Current Practices in Acceptance of Bituminous Concrete Compaction

PETER A. KOPAC

ABSTRACT

Current procedures employed by state highway agencies to determine the acceptability of bituminous concrete compaction are discussed. Both statistical and nonstatistical acceptance plans are covered. Statistical acceptance plans can provide a clear indication of the quality levels that are desired and can eliminate disagreements associated with the estimation of construction quality. However, many of the statistical acceptance plans currently in use are inadequate because they are inefficient or statistically unsound or both. In addition, there is a considerable lack of uniformity among acceptance plans and the price adjustment schedules they contain. Specific recommendations are made to improve acceptance plans. Further guidance should become available when more research information is obtained.

The term "acceptance plan" may be defined as an agreed-on method of taking and evaluating measurements for the purpose of determining the acceptability of a product or item of construction. Acceptance plans are one of the most important components of construction specifications. Such plans provide the basis for perhaps the most critical decision that has to be made by the state highway agency's engineer--whether to accept an item of construction. If the specifications do not clearly define acceptance procedures, both the agency and its contractors stand to lose.

METHODS SPECIFICATIONS

Methods specifications that are currently in use for highway construction rely on acceptance decisions that are made on the basis of the results of tests on "representative" samples. A representative sample is one taken when and where the inspector chooses so that in his opinion it represents all of the material being tested. Because it is difficult to predetermine when or where a sample that represents all of the material being tested can be taken, it is easy to understand how testing a representative sample can result in conflict.

A recent survey of bituminous concrete compaction acceptance practices (1) indicates that there are 35 state highway agencies that use methods-type compaction specifications involving representative sampling. The following is a typical example of the criteria employed by these state agencies in determining the acceptability of compaction (2,pp.74-75):

> Section 401.19 Compaction. Rolling shall be continued until all roller marks are eliminated and a minimum density of ..... percent (92 suggested) of the theoretical maximum density . . . has been obtained. . . . Any area [of the surface course] showing an excess or deficiency of bituminous material [after compaction] shall be removed and replaced.

Further guidance is provided in the following (2,pp.14-15):

> Section 105.03 Conformity with Plans and Specifications. All work performed and all materials furnished shall be in reasonably close conformity with the lines, grades, cross sections, dimensions and material requirements, including tolerances, shown on the plans or indicated in the specifications. . . .
>
> In the event the Engineer finds the materials furnished, work performed, or the finished product not within reasonably close conformity with the plans and specifications but that reasonably acceptable work has been produced, he shall then make a determination if the work shall be accepted and remain in place. In this event, the Engineer will document the basis of acceptance by contract modification which will provide for an appropriate adjustment in the contract price for such work or materials as he deems necessary to conform to his determination based on engineering judgment.

The primary problem with these instructions is that they are vague. The engineer or inspector must take samples, but he is not given the exact number of samples nor the locations for sampling. If a test fails, acceptance of the work is left to the judgment of the engineer. It is up to the engineer to decide whether the work is "within reasonably close conformity" and should be accepted, whether an appropriate adjustment should be made to the contract price, or whether the work should be corrected. The contractor has no advance assurance that the vague acceptance terms of the provision will be interpreted fairly. He must treat the acceptance requirements with uncertainty because he realizes that different engineers may not make the same decision about the same submitted work.

END-RESULT SPECIFICATIONS

The good contractor wants, and should have, uniform interpretation and enforcement of specifications in order to protect his competitive position as well as the quality of highways. The only way to ensure equitable and uniform enforcement of the specification requirements is to spell out the acceptance procedures in detail. The end-result specifications that are currently in use contain statistical acceptance plans that provide such detail. Statistical acceptance plans generally define

1. Material characteristic or characteristics on which acceptance is based;

2. Lot size (i.e., the quantity affected by the acceptance decision);
3. Point of sampling;
4. Number of samples;
5. Sampling procedure;
6. Test method;
7. Limits of acceptance for the material characteristic or characteristics;
8. Manner in which test results are to be processed; and
9. Price adjustments (or corrective action) for various degrees of noncompliance.

Statistical acceptance plans have the potential to eliminate ambiguity. They also allow both the contractor and the highway agency to ascertain and control the risks associated with acceptance decisions. However, many agencies that have statistical acceptance plans are not making full use of the associated statistical theory. In addition, there is considerable variation among acceptance plans from state to state--a situation that leads to inefficiency and confusion.

Guidance for state highway agencies in the use and application of statistical acceptance plans can be found in AASHTO R9-81, "Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction" (3). Here, two types of variables acceptance plans are recommended for use when the mean ($\bar{X}'$) and the standard deviation (σ') of submitted material are unknown, the situation most common in highway construction.

The first plan, entitled "Plan to Estimate Percent Within Tolerance," requires first the calculation of the average ($\bar{X}$) and range (R) of the random sample test results. A quality index (Q_U or Q_L) is computed next:

$$Q_U = (U - \bar{X})/R \text{ or } Q_L = (\bar{X} - L)/R$$

where U is upper tolerance, if applicable, and L is lower tolerance, if applicable.

The quality index and the number of random samples are then used to enter a table that gives the estimated percentage of material that is within tolerance. This percentage within tolerance provides the engineer with a concise and meaningful indicator of the quality achieved. The plan is based on sound statistical theory.

The second plan is entitled, "Plan to Provide Fixed Protection Against Accepting Poor Material." To design such a plan, it is necessary to specify the value of $\bar{X}'_p$ (i.e., the mean value of material that is of borderline quality but just beyond acceptability; such material should have a high probability of rejection). The desired probability of rejecting this poor material is chosen based on the criticality of the characteristic being measured. The probability of rejecting acceptable material depends on the variability of the material and, of course, on the definition of acceptable material. The acceptance decision is of the form: $\bar{X} > \bar{X}'_p + aR$, if a lower limit exists, or $\bar{X} < \bar{X}'_p - aR$, if an upper limit exists, where a is a constant dependent on the number of random samples.

The two acceptance plans are more similar than they might first appear. As stated earlier, both plans assume that the population mean and standard deviation are unknown. Both plans also use the range of sample values as the measure of variability. In addition, because the constant a in the second plan is actually a fixed quality index (Q_U or Q_L), it can be shown that the two forms of acceptance are equivalent.

CURRENT PRACTICES

Few states have experience with either of the two types of acceptance plans recommended by AASHTO. Of the 17 highway agencies that include statistical acceptance plans for bituminous concrete compaction as part of their standard specifications books, only three have plans that correspond to either of AASHTO's recommended types of plans.

Seven of the 17 agencies have acceptance plans that give no consideration to the variability in compaction. In these states, only an estimate of the mean is needed to determine acceptance. (This means that a submitted lot that has an estimated mean compaction of 98.0 percent and a standard deviation of 0 percent, for example, is treated for acceptance purposes as identical to a lot that has an estimated mean compaction of 98.0 percent and a standard deviation of 5 percent.)

Several of the 17 agencies have acceptance plans that are statistically unsound. One agency, for example, places the same minimum density requirement on individual samples taken from a lot regardless of the total number of samples in that lot. Thus, in that state, the more samples taken from a contractor's lot, the greater the probability that the contractor's work will be deemed unsatisfactory, even if it is actually good. A similar situation exists in another agency's acceptance plan. That agency requires 5 to 10 samples per lot but does not change the acceptance criteria to account for the different sample sizes. It can be demonstrated that, for the acceptance plan in question, the use of 5 samples would result in full-payment acceptance of material that is estimated to be at least 69 percent within tolerance. If 10 samples are taken, the estimated percentage within tolerance must be at least 75 percent for full-payment acceptance. A decision to use a sample size of 10 instead of 5 could therefore be harmful to a contractor who is producing good material.

Many acceptance plans are not as efficient as they might be. Those agencies that require multiple random samples and then calculate only the sample average are not making full use of available test results. Of the 10 agencies that do use available test results to assess the degree of compaction variability present in the lot, only one does so by computing the standard deviation. It can be shown that the standard deviation method is more accurate, or requires smaller sample sizes to achieve the same accuracy, than the range method. AASHTO is currently considering revision of its standard recommended practice for acceptance sampling plans; one of the changes that has been proposed is the use of the standard deviation method as an alternative to the range method.

Lot sizes, samples sizes, test procedures, and acceptance limits all vary considerably among the states. In regard to sample size (which typically ranges from n = 3 to n = 7), it is surprising that larger sample sizes are not used in conjunction with the nuclear density test. The test is nondestructive and can be quickly performed. By taking 20 samples, for example, a better estimate of quality could be obtained at little or no extra cost.

PRICE ADJUSTMENTS

The agency's response to substandard quality is probably the most controversial element of an acceptance plan. A basic point of disagreement is whether to apply a price adjustment at all. In the case of bituminous concrete compaction, several agencies permit rerolling of the material (one agency, for example, permits rerolling 3 days or more after a deficiency is found). Thus, some of these agencies do not apply price adjustments, believing minor compaction deficiencies can be corrected.

Twelve of the 17 agencies that have statistical acceptance plans for compaction also apply price adjustments. Because the relationship between degree of compaction and pavement performance has not been well defined, agencies have been forced to develop price adjustment schedules somewhat arbitrarily. Fortunately, an entirely rational schedule is not essential. A rational schedule is of course desirable, but of equal importance is that the schedule appear in the specifications and that both parties agree to its use. An arbitrarily derived price adjustment schedule, as long as it appears reasonable and has been agreed on, may be legally enforceable (4).

State highway agencies employ two basic types of price adjustment schedules, graduated and continuous. Because the difference in pay between two adjacent steps of a graduated schedule can be considerable, disputes over measurement precision, round-off rules, and so forth can result, particularly when the estimated quality falls slightly short of a higher payment step. Although graduated schedules are more common, continuous schedules are rapidly gaining favor (paper by R.M. Weed in this Record). With a continuous schedule, there is a smooth progression of adjusted payment, and disputes are avoided. Graduated schedules can easily be converted into continuous schedules.

Any comparison among the price adjustment schedules of state highway agencies should be made with caution. Preferably, the comparison should be made by constructing operating characteristics curves (OC curves), a subject to be discussed shortly. To quickly obtain a feel for the disparity that exists among price adjustment provisions, a visual comparison of the schedules might also be made. Such a comparison is difficult because of the different lot sizes, sample sizes, test procedures, and so forth that are employed. However, for those few states in which nuclear testing is conducted to determine the average percentage of control strip density, a sample average density of 95 percent results in a range from 75 percent payment in one state to 100 percent payment in another state. The disparity among the price adjustment schedules used by different highway agencies is of concern and is often much wider than illustrated in this compaction example. A study (5) noted this disparity and emphasized the confusion and dissatisfaction that result among contractors. In that study, the authors noted that a contractor could provide the same material in two different states and have the material rejected in one state and accepted at full payment in the other.

Needless to say, such a situation is undesirable. The author believes that the problem is primarily due to a lack of adequate research information. State highway agencies often develop price adjustment schedules arbitrarily because little data exist that relate material quality characteristics and performance. A better understanding of the relationship between quality and performance is necessary if truly effective and economical acceptance plans, which include price adjustment schedules, are to be developed. The matter is complicated because several quality characteristics are often necessary to define quality; because these characteristics are often interdependent, there is a need for more multicharacteristic acceptance procedures such as that developed for rigid pavements (6). Ongoing FHWA-sponsored research is addressing the problem and should result in a better understanding of the measures of quality and in improved acceptance plans. The research results should enable FHWA and AASHTO to provide better guidance and instill more uniformity.

Agency plans also suffer somewhat in the area of risk management. Statistical acceptance plans allow the state and the contractor to establish the risks involved--for the state the risk of accepting poor material and for the contractor the risk of having good material rejected. This concept is perhaps the least understood element of statistical quality assurance techniques (7).

In analyzing risks associated with acceptance plans, it is desirable to do so not only for poor and good material but also for all quality levels in between. An excellent tool for the analysis and control of risks is the OC curve. An OC curve is nothing more than a graphic presentation of the relationship between the actual quality of a lot and the probability of acceptance of that lot. For acceptance plans with price adjustment schedules, the relationship between the actual quality of a lot and the probability of the lot being assigned various pay factors can be presented. From this relationship, the contractor's expected payment for various quality levels is determined. OC curves can be used to control the magnitude of risks during the development of an acceptance plan. Because OC curves portray the way an acceptance plan operates, they are also useful when making comparisons among acceptance plans. It is unfortunate that more highway agencies have not developed OC curves for their acceptance plans. The theory behind the development of OC curves has been summarized (8), and an interactive computer program is available (9).

Under most acceptance plans, a contractor cannot in the long run expect to get 100 percent payment for producing work that falls just at the level that has been defined (or implied) to be acceptable. By assuring that poor work will be rejected or will receive a price reduction, the acceptance plan may at the same time cause the contractor's expected payment for good work to be placed at an inappropriately low level. This situation can easily be remedied, however, by allowing payment factors greater than 100 percent to offset the lower pay factors. A complete discussion can be found in the paper by Weed in this Record.

SUMMARY

Some of the problems with both statistical and nonstatistical acceptance of bituminous concrete compaction have been discussed. The discussion is also generally applicable to acceptance based on other quality characteristics.

Many acceptance plans were found to be inadequate or not used to their fullest potential or both. Improved acceptance plans could be obtained through the following:

1. Acceptance plans should provide for a measure of not only the mean but also the variability;
2. The standard deviation is a better measure of variability than the range, and it should be used in all cases;
3. Provisions should be made to adjust acceptance criteria to reflect changes in sample size;
4. Larger optimum sample sizes should be used where possible;
5. Where possible, price adjustment schedules should be related to expected performance;
6. Pay factors greater than 100 percent should be considered where increased performance can be demonstrated;

7. Continuous price adjustment schedules should replace graduated schedules; and
8. Operating characteristic curves should be used to assist in the development of acceptance plans.

Other improvements will become possible as a better understanding of materials quality characteristics is obtained. More multicharacteristic acceptance plans should come into being, and more rational price adjustment systems should be developed. A greater degree of nationwide uniformity can and should be obtained, even if in the interim it is achieved through an arbitrary but reasonable price adjustment system.

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