STATISTICAL ACCEPTANCE OF DENSE-GRADED BITUMINOUS MIXES BASED ON THE EXTRACTION OF PAVEMENT CORES

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In 1970 the Illinois Division of Highways initiated its first practical application of an "end result" type of specification on a bituminous resurfacing project. Nearly all responsibility for the design, control, and placement of the mix was placed on the contractor. Payment for the completed pavement was based on data obtained from the extraction of the uncompacted mix and from the density and thickness of the compacted pavement. Findings indicate that there is a mean shift of the core data, especially for the top size of aggregate. Adjusting target values (mix formula) by these differences indicates a very close correlation between the mix and the core extractions. In a few cases where there was considerable difference between the mix and the core extractions, there was usually as much difference between the testing of identical mix samples. The standard deviation for the core extractions, in most cases, was about the same as or less than that for the mix extractions. Based on the findings, core extraction tests could be used for the acceptance of bituminous mixtures provided judgment is used in adjusting mix formula values to coincide with the mean data shift due primarily to the cutting of larger sized aggregate during the coring operation.

•THE ILLINOIS Division of Highways has for years used modified-extraction, Marshall, and density tests for the design and control of bituminous pavement construction. Based on our experiences and knowledge as to the reliability of these tests, a contract for an "end-result" project was awarded during 1970 (1). Nearly all responsibility for the design, control, and placement of the mixture was placed on the contractors, and payment was based on the results of tests of the completed pavement taken by the state. Payment could entail a bonus or a penalty. The contractors were required to submit mix designs to the division's central laboratory for approval prior to mix placement. These designs were based on our present design criteria within mix specifications. Some mixes had to be redesigned and resubmitted before final approval was granted. The contractor's payment was based on his ability to meet the job mix tolerances, density, and thickness. Each of these items affected his unit bid price by one-third. Payment was established daily based on a predefined lot.

The intent of the end-result specification was to explore the feasibility of eliminating as many state job-control personnel as possible and still obtain a quality pavement. With this specification, state personnel were not required at either the plant or the paver. This is not to imply that the contractor was not required to do quality work. The resident engineer still had the responsibility of enforcing good construction practices. One drawback immediately encountered was that the specifications required the extraction test to be based on 5 random samples per lot of uncompacted mix taken from behind the paver. This required state personnel to be at a precise location at an exact time to obtain the necessary samples and, thereby, somewhat limited the value of the specification.

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We decided, therefore, to explore the possibility of basing mix acceptance of future jobs on extraction tests of cores required for density and thickness purposes. We reasoned that, by possibly shifting target values or job tolerances on future jobs or both, acceptance samples could be taken the day after mix placement and compaction.

SAMPLING PROCEDURES

As stated earlier 5 extraction samples of uncompacted mix were taken per lot at random locations from behind the paver. A lot was defined as "one day's production per paver, but in no case shall it exceed one mile of 2-lane pavement or its equivalent." Because a lot was in most cases a day's production, random locations, both longitudinal and transverse, were established by the use of tables of random numbers based on the contractor's estimated daily production. On most days we were able to obtain the required 5 samples.

Each mix sample was taken either with a 1-ft square template pressed into the uncompacted mix or by a pan placed ahead of the paving machine. The mix (approximately 18 lb) was placed in canvas bags and transported to the field laboratory for testing. The day following each day's construction, cores having 3⅞-in. diameters were taken at 5 random locations from the previous day's work for use in determining density and thickness. These cores were taken by the contractor under the supervision of state personnel and transported to the field laboratory. Two cores were taken at each location and constituted 1 sample.

TESTING PROCEDURES

The mix samples received by the field laboratory were heated, if required, and split by an aggregate splitter until approximately a 1,200-gram sample was obtained. The remaining material was prepared for shipment to our central laboratory where identical tests as described later were performed with different personnel and equipment.

Because this was our first end-result job, we had one of our most experienced employees perform all field tests in order to limit, as much as possible, the chances of testing error. Employees who conducted the comparison tests in our central laboratory had considerably less experience, yet the results were, in our opinion, equally as good.

The extraction tests for asphalt content were conducted in accordance with AASHO T164-70, Method B (2), except that the ash content of the filtrate was not computed. Previous investigations in our central laboratory relating various filter paper types and ash contents revealed that no appreciable material is lost through the type of filters we use.

Upon completion of the extraction test, a sieve analysis was made of the remaining aggregate in accordance with AASHO T30-70 (2), omitting the wash test. Tests conducted in the past have shown that the extraction test virtually "washes" the type of aggregates used in our primary mixes. Therefore, we base all design and control of our mixes on dry sieves as a matter of practice.

After the density tests were completed, the cores were shipped to the central laboratory for extraction and sieve analysis tests. The 2 cores (approximately 750 grams each) obtained at each location were extracted as a single sample. The actual sample size varied according to the thickness of the cores (1.03 to 2.37 in.). No attempt was made to remove the cut aggregate from the periphery of the cores.

TEST DATA AND ANALYSIS

According to the requirements of the specifications, basis of payment for the mixture was computed on the average of 5 samples per lot on the controlling sieves as given in Table 1. The contractors were also required to maintain the mix within certain percentages on other sieves according to mix specifications, but only the sieves given in Table 1 were used for basis of payment; for purposes of clarity, only the lot averages on the controlling sieves are given.

From a research standpoint we received an added dividend with this contract in that it was awarded as a joint venture. One contractor paved half of the job and a second

Table 1. Extraction and sieve analysis.

Contractor, Course, and Lot Number[b]	Gradation[a] (percent) <1 in. >½ in.[c] <½ in. >No. 4[d]				<No. 4 >No. 10				<No. 40 >No. 80				<No. 200				Asphalt Content[a] (percent)			
	M	F	L	C	M	F	L	C	M	F	L	C	M	F	L	C	M	F	L	C
1-B-MF	21.5				7.5				12.4				4.8				4.8			
1-B-1		25.9	25.4	—[e]		10.9	10.6	—[e]		8.4	8.4	—[e]		4.8	5.0	—[e]		4.36	4.32	—[e]
1-B-2		22.8	22.2	19.4		8.5	8.0	10.2		10.0	10.1	9.5		5.2	5.4	5.9		4.88	4.82	4.78
1-B-3		23.7	23.4	21.6		7.6	7.4	7.1		10.3	10.4	10.4		4.2	4.4	4.8		4.74	4.70	4.52
1-B-4		25.4	23.1	19.3		6.2	6.2	8.8		10.6	11.0	11.8		4.4	4.5	4.9		4.70	4.70	4.92
1-B-5		25.8	22.3	16.8		6.2	5.9	8.1		10.2	10.4	11.3		5.2	5.7	5.9		4.74	4.58	4.82
1-B-CF	23.0				7.5				12.4				4.8				4.8			
1-B-6		25.5	21.5	20.1		6.8	7.0	6.3		11.0	11.0	10.3		4.3	4.9	5.7		4.80	4.74	4.76
1-B-7		25.6	22.9	18.6		6.7	5.8	8.7		11.0	11.0	10.8		5.0	5.6	5.3		4.94	4.92	4.82
1-B-8		24.5	24.2	21.7		12.2	10.0	10.4		9.9	10.0	9.7		4.5	4.8	5.0		4.73	4.76	4.94
2-B-MF	22.5				13.9				7.8				4.8				4.8			
2-B-9		22.5	22.1	20.6		10.8	10.3	9.7		8.6	7.8	8.6		6.1	6.1	5.8		4.54	4.80	4.44
2-B-10		24.6	20.4	17.0		10.5	11.2	12.3		7.4	7.8	7.8		5.9	6.3	6.2		4.44	4.54	4.50
2-B-11		19.9	23.4	18.2		13.2	12.0	12.2		7.4	7.1	7.9		6.0	5.9	6.2		4.70	4.36	4.42
2-B-12		18.9	18.8	16.8		12.1	11.9	12.9		7.1	7.1	7.4		4.9	5.2	5.1		4.78	4.54	4.52
2-B-13		20.7	20.6	15.8		12.2	11.3	12.4		7.5	7.7	7.8		4.7	4.8	5.5		4.78	4.54	4.80
2-B-14		21.8	22.2	15.8		11.7	11.3	12.7		7.2	7.5	7.8		5.2	5.2	5.7		4.96	4.74	4.90
2-B-15		21.0	17.0	16.3		12.7	12.4	12.2		7.4	7.8	7.4		5.5	5.8	5.7		4.88	5.02	4.60
2-B-16		20.2	20.2	20.4		13.5	13.0	12.7		7.8	8.0	7.7		5.0	5.1	5.1		5.02	4.94	4.40
1-S-MF	38.7				20.1				12.1				5.0				5.3			
1-S-1		35.8	36.2	32.3		22.4	21.7	24.2		10.3	10.3	10.1		5.6	5.7	5.9		5.33	5.23	5.34
1-S-2		35.9	36.5	33.5		22.3	21.7	23.4		10.8	10.3	10.4		5.9	6.3	6.6		5.26	5.10	5.36
1-S-3		39.4	38.6	35.6		20.9	20.9	21.5		10.0	9.8	9.7		5.5	5.9	7.3		5.18	5.20	5.38
1-S-4		40.0	40.2	36.6		20.7	19.9	22.9		10.1	10.3	10.3		5.6	6.0	6.1		5.16	5.28	5.36
1-S-5		39.8	40.2	36.9		20.0	19.4	21.1		10.2	10.2	10.5		5.9	6.3	6.4		5.24	5.36	5.26
1-S-6		40.9	41.4	37.5		19.2	18.5	20.6		10.2	9.7	10.1		6.0	6.0	6.3		5.22	5.42	5.40
1-S-7		41.9	41.4	37.4		20.3	19.9	21.7		9.9	10.3	10.0		4.9	5.1	5.5		5.30	5.40	5.30
1-S-8		37.4	39.1	37.6		21.4	20.2	21.2		10.5	10.5	10.4		5.6	5.8	5.6		5.44	5.20	5.36
1-S-9		39.3	39.6	37.0		21.2	20.7	22.7		10.6	10.4	10.0		5.3	5.5	5.3		5.26	5.16	5.32
2-S-MF	33.7				24.5				8.1				5.5				5.5			
2-S-10		30.3	32.5	30.2		24.6	23.4	23.2		9.1	9.0	9.0		5.6	5.6	5.9		5.64	5.46	5.40
2-S-11		32.3	33.6	31.6		21.8	20.7	22.8		9.3	9.4	9.3		5.8	6.1	6.1		5.60	5.48	5.34
2-S-CF	33.7				24.5				10.0				5.5				5.5			
2-S-12		30.4	32.8	29.5		24.9	23.2	24.1		10.0	9.7	10.3		5.3	5.4	5.9		5.62	5.68	5.62
2-S-13		30.4	31.4	29.1		25.4	24.6	25.2		10.3	9.6	10.5		5.1	5.5	5.3		5.76	5.80	5.60
2-S-14		30.0	30.6	29.4		23.8	23.4	25.3		10.6	10.5	9.8		5.0	5.4	5.7		5.86	5.66	5.54
2-S-15		30.6	35.3	29.4		24.9	22.4	24.4		9.4	9.0	9.8		5.1	5.0	5.4		5.72	5.62	5.56
2-S-16		32.7	35.6	30.9		24.4	22.9	23.7		9.1	8.7	10.0		4.7	4.8	5.2		5.60	5.58	5.58
2-S-17		32.5	32.3	26.9		25.4	25.0	25.7		8.9	8.6	9.2		4.9	5.0	5.7		5.58	5.62	5.64

[a]M = mix; F = mix analysis in field laboratory; L = mix analysis in central laboratory; C = core analysis in central laboratory.

[b]1 and 2 in first position = contractor; B = binder course; S = surface course; MF = original mix formula; CF = changed mix formula; digits in last position = lot number.

[c]Binder course.

[d]Surface course.

[e]No tests made.

Table 2. Deviations from target values based on mix and core extractions.

Contractor, Course, and Lot Number	Gradation and Asphalt Content	F and L Mix Target	Mean	Standard Deviation	Number	Core Target	Mean	Standard Deviation	Number
1-B-1, 2, 3, 4, 5	<1 in. >½ in.	21.5	24.0	1.48	10	17.5	19.3	1.96	4
	<No. 4 >No. 10	7.5	7.8	1.80	10	8.0	8.6	1.30	4
	<No. 40 >No. 80	12.4	10.0	0.88	10	12.6	10.8	1.01	4
	<No. 200	4.8	4.9	0.50	10	5.2	5.4	0.61	4
	Asphalt	4.80	4.65	0.18	10	4.80	4.76	0.17	4
1-B-6, 7, 8	<1 In. >½ in.	23.0	24.0	1.58	6	19.0	20.1	1.55	3
	<No. 4 >No. 10	7.5	8.1	2.47	6	8.0	8.5	2.06	3
	<No. 40 >No. 80	12.4	10.6	0.53	6	12.6	10.3	0.55	3
	<No. 200	4.8	4.9	0.45	6	5.2	5.3	0.35	3
	Asphalt	4.80	4.82	0.09	6	4.80	4.84	0.09	3
2-B-9, 10, 11, 12, 13, 14, 15, 16	<1 in. >½ in.	22.5	20.9	1.87	16	18.5	17.6	1.94	8
	<No. 4 >No. 10	13.9	11.9	0.95	16	14.4	12.1	1.02	8
	<No. 40 >No. 80	7.8	7.6	0.40	16	8.0	7.8	0.37	8
	<No. 200	4.8	5.5	0.55	16	5.2	5.7	0.42	8
	Asphalt	4.80	4.72	0.21	16	4.80	4.57	0.18	8
1-S-1, 2, 3, 4, 5, 6, 7, 8, 9	<½ in. >No. 4	38.7	39.1	1.97	18	36.3	36.0	1.90	9
	<No. 4 >No. 10	20.1	20.6	1.06	18	20.9	22.1	1.21	9
	<No. 40 >No. 80	12.1	10.2	0.28	18	12.0	10.2	0.25	9
	<No. 200	5.0	5.7	0.37	18	5.3	6.1	0.62	9
	Asphalt	5.30	5.26	0.10	18	5.24	5.34	0.04	9
2-S-10, 11	<½ in. >No. 4	33.7	32.2	1.37	4	31.3	30.9	1.0	2
	<No. 4 >No. 10	24.5	22.6	1.72	4	25.3	23.0	0.28	2
	<No. 40 >No. 80	8.1	9.2	0.18	4	8.0	9.2	0.21	2
	<No. 200	5.5	5.8	0.24	4	5.8	6.0	0.14	2
	Asphalt	5.50	5.54	0.09	4	5.44	5.37	0.04	2
2-S-12, 13, 14, 15, 16, 17	<½ in. >No. 4	33.7	32.1	1.88	12	31.3	29.2	1.29	6
	<No. 4 >No. 10	24.5	24.2	1.02	12	25.3	24.7	0.78	6
	<No. 40 >No. 80	10.0	9.5	0.70	12	9.9	9.3	0.45	6
	<No. 200	5.5	5.1	0.25	12	5.8	5.5	0.27	6
	Asphalt	5.50	5.68	0.09	12	5.44	5.59	0.04	6

contractor paved the other half. There were also changes in mix formulas. Although those changes were small, each change had to be approved by central laboratory staff.

Data given in Table 1 were used to prepare graphs of lot test data for the mix plotted as deviations from the target for each controlling sieve; Figures 1 and 2 show a typical plot. The percentages (110, 100, 90, 70 percent) on either side of the target values represent the payment percentage allotted the contractor for deviations from the target. These percentages were made to coincide with the sieve tolerances of 1, 2, 3, and 4 standard deviations. The contractor's unit bid price was adjusted by the lowest percentage payment indicated on any sieve or asphalt content for each lot. This percentage was averaged with the bid price adjustments for both density and thickness. In effect, each had a one-third effect on the unit price.

Table 2 gives the target, mean, and standard deviation values for all tests. It was decided to use the mean of all the mix extraction tests for comparison with the cores because this mean represents the best estimate of the mix (3). As expected, there was a shift in the core means from the mix means. The mean shift was computed for each sieve fraction and asphalt content per mix formula by averaging the differences between the mix means and their corresponding core means.

$$\text{Mean shift} = \left[\left(\overline{X}_{C1} - \overline{X}_{F1+L1}\right) + \left(\overline{X}_{C2} - \overline{X}_{F2+L2}\right) + \left(\overline{X}_{C3} - \overline{X}_{F3+L3}\right)\right]/3$$

For the binder course mix, <1-in. sieve and >½-in. sieve,

$$\text{Mean shift} = [(19.3 - 24.0) + (20.1 - 24.0) + (17.6 - 20.9)]/3$$
$$= -3.97$$

The mean shift from the mix for each type of core is as follows:

Sieve	Binder (percent)	Surface (percent)
<1 in. >½ in.	-4.0	
<½ in. >No. 4		-2.4
<No. 4 >No. 10	+0.5	+0.8
<No. 40 >No. 80	+0.2	-0.1
<No. 200	+0.4	+0.3
Asphalt content	0.0	-0.06

In the core data given in Table 2, the original mix formula has been adjusted by the preceding values to obtain an "adjusted target" for comparison to core extractions. Material passing the 1-in. sieve and retained on the ½-in. sieve for the binder course, for both contractors, showed the greatest variation between the mix and the cores. Because payment was based on the field extractions, there appeared to be, in some cases, as much difference between field and laboratory extractions as between field and core extractions. When there is a difference in pay based on the cores, it is usually 10 percent, which in essence would affect the contractor's pay only by 3.34 percent. For the material passing the ½-in. sieve and retained on the No. 4 sieve for the surface course, the correlation is somewhat better than that for the binder course, and, as previously indicated, testing variation accounts for some of the difference. The relationship is very good for the material passing the No. 4 sieve and retained on the No. 10 sieve for both the binder and surface courses. For the material passing the No. 40 sieve and retained on the No. 80 sieve, the figures are nearly identical for corresponding sets. Material passing the No. 200 sieve appears to have a very good correlation between the mix and cores. Except for an occasional sample that exhibited considerable variation between the mix and the cores, the correlation between mix and cores for the asphalt content is also good.

This study could have proved more enlightening if 4 cores had been taken from each location, one set extracted at the field laboratory and the other extracted at the central

Figure 1. Deviation from target values based on mix extraction (contractor 1, binder course, ⟨1-in. ⟩½-in. sieve).

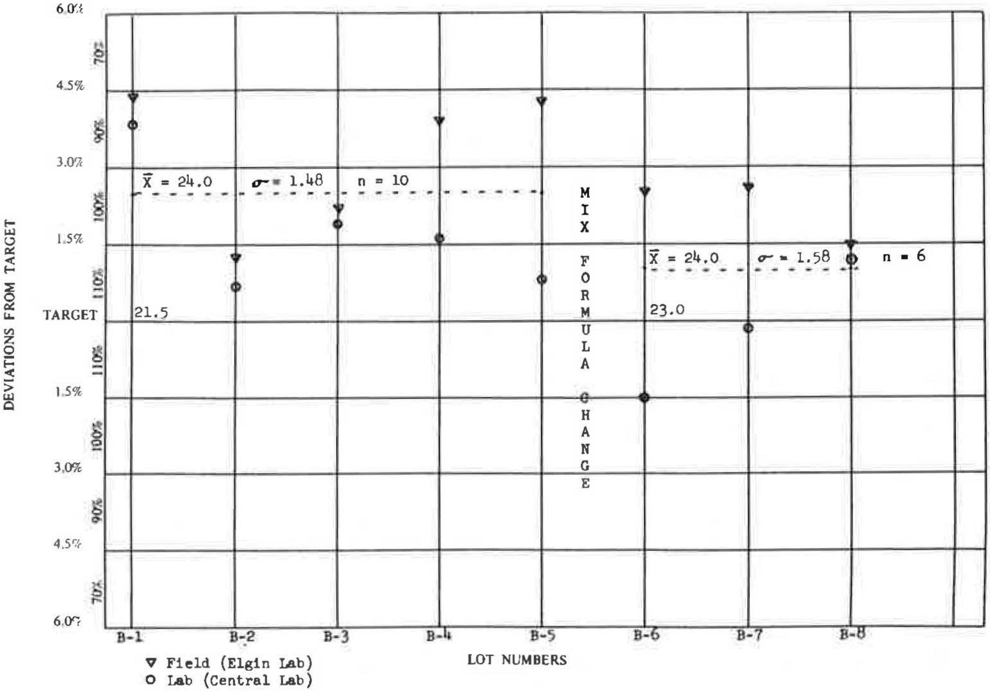
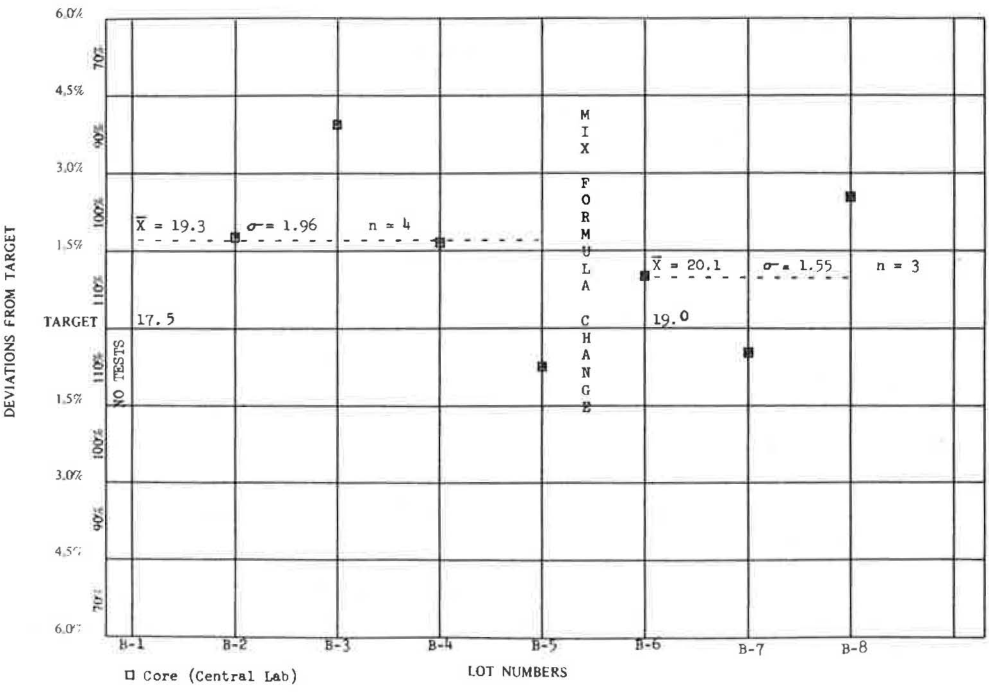


Figure 2. Deviation from target values based on core extraction (contractor 1, binder course, ⟨1-in. ⟩½-in. sieve).



laboratory. This would have given some indication of the core test variability as indicated with duplicate mix samples. Because the mix and the core samples were not of the same size or taken in the same location, we were very gratified with the results. In most cases the standard deviations for the cores were equal to or smaller than those for the mix, indicating very good uniformity.

CONCLUSIONS

The intent of this paper is to give engineers a practical tool for use in the analysis of existing bituminous pavements or a more convenient method of accepting bituminous mixtures whether by end-result or standard specifications. Based on the findings of this study, we offer the following conclusions:

1. Statistical methods of sampling and testing of pavement cores, based on 5 extraction samples per lot, should be as representative of the lot as the extraction of uncompacted mix provided certain adjustments are made;
2. A shift in target values, similar to those listed in this report, must be made when core extractions are equated to the mix formula;
3. The standard deviations for the extraction of the cores were about the same as or smaller than those for the extraction of the mix;
4. Deviations between the cores and the mix were, in some cases, no greater than between identical mix samples due to testing variations; and
5. One advantage of accepting the mix based on core extraction is that a recheck of the lot can be made by resampling when test values deviate excessively from target values.

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DISCUSSION

David G. Tunnicliff, Warren Brothers Company

Gorman has presented a very useful and timely analysis of the use of core samples for purposes of acceptance of gradation and asphalt content of bituminous mixtures. Although core samples are used for this purpose, reliable data, such as Gorman's, on what to expect from cores have not been readily available. Three points deserve additional consideration.

1. The concept of a mean shift is both correct and necessary if acceptance of gradation and asphalt content is to be based on extraction of core samples. The question that remains is, What should the magnitude of the mean shift be? Mean shifts developed in this study are not questioned, but can they be used on another project? If not, how can the correct mean shift for another project be established? The correct magnitude of mean shift probably depends on a number of variables including aggregate gradation and type, asphalt content, pavement thickness, core diameter, and sampling and testing techniques.

2. A mean shift might not be necessary if different sampling were used. Gorman indicates that mean shift is necessary primarily because the larger aggregate sizes are cut during the coring operation. If larger diameter cores or larger sawed rectangles were used, then the proportion of cut particles in the sample would be reduced, and the need for mean shift might be eliminated. For example, personal experience indicates that mean shift for 6-in. diameter cores would be small, perhaps insignificant, on the surface mixture. Yet, the sample obtained by a 6-in. diameter core is much smaller than required by AASHO T168.

3. Gorman notes that the usual difference in the contractor's pay based on cores would be 3.34 percent compared to pay based on field extractions. Although 3.34 percent of the bid price may seem to be a reasonably small penalty or bonus, as the case may be, actually it is not. A 3.34 percent penalty is deducted from the contractor's profit if he is operating at a profit, and it might represent something like a third or more of his expected return on his investment in the lot. Otherwise, it means either no profit at all or a loss.

In the case at hand, the penalty would be solely the result of core sampling, rather than production of inferior materials. In order to stay in business the contractor must either bid high enough to cover this contingency or expect enough unearned bonuses, solely the result of core sampling, to balance the loss from undeserved penalties. Acceptance methods that tend to minimize both the rejection of acceptable materials and the acceptance of inferior materials are needed. It is not clear that core samples do this, but the cost of incorrect rejection or acceptance can be significant.

AUTHOR'S CLOSURE

I agree that the mean shifts used in this paper do not necessarily apply to mixes other than those used by these 2 contractors. We plan to conduct the same study with other mixes that include the variables that Tunnicliff mentions.

Six-in. cores or large samples sawed from the pavement should lessen, as he suggests, the need for a mean shift. We used 4-in. cores because samples of this size are compatible with our present testing equipment.

As stated previously, we plan to conduct an extensive study of core extractions versus mix extractions on future jobs. Before one acceptance procedure is used to replace another, we will have to assure ourselves that both methods will give the same results whether we have to change sample sizes or adjust our specification tolerance to account for degradation or do both.