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Investigation of Premature Distress in Asphalt Overlays on IH-70 in Colorado

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Cooperative Applied Research
Performed Jointly by:

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This report summarizes the results of a one-year effort to investigate an instance of substandard asphalt pavement performance on IH-70 in eastern Colorado. When the problem was identified, the Colorado DOT and Asphalt Institute agreed to jointly analyze the cause of the distress. The main goal of this effort was to determine the cause(s) of the distress so that CDOT engineers could make more informed decisions regarding possible material and specification changes to enhance asphalt pavement performance.

Although considerable industry attention was focused on the damaged project and on this study, a relatively small core of individuals was assembled to perform this analysis. Management and technical direction of this study was provided by Dr. Scott Shuler, AI Director of Research and Mr. Denis Donnelley, CDOT State Materials Engineer. An important effort was also contributed by CDOT, Aurora District personnel, Messrs. Gerald Peterson and Jay Goldbaum in collecting project mix design and construction information. The authors performed the bulk of the experimental design and analysis of results. The conclusions and recommendations herein contained reflect a consensus of opinion of this group.

BACKGROUND

In the Fall of 1990, the Colorado Department of Highways (CDOT) rehabilitated a 12-mile, rural portion of IH-70 east of Limon, Colorado from mileposts 368 to 380. The overlay consisted of varying thickness of surface and binder courses in the ranges of 1-1/2 to 2 inches and 1-1/4 to 3-3/4, inches respectively. Where necessary, a thin, rut filling, levelling course was placed on the existing surface.

During the spring and early summer of 1991, the eastern portion of the overlay (westbound lanes) began to exhibit distress (Appendix A). The distress was manifested by channelized rutting. By July 1991, disintegration became evident. Personnel from the CDOT, Asphalt Institute (AI), and other asphalt industry officials in Colorado visited the project and concluded that the overlay structure exhibited distress consistent with moisture damage to asphalt concrete, otherwise known as "stripping." In the presence of moisture, the bond between asphalt cement and aggregate had been interrupted. The resulting mixture lacked cohesion and shear strength.

Distress exhibited by the IH-70 overlay had been a sporadic, but persistent problem on other projects in Colorado. On this basis, a joint study was undertaken by CDOT and the Asphalt Institute. The aim of the study was to closely examine the materials and procedures used on the IH-70 project and determine the factors and circumstances that caused the stripping failure. A principal element was to rapidly develop information that could be used by CDOT to develop procedures and specifications that would ensure satisfactory performance of asphalt mixtures in Colorado.

To accomplish these goals, a work plan was developed as follows:

- Task 1 - Collect and Analyze Project Data
- Task 2 - Collect and Analyze Project Materials
- Task 3 - Conduct Moisture Susceptibility Testing
- Task 4 - Joint Analysis of Information; Conclusions and Recommendations

As the investigation was performed, information was circulated among interested parties and two meetings were held to discuss intermediate results of the testing program. A preliminary report was prepared by AI and summarized information gathered in Tasks 1 through 3. Analysis of the preliminary report constituted Task 4. This report is a final summary of Tasks 1 through 4. It lists conclusions and recommendations that reflect the consensus of the Asphalt Institute and CDOT

PROJECT INFORMATION

This information was submitted by CDOT personnel to the Asphalt Institute for analysis. It consisted of preliminary design information, materials and mix design data, and a thorough summary of quality control test results.

Preliminary Design Information

This information consisted of project-specific data that was used by CDOT engineers to develop overlay thickness and materials recommendations. Project records indicated an average daily traffic (ADT) of 5,650. Truck and lane distribution factors applied by CDOT to this ADT resulted in more than 2 million 18kip equivalent single axle loads over a ten year design period.

The location of the project, MP 368 to 380 spanned several separate projects constructed between 1973 and 1975. Overlay design and materials selection was separated into three segments that exhibited similar pavement sections and patterns of performance. Considerable information was collected for these three sections by the Aurora District of CDOT. Visual observations of pavement performance were made. In addition, a falling weight deflectometer survey and component analysis were performed throughout the project. Based on these observations, a recommended overlay strategy was developed for each segment. Table 1 presents a brief summary of this information.

Prior to the overlay, transverse cracking was evident. Severe rutting was evident from MP 373 through 380 in both directions. Interestingly, one of the observations of those who performed the visual condition survey was, "....moderate stripping of the existing pavement (was observed). Knowledgeable observers have noted this stripping took place in the first year of pavement life." Evidently, CDOT maintenance forces had been very successful in keeping the pavement serviceable with thin, patch-type overlays.

The plans for the IH-70 project indicate that the recommended overlay strategy was largely followed. One difference was a change in levelling material from Grade EX to Grade CX. For two of the westbound segments, MP 373 to 377.5 and MP 377.5 to 380.0, the binder course of Grade C (rubberized) was changed to Grade C (i.e., same mix type but without modified asphalt cement). However, the total overlay thickness was as recommended. A summary of actual overlay materials and thickness is listed in Table 2.

Mix Design Information

After the project was awarded, the contractor submitted component material properties and a proposed mix design to the CDOT for analysis and approval. This process was completed for the four asphalt mixtures used on the project: Grade CX levelling course, Grade G binder course, Grade C binder course, and Grade C (rubberized) surface course. Tables 3, 4, and 5 present a summary of mix design information for these materials. Figure 1 shows the gradations of the final blends of the component aggregates for these mixtures.

TABLE 1. Summary of Preliminary Design Information, IH-70

Section	Performance Observations	Rehabilitation Recommendations
368.0-373.0	Moderate stripping in surface layer; surface looks dry and oxidized; extensive cracking throughout; thin surface patches observed and performing well.	Use heavy tack coat of 0.10 to 0.15 gal/sy over section; overlay with 2.0 inches of Grade C (rubberized).
373.0-377.5	Severe rutting in driving and passing lanes; minor cracking; moderate to severe stripping in WBL; thin surface patches observed and performing well.	EBL and WBL levelling course with Grade EX. EBL overlay with 3.25 inches of Grade G and 2.0 inches of Grade C(rubberized). WBL overlay with 2.75 inches of Grade C(rubberized).
377.5-380.0	Severe rutting and bleeding in driving and passing lane of EBL. Thin patches in EBL to correct rutting. Severe rutting in WBL driving lane and minor cracking.	EBL and WBL levelling course with Grade EX. EBL overlay with 3.75 inches of Grade G and 2.0 inches of Grade C(rubberized). WBL overlay with 3.5 inches of Grade C(rubberized).

Notes:

1. Overlay thickness recommendations were determined by using falling weight deflectometer and component analyses of the existing pavement sections. For each section, the thickness was calculated on the basis of these two methods. The recommended thickness was the largest value developed using these two methods.
2. All sections required crack filling prior to overlay.
3. All gradings correspond to CDOT specifications.
4. Grade "C(rubberized)" is a standard CDOT grading C with AC-20 asphalt cement modified using SBR latex.
5. Unless otherwise noted, required tack coat was 0.07 gal/sy.

TABLE 2. Design Recommendations for Rehabilitation, IH-70

Segment	Lane	Materials and Thickness
368 - 373	EB	2 inches of Grade C (rubberized) total overlay thickness
	WB	2 inches of Grade C (rubberized) total overlay thickness
373 - 377.5	EB	2 inches of Grade C (rubberized) 3-1/4 inches of Grade G 5-1/4 inches total overlay thickness + CX levelup
	WB	1-1/2 inches of Grade C (rubberized) 1-1/4 inches of Grade C 2-3/4 inches total overlay thickness + CX levelup
377.5 - 380	EB	2 inches of Grade C (rubberized) 3-3/4 inches of Grade G 5-3/4 inches total overlay thickness + CX levelup
	WB	2 inches of Grade C (rubberized) 1-1/2 inches of Grade C 3-1/2 inches total overlay thickness + CX levelup

TABLE 3. Mix Design Data for Grade C (rubberized) Surface and C Binder, IH-70

Sieve Interval	Component Percent Passing			Job-Mix	
	Spec Agg	Cr Fines	Monk Sand	Formula	Specifications
Blend (%)	30	50	20	100	
3/4"	100	100	100	100	100
1/2"	64	100	100	89	70-98
3/8"	31	100	99	79	60-88
No. 4	6	81	91	61	44-72
No. 8	4	57	69	44	30-58
No. 16	2	42	43	30	
No. 30	2	32	23	21	
No. 50	2	23	5	13	7-27
No. 100	1	16	2	9	
No. 200	1	10.9	1.3	6.0	3-12

Aggregate Properties:

Bulk Specific Gravity = 2.644 Effective Specific Gravity = 2.685
L. A. Abrasion = 23.1 Fractured Faces = 95.4% two or more

Mixture Properties at Design Asphat Content of 5.4%:

Unit Weight = 149 pcf VMA = 14.5 %
Air Voids = 3.4 % Hveem Stability = 38
Maximum Theoretical Specific Gravity = 2.473

Moisture Susceptibility Properties at 5.5% Asphalt:

Additive Used = 0.5% "Pavebond Special" for C (rubberized) Surface and
0.5% "Unichem 8163" for C Binder
Conditioned Tensile Strength = 43.7 psi
Unconditioned Tensile Strength = 51.6 psi
Air Voids = 6.0 %
Permeable Voids = 4.4 %
Degree of Saturation = 66.9 %
Tensile Strength Ratio = 84.7 %

Asphalt Cement: AC-20 modified with SBR latex for C (rubberized) Surface; AC-20 for C Binder;
Specific Gravity = 1.030

TABLE 4. Mix Design Data for Grade G Binder, IH-70

Sieve Interval	Component Percent Passing 1-1/2" Sp Agg	3/4" Sp Agg	Cr Fines	Monk Sand	Job-Mix Formula	Specifications
Blend(%)	35	15	40	10	100	
1-1/2"	99	100	100	100	100	100
1"	69	100	100	100	89	
3/4"	28	99	100	100	75	66-82
5/8"	15	77	100	100	67	
1/2"	5	55	100	100	60	53-69
3/8"	3	21	100	100	54	
No. 4	2	3	85	100	45	36-52
No. 8	0	0	65	78	34	25-37
No. 16	0	0	49	50	25	
No. 30	0	0	39	26	18	10-22
No. 50	0	0	29	6	12	
No. 100	0	0	21	2	9	
No. 200	0	0	14	1.6	5.8	2-8

(NOTE: Monk Sand scalped on No. 4 sieve.)

Mixture Properties at Design Asphat Content of 4.5%:

Unit Weight = 151.9 pcf   VMA = 14.1 %
Air Voids = 3.2 %   Voids Filled with Asphalt = 77 %
Maximum Theoretical Specific Gravity = 2.515

Moisture Susceptibility Properties at 4.7% Asphalt:

Additive Used = 0.5% "Unichem 8162"
Conditioned Tensile Strength = 38.8 psi
Unconditioned Tensile Strength = 46.4 psi
Air Voids = 7.4 %
Permeable Voids = 5.2 %
Tensile Strength Ratio = 83.5 %

Asphalt Cement: AC-20; Specific Gravity = 1.030

TABLE 5. Mix Design Data for Grade CX Levelling Course, IH-70

	Component Percent Passing					
Sieve Interval	1/2"-dust Spec Agg	1/2" Sp Agg	Cr Fines	Monk Sand	Job-Mix Formula	Specifications
Blend(%)	35	15	35	15	100	
1/2"	100	99	100	100	100	100
3/8"	87	64	100	99	90	74-95
No. 4	52	7	84	90	62	50-78
No. 8	38	3	61	70	46	32-60
No. 16	28	3	45	45	33	
No. 30	22	2	34	23	23	12-34
No. 50	16	2	25	5	16	
No. 100	12	2	17	2	11	
No. 200	8.0	1.6	11.7	1.4	7.3	3-12

Mixture Properties at Design Asphat Content of 6.0%:

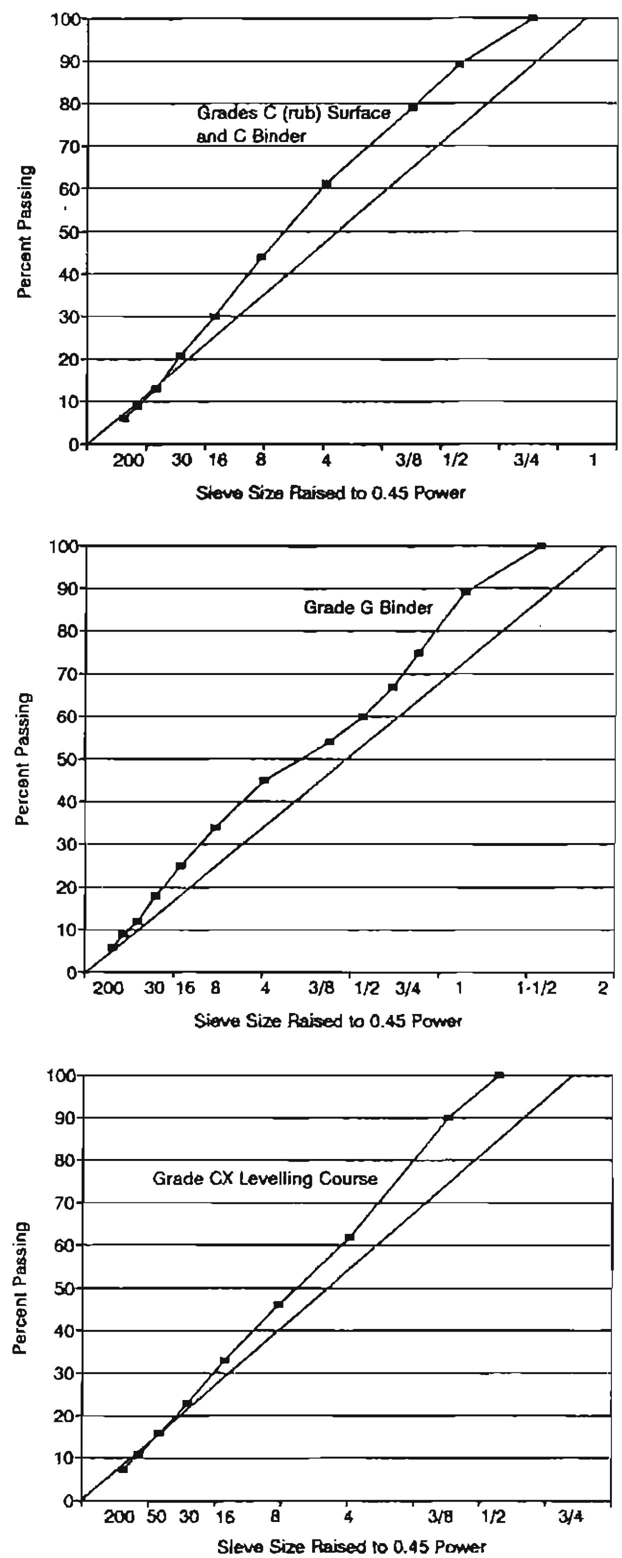
Unit Weight = 148.0 pcf
Hveem Stability = 39
Air Voids = 3.7 %
Aggr Effective Specific Gravity = 2.697
Maximum Theoretical Specific Gravity = 2.461

Moisture Susceptibility Properties at 6.0% Asphalt:

Additive Used = 0.5% "Unichem 8162"
Conditioned Tensile Strength = 43.2 psi
Unconditioned Tensile Strength = 43.6 psi
Air Voids = 6.0 %
Permeable Voids = 4.8 %
Tensile Strength Ratio = 99.1 %

Asphalt Cement: AC-20F; Specific Gravity = 1.040

Figure 1. Job-Mix Formula Gradations for Overlay Materials, IH-70



Analysis of C (rubberized) and C Mixtures

For Types C (rubberized) and C, the mix designs were almost the same. The same component aggregates were used in the same percentages. The principal difference between these two mixtures was that the C (rubberized) mix consisted of an AC-20 modified with SBR latex whereas the AC-20 asphalt cement in the C mix was not modified. The source of the AC-20 asphalt was the same although the SBR-modified asphalt was passed through a separate blending company prior to use. Both designs contained a chemical antistripping additive. However, the C (rubberized) mix used "Pavebond Special" while the C mix used "Unichem 8163."

The gradation of the combined aggregate for the C mixtures appears acceptable when compared with the maximum density gradation (Fig 1). The mixture was well graded, primarily on the fine side of the maximum density gradation, with no gaps. With 44 percent passing the No. 8 sieve, the mixture might be considered slightly fine, although not overly so.

The C (rubberized) and C aggregate possessed a high number of fractured faces at 95.4 percent. Resistance to wear was also very high with an L.A. abrasion loss value of 23.1 percent. This is much less than the maximum allowable percent wear of 45 used by CDOT and many other states.

At the design asphalt content, 5.4 percent, the C mixtures had 3.4 percent air voids. This asphalt content, 5.4 percent, corresponded to the minimum acceptable master range value allowed by CDOT specifications at the time. The VMA was 14.5 percent, which is higher than the minimum allowable of 12.4 percent according to the Asphalt Institute (Ref 1.) However, 77 percent of the VMA was filled with asphalt, which is slightly outside of the acceptable range of 65 to 75 percent for more heavily trafficked pavements (Ref 1) and suggests that the C mixtures were slightly overasphalted. It should be noted that all VMA values were calculated using aggregate bulk specific gravity which is in accordance with Asphalt Institute and most other established industry standards.

Moisture susceptibility testing performed by the contractor (CDOT Method L-5109) indicated a passing tensile strength ratio (TSR) of about 85 percent. Project records showed two chemical antistripping additives were used: "Pavebond Special" for the C (rubberized) mixture and "Unichem 8163" for the C mixture. Unfortunately, only one set of moisture susceptibility test results was provided by the contractor. The chronological sequence of mix design test results suggests that the stripping test was performed using "Unichem 8163" and not the "Pavebond Special." As such, no effort was made, during the mix design stage, to verify the effectiveness of the "Pavebond Special" with the designed mix.

Analysis of G Binder Mixture

The binder course consisting of Grade G (Fig 1) is slightly gap graded. Practically the entire gradation exists on the fine side of the maximum density gradation. Of the fine fraction between about the No. 4 and No. 200 sieve, the gradation is slightly deficient in the material between the No. 4 and No. 30 sieve.

At the design asphalt content, 4.5 percent, the air void content was 3.2 percent, a value in the lower end of the normally accepted range of 3 to 5 percent. At this asphalt content the VMA, 14.1 percent, was much higher than 10.2 percent, the minimum acceptable value according to the Asphalt Institute (Ref 1). The percent of VMA filled with asphalt was high at 77 percent.

Moisture susceptibility tests showed a very high TSR in excess of 80 percent. A chemical antistripping additive, "Unichem 8162," was used. Although the TSR was in excess of the minimum requirement, the tensile strength values, approximately 40 psi, were on the low side of the range normally expected. CDOT engineers indicated that such values are common and consistent with the relatively slow loading rate (0.2 inches per minute) in CDOT Method 5109.

<u>Analysis of CX Mixture</u>

The Grade CX rut filling course (Fig 1) is very dense. Its gradation plots in a straight line on the fine side of the maximum density gradation. Because this mixture was expected to be placed in very thin lifts, mostly less than 1-inch, it was designed to be entirely finer than 1/2-inch. If covered immediately by a binder or wearing course, it would likely serve its only intended function: rut filling and levelling.

At the design asphalt content, 6.0 percent, the air void content was 3.7 percent. In the design furnished by the contractor, no VMA was reported. In addition, VMA could not be calculated from this information since no aggregate bulk specific gravity was reported. Information provided by CDOT suggested that the combined aggregate bulk specific gravity was about 2.63. Using this value, VMA and percent voids filled are 15.3 and 75.8, respectively, both reasonable values when compared to Asphalt Institute criteria (Ref 1) and considering what was expected of the CX mixture.

The Hveem stability value was reported to be 39 at the design asphalt content. A TSR of close to 100 percent was reported using "Unichem 8162." Tensile strength values exhibited the same trend at about 43 psi.

Quality Control Test Results

No information was provided that tracked the characteristics of the Grade CX mix, as produced. Examination of project records indicate it was most likely placed during the latter half of September 1990. CDOT exercises less control over thin, rut filling courses. According to CDOT, no in-place density checks were made; however, construction of such layers is closely monitored by visual inspection.

Analysis of Construction Sequence

All binder and surface courses were placed between October 1 and November 29, 1990. Figure 2 shows a plan view of the project showing the location where each mixture type was placed. Figure 3 shows the sequence of placement.

Construction began at the eastern end of the project in the westbound lane. The Grade C binder course was placed from MP 380 to 373 continuously during the period from October 1 to 4. On October 5, the crews went back to MP 380 and began covering the Grade C binder with Grade C (rubberized) surface. They continued past MP 373 and completed overlay operations in the westbound lane with the exception of a 2800-foot undisclosed section. This section was subsequently overlaid on November 29, the final day of construction.

Eastbound construction began on October 22 at MP 368. It took three days for the contractor to place the C (rubberized) surface from MP 368 to 373. From October 26 through November 20, the contractor intermittently placed Grade G binder and Grade C (rubberized) surface from MP 373 to 380. The intermittent placement of these binder and surface courses suggests that the fresh binder course would not be exposed for extended periods to the effects of weather and traffic.

Analysis of Contractor Quality Control Test Results

On the IH-70 project, materials were tested by the contractor at intervals specified by CDOT. These tests included belt sample gradations, asphalt content using a nuclear gauge, and in-place density measured by a nuclear density gauge. Following approval of the contractor's mix design, CDOT verified that the design properties were achieved. At frequent intervals, CDOT also performed independent assurance tests to verify the contractor's quality control tests. Figures 4, 5, and 6 graphically summarize the contractor quality control test results. Appendix C provides a tabular version of this data.

C (rubberized) Surface. Figure 4 illustrates contractor quality control test results for the C (rubberized) surface. The percent passing the No. 200 sieve (P200) averaged 7.2 percent, which is 1.2 percent higher than the design value of 6.0 percent. For over 120 test results, the asphalt content averaged 5.5 percent, about 0.1 percent higher than the design value of 5.4 percent. Figure 4 indicates that there was a high degree of control on asphalt content of the as-produced asphalt mixture. The in-place density of the C (rubberized) surface averaged over 93 percent of maximum theoretical density. No test result was below 92 percent, a typical industry standard.

G Binder. Figure 5 illustrates contractor quality control test results for the G binder course. As produced, this asphalt mixture did not possess significantly more P200 than the design value. Twenty test results showed the P200 to average about 6.1 percent as compared to the design value of 5.8 percent. The average asphalt content shown by the test results in Fig 5, 4.64 percent, was practically the same as the design value, 4.65

Figure 2. Locations of Overlay Components, IH-70

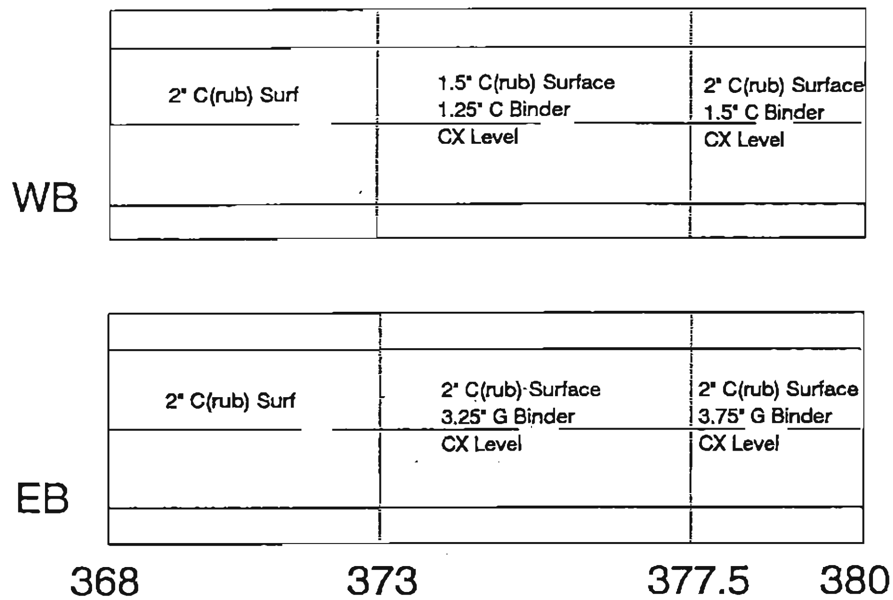


Figure 3. Construction Sequence, IH-70

Sun	Mon	Tues	Wed	Thurs	Fri	Sat
	OCT 1 C-bind WB	2 C-bind WB	3 C-bind WB	4 C-bind WB	5 C-surf WB	6 C-surf WB
7	8	9	10 C-surf WB	11	12 C-surf WB	13 C-surf WB
14 C-surf WB	15 C-surf WB	16 C-surf WB	17	18 C-surf WB	19	20
21	22 C-surf EB	23 C-surf EB	24 C-surf EB	25	26 G-bind EB	27 G-bind EB
28 G-bind EB	29 C-surf EB	30	31 C-surf EB	NOV 1 C-surf EB	2	3
4	5 G-bind EB	6	7	8 G-bind EB	9	10 G-bind EB
11	12 G-bind EB	13 C-surf EB	14	15	16 G-bind EB	17 G-bind EB
18	19 C-surf EB	20 C-surf EB	21	22	23	24
25	26	27	28	29 C-surf WB	30	

(Source: Quality control charts for IH-70 project.)

Figure 4. Quality Control Test Results for C (rub) Surface Course, IH-70

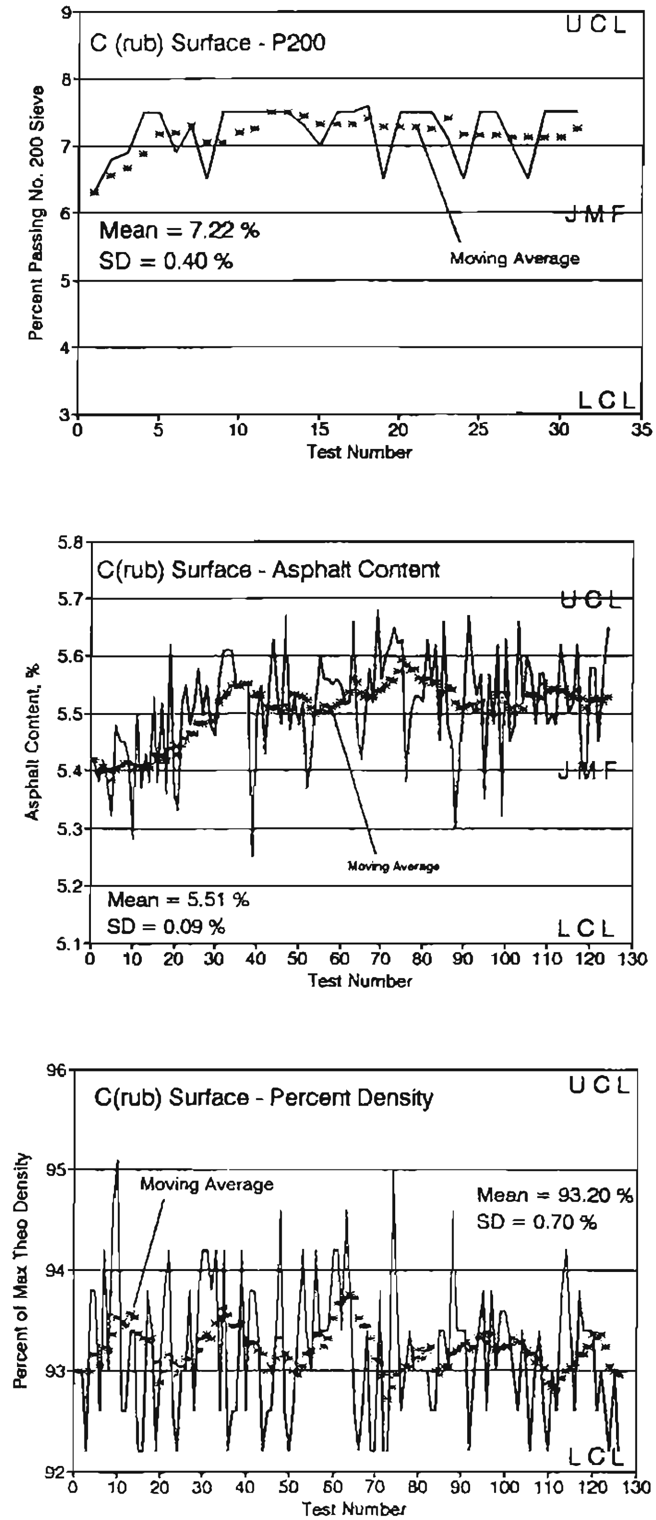


Figure 5. Quality Control Test Results for G Binder Course, IH-70

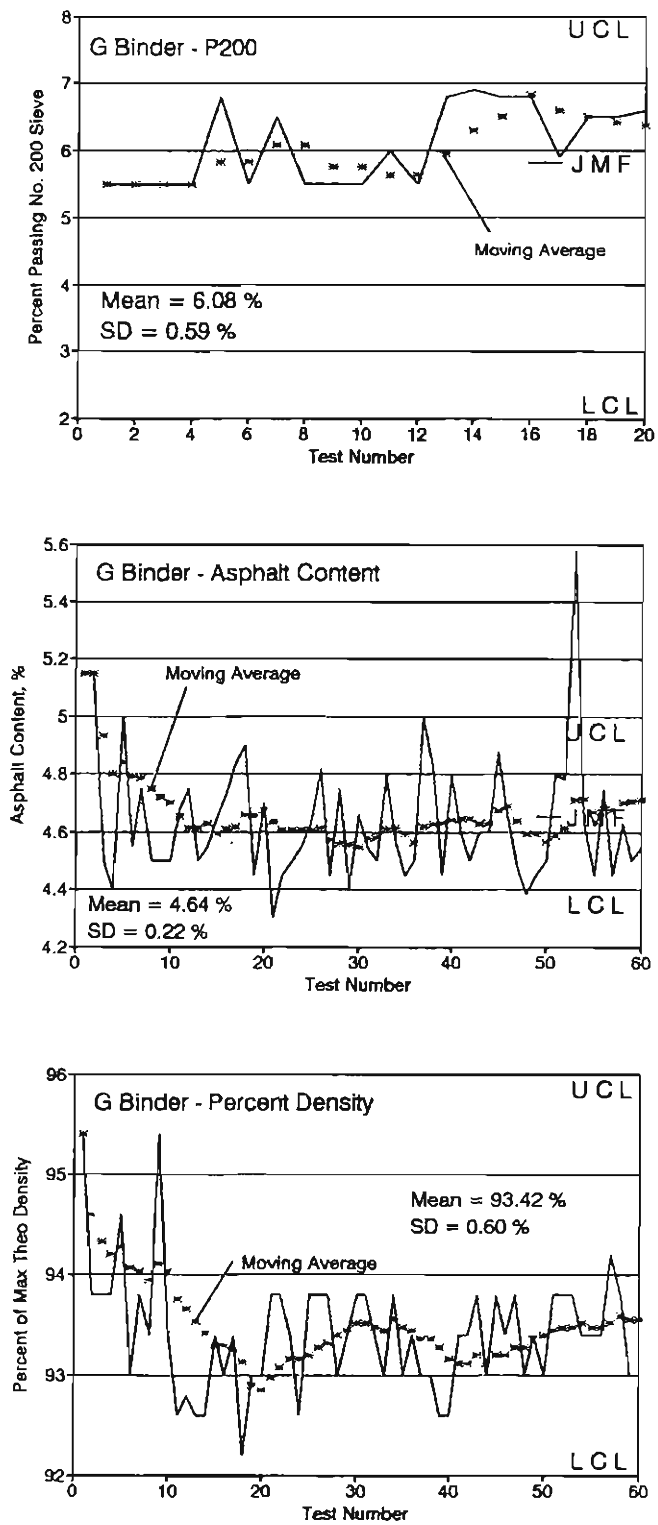
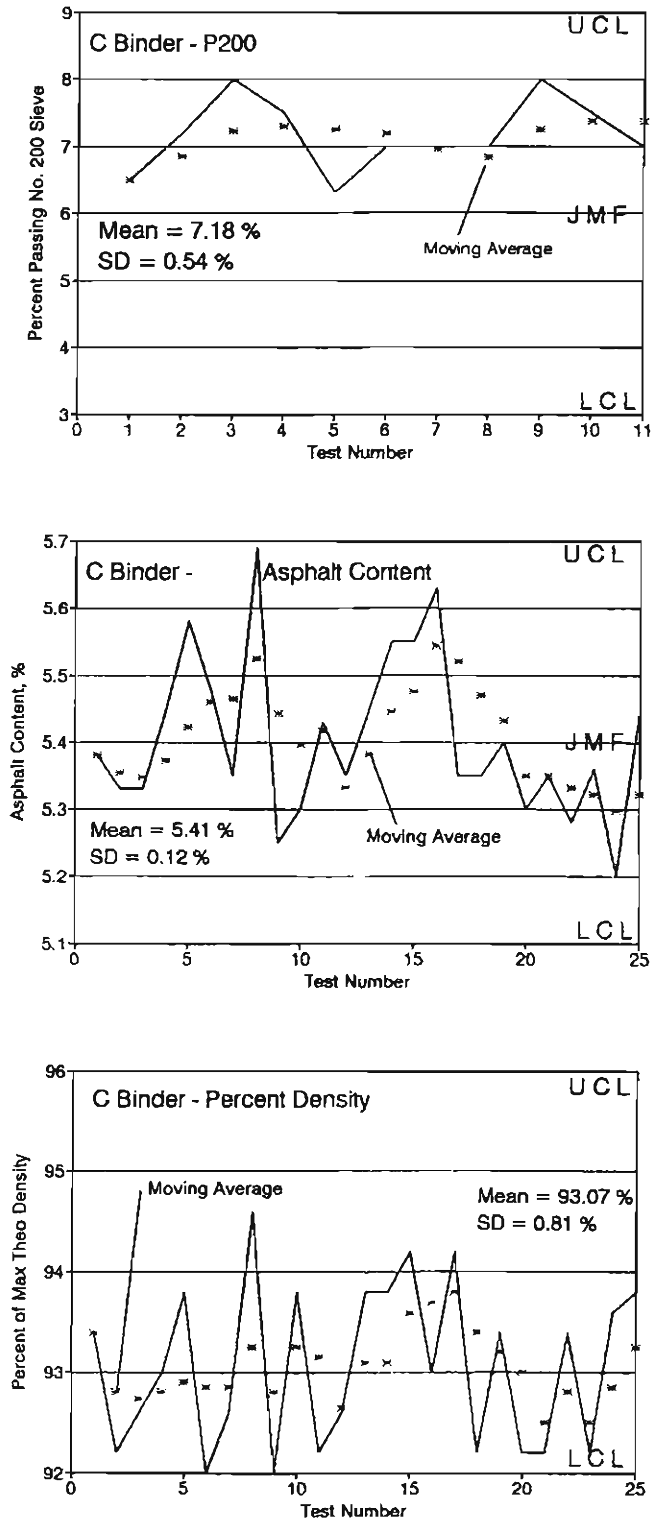


Figure 6. Quality Control Test Results for C Binder Course, IH-70



percent. In-place density averaged over 93 percent.

C Binder. Contractor quality control test results are shown in Fig 6. Test results on the C binder course exhibited similar trends to the C (rubberized) surface. The P200 averaged about 7.2 percent which is 1.2 percent higher than the design value, 6.0 percent. The measured asphalt content was identical to the design value, both at 5.4 percent. In-place density averaged over 93 percent.

Comments on Contractor Quality Control Test Results. There are two notable observations concerning the quality control data presented in Figs 4 through 6. First, no values exceeded the upper or lower control limits (UCL or LCL). In almost 500 quality control tests, no parameter (asphalt content, P200, or in-place density) was out of specifications. Based only on these test results, the contractor exercised considerable control of asphalt mixture production. CDOT engineers indicated they were impressed with the quality control of the contractor.

Second, the P200 for the C (rubberized) surface and C binder courses trended over one percent higher than design. Such gains in P200 are well recognized by asphalt technologists (Ref 2) and in all cases were within the control limits. Nevertheless, a consistent excess of P200, in the range of seven to eight percent, is undesirable (see following paragraphs for explanation of this hypothesis). If the P200 is ultrafine, e.g., mostly less than 10 microns, it would function as an asphalt extender, thus, facilitating a plastic asphalt mixture. Conversely, if the P200 is coarse, e.g., mostly greater than 10 microns, it would function as an asphalt blotter, thus creating a dry, uncohesive mixture prone to durability problems. It should also be noted that the P200 values were the result of belt sample gradations, identifying material properties before plant mixing. According to Ref 2, it is likely that plant mixing would further increase the P200 content.

The maximum tolerable amount of P200 in an asphalt mixture is a difficult quantity to establish. Work by Anderson (Refs 3, 4, and 5) is the most recent, comprehensive study on the effect of very fine aggregate on asphalt mixture properties. In these references, Anderson recommends that a maximum dust to asphalt ratio (weight basis) in the range of 1.2 to 1.5 be used. For a given mixture, this ratio would establish the maximum tolerable amount of P200. For example, the C (rubberized) surface had an average asphalt content and P200 of 5.51 and 7.22 percent. These result in a dust to asphalt ratio of 1.24 [(1-0.0551)(0.072)/0.0551]. Thus, the amount of P200 in the C (rubberized) surface averaged very close to the maximum tolerable amount.

In his research, Anderson cautions (Ref 4) that when high percentages of fine dusts are present, "mix properties can be very sensitive to changes in asphalt content." He further states (Ref 5) that his maximum recommended dust to asphalt ratio was developed using asphalt mixtures that had been designed to allow for additional dust and that otherwise, "increasing the dust content might have had a much greater effect."

It should be noted that even after considerable research, Anderson still listed a range of maximum dust to asphalt ratios. He indicates (Ref 3) that gradation of dust alone is not enough to characterize the effect of P200 on mixture properties and that "physico-chemical interactions" may also be present. The Federal Highway Administration (Ref 6) has developed a guideline that states the maximum dust to asphalt ratio should be 1.2.

Although it is difficult to firmly establish a maximum amount of P200 that will apply to all materials and pavements in a given region, the dust to asphalt ratio offers the best and most accepted approach at present. In fact, dust to asphalt ratios for the IH-70 project were generally higher than the FHWA guideline for the C mixtures. Based on observations from this project, the authors believe that the consistent excess of P200 was a causative factor in the distress that has become apparent and may become apparent in the future.

Analysis of CDOT Quality Assurance Tests

Although the contractor on the IH-70 project performed the principal quality control duties, CDOT performed a limited number of tests to measure the veracity of the contractor's quality control program and test results. During this investigation, no information was presented that indicated any compositional, volumetric, or stability checks on the Grade CX rut filling course. Table 6 summarizes CDOT quality assurance test results for the C (rubberized) surface, C binder, and G binder.

Test results for the C (rubberized) surface agree very closely with contractor quality control tests for asphalt content and P200. Average air void content was 3.8 percent. Hveem stability averaged 34 which is less than the design minimum of 37.

CDOT performs moisture susceptibility tests on plant-produced materials. Results of these tests in Table 6 closely agree with the same tests during the design phase. The average TSR for the C (rubberized) mixture, 83 percent, is above the specified minimum. Only one test result, 58 percent, indicated a low TSR.

There were relatively few independent assurance tests for the C and G binder courses. Once again, asphalt content and P200 mostly agreed with contractor test values; however, the average P200 for the C binder was somewhat higher at 7.6 percent. The average Hveem stability for the C binder was 37. No air void or Hveem stability values were reported for the G binder course.

TSR values for the C binder were all in excess of 80 percent. Two of the four field TSR values for the G binder were below specified minimums.

The most notable CDOT test result was the relatively low Hveem stability values for the C (rubberized) surface. CDOT engineers have observed that rubberized mixtures tend to exhibit lower Hveem stability values than identical, unmodified mixtures. As such,

TABLE 6. Summary of CDOT Quality Assurance Tests, IH-70

Mix		Asphalt Content	P(200)	Air Voids	Moisture Damage Tests St(wet)	St(dry)	TSR	Hveem Stability
C (rub)		5.32	6.9	3.9	35	46	75	36
Surface		5.38	6.6	4.1	37	38	97	33
		5.25	7.2	3.1	37	40	91	30
		5.36	7.4	4.9	36	43	83	34
		5.50	6.9	3.7	40	36	111	34
		5.64	6.6	3.9	35	43	81	32
		5.55	6.4	3.0	31	38	80	37
		5.45	7.5	4.1	29	50	58	38
	Avg	5.43	6.9	3.8	35	42	83	34
C Binder		5.46	7.9	2.1	34	41	81	38
		5.30	7.6	4.6	37	45	82	35
		5.36	7.3	4.6	41	50	83	37
	Avg	5.37	7.6	3.8	37	45	82	37
G Binder		5.49	5.6	-	28	43	66	-
		4.70	5.3	-	28	30	92	-
		4.80	6.5	-	30	29	105	-
		4.78	6.6	-	19	36	52	-
	Avg	4.94	6.0	-	26	35	76	-

Notes:

1. Asphalt content percent by weight of total mix
2. P(200) percent by weight of aggregate
3. Air Voids percent by weight of total volume of mix
4. St(wet) is conditioned tensile strength in psi
5. St(dry) is unconditioned tensile strength in psi
6. Tensile Strength Ratio (TSR) is [St(wet)/St(dry)]x100%

their local experience indicated that the borderline low stabilities were not a cause for concern.

The other notable feature of the CDOT test results is the low TSRs for the G binder course. TSR values for the G binder course were highly variable with two of four values lower than desired. These values suggest that the G binder course was, at times, moisture susceptible.

One perplexing aspect of the CDOT test results is the relatively high air void content for the C (rubberized) and C mixtures shown in Table 6. The mix design for these two materials indicated an air void content of 3.4 percent at the design asphalt content of 5.4 percent. However, the P200 during design was about 1 percent lower than what was actually produced and measured by both CDOT and the contractor on cold feed belt samples. Recent findings by the FHWA (Ref 2) would have suggested a corresponding decay in air voids with this increase in P200 at the same asphalt content.

Because of this anomaly, an analysis was performed to test the veracity of the air void data presented in Table 6. Figure 7 illustrates a plot of theoretical maximum specific gravity (TMSG) versus asphalt content for the C (rubberized) and C mixtures. The solid line represents the design relationship evident from trial mix specimens and the "+" symbol represents the job-mix formula. Five of the independent assurance test results plot exactly on the design line. This is the expected relationship. Five other points plot in an exact parallel straight line, approximately 0.031 above the design line. One point does not plot in either group of data.

A possible explanation of this data is that a consistent error was made in the TMSG test for one of the two groups of data, either the upper or lower. The upper points exhibit exactly the same change in TMSG with asphalt content but with a TMSG that is higher, by 0.031. The possible net result of these TMSG values is a calculated air void content that is too high. Table 7 is a revision of Table 6 showing a comparison of the air void contents. Hveem stability is also shown on Table 7.

If this analysis is correct, the "adjusted" average air void content would be about 3.3 percent for the C (rubberized) surface mix and 3.0 percent for the C binder mix. This data suggests that there was not an increase in voids from design to field but rather, an overall slight decrease. This scenario is more consistent with the over 1 percent gain in P200 exhibited by both C mixtures. Four of the eight independent assurance tests for the C (rubberized) mixture would exhibit an air void content at or below the industry standard of 3 percent.

Support for this theory is provided by Figure 8 which shows plots of Hveem stability versus air void content for the original and adjusted air void contents. The plot of stability versus original air void content exhibits no correlation (R-squared = 0.01). None of the variation in stability is explained by the air void content and stability appears to be insensitive to air voids. The plot of stability versus adjusted air void content indicates a

Figure 7. TMSG Independent Assurance Test Results for C Mixtures, IH-70

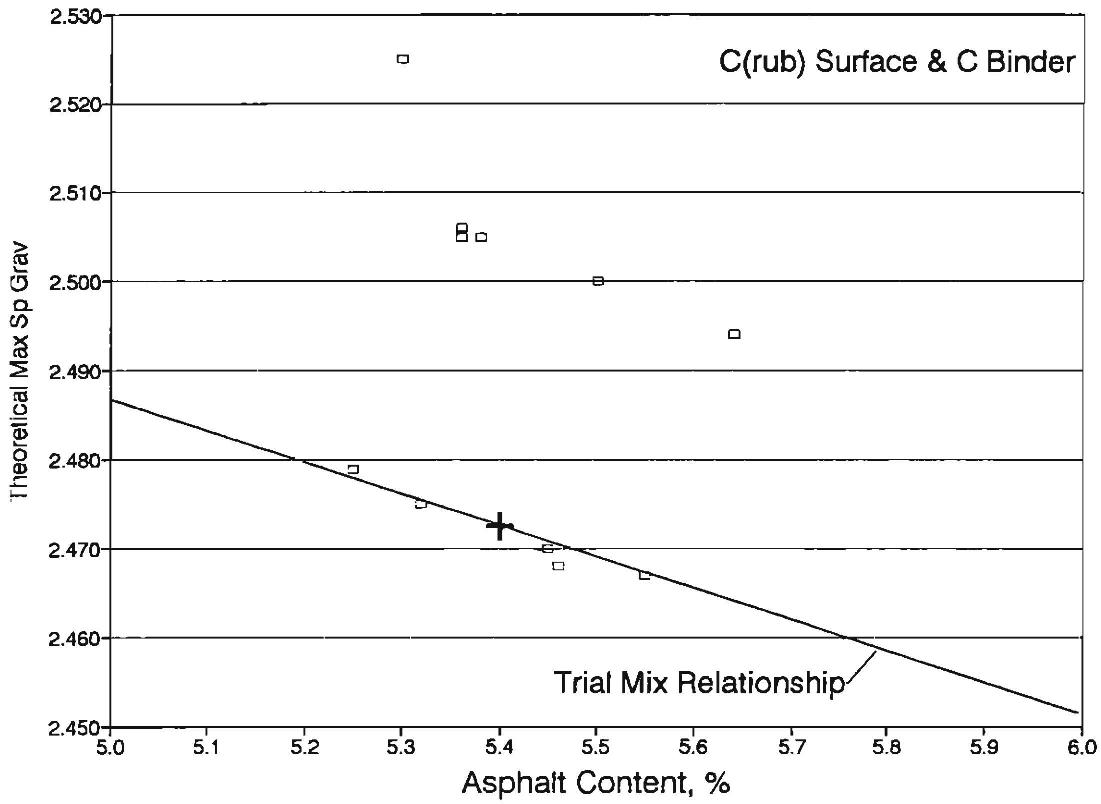


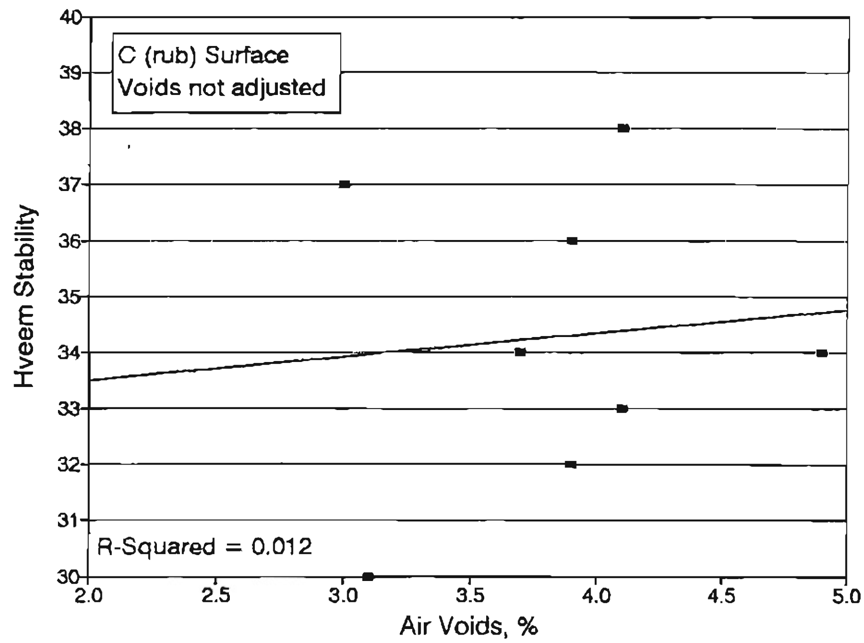
Table 7. Revised Table 6 Showing Adjusted Air Void Contents

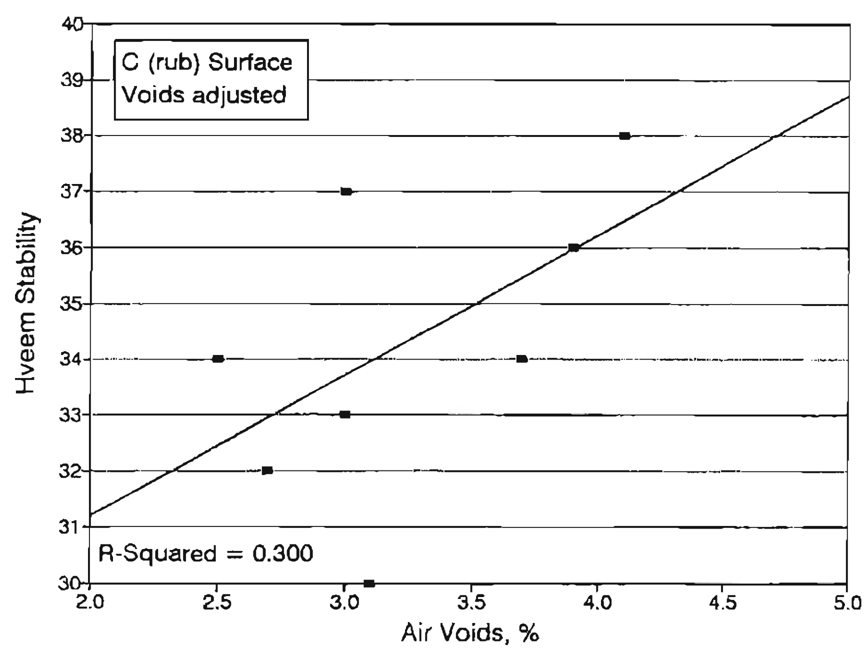
Mix	Asphalt Content	Theo Max Sp Grav Meas	Theo Max Sp Grav Adjusted	Air Voids Meas	Air Voids Adjusted	Stability
C(rub)	5.32	2.475	same	3.9	3.9	36
surf	5.38	2.505	2.474	4.1	3.0	33
	5.25	2.479	same	3.1	3.1	30
	5.36	2.506	2.475	4.9	3.7	34
	5.50	2.500	2.469	3.7	2.5	34
	5.64	2.494	2.463	3.9	2.7	32
	5.55	2.467	same	3.0	3.0	37
	5.45	2.470	same	4.1	4.1	38
Avg	5.43			3.8	3.3	34
G Bin	5.46	2.468	same	2.1	2.1	38
	5.30	2.525	2.494	4.6	3.4	35
	5.36	2.505	2.474	4.6	3.4	37
Avg	5.37			3.8	3.0	37

Notes:

1. Theoretical maximum specific gravity (TMSG) adjusted down by 0.031.
2. Adjusted air voids calculated using adjusted TMSG.

Figure 8. Hveem Stability versus Non-Adjusted and Adjusted Air Void Content, IH-70





better correlation (R-squared = 0.30). At least some of the variation in stability is explained by air void content. In addition, the shown trend is logical; that is, stability is proportional to air void content.

PROJECT MATERIALS

To more thoroughly investigate the causes of the observed distress, CDOT secured 52 cores from four locations within the project. Core sites are shown in Fig 9. Approximately 1000 pounds of mineral aggregate and two gallons of asphalt cement were also collected. These materials were packaged and sent to the AI Research Center in Lexington, KY for testing. During this investigation, CDOT secured an additional six cores to determine air void content. These cores were tested by the CDOT central materials laboratory.

Analysis of Cores

Figure 9 indicates that all asphalt mixture combinations were sampled. Each core site included 12 cores consisting of six cores each between wheelpaths and in the inside wheelpath. At site 2, an additional four cores were taken from the shoulder area. The coring procedure involved advancing a four-inch core barrel throughout the entire depth of asphalt materials. This included the distressed overlay as well as the previously existing surface.

Visual Examination of Cores

Cores from sites 1, 2, and 3 exhibited varying degrees of stripping. Some cores were so moisture damaged that they were of no use for testing purposes. This was especially true of site 3. In some extreme cases, entire layers were damaged. These layers were practically stripped of asphalt and had to be collected in plastic bags. Free asphalt in these bags appeared shiny, black, and sticky. Site 4 cores exhibited very few signs of distress. All cores exhibited a light surface coating of asphalt cement and it was later ascertained that a fog seal had been placed during Spring 1991as a remedial measure to impede the advancing rutting and disintegration distress.

This visual examination showed that most of the moisture damage was occurring in Grades C and G binder or Grade CX rut filling courses. Because of the varying thickness of these layers, it was very difficult to establish which of these materials was undergoing the most distress. In fact, all of these layers exhibited varying degrees of stripping. Figure 10 illustrates a schematic of a typical damaged core from sites 1, 2, and 3. In some cases, moisture damage occurred at the interface between the old and new asphalt materials. In other cases, it occurred above this interface, completely in the new binder or rut filling course. A serious problem in the visual examination was evaluating whether a rut filling course was present. In fact, in some cases, stripping was even visible

Figure 9. Locations of Cores, IH-70

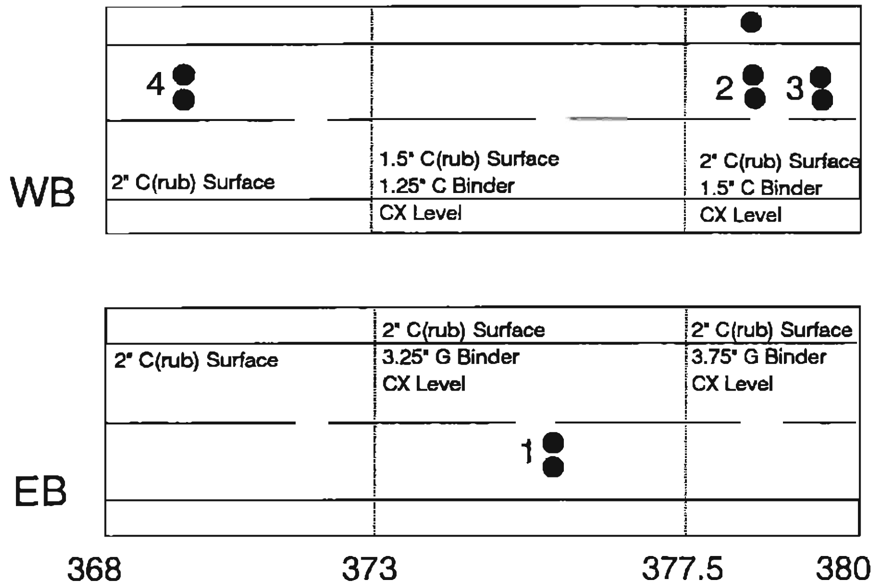
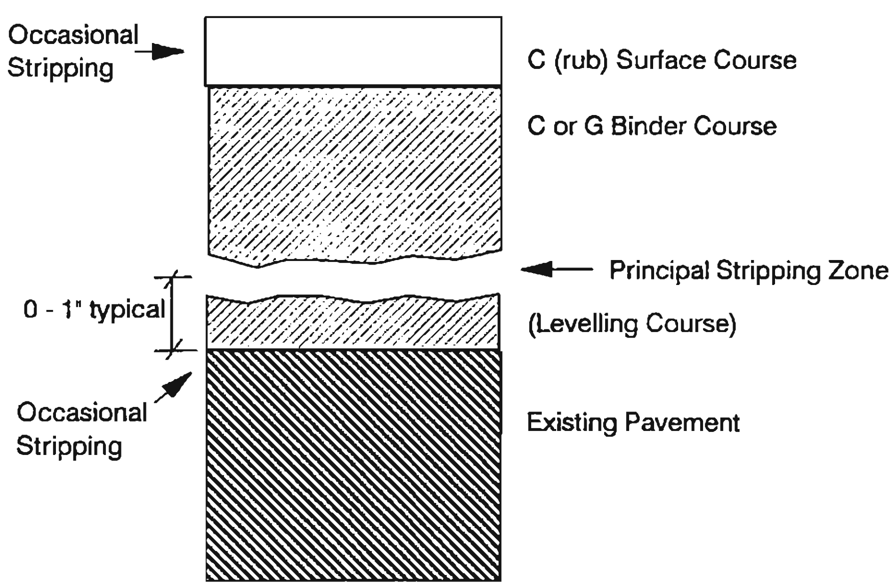


Figure 10. Schematic of Moisture Damage in Cores, IH-70



in the old surface material which agreed with the IH-70 performance observations made by CDOT, Aurora District personnel.

During this investigation, this information was conveyed to CDOT. Joint discussion arrived at a consensus that a trench should be excavated to gain a more thorough observation of the failed pavement structure. A trench was excavated at MP 375 WB in the driving lane and outside shoulder. Observations of the pavement section corroborated the findings of the core observations. That is, the C binder layer was damaged. This layer also tended to retain moisture from wet sawing. Alternatively, it may have been wet prior to sawing.

Density-Voids Analyses of Cores

Individual cores were split into component layers by sawing. Cores with obvious damage were discarded or used in other testing. For each core, the bulk specific gravity of each component layer was measured using the procedure described in ASTM D2726. In addition, the bulk specific gravity of the existing pavement below the core was measured. At a given site, core slices from like layers were heated in a 140 degree F oven, trimmed of cut faces, and combined to achieve a loose sample large enough to measure the maximum theoretical specific gravity. Appendix B (Table A) contains bulk and maximum theoretical specific gravities of materials handled in this manner. Figures 11 through 14 illustrate average air void contents for layers at sites 1 through 4, respectively.

A notable feature of the air void data is that the existing surface, upon which the overlay was placed, had extremely low air voids, in the range from about one to four percent. Such low values would suggest that moisture trapped in the overlay layers had no escape route below.

The CX levelling course at sites 1 and 2 exhibited the highest air void contents, between about seven and nine percent. Air void contents in this range and higher are considered by most asphalt technologists to be permeable to moisture.

The C binder course exhibited air void contents of slightly more than seven percent. Shoulder (untrafficked) specimens at site 2 suggested that the C binder course densified under traffic from about nine percent down to the seven percent level. The only air void content for G binder was at site 1 at about 3 percent.

Another striking feature of this data is the relatively low air void contents exhibited by the C (rubberized) surface. The highest value, about five percent, was at site 3 for a between wheelpath value. (Site 3 cores were so damaged that no wheelpath cores were suitable for density-voids analyses.) At sites 1, 2, and 4, the C (rubberized) air void content was between two and 3.5 percent. These very low air void contents suggest a mixture susceptible to plastic flow. Furthermore, such low values indicate a mixture impermeable to moisture.

Figure 11. Core Air Void Contents, Site 1, IH-70

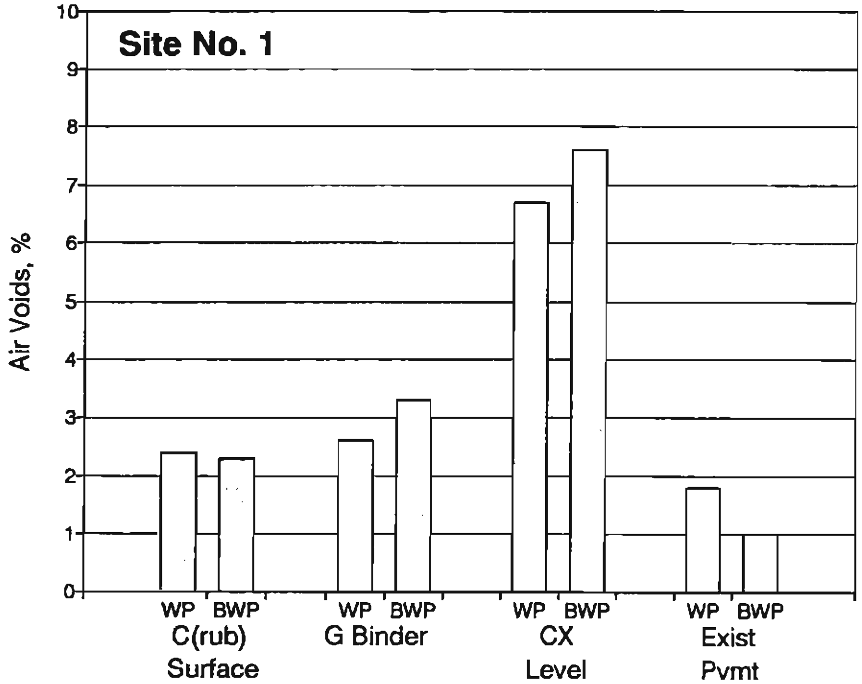


Figure 12. Core Air Void Contents, Site 2, IH-70

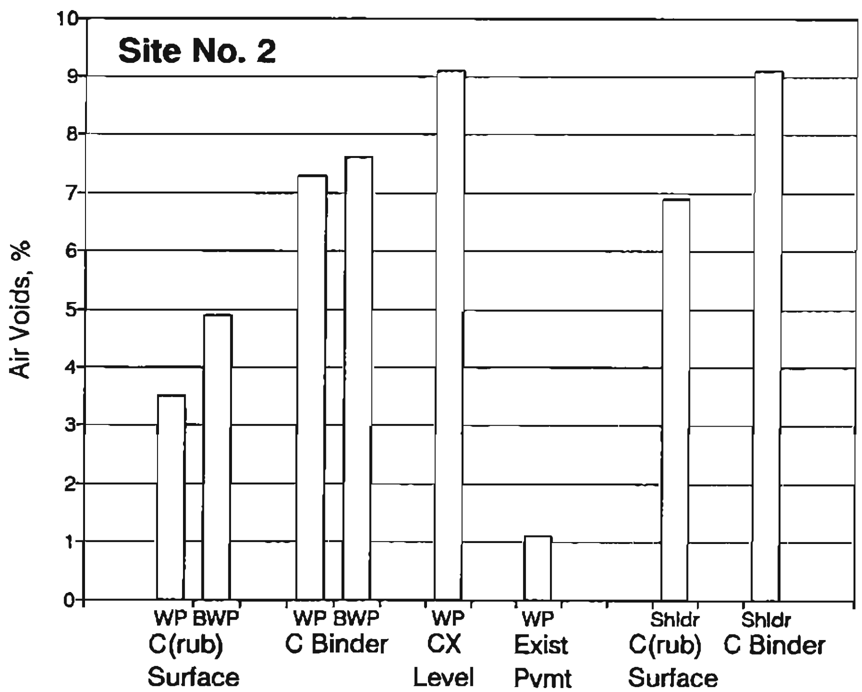


Figure 13. Core Air Void Contents, Site 3, IH-70

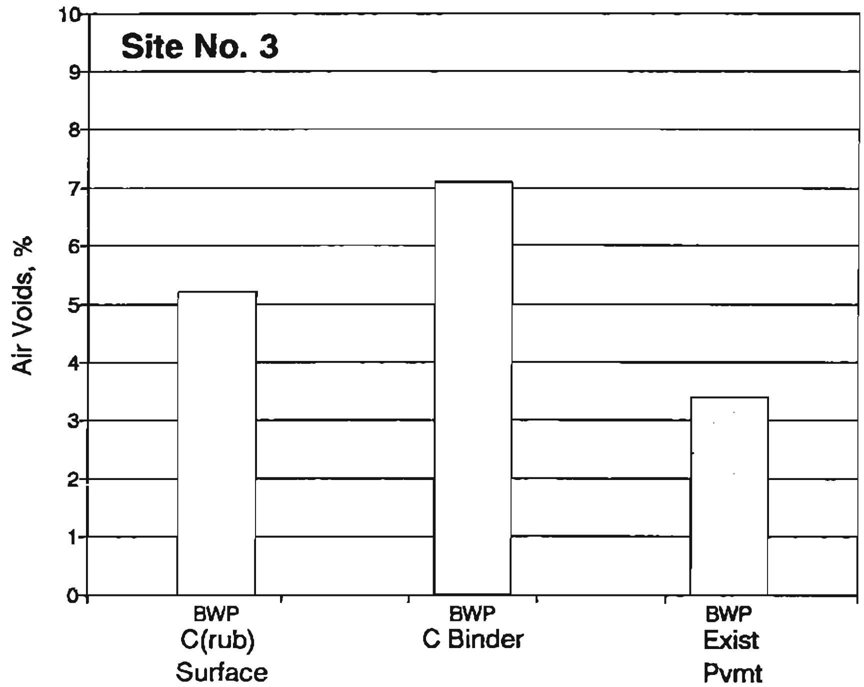
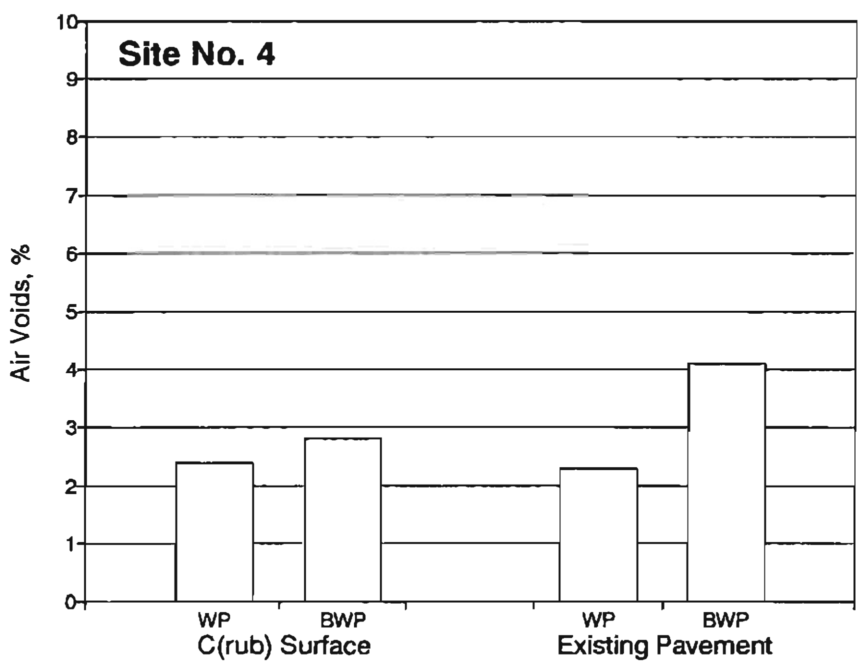


Figure 14. Core Air Void Contents, Site 4, IH-70



The results of the core tests performed by CDOT are shown in Table 8. The C (rubberized) surface for these cores exhibited air void contents in the range from about four to five percent. The C binder course for these cores showed air void contents from about 4.5 to eight percent. These test results are very similar to those measured for C (rubberized) surface and C binder courses at the AI Research Center.

Analyses of Extraction Test Results

Following the maximum theoretical specific gravity determination on core component layers, the loose mixture was extracted. The asphalt cement was recovered for viscosity and penetration tests.

Figures 15 through 18 show extracted gradations for the various mix types at sites 1, 2, 3, and 4, respectively. In all cases, the extracted gradation was finer than the job-mix formula. Asphalt contents (by weight of mix) for the samples were as follows:

Site 1, Grade G binder = 5.5 percent,
Site 2, Grade C binder = 6.0 percent,
Site 3, Grade C binder = 6.6 percent, and
Site 4, Grade C (rubberized) surface = 6.0 percent.

Asphalt contents were half to one percent higher than the job-mix formulas. These data suggest that when the core component layers were trimmed and combined with like layers at the same site, the samples were segregated. As such, the sample extractions were probably too disturbed to be of value in this investigation.

The properties of the recovered asphalt are shown in Table 9. As expected, the rate of hardening is a direct function of air void content. That is, higher air void contents resulted in harder asphalt cement. For the C (rubberized) mixture at site 1, the asphalt cement appears to be slightly softer (3948 poises) than would normally be expected, and clearly, softer than the asphalt cement at sites 2, 3, and 4. In addition, the C (rubberized) mixture at site 4 had a slightly high viscosity (7024 poises) considering the low air void content (2.4 percent). In general, the recovered properties are in the range normally expected for relatively new, in-place asphalt cements and do not suggest a relationship with the observed distress.

Analysis of Aggregate Materials

Because this investigation occurred about a year after construction, there was concern that the aggregate samples did not represent material used during construction. CDOT and contractor personnel indicated that the material should have been very similar. To address this concern, a washed gradation analysis was performed on the aggregate materials received at the AI Research Center. This information, along with gradations evident a year earlier during the mix design phase, is shown in Table 10.

TABLE 8. CDOT Core Test Results, IH-70

Mixture	M.P.	Bulk S. G.	Max S.G.	Percent Density	Air Voids
C (rub)	373.5	2.39	2.485	96.2	3.8
Surface	375	2.33	2.451	95.1	4.9
	376.5	2.35	2.459	95.6	4.4
				AVG	4.4
C	373.5	2.33	2.475	94.1	5.9
Binder	375	2.36	2.471	95.5	4.5
	376.5	2.28	2.484	91.8	8.2
				AVG	6.2

Notes:

1. All cores taken in westbound lane
2. Bulk specific gravity only reported to three significant figures
3. No values available for G binder mixture

Figure 15. Extracted Gradations of G Binder Course, Site 1, IH-70

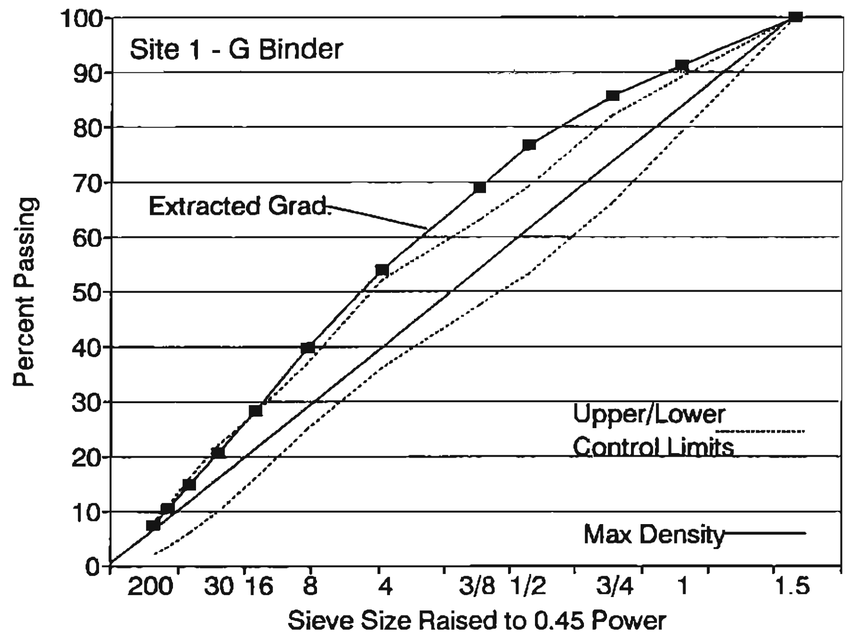


Figure 16. Extracted Gradation of C Binder Course, Site 2, IH-70

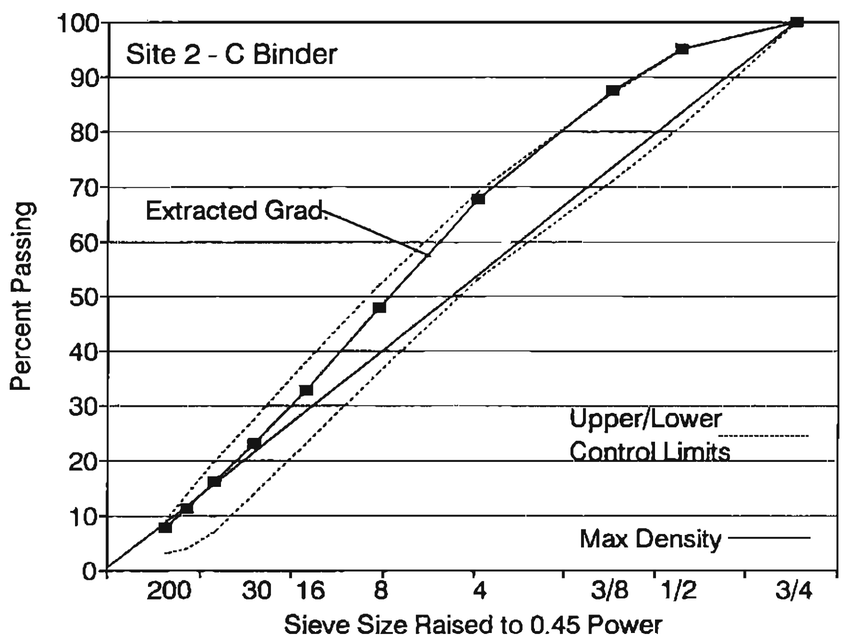


Figure 17. Extracted Gradations of C Binder Course, Site 3, IH-70

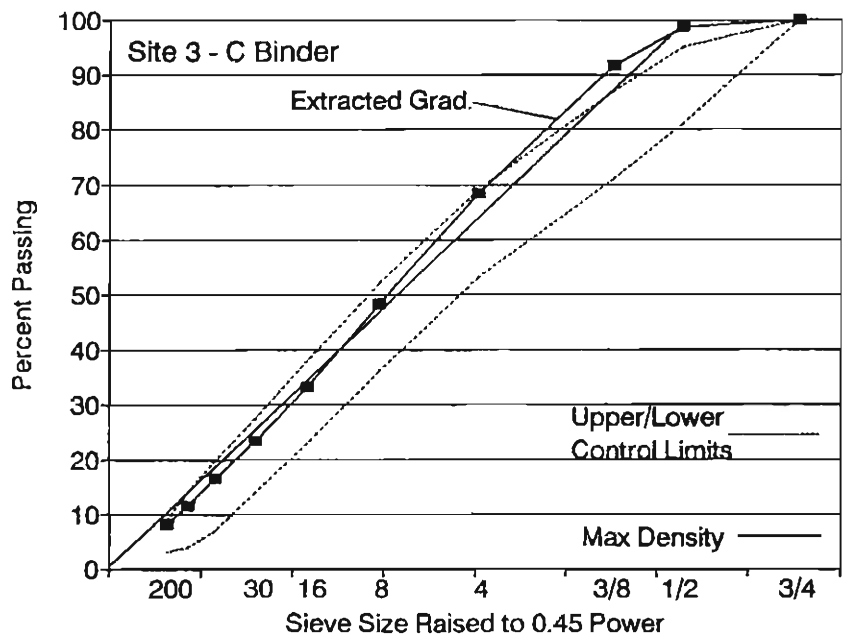


Figure 18. Extracted Gradation of C (rub) Surface Course, Site 4, IH-70

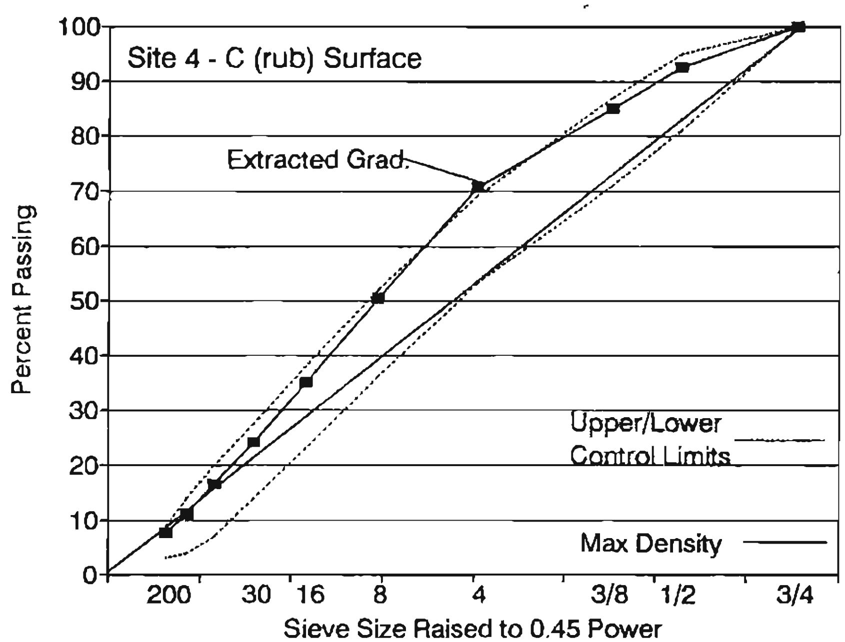


TABLE 9. Properties of Recovered Asphalt Cements, IH-70

Site No.	Layer	Penetration	Absolute Viscosity	Air Voids
1	C (rub) Surface	67	3948	2.4
	G Binder	56	4448	3.0
2	C (rub) Surface	49	7166	4.0
	C Binder	43	7698	7.4
3	C (rub) Surface	45	7198	5.2
	C Binder	42	6042	7.1
4	C (rub) Surface	54	7024	2.7

Notes:

1. Penetration 0.1 mm at 77 degrees F
2. Absolute viscosity poises at 140 degrees F
3. Air voids percent by volume total mixture

TABLE 10. Gradations of Component Aggregates, IH-70

	Spec Aggr		Crusher Fines		Monk Sand	
Sieve	AI	Contr	AI	Contr	AI	Contr
3/4"	100	100	100	100	100	100
1/2"	56.2	64	100	100	99.6	100
3/8"	22.0	31	100	100	98.7	99
No. 4	1.1	6	89.8	81	94.0	91
No. 8	0.4	4	69.3	57	77.6	69
No. 16	0.4	2	53.4	42	51.9	43
No. 30	0.4	2	41.9	32	25.3	23
No. 50	0.4	2	32.0	23	7.3	5
No. 100	0.4	1	22.9	16	3.1	2
No. 200	0.3	1	17.0	11	2.7	1.3

Notes:

1. AI - gradation determined by Asphalt Institute Research Center
2. Contr - gradation determined by contractor mix design laboratory
3. All values percent passing for material indicated

The coarse "Specification Aggregate" fraction tested by AI was somewhat coarser than the material used during the mix design phase. The intermediate and fine aggregates, "Crusher Fines" and "Monk Sand," were slightly finer than the original materials. While there appeared to be a difference in gradation, the difference was not considered enough to invalidate use of these materials for further investigation. Nevertheless, conclusions drawn from this data must be moderated by the irrefutable fact that these materials were sampled and tested a year apart from the IH-70 project.

As part of this investigation, a sample of the Crusher Fines was sent to the CDOT central laboratory for mineral identification. This analysis indicated a high percentage of orthoclase feldspar, especially in the coarser fractions. A small percentage of magnetic rock, either ilmenite or magnetite, was also detected. The mineral identification also detected a high percentage of silt sized particles.

Atterburg limits were determined for the fine portions of the Crusher Fines and Monk Sand. Neither material exhibited plasticity. Sand equivalence was measured on the minus No. 4 fractions of these materials. The Monk Sand had a sand equivalent value of 70, far above the normal industry standard of 45. The Crusher Fines had a value of 30, which indicates a relatively high proportion of fine dust particles. This corroborated the CDOT mineral identification that detected "silt sized particles." Thus, half of the C type mixtures were composed of an aggregate with excessive dusty, silt sized material.

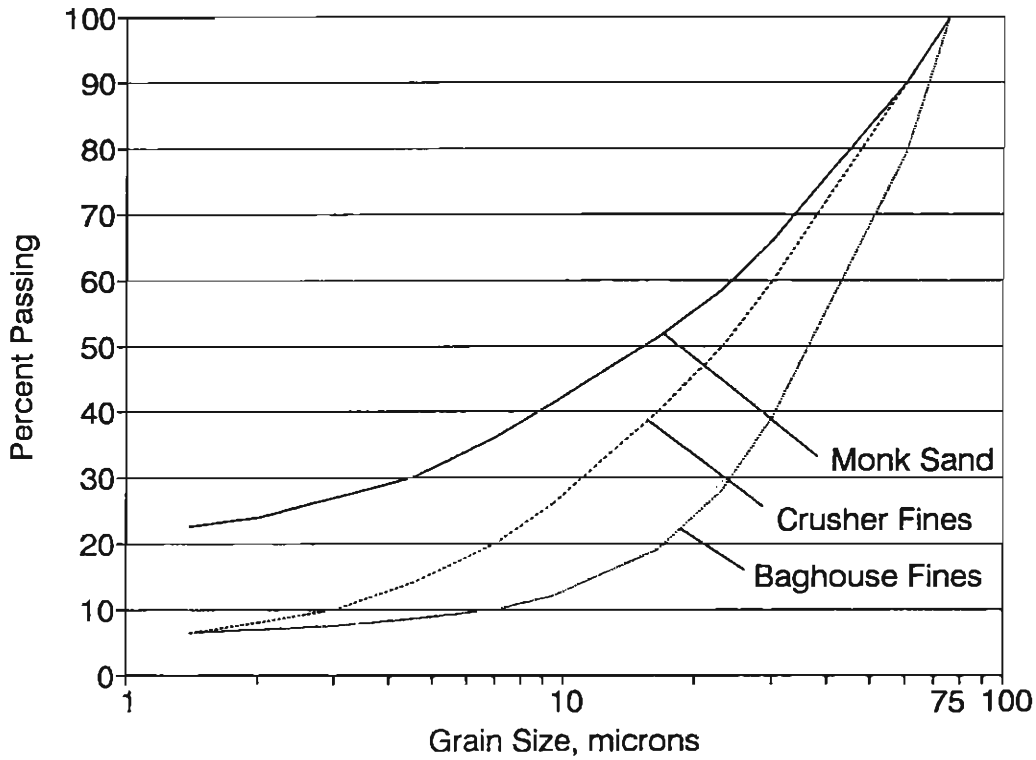
In order to better characterize this fine material, a hydrometer analysis was performed on the P200 fraction from the Crusher Fines and Monk Sand. The result (Fig 19) of this test is a particle size distribution of the dust fraction of these aggregates. For comparative purposes, a sample of baghouse fines from the contractor's plant was also characterized. Again, the baghouse fines were collected from materials processed about a year after original construction and are of limited use to the investigation.

The P200 fraction of the Crusher Fines and Monk Sand exhibit about 25 and 40 percent finer than 10 microns, respectively. These materials collectively make up about 50 to 70 percent of all asphalt mixtures on the project. As such, the hydrometer analyses indicate that the asphalt mixture has P200 material that tends to be very fine.

Interestingly, the baghouse fines are considerably coarser than either material. This suggests that the baghouse fines were produced from different parent material, or that a separate collection system upstream of the baghouse had already collected the ultrafine particles.

A simple calculation for the C mixtures indicates an asphalt film thickness of about 8 microns at the design asphalt content. Thus, a significant portion of the P200 in the mixture was in the same size range as the asphalt film coating. According to the sand equivalent tests, much of these fines tended toward silty, clayey, or dusty material.

Figure 19. Particle Size Distribution of P200 Materials, IH-70



Analysis of Slab Sample Using French Rutting Tester

During the course of this investigation, CDOT obtained a French rutting tester and began developing rutting performance predictive models for Colorado materials. This device cyclically loads a 4-inch by 7-inch by 20-inch asphalt slab using a small pneumatic tire inflated to 87 psi. Loads are applied to the slab in a temperature chamber to maintain the 140°F test temperature. French experience indicates that an acceptable mix will have less than a 10 percent rut depth based on total beam depth after 30,000 load cycles.

Another test characteristic, the slope of the rut depth versus log load cycles plot, is also considered a rutting indicator. Steeper slopes indicate higher rutting potential. Tests on 33 asphalt samples secured throughout Colorado with known performance characteristics show that a slope of less than 0.4 indicates good rutting performance. Slopes of greater than 0.6 correlate with pavements that have unacceptable rut depths.

A slab was secured from between the wheelpaths in the westbound lane at MP 372. At this location, the slab was composed of two inches of C (rubberized) surface. This material exhibited 10 percent rut depth after only 3,000 load cycles. The slope of the rut depth versus load cycles plot was 0.835. These results indicate the mix is very susceptible to plastic flow.

MOISTURE SUSCEPTIBILITY TESTING

During the mix design phase for the IH-70 project, moisture susceptibility tests (CDOT L-5109) did not predict stripping-prone mixtures. Field moisture susceptibility tests were performed on plant-produced materials (Table 6). Although most values were above established minimums, they varied considerably for the C (rubberized) surface and G binder courses. Of the 15 tests performed on plant-produced materials, three TSRs were less than 70 percent. Two of the three low values, 66 and 52 percent, were for the G binder course. CDOT engineers attribute a possible source of variability in the C (rubberized) surface to the difficulty in blending antistripping additive into the rubberized asphalt. They also believe the variation in the G binder TSRs is inherent in testing 6-inch specimens.

Another consideration with the moisture susceptibility testing is that the mixtures were always tested with an antistripping agent. Every mix design was performed using one of three antistripping chemicals. In fact, the CX mix design indicated the CDOT L-5109 procedure was used with all three chemicals. However, in no case was the stripping potential measured without an additive.

AI Research Center Testing Program

Considering these facts and also the fact that aggregate tests suggested dusty materials, potentially prone to stripping, a brief moisture sensitivity study was performed using the raw materials sent to the AI Research Center. A version of the boil test used by the Texas DOT (Tex 530-C) was used to evaluate the stripping potential of the Crusher Fines and Monk Sand. ASTM D4867, otherwise known as the "Root-Tunnicliff Procedure," was employed to estimate the moisture sensitivity of the C mix. Companion tests were also performed using Colorado Method L-5109. Additional tests were performed by the CDOT Materials Laboratory in Denver.

Boil Test Results

To roughly simulate mix conditions, the average particle film coating was calculated for the C type mix. This value was about 8 microns. An amount of asphalt was added to samples of Crusher Fines and Monk Sand to achieve this film thickness. When subjected to boiling water, the Monk Sand exhibited about 50 percent loss of asphalt. Interestingly, the Crusher Fines showed no loss of asphalt. This was unexpected since the Crusher Fines showed a low sand equivalent value. Although less dusty, the Monk Sand exhibited more moisture susceptibility according to the boil test. CDOT engineers performed the these same tests, both with and without antistripping additives. The tests without additives verified the AI results. With an additive, CDOT test results indicated no moisture damage.

TSR Tests

Table 11 summarizes the TSR testing program and test results. For each treatment, a direct comparison was made between test results from ASTM D4867 and CDOT L-5109. Because there was a belief that the original design and quality control TSR test results may have resulted from erroneously low air voids, a set of specimens was fabricated at between four and five percent air voids. These lower void specimens were tested with and without antistripping agent. All AI Research Center specimens were fabricated using the Texas gyratory compactor since that is the compaction device now specified by CDOT. These specimens were compacted to a height of 2.0 inches since this is the standard specimen height normally used for the Texas gyratory compactor. However, it should be noted that the L-5109 procedure requires specimen heights of 2.5 inches. As an adjunct to this study, the CDOT Central Materials Laboratory performed a companion series of tests to verify AI Research Center results and to estimate the effect of Colorado kneading compaction, which was in use during the time when the IH-70 project was constructed. CDOT specimens were fabricated to a height of 2.5 inches. In addition, three of the four CDOT tests were performed at an asphalt content of 6.0 percent. One CDOT test also was performed at a non-standard, low air void content. In all cases, a freeze-thaw conditioning cycle was used to more closely simulate potential weather conditions for the IH-70 project.

None of the mixtures or treatments shown in Table 11 passed CDOT's minimum TSR requirement of 80 percent. Under standardized test conditions for voids (7.0 $\pm$ 1.0 percent) and degree of saturation (55 to 80 percent), TSRs ranged from 25 to 72 percent. Mixtures with antistripping additives had TSR's in the range from 39 to 72 percent with

Table 11. Summary of TSR Moisture Susceptibility Testing, IH-70

Test Method	Additive	Compaction Method	Asphalt Content, %	Air Voids, % Cond.	Air Voids, % Uncond.	Degree of Saturation, % Partial	Degree of Saturation, % Final	Swell, % Partial	Swell, % Final	Tensile Strength, psi Cond.	Tensile Strength, psi Uncond.	TSR, %	Visual Observations
AI RESEARCH CENTER TESTS:													
ASTM D 4867	None	TX Gyr (2")	5.4	7.1	7.1	65.3	130.1	0.2	4.1	20.8	83.9	25	1
CDOT L-5109	None	TX Gyr (2")	5.4	7.3	7.3	58.2		-	3.9	11.5	40.7	28	1
ASTM D 4867	Pavebond	TX Gyr (2")	5.4	7.5	7.5	63.2	121.1	0.2	3.7	31.2	81.1	39	1
CDOT L-5109	Pavebond	TX Gyr (2")	5.4	7.7	7.1	57.2	-	-	4.0	19.3	44.9	43	2
ASTM D 4867	Unichem	TX Gyr (2")	5.4	8.0	8.0	65.5	114.8	0.5	3.6	34.1	83.6	41	1
ASTM D 4867(*)	Unichem	TX Gyr (2")	5.4	7.1	7.2	65.1	114.1	0.2	3.4	39.5	82.7	48	1
CDOT L-5109	Unichem	TX Gyr (2")	5.4	7.5	7.5	55.6	-	-	3.4	21.0	39.6	53	2
AI RESEARCH CENTER TESTS (Low Air Voids):													
CDOT L-5109	None	TX Gyr (2")	5.4	4.4	5.0	57.5	-	-	3.1	28.3	61.7	46	1
CDOT L-5109	Unichem	TX Gyr (2")	5.4	4.6	5.1	50.8	-	-	2.6	35.8	58.4	61	2
CDOT MATERIALS LAB:													
CDOT L-5109	Pavebond	Kneading	6.0	6.60		61	-	-	-	21	54	39	-
CDOT L-5109	Pavebond	Kneading	5.4	6.72		59	-	-	-	18	56	33	-
CDOT L-5109	Pavebond	TX Gyr (2.5")	6.0	6.80		60	-	-	-	25	35	72	-
CDOT MATERIALS LAB (Low Air Voids):													
CDOT L-5109	Pavebond	Kneading	6.0	4.25		58	-		-	33	65	51	

Key to visual observations:
1. Severe stripping coarse and fine aggr; coarse aggr fractured in unconditioned specimens.
2. Moderate stripping coarse and fine aggr; coarse aggr fractured in unconditioned specimens.

Notes:
1. CDOT partial degree of saturation does not include volume of absorbed surface moisture.
2. CDOT swell shown for informational purposes only; not reported in standard procedure.
3. * - Duplicate test.

most values in the 30 and 40 percent range. This was consistently higher than mixtures tested without additives, which were below 30 percent. All conditioned mixtures, with or without antistripping additives, showed moderate to severe stripping when examined visually.

Thus, all mixtures exhibited stripping; yet antistripping additives seemed to improve TSR, but not enough to achieve a passing value. Figure 20 illustrates a possible explanation for this phenomenon. This is a plot between wet tensile strength and swell; the data points are sorted according to test method. For both groupings of data, there is a strong, expected relationship between swell and wet tensile strength; that is, higher swell indicates lower wet tensile strength. Because mixtures with additives always swell less, they tend to have a higher wet tensile strength and thus, a higher TSR. However, their resistance to stripping, that is, asphalt cement debonding from aggregate, does not seem to be improved.

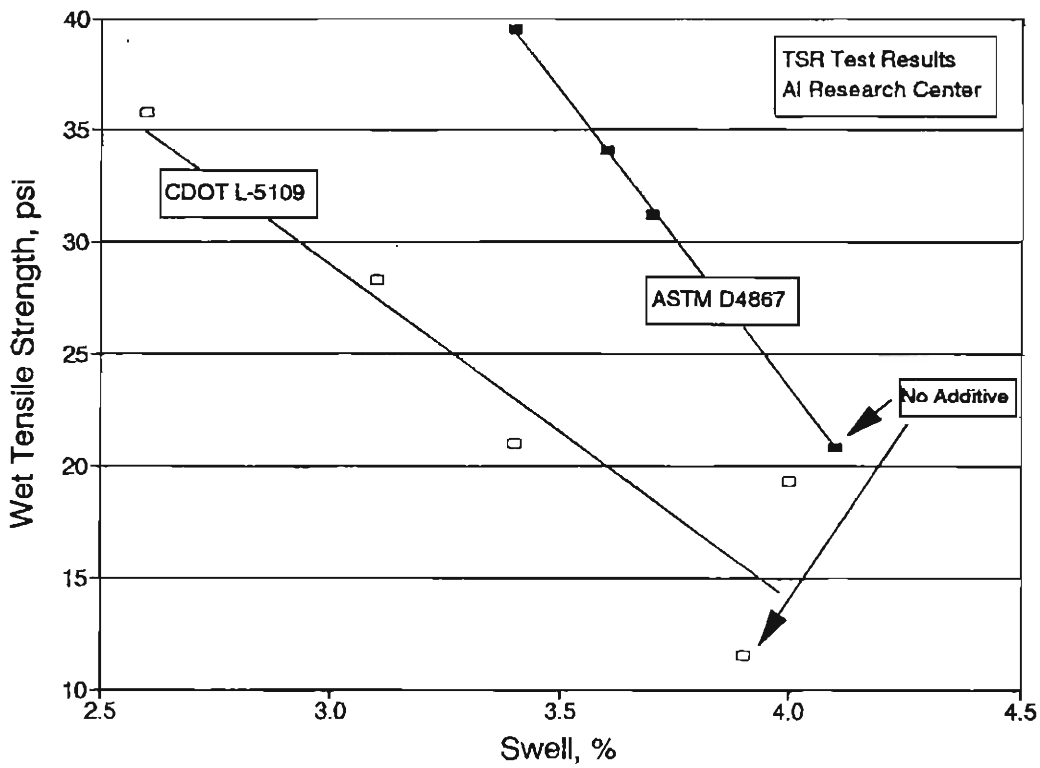
Final swell values were in the range from about three to four percent. These values are very high when compared with other mixtures tested at the AI Research Center. Partial swell values, that is, measured after vacuum saturation, were within the range normally encountered by the AI Research Center. One partial swell value, 0.5 percent, was unusually high. These results indicate that the freeze-thaw conditioning cycle caused an abnormally high volume change in the specimen.

Final degrees of saturation were all in excess of 110 percent with one value as high as 130 percent. As with the swell values, this result also indicates a mix severely weakened by abnormally high volume change.

AI specimens tested at non-standard, low air void contents also failed the minimum TSR requirement. The low void mix without antistripping additive had a TSR of 46 percent. This is almost twice as high as 28 percent, the value for the same mix at the higher, standard void content. The low void mix with antistripping additive had only a slightly higher TSR, 61 percent, when compared to the TSR for the same mix under standard void conditions, 53 percent. CDOT's TSR test result for a low air void mixture, 51 percent, fell within this range of values, even with the higher asphalt content. These results exhibit the expected trend that an error in air voids would cause an error in TSR. However, it is important to note that even with the lower than standard air void content, the mixtures still did not meet minimum tensile strength requirements and still exhibited stripping.

These test results clearly show that CDOT's moisture susceptibility test, L-5109, compares favorably with ASTM D4867 in terms of predictive ability. Two items specific to the L-5109 procedure are worth noting. First, tensile strength values are approximately half when compared to the ASTM D4867 values. Conversations with CDOT verified that this difference was caused by the difference in loading rates between the test methods. The L-5109 procedure requires a loading rate of 0.2 inches per minute whereas the ASTM D4867 approach uses a loading rate of 2.0 inches per minute. CDOT has considerable

Figure 20. Wet Tensile Strength Versus Swell for AI Moisture Susceptible Tests, IH-70



experience that shows the slower loading rate consistently results in low tensile strength values.

The second item of interest with respect to the L-5109 procedure is that swell, either partial or final, and final degree of saturation are not routinely reported. This is because the CDOT test procedure does not require measurement of an saturated surface dry (SSD) mass after vacuum saturation. The procedure determines the volume of absorbed water by the difference between the mass of the vacuum saturated specimen in water and the mass of the unsaturated specimen in water. By not measuring an SSD mass, the volume of moisture in the specimen surface irregularities is not included in the total volume of absorbed water. The net result is that the degree of saturation reported in the L-5109 procedure is consistently lower than the same value in the ASTM D4867 procedure. Of course, the actual degrees of saturaion are the same, the L-5109 procedure merely reports a lower value.

The most significant finding of these tests was the visual appearance of the conditioned specimens. That is, they appeared strikingly similar to many of the damaged cores collected from IH-70. Like the cores, the specimens were friable and stripped coarse and fine aggregate were clearly visible. The visual appearance of the TSR test specimens suggests that the tests, either ASTM D4867 or CDOT L-5109, very closely simulated actual pavement conditions. On the basis of the specimens' appearance (as well as on the cores), the C mixture was highly moisture susceptible. Neither a low air void content, nor antistripping additives seemed to improve stripping resistance of the mixture.

CONCLUSIONS AND RECOMMENDATIONS

This investigation verified the visual observations of CDOT and asphalt industry personnel. That is, the IH-70 overlay failure was due to stripping. A potential failure mode is plastic deformation.

Conclusions

The stripping failure plane occurred in one, or most likely, a combination of the levelling and binder courses. The western third of the project from MP 368 to 373 did not exhibit signs of moisture damage in either the east or westbound lanes. This section of the overlay consisted only of a Grade C (rubberized) surface. No binder and levelling courses were used. The eastern two-thirds of the project from MP 373 to 380 in the westbound lanes exhibited severe moisture damage. It was in this section that varying thickness of levelling and binder courses were placed. The eastbound lanes from MP 373 to 380 did not exhibit signs of stripping distress although a single set of cores from this section indicated that the same moisture damage was occurring in the bottom regions of the overlay, either in the G binder, CX levelling, or both. It is likely that the increased thickness of overlay in this region has precluded surficial evidence of moisture damage.

The laboratory analysis of project materials conducted by the AI Research Center and CDOT suggested that the asphalt mixtures were highly moisture susceptible. A high percentage of the levelling and binder courses consisted of component materials that were prone to stripping. The Monk Sand exhibited a high degree of moisture susceptibility. The Crusher Fines aggregate was not moisture susceptible according to the boil test results. However, it was so dusty that it impaired the stripping resistance of the other materials in the mixture.

The stripping failure was a function of the entire pavement system. The overlaid pavement was very dense and impermeable. Cores from failed sections showed that the levelling course was left with air voids of about seven to nine percent. Binder course air void contents ranged from three to seven percent. The G binder course tended to be denser than the C binder course. The C (rubberized) surface was very dense and impermeable. This structure resulted in moisture susceptible mixtures being sandwiched between dense, impermeable layers. Under the action of traffic and with moisture present, the CX levelling and C binder courses stripped. The G binder course stripped at the site 1 coring location. This failure scenario was verified by close visual examination of the cores as well as the trench excavated in IH-70.

The contractor and CDOT performed considerable moisture damage tests (Method L-5109) before and during the project. None of the mix design tests (contractor) and only three of 15 quality control tests (CDOT) predicted moisture susceptible mixtures.

During this investigation another potential problem was identified. That is, the C (rubberized) surface may be a rutting-prone asphalt mixture. Air void contents for this material ranged from two to seven percent. Air void contents in the lower end of this range indicate a mixture that has, or soon will, exhibit rutting. As-built air void contents from quality control records compared to core air void contents show that the C (rubberized) surface has, in fact, densified under traffic beyond the density level achieved using the Colorado kneading compactor. Limited core data suggests that the mix may have densified to a lower air void content than the design value. Tests on the C (rubberized) surface mixture with the French rutting tester also indicate this mixture is susceptible to permanent deformation.

Quality control records do not directly show that the C (rubberized) mixture experienced a reduction in voids from the mix design to construction phases. In fact, they indicate an increase in voids from design to plant production. However, close examination of the quality assurance tests suggest that the average air void content of the plant produced material may have been slightly lower than the design, not higher.

The most likely cause was the moderate increase in P200 material. While the job-mix formula called for 6.0 percent P200, construction records and core analyses showed as-built values about one to two percent higher. This resulted in dust to asphalt ratios which were at or exceeded the FHWA guideline of 1.2. The actual dust to asphalt ratios may have been slightly higher since most P200 values were the result of cold feed samples and did not reflect the potential degradation of mixtures during mixing operations.

Analyses of P200 particle size distributions indicated that the Monk Sand was very fine with about 40 percent of the P200 finer than 10 microns. The Crusher Fines P200 had about 25 percent finer than 10 microns. Particles this small tend to increase the effective volume of asphalt with a resulting lowering of air voids.

While this analysis might suggest a quality control problem, more important is the fact that the C (rubberized) mixture was designed too close to the limits of industry accepted norms on air voids and voids filled with asphalt. This was caused by the asphalt content being selected at a minimum master range value rather than at a value that resulted in optimum mixture volumetric properties. Furthermore, discussions with CDOT indicates their belief that the (previously used) Colorado kneading compaction procedure chronically under predicted traffic densification on high volume roadways. Evidently, the mix was overasphalted.

Recommendations

This investigation only involved one relatively short section of one pavement in eastern Colorado. Omniscient recommendations that apply to all pavements in Colorado are difficult to make on this basis. Nevertheless, there remain some unanswered questions regarding the IH-70 project that would clearly be of issue on other projects. They are as follows.

It is unclear why the mix design and quality control stripping tests did not accurately predict such a severe stripping failure. All design and most of the quality control TSRs were very high. It is reasonable to assume that the antistripping agents, asphalt cement/mineral aggregate combination, and high P200 levels acted in concert with the test method (L-5109) and sequence of testing to predict better performance than actually occurred. Thus, one recommendation is that CDOT perform a full factorial analysis on the L-5109 test method with a variety of mixtures of known performance characteristics. Independent variables should be mineral aggregate, asphalt cement, and antistripping agent. The results of such an experiment would allow CDOT engineers to make better decisions regarding the stripping resistance of asphalt mixtures submitted for approval. The experiment may also explain why some combinations of materials perform so well in predictive tests but not in actual pavements.

An interim recommendation of this project was that CDOT consider performing the L-5109 procedure without antistripping agents. The objective of these tests was to establish that mixtures with extremely low TSRs would not be permitted, even if an additive increased a low TSR to a passing value. Project investigators believe that an antistripping additive, either chemical or lime, should not be expected to overcome deficiencies such as those exhibited by the IH-70 materials. An antistripping additive should be expected to improve a marginal asphalt mixture or at least, one that has mostly demonstrated satisfactory performance characteristics. However, current CDOT practice requires addition of hydrated lime in all asphalt mixtures and any additional routine testing would be beyond the current or expected resources of CDOT. Because project investigators still believe this is a critical issue, CDOT should, as a minimum, add a task to the above-mentioned L-5109 experiment that studies the issue of treated versus untreated TSR values. The main benefit would be that CDOT could probably develop a specification TSR value below which a mixture would fail and not be considered for treatment. Most important, this experiment would allow CDOT to develop practices leading to greater confidence in moisture damage testing and thus, save the added expense of treating mixtures that are not moisture susceptible.

The CDOT should perform a study to evaluate the necessity of implementing a sand equivalent requirement. This test measures the presence of silty or clayey dust in an aggregate source. Only 13 out of 50 states use sand equivalent as a specification test. However, many western states with a similarly wide variety of aggregate sources specify a minimum sand equivalent value. California, Idaho, Arizona, Washington, Texas, and Oklahoma are western states that use the sand equivalent test.

The CDOT should consider performing a study aimed at developing a better dust management strategy. The gain in P200 during plant production on the IH-70 project as well as the ultrafine characteristics of the P200 material will most likely cause permanent deformation problems and may promote stripping. This phenomenon is a problem in many states.

The CDOT should consider limiting the amount of P200 in mixtures used on higher volume pavements. This could take the form of either a maximum dust to asphalt ratio or a maximum permissible P200 (mix design and plant produced).

Quality control information suggests that the level of field control over thin, rut-filling or levelling courses is not at a high enough level. CDOT should consider exercising greater control over these courses. If placed in sufficient thickness, perhaps 1.5-inch or more, in-place density should be the primary control point. A better alternative to rut-filling or levelling courses would be for CDOT to specify cold milling as part of the overall rehabilitation strategy. In these cases, the plane of milling should extend to a depth slightly below the observed plane of failure.

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Appendix A
Selected Photographs of
IH-70 Investigation

Figure A. Wheelpath Rutting in Driving Lane, IH-70

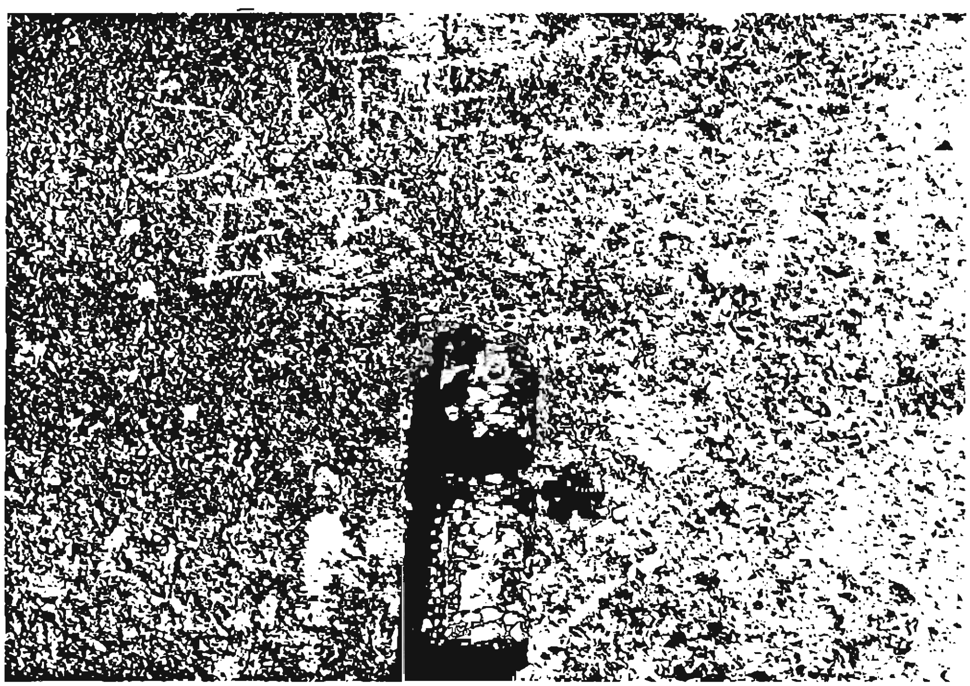

Figure B. Core Secured from Site 1, IH-70
(Note damage near bottom of new layers.)

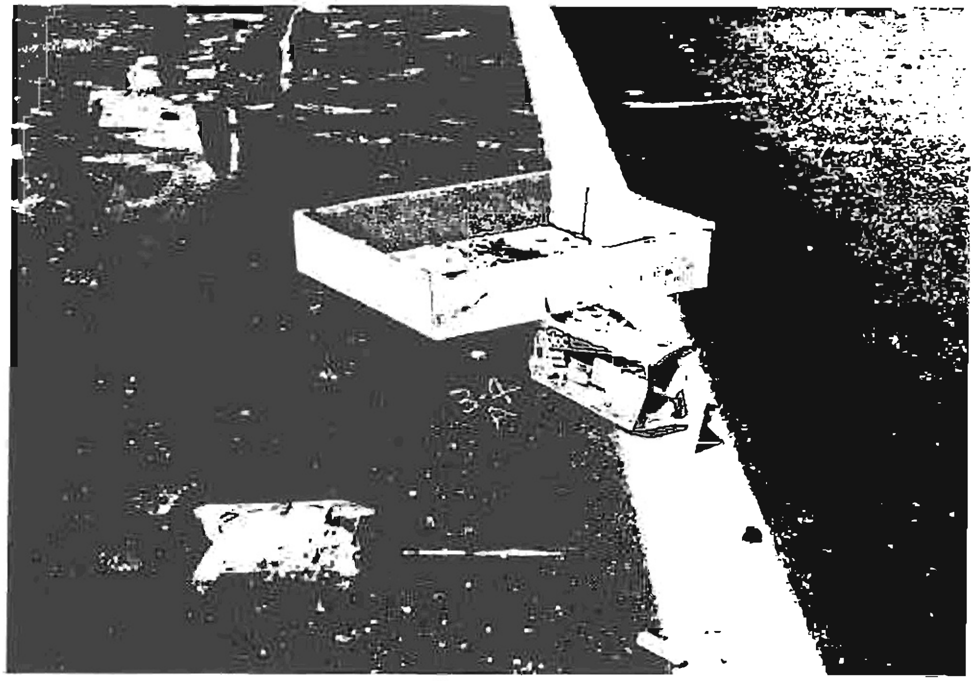

Figure C. Core Secured for Site 3, IH-70
(Note damage throughout and loose material in bag.)

Figure D. Trench Cross Section at MP 375 WB, IH-70
(Note wet, damaged C binder layer.)

Appendix B
Core Density-Voids Analyses

TABLE A. Core Density-Voids Analyses, IH-70

Site No.	Layer	Position	Core No.	Max Theo Sp Grav	Bulk Sp Grav	Air Voids
1	C (Rub) Surface	Wheelpath	1	2.456	2.393	2.6
			2	2.456	2.400	2.3
			3	2.456	2.395	2.5
			6	2.456	2.399	2.3
					AVG	2.4
		Between Wheelpath	7	2.456	2.387	2.8
			8	2.456	2.401	2.3
			9	2.456	2.411	1.8
			10	2.456	2.399	2.3
					AVG	2.3
					SITE AVG	**2.4**
1	G Binder	Wheelpath	1	2.469	2.394	3.0
			2	2.469	2.382	3.5
			3	2.469	2.426	1.7
			6	2.469	2.413	2.6
					AVG	2.6
		Between Wheelpath	7	2.474	2.380	3.9
			8	2.474	2.393	3.3
			9	2.474	2.404	2.8
			10	2.474	2.396	3.0
					AVG	3.3
					SITE AVG	**3.0**
1	CX Levelup	Wheelpath	1	2.449	2.288	6.6
			2	2.449	2.299	6.1
			3	2.449	2.248	6.2
			6	2.449	2.260	7.7
					AVG	6.7
		Between Wheelpath	10	2.449	2.263	7.6
					SITE AVG	**6.8**

Site No.	Layer	Core Position	No.	Max Theo Sp Grav	Bulk Sp Grav		Air Voids
1	Existing Pavement	Wheelpath	1	2.444	2.396		2.0
			2	2.444	2.393		2.1
			3	2.444	2.403		1.7
			6	2.444	2.415		1.2
						AVG	1.8
		Between Wheelpath	7	2.444	2.418		2.0
			8	2.444	2.422		0.9
			10	2.444	2.416		1.1
						AVG	1.0
						SITE AVG	**1.4**
2	C (Rub) Surface	Wheelpath	1	2.460	2.377		3.4
			4	2.472	2.379		3.9
			5	2.460	2.378		3.3
			6	2.460	2.379		3.3
						AVG	3.5
		Between Wheelpath	9	2.472	2.344		5.2
			10	2.472	2.358		4.6
						AVG	4.9
						SITE AVG	**4.0**
2	C Binder	Wheelpath	1	2.452	2.255		8.0
			4	2.452	2.252		8.4
			5	2.452	2.279		7.1
			6	2.452	2.315		5.6
						AVG	7.3
		Between Wheelpath	9	2.459	2.344		8.2
			10	2.459	2.358		6.9
						AVG	7.6
						SITE AVG	**7.4**

Site No.	Layer	Position	Core No.	Max Theo Sp Grav	Bulk Sp Grav	Air Voids
2	CX Level	Wheelpath	6	2.449	2.226	9.1
2	Exist. Pvmt.	Wheelpath	1	2.430	2.401	1.2
			5	2.430	2.408	0.9
			6	2.430	2.398	1.3
					AVG	1.1
2	C (Rub) Surface	Shoulder	1	2.474	2.322	6.1
			2	2.474	2.264	8.5
			3	2.474	2.324	6.1
					AVG	6.9
	C Binder	Shoulder	1	2.483	2.269	8.6
			2	2.483	2.264	9.3
			3	2.483	2.324	9.5
					AVG	9.1
3	C (Rub) Surface	Between Wheelpath	7	2.465	2.334	5.3
			8	2.465	2.338	5.2
			9	2.465	2.339	5.1
					AVG	5.2
3	C Binder	Between Wheelpath	7	2.446	2.267	7.3
			8	2.446	2.283	6.7
			9	2.446	2.268	7.3
					AVG	7.1
3	Existing Pavement	Between Wheelpath	8	2.426	2.406	0.8
			11	2.426	2.284	5.9
					AVG	3.4

Site No.	Layer	Position	Core No.	Max Theo Sp Grav	Bulk Sp Grav	Air Voids
4	C (Rub) Surface	Wheelpath	1	2.450	2.381	2.8
			6	2.450	2.404	1.9
					AVG	2.4
		Between Wheelpath	7	2.450	2.385	2.7
			8	2.450	2.405	1.8
			9	2.450	2.366	3.4
			10	2.450	2.362	3.6
			11	2.450	2.378	2.9
			12	2.450	2.393	2.3
					AVG	2.8
					SITE AVG	**2.7**
4	Existing Pavement	Wheelpath	6	2.386	2.331	2.3
		Between Wheelpath	7	2.386	2.297	3.7
			10	2.386	2.297	3.7
					AVG	4.1
					SITE AVG	**3.5**

Appendix C
Summary of Contractor
Quality Control Test Data

Analysis of QC Test Results, IH-70, C (rub) Surface

Test No.	%Asphalt	%Density	P200
1	5.42	93.0	6.3
2	5.38	93.0	6.8
3	5.42	92.2	6.9
4	5.38	93.8	7.5
5	5.32	93.8	7.5
6	5.48	92.6	6.9
7	5.45	94.2	7.3
8	5.45	93.0	6.5
9	5.42	94.6	7.5
10	5.28	95.1	7.5
11	5.50	92.6	7.5
12	5.37	92.6	7.5
13	5.43	93.4	7.5
14	5.38	93.4	7.3
15	5.53	92.2	7.0
16	5.38	92.2	7.5
17	5.52	93.8	7.5
18	5.36	93.4	7.6
19	5.62	92.2	6.5
20	5.36	93.0	7.5
21	5.33	93.8	7.5
22	5.52	94.2	7.5
23	5.55	92.6	7.1
24	5.48	92.2	6.5
25	5.52	93.0	7.5
26	5.58	93.0	7.5
27	5.50	93.8	7.0
28	5.55	92.6	6.5
29	5.48	93.8	7.5
30	5.46	94.2	7.5
31	5.56	94.2	7.5
32	5.61	93.8	
33	5.61	94.2	7.22
34	5.61	92.6	0.40

Analysis of QC Test Results, IH-70, C (rub) Surface

Test No.	%Asphalt	%Density	P200
35	5.55	94.2	
36	5.55	92.2	
37	5.55	92.6	
38	5.55	92.6	
39	5.25	94.2	
40	5.50	92.6	
41	5.55	93.8	
42	5.43	93.8	
43	5.55	93.4	
44	5.63	92.2	
45	5.53	92.6	
46	5.48	92.6	
47	5.67	93.4	
48	5.47	94.6	
49	5.53	92.6	
50	5.48	92.2	
51	5.52	92.6	
52	5.37	93.4	
53	5.42	94.2	
54	5.52	93.4	
55	5.60	93.0	
56	5.56	94.2	
57	5.56	93.4	
58	5.55	93.4	
59	5.56	93.4	
60	5.55	94.2	
61	5.52	94.2	
62	5.52	93.4	
63	5.66	94.6	
64	5.47	93.8	
65	5.42	92.6	
66	5.48	92.2	
67	5.58	92.6	
68	5.52	93.4	

Analysis of QC Test Results, IH-70, C (rub) Surface

Test No.	%Asphalt	%Density	P200
69	5.68	92.2	
70	5.56	92.2	
71	5.6	93.8	
72	5.62	92.2	
73	5.65	92.2	
74	5.62	95.0	
75	5.63	93.8	
76	5.38	92.6	
77	5.5	93.0	
78	5.53	93.4	
79	5.53	93.0	
80	5.52	93.0	
81	5.63	93.0	
82	5.55	93.0	
83	5.62	92.6	
84	5.45	92.6	
85	5.66	93.4	
86	5.48	93.4	
87	5.45	93.0	
88	5.3	94.6	
89	5.43	93.4	
90	5.52	93.4	
91	5.67	93.4	
92	5.58	92.2	
93	5.53	93.0	
94	5.57	93.4	
95	5.35	93.8	
96	5.57	92.6	
97	5.48	93.8	
98	5.62	93.0	
99	5.32	93.6	
100	5.63	93.6	
101	5.45	93.4	
102	5.48	93.0	

Analysis of QC Test Results, IH-70, C (rub) Surface

Test No.	%Asphalt	%Density	P200
103	5.66	92.6	
104	5.52	93.4	
105	5.60	93.0	
106	5.57	92.2	
107	5.48	93.0	
108	5.57	93.4	
109	5.57	92.6	
110	5.48	92.2	
111	5.50	93.0	
112	5.48	92.6	
113	5.62	93.8	
114	5.56	94.2	
115	5.50	93.4	
116	5.52	92.6	
117	5.62	93.8	
118	5.42	93.4	
119	5.40	93.4	
120	5.58	93.4	
121	5.58	92.6	
122	5.45	93.0	
123	5.57	92.6	
124	5.65	92.2	
		93.0	
Mean	5.51	92.2	
Std Dev	0.09		
		93.20	
		0.70	

Notes:

1. Test results from left to right do not correspond.
2. Average shown is not weighted.
3. See Fig 4 for plot of data.

Analysis of QC Test Results, IH-70, G Binder

Test No.	%Asphalt	%Density	P200
1	5.15	95.4	5.5
2	5.15	93.8	5.5
3	4.50	93.8	5.5
4	4.40	93.8	5.5
5	5.00	94.6	6.8
6	4.55	93.0	5.5
7	4.75	93.8	6.5
8	4.50	93.4	5.5
9	4.50	95.4	5.5
10	4.50	93.4	5.5
11	4.68	92.6	6.0
12	4.75	92.8	5.5
13	4.50	92.6	6.8
14	4.55	92.6	6.9
15	4.65	93.4	6.8
16	4.73	93.0	6.8
17	4.84	93.4	5.9
18	4.90	92.2	6.5
19	4.45	93.0	6.5
20	4.70	93.0	6.6
21	4.30	93.8	
22	4.45	93.8	6.08
23	4.50	93.4	0.59
24	4.55	92.6	
25	4.63	93.8	
26	4.82	93.8	
27	4.45	93.8	
28	4.75	93.0	
29	4.40	93.4	
30	4.66	93.8	
31	4.55	93.8	
32	4.50	93.4	
33	4.80	93.0	
34	4.57	93.8	

Analysis of QC Test Results, IH-70, G Binder

Test No.	%Asphalt	%Density	P200
35	4.45	93.0	
36	4.50	93.4	
37	5.00	93.0	
38	4.82	93.0	
39	4.45	92.6	
40	4.80	92.6	
41	4.60	93.4	
42	4.50	93.4	
43	4.60	93.8	
44	4.60	93.0	
45	4.88	93.8	
46	4.66	93.4	
47	4.48	93.8	
48	4.38	93.0	
49	4.45	93.4	
50	4.50	93.0	
51	4.80	93.8	
52	4.78	93.8	
53	5.58	93.8	
54	4.63	93.4	
55	4.45	93.4	
56	4.75	93.4	
57	4.45	94.2	
58	4.63	93.8	
59	4.50	93.0	
60	4.55	93.0	
Mean	4.64	93.42	
Std Dev	0.22	0.60	

Notes:

1. Test results from left to right do not correspond.
2. Average shown is not weighted.
3. See Fig 5 for plot of data.

Analysis of QC Test Results, IH-70, C Binder

Test No.	%Asphalt	%Density	P200
1	5.38	93.4	6.50
2	5.33	92.2	7.20
3	5.33	92.6	8.00
4	5.45	93.0	7.50
5	5.58	93.8	6.30
6	5.48	92.0	7.00
7	5.35	92.6	7.00
8	5.69	94.6	7.00
9	5.25	92.0	8.00
10	5.30	93.8	7.50
11	5.43	92.2	7.00
12	5.35	92.6	
13	5.45	93.8	7.18
14	5.55	93.8	0.54
15	5.55	94.2	
16	5.63	93.0	
17	5.35	94.2	
18	5.35	92.2	
19	5.40	93.4	
20	5.30	92.2	
21	5.35	92.2	
22	5.28	93.4	
23	5.36	92.2	
24	5.20	93.6	
25	5.45	93.8	
Mean	5.41	93.07	
Std Dev	0.12	0.81	

Notes:

1. Test results from left to right do not correspond.
2. Average shown is not weighted.
3. See Fig 6 for plot of data.