Development of Air Voids Specification for Bituminous Concrete

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The New Jersey Department of Transportation (NJDOT) has been using statistical quality assurance (SQA) specifications for various construction items since the late 1960s. Throughout this period, there has been a continuing process leading to a better understanding of the operation and implementation of SQA procedures. The NJDOT specification for air voids in bituminous concrete was one of the first to be developed and, as such, was a prime candidate for upgrading. A major change is to base the acceptance procedure on the percentage defective rather than the average of the test values in order to control both the level and the variability of the air voids in a statistically efficient way. Doing this required new definitions of the acceptable and rejectable quality levels (AQL and RQL) and a reexamination of the adjusted pay schedule to be applied when other than AQL work is received. It was decided to use a positive incentive (bonus) provision for superior quality, an approach that has worked well with other recently developed NJDOT specifications. Another change is to use a continuous (equation-type) pay schedule to provide a smooth progression of payment as the quality varies, thus avoiding potential disputes over measurement precision when a quality estimate falls just on one side or the other of a boundary in a stepped pay schedule. The various developmental steps are described, including the construction of the operating characteristic curve to verify the performance of the specification and the field trials leading to its successful implementation.

The AASHO Road Test provided a wealth of statistical data in the early 1960s that could be used to relate various construction quality measures to performance. As did several other states at the time, New Jersey began to explore the use of this information to develop specifications that described the desired quality in statistical terms. This approach turned out to be effective, but it was discovered that for most construction items, it was not possible to define a single level of quality that clearly separated acceptable and unacceptable work. It was possible, however, to define a high level of quality that was clearly acceptable (AQL) and a substantially lower level that was clearly rejectable (RQL). In between these two extremes, work was judged to be sufficiently defective that it did not deserve full payment but not so defective that removal and replacement were warranted. Thus was born the concept of adjusted payment, which provided a convenient and practical way to accept minimally defective items for a prearranged level of reduced payment.

The New Jersey Department of Transportation (NJDOT) began to develop random sampling plans, statistical acceptance procedures, and adjusted pay schedules for various properties of bituminous concrete, including air voids, which are a surrogate measure for level of compaction. Because statistical quality assurance (SQA) was new to almost everyone in the transportation field, the early specifications were based on the simplest concepts. For example, the range was often used in favor of the standard deviation as a measure of variability because it was easier to understand and apply. Now it is recognized that a price in statistical efficiency must be paid for simplifications such as this, and that when acceptance procedures are based on the standard deviation, the same discriminating power can be obtained with a reduced sampling and testing effort.

The original air voids specification was simplified by using the process average as the acceptance parameter. The drawback of this is that it ignores variability. If the variability were to become unusually large, there could be a considerable amount of out-of-specification material even though the process average was at a normally satisfactory level.

Early SQA specifications typically assessed pay reductions for deficient quality but did not award extra payment for quality that was above that required. More recently, the use of positive incentive (bonus) payments for truly superior quality has been judged to be in the public interest (*1*); this is now a common practice in many states.

The first pay schedules to be developed typically had several distinct steps with a declining series of percentage pay factors corresponding to specific ranges of the quality measure. The problem with this approach is that whenever the true quality level falls close to one of the boundaries in such a pay schedule, the quality estimate may fall on either side of the boundary, primarily by chance. Depending on which side of the boundary the estimate falls, there may be a substantial difference in pay level, which can lead to disputes over test procedures, measurement precision, round-off rules, and so forth. Many recent SQA specifications avoid this problem by using continuous (equation-type) pay schedules that provide a smooth progression of payment as quality varies.

The development of the first SQA specifications was largely a trial-and-error process; several tries were often needed before a workable specification was obtained. Modern SQA specifications are the result of a continuing evolutionary process and contain many improvements and refinements not present in the earlier versions. As highway engineers have developed a better understanding of both the operation and implementation of SQA procedures, this newly acquired knowledge has been reflected in more effective acceptance procedures with properly balanced risks and fair and equitable adjusted payment provisions. As the level of sophistication has increased, the computer has emerged as a valuable aid in performing much of the developmental and analytical work. As the result of this steady progress, SQA specification writing is now far less of an empirical art and may begin to be regarded as a scientific process.

OBJECTIVES

One objective of an ongoing study was to establish a list of fundamental principles to guide the long-term upgrading of the NJDOT quality-assurance program. This goal has been completed, and a list

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TABLE 1 Effect of Compaction on Bituminous Pavement Life

AIR VOIDS (PERCENT)	REDUCTION IN PAVEMENT LIFE (PERCENT) LITERATURE	SHA SURVEY	STUDY
7	0	7	0
8	10	13	2
9	20	21	6
10	30	27	17
11	40	38	--
12	50	46	36

of 28 basic SQA concepts has been published (*2*, Part 3). One of the tasks of the study described in this paper was to apply these principles to improve the NJDOT acceptance procedure for air voids in bituminous pavement.

It is widely recognized that level of compaction is one of the most important variables relating to long-term pavement performance. Table 1 has been reproduced from a recent publication (*3*) and summarizes the effect of compaction, measured in terms of air voids content, on the performance of bituminous concrete pavement.

The level of compaction can be controlled in either of two ways: by controlling the density of the pavement directly or by controlling the air voids content. NJDOT has elected to base its acceptance procedure on air voids because this approach accounts for additional important performance factors such as permeability, intrusion of road chemicals, oxidation, and potential for creating a hazardous condition by extruding asphalt onto the pavement surface when the voids content is too low.

Lot size is defined as either 4180 m^2 (5,000 yd^2) of bituminous concrete surface area of uniform thickness or 8360 m^2 (10,000 yd^2) of a pavement layer that is of variable thickness. For simplicity, the original acceptance procedure had been based on the average air voids content obtained from $N = 5$ cores, taken at random locations and evaluated in accordance with standard test methods. The average was required to be between 2.0 and 8.0 percent.

Provided that the five-sample average was between the limits of 2.0 and 8.0 percent, full payment was made. For averages falling outside these limits, the stepped pay schedule presented in Table 2 provided a decreasing level of payment. The minimum pay factor was PF = 80 percent, and there was no formal RQL provision requiring removal and replacement for extremely high voids content.

Although this procedure performed reasonably well initially, it was eventually discovered that there were an increasing number of cases in which the average air voids content was within the required range of 2.0 to 8.0 percent but that a substantial number of test values fell outside these limits, usually on the high side. Air voids measurements well above 10.0 percent were commonly encountered, and basic statistical reasoning suggests why this was the case. Provided that the average value is not unusually low, historical data have shown that percentage air voids is approximately normally distributed and the standard deviation may occasionally be as large as $\sigma = 2.0$ percent. If the average level were just within the upper limit of 8.0 percent, individual values could be as large as 14.0 percent, as shown in Figure 1. To emphasize the effect of this, an approximate smooth-curve fit of the information provided by Table 1 is drawn on this same figure. If Table 1 is correct, it is apparent that a substantial portion of the lot illustrated in Figure 1 would have a significantly shortened life.

TABLE 2 Original Pay Schedule for Percent Air Voids

AVERAGE AIR VOIDS (PERCENT)	PAY FACTOR (PERCENT)
0.0 - 1.4	80
1.5 - 1.9	90
2.0 - 8.0	100
8.1 - 9.0	95
9.1 - 10.0	90
Over 10.0	80

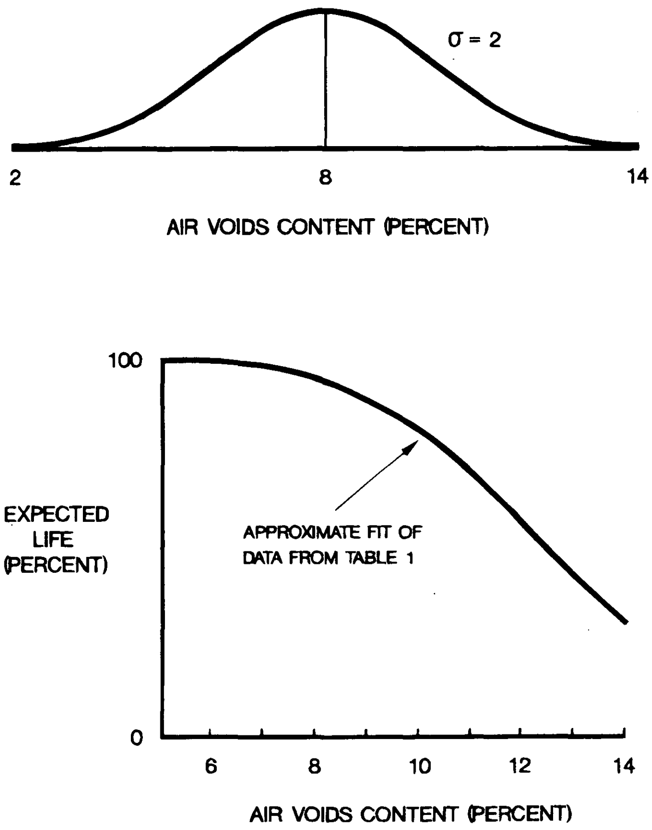

FIGURE 1 Air voids distribution with large standard deviation and associated life expectancy.

NEW TYPE OF SPECIFICATION NEEDED

It was concluded that a different type of acceptance procedure was needed, one that would provide an incentive to the contractor to control not only the average voids content but the variability as well. This need led to the decision to base the new specification on a different statistical measure of quality: percent defective (PD), the percentage of the lot falling outside specification limits.

It was decided to use the same specification limits, 2.0 and 8.0 percent air voids content, and define the AQL to be a lot for which no more than 10.0 percent of the material falls outside these limits. It was believed that this level of quality would ensure good performance and, at the same time, could be achieved by the construction industry. Another consideration was that this AQL had proven to be a practical choice for several other NJDOT specifications.

It was also necessary to define the RQL, the level at which the highway agency reserves the option to require removal and replacement, corrective action, or the assignment of a substantial pay reduction for the lot. As a general rule, RQL values must be set low enough that such drastic action is truly warranted. Since pavement failure does not pose a major safety hazard (such as the catastrophic failure of a bridge member), the RQL limit for percentage air voids has been set at a relatively high level of PD = 75. However, as an additional safeguard, another provision has been included that gives NJDOT the option of reevaluating the lot by means of additional cores whenever the estimated PD equals or exceeds 50.

DEVELOPMENT OF PAY SCHEDULE

In between the AQL of PD = 10 and the RQL of PD = 75, the work will be accepted at reduced payment. If specifications such as this are to be effective, the amount of payment reduction must be related in at least an approximate way to the economic loss expected to result from deficient quality. For truly superior levels of quality, ranging from PD = 0 to PD = 10, it is believed that additional service life of the pavement is obtained and, accordingly, an appropriate level of bonus payment is justified.

Besides providing an additional incentive to produce high quality, a bonus provision is an essential feature if specifications of this type are to perform fairly. Because there is inherent uncertainty in any sampling and testing process, some samples will underestimate the quality and others will overestimate it. Unless there is some way for bonuses and reductions to balance out naturally, the average pay factor will be biased downward at the AQL and acceptable work may be penalized unfairly. The importance of this feature becomes apparent when the operating characteristic (OC) curve (*2*, Part 3, Item 6) for the acceptance procedure is examined. A conceptual model of an OC curve for a statistical acceptance procedure with an adjusted pay schedule is shown in Figure 2.

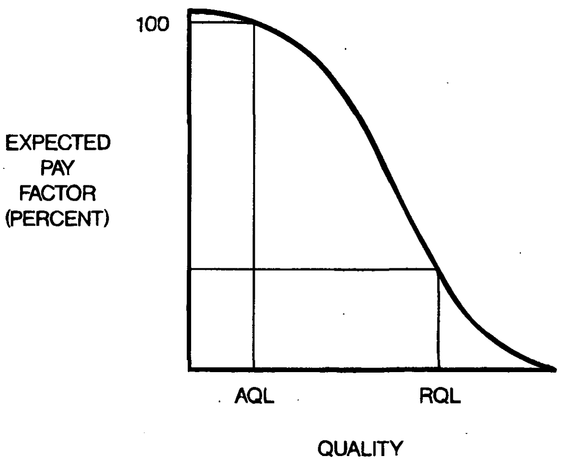

FIGURE 2 Conceptual model of OC curve for statistical acceptance procedure with adjusted pay schedule.

For lower levels of quality (PD > 10), the same techniques that have proved successful in engineering economics and life-cycle cost analysis may be used to develop sound and defensible adjusted pay schedules. The fundamental assumption is that it is justifiable to withhold sufficient payment at the time of construction to cover the cost of future repairs made necessary by deficient quality. If a pavement is constructed with insufficient thickness, for example, it is possible to work backward through the design procedure to estimate the amount by which its service life will be shortened. The series of overlays that will commence at the end of the pavement's design life now must be initiated sooner. Since this will occur some time in the future, both the interest rate on capital and the inflation of construction costs must be properly accounted for in order to estimate the monetary impact in terms of present worth. This approach is consistent with the legal principle of liquidated damages and is discussed in more detail in a recent publication (*2*, Part 3, Items 10 and 28), where Equation 1 is presented. Sensitivity tests have shown that pay schedules developed from this equation are relatively stable because costs as well as interest and inflation rates tend to track in parallel over long periods of time.

$$\mathrm{PF} = 100\,[1 + (C_{\mathrm{overlay}}/C_{\mathrm{pavement}})\,(R^{L_{\mathrm{design}}} - R^{L_{\mathrm{expected}}})/(1 - R^{L_{\mathrm{overlay}}})] \qquad (1)$$

where

PF = appropriate percentage pay factor (dependent variable),
L_{expected} = expected life of pavement (years) (independent variable),
C_{pavement} = present unit cost of pavement (bid item only, same units as C_{overlay}),
C_{overlay} = present unit cost of future overlay (total in-place cost, same units as C_{pavement}),
L_{design} = design life of pavement (years),
L_{overlay} = expected life of overlay (years),
$R = (1 + R_{\mathrm{inflation}}/100)/(1 + R_{\mathrm{interest}}/100)$,
$R_{\mathrm{inflation}}$ = long-term annual inflation rate (%), and
R_{interest} = long-term annual interest rate (%).

To apply this procedure, it is necessary to determine appropriate values for unit cost, design life, and interest and inflation rates. It is also necessary to have a performance model that relates level of quality to expected service life in order to determine the value of L_{expected} required by Equation 1.

Typical costs, design life, and expected overlay life were readily available from the design and construction units. Long-term interest and inflation rates could be estimated from our own records and published data. An approximate performance model, obtained by fitting a smooth curve through the data in Table 1, is shown in Figure 1 and is given by Equation 2:

$$\mathrm{PCTLIF} = 100 - 0.756(\mathrm{VOIDS} - 5)^{2.1} \qquad (2)$$

where PCTLIF is the life expectancy in percentage of design life, and VOIDS is the percentage air voids content.

Since this model curves downward at higher levels of percentage air voids, it reflects a greater degree of shortening of pavement life for the upper tail of any air voids distribution to which it is applied. As a result of this nonlinear effect, the use of a single average value for air voids content in Equation 2 will tend to overestimate the average life of the pavement to some degree. Tests with a numerical integration procedure suggest that the value of PCTLIF obtained in this manner may be overstated by about two or three units, depending on the mean and the standard deviation of the air voids distribution. However, this overstatement will not be accounted for in the analysis that follows; it will be treated only as further justification for a general tightening of the air voids acceptance procedure.

The procedure for developing the pay equation is as follows:

1. The appropriate percentage pay level is determined at two specific points: the AQL and RQL.
2. A trial pay equation is selected, including the minimum percentage pay level to be assigned when RQL work is allowed to remain in place. A linear pay equation usually will be sufficient.
3. The OC curve is constructed and the resulting average pay levels at the AQL and RQL are checked. This trial-and-error process is repeated until the desired results are obtained.

Like other NJDOT specifications, the AQL for the new air voids specification has been defined as a level of PD = 10. It is a fundamental requirement that when the work is precisely at the level defined as acceptable, the average pay factor must be 100 percent. Therefore, the location of the point at the AQL is already established.

To determine the appropriate pay level at the RQL of PD = 75, and for work of still lower quality that for practical reasons may be allowed to remain in place, the following values have been assumed:

$\sigma = 1.5$ (typical value for percentage air voids)
$C_{\text{pavement}} = \$6.91/\text{m}^2$ ($\$5.78/\text{yd}^2$) (assumes \$33/Mg bid price, average thickness of 8.9 cm, and compacted density of 23.5 kg/cm/m^2; in U.S. customary units, \$30/ton bid price, average thickness of 3.5 in, and compacted density of 110 lb/in/yd^2)
C_{overlay} = total in-place cost of overlay of \$11.96/m^2 (\$10.00/yd^2)
L_{design} = 15 years
L_{overlay} = 10 years
R_{interest} = 8 percent (long-term annual rate)
$R_{\text{inflation}}$ = 4 percent (long-term annual rate)

Assuming a typical level of variability, the RQL of PD = 75 corresponds to an average air voids level of 9.0 percent. This value is substituted into Equation 2 to obtain an approximate value of PCTLIF = 86.1 percent which, when applied to the design life of 15 years, produces an expected life of 12.9 years. This value is then substituted into Equation 1 to obtain an appropriate pay factor for RQL work of about 74 percent. It is apparent that, on the basis of current costs and conditions, the previous minimum pay factor of 80 percent that was used with the original specification is not low enough to recoup the future anticipated costs associated with seriously defective work. In fact, it will be found that a pay factor of even lower than 74 percent must be assigned when RQL work is allowed to remain in place. Like the condition at the AQL where the opportunity to receive bonus pay factors greater than 100 percent allows the process to fairly award a long-term average pay factor of 100 percent, correspondingly lower lot pay factors are necessary at the RQL if the long-term average is to be at the desired level. It will be seen when the OC curve is constructed that an RQL pay factor of about 60 percent is required.

The third step of this process involves constructing the OC curve to determine how the pay equation will perform—that is, to verify that the desired average pay levels of 100 percent at the AQL of PD = 10 and 74 percent at the RQL of PD = 75 have been achieved. A computer program recently developed for FHWA Demonstration Project 89 on Quality Management (*4*) proved to be an extremely useful tool for this step; this program, OCPLOT, is described in another paper in this Record (see p. 18). The pay schedule given by Equation 3, when combined with an RQL pay factor of 60 percent, is shown in Figure 3 to produce a satisfactory OC curve. The actual wording of the specification and the necessary computations are described in the next section.

$$\text{PF} = 102 - 0.2\ \text{PD} \qquad (3)$$

NEW AIR VOIDS SPECIFICATION

It has been NJDOT practice to use somewhat relaxed pay schedules when phasing in new construction specifications in order to allow the construction industry time to become familiar with the new procedures. The pay equation included in this specification reduces all pay adjustments by exactly half. The pay reduction for RQL work that is allowed to remain in place is similarly about half of what the theoretical development suggests is warranted. It is planned to revert to more appropriate pay levels after sufficient experience has been gained with the new specification.

It is recognized that a slight improvement in statistical efficiency could be realized by using two different PD estimation tables: one for a sample size of $N = 5$ for initial tests, and another for $N = 10$ when the option to require a retest is exercised. The decision to use a single table is a concession to practicality that sacrifices very little in the way of performance.

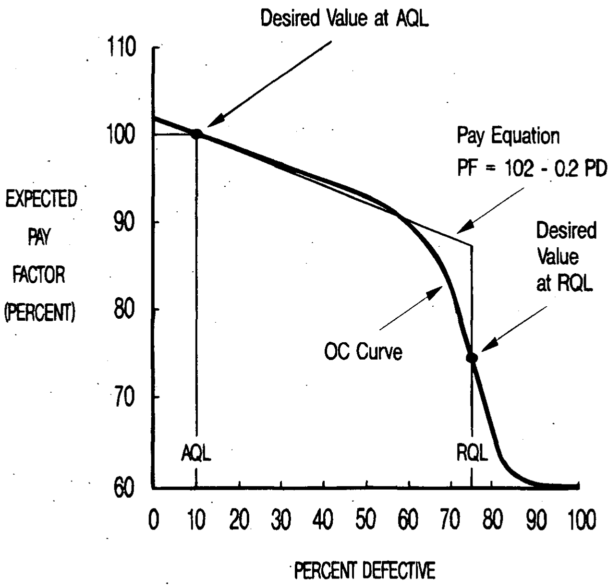

FIGURE 3 OC curve for new air voids acceptance procedure.

The new acceptance procedure is worded as follows in the NJDOT supplemental specifications:

> Each mixture in a completed lot shall be compacted so that the combined percentage of material below 2.0 percent voids and above 8.0 percent voids shall be no more than 10 percent. Air voids will be determined from drilled cores taken by the Engineer and tested in accordance with Section 903, Table 903-5 (combined AASHTO/NJDOT procedure). Five cores will be taken at random locations from each lot of approximately 4180 square meters (5,000 square yards) of bituminous concrete of uniform thickness and of approximately 8360 square meters (10,000 square yards) of variable thickness material. Conformance will be judged on the basis of the amount of material estimated to fall outside specification limits as follows:
>
> 1. Compute the sample mean ($\bar{X}$) and the standard deviation (S) of the $N = 5$ test results (X_i):
>
> $$\bar{X} = \Sigma X_i/N$$
>
> $$S = [\Sigma (X_i - \bar{X})^2/(N - 1)]^{1/2}$$
>
> 2. Compute $Q_L = (\bar{X} - 2.0)/S$ and $Q_u = (8.0 - \bar{X})/S$.
> 3. Using Table 3, determine the percentage of material falling outside specification limits associated with Q_L and Q_u. Add these two values to obtain the total percent defective, PD.
>   a. If PD is less than 50, proceed to Step 5.
>   b. If PD is greater than or equal to 50, the NJDOT may elect to reevaluate the lot with additional cores as described in Step 4. If no additional cores are taken, proceed to Step 5.
>   c. If PD is greater than or equal to 75, the NJDOT may require the removal and replacement of the defective lot (including any overlying layers) at the Contractor's expense. If this option is not exercised, the Contractor may elect to replace the lot or leave it in place subject to a pay factor of PF = 80 percent.
> 4. If the NJDOT elects to reevaluate the lot, five additional cores are to be taken at new random locations. Using the five new test results, repeat Steps 1 and 2. Using Table 3 and the computed Q_L and Q_U values, determine the total PD based on the second set of tests. The final PD value is the average of the values obtained from the two sets of tests and is subject to the requirements of Paragraph 3c.
> 5. Compute the percent payment for the lot as follows:
>
> $$PF = 101 - 0.1\ PD$$
>
> Note that for PD values less than 10, the percent payment exceeds 100, representing a bonus payment.

FIELD TRIALS

The first test of the new specification was a paper exercise applied to several recent jobs that, in the judgment of NJDOT engineers, spanned the range of quality from good to very poor. Because it was the custom with the older specification to assess reductions in terms of material tonnage rather than in terms of a percentage pay factor, the two specifications initially were compared in this manner. The results of this comparison are presented in Table 4.

TABLE 3 Estimation of Percent Defective (PD)

VARIABILITY-UNKNOWN PROCEDURE SAMPLE SIZE 5 STANDARD DEVIATION METHOD

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	49.64	49.29	48.93	48.58	48.22	47.87	47.51	47.15	46.80
0.1	46.44	46.09	45.73	45.38	45.02	44.67	44.31	43.96	43.61	43.25
0.2	42.90	42.54	42.19	41.84	41.48	41.13	40.78	40.43	40.08	39.72
0.3	39.37	39.02	38.67	38.32	37.97	37.62	37.28	36.93	36.58	36.23
0.4	35.88	35.54	35.19	34.85	34.50	34.16	33.81	33.47	33.13	32.78
0.5	32.44	32.10	31.76	31.42	31.08	30.74	30.40	30.06	29.73	29.39
0.6	29.05	28.72	28.39	28.05	27.72	27.39	27.06	26.73	26.40	26.07
0.7	25.74	25.41	25.09	24.76	24.44	24.11	23.79	23.47	23.15	22.83
0.8	22.51	22.19	21.87	21.56	21.24	20.93	20.62	20.31	20.00	19.69
0.9	19.38	19.07	18.77	18.46	18.16	17.86	17.55	17.26	16.96	16.66
1.0	16.36	16.07	15.78	15.48	15.19	14.91	14.62	14.33	14.05	13.76
1.1	13.48	13.20	12.93	12.65	12.37	12.10	11.83	11.56	11.29	11.02
1.2	10.76	10.50	10.23	9.97	9.72	9.46	9.21	8.96	8.71	8.46
1.3	8.21	7.97	7.73	7.49	7.25	7.02	6.79	6.56	6.33	6.10
1.4	5.88	5.66	5.44	5.23	5.02	4.81	4.60	4.39	4.19	3.99
1.5	3.80	3.61	3.42	3.23	3.05	2.87	2.69	2.52	2.35	2.19
1.6	2.03	1.87	1.72	1.57	1.42	1.28	1.15	1.02	0.89	0.77
1.7	0.66	0.55	0.45	0.36	0.27	0.19	0.12	0.06	0.02	0.00

VALUES IN BODY OF TABLE ARE ESTIMATES OF PERCENT DEFECTIVE CORRESPONDING TO SPECIFIC VALUES OF Q = (AVERAGE - LOWER LIMIT) / (STANDARD DEVIATION) OR Q = (UPPER LIMIT - AVERAGE) / (STANDARD DEVIATION). FOR NEGATIVE Q VALUES, THE TABLE VALUES MUST BE SUBTRACTED FROM 100.

TABLE 4 Comparative Performance of New Air Voids Specification

PROJECT	RATING	TONNAGE ADJUSTMENTS OLD SPECIFICATION	NEW SPECIFICATION
1	Good	0	+44
2	Good	0	+27
3	Average	0	-14
4	Average	0	-197
5	Average	-64	-211
6	Poor	-57	-331
7	Poor	-344	-708
8	Poor	-317	-945
9	Very Poor	-1324	-1613

TABLE 5 Data from Pilot Projects with New Air Voids Specification

		VOIDS CONTENT (PERCENT)		
LOT	TYPE	AVERAGE	STANDARD DEVIATION	PAY FACTOR (PERCENT)
Project #1:				
1	Surface	8.06	1.61	95.9
	Base	5.66	0.75	101.0
2	Surface	6.88	1.43	98.7
	Base	5.34	0.61	101.0
3	Surface	7.56	1.68	96.9
	Base	5.26	0.98	101.0
4	Surface	7.22	1.54	97.8
	Base	5.74	1.36	100.9
5	Surface	7.04	1.79	97.9
	Base	4.38	0.69	101.0
6	Surface	7.12	2.52	97.2
	Base	5.72	1.17	101.0
7	Surface	8.06	2.09	95.1
	Base	5.72	1.18	101.0
8	Surface	7.30	2.13	97.2
	Base	4.92	0.89	101.0
9	Surface	6.26	0.82	101.0
	Base	5.06	1.02	101.0
10	Surface	9.66	2.44	93.6
	Base	5.48	0.79	101.0
11	Surface	5.90	1.14	101.0
	Base	5.32	0.73	101.0
12	Surface	8.10	1.62	95.8
	Base	6.74	1.59	98.7
Project #2:				
1	Surface	6.12	1.38	100.4
	Base	5.16	0.62	101.0
2	Surface	8.00	4.12	95.5
	Base	5.48	0.87	101.0
3	Surface	9.38	3.01	94.4

The following observations can be made from the data in Table 4. The two jobs judged to be of good quality would have received small bonuses under the new specification; the three regarded as average would have received some amount of pay reduction; the four considered to be either poor or very poor would have received substantially greater pay reductions than under the older specification. This result was both expected and desired and, on the basis of these results, it was decided to proceed with actual field trials.

Two jobs were selected to serve as pilot projects. They were chosen to be as nearly representative as possible of typical construction, they were constructed by different contractors in different geographic areas of the state, and they were completed during the regular construction season. The data, representing a total of 29 lots of both base and surface courses, are presented in Table 5.

It can be seen from the data in Table 5 that the air voids levels in the base layers were well controlled but that some difficulty was encountered with the surface layers. This situation has often been the case and was part of the motivation for revising the specification.

There are several possible reasons for this difference in level of compaction. One is that the base layers generally benefit from the additional compactive effort applied to the surface layers. Another possible reason is that because of the normal sequence of events as the job is constructed, the surface layers are sometimes placed later in the year when cooler weather makes compaction more difficult. It has also been suggested that, because the base layers are often placed on underlying layers with rougher surface texture, there may be less slippage, which results in more efficient roller action. Finally, roller patterns that have been established to be effective when the base layers are placed may not necessarily be optimal when the surface layers are placed.

IMPLEMENTATION

It was concluded from the experience on the two pilot projects that the requirements of the specification could be achieved but that an additional trial period would be beneficial. Consequently, it was decided to implement the new specification on all future projects but to retain the relaxed pay equation and RQL requirements for at least another construction season.

Several additional projects have been completed and the overall performance continues to improve. In the few cases in which problems have been encountered, it has usually been possible to identify a cause. Clearly, the specification makes it incumbent on the contractor to pay close attention to quality control, good construction practices, and the appropriate design level for air voids. Another evaluation will be made after more experience is gained with this specification, and a decision will then be made regarding future refinements.

SUMMARY

The NJDOT specification for air voids in bituminous concrete has been upgraded in accordance with the following objectives:

- The specification is to be performed-based.
- It must provide sufficient incentive to produce high-quality work.
- It must be technically sound and fair to all parties.
- It must be practical and administratively efficient.

The new specification is performance-related in that it controls air voids, a surrogate measure of compaction, which is highly correlated with service life. The pay schedule, which awards bonus payments for superior quality and assesses pay reductions for deficient quality, is believed to provide ample incentive to produce good work. The procedure is technically sound in that it uses efficient statistical measures in a correct way. OC curves were constructed to verify that the procedure fairly provides 100 percent payment at the AQL and withholds sufficient payment at lower quality levels to cover the anticipated costs of future repairs. It is practical in that the acceptance procedure is easy to understand and administer.

Two pilot projects were completed successfully, and the new specification was adopted for all future projects using an interim form of the pay schedule. A continuing evaluation will determine when and if additional modifications should be made.

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