Engineering Brief # 30

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In Reply Refer To: AAS-200

Subject: INFORMATION: Engineering Brief No. 30, Acceptance Plan for Density, Item P-401

From: Manager, Engineering and Specifications Division, AAS-200
To: All Regions

Attn: Manager, Airports Division

Engineering Brief No. 30 discusses the rationale and use of a statistical acceptance plan for the pavement density of Item P-401, as contained in the draft copy of this specification sent to your office for comment in January.

ORIGINAL SIGNED BY:
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for
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ENGINEERING BRIEF NO. 30

ACCEPTANCE PLAN FOR DENSITY, ITEM P-401

1. GENERAL.

The draft copy of P-401 sent to the field for comment in January provides for statistical acceptance of the pavement, for density, based on a percent within limits concept. This engineering brief explains the rationale and use of this type of specification.

The reason for going to a statistical acceptance specification is contained in Engineering Brief #17, Statistical Quality Control Specifications. In summary, current specifications contain requirements with which 100 percent compliance is highly improbable due to the normal variation of the measured characteristics. Studies have shown that measurements made on unbiased samples of materials and construction are highly variable. A large part of the variation is due to the methods of sampling and testing, and it is apparent that the precision of a single test result applies only to the small amount of material that was included in the test portion. Therefore, decisions must be made about a large quantity of material (population) on the basis of a much smaller amount. Random sampling and application of statistical procedures can be used to make decisions about the population based on an evaluation of the test results obtained from a sample from that population.

The objective of sampling is to estimate the value of the mean (average) and variation about the mean, (standard deviation) of some characteristic of a LOT of material on the basis of a limited number of sample measurements from the LOT. This is accomplished by means of random sampling which gives every part of a material an equal chance of being selected. This technique of sampling takes into account variability in materials and methods of sampling and testing, and provides an unbiased representative estimate of the material characteristics. Unless the samples are chosen on a random basis (by probability sampling) the method of statistics cannot be correctly applied.

2. NORMAL DISTRIBUTION.

It has been shown that the test results for pavement materials follow a normal distribution. The normal distribution can be defined using two parameters, the mean (x) and the standard deviation (sigma). The properties of the normal distribution are shown in Figure 1. Note that 68% of the data falls within + 1 standard deviation, 95% within + 2 standard deviations and 99.7% within + 3 standard deviations of the mean. Both the mean and the standard deviation are necessary to define the normal distribution curve. The curves in Figure 2 indicate materials with good and poor uniformity. Note that the mean is the same for each curve, but that the standard deviation, which defines the variation, would be greater for the product with poor uniformity.

3. PERCENT WITHIN LIMITS ACCEPTANCE PLAN.

a. General. The acceptance plan for P-401 (density) uses the percentage within limits (PWL) approach. In this type of plan the acceptable quality level (AQL) is identified, material is sampled and tested, and the test results used to estimate the percentage of material above the specification tolerance limit. (L)

b. Specification Tolerance Limit. The specification tolerance limit has been set taking into consideration the risks involved in making acceptance decisions. Two types of risks occur each time a decision is made. Unsatisfactory material may be accepted, or a satisfactory material may be rejected, due to the probability of making errors in estimating the values.

The sellers risk (the probability of material being rejected that has a mean at or above a particular tolerance limit) was set at 2% and the buyers risk (the probability of material being accepted that has a mean at or below a particular tolerance limit) was set at 5%. This means that the probability of rejecting lots of acceptable mean quality is 2% and the probability of accepting lots of rejectable material is 5%. These risk levels were determined from a literature search and are normally used for a characteristic such as density.

c. Acceptable Quality Level. The Acceptable Quality Level (AQL) of 98% was set in order to limit the in-place air voids in the pavement to 7%. This is an attempt to prevent premature oxidation and surface cracking. Research has indicated that air voids in the 10% range can reduce the pavement life by 50 percent.

The standard deviation (sigma) of 1.3 was determined from historical data and confirmed in a study for FAA by the Pennsylvania State University (Report No. FAA-RD-79-89).

d. Rejectable Quality Level (RQL). Given that 98% is an acceptable quality level, a rejectable quality level also has to be set. The RQL is the density at which the material would be detrimental to the overall performance of the pavement.

Setting the buyers risk (beta) at 5% means that 5% of the time bad lots would be accepted if offered by a contractor. This is shown graphically in Figure 3.

e. Determination of Specification Tolerance Limit. Summarizing, the following data was used to determine the specification tolerance limit of L = 96.7% and the Rejectable Quality Level (RQL) of 95.6%:

Acceptable Quality Level (AQL)	= 98%
standard deviation (sigma)	= 1 .3%
sellers risk (alpha)	= 0.02
buyers risk (beta)	= 0.05
sample size (n)	= 4

The calculations are shown in Figure 3.

f. PWL Concept. The PWL method combines the measurements of the mean and standard deviation into a single calculation to estimate the percentage of material within specification limits. In this specification the range (R) is used to measure the variation in lieu of the standard deviation. The range is the difference between the highest and lowest test results within a lot.

The PWL concept is depicted in Figure 4. Figure 4A depicts the specified population, that is, all material above the tolerance limit of 96.7%.

g. Price Adjustment. The density acceptance plan also provides for reduced payment for material that does not meet the specification requirements. The specification (P-401) defines substantial compliance as 90 percent of the material exceeding the density tolerance limits (see Figure 4B). This constitutes 100 percent payment. Table 7 of the draft specification provides for reduced payment for less than 90 percent of the material exceeding the tolerance limits. Table 7 is a graduated schedule with reduced payment determined as a function of percent within limits.

h. Sample Calculation. The operation of the acceptance plan is shown in the following example:

pavement densities:

sublot 1 = 98.3

sublot 2 = 98.1
sublot 3 = 97.2
sublot 4 = 96.3

x (average) = 97.5
R (range) = 2.0
L (lower limit) = 96.7

Q = (X - L) / R = (97.5 - 96.7) / 2 = 0.400

PWL (percent within limit) from Table 6 of draft specification = 79%

Payment (from Table 7)
= 2.0 X (PWL) - 65.0
= 2.0 X (79) - 65.0
= 93%

Figure 4C depicts an example where the PWL calculations resulted in 79% of the material above the specification tolerance limit.

4. SIMULATION OF PLAN

Application of the acceptance plan was simulated on the test results of three projects studied in Report No. FAA-RD-79-89. On two of the projects the percent payment would have been almost 100, while on the remaining project approximately one-third of the lots would have received only 50 percent payment reflecting an average density of 95.9%.

Further research is currently underway in which a field simulation is being conducted to evaluate the acceptance plan. This simulation will help to determine the appropriateness of the plan and to identify any potential field application problems which might be associated with it.

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Figure 1. Standard Normal Distribution Curve

Figure 2. Normal Distributions Showing Good and Poor Uniformity

Figure 3. Specification Tolerance Limit

Figure 4. a. Specified Distribution
b. Substantial Compliance
c. Actual Distribution