Implementation of Quality Assurance Specifications for Excavation and Embankment Construction in West Virginia

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Current West Virginia quality assurance specifications for excavation and embankment construction are the result of a research demonstration project that was constructed and evaluated in 1971 and 1972. The tests required of the contractor and their frequency and evaluation are described. The current specifications are not end-result specifications in that, rather than requiring that a total project be built and presented for acceptance, they require the contractor to present parts or segments of a project as lots for individual acceptance. They also require the contractor to perform his or her own quality control testing and allow the contractor to manage operations more efficiently. Acceptance by the West Virginia Department of Highways is based on the percentage of a lot that is within the specifications. Acceptance of individual lots can be based on departmental testing or on tests performed by the contractor. Lot-by-lot acceptance allows the reworking of individual lots to bring them within the specifications. All density testing by the contractor and the highway department is done by nuclear methods, and reporting is done on computer mark-sense forms.

The objective of the quality assurance specifications of the West Virginia Department of Highways is to provide realistic limits and tolerances that will ensure an acceptable level of quality in completed construction. This type of specification enables the contracting authority to estimate the percentage of material that is within specification tolerances. The acceptance procedures can be tailored to measure the uniformity of the material and produce a low risk of rejecting acceptable material or accepting substandard material.

SCOPE OF SPECIFICATIONS

If quality assurance specifications are to accomplish their purpose at the most appropriate level of construction, it is imperative that the contractor have an adequate quality control program. These specifications define the contractor's responsibility for the quality control of the product and its construction as well as the buyer's responsibility for acceptance testing. It is important that the contractor describe his or her method of quality control to ensure an adequate and acceptable level of quality by filing a quality control plan before the start of work. It is the intent of the specifications to allow the contractor as much leeway as possible so as not to restrict new methods and ideas. It is necessary, however, to specify a minimum of measurements and testing so that a realistic estimate of quality can be made.

The current West Virginia specifications, which are in the process of being implemented, require that the contractor control the quality of the unclassified excavation to be used to form the embankment and subgrade. This quality control includes the density, percentage of organic content, lift thickness, and, to a certain degree, placement of material. Although the specifications do not classify the material from the excavation into different pay items, the specifications do require that a certain quality of material be placed at designated locations, such as select embankment for drainage purposes, which consists of limestone or sandstone with a limit of 15 percent of other suitable random material. After the contractor has placed a "measured amount of specified material"—the definition for one lot of embankment or subgrade material—and has performed quality control tests, the lot is offered to the highway department for acceptance.

EXPERIMENTAL PROGRAM

Initial Research

Current quality assurance specifications for embankment and subgrade in West Virginia are based on experience and knowledge gained from research that included a demonstration construction project (1). The demonstration project accompanied the construction of RS-S-733(3), a two-lane, controlled-access connector between US-21 and I-77 in Kanawha County. Construction began on January 12, 1971.

The project was 3.38 km (2.1 miles) long and had 690 244 m^3 (902 805 yd^3) of unclassified excavation. The unclassified excavation consisted of A-2-4 to A-6 soil and bedrock of sandstone and various grades of shale. The project was completed and opened to traffic in November 1972, and the completed project carried all of the southern terminus traffic for I-77 for 2 years until the next segment of the Interstate was completed into Charleston, West Virginia.

Testing and Lot Size

The contractor elected to use both procedures of the American Association of State Highway and Transportation Officials (AASHTO) and materials procedures (MP) of the West Virginia Department of Highways, departmental forms, and a nuclear moisture-density gauge of the direct transmission type for testing. All test sites were selected on a random basis, and the contractor conducted approximately one test for each 1538 m^3 (2000 yd^3) of embankment and subgrade as specified by the contract documents. The lot size of embankment and subgrade material that the specifications suggested be used to present material to the highway department for acceptance was 2508 m^2 (3000 yd^2). The lot size could be increased if production were greater than 8360 m^2/d (10 000 yd^2/d). The contract documents approved for the research project allowed the department to select any lot size. As a result, highway department lot sizes did not always coincide with the contractor's lots. The lot sizes offered by the contractor actually varied from 670 to 6690 m^2 (800 to 8000 yd^2). The lot size selected by the department varied from 926 to 10 786 m^2 (1108 to 12 900 yd^2).

Contractor Quality Control

The contractor's quality control program for the re-

Table 1. Estimating the percentage of a lot within tolerance: positive values of Q_L.

Percentage Within Tolerance	Number of Tests Three	Four	Five	Percentage Within Tolerance	Number of Tests Three	Four	Five
99	0.60	0.66	0.66	78	0.47	0.38	0.33
98	0.60	0.64	0.65	77	0.46	0.36	0.32
97	0.60	0.63	0.62	76	0.44	0.35	0.30
96	0.60	0.62	0.60	75	0.43	0.34	0.29
95	0.60	0.60	0.58	74	0.41	0.32	0.28
94	0.59	0.59	0.57	73	0.40	0.31	0.27
93	0.59	0.58	0.55	72	0.39	0.30	0.25
92	0.59	0.56	0.53	71	0.37	0.28	0.24
91	0.58	0.55	0.51	70	0.36	0.27	0.23
90	0.58	0.54	0.50	69	0.34	0.26	0.22
89	0.57	0.52	0.48	68	0.32	0.24	0.21
88	0.56	0.51	0.46	67	0.31	0.23	0.19
87	0.55	0.50	0.45	66	0.29	0.21	0.18
86	0.54	0.48	0.44	65	0.27	0.20	0.17
85	0.54	0.47	0.42	64	0.26	0.19	0.16
84	0.53	0.46	0.41	63	0.24	0.17	0.15
83	0.52	0.44	0.40	62	0.22	0.16	0.14
82	0.51	0.43	0.38	61	0.20	0.15	0.13
81	0.50	0.42	0.37	60	0.19	0.13	0.11
80	0.49	0.40	0.36	55	0.09	0.07	0.06
79	0.48	0.39	0.34	50	0.00	0.00	0.00

Table 2. Estimating the percentage of a lot within tolerance: negative values of Q_L.

Percentage Within Tolerance	Number of Tests Three	Four	Five	Percentage Within Tolerance	Number of Tests Three	Four	Five
50	0.00	0.00	0.00	21	0.48	0.39	0.34
45	0.09	0.07	0.06	20	0.49	0.40	0.36
40	0.19	0.13	0.11	19	0.50	0.42	0.37
39	0.20	0.15	0.13	18	0.51	0.43	0.38
38	0.22	0.16	0.14	17	0.52	0.44	0.40
37	0.24	0.17	0.15	16	0.53	0.46	0.41
36	0.26	0.19	0.16	15	0.54	0.47	0.42
35	0.27	0.20	0.17	14	0.54	0.48	0.44
34	0.29	0.21	0.18	13	0.55	0.50	0.45
33	0.31	0.23	0.19	12	0.56	0.51	0.46
32	0.32	0.24	0.21	11	0.57	0.52	0.48
31	0.34	0.26	0.22	10	0.58	0.54	0.50
30	0.36	0.27	0.23	9	0.58	0.55	0.51
29	0.37	0.28	0.24	8	0.59	0.56	0.53
28	0.39	0.30	0.25	7	0.59	0.58	0.55
27	0.40	0.31	0.27	6	0.59	0.59	0.57
26	0.41	0.32	0.28	5	0.60	0.60	0.58
25	0.43	0.34	0.29	4	0.60	0.62	0.60
24	0.44	0.35	0.30	3	0.60	0.63	0.62
23	0.46	0.36	0.32	2	0.60	0.64	0.65
22	0.47	0.38	0.33	1	0.60	0.66	0.66

search project included responsibility for the design, adjustment, and control of his or her processes and all materials submitted to the highway department for acceptance. As part of the project requirement, it was necessary for the contractor to document his or her quality control system and submit it to the department for review and approval. The minimum requirements specified were that the contractor provide a quality control system that would provide reasonable assurance that all materials and products submitted to the department for acceptance conform to the contract requirements. This included sampling and testing methods, sampling frequency, types of forms, type of documentation of process control, and a procedure for reworking or disposing of nonconforming material. The initial documentation of the contractor's quality control system was very brief and, since this was a pioneer effort on the part of the contractor, as much assistance as possible was ultimately provided by the department to make the documents more responsive to project requirements. This was accomplished through questionnaires and orientation and training sessions. The orientation and training sessions were conducted for personnel of the contractor and the Federal Highway Administration and for project and district personnel of the West Virginia Department of Highways.

The contractor tested at the required frequency but did not in all cases record types of deficiencies or corrective action as required by the specifications. The contractor's quality control system detected three nonconforming lots that were reworked before the department was notified that the lots were ready for acceptance. The contractor did not evaluate the tests according to MP106.00.20—West Virginia Acceptance Plan "A" Method of Estimating Percentage of Material or Construction That Will Fall Within Specification Limits (2)—which consists of a set of tables that indicate the percentage of a lot within tolerance (Tables 1 and 2). The percentage within tolerance was determined by evaluating the dry density according to the following equation:

$$Q_L = (\bar{X} - L)/R \tag{1}$$

where

Q_L = lower quality index,
$\bar{X}$ = average dry density of lot,
L = 0.95 (maximum T99 density) for embankment and 0.98 (maximum T99 density) for subgrade, and
R = range of dry densities in lot (highest minus lowest value).

Acceptance

The department's acceptance testing found one lot outside specification limits, and it was rejected. The specifications required that 80 percent of the lot have a target percentage of density of ≥95 percent for embankment and ≥98 percent for subgrade. The contractor's three tests for the rejected lot had a range of 160 kg/m^3 (10 lb/ft^3), a $\bar{X}$ of 1984 kg/m^3 (124 lb/ft^3), and a Q_L of 0.20. Even though all the tests passed, had the contractor evaluated them by MP106.00.20, he would have realized that areas of low density were probable and that the estimate within tolerance was 61 percent based on his minimal number of tests. The department's actual acceptance tests, which required five density tests within a lot, estimated that 63 percent was within tolerance. Highway department testing indicated a range of 304 kg/m^3 (19 lb/ft^3), a $\bar{X}$ of 1977 kg/m^3 (125 lb/ft^3), and a Q_L of 0.15 and actually had one test result within only 88 percent of the maximum density. Although the contractor's testing was minimal, the estimate of the percentage within tolerance was very close to the department's estimate. The two evaluations plus the one test with very low density indicate that the estimate is reasonable.

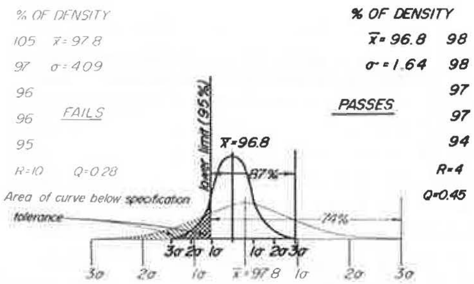
In accordance with the specifications, the department tested the reworked lot for acceptance. This was at the contractor's expense at a unit cost of $125/lot, which included five tests. After more compactive effort, the reworked lot met specifications. This failure occurred early in the progress of the project and, although the penalty was not excessive, it did cause the contractor to control the quality of density more carefully.

Evaluation of Demonstration Project

After completion of the research project, it was thoroughly evaluated. This evaluation found that the contractor's and department's personnel associated with this project demonstrated through the operation that the performance specifications are workable, equitable, and enforceable.

Conclusions from the research indicated that all concerned were benefited. The contractor benefited be-

Figure 1. Theoretical estimate of percentage within tolerance.



cause he was allowed better control of his work. The highway department benefited because this type of specification has the potential for producing more uniform compaction and allows much greater flexibility in the use of available inspecting forces. The statistically based acceptance plan, in conjunction with random sampling plans, provided a reasonably accurate estimate of the density for embankment and subgrade.

DEVELOPMENT OF CURRENT SPECIFICATIONS

As a result of these findings, it appeared to be feasible to use this type of specification for statewide control of density in the standard specifications. To adopt this type of specification on a statewide basis, it was necessary to consider whether variation in materials would affect the specifications.

The bedrock in West Virginia is composed almost entirely of sedimentary rock units that consist of shale, siltstone, sandstone, limestone, and coal; some of these units are slightly metamorphosed in the eastern part of the state. Shale is the predominant rock type in many areas. The topography is almost entirely mountainous. As a result, most projects of any size require large volumes of earthwork. The earthwork often contains many types of soil and a variety of types of bedrock. Because of this, the specifications for statewide control of density had to consider that the materials would vary considerably within a given project and could vary within a given lot. Therefore, instead of using the value for dry density to determine the quality index, it was necessary to use the percentage of density.

Determination of Percentage of a Lot Within Tolerance

The percentage of a lot that is within density tolerance, as determined by the formula in Equation 1, required a change because the material within a lot could vary. Although Equations 1 and 2 are essentially the same, the data used for the statistical values had to be changed because the maximum density required for an individual test within a lot of five tests might be different. Therefore, the following changes were made in regard to the data used in Equation 1:

$$Q_L = (\bar{X} - L)/R \qquad (2)$$

where

- $\bar{X}$ = average percentage of dry density for the five tests,
- L = lower tolerance limit in percentage or target percentage of dry density, and
- R = range or difference between largest and smallest percentage of dry density.

Q_L is used to enter the tables in West Virginia Department of Highways MP106.00.20 to determine the percentage of the lot within tolerance. L is the percentage of density on which the decision of acceptance is based and is not to be confused with the percentage of density that the contractor may try to achieve to ensure that the lot has the minimum of 80 percent within tolerance. In Figure 1, two examples are shown in which the lots are of similar size. In this example, both lots have an average percentage of dry density ($\bar{X}$) above the target percentage of density. However, the range of the percentage of dry density (R) for the lot on the left is much greater than the range for the lot on the right. When Table 1 is entered with a Q_L value of 0.28 and five tests, it is found that only 74 percent of the lot on the left is estimated to have a percentage of the required maximum dry density of 95 percent or above. Thus, the lot fails because it does not meet the minimum of 80 percent within tolerance required in the specifications. After the calculations for Q_L are performed, an estimated 87 percent of the lot on the right side of Figure 1 is densified to a percentage of the required maximum dry density of 95 or greater. The illustration on the left in Figure 1 exemplifies that, when the percentage of density for tests within a lot have a large R and standard deviation (σ), it is possible for a relatively high percentage of the lot to be substandard even though all of the test results are above the target percentage of density. This normally indicates poor quality control of the densification of the lot. In contrast, the illustration on the right of the figure, which has a smaller R and σ, can tolerate a lower $\bar{X}$ and an actual test below the target percentage of dry density.

Other significant changes that resulted from evaluation of the research project are described below:

1. Lot size—In the research project, the contractor's lot size and the department's lot size were not always analogous and, further, the research project specifications often resulted in a lot size where the contractor had only one or two tests. In actuality, 63 percent of the lots offered to the highway department had three or fewer tests. Since the size of the lot has considerable influence on the financial risk to the contractor, a sublot size of 1910 m^3 (2500 yd^3) for embankment and 120 linear m (400 ft) for subgrade was selected and judged to be the best compromise for this evaluation. Each lot has at least five sublots of approximately equal dimensions. As a result of the experience gained from the research demonstration project, the lots presented to the department by the contractor are the same lots that are evaluated for acceptance.
2. Number of tests—Based on the research, at least five tests per lot were desirable to provide a reasonably accurate estimate of the percentage of dry density within tolerance for an individual lot. Because it was also desirable to have the option to use the contractor's quality control testing in the acceptance evaluation, it was necessary to revise the contractor's minimum testing. Thus, the contractor's quality control testing is to include at least one nuclear moisture-density measurement made at a random location in each sublot. The random locations are selected in accordance with MP712.27.26—Procedure for Determining Random Locations for Compaction Tests on Embankment, Subgrade and Base. For lots that consist of more than one lift, the contractor is to include testing on each lift.

Test Methods

Moisture Control

The lots of embankment and subgrade material are required (as in the research project) to be within the specified moisture tolerance of 4 percent below optimum to 3 percent above optimum. This tolerance was evaluated and adopted as a result of a study conducted before 1968. Moisture tolerance has proved to be a suitable control for most soil material found in West Virginia. The only exception is soil that has a high silt content. The specifications and procedures for this material require that moisture be controlled at optimum or below until pumping has been checked. This type of soil, however, is not commonly encountered in current construction in West Virginia. The percentage of moisture is determined in conjunction with density testing by using MP712.21.25 and MP300.01.01 and the nuclear gauge.

Density Testing

Soil that has less than 35 percent retained on the 19-mm (0.75-in) sieve is tested in accordance with the department's MP712.21.25—Nuclear Field Density Test for In-Place Density for Compacted Soils, Soft Shales, or Random Material Layers Having Less Than 35 Percent Retained on the [19-mm] ¾-Inch Sieve and Soil Cement Stabilization—which uses a direct-transmission type of nuclear gauge. No laboratory testing is normally required since a table of maximum density and optimum moisture values is used in conjunction with the one-point Proctor test to determine AASHTO T99 optimum moisture and maximum density. Only one determination of optimum moisture and maximum density is required for individual lots in cases in which the material remains uniform.

For soil material that has 35 percent or more retained on the 19-mm (0.75-in) sieve, the research project found that very little of the material from the excavation could be tested by the highway department's roller pass procedure because of the nonuniform nature or the nominal particle size of the material. This procedure required that the material remain uniform and somewhat homogeneous. In addition, the method for determining the maximum density used in the research project was quite time consuming. Only one lot of 2470 m^2 (2950 yd^2), or less than 1 percent of the excavation, was tested.

Because of the excessive settlement observed in various areas of the state in many embankments formed of shale and lifts that contained combinations of soil and bedrock (3), it was decided to initiate and document control of compaction on these embankments. The nuclear testing equipment currently owned by the West Virginia Department of Highways has a maximum depth reading in the direct-transmission mode of 305 mm (12 in). The department allows loose lifts that vary from 200 to 610 mm (8 to 24 in) in placing shale. Since the quality of the shale can vary from soil to rocklike material, it was decided to adapt the specifications to this type of material instead of processing the material to accommodate methods of testing.

Two methods of compaction control are used for material (other than rock lifts) that has 35 percent or more retained on the 19-mm (0.75-in) sieve:

1. MP300.01.01—Method of Test for Quality Assurance of Compaction of Untreated and Stabilized Aggregate and Granular Embankment Material by Roller Pass Method—a new and less time-consuming roller pass test, is used for soil that is relatively uniform in gradation and is composed of particles of a nominal 254 mm (10 in) or less. The material is controlled to a target percentage of dry density of 95 percent. In part 1 of the materials procedure, the maximum density is developed in the field by the contractor's equipment by using a specified minimum compactive effort (roller weight) and a growth curve. The growth curve is evaluated after a specified number of passes have been conducted on the test section. The required maximum density is considered to be achieved when a minimum change of 32 kg/m^3 (2 lb/ft^3) or less occurs after two passes of the roller. The two passes normally evaluated are numbers 13 and 14. The method is normally used on subgrade material that is specified to be natural or synthetic mineral aggregate—e.g., broken or crushed rock, gravel, or slag that can be incorporated in a 200-mm (8-in) loose-depth lift. It may also be applicable to some embankment material.
2. Material that either has a nonuniform gradation or includes particles larger than a nominal 250-mm (10-in) top size or both is proof rolled by making two or more passes over the entire area at a speed of not more than 8 km/h (5 mph) with a 45-Mg (50-ton) roller. All unstable areas or soft spots that are disclosed are to be corrected before placement of overlying lifts.

Documentation of Results of Density Tests

All test results for MP712.21.25 and MP300.01.01 are recorded on computer mark-sense forms. This includes tests performed by the contractor and the highway department. The original of these forms is submitted by project personnel to the central office of the West Virginia Department of Highways. The data on the forms are evaluated for completeness and correctness by the computer. If errors or missing data are found, they are identified and printed out. After corrections have been made, the data are permanently stored on magnetic tape. Various subroutines are used to evaluate the data. Two of the most significant ones are (a) a statistical analysis of the percentage of density for the project on a timed sequence and on the completed project, which includes an evaluation of the uniformity of the embankment and subgrade density, and (b) an analysis of moisture control on a timed sequence and on the final project.

Organic Test

Organic material contained in the material used to form the embankment and subgrade is limited to 7.5 percent by weight. At this limit, the possibility exists that the organic material could occupy as much as 15 percent of the volume of the material being placed. Should the percentage exceed that specified, it could result in excess consolidation or an adverse effect on the strength of the material or both. Test method MP716.04.20—Determination of the Organic Content of Soils by the Dry Combustion Method—determines the organic content at a controlled temperature of 440°C (824°F) for 5 h (4).

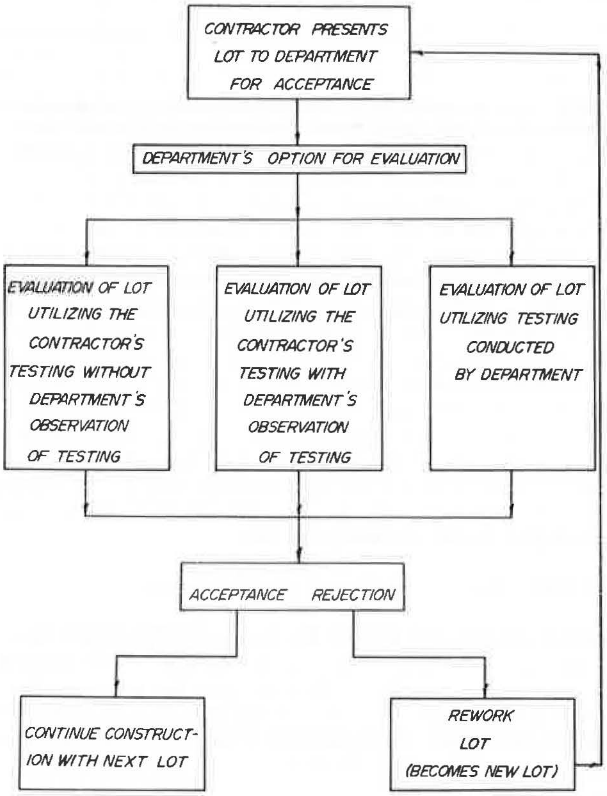
Lift Thickness

Lift thickness must be measured three times per lift and documented by the contractor.

Quality Control

MP717.04.21—Guide for Quality Control and Acceptance Plan for Embankment and Subgrade—is specified in the contract documents and is intended to be used by the contractor for designing his or her quality control system. It requires that the contractor's plan be submitted at the preconstruction conference, and it defines the acceptable test procedures. A direct-transmission type

Figure 2. Procedure for acceptance of embankment and subgrade.



of nuclear gauge is required for density testing. The minimum number of tests, reports, and measurements per lot is indicated for the several types of gradation in the material placed. The reports for proof rolling are to include the make, size, and compactive force of the roller and the number of rolls performed on each lift. The plan is also to include the time schedule and distribution of data.

The document is to include the names of the contractor's personnel who are responsible for quality control and liaison and the personnel who are conducting the tests and measurements. It is recommended that personnel who conduct the density tests be certified compaction technicians. The West Virginia Department of Highways has been conducting a certification program for departmental personnel for 9 years. This program, which includes a written and practical examination, has been extended to industry personnel in conjunction with the Contractors' Association of West Virginia. The department also conducts a training program that has been extended to industry personnel. The training program includes programmed instruction, lectures, and practical exercises. Audiovisual tape instructions are also used where "hands-on" training is not practical.

Lots Offered for Acceptance

Acceptance of a Lot

The highway department has the option of acceptance of the contractor's lots according to the methods shown in Figure 2. Say the percentage of a lot within a tolerance of 80 percent has been retained. An analysis of the data finds that the department has approximately a 6 percent probability of accepting substandard material that is evaluated by five density tests. Although the contractor's actual risk cannot be determined before he or she performs the work because the risk is dependent on control by the contractor, an average value can be estimated. Therefore, based on historical data from the research project that were used to determine an average quality of density, a contractor with adequate control could expect to have approximately a 3 percent probability of rejection on acceptably densified material. It should be noted that a very important feature of the acceptance plan used is that, if the contractor's quality control of density is poor, his or her risk is greatly increased.

A recent evaluation of the demonstration project that was constructed by using these controls shows that the project has performed satisfactorily for 5 years with negligible settlement or pavement failure. The evaluation of the percentage within tolerance indicated that, had a value greater than 80 percent been used, it would have been necessary for the contractor to have a much smaller range in dry density per lot or a higher average density or both; otherwise, as indicated by the performance of the project, many more lots would have been unnecessarily rejected.

Rejection of a Lot

When a lot fails to meet the specifications, reworking is required before another lot can be placed on it (Figure 2). Testing of the reworked lot for acceptance is done at the expense of the contractor if the highway department conducts the testing. The unit cost for testing of a reworked lot when tests are conducted by the department is published in MP109.00.20—Basis of Charge for Additional Testing. The amounts are updated to reflect current testing costs. The cost is for five tests since that is the minimum acceptable for evaluation. Since reworking a lot in effect produces a new lot, the reworked lot is evaluated only by the five tests conducted after reworking.

SUMMARY AND CONCLUSIONS

Current quality assurance specifications in West Virginia have been reviewed by industry personnel, and informative seminars have been given for industry management. The specifications have been received quite favorably to date. During the first 6 months of the certification program for industry personnel, 68 people have entered the program and 24 have been certified.

The cost of this type of specification for embankment and subgrade can only be evaluated after several years of use. The cost would normally be reflected in the unit price bid for the unclassified excavation. That cost was \$1.54/m^3 (\$1.18/yd^3) for the research project. The average cost for all types of roadways and construction for unclassified excavation in 1970, the year the project was bid, was \$1.67/m^3 (\$1.28/yd^3). It was anticipated that the bid might be high because of uncertainty on the part of the contractor about this type of specification and because it was the first time the highway department had required this type of quality control on earthwork. It would appear, however, that for the research project the required quality control did not materially affect the contractor's bid.

The current specifications require that the contractor be responsible for quality control of the embankment and the subgrade. This is quite appropriate since the contractor has the fundamental control of the work process. The current specifications for embankment and subgrade are not true end-result specifications because of the nature of the material placement.

As determined by the research demonstration project, the quality assurance specifications discussed here do offer a level of quality control and acceptance that inter-

feres as little as possible with the contractor's management of his or her processes. Further, the research demonstration project and the current specifications accept the premise that there will be a certain percentage of material that will fall below a given standard. The method of acceptance makes reasonable estimates of substandard material. These estimates are used to keep nonspecification material to a minimum. Because the method of acceptance requires control of variance in the quality control of density, it encourages a more uniform density in the final product.

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