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16. Abstract

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Further evaluation of the ERS is recommended to address outstanding issues on lot size, testing, quality characteristics, selection of limits, and pay factors. The implementation of an ERS would lead to innovations and higher quality concrete in the finished product that, in turn, would result in longer lasting structures with minimal maintenance. If as little as a 5 percent increase in the service life were achieved, the savings would be in the millions of dollars. In addition, in cases of dispute, an ERS is more defensible than is a method specification.

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FINAL REPORT

END-RESULT SPECIFICATION FOR HYDRAULIC CEMENT CONCRETE

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(A Cooperative Organization Sponsored Jointly by the
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ABSTRACT

The purpose of this research was to develop and implement an end-result specification (ERS) for hydraulic cement concrete for structural and paving use. This report details the development of the specification, in the form of a special provision, including the decisions that went into the choice of quality characteristics to be measured and the selection of items on which pay factors were to be based. It also shows and discusses the results of a simulation effort to determine pay factors under actual construction conditions that used the traditional specification. Finally, it includes data from two pilot bridge projects that used the special provision.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) has used an end-result specification (ERS) for acceptance of hot-mix asphalt and aggregate bases since the mid-1960s. At present, a study is underway to extend the use of this type of specification to hydraulic cement concrete (HCC).

What is an ERS and how does it differ from the traditional HCC specification? As defined in Transportation Research Circular Number E-C037, *Glossary of Highway Quality Assurance Terms,*[1] "End Result Specifications are those that require the contractor to take the entire responsibility for supplying a product or an item of construction. The agency's responsibility is to either accept or reject the final product or to apply a price adjustment commensurate with the degree of compliance with the specifications." Further: "End Result Specifications have the advantage of affording the contractor flexibility in exercising options for new materials, techniques, and procedures to improve the quality and/or economy of the end product." On the other hand, the traditional HCC specifications, often called method specifications, are defined in the glossary as "specifications that direct the contractor to use specified materials in defined proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency." The glossary concludes this definition as follows: "Experience has shown that this tends to obligate the agency to accept the completed work regardless of quality." Thus, a primary concept behind an ERS is shared responsibility between the contractor and VDOT and freedom for the contractor to achieve the desired level of quality with minimal constraints.

PURPOSE AND SCOPE

The purpose of this ongoing research is to develop and implement an ERS for HCC for paving and structural use.

The present effort to develop the ERS for HCC has been underway since 1999. It has been reviewed by several VDOT units and modified based on comments from these reviews. However, before the ERS can be implemented fully, several steps are necessary to ensure that both VDOT personnel and contractors are familiar with the concepts included in the ERS and that the specification is fair to both VDOT and contractors.

This report details the development of the specification, in the form of a special provision, including the decisions that went into the choice of quality characteristics to be measured and the selection of items on which pay factors are based. It also shows and discusses results of a simulation effort to determine pay factors under actual construction conditions that used the traditional specification. Finally, it includes data from two pilot projects that used the special provision.

To date, only HCC for bridges has been evaluated under the special provision.

METHODOLOGY

This research began with the review of VDOT's traditional HCC specification and an examination of those of other highway agencies (e.g., Iowa, Kansas, Maryland, New Hampshire, and Texas). This resulted in the first draft of the proposed ERS for HCC that was reviewed and revised until a fourth draft was developed and used in two pilot studies.

The second step was to simulate the draft ERS under actual construction conditions. Three approaches are being used.

1. *Use of data already obtained in projects.* Data from this source have several deficiencies. Among those are that the sample selection was not randomized and the sublot size varied and did not match that used in the ERS.

2. *Application of the ERS in pilot studies that collected data concurrent with the required method type specification.* Two pilot projects were completed for this purpose. The intent was that specimens were to be collected randomly and sublots were to be selected as in the ERS. The contract was administered under the method-type specification.

3. *Inclusion of the ERS in the bidding process (which will be implemented in the next phase of the ERS).* In this approach, the contract will be administered under the ERS, the contractor will be responsible for quality control, and the percent within limits (PWL) will be calculated for compressive strength and permeability, but the pay factors will not be enforced.

In accordance with the first approach, VDOT districts were asked to supply construction data from ongoing projects to use in the specification to determine the pay factors that would have resulted had the ERS been in effect for this construction. The data were obtained from different bridge projects; however, the majority of the data came from the Springfield Bypass construction.

The second approach, using pilot projects, provided limited data. (Only two projects were found in which to use the special provision.) Nevertheless, sufficient insight was gained to allow the special provision to be modified and improved.

Development

The development of the ERS used the traditional specification as a starting point. For example, the classes of concrete remained the same; i.e., there was no desire to redefine the general quality of concrete being supplied, only to have better estimates of the quality being produced. The additions and changes primarily involved wording to eliminate the restraints on the proportions, to ensure that the desired quality was defined and to provide guidance to contractors for obtaining at least that level of quality. The decisions necessary in the development of the special provision are discussed here.

Trial Batches

To ensure that the desired properties can be achieved, before the initiation of a project, trial batches are desired. The product average and variability are calculated and compared with the specifications. But in deference to contractors and material suppliers, the special provision allows recent historical concrete mix test data (with sufficient documentation from the supplier) to be used in lieu of trial batches.

Lot and Sublot Size

One of the first decisions involved the determination of lot size (i.e., that quantity of product subject to the acceptance decision) and sublot size (a subset of equal quantity product that constitutes a lot). Naturally, this decision involved whether the specification was being used for structural, paving, or miscellaneous concrete. The intent was to make the lot sufficiently large to balance the risks between the contractor and VDOT when the acceptance decision was made and to ensure that enough samples could be obtained for statistical evaluation. However, a limit on the lot size is envisioned to ensure that the pay adjustment does not apply to an exceptionally large portion of the project. The choice of a sublot was intended to make the number of test results acceptable from a resource standpoint, i.e., not so large as to increase the number of testing personnel but sufficiently large to ensure an adequate measure of quality.

Quality Characteristics

Another necessary decision was to describe which quality characteristics should be measured. This involved the separation of screening tests and pay factor (acceptance) tests. Screening tests are those tests for which the quality of the product is measured at such time that if the quality does not meet the specifications, the product can be corrected or rejected, and thus not incorporated in the finished construction. Pay factor tests are acceptance tests that are performed on product being incorporated in the product and are used to determine quality levels and, subsequently, pay adjustments.

Screening Tests

The screening tests chosen are air content and temperature. (Slump and unit weight will also be considered for screening in the next phase of the ERS.) These are pass/fail tests and are not used for pay adjustments. These tests are performed by the contractor and monitored by VDOT. The requirement for air content allows the contractor to choose a retest if the first test fails.

Pay Factor Tests

The pay factor tests chosen for concrete quality are 28-day compressive strength and permeability. For the evaluation of the construction practice, the tests chosen were cover depth, thickness, and smoothness. (Problems incurred during the collection of cover depth and thickness data in the two pilot projects led the researchers to rethink the inclusion of these two items in the ERS. This is discussed in more detail under Data Collection.)

Acceptance Criteria

Acceptance for the pay factor parameters are based on the determination of the quality level as defined by the quality index (Q) using tests for each lot. The Q value uses both the sample average and standard deviation as estimates of the population average and standard deviation. The Q value is, thus, used to estimate of the percentage of each lot within the specification limits (PWL).

Quality Index, Q

There are two quality indices that may be calculated; one, Q_l, the quality index relative to a lower specification limit, and the other, Q_u, the quality index relative to an upper specification limit. The equations used to calculate Q are:

$$Q_l = (\overline{X} - LSL)/s$$
$$Q_u = (USL - \overline{X})/s$$

where

Q_l is the Lower Quality Index
Q_u is the Upper Quality Index
$\overline{X}$ is the average
s is the standard deviation
LSL is the Lower Specification Limit
USL is the Upper Specification Limit

Generally, Q_l is used for strength, cover depth, and thickness, and Q_u is used for permeability and smoothness.

AQL

The acceptable quality level (AQL) is the minimum level of quality at which the product can be considered fully acceptable (for that quality characteristic). For example, the AQL is the actual (not estimated) PWL at which the quality characteristic can be considered just fully acceptable and should receive 100 percent pay. This value was chosen to be 90 PWL in accordance with the *AASHTO Quality Assurance Guide Specification.*[2] This means that to be fully acceptable, the sample statistics must produce a Q value that when used with the sample size and the appropriate PWL table estimates the quality to be at least 90 percent within limits.

RQL

The rejectable quality level (RQL) is the maximum level of quality at which the product can be considered unacceptable (rejectable). For example, the RQL is that actual (not estimated) PWL at which the quality characteristic can be considered just fully rejectable. The RQL of 50 PWL was chosen, which means the average is at the specification limit and 50 percent of the product is in specification and 50 percent is out of specification.

Specification Limits

The specification limits were established to achieve the same quality level as received under the traditional specification. Under traditional specifications, 100 percent of the product is assumed to be in specification. However, under the ERS, only 90 percent (the AQL) of the product has to be estimated to be within specification limits to be acceptable. The selection of the PWL procedure means that an area is being estimated, and this requires the use of a standard deviation. To set the new specification limits, a standard deviation had to be assumed. An example may help to clarify this difference.

Compressive Strength Specification Limits

A3 concrete under the traditional specification required that no product have a compressive strength less than 3,000 psi. Under the ERS, a specification limit had to be established that would provide comparable quality if 10 percent (100-90) was allowed to be below this limit.

The vertical line designated the lower specification limit (LSL) in Figure 1 is set at 1.28 standard deviations below the mean (0 standard deviations on the abscissa). This is established to allow 10 percent of the population to be below the LSL. The establishment of the LSL requires using the standard deviation on a lot-by-lot basis. Selecting an appropriate standard deviation is important but requires some judgment. For example, using historical data from 1997 to 2000 provided a pooled standard deviation for both A3 and A4 concrete of approximately 740 psi. However, if this value were to be used to establish the LSL, the LSL for A3 concrete would be 4,270 psi and for A4 concrete would be 5,270 psi. Values this high would be difficult to explain to the industry and could possibly become such a great issue as to impede implementation. Discussion with individuals from the industry revealed that based on their experience, a standard deviation of 500 psi is more appropriate. By using a table of areas under the normal curve, the desire to maintain the integrity of accepting no product below 3,000 psi (for A3 concrete), the AQL of 90 PWL, and an expected standard deviation of 500 psi, the LSL of 3,800 psi was developed. It should be understood that although the LSL (3,800 psi) is higher than the engineering limit (3,000 psi), the same quality concrete is being specified. This calculation of the LSL is shown here:

$$LSL = 3000 + 3(500) - 1.28(500) = 3860 \sim 3800 \text{ psi}$$

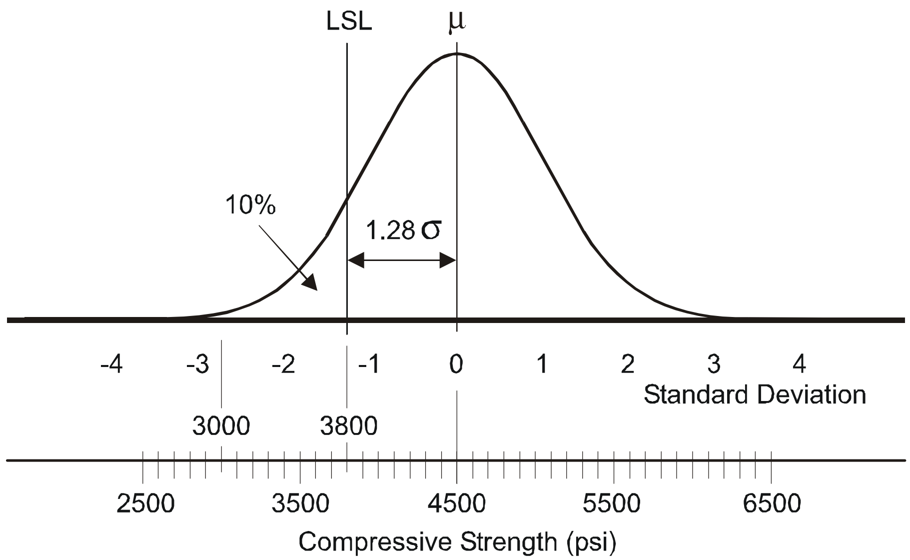

Figure 1. Normal Curve for Compressive Strength

This same calculation was used for the other classes of concrete to establish the LSLs in Table 1.

Permeability Specification Limits

The concept for establishing the upper specification limit (USL) for permeability was similar to that discussed for compressive strength. However, the historical database used provided a high standard deviation for permeability, i.e., 450 coulombs for A4 and 400 coulombs for A3 concretes. These values are derived from the early test results where unfamiliarity with the test would have produced the high variability. Further work and discussions led to the selection of 200 coulombs as an acceptable standard deviation for the initial trials. A3 concrete under the traditional specification stated that no product should have a permeability value greater than 3,500 coulombs. Under the ERS, a specification limit had to be established that would provide comparable quality if 10 percent (AQL =90 PWL) was allowed to be above this limit.

The vertical line designated the USL in Figure 2 is set at 1.28 standard deviations above the mean (0 standard deviations on the abscissa). That is established to allow 10 percent of the population to be above the USL. By using a table of areas under the normal curve and the desire to maintain the integrity of no product above 3,500 coulombs (for A3 concrete), and an expected standard deviation of 200 coulombs (based on experience of VTRC research), the USL of 3,200 coulombs was developed. This calculation is shown here:

$$USL = 3500 - 3(200) + 1.28(200) = 3156 \sim 3200 \text{ coulombs}$$

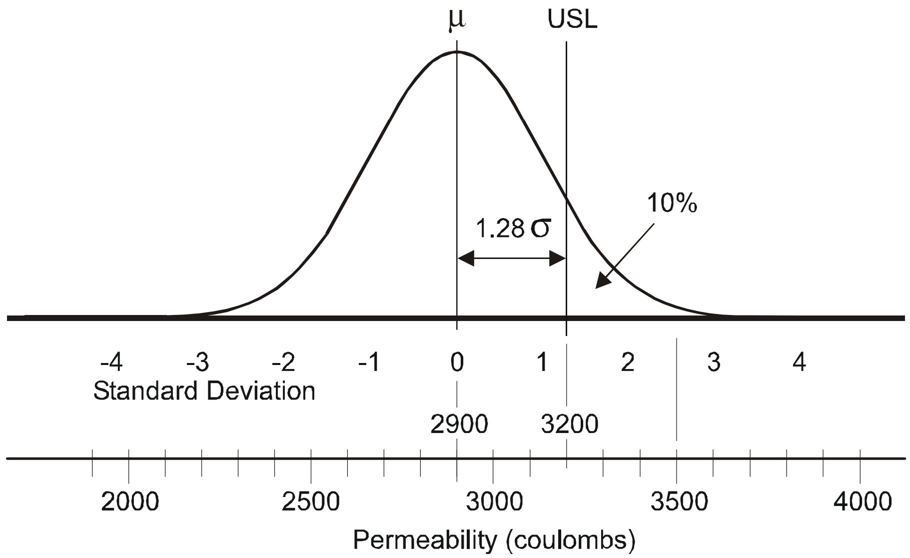

Figure 2. Normal Curve for Permeability

This same calculation was used for the other classes of concrete to establish the LSL in Table 1.

In addition, because the PWL procedure requires a sample size of three or larger, accommodations had to be made for the unusual circumstance of sample sizes of n = 1 and n = 2. Both of these situations recognize that the risk to VDOT of accepting less than desirable quality product is high and were addressed in a simplified manner, not necessarily a statistically desirable manner.

Table 1. Upper and Lower Specification Limits

Class of Concrete	LSL for Strength, psi	USL for Permeability, coulombs
A5	5800	1200
A4.5	5300	2200
A4	4800	2200
A3	3800	3200
A25	4400	3200
A30	5100	2200

Pay Factor Equation

The pay factor equation chosen was linear and similar to that suggested in the *AASHTO Quality Assurance Guide Specification*.[2] The AASHTO equation is Pay actor = 55 + 0.5(PWL) that provides for a maximum incentive of 5 percent. VDOT decided that a maximum incentive of 4 percent was desirable, and this decision resulted in the pay factor equation of 64 + 0.4(PWL) being used.

Further, a decision was necessary as to how to combine the pay factor quality characteristics of compressive strength, permeability, cover depth, thickness, and smoothness. It was decided that all contribute equally to final product quality, so the decision was made to average the results. (The next version of the special provision will require a change in this procedure as determined from the inspector's comments and data from the first two pilot projects. In addition, weighting factors for each quality characteristic may be introduced to emphasize the most desirable characteristic.)

Conflict Resolution

As suggested in the *AASHTO Quality Assurance Guide Specification,*[2] a conflict resolution statement was included to address the procedure to use when the contractor and VDOT disagree on the quality level or pay factor based on a technical reason. The procedure allows inspection, sampling, and testing of cores from the hardened concrete but is invoked only when a physical problem is detected and not necessarily when a failure occurs.

SIMULATION

As mentioned earlier, one of the first steps to see how the specification would likely work is to simulate the specification by using actual construction data based on the traditional method specifications. This is an economical procedure that used data from construction without having to do additional testing. However, the results from using this procedure must be viewed carefully for three reasons: (1) the data analyzed were not collected in the same manner, e.g., frequency, as that required in the specification; (2) the contractor was not operating under the acceptance plan and thus, did not react to "out-of-specification" product the same way as if the ERS was in effect; and (3) only compressive strength and permeability results were used; i.e., no measurements for cover depth, thickness, or smoothness were available. Thus, these reasons are important to recognize when viewing the simulated data. Nonetheless, simulation does allow the ERS to be viewed using actual construction data.

The data used in this step were collected for three years: 2000, 2001, and 2002. Table 2 provides the 2000 data, and Table 3 the 2001 and 2002 data. The data reported are the location of the production plant; the class of concrete; and the mean, standard deviation, and total sample size. This information was used with the appropriate specification limit to determine the quality index, PWL, and simulated pay factor for each product. No construction data such as cover depth, thickness, or smoothness, were available. Only concrete quality data, i.e., strength and permeability data, were collected. Thus, it was not possible to determine a composite pay factor of all five factors.

These data show that most pay adjustments were positive; i.e., an incentive would have been paid on most production. In each data set, only one negative pay factor would have been assessed. This is a clear indication that the use of the proposed specification would not impose an economic hardship on the contractor. It may also indicate that the maximum pay factor is too high.

Table 2. End-Result Specification Applied to Springfield Bypass: Fall 2000

Permeability									
Plant	**Class**	**Element**	**Mean**	**Std. Dev.**	**n**	**USL**	**Q**	**PWL**	**PF**
Newington Concrete	30	Deck	1359	315	65	2200	2.67	100.00	104.00

Strength									
Plant	**Class**	**Element**	**Mean**	**Std. Dev.**	**n**	**LSL**	**Q**	**PWL**	**PF**
Cardinal Concrete	A4	Parapet Wall	6812	651	18	4800	3.09	99.99	104.00
Cardinal Concrete	A3	Miscellaneous	5999	739	24	3800	2.98	99.98	103.98
Cardinal Concrete	A3	Curb and Gutter	6674	885	6	3800	3.25	100.00	104.00
Cardinal Concrete	A3	Sidewalk	5692	1257	3	3800	1.51	100.00	104.00
Newington Concrete	A4	Approach Slab	6510	1356	11	4800	1.26	89.15	99.98
Newington Concrete	A3	Bridge	6067	777	42	3800	2.92	100.00	104.00
Newington Concrete	A4	Bridge	5714	659	71	4800	1.39	100.00	104.00
Newington Concrete	SPECSG	Bridge	6300	733	9	4800	2.05	98.85	103.67
Newington Concrete	A3	Miscellaneous	6193	573	18	3800	4.18	100.00	104.00
Newington Concrete	SPECSG	Miscellaneous	6600	1031	3	4800	1.75	100.00	104.00
Newington Concrete	A3	Retaining Wall	6027	716	14	3800	3.11	100.00	104.00
Newington Concrete	A4	Retaining Wall	6359	410	3	4800	3.80	100.00	104.00
Virginia Concrete	A3	Bridge	7260	719	19	3800	4.81	100.00	104.00

Table 3. End Result Specification Applied to Springfield Bypass: 2001-2002

Permeability

Plant	Class	Element	Project No.	Mean	Std. Dev	n	USL	Q	PWL	PF
Newington Concrete	30	Deck	B610	1487	207	15	2200	3.45	100.00	104
Newington Concrete	30	Deck	B613	1367	196	27	2200	4.25	100.00	104
Newington Concrete	30	Deck	B635	1592	231	14	2200	2.63	100.00	104

Strength

Plant	Class	Element	Project No.	Mean	Std. Dev	n	LSL	Q	PWL	PF
Cardinal Concrete	A3 Slag	Wall Moment Slab Parapet	C502	5677	1086	9	3800	1.73	97.06	102.82
Cardinal Concrete	A3 Slag	Retaining Wall	C503	5528	365	4	3800	4.74	100.00	104.00
Cardinal Concrete	A4000S	Wall	C502	5678	82	3	4800	10.68	100.00	104.00
Cardinal Concrete	Spec SG	Pole Found. & Ret. Wall	C518	5114	1496	3	3800	0.88	77.58	95.03
Newington Concrete	A3 Slag	Bridge (except deck)	B610	6254	511	12	3800	4.80	100.00	104.00
Newington Concrete	A3 Slag	Bridge (except deck)	B635	5791	488	6	3800	4.08	100.00	104.00
Newington Concrete	A3 Slag	Retaining Wall	C503	6599	603	10	3800	4.64	100.00	104.00
Newington Concrete	A4000S	Deck, Bridge, and Appr. Slab	B613	6594	434	27	4800	4.13	100.00	104.00
Newington Concrete	A4000S	Deck, Bridge, and Appr. Slab	B635	6324	556	9	4800	2.74	100.00	104.00
Newington Concrete	A4000S	Deck	B644	5788	67	3	4800	14.72	100.00	104.00
Newington Concrete	A4000S	Deck and Approach Slab	B646	5799	497	3	4800	2.01	100.00	104.00
Newington Concrete	A4000S	Walls, Caissons, Posts	C503	7373	709	9	4800	3.63	100.00	104.00
Virginia Concrete	A3 Slag	Bridge (except deck)	B604	6991	459	4	3800	6.95	100.00	104.00
Virginia Concrete	A3 Slag	Bridge (except deck)	B638	5381	617	5	3800	2.56	100.00	104.00
Virginia Concrete	A3 Slag	Retaining Wall	C518	5800	529	38	3800	3.78	100.00	104.00
Virginia Concrete	A3 Slag	Bridge (except deck)	SR04	5964	703	5	3800	3.08	100.00	104.00
Virginia Concrete	A4000S	Wall Coping and Slab	C518	5635	345	4	4800	2.42	100.00	104.00
Virginia Concrete	A4000S	Box Culvert	D679	5900	648	9	4800	1.70	96.76	102.70

PILOT PROJECTS

The next step in the implementation process was to gather data from pilot projects according to the frequency stipulated in the ERS. This was done to ensure that the sampling and testing requirements were reasonable. Only limited data have been obtained thus far from two pilot projects: (1) Project Rte. 28 Fauquier County (Culpeper Distrct), and (2) Project Rte. 11 City of Radford (Salem District). The special provision used by VDOT inspectors on these two projects is provided in Appendix A. It can be noted that the LSL contained in the special provision for compressive strength was changed to the minimum strength plus 400 psi to reflect concerns of the industry and to provide an example of an extremely low standard deviation. To obtain this low an LSL, a standard devaition of 245 psi would have to be used for compressive strength. This is considered to be inappropriately low. Therefore, Table 4 computes pay factors for the LSL for both the previously selected value of minimum strength plus 800 psi, which is derived from a standard deviation of 500 psi, and the one in the special provision. The USL for the permeability value in the special provision was 185 coulombs, again, an unacceptably low value but one that would provide an analysis of an extremely low standard deviation. Thus Table 4 computes pay factors for the permeability with an USL value of 3300 coulombs for A3 concrete and 2300 for A4 concrete and the more realistic values of 2200 and 3200 coulombs.

The benefit of innovations was well demonstrated in the pilot project undertaken in the Salem District. In this case, the mixture designed by the producer would not meet the current specifications but did produce very good quality concrete under the special provision.

Table 4. End Result Specification Applied to Two Pilot Projects

Permeability										
Plant	**Class**	**Element**	**Project No.**	**Mean**	**Std. Dev**	**n**	**USL**	**Q**	**PWL**	**PF**
Salem	A-4	Bridge Deck	B602	391	72	31	2200	25.13	100.00	104.00
							2300	26.52	100.00	104.00
Culpeper	A-3	Bridge Piers	B601	1453	493	11	3200	3.54	100.00	104.00
							3300	3.74	100.00	104.00
Culpeper	A-4	Bridge Walls and Deck	B601	1411	149	5	2200	5.30	100.00	104.00
							2300	6.04	100.00	104.00
Strength										
Plant	**Class**	**Element**	**Project No.**	**Mean**	**Std. Dev**	**n**	**LSL**	**Q**	**PWL**	**PF**
Salem	A-4	Bridge Deck	B602	5016	305	31	4400	2.02	98.13	103.25
							4800	0.71	76.01	94.40
Culpeper	A-3	Bridge Piers	B601	4886	512	11	3400	2.90	100.00	104.00
							3800	2.12	99.21	103.68
Culpeper	A-4	Bridge Walls and Deck	B601	5457	877	5	4400	1.21	89.50	99.80
							4800	0.75	75.89	94.36

Only concrete data on the bridge deck were obtained for the Salem project. Both bridge deck and substructure concrete data were obtained in the Culpeper project. Table 4 shows for permeability there was no difference in the pay factor irrespective of the USL used for either project. All lots would have received the 4 percent incentive. Compressive strength results for both projects are also shown in Table 4. In the Salem project, an increased pay factor would be applicable for an LSL of 4,400 psi, but a reduced pay factor would be enforced for an LSL of 4,800 psi for strength. In the Culpeper project, A3 concrete would have an increased pay factor for both LSLs and the A4 concrete would have a reduced pay factor for both LSLs. As expected, a higher reduction would result for the higher LSL. It is interesting to note that for the A4 concrete for the Salem and Culpeper project using the higher LSL, both would have paid about 94.4 percent although one (Salem) had a sample size of 31 and the other (Culpeper) had a sample size of 5.

In neither project was the mix design verification by the trial batch procedure used. Mix design verification was based on previous experience with the producer.

The inspectors on the Rte. 28 Bridge in Fauquier County provided in-depth comments on the application of the special provision. These comments are invaluable and will allow modifications to be made to the special provisions before they become official contract documents. The comments are also very beneficial because they come from field personnel who must try to apply the special provisions. The comments will become the basis for modifying the special provisions to include only the HCC material quality properties and eliminating the construction properties in the next phase of this study area. The comments are provided in their entirity in Appendix B. The requirement of testing in the middle third and the need to test as many sublots caused delays and increased the number of samples.

The use of PWL procedures, as well as all statistical tools, requires the data to be obtained by random sampling. All other sampling techniques, such as systematic sampling, produce potentially biased data. The comments from the inspectors indicate that obtaining both thickness and depth of cover data does not lend itself to random sampling. Thus, it was decided that for the next iteration of the special provisions for Section 217 applying solely to bridge decks, only compressive strength and permeability data would be used for pay factor tests. Thickness and depth of cover would be administered just as in a non-ERS specification. Until data are obtained from a paving pilot project, it will not be known if PWL procedures can be applied to thickness and depth of cover.

PHASE II

A few more steps need to be taken before fully implementing the special provision. The next step is to gather additional data from more pilot projects. The data gathered to date from pilot projects are not sufficient to move forward with the special provision in a bidding mode. No data have been collected from concrete paving projects. After more pilot project data are gathered, the next step will be to let the ERS under a bidding situation either without applying the pay factor adjustments or minimizing their impact. This will allow contractors to bid on the

ERS without fear of severe economic consequences. Both of these steps are necessary in the implementation process and are the reasons the ERS for HCC cannot move forward.

CONCLUSIONS

- In the two pilot projects, compressive strength and permeability could be addressed by the PWL approach; however, smoothness, cover depth, and thickness were difficult to evaluate by this approach mainly because of the difficulty in performing randomized testing.

- The requirement of testing in the middle third of the truck and the need to test a relatively high number of sublots causes delays and increases the number of samples.

- It is envisioned that in the future, sampling and testing responsibility will be transferred to the contractor with verification testing by VDOT. Freeing VDOT staff from such activity would enable more and better inspection of the construction, leading to an improved product.

- The benefit of innovations was well demonstrated in the pilot project undertaken in the Salem District. In this case, the mixture designed by the producer would not meet the current specifications but did produce very good quality concrete under the special provision.

RECOMMENDATIONS

1. *The development of the ERS should be continued.* Additional pilot projects are needed to assess the modifications that will be made in the next version of the ERS special provision. In addition, since the ERS has not been used in pilot projects for paving, this will be necessary before trying to implement the ERS for paving.

2. *The ERS used in the pilot projects should not apply the pay adjustments.* After more data are gathered from the pilot projects, the ERS should be reviewed and modified if necessary and a decision as to how to implement the pay adjustments should be made. Then the use of ERS with the pay factors rather than the present method type should be considered.

3. *The structural concrete should be tested at the beginning of the load rather than the middle third of the load, as is currently done in the regular projects.*

COSTS AND BENEFITS ASSESSMENT

The implementation of an ERS would lead to innovation and higher quality concrete in the finished product that, in turn, would result in longer lasting structures with minimal maintenance. If as little as a 5 percent increase in the service life was achieved, the savings would be in the millions of dollars.

In addition, in cases of dispute, an ERS is more defensible than a method specification. With a method specification, VDOT is obligated to accept the product when the contractor can show that the approved mixture proportions were used and the inspector was present. However, it is very well known that many poor construction practices can render concrete that performs less than desired. More inspection by VDOT and the contractor would detect these shortcomings before costly repairs are needed. In an ERS, the responsibility for good quality is shared by VDOT and the contractor.

Another benefit of an ERS is that the testing responsibility can be shared by VDOT and the contractor, leading to reduced personnel for VDOT. However, a better approach is keeping the personnel but diverting attention to a more thorough inspection. It has been proven over the years that an ERS cannot replace inspection but can complement it. VDOT personnel, freed from testing, would have more time for a more thorough inspection of structures.

ACKNOWLEDGMENTS

The help and cooperation of personnel from the Culpeper District, Moore Brothers Construction, the Salem District, and Fairfield-Skanska Contracting who volunteered for the evaluation of the special provision at the subject projects are greatly appreciated. Special thanks go to the contractors, concrete suppliers, and VDOT personnel who have spent many hours in the development of the provisions.

REFERENCES

1. Transportation Research Board. Glossary of Highway Quality Assurance Terms. *Transportation Research Circular Number E-C037.* Washington, D.C., April 2002.

2. Virginia Department of Transportation. Materials Quality Assurance Task Force. Richmond, June 1995.

APPENDIX A

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
HYDRAULIC CEMENT CONCRETE - END-RESULT SPECIFICATION

06/03/2004

Note: The penalties and bonuses outlined in this Special Provision do not apply. Acceptance/Rejection and handling of out of Specification material shall be addressed under the 2002 Virginia Department of Transportation Road and Bridge Specifications.

(The purpose of this Special Provision is to provide the Contractor more flexibility in providing the Department a quality product and at the same time ensure that proper materials and construction practices are used that produce the desired product. Several sections in the 2002 Specification that require the Contractor to use a particular method have been deleted and replaced with end result requirements that shall be controlled by the Contractor.)

SECTION 217- HYDRAULIC CEMENT CONCRETE of the Specifications is amended as follows:

Section 217.04 - Measurement of Materials is replaced with the following:

Section 217.04 - Quality Control - The Contractor shall provide process Quality Control adequate to produce work of acceptable quality. The Contractor shall perform process Quality Control sampling, testing, and inspection during all phases of the work at a rate sufficient to ensure that the end result work consistently conforms to the contract requirements and the minimum guidelines specified for that item of work.

The Contractor shall provide and maintain a process Quality Control Plan, hereinafter referred to as the "Plan." The Plan shall include a list and function of all personnel, equipment, supplies, and facilities necessary to obtain Quality Control samples, perform tests, and otherwise control the quality of the product to meet specified requirements contained herein.

Quality Control testing shall be performed by the Contractor using certified technicians, as defined in Section 217.07, and in laboratories approved by the Department's Materials Division. Laboratory facilities shall be kept clean and all equipment shall be maintained in proper working condition. The Engineer shall be permitted unrestricted access to inspect and review the Contractor's laboratory facility, equipment, process and production methodology, and all Quality Control data.

The Plan shall describe the random sampling procedure that shall be used for obtaining Quality Control samples. The Contractor shall maintain a complete record of all Quality Control tests and inspections. All Quality Control samples shall be obtained in accordance with Department, AASHTO, or ASTM procedures using a random sampling procedure except for check samples that shall be obtained if the Quality Control sample result indicates that the process is Out-of-Control. In the event a check sample is obtained, both the results from the original test and those from the check sample shall be individually noted as such and retained in the Contractor's database.

As a minimum a Control Chart of Unit Weight shall be one part of the Plan and it shall be kept current, i.e., data shall be plotted within one working day of testing and displayed in a location designated by the Contractor. The location shall be accessible to the Engineer at all times. As a minimum, the Control Chart shall identify the test number, test date, upper and lower control limits and the Contractor's test results. The Control Chart shall contain the plot of individual results and the moving average of the last 3 test results.

The Plan shall address all elements that affect the quality of the concrete including but not limited to the following:

a) Mix designs

b) Aggregate source

c) Quality of all components including aggregates, water, admixtures, and cementitious materials

d) Stockpile management

e) Mix properties, including temperature, air content, consistency, unit weight, and water/cementitious material ratio

f) Process Quality Control testing, including type of test and frequency

g) Compressive strength

h) Permeability

Section 217.06 - Classification of Concrete Mixtures is amended as follows:

Table II-17 is replaced with the following:

TABLE II-17
Requirements for Hydraulic Cement Concrete

Class of Concrete		Design Min. Laboratory Compressive Strength at 28 Days (f'_c) (psi)	Design Max. Laboratory Permeability at 28 Days (coulombs)	Air Content (%)
A5	Pre-stressed and Other special Designs[1]	5,000 to 10,000	1,500	4.5 ± 1.5
A4	General	4,000	2,500	6.5 ± 1.5
A4	Posts & rails[2]	4,000	2,500	7 ± 2
A3	General	3,000	3,500	6 ± 2
A3	Paving	3,000	3,500	6 ± 2
B2	Massive or Lightly Reinforced	2,200	NA	4 ± 2
C1	Massive Un-reinforced	1,500	NA	4 ± 2
T3	Tremie seal	3,000	NA	4 ± 2

[1]When Class A5 concrete is used as the finished bridge deck riding surface, or when it is to be covered with asphalt concrete with or without waterproofing, the air content shall be 5.5 ± 1.5%.

[2]When necessary for ease in placement, aggregate No. 7 shall be used in concrete posts, rails, and other thin sections above the top of bridge deck slabs.

Note: The Contractor may substitute a higher class of concrete for that specified at his expense.

When a High Range Water Reducing Admixture (HRWRA) is used, the upper limit air content shall be increased 1 percent.

Section 217.07 - Proportioning Concrete Mixtures is amended as follows:

Section 217.07 paragraphs 8, 14, and 15 are deleted.

Section 217.07 - Mix Design Verification is added

The Contractor shall submit Mix Designs for the various classes of concrete required to the Engineer for review, along with documentation indicating that the proposed mix designs shall meet the verification requirements listed in Table II-17. The documentation may be from past experience with the same materials and mix design or from trial as determined by the Engineer.

Mix design documentation shall consist, as a minimum, of the following:

a) Description and amount of cementitious material.

b) Description of individual coarse aggregate sizes, aggregate source, bulk specific gravity, absorption, and gradation. A combined coarse aggregate blended gradation may be required.

c) Target water content by weight

d) Type and quantity of all admixtures.

e) Description of fine aggregate, aggregate source, bulk specific gravity, absorption gradation, and fineness modulus (FM).

f) Target water/cementitious material ratio

g) Target air content, consistency, and concrete temperature

h) Target concrete unit weight.

i) Target compressive strength

j) Target permeability

If the same mix design with the same material sources as those proposed for use have been used on other work within the previous 12 month period, certified copies of concrete test results from this work that indicate full compliance with these Special Provisions may be used instead of trial batches with the Engineer's permission. The average results of 10 or more compressive strength tests shall be at least 1.28 standard deviations above the specified minimum compressive strength and the average results of 10 or more permeability test results shall be at least 1.28 standard deviations below the specified maximum permeability.

Mix design documentation using trial batches shall be based on the same materials and proportions proposed for use on the project. Trial batch results shall be prepared at least 30 days prior to the start of concrete placement. For Mix Design approval based on a trial batch, the average compressive strength of a minimum of three cylinders (one strength sample) taken from the trial batch shall be at least 1200 psi (8.3 MPa) greater than the Lower Specification Limit (LSL) for the design minimum compressive strength requirement shown in Table II-17 and the average permeability of a minimum of two permeability results (one permeability sample) shall be at least 500 coulombs less than the Upper Specification Limit (USL) for the design maximum permeability in Table II-17.

At the Contractor's option, the trial Mix Design may include compressive strength and permeability vs. time curves to indicate the relationship between these two parameters and time that can be used in Section 217.08 Acceptance under item 5 "Conflict Resolution."

At the Engineer's option, verification may be done on an annual basis rather than on a project-by-project basis provided the sources, properties, ingredients, and proportions of the materials do not change.

Section 217.08 - Acceptance is replaced by the following:

Acceptance tests shall be either screening tests or tests used to determine the pay factor. The Engineer shall sample and test hydraulic cement concrete for screening and acceptance of pay factor tests.
Acceptance tests shall be either screening tests or tests used to determine the pay factor. The contractor shall conduct the screening tests The Engineer shall sample and test hydraulic cement concrete for acceptance of pay factor tests.

Acceptance of bridge deck and paving concrete shall be on a lot-by-lot basis as defined below:

(a) Definition of a Lot: For the purposes of this Special Provision a lot is defined as a quantity of concrete manufactured during a single condition of production that is considered to be uniform and where the source and proportions of all major ingredients are the same.

1. Bridge Deck Concrete - A lot shall consist of a complete class of concrete. Normally, each lot shall consist of sublots defined as one day's placement or a maximum of 100 yds^3 (80 m^3) of a class of concrete. One compressive strength sample and one permeability sample shall be obtained from each sublot on a randomly selective basis. Alternatively, for small projects, i.e., up to 100 yds^3 (80 m^3) total, two samples shall be selected on a random basis and the definition of sublot shall not apply. A strength sample is defined as the average of 3 cylinders and a permeability sample as the average of 2 cylinders.

2. Paving Concrete - A lot shall consist of one lane-mile (1.6 lane-km) of pavement. Each lot shall consist of sublots defined as 0.2 mile (0.32 lane-km) of pavement. One set of compressive strength and permeability samples shall be taken from each sublot.

(b) Acceptance Sampling and Testing

Acceptance tests shall be either screening tests or tests used to determine the pay factor. Screening tests shall be for air content and temperature and shall be sampled from each truckload by the Contractor. These tests shall be used to determine whether or not the truck can discharge its contents on the project. Tests made to determine the pay factor shall be made on a sublot basis by the Department for different construction activities. These tests are described as follows:

1. Screening Tests

Sampling and testing for Air Content and Temperature: Each load of bridge deck concrete during each production day shall be sampled and tested by the Contractor for air content and temperature. Paving concrete shall be sampled for the first two loads per day and once each hour thereafter. The Contractor is responsible for furnishing concrete within the air content and temperature ranges established in Section 217. All batches with either air content or temperature not in compliance with Section 217 shall be rejected and removed from the job.

a. Air Content Tests: Air content tests shall be performed by the Contractor to ensure that specification requirements are consistently being complied with for each class of concrete.

   Air content shall be determined after all the mix water has been added in accordance with the requirements of AASHTO T152 or T196. The sample secured for the tests shall be taken after at least 2 ft^3 (0.06 m^3) of concrete has been discharged from the delivery vehicle.

   If the determination of any test yields a result that is outside the allowable range for air content, the following procedure will be used:

   1. The Contractor has the option of (1) immediately performing a recheck determination or (2) adding sufficient material to bring the air content within specification limits while also meeting the time, temperature and number of revolutions constraints. Air-entraining admixture may be added one time to the concrete in those loads that are on site or in transit. For option (1), if the average of the two air content results is within the specification limits for air content the material can be used; if the average of the two tests is outside this limit the material shall be rejected. For option (2), the concrete with the additional material shall be sampled as a new truckload and the above acceptance procedure used. If the test result is outside the allowable range for air content, the material shall be rejected.

   2. If the load is rejected, the Contractor's representative shall notify the producer of the test results through a pre-established means of communication.

b. Temperature Tests: Temperature tests shall be performed by the Contractor at the same time as air content tests to assure that specification requirements are consistently being complied with for each class of concrete. All temperature tests shall meet the specification requirements or the load shall be rejected.

2. Pay Factor Tests

   a. Compressive Strength Tests: The 28-day strengths specified in Table II-17 shall be the strengths used in the design calculations. The Engineer will verify design strengths by tests made in accordance with the requirements of AASHTO T22, T23, or T24.

The Contractor shall provide a storage chamber at his expense for temporary storage of the concrete cylinders. The chamber shall be designed to maintain test cylinders in a continuously moist condition within a temperature range specified in the AASHTO requirements and shall be equipped with a continuously recording thermometer. The chamber shall be located near the concrete placement site in an area where test cylinders will not be subject to vibration and shall be of sufficient size or number to store, without crowding or wedging, the required number of test cylinders as determined by the Contractor based on his plan of operations and approved by the Engineer.

When use of high-early-strength hydraulic cement concrete is authorized, it shall conform to the requirements of Table II-17. except that the 28-day strength shall be obtained in 7 days. Types I, II, or III cements may be used to produce high-early-strength concrete, however, the total cementitious material content shall not exceed 850 lbs/yd^3 (505 kg/m^3).

One strength sample shall be taken randomly for each sublot. Each strength sample is to be taken according to the procedures of AASHTO T 141 (ASTM C 172). At the option of the Engineer or the Contractor, more than one strength sample may be taken from each sublot. When so taken, all results shall be used in judging the acceptability of the lot, except where a cylinder or set of cylinders is obviously faulty.

b. Permeability Tests: The 28-day permeability values specified in Table II-17 shall be the target values required for durability. Normally, one permeability sample shall be taken randomly for each sublot. Each permeability sample shall be taken according to the procedures of AASHTO T 141 (ASTM C 172), from the middle 1/3 of the load. At the option of the Engineer or the Contractor, more than one permeability sample may be taken from each sublot. When so taken, all results shall be used in judging the acceptability of the lot.

   Cylinders shall be tested by the Department at 28 days in accordance with the procedures of AASHTO T277 (ASTM C 1202) after moist curing for one week at 73^{0}F (23^0 C) and 3 weeks at 100^{0}F (38^0 C) except for latex-modified concrete (LMC). LMC shall be moist cured for 2 days and air-dried at room temperature until tested at 56 days.

3. Acceptance Criteria

Acceptance for compressive strength and permeability shall be based on the Quality Index (QI) calculated using the results of the tests per lot described above. The QI uses both the average and the standard deviation within each lot to estimate the population parameters and determine the percentage of the lot within specification limits. The Acceptable Quality Level (AQL) is that quality of concrete for which the Contractor will receive 100 percent pay. Rejectable Quality Level (RQL) is that quality of concrete requiring removal and replacement by the Contractor or for which the Contractor will provide remedial action. The AQL has been established at 90 Percent Within Limits (PWL) and the RQL at 50 PWL. The QI shall be calculated using the following equations:

$QIL = (\overline{X} - LSL)/s$ $QIU = (USL - \overline{X})/s$

Where:
QIL is the Lower Quality Index*
QIU is the Upper Quality Index*
$\overline{X}$ is the average
s is the standard deviation
LSL is the Lower Specification Limit (Table 1)
USL is the Upper Specification Limit (Table 1)
QIL shall be used for strength and QIU shall be used for permeability.

Table 1 Upper and Lower Specification Limits

Class of Concrete	LSL for Strength, psi	USL for Permeability, coulombs
A5	5400	1300
A4	4400	2300
A3	3400	3300

Note: For higher design compressive strengths add 400 psi (i.e., for 8,000 psi concrete, LSL is 8,400 psi)

QIL and QIU are used to enter Table II-18 (n=3 or greater) for the estimation of the lot PWL. The PWL is, in turn, used to determine the pay factor through the appropriate pay factor equation as discussed below.

All material that has a PWL less than 50 shall be accepted at the calculated pay factor or rejected and removed from the project at the Engineer's option. If the rejectable product can be corrected, it may be accepted upon correction, at the Engineer's option.

a. Acceptable compressive strength

1. When the number of samples tested (n) on the lot is 3 or more, the QIL and QIU shall be used to estimate the PWL and pay factor.

2. When the number of samples tested on the lot is less than 3, the acceptable average compressive strength for a sample size of n=2 shall be the LSL + 200 psi (1.4 Mpa); and for a sample size of n=1 the minimum acceptable compressive strength shall be the LSL.

b. Acceptable permeability

1. When the number of samples tested (n) on the lot is 3 or more, the QIL and QIU shall be used to estimate the PWL and pay factor.

2. When the number of samples tested on the lot is less than 3, the acceptable average permeability for a sample size of n=2 shall be the USL - 100 coulombs, and for a sample size of n=1, USL for permeability shall be met.

c. Acceptable Ride Quality - Refer to the Rideability Special Provision if provided in the contract documents.

4. Basis of Payment

a. When the PWL for the 28-day minimum design compressive strength or design maximum permeability and, when appropriate, thickness and depth of cover (Sections 316.05 and 406.06) of the lot is equal to or exceeds 50, the pay factor shall be determined by the following equation:

Pay Factor for Individual Properties = 64 + 0.4 (PWL)

b. The Lot Pay Factor shall be an average of the individual pay factors for compressive strength, permeability, and when appropriate, thickness and depth of cover (Sections 316.05 and 406.06).

The Average Pay Factor = Pay Factor for Individual Properties/N,
Where N = number of individual properties.
The Average Pay Factor = C_1(Permeability) +C_2(Strength)+ C_3(Thickness) +C_4(Cover Depth) +C_5(Ride Quality) divided by $C_1+C_2+C_3+C_4+C_5$
C_1=weighted factor for permeability = 1.0
C_2=weighted factor for strength = 1.0
C_3=weighted factor for thickness = 1.0
C_4=weighted factor for cover depth = 1.0
C_5=weighted factor for ride quality = 1.0

The Average Pay Factor is multiplied by the unit bid price to determine the pay quantity.

c. To receive a pay factor greater than 100 percent, all individual properties shall be 90 PWL or more for all lots in the project.

d. For compressive strength and/or permeability results of lots for samples of size n = 1 or 2, material meeting the requirements described under acceptable compressive strength and acceptable permeability shall be accepted at the full unit bid price. Material not meeting the acceptable values, as described above, the pay factor shall be as indicated in the VDOT Materials Division Manual of Instructions, Section 416.01 (g).

5. Conflict Resolution

In any case that the Contractor and the Department disagree on the quality level or pay factor, and in which a technical reason for the disagreement is known, the procedure described herein for conflict resolution shall be used. Additional inspection and tests on the hardened concrete may be made and the Engineer may base the acceptance and pay factor for strength and permeability of the concrete on results obtained from cores.

Cores shall be taken by the Engineer to ensure that structural adequacy is maintained. If strengths or permeabilities meet the Specification limits, concrete will be accepted as indicated in the VDOT Materials Division Manual of Instructions, Section 416.01 (g). If the concrete is below the acceptable level but kept in place, the payment shall be 64 percent of the full price for that lot.

SECTION 316—HYDRAULIC CEMENT CONCRETE PAVEMENT of the Specifications is amended as follows:

Section 316.04 (c) - Placing Reinforcing Steel for Continuously Reinforced Pavement is amended to add the following:

1. Depth of Cover

Continuously Reinforced Concrete Pavements: As measured in the fresh concrete, a minimum of 6 cover depth readings shall be taken by the Engineer on each sublot and the average and standard deviation determined for each lot. Two readings shall be taken on each 1/3 of sublot length selected in a randomly stratified manner in the longitudinal and transverse directions with locations provided to the Engineer prior to placement.

Acceptance for cover depth shall be based on the QI calculated using the results of the measurements per lot described above. The QI uses both the average and the standard deviation within each lot to estimate the population parameters and determine the percentage of the lot within specification limits. The AQL is that quality receiving 100 % pay. RQL is that quality requiring removal and replacement or receiving the minimum pay. The AQL has been established at 90 PWL and the RQL at 50 PWL. The QI shall be calculated using the following equations:

$QIL = (\overline{X} - LSL)/s$

Where:
QIL is the Lower Quality Index

$\overline{X}$ is the average
s is the standard deviation
LSL is the Lower Specification Limit, which is the target minus 3/8 inch (9 mm) for pavements and 1/4 inch (6 mm) for bridge decks.

QIL is used to enter Table II-18 for the estimation of the lot PWL. The PWL is, in turn, used to determine the pay factor through the appropriate pay factor equation as discussed in Section 217.08 (b) 4 - Acceptance.

All material that has a PWL less than 50 shall be accepted at the calculated pay factor or if the rejectable quality level product can be corrected, it may be accepted for this item.

Section 316.05 - Tolerances is replaced with the following:

The thickness of pavement shall be determined as stated below based on the average core thickness, as described in VTM-26 and modified herein and tested in accordance with the requirements of AASHTO T148.

A minimum of 1 core shall be taken by the Engineer on each sublot and the average and standard deviation determined on a lot basis. The core locations shall be determined in a random manner both transversely and longitudinally.

Acceptance for thickness shall be based on the QI calculated using the results of the measurements per lot described above. The QI uses both the average and the standard deviation within each lot to estimate the population parameters and determine the percentage of the lot within specification limits. The AQL is that quality receiving 100 percent pay. RQL is that quality requiring removal and replacement or receiving the minimum pay. The AQL has been established at 90 PWL and the RQL at 50 PWL. The QI shall be calculated using the following equations:

$$QIL = (\overline{X} - LSL)/s$$

Where:
QIL is the Lower Quality Index
$\overline{X}$ is the average
s is the standard deviation
LSL is the Lower Specification Limit, which is the target minus 3/8 inch (9 mm).

QIL is used to enter Table II-18 for the estimation of the lot PWL. The PWL is, in turn, used to determine the pay factor through the appropriate pay factor equation as discussed in Section 217.08 (b) 4 - Acceptance.

All material that has a PWL less than 50 shall be accepted at the calculated pay factor or if the rejectable quality level product can be corrected, it may be accepted for this item up to 100 percent of the bid price upon correction, at the Engineer's option.

Section 316.06 - Measurement and Payment is amended to add the following:

Basis of payment shall be based on criteria in accordance with Section 217.08 (b) 4 - Acceptance and Section 316.04 (c) 1 - Depth of Cover of these Special Provisions.

SECTION 404—HYDRAULIC CEMENT CONCRETE OPERATIONS of the Specifications is amended as follows:

Section 404.04 - Tolerances is amended to add the following:

(a). Depth of Cover

Bridge Decks: As measured in the fresh concrete, a minimum of 12 cover depth readings shall be taken by the Engineer on each span and the average and standard deviation determined for each lot. The readings shall be stratified by equal 1/3 of the longitudinal length and randomly selected in both the transverse and longitudinal directions.

The depth of cover of the bridge deck shall be determined by the Engineer at 12 points per span during placement at or near the locations probed for thickness.

Acceptance for cover depth shall be based on the Quality Index (QI) calculated using the results of the measurements per lot described above. Each span is a sublot, and the total deck is a lot. The QI uses both the average and the standard deviation within each lot to estimate the population parameters and determine the percentage of the lot within specification limits. The AQL is that quality receiving 100 % pay. RQL is that quality requiring removal and replacement or receiving the minimum pay. The AQL has been established at 90 PWL and the RQL at 50 PWL. The QI shall be calculated using the following equations:

$$QIL = (\overline{X} - LSL)/s$$

Where:

QIL is the Lower Quality Index

$\overline{X}$ is the average

s is the standard deviation

LSL is the Lower Specification Limit, which is the target minus 3/8 inch (9 mm) for pavements and 1/4 inch (6 mm) for bridge decks.

QIL is used to enter Table II-18 for the estimation of the lot PWL. The PWL is, in turn, used to determine the pay factor through the appropriate pay factor equation as discussed in Section 217.08 (b) 4 - Acceptance.

All material that has a PWL less than 50 shall be accepted at the calculated pay factor or if the rejectable quality level product can be corrected, it may be accepted for this item up to100 percent of the bid price upon correction, at the Engineer's option.

(b). Thickness of Bridge Deck

The thickness of the bridge deck shall be determined by the Engineer at 12 points per span during placement. The fresh concrete shall be probed randomly at points between the flanges of beams and 3 feet from joints to avoid larger thickness at those areas. When corrugated stay-in-place forms are used, the top of the corrugations shall be probed for thickness.

Acceptance for thickness shall be based on the QI calculated using the results of the measurements per lot described above. Each span is a sublot, and the total deck is a lot. The QI uses both the average and the standard deviation within each lot to estimate the population parameters and determine the percentage of the lot within specification limits. The AQL is that quality receiving 100 % pay. RQL is that quality requiring removal and replacement or receiving the minimum pay. The AQL has been established at 90 PWL and the RQL at 50 PWL. The QI shall be calculated using the following equations:

$$QIL = (\overline{X} - LSL)/s$$

Where:

QIL is the Lower Quality Index
$\overline{X}$ is the average
s is the standard deviation
LSL is the Lower Specification Limit, which is the target minus ¼ inch (6 mm).

QIL is used to enter Table II-18 for the estimation of the lot PWL. The PWL is, in turn, used to determine the pay factor through the appropriate pay factor equation as discussed in Section 217.08 (b) 4 - Acceptance.

All material that has a PWL less than 50 shall be accepted at the calculated pay factor or if the rejectable quality level product can be corrected, it may be accepted for this item up to 100 percent of the bid price upon correction, at the Engineer's option.

Section 404.08 - Measurement and Payment is amended to replace the second paragraph with the following:

The volume of bridge deck slab concrete allowed for payment will be based on plan thickness. If prestressed concrete deck panel forms are used, the volume they displace will be computed using plan dimensions and the volume of the cast-in-place portion will be measured as provided herein.

Section 404.08 - Measurement and Payment is amended to add the following:

Basis of payment shall be based on criteria in accordance with Section 217.08 (b) 4 - Acceptance and Section 404.04 (a) - Depth of Cover of these Special Provisions.

APPENDIX B

END RESULT TRIAL
FOR
PROJECT # 0028-030-101,B601

(Fauquier County)

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General information:

The purpose of this trial is to evaluate the current draft of the End Result Specifications, applied to a project/structure with less than one thousand (1000) cubic yards of total concrete required. The above project consist of one three (3) span bridge structure containing an estimated three hundred five (305) cubic yards of class A3 concrete and three hundred sixty six (366) cubic yards of class A4 concrete.

Prior to the commencement of the trial a meeting was held at the VTRC to discuss its implementation. At that time the following was decided:

1) The trial would be for research purposes only and the price adjustments enumerated in the draft specification would not be enforced.

2) VDOT personnel would perform all testing, with assistance accepted from the contractor.

3) The specified contractor quality control plan was not mandatory but desirable.

4) Lot/sub-lot sizes were to be based upon plan quantities.

5) Unit weight and slump tests would be performed in conjunction with all screening and pay-factor tests if possible.

6) The sub-structure as well as the superstructure concretes would be included in the study.

7) Lot identification, random sample selection procedure, and data input worksheet, on the Excel program, to be established by project personnel.

8) A continuous recording thermometer for the curing chamber was desirable, if available.

9) Trial batch testing would be desirable, however the project was not to be delayed waiting for the results from the trial batches and if the producer(s) were comfortable with their designs, trial batches would not be mandatory.

10) VTRC will perform the evaluation of the trial results.

11) The plants' batch recordation report would be accepted in lieu of the TL-28, to evaluate this method of obtaining batch information.

12) At any time the trial interfered with the progress of the project or became too cumbersome for the VDOT personnel, it was to be terminated and the project personnel would complete the project under current specifications and testing procedures.

The lot identifications were determined to coincide with the particular mix design used, due to the mix design and the lot description criteria being nearly identical. Sub-lots are to be identified in numerical sequence within the corresponding lot. Random sample determinations were to be selected by drawing a set of three random numbers from a can (borrowed from the CMA and Asphalt programs). These numbers would then be expressed as a decibel and multiplied by the plan yardage of the placement.

Example:

Numbers drawn: 6-2-6
Plan size of the placement: 38 cubic yards
The sample location is determined as: 0.626 X 38.0 = 23.8 C.Y.

The sample for the pay factor test, in the example, would be obtained from the load/batch containing useable yard 23.8 (batches found by the screening test not to be in compliance are not included in the sub-lot running total).

Note: All batch data provided is the actual quantity batched per the plant recordation provided with each load.

Observations and Comments:

1) The performance of the unit weight test adds significantly to the time required to complete the battery of required tests. This is due primarily to obtaining the necessary weights under field conditions. Basically the more windy the conditions the longer it takes to obtain the weights (i.e. you must wait until the wind subsides enough to allow the scales to stabilize before obtaining the readings). This situation has the potential in delaying placements, especially in situations when rapid discharge of the mix is possible such as placements by pump. It may also increase the test variability well beyond that of established precision statements.

2) The issue of scales to perform the unit weight determination needs to be addressed as well. Some of the factors to be considered are cost, who will be responsible for providing them, what certifications will be required, and if any description is necessary or specification compliance is required. Currently very few contractors' own scales suitable for this purpose, and VDOT has only a limited supply, in most cases one or two sets per District.

3) There have been a few instances where the contractor has ordered additional concrete to complete the placement (above the plan quantity). This situation affects the statistical concept of the specification in regards to pay factor sample selection. Since the pay factor sample yard is determined in advance (based on plan quantity) the "add on" quantity would never be tested for the pay factor determination.

4) The rate of pay factor sampling and testing on this project, to date, is approximately one (1) pay factor test per 43.2 cubic yards of concrete placed (including the deck placement). It is not difficult to imagine that on larger structures the quantity represented per test would generally be somewhat greater, i.e. up to 100 cubic yards per test (the maximum sub-lot size). It is therefore conceivable that the pay factor sampling rate on smaller structures, such as this one, could (and in all probability would), be significantly greater than the larger projects/structures.

5) There were two instances of placements on this project where the concrete was supplied from two (2) separate batching facilities. This is a practice allowed in some locations, due to the volume of given placements, provided that all the materials are compatible. Since the timing and quantity of materials to be delivered from each location is unknown it is impossible to separate them into sub-lots for pay factor sampling and testing. This is a situation that definitely needs to be addressed in the special provision.

6) The occurrence identified in item 5 above, brings to mind that there are also other changes in mix design, which routinely occur during placements, especially in the warmer months. Two examples of these changes are in the amount of water added, and the addition or deletion of retarder. In hot weather it is common practice to start with a lower water/cement ratio mix then change to a higher (within specification limits) w/c ratio mix as the haul or atmospheric conditions dictate. While not as

frequent in occurrence, a similar procedure (in reverse) is done with retarder. It is not uncommon to commence a placement with a retarded mix (for ease of handling, to compensate for atmospheric conditions, or to attempt a uniform cure) then reduce and eventually delete it in the latter stages of the placement. Traditionally either of these situations would constitute a design change thus, by the current special provision definition, a lot change. Since these adjustments are dictated by job site conditions they are all but impossible to plan for in respect of pay factor sample selection. I suggest we review and revise the lot definition to allow for such "in the heat of battle adjustments". One approach may be to define a specific class (such as A-3 General) of concrete as a lot "period", remembering all mix designs must be approved by trial batch prior to use in the structure.

7) During the progress of this trial it has been noted that it is typical for the screening test and pay factor test to yield differing results. Typically the pay factor test will yield a lower slump and air content than the screening test on the same load. This creates a situation that allows batches that are at or near the lower limits of our specification ranges to be placed when at least a portion of the batch is actually failing to meet specifications. In some cases the pay factor test air results was a half percent less than the screening test results. In this case the batch could, if class A3, be placed with 4.0 percent air while at some point during placement it could drop to as low or lower than 3.5 per cent. This is a situation that I feel should definitely be investigated and considered in our specifications regardless of which specification is selected.

8) Deck Placement Comments and Observations

    a) For this particular placement the Contractor requested and received approval for a continuous placement plan. This plan included a pump(s) to be utilized as the HCC transfer system for the method of placing the concrete. Due to the volume, site conditions, and timing of the deliveries, a remote or staging area was utilized for the screening testing with two sets of testing equipment and personnel. The pay factor samples were obtained at the point of discharge and were tested by a third set of personnel and equipment to include the unit weight container and scales. **Note: all previous testing was accomplished utilizing the same equipment and personnel for the screening as well as the pay factor test.**

    b) The testing of the pay factor samples was performed without any unusual problems other than the limited area available for this purpose, which was a result of this specific site. The concentration, communications, and coordination involved in the testing and recordation process were intense. With the utilization of multiple testing stations and the delivery schedule considered, one individual was assigned the duty of tracking and recording only. This individual tracked which team was testing which delivery, and insured that the results of each test were properly recorded, with the correct corresponding delivery. In addition he had to keep a running total of useable yardage and communicate to the pay factor test personnel the identification of the hauling unit containing the pay factor test yardage as well as recording the results of the pay factor test with the correct delivery. It was very evident that the success or failure of this testing program was dependent upon this individual's professionalism, dedication, and attention to detail.

c) While the pay factor testing was without notable problems. The sampling procedure had several. The samples were obtained as specified (three points, during discharge, commencing after ten percent and completing the procedure prior to ninety per cent of the discharge). There were situations noted which needs, in my opinion, some consideration.

    1. It was very difficult to equally space the portions of the composite sample. This was due primarily to two factors. The first was the rate of discharge into the pump equipment. Unlike the crane and bucket method of placement where you can count buckets of known volume, the discharge into a pump is highly variable with little point of reference, thus making the spacing of the increments little more than educated guesses. The second issue noted concerns the coordination required to obtain an increment of the sample. To obtain an increment, the sampler must determine when it is due, advise the transit mixer operator what is needed, notify the pump operator, who may be anywhere in the area (so they can shut off the pump to prevent the loss of prime while the sample is being obtained), then wait until everyone is ready, obtain the sample, and then advise all involved that operations may be resumed. These procedures must be repeated three times for each pay factor sample obtained.

    2. The second issue noted is one of safety for the personnel involved in the sampling process. In order to minimize the delays involved in obtaining the composite sample, we elected to obtain these samples at the pump by raising the chute, swinging it to one side and removing a cross section of material into the sample container. This procedure was used in lieu of pulling the mixer unit forward, away from the pump unit, prior to obtaining a sample increment due to the time and inconvenience this approach would require. It was soon evident that the selected procedure, although the most efficient, was placing the sampler(s) between two or more operating pieces of equipment with little or no avenue of escape and operators concentrating on other responsibilities (not an enviable or comfortable position for personnel). This is not as much of an issue when the crane and bucket method of placement is used due to the time required to swing the bucket to and from the actual point of placement; however, the sampling personnel must be ever watchful of the returning bucket. In my opinion safer alternative methods of

obtaining the composite samples for pay factor testing should be explored.

The final placement of the trial was accomplished February 22, 2005.

Notes concerning superstructure overdepth measurements by C. Funkhouser:

- Prior to the deck placement, a system for random probing was devised in accordance with the End Result Specification draft. The system involved subdividing the deck into three spans (Abut. To pier, pier to pier and pier to abut.). Each span was then further subdivided into three equal sections with four random points to be probed in each of these sections.

- Random numbers were drawn to determine each point in two directions. The first number represented a distance out longitudinally from Abutment “A”. The second number represented a distance out transversely from the downstream side of the bridge.

- Prior to concrete placement, the longitudinal distances were marked on the overhang formwork on both sides of the bridge. The intention of the exercise was to pull a 100’ tape measure across the deck at the bridges skew angle and find the corresponding transverse point on the tape.

- The contractor was informed of the plan described above and asked to provide assistance to the Inspector during the pour. This is necessary because the work bridge that spans the deck transversely needs to be moved back and forth to allow the Inspector to find the points on the deck. Typically, the contractor uses these work bridges for two purposes: To perform finish work behind the screed, and to place wet burlap on the fresh concrete.

- At the time of the pour, the contractor’s foreman was reminded of the plan, but ended up not providing any assistance at all. Therefore, the method of probing described above had to be abandoned and more traditional probing techniques were used. Here are some reasons why the new system did not work:

    1. To use this method it requires significant cooperation and participation by the contractor. This means additional crew members and time for their operation. The contractor is not contractually required to provide these provisions.
    2. It is practically difficult to locate the positions when concrete has been placed and the marks on the formwork get covered in splattered concrete.
    3. The work bridge is configured perpendicular to the sides of the forms, but the probe measurements are taken off of the skew angle. This makes locating the points difficult and forces the contractor to move the work bridge back and forth much more often. This takes away from the prescribed finish work by the contractor after the screed passes.

4. To take the measurements under the new system would require additional Inspection staff, and could possibly slow down the contractor's operation. In addition, this method creates more confusion and congestion in an already confined and chaotic operation.
5. Several of the random points were discovered to be located at the bolstered areas over the steel girders. These points had to be manually adjusted affecting the original random locations. In addition, because of the bridge's skew angle, some points were found to be off the deck at both ends and had to be moved.
6. During the dry run, all the same problems above apply. To measure the exact locations is very time consuming for both the contractor and the Inspector.