REVIEW OF A STATISTICAL SPECIFICATION FOR PUGMILL MIXED MATERIAL

by

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SUMMARY

Since the spring of 1964, the Virginia Highway Research Council has been developing and implementing statistical specifications for highway operations. One of these specifications is used for the acceptance of pugmill mixed materials. The purpose of this study was to review the data obtained under the present statistical specification for pugmill mixed material, and to recommend any revisions thought to be needed in the tolerances. It was found that:

1. The variability as measured by standard deviations of materials produced under the statistical specification is more than, and probably less than, the variability values the specification was based on.

2. Generally, producers are unable to attain an average percentage passing a given sieve exactly equal to the job mix specified. Thus, the ability to remain within tolerances on means is a function of variability plus the ability to "hit" the job mix. In fact, in this study a large percentage of material out of tolerance was usually the result of a large miss from the specified job mix.

3. Considering the average variabilities and average miss from the job mix, the current statistical tolerances for means are such that for the average producer no more than 2.5% of material will fall outside the tolerances.

4. The tolerances on means are somewhat inconsistent in that those on the smaller sieve sizes are more restrictive relative to average conditions.

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INTRODUCTION

Since the spring of 1964, the Virginia Highway Research Council has been developing and implementing statistical specifications for highway operations. One of these specifications (Appendix A) is used for the acceptance of pugmill mixed materials (Sizes 21, 21A, and 22). This specification, developed by M. C. Anday, has been in use on a special provision basis since the spring of 1970 and thus far has been used for acceptance purposes on 28 projects.*

The specification involves tolerances on two production characteristics. The first tolerance is on the amount the average of four samples drawn randomly from a lot of 2,000 tons (stratified so that one sample is drawn from each 500 tons) may vary from the job mix. (The job mix is chosen from a job mix band prior to production.) The second tolerance is on the total variability of all individual samples.

The specification pertains to all sieves in the gradation analysis as well as the liquid limit and plasticity index.

PURPOSE AND SCOPE

The purpose of this study was to review the data obtained under the present statistical specification for pugmill mixed material, and to recommend any revisions thought to be needed in the tolerances. A secondary analysis dealt with within-plant variability as measured from the current specification sampling plan. Data were obtained on Form TL-52A (Appendix B) on all projects completed or under way. Included were 26 projects using size 21A material, four using size 21 material, and one using size 22 material. Since all material included in the study is nonplastic, it was not possible to make any evaluations concerning the tolerance for the plasticity index.

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*Anday, M. C., "Statistical Quality Control — Phase VI, Soils: Statistical Specification for Pugmill Mixed Materials," Virginia Highway Research Council, June 1970.

ANALYSIS

As mentioned previously, the present statistical specification for pugmill mixed materials includes tolerances on the means of four samples and on total variability. These tolerances are discussed in the following two sections, with a section following on within-plant variability.

Tolerances for Means of Four Samples

Table 1 shows a summary of some of Anday's work as well as the current tolerances on means.

The first four columns show the average standard deviations and ranges in standard deviations for each sieve size, the liquid limit, and the plasticity index for material sizes 21 and 21A as found in Anday's study. The next four columns show the tolerances suggested by Anday and the implied standard deviations these tolerances were based on. Since Anday's tolerances were based on three standard error limits for sample sizes of four, the relationship between the standard deviation and the tolerance is

$$T = \frac{3\sigma}{\sqrt{n}} = 1.5\sigma$$

where

T = tolerance,

σ = standard deviation, and

n = sample size = 4 in the current specification.

In developing the current specification, it was decided that one set of tolerances was desirable, thus the tolerances shown in the next to last column were chosen. The final column indicates the standard deviations these tolerances were based on, again assuming the intent was to have the tolerances equivalent to three-standard error limits.

It should be stressed that the current specification was developed using average variability measures. This, of course, meant that some plants would have to decrease their production variability in order to meet the statistical specification tolerances.

Table 2 shows a summary of the data collected under the new statistical specification and Appendix C contains the detailed information on which Table 2 is based. On all sieve sizes and the liquid limit the standard deviations shown in Table 2 are equal to or less than the implied standard deviations (Table 1) on which the current specification is based. As mentioned above, variabilities for the plasticity index are not computed since all material for which data were received is nonplastic.

Table 1

Summary of Anday's Findings and Current Specification Tolerances

Property	Material Size				Anday's Tolerance		Implied σ's		Current Tolerances	Implied σ's
	21		21A		21	21A	21	21A		
	Avg. σ	Range	Avg. σ	Range						
% Passing 1" Sieve	3.9	2.5 - 5.7	0.9	0 - 3.5	±6	±3	4.0	2.0	±5.0	3.3
% Passing 3/8" Sieve	6.6	5.1 - 9.0	5.6	3.8 - 8.5	±10	±9	6.7	6.0	±9.5	6.3
% Passing #10 Sieve	4.9	4.1 - 6.1	4.5	3.7 - 5.2	±7	±7	4.7	4.7	±7.0	4.7
% Passing #40 Sieve	3.2	1.9 - 3.9	2.8	2.4 - 3.9	±4	±4	2.7	2.7	±4.0	2.7
% Passing #200 Sieve	1.9	1.2 - 2.5	1.6	1.2 - 2.0	±2	±2	1.3	1.3	±2.0	1.3
Liquid Limit, %	1.2	0.7 - 1.6	1.3	0.9 - 2.2	+2	+2	1.3	1.3	+2	1.3
Plasticity Index, %	0	0	0.6	0 - 1.9	+1	+1	0.7	0.7	+1.0	0.7

Table 2

Summary of Results Obtained Under Statistical Specification

Property	STANDARD DEVIATION				JM - $\bar{x}$				$\lvert JM - \bar{x} \rvert + 3\sigma\bar{x}$		$\lvert JM - \bar{x} \rvert + 2\sigma\bar{x}$		Current Tol.
	21		21A		21		21 A		21	21 A	21	21 A	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range					
% Passing 1" Sieve	1.8	1.4 - 2.3	0.3	0 - 1.7	2.9	2.0 - 3.6	3.4	0 - 5.0	5.6	3.8	4.7	3.7	±5.0
% Passing 3/8" Sieve	2.8	2.2 - 3.7	4.8	2.8 - 9.3	1.0	0.2 - 2.6	2.8	0 - 9.9	5.2	10.0	3.8	7.8	±9.5
% Passing #10 Sieve	2.2	1.6 - 2.7	4.3	2.5 - 6.8	1.6	0 - 4.9	2.5	0.3 - 9.8	4.9	8.9	3.8	6.8	±7.0
% Passing #40 Sieve	1.3	0.9 - 1.7	2.6	1.3 - 5.1	1.5	0.2 - 2.5	1.5	0 - 4.5	3.5	5.4	2.8	4.1	±4.0
% Passing #200 Sieve	0.9	0.8 - 1.2	1.3	0.7 - 2.8	0.4	0.2 - 0.7	0.9	0.1 - 2.3	1.8	2.9	1.3	2.1	±2.0
Liquid Limit, %	0.5	0.2 - 0.9	1.3	0.1 - 2.8	-	-	-	-	-	-	-	-	+2
Plasticity Index, %	-	-	-	-	-	-	-	-	-	-	-	-	+1.0

Based on the average standard deviations shown in Table 2, it would seem that producers, if they are capable of maintaining average variability, should have little trouble staying within the current process tolerances. However, the ability to remain within the process tolerances for the various sieve sizes is based on two characteristics.

1. Production variability as discussed above.

2. Ability to "hit" the job mix, which is measured by the difference between the job mix (JM), and the actual production average $(\bar{x})$. The average absolute differences ($|JM - \bar{x}|$) for the data collected under the current specification are also shown in Table 2.

How these two characteristics combine to determine the ability to remain within tolerances is best described using some of the data shown in Table 2. For instance, for size 21A material the average absolute difference ($|JM - \bar{x}|$) plus three standard errors (1.5 x standard deviation for sample size of 4) equals 3.8% for the 1-inch sieve, which has a tolerance of ±5.0%. This concept is illustrated below in Figure 1. In this sample the total of $|JM - \bar{x}|$ plus three standard errors was well within the process tolerance and producers should have no problems staying within the tolerance. However, in looking at the right-hand portion of Table 2, it can be seen that in most cases the sum of $|JM - \bar{x}|$ plus $3\sigma_{\bar{x}}$ exceeds the process tolerances for average conditions.

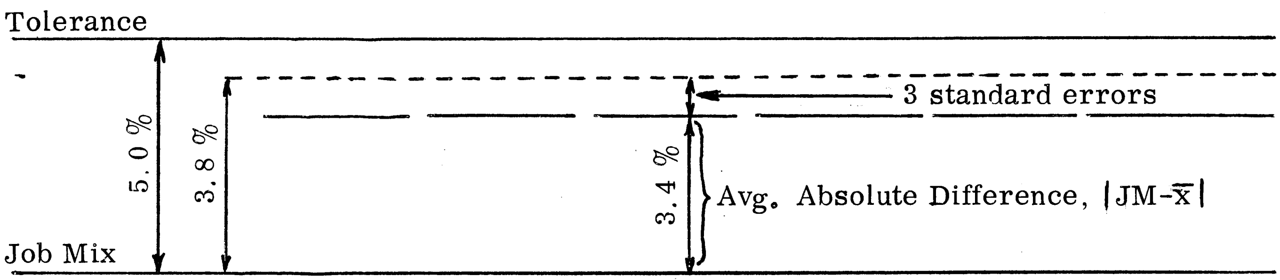

Figure 1. Relation of $|JM - \bar{x}|$ plus 3 standard errors ($3\sigma_{\bar{x}}$) to tolerance.

The question arises as to how much the process tolerances are exceeded, i.e., on the average, how much material is out of tolerance. This question is basically answered by looking at the columns in Table 2 shown under $|JM - \bar{x}| + 2\sigma_{\bar{x}}$. These data show that the sum $|JM - \bar{x}| + 2\sigma_{\bar{x}}$ is less than or approximately equal to the tolerances on all sieves. Thus, for average conditions, the worse situation is that 2.5% of the material produced would fall outside tolerance with the worse conditions occurring on the smaller sieve sizes. With regard to the liquid limit, there is no problem in staying below the tolerance. For the projects evaluated the maximum liquid limit allowable is 23% (including the +2% tolerance). It can be shown by using the detailed data in Appendix C that for all projects except one the entire population for liquid limit fell well below the maximum tolerance of 23%. For the one exception, only about 3% of material was above tolerance.

It is of interest to note the distribution of the differences between the job mixes and the actual production averages considering the sign of these differences. This information is shown in Table 3, where the difference is expressed as a positive value when the production average exceeds the job mix, and a negative value when the production average is less than the job mix. As can be seen from Table 3, the distribution is evenly divided on either side of zero except on the 1" sieve and to a very slight degree on the #200 sieve. On the 1" sieve the production average is almost always greater than the job mix, probably because the job is set the tolerance width away from 100% passing (thus 95%), and the actual production average is near or equal to 100% passing.

Table 3

Distribution of Differences Between JM and $\bar{x}$

	Sieve Size 1"		Sieve Size $\frac{3}{8}$"		Sieve Size #10		Sieve Size #40		Sieve Size #200	
$\bar{x}$ - JM	No.	%	No.	%	No.	%	No.	%	No.	%
$\geq$5.0	12	39	1	3	2	6				
4.0 to 4.9	2	6	2	6			1	3		
3.0 to 3.9	5	16	3	10	2	6				
2.0 to 2.9	5	16	2	6	4	13	4	13		
1.0 to 1.9	1	3	3	10	3	10	6	19	3	10
0.0 to 0.9	3	10	4	13	4	13	5	16	10	32
-0.1 to -0.9	3	10	5	16	3	10	5	16	12	39
-1.0 to -1.9			1	3	7	23	9	29	4	13
-2.0 to -2.9			6	19	2	6	1	3	2	6
-3.0 to -3.9					2	6				
-4.0 to -4.9			2	6	1	3				
$\leq$ -5.0			2	6	1	3				
$\bar{x}$ $\geq$ JM	28	90	15	48	15	48	16	52	13	42
$\bar{x}$ < JM	3	10	16	52	16	52	15	48	18	58

As a further analysis, those instances in which the tolerance was exceeded by $|JM - \bar{x}| + 2\sigma_{\bar{x}}$ or in which failures occurred, i.e., the mean of four samples fell outside the tolerance, were determined and summarized as shown in Table 4. In Table 4, under each sieve size the number of failures refers to the number of lots in which the lot mean fell outside the tolerances as applied to the job mix. The percentage of failures is simply the number of failing lots (those having means outside the tolerance) divided by the total number of lots, while the percentage out of tolerance is the amount of material estimated to be outside of the tolerance for the project based on the overall production average and standard deviation. At the bottom of Table 4, the total number of failures is the total number of lots failing, and the percentage of failures is the total number of lots failing divided by the total number of lots produced in all 31 projects. The totals shown under percentage out of tolerance refer to the total number of projects having some material out of tolerance (n) and the percentage of projects having some material out of tolerance (%).

Most out of tolerance material and failures occurred on the smaller sieves, with the number of failures and the highest failure rate being 28 and 9% on the #200 sieve and the percentage of projects having some material out of tolerance being 42% on the #40 sieve and 48% on the #200 sieve. The findings are as expected from the information shown in Table 2, where $|JM - \bar{x}| + 2\sigma_{\bar{x}}$ was approximately equal to the tolerances for the smaller sieves. An important fact is that in most cases the percentage of material out of tolerance is relatively small and exceeds 20% only 10% of the time on the #10 sieve, 6% of the time on the #40 sieve, and 19% of the time on the #200 sieve.

The primary cause of material being out of tolerance is also indicated in Table 4. A (b) by percentage of material out of tolerance indicates a higher than average standard deviation while (c) indicates that the $|JM - \bar{x}|$ difference is higher than average with the averages being determined from Table 2. An (a) indicates that both the standard deviation and $|JM - \bar{x}|$ are higher than average.

As can be seen from Table 4, all out of tolerance material on the 1" sieve resulted from the $|JM - \bar{x}|$ being relatively large. In fact, on this sieve the distribution is not normal but rather skewed toward 100% passing, thus making the percentages shown out of tolerance inaccurate. On all of these projects except 10015, the job mix was set as 95% passing and the actual production average was almost 100% passing.

On the remaining sieves having some material out of tolerance it is of interest to note that 38% have a higher than average standard deviation, 24% have a $|JM - \bar{x}|$ difference larger than average, and 38% have both a standard deviation and $|JM - \bar{x}|$ difference larger than average. However, on those sieves having 20% or more material out of tolerance, 58% have a $|JM - \bar{x}|$ larger than average and 42% have both a standard deviation and $|JM - \bar{x}|$ larger than average. Thus, it seems obvious that a large percentage of material out of tolerance will most likely be due to a relatively large miss from the job mix.

Table 4

Failures and Material Out of Tolerance

Material	Project	N	Sieve Size 1" Failures No.	Sieve Size 1" Failures %	Sieve Size 1" % Out of Tol.	Sieve Size 3/8" Failures No.	Sieve Size 3/8" Failures %	Sieve Size 3/8" % Out of Tol.	Sieve Size #10 Failures No.	Sieve Size #10 Failures %	Sieve Size #10 % Out of Tol.	Sieve Size #40 Failures No.	Sieve Size #40 Failures %	Sieve Size #40 % Out of Tol.	Sieve Size #200 Failures No.	Sieve Size #200 Failures %	Sieve Size #200 % Out of Tol.
21-A	10001-1	11	--	--	---	--	--	--	--	--	--	0	0	8[a]	--	--	--
21-A	10001-2	5	--	--	--	0	0	9[a]	0	0	4[b]	0	0	16[a]	--	--	--
21-A	10003-1	10	--	--	--	--	--	--	--	--	--	--	--	--	0	0	3[b]
21-A	10005-1	11	0	0	40[c]	0	0	5[b]	0	0	4[b]	1	9	14[b]	0	0	12[b]
21-A	10007-1	11	--	--	--	2	18	9[a]	2	18	4[c]	1	9	4[b]	--	--	--
21-A	10008-1	33	--	--	--	--	--	--	2	6	0	1	3	0	5	15	8[b]
21-A	10009-1	11	0	0	38[c]	--	--	--	--	--	--	--	--	--	0	0	7[c]
21-A	10010-1	10	--	--	--	--	--	--	--	--	--	0	0	3[b]	0	0	3[b]
21-A	10011-1	25	--	--	--	--	--	--	--	--	--	1	4	2[a]	1	4	27[c]
21-A	10013-1	22	--	--	--	--	--	--	--	--	--	--	--	--	12	55	76[c]
21-A	10014-1	19	--	--	--	4	21	54[a]	1	5	21[a]	0	0	8[a]	1	5	53[c]
21	10015-1	12	0	0	4[c]	--	--	--	--	--	--	--	--	--	--	--	--
21-A	10016-1	6	--	--	--	--	--	--	1	17	12[a]	1	17	4[b]	1	17	5[b]
21-A	10018-1	9	0	0	23[c]	--	--	--	--	--	--	0	0	8[a]	0	0	21[c]
21-A	10019-1	2	--	--	--	--	--	--	--	--	--	--	--	--	1	50	39[a]
21-A	10020-1	5	--	--	--	0	0	7[b]	0	0	7[b]	0	0	6[b]	1	20	12[b]
21-A	10021-1	20	--	--	--	--	--	--	1	5	0	--	--	--	--	--	--
21-A	10022-1	12	--	--	--	--	--	--	2	17	6[a]	2	17	21[c]	2	17	17[a]
21-A	10023-1	4	--	--	--	--	--	--	--	--	--	--	--	--	2	50	42[c]
21-A	10025-1	20	0	0	31[c]	--	--	--	--	--	--	--	--	--	1	5	7[c]
21-A	10026-1	14	--	--	--	--	--	--	7	50	31[a]	0	0	2[a]	--	--	--
21-A	10028-1	24	0	0	38[c]	--	--	--	--	--	--	1	4	0	1	4	0
21-A	10030-1	2	--	--	--	--	--	--	2	100	95[c]	1	50	62[a]	--	--	--
	TOTAL	298	0	0	n = 3 % = 16	6	2	n = 5 % = 16	18	6	n = 13 % = 29	9	3	n = 13 % = 42	28	9	n = 15 % = 48

(a) both (b) and (c)

(b) σ exceeds average σ for material

(c) $|JM - \bar{x}|$ exceeds average for material

Tolerances for Total Variability

The initial adjustment values, i.e., those values below which no penalties are imposed for each sieve, are shown in Table 5 along with the variability data obtained during this study and shown previously in Table 2. The tolerances for total standard deviation were not suggested by Anday, but were incorporated into the statistical specification to penalize highly variable material. In addition, since the total variability tolerance would apply to the entire project rather than a single lot, it was made relatively large in comparison to the expected average variability.

Table 5

Total Variability Adjustment Values

Sieve Size	Initial Adjustment Values, %	Standard Deviations				% (a)
		21 Material		21-A Material		
		Avg.	Range	Avg.	Range	
2"	0.6	-	-	-	-	-
1"	4.6	1.8	1.4 - 2.3	0.3	0 - 1.7	39
3/8"	7.1	2.8	2.2 - 3.7	4.8	2.8 - 9.3	68
#10	5.6	2.2	1.6 - 2.7	4.3	2.5 - 6.8	80
#40	3.6	1.3	0.9 - 1.7	2.6	1.3 - 5.1	72
#200	3.1	0.9	0.8 - 1.2	1.3	0.7 - 2.8	42

(a) The largest average standard deviation for either material size 21 or 21A divided by the initial adjustment value.

It is obvious in looking at Table 5 that the variability would have to be extremely high in order for the contractor to be penalized for excessive total variability. In this study there were no penalties for excessive total variability on the 1" sieve, one case (3%) on the 3/8", six cases (19%) on the #10 sieve, three cases (10%) on the #40 sieve, and no cases on the #200 sieve.

Within-Plant Variability

The present specification designates which quadrant of the truck bed the sample should be taken from — either — A, B, C or D as shown in Figure 2. This sampling scheme permits an evaluation to determine if significant differences exist between the quadrant means, i.e., if there is significant with-in plant variability.

This analysis was performed useing the statistical T test at a 95% confidence level and the results are shown in Table 6. Tests were not done on the 1" sieve since, as shown earlier, the distribution for this sieve is likely to be skewed toward 100% passing.

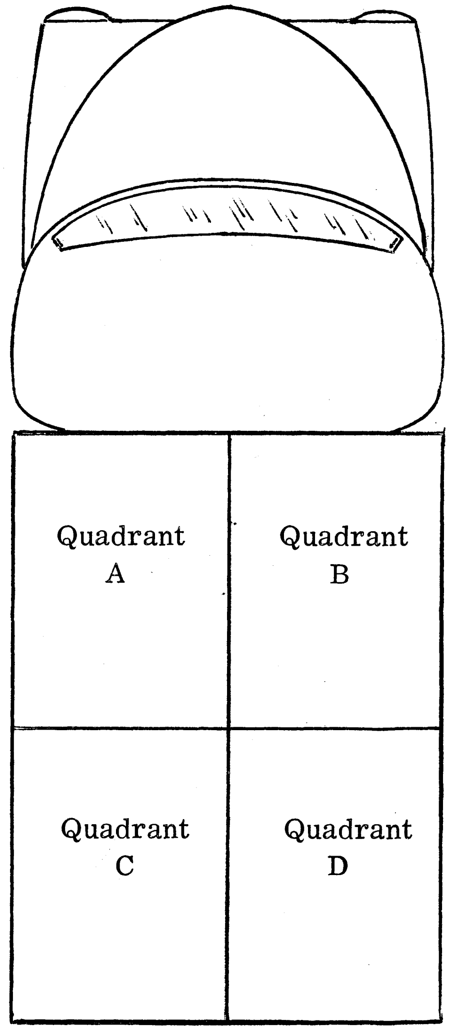

Figure 2. Designation of truck quadrants.

As can be seen from Table 6 there are a fairly high number of projects which have significant differences between quadrants, and the results are fairly significant from sieve to sieve, i.e., a project showing significant differences between quadrants on one sieve is likely to show significant differences on other sieves. However, it is not true that all the projects shown in Table 6 have a high overall variability. Only those projects for which an asterisk appears by the standard deviation have a standard deviation higher than average for the sieve indicated, and this occurs for no more than one third of the sieves shown.

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Table 6

Results of T Tests Between Quadrants — 95% Confidence Level

Project	Sieve Size 3/8"								Sieve Size #10								Sieve Size #40								Sieve Size #200							
	A B	A C	A D	B C	B D	C D	RANGE OF MEANS	σ	A B	A C	A D	B C	B D	C D	RANGE OF MEANS	σ	A B	A C	A D	B C	B D	C D	RANGE OF MEANS	σ	A B	A C	A D	B C	B D	C D	RANGE OF MEANS	σ
10001-1																																
10001-2																																
10002																																
10003																																
10004																																
10005	X			X			63.3 - 70.8	8.3*	X			X			39.2 - 45.2	6.8*	X		X	X		X	22.3 - 27.5	5.0*	X			X		X	7.6 - 9.5	2.1*
10006		X		X			59.1 - 64.5	3.7				X			30.0 - 32.5	2.4																
10007											X				36.6 - 38.1	4.1										X	X				6.8 - 8.0	1.1
10008																																
10009																																
10010	X		X	X	X		68.7 - 75.5	4.6		X	X	X	X		37.0 - 42.7	4.7*		X	X	X	X		21.2 - 24.4	2.7*			X		X		8.5 -10.6	1.4*
10011	X		X				64.7 - 67.3	3.8	X						37.0 - 38.9	3.3																
10012																																
10013									X			X			37.0 - 39.4	3.1	X			X			18.0 - 19.8	2.2				X			5.4 - 5.9	0.7
10014											X		X	X	34.0 - 37.5	4.5*			X		X	X	19.6 - 22.2	3.0*			X		X		6.8 - 7.6	1.2
10015												X	X		27.2 - 29.0	1.6	X			X	X		13.4 - 14.6	0.9								
10016																																
10017																																
10018																	X						17.9 - 21.4	3.2*	X	X					5.8 - 7.4	1.2
10019											X				27.8 - 35.6	4.3			X				15.8 - 18.6	2.4								
10020	X			X			55.7 - 72.8	9.3*	X		X	X		X	24.4 - 38.5	7.6*			X				13.1 - 20.9	4.7*								
10021					X		66.2 - 69.4	4.0			X		X	X	30.7 - 33.7	3.1					X		14.0 - 15.4	1.7					X		7.8 - 8.4	0.9
10022																																
10023																																
10024																		X	X				16.8 - 18.8	1.4	X		X				9.4 - 11.1	1.2
10025																																
10026																					X		20.8 - 23.1	2.5		X		X			7.4 - 8.8	1.3
10027												X			33.3 - 36.3	2.5																
10028																												X			9.6 - 10.6	1.7*
10029	X						66.7 - 72.6	3.4	X				X		37.3 - 43.6	3.6	X				X		21.2 - 24.4	1.9	X				X		8.6 - 10.4	0.9
10030																																
Percent[(a)]			8								15								13								11					
Projects[(b)]			7								13								12								11					
Percent[(c)]			23								42								39								35					

(a) Percentage of quadrant comparisons in which the means were significantly different.

(b) Number of projects for which there was a significant difference between means for at least one quadrant comparison.

(c) Percentage of projects for which there was a significant difference between means for at least one quadrant comparison.

CONCLUSIONS

Based on the results of this evaluation, the following conclusions were made.

1. The variability as measured by standard deviations of materials produced under the statistical specification is no more than, and probably less than, the variability values the specification was based on.

2. Generally, producers are unable to attain an average percentage passing a given sieve exactly equal to the job mix specified. Thus, the ability to remain within tolerances on means is a function of variability plus the ability to "hit" the job mix. In fact, in this study a large percentage of material out of tolerance was usually the result of a large miss from the specified job mix.

3. Considering the average variabilities and average miss from the job mix, the current statistical tolerances for means are such that for the average producer no more than 2.5% of material will fall outside the tolerance.* The tolerances on means are somewhat inconsistent in that those on the smaller sieve sizes are more restrictive relative to average conditions.

4. No problems were observed with regard to staying below the maximum tolerance of 23% for the liquid limit.

5. The sign of the difference of the actual production average from the job mix is evenly distributed on either side of zero, with the exception of the 1" sieve. On the 1" sieve the production average frequently is set at least the tolerance width under 100% passing (thus 95%) and the actual production average approaches 100%, thus creating a large positive difference from the job mix.

6. The initial adjustment values for the tolerances on total variability are extremely large relative to the average variability values. Also, the tolerances are inconsistent relative to the average standard deviations from sieve to sieve, with the tolerance on the #10 sieve being the most restrictive.

7. In several projects significant differences were found between two or more of the four truck quadrants for the various sieves sizes. However, when considering all projects, only about 11% of the sieves had an overall standard deviation greater than average.

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*In this study the percentage of material out of tolerance exceeded 20% infrequently, with the possible exception of the #200 sieve for which more than 20% of material was outside tolerance for about 19% of the projects.

RECOMMENDATIONS

It is not the opinion of the author that it is necessary to change any of the existing tolerances, unless it is deemed desirable to make them equivalent with regard to severity from sieve to sieve. Some may argue consistency of this type is desirable while others may consider it desirable to have the tolerances more stringent on the smaller sieves.

If consistency from sieve to sieve is desired, then the revisions shown in Table 7 are suggested.

Table 7

Suggested Revisions in Tolerances

Property	Current Tolerances		Suggested Revisions	
	Means	Total Variability*	Means	Total Variability**
% Passing 1" Sieve	±5.0	4.6	±5.0	2.6
% Passing 3/8" Sieve	±9.5	7.1	±8.0	6.1
% Passing #10 Sieve	±7.0	5.6	±7.0	5.6
% Passing #40 Sieve	±4.0	3.6	±4.0	3.1
% Passing #200 Sieve	±2.0	3.1	±2.0	1.6
Liquid Limit, %	+2.0		+2.0	
Plasticity Index, %	+1.0		+1.0	

* Adjustments are shown for the initial adjustment values only. The same type of adjustment should be made to all tolerances on total variability if the specification is changed.

** Initial adjustment values only.

ACKNOWLEDGEMENTS

The author thanks Sarah Kelley, programmer trainee in the Data Systems and Analysis Section, for her assistance in the preparation and analysis of the data. Thanks are also extended to M. C. Anday, Head of the Soils, Geology and Physical Environment Section, for his assistance in the interpretation of some of the results.

VIRGINIA DEPARTMENT OF HIGHWAYS
SPECIAL PROVISIONS FOR
SUBBASE AND AGGREGATE BASE COURSES
(STATISTICAL QUALITY CONTROL SPECIFICATIONS) Rev.6-1-71

Subbase and aggregate base materials on this contract shall be furnished in accordance with the applicable requirements of the 1970 Specifications as amended hereinbelow.

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

Description - Subbase material 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 material will be designated as Type I or Type II.

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 of 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 material shall conform to the following requirements:

(a) Grading shall conform to the job-mix formula selected from 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.

Aggregate base material shall conform to the following requirements:

(a) Grading shall conform to the job-mix formula selected from 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 materials shall conform to the requirements of the 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.

209
(Continued)

Section 209 (Continued)

Mixing - Subbase or aggregate base materials shall be mixed in an approved central mixing plant of the pugmill 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 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 Section 517. In addition to the equipment specified in Section 517, the Contractor shall equip the laboratory with those items listed in Section 106.06(d).

Acceptance - Sampling and testing for determination of gradation, liquid limit and plasticity index will be performed at the plant and no further sampling or testing 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.

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 malfunction 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 %
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.

209
(Continued)

Section 209 (Continued)

In the event that the job requires less than 2000 tons of material; or that the amount of material necessary to complete the job is less than 2000 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:

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

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

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

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 2000 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
2"	1
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
Liquid Limit	3
Plasticity Index	7

In the event the total adjustment for a 2000 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 1000 tons and an adjustment is necessary as indicated in the following table, it shall be for the entire quantity of the type material on the project based upon its variability as measured by the standard deviation.

Section 209 (Continued)

Standard Deviation			
Sieve Size	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 "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 tolerance. 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.

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.

FORM TL - 52A Rev. 6-72

APPENDIX B

VIRGINIA DEPARTMENT OF HIGHWAYS
MATERIALS DIVISION
CENTRAL MIX AGGREGATE PLANT INSPECTOR'S REPORT
(STATISTICAL)

RT. ________ PROJ. ________________
____
F.H.W.A. NO. ________________
________________ COUNTY
DATE ________________

MATERIAL ________________ INSPECTOR'S REPORT NO. (LOT NO.) ________
FOR USE IN ________________ AT ________________
MFD. BY ________________ AT ________________
CONSG'D. TO ________________ AT ________________

ANALYSIS OF MIXES

TEST/TON	HOUR	DATE	% MOIST.									L.L.	P.I.
1( )													
2( )													
3( )													
4( )													
AVERAGE													
ACC. RANGE													
JOB MIX													

PERCENT MOISTURE OF MIXES

TIME															
% MOIST.															
DATE															

MATERIAL PLACED ________________

REMARKS ________________

REPORTED AS: PASS ______ FAIL ______
☐ UNIT PRICE REDUCTION ________%

☐ LOT TO BE REMOVED FROM ROAD

PRODUCTION (MATERIAL) ________________
TONS PREVIOUS ________________
TONS THIS REPORT ________________
TOTAL ________________

________________ INSPECTOR
________________ ADDRESS
LAB NO. ________________

CODE NO. ________
INSP. TEST COST ________
DEBIT MEMO NO. ________

(SIGNATURE) ________________
DISTRICT MATERIALS ENGINEER

APPENDIX C

DETAILED DATA

Mat.	Project	N	Sieve Size 1" JM - $\bar{x}$	Sieve Size 1" σ	Sieve Size 3/8" JM - $\bar{x}$	Sieve Size 3/8" σ	Sieve Size #10 JM - $\bar{x}$	Sieve Size #10 σ	Sieve Size #40 JM - $\bar{x}$	Sieve Size #40 σ	Sieve Size #200 JM - $\bar{x}$	Sieve Size #200 σ	Liquid Limit σ	Liquid Limit 23 - $\bar{x}$
21-A	10001-1	45	-2.96	0.24	-3.90	5.13	-1.15	4.66	-2.06	2.86	0.19	0.98	0.97	4.4
21-A	10001-2	21	-3.00	0.00	-6.13	5.05	-2.09	5.69	-2.19	3.62	-0.23	1.37	0.94	4.4
21-A	10002-1	29	-1.41	1.74	-1.12	5.48	-0.15	4.57	0.99	2.73	0.92	0.99	1.80	6.9
21-A	10003-1	39	-3.75	0.64	0.05	4.86	1.47	3.08	0.47	1.50	0.69	1.36	1.08	9.0
21	10004-1	28	-3.51	1.41	2.57	2.25	.43	2.73	-2.11	1.66	0.17	1.16	0.49	7.6
21-A	10005-1	45	-4.98	0.16	2.60	8.28	-1.07	6.80	-1.32	5.05	-0.77	2.08	0.83	4.2
21	10006-1	23	-2.47	2.28	0.70	3.66	1.24	2.40	1.31	1.39	-0.42	0.81	0.21	8.0
21-A	10007-1	45	-2.00	0.00	5.55	5.86	3.53	4.10	-1.11	3.48	0.58	1.06	0.93	4.4
22	10008-1	132	0.01	0.06	-1.62	5.19	-0.18	5.04	-0.02	2.94	0.72	1.82	1.26	5.2
21-A	10009-1	45	-4.98	0.15	2.20	4.29	2.90	3.46	0.90	2.23	1.40	0.79	1.29	3.5
21-A	10010-1	40	-5.00	0.00	-2.23	4.61	1.31	4.67	1.34	2.73	0.67	1.42	1.68	3.5
21-A	10011-1	102	-2.61	1.09	-1.79	3.81	-1.77	3.30	-1.65	2.39	1.24	1.15	2.48	4.4
21	10012-1	42	-1.97	1.75	0.62	2.54	-0.01	2.09	0.20	1.20	-0.66	0.77	0.53	7.7
21-A	10013-1	86	0.13	0.37	-2.06	2.76	-2.51	3.06	-0.25	2.17	2.26	0.71	1.14	5.4
21-A	10014-1	76	-5.00	0.00	9.89	6.17	5.26	4.52	1.89	2.98	2.04	1.17	0.60	4.6
21	10015-1	48	-3.55	1.65	-0.19	2.88	4.89	1.57	2.50	0.92	0.31	0.81	0.91	7.2
21-A	10016-1	24	-5.00	0.00	-0.38	5.87	-3.38	6.14	-0.90	3.45	-0.65	1.68	0.82	3.4
21-A	10017-1	58	-4.01	0.57	-0.13	3.54	2.09	2.82	1.41	1.30	0.73	0.78	1.26	8.2
21-A	10018-1	36	-4.94	0.20	2.73	5.68	0.56	5.74	1.67	3.25	1.51	1.22	1.88	4.3
21-A	10019-1	8	-5.00	0.00	-3.06	6.27	-0.25	4.29	-1.51	2.43	-1.71	1.96	1.06	5.6
21-A	10020-1	20	0.34	0.78	2.65	9.28	1.35	7.58	0.28	4.74	-0.32	2.77	2.13	2.0
21-A	10021-1	78	-5.00	0.00	-4.24	4.02	3.45	3.12	1.18	1.74	-0.13	0.91	0.71	9.4
21-A	10022-1	48	-5.00	0.00	0.79	5.92	-2.92	5.10	-2.12	2.59	-1.15	1.77	1.40	7.0
21-A	10023-1	16	-5.00	0.00	4.27	3.42	1.98	2.58	-0.12	2.71	1.88	1.08	2.84	6.9
21-A	10024-1	24	-2.00	0.00	-3.54	3.12	-3.10	3.16	-1.87	1.37	-0.24	1.20	1.77	6.0
21-A	10025-1	80	-4.94	0.27	0.94	3.15	1.28	2.51	1.14	1.31	-1.35	0.88	0.79	10.2
21-A	10026-1	57	0.00	0.00	-0.05	3.02	-5.59	5.68	-1.57	2.46	0.25	1.29	0.13	3.9
21-A	10027-1	7	0.00	0.00	4.57	2.92	-2.59	2.46	0.03	1.83	0.44	0.67	1.59	3.7
21-A	10028-1	94	-4.90	0.65	0.95	5.99	0.39	4.19	-0.51	2.61	-0.14	1.73	1.97	5.4
21-A	10029-1	12	-5.00	0.00	2.44	3.35	1.08	3.59	1.39	1.91	0.44	0.90	0.50	3.8
21-A	10030-1	8	0.00	0.00	-4.21	3.85	-9.85	3.54	-4.40	2.95	-0.36	1.02	1.20	4.2