# Realistic Job-Mix Formula Tolerances for Asphalt-Concrete

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In 1960, the Department initiated a study to determine the uniformity of asphalt-concrete top course mix to establish realistic gradation control specifications. During the years between 1961 and 1964 research crews visited 55 asphalt plants where they obtained 868 hot-bin samples and 682 mix samples. Data were processed and analyzed by electronic computer and from the results it is concluded that the mix gradation $(\bar{x}, \sigma)$ depends on the method of testing (i.e., hot-bin analysis or extraction test). Neither method is totally superior to the other, but each complements the other. The hot-bin method is more meaningful when related to coarse aggregate than when related to fine aggregate, whereas the reverse is true with the extraction test.

Job-mix formula tolerances developed from this study are realistic and fair to both the producer and to the Department, and are now being used on a statewide basis.

•IN 1960 the New York State Department of Public Works, in cooperation with the U.S. Bureau of Public Roads, started a research project to determine those asphalt plant and construction procedures which produce the most serviceable asphalt-concrete pavement. The first characteristic studied was the uniformity of asphalt-concrete mixes being supplied to state projects.

Once a satisfactory asphalt-concrete mix design is selected, there should be as little deviation as possible from this aggregate gradation and asphalt content, to minimize the necessity for making adjustments in the placement and compaction operations. In addition, a well-graded and uniform pavement surface mix develops fewer distressed areas and thereby increases pavement service life. However, some variation is unavoidable because of the nature of the product. Thus, the question arises as to how much inherent variation is associated with the production, sampling, and testing of asphalt-concrete mixes. If this can be established, it is then possible to identify variations which exceed this amount as a change in product which is unacceptable.

When the investigation began, the Department specifications for asphalt-concrete required aggregate gradation and asphalt content to fall within rather wide specification limits. These requirements did not prevent a plant from supplying a mix which constantly varied from one side of the specification band to the other. Understandably, much interest was shown in a specification which would establish tolerance limits around a job-mix formula and thereby reduce the allowable variation in aggregate gradation.

Therefore, the purpose of this uniformity study was to gather information on product variation to permit the establishment of specification tolerances which would minimize the acceptance of poor material and the rejection of good material. Further, it would permit the development of a practical control procedure for asphalt-concrete plant production.
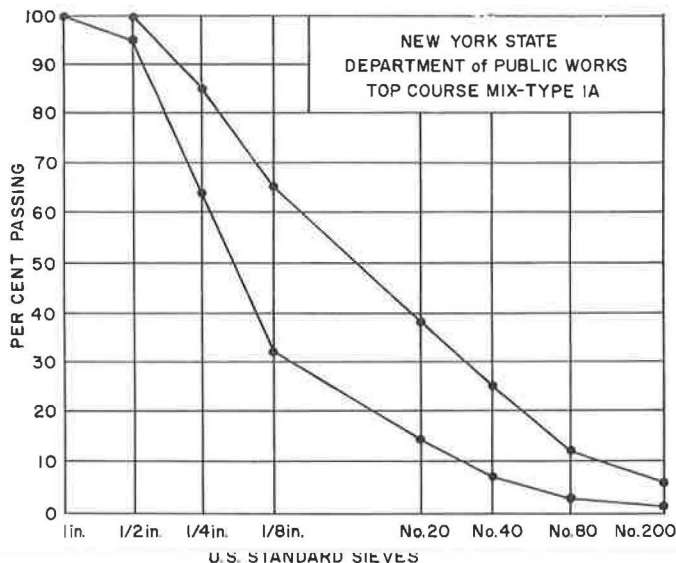
Figure 1. Asphalt-concrete specification limits.

SCOPE

### Mixes

Six types of top course, one binder, and one base course mix are used by the New York State Department of Public Works. In general, traffic character and volume govern the selection of the top course mix. Type 1A is most commonly used on primary and interstate highways. Therefore, this report is concerned only with the type 1A mix. The current (1) aggregate specification limits for type 1A top course are shown in Figure 1.

### Sampling

To obtain a realistic measure of product variation, it was important that a sufficient number of samples be obtained daily from each plant over a reasonable period of time and that a wide variety of plants be included in the program. A total of 55 plants in New York State producing top course mix were visited during this four-year uniformity study. Of these plants, 51 were batch type and 4 were continuous. In 16 of the plants, batching was performed manually, whereas in 32 plants batching was semiautomatic (i.e., hand levers had power assists). The remaining three batch plants were operated automatically, as were the four continuous mixing plants.

Ten or more batches were sampled in 80 percent of the plants visited, while 15 or more batches were sampled in half of the plants visited. A total of 868 hot-bin samples and 682 mix samples were gathered. A year-by-year listing of plants visited and samples taken is given in Table 1. This sampling covered the entire state, and the large number of samples obtained provided a reliable measure of the uniformity of asphalt-concrete being produced for Department projects.

TABLE 1

TOP COURSE SAMPLES

| Year | No. of Plants | No. of Samples | |
|------|---------------|---------|-----|
| | | Hot-Bin | Mix |
| 1961 | 22 | 297 | 118 |
| 1962 | 19 | 282 | 275 |
| 1963 | 9 | 223 | 223 |
| 1964 | 5 | 66 | 66 |
| Total | 55 | 868 | 682 |

## SAMPLING PROCEDURE

To produce type 1A top course, the majority of plants use three hot bins. The usual hot-bin designations are: No. 1 (predominantly ½ to ¼-in. stone); No. 1A (predominantly ¼ to ⅛-in. stone); and the fines or sand bin (all passing the ⅛-in. sieve). A few plants insert a No. 1B bin between the No. 1A and fines bin, and a very few plants use a mineral filler bin.

All hot-bin samples were obtained as the aggregate was dropping from the hot bin into the weigh hopper. However, the method of obtaining the sample varied, depending on the type of plant. Newer plants had built-in devices which facilitated sampling the hot bins. In older plants, samples were obtained whenever possible with an aggregate sampling device similar to that shown in Figure 2. This device was placed across the aggregate flow and is designed to reduce sample bias caused by aggregate segregation in the hot bins.

Approximately 15 lb of aggregate were obtained from each hot bin. The material was then passed several times through a sample splitter to produce 2½ to 3½ lb (i.e., 1,000 to 1,500 gm) of aggregate for final sieve analysis. One-half to 1½ hours elapsed between batches that were sampled for hot-bin analysis. The time range was caused by fluctuations in contractor paving demands, and by the general layout of the asphalt plant facilities. However, the randomness of sampling was statistically beneficial, because it precluded the possible introduction of bias due to a constant time interval between truckloads.

In 1961, hot-bin samples were taken whenever convenient, and consideration was not given as to which particular batch was being loaded into a truck. The same random procedure was followed in obtaining mix samples from the trucks, and only one mix sample was obtained for every three hot-bin samples. However, in 1962, 1963, and 1964 the hot-bin samples were obtained from the last batch of a truckload, and the mix samples were taken from that same batch after it was deposited in the truck. Therefore, during these latter three years of the study, for every hot-bin analysis there was a "companion" sample of mix. With regard to extractions, there was a possibility that an operator bias might have been introduced in the manual or semiautomatic plants because the plant operator shortened the mixing time of the last batch to get started sooner on the next truckload. However, a comparison of plant uniformity with method of production (i.e., automatic or manual) did not reveal such a trend.
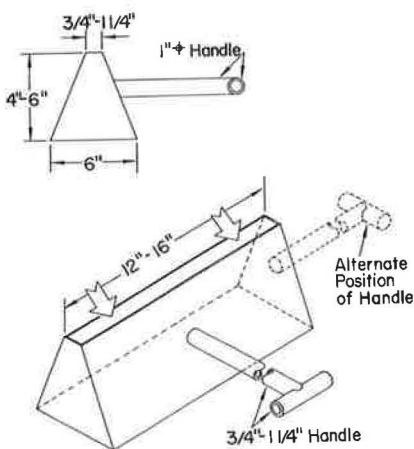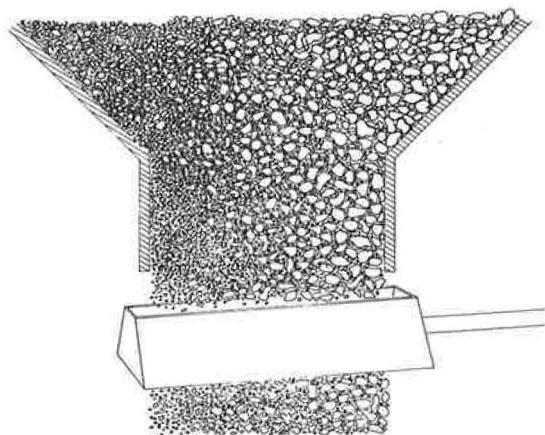


Sampling Device                    Correct Use of Sampling Device

Figure 2. Hot-bin aggregate sampler.

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In 1961, 1962, and 1963, samples of mix were obtained from the trucks in such a way as to minimize sample bias. The portion of the truck bed covered by the last batch was divided longitudinally and laterally into four equal areas. The average batch covered between 40 to 50 sq ft. A 1 to 2-qt sample was taken from the midpoint of each of these four sections. The four samples were combined, mixed and quartered to provide a 1-qt sample for extraction. In 1964, larger size, but single, samples were removed from the left and right side of the batch in the truck and were processed separately. The 1964 extraction data represent the average of the left and right side samples.

## TESTS AND COMPUTATIONS

Hot-bin samples were sieved either at the plant or at the main office laboratory. Location was determined by operating circumstances and not by any predetermined design. All sieving was performed dry, but representative samples were set aside for washed sieve analyses. About 95 percent of the extraction tests were performed at the main office laboratory by the reflux process. The remainder were extracted at the plants by the centrifuge method. Sieve analysis of extracted samples was performed at the place of extraction.

The sample from each hot bin was individually sieved, and its gradation was computed. The gradation percentages from each bin were multiplied by the proportion of the total batch weight theoretically drawn from that bin. The adjusted percentages were then totaled for each sieve size to obtain the mix gradation. The combined computed gradation is based on the assumption that the correct weights were drawn from each bin.

Basic computations and statistical analyses were performed by an electronic data processing system because of the volume of data collected. Computer programs were developed which, in addition to performing the basic computations of transforming weights into percents, performed statistical analyses by computing for each sieve size: a plant average (the arithmetic mean), standard deviation (a measure of how the individual test results are distributed about the plant average), and a coefficient of variation (a ratio of the standard deviation to the arithmetic mean, expressed as a percent). The Department's Bureau of Electronic Data Processing has published a detailed explanation of these hot-bin analysis and extraction computer programs (2).

## RESULTS AND DISCUSSION

This study was undertaken to determine the variability of top course mix as measured by dry sieved hot-bin samples. The information would then be used to arrive at realistic gradation tolerance limits about a job-mix formula. Dry sieving of hot-bin samples is the most desirable method of measuring aggregate gradation of asphalt-concrete because it is a simple, rapid test. This advantage is essential if expedient corrective action is to be taken when the product does not meet specifications. In addition, the average gradation result of the dry sieved hot-bin test were compared with those of the wash sieved hot bins and extractions.

The gradation results from the large number of samples provided a reliable base for a statistical analysis of the uniformity of asphalt-concrete. A common basis had to be selected for computing the scatter or spread of values typical of bituminous plant production in the state. The plant average for each sieve was established as a datum, from which the deviation (difference) of individual sample results was computed. These deviations were then used to compute a standard deviation, indicating the variability of the product. This was accomplished using the formula:

$$\sigma = \left[ \frac{\Sigma (\overline{x} - x)^2}{n - 1} \right]^{1/2}$$

where

$\sigma$ = standard deviation,
$\overline{x}$ = average (arithmetic mean),

$$x = \text{individual values,}$$
$$(\bar{x} - x) = \text{individual deviation from the average, and}$$
$$n = \text{number of values.}$$

## Gradation Tolerances

From statistics it is known that in a normal distribution approximately 95 percent of the samples fall within $\pm 2\sigma$ of the average. Considering the job-mix formula to be the average, which indeed it should be, establishing tolerance limits at $\pm 2\sigma$ should result in only 5 percent of the samples falling outside this limit unless production has shifted away from the job-mix formula or unless test results are not normally distributed. It is believed that 95 percent is a reasonable requirement, and that percentage was selected as the confidence level for providing realistic tolerances about a job-mix formula.

The statewide uniformity of the material passing the $\frac{1}{4}$ and $\frac{1}{8}$-in. sieves improved appreciably after 1961. Consequently, 1961 data were not included in the summation of standard deviations because this would have resulted in unnecessarily broad tolerances for material passing the $\frac{1}{4}$ and $\frac{1}{8}$-in. sieves. The fact that this uniformity study was initiated on a statewide basis in 1961 probably focused the producers' attention on their general quality control methods and, as a result, they began improving them.

In addition to the data omitted from the 1961 plants, data were omitted from 4 of the 33 plants visited between 1962 and 1964. The number of samples obtained from two of the plants was less than five, and this was considered insufficient to be statistically significant. At the conclusion of sampling in the third plant it was discovered that one of the hot-bin screens had torn, and the data collected were therefore considered unreliable. The fourth plant omitted from consideration had been newly erected, and the data taken from it were not considered representative of a typical plant. Therefore, 29 asphalt plants, from which 491 combined hot-bin analyses had been obtained, were used as the basis from which to develop realistic job-mix formula tolerances for top course mix. For tolerances to be applied in practice, they must include variability due to sampling and testing as well as variability inherent in the material. Therefore, it was not considered necessary, or even desirable, to determine how much each of these three factors contributed to overall variability.

The standard deviation for overall production during the period from 1962 to 1964 was determined by two procedures. First, a pooled standard deviation was computed by combining the individual sample deviations; this might be thought of as a weighted average value. Second, a median standard deviation was determined; i.e., the value at which 50 percent of the plants had a greater variability or a higher standard deviation and 50 percent of the plants had less variability or a smaller standard deviation. There is relatively little difference between the standard deviations determined by each method (Table 2). Either of these standard deviation values could be considered as

TABLE 2

GRADATION TOLERANCES
(Total Percent Passing)

| Sieve Size | Standard Deviations[a] | | Tolerances Around the Job-Mix Formula |
|---|---|---|---|
| | Pooled | Median | |
| $\frac{1}{2}$ In. | 0.3 | 0.2 | 5 |
| $\frac{1}{4}$ In. | 2.5 | 1.9 | 5 |
| $\frac{1}{8}$ In. | 3.0 | 2.6 | 6 |
| No. 20 | 3.7 | 3.8 | 7 |
| No. 40 | 3.3 | 3.4 | 6 |
| No. 80 | 1.9 | 1.7 | 3 |
| No. 200 | 1.0 | 0.8 | 2 |

[a]Data based on 491 combined hot-bin analyses from 29 asphalt plants during 1962, 1963, and 1964.

representing the variation in a typical asphalt-concrete plant producing for a Department project. Tolerances for 1A top course (Table 2) were established by doubling the larger measured standard deviation and rounding down to the nearest percent. The only exception is on the $\frac{1}{2}$-in. sieve where the standard deviation was only 0.3. The ±5 percent tolerance is not related to the σ actually determined and is unnecessarily large, but for convenience was made equal to the tolerance on the $\frac{1}{4}$-in. sieve. The standard deviation is very low because so little material is retained on the $\frac{1}{2}$-in. screen in our 1A top mix.

The tolerances given in Table 2 were adopted by the Department in 1965 for top course bituminous mix gradation. It is believed that these tolerances, in whole percentages, are the most realistic possible, because they are based on three years of intensive hot-bin sampling and testing. It is anticipated that uniformity will increase due to better control procedures and the continual modernization that is taking place in plant equipment. Consequently, it does not appear that producers will have any difficulty meeting these tolerances even though they are slightly less than 2σ on some sieves.

The assumption was made at the beginning of this study that the test results would be normally distributed. A control level was selected at ±2σ, because 95 percent of the samples should fall within this range. To check data normality, the percentage of samples that fell outside of each plant average ±2 pooled standard deviations was computed for each sieve. The $\frac{1}{2}$ in., $\frac{1}{4}$ in., $\frac{1}{8}$ in., and No. 200 sieve had 5 percent outside these limits. The Nos. 20, 40 and 80 sieves had, respectively, 6, 6 and 7 percent outside. This rather rudimentary check indicates that the test results were very close to being normally distributed, and justifies the use of standard deviations to establish tolerances.

## Plant Operation and Uniformity

These pooled standard deviations were compared with the standard deviations computed at the AASHO Road Test (3) for surface course mix. This was done to compare the uniformity of the "typical" plant in New York State with a plant operated under almost optimum conditions for quality control. Conditions, as they existed, were as follows:

1. At the Road Test, the mix was produced from two sizes of coarse aggregate, two sizes of fine aggregate, and mineral filler. Material sources were kept constant. The typical New York State plant also uses two sizes of coarse aggregate, but only one size of fine aggregate and no separate mineral filler bin. Material sources are usually constant.

2. Road Test aggregates were stockpiled separately and prevented from mixing by wooden barriers; the storage area was paved with bituminous stabilized gravel. The typical plant in New York State separates the stockpiles by distance, but not barriers. The storage area surfaces are not paved.

3. At the Road Test four cold-feed bins were used in conjunction with four hot bins, a mineral filler bin and a dust recovery system. In the New York plants, a cold bin fed each of the three hot bins. A mineral filler bin was not used, but dust collectors were standard equipment.

4. The amount of oversize and undersize material in any one hot bin at the Road Test could not exceed 5 and 10 percent, respectively. Therefore, the minimum amount of primary size material in any one hot bin was 85 percent. The typical New York State plant had a minimum primary size requirement of 75 percent and this applied only to the coarse aggregate bins.

5. At the Road Test a continuous type of plant was employed, and this facilitated hot-bin sampling which may have minimized sampling bias. In New York State, the typical plant was a semiautomatic batch type, with hand-held sampling devices.

6. At the Road Test three or more samples were obtained and combined to provide a hot-bin analysis during each hour of production, and results were used for quality control. Stockpile gradations and cold-feed analyses were also performed to assist in control. In the typical New York State plant, hot-bin samples were obtained every hour

for the purposes of this study. However, normal quality control was based on a hot-bin analysis and an extraction test performed for each day of production.

Table 3 gives the average total percent passing each sieve and the standard deviation on that sieve. All of the Road Test sieve sizes did not correspond with those used by the Department. Consequently, the Road Test values for the $\frac{1}{4}$ and $\frac{1}{8}$-in. sieves were obtained by graphical interpolation from the values of the adjacent sieves ($\frac{3}{8}$ in., No. 4, and No. 10). The average gradation of the Road Test mix was reasonably similar to the average mix gradation produced in the 29 plants from which the pooled standard deviations were computed. Consequently, a direct comparison of standard deviations was possible without introducing an undue bias. However, each Road Test hot-bin analysis was performed on a composite of at least three separate samples, whereas the gradation of each sample obtained at the New York State plants was determined separately. Because the physical combining of subsamples before sieving should give nearly the same answer as averaging the results of three separate sieve analyses, the standard deviation of the results is smaller for the combined samples than for individual samples. The principle involved here is that the scatter of sample averages is less than the dispersion of individual values and is reduced in proportion to the square root of the number of samples making up each average ($\sigma \bar{x} = \sigma/n^{1/2}$). Therefore, the Road Test standard deviations were each multiplied by $\sqrt{3}$ to place them on a reasonably comparable basis with the standard deviations computed for individual samples, and these modified values are given in Table 3 for comparison purposes.

The pooled standard deviations are about the same as those computed at the Road Test (Table 3). What this might mean is that the production uniformity of the typical New York State plant and the optimum plant at the Road Test are not too far apart. It is probable that the method used to convert Road Test standard deviations so that they could be compared with those measured in New York State slightly distorted the Road Test results. However, there is an independent basis here for roughly evaluating the level of quality control achieved throughout the state and it appears that this control is reasonable. Therefore, the development of job-mix formula tolerances based on the standard deviations of the typical plant has resulted in tolerances that apparently represent good quality control practice, and which can probably be adhered to by the implementation of simple, common-sense quality control procedures.

TABLE 3

COMPARISON OF NEW YORK STATE AND AASHO
ROAD TEST STANDARD DEVIATIONS

| Sieve Size | Average Gradation[a] | | Standard Deviation | |
|---|---|---|---|---|
| | NYS DPW | Road Test | DPW Pooled[b] | Road Test[c] |
| 1 In. | 100.0 | 100.0 | — | — |
| $\frac{1}{2}$ In. | 99.6 | 91.5 | 0.3 | 1.9 |
| $\frac{1}{4}$ In. | 78.6 | 73.0 | 2.5 | 2.4 |
| $\frac{1}{8}$ In. | 47.5 | 57.0 | 3.0 | 3.5 |
| No. 20 | 21.0 | 33.3 | 3.7 | 4.0 |
| No. 40 | 13.3 | 19.8 | 3.3 | 3.8 |
| No. 80 | 6.3 | 10.7 | 1.9 | 1.6 |
| No. 200 | 2.8 | 4.8 | 1.0 | 0.5 |

[a]Cumulative percent passing, total aggregate.
[b]Based on 491 combined hot-bin analyses from 29 plants.
[c]Based on 130 composite hot-bin combined analyses (3 or more subsamples per composite sample).

## Washed vs Dry Sieving of Hot-Bin Samples

To determine if serious inaccuracies were introduced by dry sieving the hot-bin samples, a portion of the material retained on each sieve was held and later washed on a No. 200 sieve. This operation was performed on about 150 samples collected during 1962, 1963, and 1964. The results showed a general increase in the average percent of total material passing the No. 200 sieve. In some plants no increase was measured and in one plant the increase was 1.8 percent. For the asphalt plants included in this study, the average increase was 0.5 percent. About 0.2 percent of the passing No. 200 material washed off the stone and about 0.3 percent washed off the fines (passing ⅛ in.).

This slight increase in the total percent of material passing the No. 200 sieve does not significantly influence the amount passing the larger sieves. Within the tolerance limits established, variations up to 0.1 percent on an individual sieve should not be a cause for concern. Therefore, the inability of the dry sieved hot bin to detect all of the fine material does not affect its applicability in controlling gradation.

## Extraction vs Dry Sieving of Hot-Bin Samples

Because gradation determined by dry sieved hot-bin samples is a rapid and simple test to perform, it was selected as the primary plant control procedure. Tolerances around a job-mix formula were developed from the variability measured with this test and are therefore applicable when the test is used. However, as a matter of policy, the extraction test is currently used for determining the passing No. 80 and No. 200 material.

The question arose as to how much the gradation of companion samples would differ when tested by these two methods, and also what average difference might be expected and how the variability of the two tests compared. Table 4 gives the average percent passing measured by each method and the average difference. Also listed are the pooled standard deviations for each method.

In regard to uniformity, the pooled standard deviations for each test method are significantly different (99 percent level) for all sieves except the No. 200. Gradation determined by dry sieving the hot-bin samples is more uniform on the ½ and ¼-in. sieves while extraction results are more consistent for all sieves below that size except the No. 200.

The difference in average results is what would be expected on the No. 200 sieve. The extraction test indicates an average of 1.7 percent more than the hot-bin tests. An unexpected result was the lower percent of material passing the ½, ¼, and ⅛-in.

TABLE 4

COMPARISON OF DRY HOT-BIN AND EXTRACTION RESULTS[a]

| Sieve Size | Total Percent Passing | | | Standard Deviation | |
|---|---|---|---|---|---|
| | Avg. Hot Bin | Avg. Extraction | Avg.[b] Difference | Pooled Hot Bin | Pooled Extraction |
| ½ In. | 99.6 | 99.6 | 0.0 | 0.3 | 0.5 |
| ¼ In. | 78.6 | 77.8 | 0.8 | 2.5 | 3.7 |
| ⅛ In. | 47.5 | 46.2 | 1.3 | 3.0 | 2.3 |
| No. 20 | 21.0 | 21.4 | -0.4 | 3.7 | 2.3 |
| No. 40 | 13.3 | 14.7 | -1.4 | 3.3 | 1.3 |
| No. 80 | 6.3 | 7.8 | -1.5 | 1.9 | 1.3 |
| No. 200 | 2.8 | 4.5 | -1.7 | 1.0 | 1.0 |
| Percent AC | — | 6.3 | — | — | 0.3 |

[a]Data based on 491 combined hot-bin analyses and 491 extraction tests from 29 mix plants during 1962, 1963, and 1964.

[b]Difference is significant at 99 percent confidence level for all sieves excepting No. 20, which is significant at 95 percent confidence level.

sieves in the extraction test as compared to the hot-bin test. When the same data were analyzed in percent passing-retained form, this trend was even more evident. The extraction samples apparently contained a proportionately larger amount of coarse material than the hot-bin samples, possibly because the extraction samples were taken from the sides of a truckload where the coarser aggregate migrate. High-speed movies of a pug mill discharging into a truck were taken and appear to substantiate this theory.

The data in Table 4 indicate that extraction test results, with the exception of the $\frac{1}{4}$-in. sieve, would fall within tolerances developed on the basis of dry sieved hot-bin samples. Therefore, this allows the substitution of the extraction test when determining the quantities passing the No. 80 and No. 200 sieves without penalizing the producer.

## Difference Between Plant Average and Job-Mix Formula

The tolerances established are based on deviations measured from the plant average. No additional allowance is made for any difference between a plant average and job-mix formula. During 1963 and 1964, the eleven plants visited had selected a job-mix formula. The median differences between job-mix formula and average gradation were 3.0, 2.7, 1.7, 2.8, 1.0 and 0.9 percent on the $\frac{1}{4}$ in., $\frac{1}{8}$ in., and Nos. 20, 40, and 80 and 200 sieves, respectively. The typical plant average gradation was $2\frac{1}{4}$ percent different than the job-mix formula. Such occurrences increase the probability of samples being outside the tolerance limits on the side toward which the average shifts. However, assuming the selection of a job-mix formula is based on the past gradation records of the plant, there should be little difference between the two unless some change takes place in the source of aggregate. If the average gradation being produced shifts away from the job-mix formula, positive corrective action is indicated.

## Plant Control Procedure

While the Bureau of Physical Research was measuring asphalt-concrete uniformity to establish realistic job-mix formula tolerances, the Bureau of Materials was developing a method of quality control in which the tolerances would be employed. This control method is included in a comprehensive manual entitled, Materials Method 5—Plant Inspection of Bituminous Concrete. The manual covers all phases of asphalt plant inspection, from the acceptance and handling of raw materials to the inspection of the automation and recordation equipment which is now a prerequisite to plant acceptance by the Department. As it pertains to quality control, the manual states:

> In general, production is accepted by obtaining gradation test results
> within the limits of a job-mix formula. Hot-bin analyses and uniformity
> tests determine the gradation of material larger than the No. 80 sieve.
> The extraction test is used to determine gradation of material smaller
> than the No. 80 sieve and also indicates the approximate bitumen content. Actual bitumen content is determined by verifying batch quantities.

A uniformity test is run for every 100 batches and a hot-bin analysis is performed after every four uniformity tests. If the specified mix gradation includes material below the No. 80 and No. 200 sieves, one extraction test is performed each day.

The dry sieved hot-bin gradation test and the extraction test are similar to those employed by most highway departments. The uniformity test was developed by the Bureau of Materials as a rapid test which would give the plant inspector a general indication of how mix gradation was deviating from tolerance limits. The test is based on the fact that in each hot bin there is usually a predominant, or "primary size" material. If the percentage of primary size material remains reasonably constant and material is weighed properly, the resulting mix will be uniform. During the uniformity study it was determined that when the amount of primary size material in the coarse aggregate hot bins (i.e., No. 1 and No. 1A) fell below 70 percent, the mix generally

became nonuniform. Consequently, the uniformity test consists of determining just the percentage of primary size material in a hot bin (i.e., $\frac{1}{2}$ to $\frac{1}{4}$ in. in No. 1 bin; $\frac{1}{4}$ to $\frac{1}{8}$ in. in No. 1A bin) and only two sieves are needed per hot-bin uniformity test. The fines hot bin does not always contain a primary size aggregate as do the No. 1 and 1A hot bins. Usually a maximum of half of the fine aggregate is retained on the No. 20 sieve, and the remainder is distributed among the smaller sieve sizes. Thus, there is no primary size fraction requirement (70% of the material) as in the coarse aggregate bins.

Fluctuations in the percentage of primary size coarse aggregate above the 70 percent minimum requirement also influence plant uniformity. Consequently, a $\pm 12$ percent tolerance is specified, measured from the primary size percentage determined in the last hot-bin analysis. The same tolerance is specified for the No. 20 sieve material, although a minimum primary size percentage is not specified. The 12 percent tolerance was selected by comparing the primary size fluctuations with the fluctuations in the total mix. Total mix fluctuations as allowed within the gradation tolerances were mathematically converted to obtain maximum anticipated fluctuations in the primary sizes. A trial and error analysis was then performed using 8, 12 and 15 percent. It was found that 12 percent was a practical limit because it provides advance warning when production is approaching the job-mix formula limits.

To determine how well the Materials Method 5.0 quality control procedure worked, it was applied to the results of hot-bin tests performed in 24 plants during 1962 and 1963. The tolerances were first applied about the plant averages using all data. They were then applied about the individual job-mix formula being used by each plant visited during 1963. Applying a quality control procedure to data already collected introduces a bias against the producer, because he has no opportunity to make adjustments, and rejections will be disproportionately high. However, the results are of value because they make it possible to compare the ability of the method to differentiate between uniform and nonuniform plants.

If the quality control procedure performed its task properly, the following would occur.

1. The simple and fast uniformity test would be performed more often than the hot-bin analysis.

2. Any samples out of tolerance would be detected.

3. Mix rejection would be evenly distributed among the sieves used for gradation control.

4. More mix would be unacceptable in the plants having poor uniformity than in the plants having good uniformity.

In general, Materials Method 5.0 met the foregoing criteria. Approximately half of the tests that theoretically would have been performed were uniformity tests, whereas the other half were hot-bin analyses. As a result of this ratio of 1:1, the plant inspector would have had available for other uses about one-third of the testing time that would normally have been spent performing complete hot-bin analyses. This saving is based on an estimate that a hot-bin analysis takes about one hour, while a uniformity test takes only about 20 minutes.

The second requirement for an adequate quality control procedure is detection of any samples that are out of tolerance. Of the uniformity tests performed, less than 5 percent were unsuccessful in indicating that the hot bins contained gradations which would produce an out-of-tolerance mix. About 20 percent of the uniformity tests helped detect out-of-tolerance mix, whereas approximately 25 percent of the uniformity tests initiated the running of a complete hot-bin analyses on the next sample which proved unnecessary, because the mix gradation was within tolerances. The remaining 50 percent of the uniformity tests indicated the hot-bin gradations were within tolerances, and this was substantiated by the actual hot-bin analysis results.

Approximately 20 percent of the samples analyzed showed one or more sieves were out of tolerance. The occurrences were fairly evenly divided among the $\frac{1}{4}$ in., $\frac{1}{8}$ in., No. 20, and No. 40 sieves. The $\frac{1}{2}$-in. sieve was not included because very little material is retained above it and material passing the No. 80 sieve was not included be-

cause Materials Method 5.0 specifies it be controlled by extractions. The relatively even distribution of "outside-of-tolerance" by sieve size indicates each individual sieve tolerance is in balance with the others.

The 24 plants to which Materials Method 5.0 was applied were classified into three uniformity groups: good, fair and poor, based on the average standard deviation of hot-bin gradations. The quality control procedure detected more out-of-tolerance mix in the poor uniformity group than in the good uniformity group. Of the production not considered acceptable about 5 percent was from the plants in the good uniformity group, 35 percent from the fair group and 60 percent from the poor groups.

In the foregoing analysis, gradation tolerances were applied about the plant averages. When the procedure was applied about the job-mix formulas the results were modified to the extent that each plant average deviated from its job-mix formula gradation. The more uniform plants were in better accord with their job-mix formula than the less uniform plants. Accordingly, the plants in the poor uniformity classification required almost continuous theoretical checking by hot-bin analyses, and in some cases entire production runs would have been out of specification because one or two sieves deviated widely from their job-mix formula. The plants in 1963 were producing for the first time under a job-mix formula requirement. Therefore, as they gain experience in selecting more realistic job-mix formulas their noncompliance should decrease accordingly.

## CONCLUSIONS

1. This study has resulted in job-mix formula tolerances for asphalt-concrete top course mix which have been incorporated into New York State Department of Public Works specifications. These tolerances are based on actual variations measured among 491 hot-bin samples obtained from 29 asphalt-concrete plants. They are set at approximately two standard deviations as computed by pooling test results. Variability due to sampling and testing, as well as the inherent variability in the material itself, are included in the tolerances selected.

2. A control procedure was developed for asphalt-concrete plants taking into account statistical data accumulated in this study. It is based on sequential sampling of hot bins and has proven an effective quality control procedure.

3. There is a significant difference between the results of dry sieved hot-bin analyses and extraction tests. Further, the hot-bin test is more uniform in the coarse sizes, whereas the extraction test shows greater uniformity in the finer sizes.

## ACKNOWLEDGMENTS

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