.5	5.6 - 6.5
#200	3.1 - 4.0	4.1 - 5.0	5.1 - 6.0

The unit bid price shall be reduced by 0.5% for each adjustment point applied.

The disposition of material having standard deviations larger than those shown in the table shall be determined by the Engineer.

#### Referee System

- (a) In the event the test results obtained from one of the four samples taken to evaluate a particular lot appear to be questionable, the Contractor or the Engineer may request that the results of the questionable sample be disregarded; whereupon, tests will be performed on five additional samples taken from randomly selected locations in the roadway where the lot was placed. The test results of the three original (unquestioned) samples will be averaged with the test results of the five road samples and the mean of the test values obtained for the eight samples will be compared to the following process tolerance:

$$\text{Process tolerance for mean of eight tests} = \frac{\text{Process tolerance for mean of four tests}}{1.4}$$

- (b) In the event the Contractor elects to question the mean of the four original test results obtained for a particular lot, he may request additional testing of that lot. Upon receipt of written request for additional testing, the Department will test four samples taken from randomly selected locations in the roadway where the lot was placed. The test results of the original four samples will be averaged with the test results of the four additional road samples and the mean of the test values obtained for the eight samples will be compared to the "process tolerance for mean of eight tests" as described hereinabove.

In the event the mean of the test values obtained for the eight samples is within the process tolerance for the mean of the results of eight tests, the material will be considered acceptable. In the event the mean of the test values obtained for the eight samples is outside of the process tolerance for the mean of the results of eight tests, the lot will be adjusted in accordance with the adjustment rate specified hereinabove.

Additional tests, requested by the Contractor under the provisions of Referee System Section (a) and (b), shall be paid for by the Contractor in the event the mean of the test values obtained for the eight samples falls outside of the process tolerances. Such additional tests shall be paid for at a rate of five times the bid price per ton of material per sample.

In the event that cement or other admixtures which would alter the characteristics of the material are used, the Referee System does not apply.