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HOT MIX RECYCLING DURANGO–HESPERUS

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16. Abstract

THIS REPORT DESCRIBES THE PERFORMANCE OF A HOT BITUMINUS PAVEMENT RECYCLING PROJECT LOCATED WEST OF DURANGO, COLORADO. THIS PROJECT, CONSTRUCTED IN 1978, WAS COLORADO'S SECOND WHERE ASPHALT PAVEMENT WAS REMOVED FROM THE ROADWAY, REPROCESSED IN A CENTRAL HOT PLANT AND REPAVED ON THE ROADWAY. PERFORMANCE OF THE PROJECT WAS MONITORED UNTIL SPRING 1984. ALTHOUGH DISTRESS ON THE NEW PAVEMENT WAS OBSERVED, PRIMARILY IN THE FORM OF SURFACE CRACKS, LITTLE VARIATION EXISTS BETWEEN THE RECYCLED AND VIRGIN MATERIAL.

Implementation

RESULTS FROM THIS AND SIMILAR PROJECTS IN COLORADO HAVE LED TO SPECIFICATIONS PERMITTING THE USE OF HOT RECYCLED BITUMINUS PAVEMENT. A COPY OF THESE SPECIFICATIONS ARE INCLUDED IN THE APPENDIX.

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PROJECT C 20-0160-12

I. INTRODUCTION

This report addresses Colorado's third hot mix recycling job, Project C 20-0160-12 on US Highway 160 west of Durango. The project begins at the junction of US Highway 160 and State Highway 140 eleven miles west of Durango and extends easterly for 5.2 miles. The original 3-lane highway was constructed by widening an existing 2-lane facility in 1965. This widening was facilitated by building up the outside lanes with a sand layer to meet the level of the center lane. The resulting roadway has a 44 foot width with approximately 3 1/2 inches of pavement on the driving lanes and 8 inches in the center passing lane. The driving lanes have been overlaid once by maintenance forces with a 3/4 to 1 inch mat to correct severe cracking problems. Since that time, the pavement condition has greatly deteriorated. The overlay displayed raveling, and numerous thermal cracks were reflected to the surface. In addition, a great deal of block type cracking was visible, and the entire 5.2 mile project contained numerous maintenance cold mix patches, some of which show flushing in the wheelpaths.

Because of the poor condition of this roadway, the feasibility of recycling the pavement was investigated.

A cost estimate for removing and recycling the top two inches of the old asphalt pavement, along with the preliminary test data, was submitted to the FHWA as part of a request for demonstration funds for recycling. FHWA demonstration funds contributed $2.00/ton of recycled mix to the project construction funds. Following approval of the recycling research proposal, members of the Research Section conducted a preconstruction evaluation of the project. Test sections were selected in areas typical for the project with good sight distances and safe access for evaluation. Preconstruction data included deflections using the Dynaflect, PSI from the CHLOE Profilometer, rut depths, and cracking and patching surveys. Photographs and visual observations were also made to document the pavement condition.

The preliminary design, construction and initial evaluation of this project's performance were covered in detail in an Interim Report, "Hot Mix Recycling, Durango-Hesperus, Project C20-0160-12."

II. PROJECT DESIGN AND CONSTRUCTION

Construction on this project began on September 20, 1979 with the removal of the top 2 inches of the old roadway using a Roto-Mill PR 750. The material from the three-lane roadway was hauled to the plant site where it was screened to remove any plus 2 inch material. The plus 2 inch material (approximately 2 percent of the total removed) was used to stabilize haul roads at the plant site. The minus 2 inch material was stockpiled to be recycled. Recycled material not used on this project was given to highway maintenance for roadway patching and stabilization.

The overlay asphalt pavement was produced using 70, 65, and 60 percent reclaimed pavement as well as the virgin mix. Table A contains a summary of the mix properties.

A modified CMI 9 x 36 foot dryer drum asphalt plant was set up on the project. The mix was initially placed at 240°F, however, in an attempt to reduce air pollution from the stack the mix temperature was reduced to 190-200°F. A Blow Knox paver and a large steel wheeled vibratory roller was used to place the 2 inch x 14 foot lift. With the lower mix temperatures it was found that one extra vibrating roller pass was required to obtain the desired compaction.

A detailed discussion of the equipment used on the project and air quality tests is included in the project Interim Report. The Interim Report also details the savings realized in material resources, energy, and dollars.

On the project, 131,598 square yards of pavement were removed with 16,251 tons of new pavement placed on the roadway. Approximately 600 tons of this pavement was virgin mix with the remainder being recycled material. 1,563 tons of milled pavement were not used and given to maintenance for their use.

III. PROJECT PERFORMANCE

Test sections were set up on the project to evaluate the long-term performance of the various overlay mix designs. Because of the variation in thickness of the pavement remaining after milling, each of the three lanes were identified and tested separately. Figure 1 illustrates the layout and location of the test sections.

TABLE A

Project C20-0160-12 Durango-Hesperus Hill

Summary of Central Laboratory Mix Testing

As Constructed

Specification Designation	Mix Blend 70/30	60/40	65/35	Virgin Mix
% Asphalt	5.17	5.37	5.19	5.86
% Passing 3/4"	100	99	100	100
% Passing #4	58	56	57	44
% Passing #200	10.6	10.3	10.5	7.1
% Voids	3.80	3.90	4.79	2.57
Stability Value	43	45	44	35
R_T Value	106	104	103	101
Index of Ret. Strength	107	104	112	100
Pen @ 77 F	128	109	110	85
Vis @ 140 F	586	717	737	1358
Vis @ 275 F	164	220	181	291

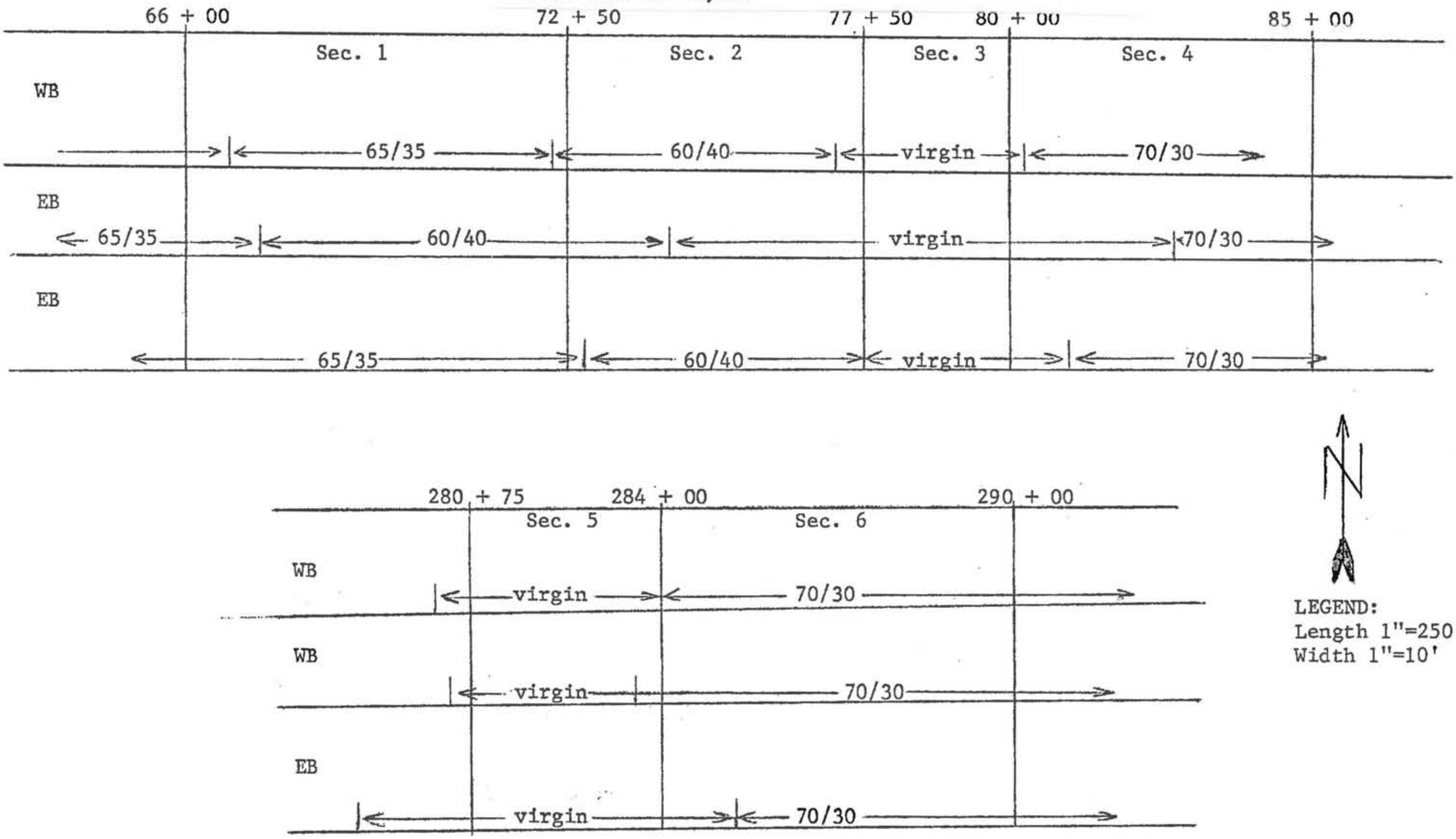
NOTE: Recycled mix contained 1% Dutrex based on the weight of the recycled material.

Figure 1

Project C 20-0160-12

Durango - Hesperus Hill

Test Section Layout



NOTE: In Figure 4 the data is referenced to the predominant mix in each test section. Cores were taken from the westbound driving lane of Sections 1-4.

The preconstruction test data in Figure 1 is located as follows.

Sec. 1-Sta. 70+00 to 75+00
Sec. 2-Sta. 75+00 to 80+00
Sec. 2a-Sta. 80+00 to 85+00
Sec. 3a-Sta. 275+00 to 280+00
Sec. 3-Sta. 280+00 to 285+00
Sec. 4-Sta. 285+00 to 290+00

A. Material Properties

Pavement samples taken during construction of each mix produced were submitted to the Central Materials Laboratory for extensive compliance testing. Specimens made in the laboratory were tested for voids, stability, Cohesiometer Value, modulus, and retained strength, (Immersion-Compression). Viscosity and penetration of the extracted asphalt cement and aggregate gradation were also determined. Table A lists a summary of the test data taken during construction. A review of this data shows that all four of the pavement mixes are adequate and comparable in R_T value, and Index of Retained Strength.

There were no gradation specifications for the recycled mixes, but the gradation is fairly uniform and as expected finer than normal grading E hot bituminous pavement.

Table B lists the test results from roadway cores taken annually from each test section starting shortly after construction was completed. As can be seen in Table B, the virgin mix is slightly coarser than the recycled mix and also contains more minus 200 material. Additionally, the virgin mix contains approximately 0.6% more asphalt cement.

As mentioned earlier, the recycled mix was placed at 190-200°F. The virgin mix, however, was placed at 140-250°F which along with the higher asphalt content helps explain the difference in % voids between the recycled and virgin mixes. The

TABLE 8

PROJECT C20-0160-12, DURANGO TO HESPERUS HILL

SUMMARY OF MATERIAL TEST PROPERTIES

Specification Designation	As Constructed Fall 1979	After Construction Fall 1979	Fall 1980	Fall 1981	Spring 1982
Location: 70/30 Blend (Section 4 & 6)					
% Asphalt	5.17	5.75	-	5.29	5.07
% Passing 3/4"	100	100	100	100	100
% Passing #4	58	59	57	56	56
% Voids	3.80	7.89	3.98	7.03	5.64
% Passing #200	10.6	11.0	11.7	10.6	10.8
Stability Value	43	22	41	34	33
R_T Value	106	83	102	96	97
Index of Retained Strength	107	-	-	-	-
Pen @ 77 F	128	63	61	33	67
Vis @ 140 F	586	1377	1428	3829	1458
Vis @ 275 F	164	231	224	314	221

* Lab molded samples. All later samples are from roadway coves.

TABLE B (cont.)

PROJECT C20-0160-12, DURANGO TO HESPERUS HILL

SUMMARY OF MATERIAL TEST PROPERTIES

Specification Designation	As Constructed Fall 1979	After Construction Fall 1979	Fall 1980	Fall 1981	Spring 1982
Location: 60/40 Blend (Section 2)					
% Asphalt	5.37	5.30	5.22	5.34	5.22
% Passing 3/4"	99	100	99	100	100
% Passing #4	56	59	57	57	60
% Passing #200	10.3	10.3	11.2	10.0	10.4
% Voids	3.90	7.71	4.71	5.55	4.81
Stability Value	45	31	37	30	33
R_T Value	104	92	100	94	97
Index of Retained Strength	104	-	-	-	-
Pen @ 77 F	109	136	89	46	60
Vis @ 140 F	717	587	1030	2400	1688
Vis @ 275 F	220	172	210	277	238

TABLE B (cont.)

PROJECT C20-0160-12, DURANGO TO HESPERUS HILL

SUMMARY OF MATERIAL TEST PROPERTIES

Specification Designation	As Constructed Fall 1979	After Construction Fall 1979	Fall 1980	Fall 1981	Spring 1982
Location: 65/35 Blend (Section 1)					
% Asphalt	5.19	5.10	4.94	4.97	4.83
% Passing 3/4"	100	100	100	100	100
% Passing #4	57	57	59	57	57
% Passing #200	10.5	10.1	11.4	10.0	9.9
% Voids	4.79	10.17	9.02	8.49	6.34
Stability Value	44	20	30	36	37
R_T Value	103	79	92	95	98
Index of Retained Strength	112	-	-	-	-
Pen @ 77 F	110	118	130	37	42
Vis @ 140 F	737	634	676	3250	2810
Vis @ 275 F	181	165	251	296	291

TABLE B (cont.)

PROJECT C20-0160-12, DURANGO TO HESPERUS HILL

SUMMARY OF MATERIAL TEST PROPERTIES

Specification Designation	As Constructed Fall 1979	After Construction Fall 1979	After Construction Fall 1980	After Construction Fall 1981	After Construction Spring 1982
Location: Virgin Mix (Sections 3 & 5)					
% Asphalt	5.86	6.46	5.28	6.36	5.94
% Passing 3/4"	100	100	100	100	100
% Passing #4	44	50	45	51	48
% Passing #200	7.1	8.0	7.1	7.8	7.9
% Voids	2.57	2.55	3.97	2.26	2.48
Stability Value	35	23	34	20	26
R_T Value	101	89	100	82	90
Index of Retained Strength	100	-	-	-	-
Pen @ 77 F	85	86	63	51	66
Vis @ 140 F	1358	1254	1784	2143	2015
Vis @ 275 F	291	275	321	332	329

recycled mixes averaging just over 6% voids, with the virgin mix just under 3%.

The differences in asphalt content, voids, and somewhat harder asphalt in the recycled mix shows up in higher stabilities and R_T values for the recycled mixes than for the virgin mix.

Although quite variable, the stabilities for all of the mixes are adequate. To cover the two extremes with the low voids and high asphalt content in the virgin mix, one might have expected some bleeding which did not occur, and with the high voids and low asphalt content in the 65/35 recycled mix, raveling might have been expected, which also did not occur.

The reclamite mentioned earlier may have helped prevent raveling, but it was primarily applied to treat the sections of roadway where early production was placed without enough modifying agent.

The primary mix used on this project with 70% reclaimed material appears to have properties and performed almost the same as the virgin mix.

B. Deflection Data Analysis

Deflection data was recorded during five time intervals from the preconstruction phase to three years after construction. With the exception of the deflection survey immediately after construction all surveys were taken at approximately the same time of the year (spring) to avoid seasonal variations. The central lab's Dynaflect equipment was used to measure deflections (both maximum deflections as well as four sensors spaced one foot apart longitudinally along the pavement). Temperature correction factors were applied to sensor number one only to adjust for a standard 70°F temperature. Deflection values represent an average deflection for each test section.

1. Maximum Deflections

Maximum deflections, as measured and recorded by sensor number 1 of the Dynaflect, were analyzed and graphically depicted on a bar chart (Figure 2) for the six test sections. These charts show a decrease in deflection values after project completion on all test sections. Subsequent testing indicate variations in some instances approaching pre-construction values. High subgrade moisture values during a particular testing period would be a logical explanation for this phenomena. Overall results, as shown in Table C, indicate a decreasing trend in deflections as compared to the preconstruction phase.

The values in Table C represent average deflections for all sections along with their standard deviations. Typical deflection reduction for the test sections average 28% with respect to preconstruction values. Deflection values range from a maximum of 1.12 mils to a minimum of 0.52 mils. These values represent averages of 5 readings per test section. In general, deflection values of low magnitudes as seen in this project, along with low standard deviations would

FIGURE 2

HOT MIX RECYCLING - DURANGO-HESPERUS

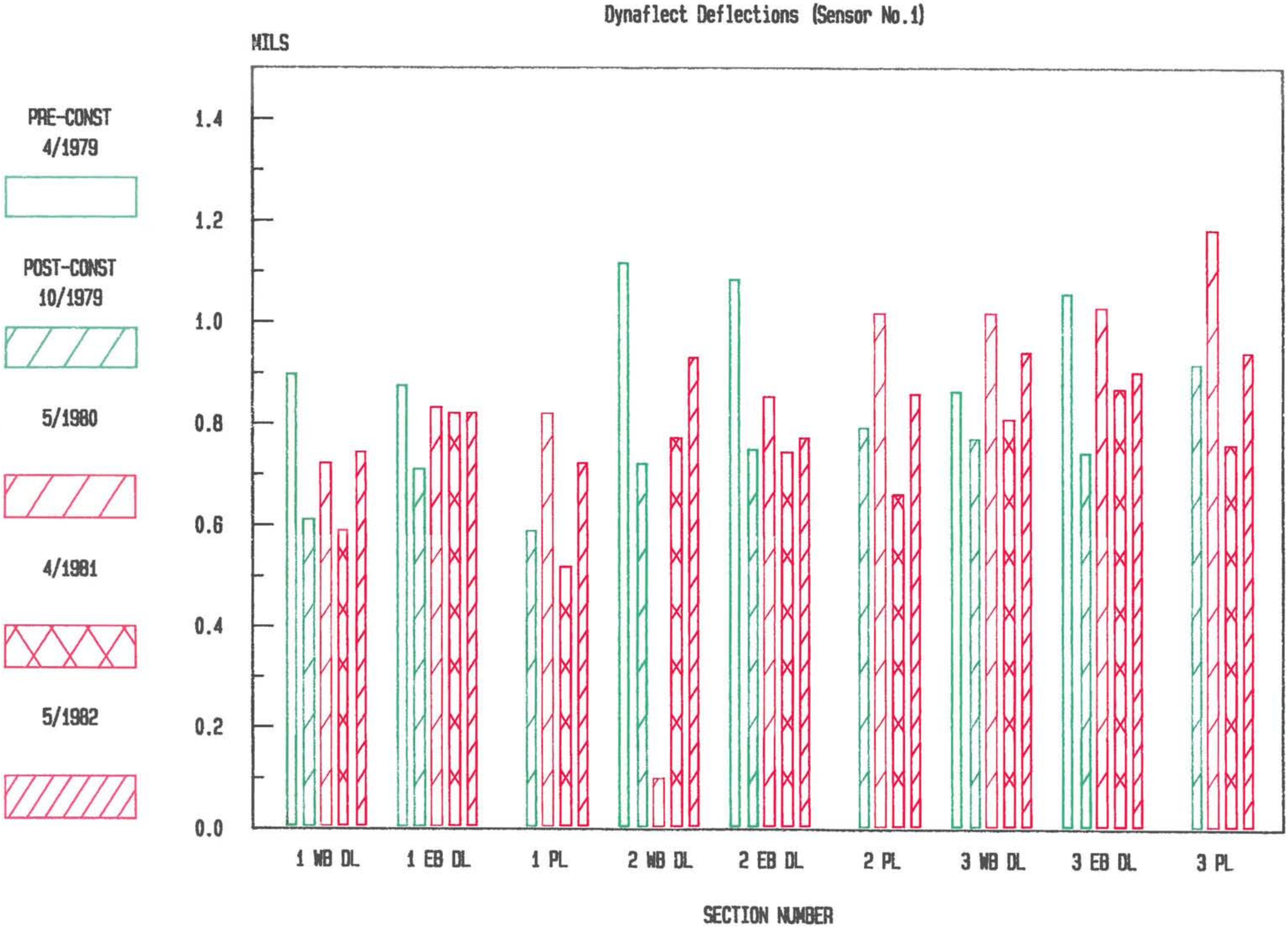


FIGURE 2

HOT MIX RECYCLING - DURANGO-HESPERUS

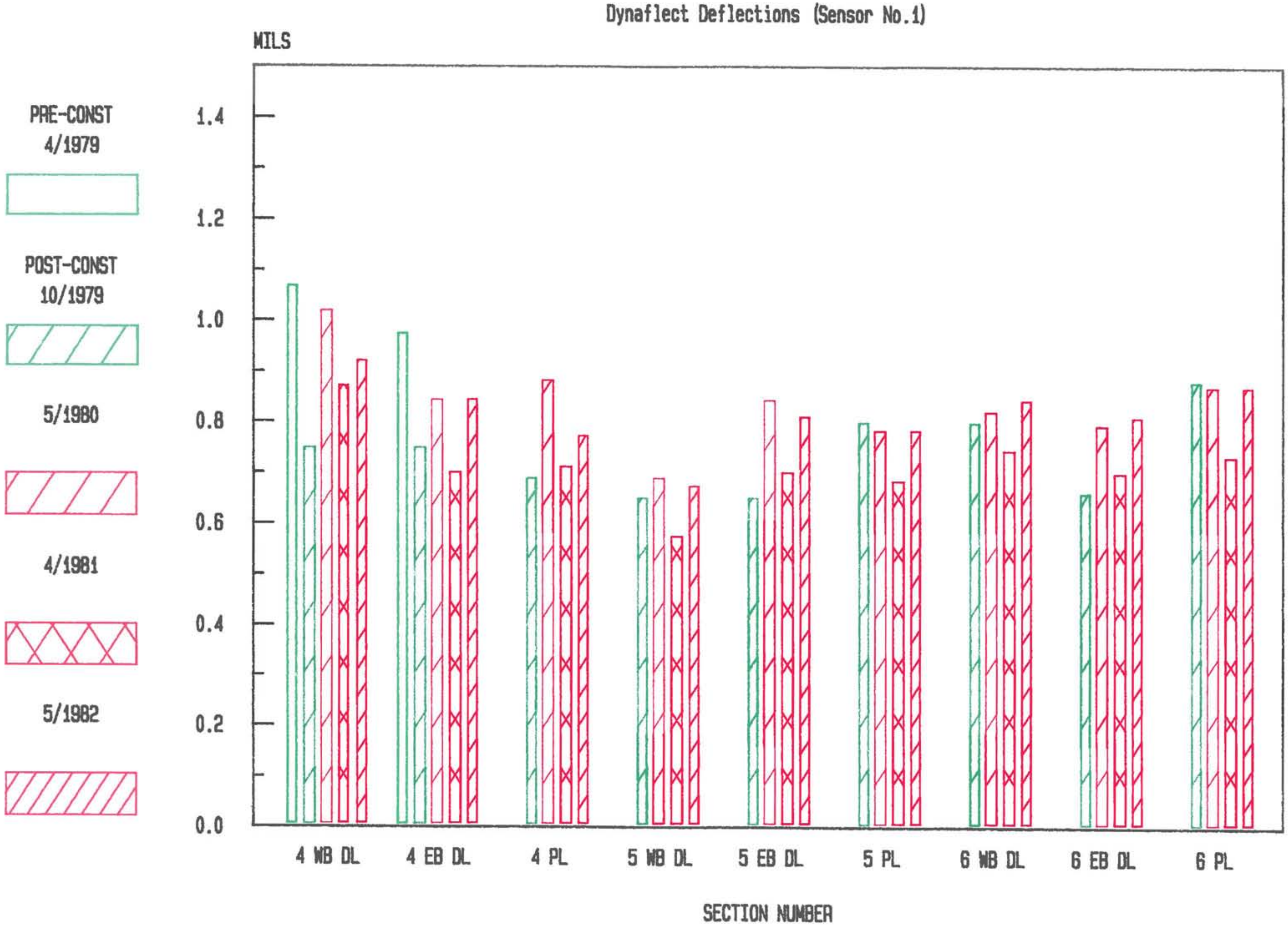


TABLE C

DURANGO-HESPERUS

MAXIMUM DYNAFLECT DEFLECTIONS

(SECTION AVERAGE BY LANES)

		Pre Const 4/79	Post Const 10/79	5/80	5/81
WESTBOUND LANE	AVG	.99	.72	.94	.76
	S.D.	.12	.07	.15	.12
EASTBOUND LANE	AVG	1.00	.71	.89	.75
	S.D.	0.09	.04	.09	.08
PASSING LANE	AVG	N/A	.78	.97	.66
	S.D.		.12	.16	.10

indicate adequate overall pavement performance. Refinements on this statement will be made in the following section dealing with the five-sensor analysis. At this point, three years after construction, there was no significant difference between driving lane vs. passing lane structural performance.

2. Five Sensor Analysis

The Colorado method*** of deflection analysis was used to determine the condition of the test sections. This method provides an assessment of the pavement's overall structure, and subgrade condition. Rating is limited to poor or good condition.

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The analysis method is based on sensor number 1, 3, and 5. Maximum deflection, surface curvature, and base curvature indices can be obtained from these three values. While the surface curvature index traditionally is the difference between sensor one and two, the Colorado method uses no temperature correction factor for sensor number three, thus simplifying these multi-sensor analysis as used in this report.

Traffic volumes are used to determine the allowable deflections for a given roadway and thus the criteria for roadway conditions. The traffic category for the test sections in this project was determined from the traffic volume study. The interpretation of "good" or "poor" is based on maximum deflection (Sensor #1) for Overall Condition, surface curvature index (SCI) for pavement Structure, and base curvature index (Sensor #3 minus Sensor #5) for the Subgrade condition.

Table D is a summary of the analysis using the Colorado method for the four dates indicated. The values in the table represent the project status based on the test section conditions. Particularly, they represent what percentage of the test sections is "good" according to the criteria outlined in the method. As can be seen in this table, all the sections had a good Overall Condition rating throughout the observation period based on Sensor #1. Structure ratings (SCI) range from 0% to 39%, with the values for post construction lower than the 1978 preconstruction value. Time of year could possibly be a factor in the outcome of this analysis. The decrease in "goodness" of condition is evident for the Subgrade also, indicating that spring moisture not only affected the subgrade

TABLE D

PAVEMENT CONDITION SUMMARY

PERCENTAGE OF TEST SECTIONS IN GOOD CONDITION

Date	Overall Conditions	Structure	Subgrade
1978 Preconstruction			
October/1978	100%	17%	50%
1979 Preconstruction			
Spring	100%	0%	33%
May/1980	100%	16%	61%
May/1982	100%	39%	61%

condition, but also affected the Structure. While the percent increase from pre-to-post construction for the Structure category is improved (0 to 16%) the absolute condition is less than anticipated. In summation, the project saw an improvement in condition ratings both in the Structure as well as Subgrade categories.

C. Surface Distress

Prior to construction, the pavement smoothness measurements indicated an overall PSI (using the CHLOE Profilometer) of 2.8. An average increase of 30 percent was found after construction with an average PSI of 3.7. Table E shows the observed measurements for each test section before and after construction. The surface of Section 5 eastbound (virgin mix) is somewhat rougher than the remainder; however, the difference is not believed to be significant. The difference is attributed to construction problems (material placement) and not the material itself.

TABLE E

PROJECT C20-0160-12, DURANGO-HESPERUS

SUMMARY OF SURFACE PROPERTIES

Section No.	Mix Used	Oct '78	Oct '79	Aug '80
Present Serviceability Index, PSI (CHLOE)				
1WB		3.0	3.8	3.6
1EB		2.6	3.6	3.5
1PASS		3.1	3.6	3.5
2WB		-	-	3.8
2EB		-	3.6	3.5
2PASS		-	3.7	3.7
3WB	2.7	3.8	3.7	
3EB	3.2	3.8	3.9	
3PASS	2.5	3.8	3.89	
4WB	2.5	3.6	3.7	
4EB	2.6	3.7	3.7	
4PASS	2.7	3.4	3.7	
5WB	3.0	3.8	3.7	
5EB	2.5	3.4	3.4	
5PASS	3.1	3.5	3.8	
6WB	2.7	3.9	3.6	
6EB	2.7	3.7	3.5	
6PASS	3.1	3.7	3.7	

During the observations made in August 1980, approximately one year after construction the cracking survey showed numerous transversed cracks on the shoulders where no milling occurred and the new overlay is only 1/2" to 1" thick. In the test sections where the full two-inch thickness of recycled pavement was placed, there were four linear feet of cracking in Section 3 (virgin mix) and one linear foot in Section 1 (65/35 Blend). There was no linear cracking in any other sections. The only alligator cracking in any of the sections was in the westbound driving lane of Section 1. Here 66 square feet occurred in the wheelpaths in the west 40 feet of the section.

Rut depths in the test sections averaged 0.1 inch or less in all of the test sections except the westbound driving lanes of Section 5 which had an average rut depth of 0.2 inch.

The entire project was treated with Reclaimite in April 1980. The Reclaimite was applied at a rate of 0.05 gal/yd^2 and appears to have gone into the pavement well. No slick spots were noticed and the entire project appeared to be holding up well.

In Spring 1981 the pavement in the test sections was generally in good condition but there were a few isolated areas of alligator cracking in adjacent sections of the roadway. (See Table F) This was believed to be caused by the weak base material in these localized areas. The cracking beginning to be observed in Sections 1 and 4 were in areas which were patched prior to construction.

Cracking had increased significantly on the project between 1981 and 1982, especially longitudinal cracking in the wheel paths and alligator cracking near the west end of the project. A small

TABLE F

CRACKING DATA SUMMARY

HOT MIX RECYCLING, DURANGO-HESPERUS

PROJECT C 20-0160-12

Section No.		8-13-80				5-13-81				6-23-82			
No.	Length	Linear (ft)		Alligator (ft)		Linear (ft)		Alligator (ft)		Linear (ft)		Alligator (ft)	
		ft	ft/1000 ft^2	ft^2	ft^2/1000 ft^2	ft	ft/1000 ft^2	ft	ft/1000 ft^2	ft	ft/1000 ft^2	ft	ft/1000 ft^2
(1)	650'	1	.04	66	2.8	36	1.5	133	5.7	762	32.6	443	18.9
(2)	500'	0	0	0	0	4	0.2	0	0	835	46.4	68	3.8
(3)	250'	4	0.4	0	0	4	0.4	0	0	206	22.9	0	0
(4)	500'	0	0	0	0	153	8.5	54	3.0	734	40.8	175	9.7
(5)	325'	0	0	0	0	0	0	0	0	18	1.5	0	0
(6)	600'	0	0	0	0	0	0	0	0	181	8.4	0	0

NOTE: Almost without exception, the areas with alligator cracking in sections 1, 2, and 4 were areas which were patched prior to construction in 1979.

Section No. 1 - 65% Recycled/35% virgin mix

2 - 60% Recycled/40% virgin mix

3 - 100% virgin mix

4 - 70% Recycled/30% virgin mix

5 - 100% virgin mix

6 - 70% Recycled/30% virgin mix

amount of patching had also been required near the west end of the project. One cause of this increase was the very wet winter of 1981-82. In one area of the project, slides removed part of the shoulder and westbound driving lane.

Except for the large increase in cracking near the west end of the project, the pavement appeared to have performed well since construction in 1979. There did not appear to be any significant raveling or bleeding at this time, and the pavement ride was good for most of the project. The CHLOE profilometer deteriorated to a point beyond repair so a qualitative PSI measurement was not available throughout the evaluation period of the project. Wheelpath rutting was not a significant problem. The only occurrences of rutting observed were in areas with alligator cracking resulting from base failures. Consequently, consolidation of the asphalt pavement is not believed to be in existence.

As part of the preparation of the final report a field review of the project was made to observe its condition 5 years after construction. A major observation on the project was that the distress reflects the pavement structure's ability to carry wheel loads on the site and not the difference in asphalt surface materials. Thus, the distress observed was primarily in the driving lanes where only the pavement thickness is only 3 1/2". In these areas the distress is believed to be attributed to the performance of the base and pavement foundation and not the surface. In the central passing lane where the original 6 inch pavement exists below the 2 inch recycled material, minor distress was observed throughout the project.

Table G lists distress ratings observed in the centerline lane. These observations, believed to be representative of the recycled asphalt performance, indicate that a strong performance trend does not exist from section to section. In most conditions the recycled pavement is performing as well as the virgin mix. Appendix A contains a series of photographs taken on the project. These include photo taken during construction as well as those showing the long-term distress observed in the project.

IV Savings

The total amount of recycled mix produced on this project was 15,638 tons. A savings of 10,041 tons of virgin aggregate and 811 tons of AC-10 was realized through recycling of the old pavement. 1,563 tons of milled pavement remained following completion of the paving. This material was taken to the district maintenance forces to be made into cold mix for pavement patching in other areas. The use of this crushed pavement represents a further savings in virgin aggregate and also asphalt cement resulting from this recycling project.

On this project the recycling option cost $4,643 more than a conventional 2 inch overlay of approximately 30 cents per ton of mix preserved. However, in a normal overlay, leveling course is often required and the use of only 207 tons of leveling course would make the comparative cost the same for a project of this length.

Because of the contractor's inexperience with recycling asphalt there were major problems with early production, eg. Dutrex softening agent was not added. Severe raveling took place and maintenance patching was needed in these areas.

TABLE G

HOT MIX RECYCLING, DURANGO-HESPERUS

OBSERVED DISTRESS AFTER 5 YEARS

CENTER PASSING LANE ONLY

Section	Mix	PSR	Remarks
1	65/35	3.0	Randsom transverse cracks only @ 15-20feet. Some cracks half width.
2	60/40	4.5	Almost perfect. Minor linear cracks.
3	Virgin	4.0	Longitudinal linial cracking.
4	70/30	2.5	Transverse cracks @ 25' opening up and beginning to spall.
5	Virgin	3.0	Transverse cracks @ 30', some hairline cracks beginning to spall.
6	70/30	4.5	Some transverse cracks at west end of section.

NOTE: PSR rating based on overall appearance, scale 0 (failure) to 5 (perfect).

Throughout most of the project, with the 70/30 blend, longitudinal cracking was progressing to alligator cracking in the driving lane wheelpaths. The passing lanes with greater base support shows no longitudinal cracking after 5 years of performance. Some transverse thermal cracking is beginning to appear in the passing lanes. Because of the added thickness the performance of the passing lane is believed to be more representative of the recycled asphalt and not the overall pavement structure.

The observations made in Spring 1984 included a distress survey of the project to the west, constructed one year later. Its rate of observed distress is almost identical to the recycled project. This further substantiates the researchers' feeling that the recycled mix did not contribute to the deterioration of the project.

V. CONCLUSIONS

Much was learned from this recycling project. From an air pollution standpoint, the 70% recycled-30% virgin material was never produced with acceptable capacities. The 60/40 blend, however, did show that air pollution regulations could be met with recycled mix. Future recycling projects may reflect this in mix designs. Future research should be aimed at producing mixes with a higher percentage of recycled material while meeting air pollution regulations because in many cases a higher percentage of recycled material will be more economical.

From an economic standpoint, recycling on this project cost approximately $0.30 per ton more than an equivalent amount of virgin mix. However, this project was the first recycling job for this contractor and at that point recycling was still in the experimental stages. Since this project has been built, contractors and highway personnel have become more knowledgable about recycling and a savings in energy and virgin materials has been reflected in the cost of recent recycling projects.

On this project, a savings in energy equivalent to 0.87 gallons of gasoline per ton of mix was realized. This savings was located in the area of crushing and haul of virgin aggregate, and also processing and delivery of asphalt cement. In addition, 10,000 tons of virgin aggregate, and 811 tons of AC-10 were saved.

The initial testing of the recycled mixes show that they are comparable to virgin aggregate mix in strength and stability Throughout the history of this project, distress was observed in the pavement surface. However, when a determination was attempted regarding the advantages or disadvantages of the recycled mix, the performance was overshadowed by the performance of the pavement's structure. Therefore, it was concluded that there was no significant difference in performance of the recycled vs the virgin mix. This finding was substantiated when an adjacent project, constructed a year later with a virgin mix performed no better and exhibited similar distress to the subject experimental project.

VI. IMPLEMENTATION

Experiences gained from this and other similar asphalt recycle projects resulted in a standard acceptance of recycled asphalt pavements in Colorado. Appendix B contains a revised construction specification available to a contractor who chooses to recycle asphalt pavement. This alternative is used to give the contractor an option between the standard specification for new asphalt concrete and recycled mix.

Appendix C contains a draft revision to the standard specification for asphalt plant mix pavements. It contains the standard options which may be used by the contractor in producing hot mix including the use of recycled material. Thus, an alternative hot bituminous pavement specification need not be considered when recycled material is used. This concept liberalizes recycling asphalt pavements.

APPENDIX A

PHOTO HISTORY OF PROJECT

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 1

PRECONSTRUCTION ROADWAY CONDITION. NOTE: RICH WHEELPATHS IN THE DRIVING LANE AND NUMEROUS TRANSVERSE AND LONGITUDINAL CRACKS.

PHOTOGRAPH NO. 2

ROTOMIL PLAINING ON CENTER LANE.
NOTE: CRACKING AND ROADWAY CONDITION IN FOREGROUND.

PHOTOGRAPH NO. 3

MILLED PAVEMENT STOCKPILE FOLLOWING SCREENING WITH 2 INCH SCAPLING SCREEN. SAMPLES FROM STOCKPILE AVERAGED 6.0% ASPHALT CEMENT.

PHOTOGRAPH NO. 4

BEGINNING OF PAVING OPERATION. RECYCLED MIX BEHAVED SIMILAR TO STANDARD MIX.

PHOTOGRAPH NO. 5

CMI 9' x 36' DRYER DRUM PLANT. NOTE DUAL FEED BELTS FOR VIRGIN AGGREGATE AND MILLED PAVEMENT.

PHOTOGRAPH NO. 6

FINISHED ROADWAY AFTER CONSTURCTION HAS GOOD APPEARANCE, SMOOTH RIDE, AND GOOD SKID RESISTANCE.

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 7

SECTION 1 (65/35 BLEND) OVERALL VIEW SHOWING MAINTENANCE OVERLAY ON LEFT.

PHOTOGRAPH NO. 8

SECTION 1 SHOWING SURFACE DISTRESS IN MAINTENANCE OVERLAY. BASE FAILURE IS BELIEVED TO BE THE PRIMARY CAUSE OF DISTRESS HERE.

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 9

SECTION 1 (65/35 BLEND) OVERALL VIEW SHOWING GOOD PERFORMANCE IN THICKER SECTIONS.

PHOTOGRAPH NO. 10

SECTION 1 SHOWING CLOSE-UP OF WHEEL-PATCH CRACKING IN WORST AREA OF DISTRESS.

HOT MIX RECYCLING

DURANGE-HESPERUS

PHOTOGRAPH NO. 11

SECTION 2 (60/40 BLEND) OVERALL VIEW.

PHOTOGRAPH NO. 12

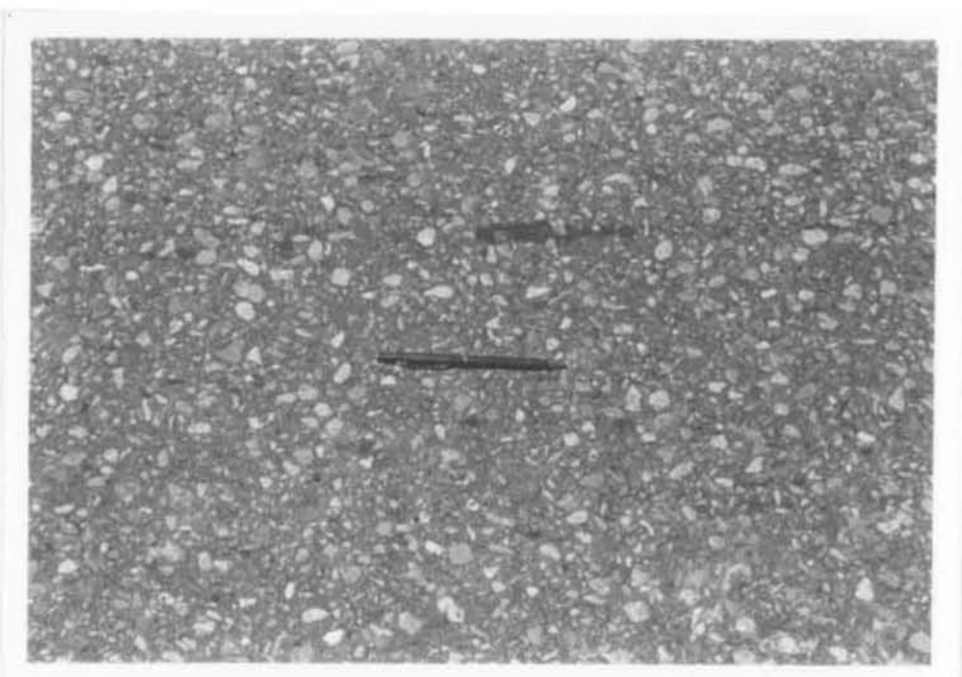
CLOSE-UP OF WORST CASE CRACKING IN WHEELPATH.

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 13

SECTION 3 (VIRGIN MIX) OVERALL VIEW SHOWS A RICHER LOOKING SURFACE



PHOTOGRAPH NO. 14

SECTION 3 CLOSE-UP

HOT MIX RECYCLING

DURANGO-HESPERUS

SECTION 4
(70/30 BLEND)

SECTION 3
(VIRGIN MIX)

PHOTOGRAPH NO. 15

INTERFACE BETWEEN SECTIONS SHOWING RICHER VIRGIN MIX ON RIGHT AND LEANER MIX ON LEFT

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 16

SECTION 4 (70/30 BLEND)
OVERALL VIEW

PHOTOGRAPH NO. 17

SECTION 4 SHOWING CLOSE UP OF WHEELPATH CRACKING. ALLIGATOR CRACKING ON LEFT IS ATTRIBUTED TO BASE FAILURE, LINEAR CRACKING ON RIGHT IS ATTRIBUTED TO EDGE OF UNDERLYING PAVEMENT.

PHOTOGRAPH NO. 18

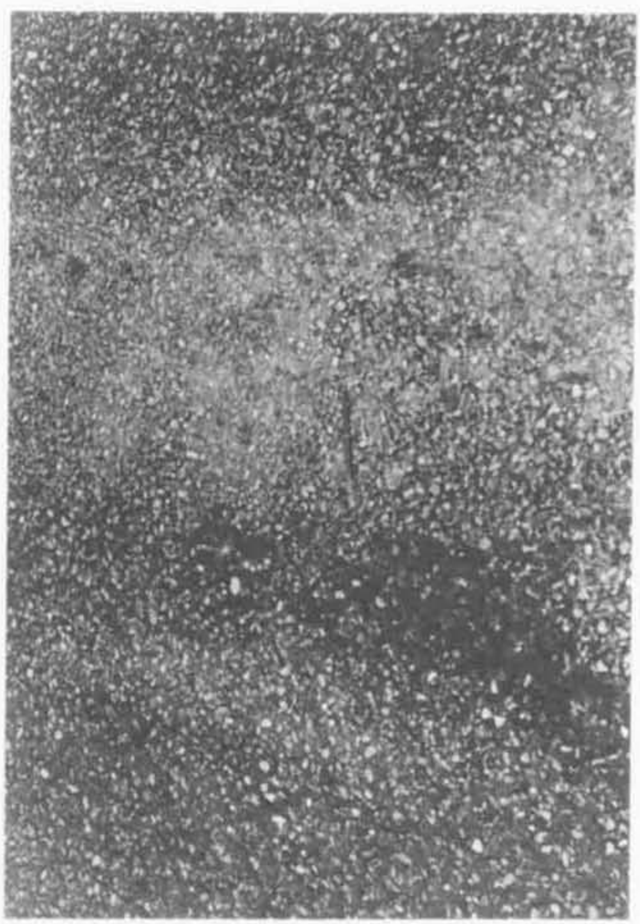
SECTION 5 (VIRGIN MIX)
OVERALL VEIW VIRGIN MIX
SECTION APPEAR RICHER THAN
RECYCLED SECTIONS WITH
BLEEDING OCCURING

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 19

SECTION 5 CLOSE-UP OF TRANSVERSE CRACKING IN LEANER AREA OF THE SECTION



PHOTOGRAPH NO. 20

SECTION 5 CLOSE-UP OF BLEEDING TYPICALLY OBSERVED IN VIRGIN MIX SECTIONS

PHOTOGRAPH NO. 21

SECTION 6 (70/30 BLEND)
OVERALL VIEW

HOT MIX RECYCLING

DURANGO-HESPERUS

PHOTOGRAPH NO. 22

SECTION 6 CLOSE-UP OF WORST CASE CRACKS IN WHEELPATHS OF DRIVING LANE.

PHOTOGRAPH NO. 23

SECTION 6 CLOSE-UP OF CENTER PASSING LANE SHOWING PERFECT CONDITION.

APPENDIX B

CONSTRUCTION SPECIFICATIONS FOR RECYCLED ASPHALT PAVEMENT

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT
COLORADO PROJECT NO.

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.02 shall include the following:

The job-mix formula as defined in subsection 401.02 for the Hot Bituminous Pavement (Grading EX AND PATCHING) shall be as follows:

Passing 1/2"	Sieve	-	100%
Passing #4	Sieve	-	65%
Passing #8	Sieve	-	50%
Passing #200	Sieve	-	7%

Asphalt Cement Viscosity Grade . . . . AC -10
Temperature of mixture when emptied from the mixer . . . . 280°F.

The source of materials is not designated. The job-mix formula asphalt content for the Contractor's proposed source of materials will depend on the physical characteristics of the proposed aggregate and will be established by the Laboratory on aggregate actually produced for the project. The estimated asphalt content is 6.0% by weight of mix. Due to variations in materials from different sources, this percentage can vary as much as one-half percent with no adjustment in contract unit price.

Initial approval of the Contractor's source of materials will be contingent on the job-mix formula mixture, using aggregate from the proposed source, meeting the specifications listed in the table below. If after initial approval of the source of materials, the job-produced material fails to meet the specifications shown in this table, the Engineer will suspend use of such material until laboratory tests indicate that the corrective measures taken by the Contractor yield material that is in compliance with this specification.

The Division will process a maximum of three asphalt design mixes at no charge to the Contractor. In the event additional design mix tests are required, the cost of such tests shall be borne by the Contractor and will be deducted from payments made to him.

The Contractor may use an additive such as an anti-stripping material, hydrated lime, or fillers to meet the mix design specifications. Additives will not be measured and paid for separately, but shall be included in the work.

When ordered by the Engineer, a tack coat shall be applied between the courses of pavement to improve bond.

Subsection 403.05 shall include the following:

Material used for tack coat will be measured and paid for as provided in Section 411.

-continued-

-2-
REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT
COLORADO PROJECT NO.

MIX DESIGN SPECIFICATIONS
HOT BITUMINOUS PAVEMENT (GRADING EX AND PATCHING)

Property	Test Method	Value	
Job-Mix Formula Asphalt Content, min., %	CP 42	Below Top	5.2
		Top Layer	5.7
Percent Voids	CPL 5105	Below Top	2-6
		Top Layer	2-5
Stability, min.	CPL 5105	34	
Strength Coefficient, * min.	CPL 5105	0.44	
Index of Retained Strength, min.	CPL 5104	75	
Accelerated Moisture Susceptibility Retained Tensile Strength, min.	CPL 5109	--	

* CDOH Design Manual

REVISION OF SECTIONS 403 AND 703
HOT BITUMINOUS PAVEMENT
COLORADO PROJECT NO.

Sections 403 and 703 of the Standard Specifications are hereby revised for this project as follows:

Subsection 403.01 shall include the following:

Hot bituminous paving mixtures containing reclaimed asphalt pavement materials will be accepted on an equal basis as hot bituminous pavement provided that all the requirements of the mix containing all new materials are met.

Delete the second paragraph of subsection 403.01 and replace with the following:

The bituminous pavement shall be composed of a mixture of aggregate, reclaimed asphalt pavement, if used, filler if required, and bituminous material.

Subsection 403.02 shall include the following:

The reclaimed asphalt pavement shall conform to subsection 703.04 of the Standard Specifications and revisions thereof included elsewhere in this Special Provision.

Asphalt Cement Recycling Agent. The recycling agent, if required, shall conform to the following requirements:

Specification Designation	Test Method	Requirements
Viscosity @ 140°F cSt	ASTM D2170	200-800
Specific Gravity	ASTM D70	Report
Flash Point C.O.C., °F	ASTM D92	400 min.
Oven Weight Change, 5 hrs. @ 325°F	ASTM D1754	4.0% max.
Viscosity Ratio **	ASTM D2170	3.0% max.
Saturates, wt.	*	30% max.

* Proposed ASTM Procedure for Asphalt Composition Analysis - Part 15, 1981 Edition.

** Viscosity Ratio = $\frac{\text{Viscosity after Oven Wt. Change Test, measured @ 140°F cSt}}{\text{Original Viscosity @ 140°F cSt}}$

The Contractor shall furnish the Engineer written documentation that the material supplied complies with the above requirements.

-continued-

-2-
REVISION OF SECTIONS 403 AND 703
HOT BITUMINOUS PAVEMENT
COLORADO PROJECT NO.

Delete subsection 403.03 and replace with the following:

The construction requirements shall be in accordance with subsections 401.07 through 401.20 and, if appropriate, as modified herein.

The job-mix formula for the combination of reclaimed asphalt pavement, new aggregate, asphalt cement, and recycling agent to be used will be established by the Laboratory. The combination of reclaimed asphalt pavement material and new material shall be determined by agreement of the Contractor and the Engineer. Asphalt cement shall be added at the rate of 6% by weight of new aggregate. Due to variations in materials from different sources, this percentage can vary as much as one-half percent with no adjustment in contract unit price.

Recycling agent shall be added to soften the asphalt cement of the reclaimed asphalt pavement to the consistency of the new asphalt specified for the project. Asphalt recycling agent shall be added at the Laboratory established rate (± 0.2%), but not to exceed 1% by weight of the reclaimed asphalt pavement (on a daily yield basis). If 40% or less reclaimed asphalt pavement material is used in the mix, a recycling agent will not be required.

The top lift of the bituminous pavement shall not contain more than 30 percent reclaimed asphalt pavement material.

At the pre-construction conference, the Contractor shall furnish a description of how he intends to introduce the reclaimed asphalt pavement, if used, into the bituminous mixture.

Subsection 403.05 shall include the following:

Haul, asphalt, asphalt cement recycling agent and all other work necessary to complete the item will not be paid for separately but shall be included in the unit price bid.

Section 703 of the Standard Specifications is hereby revised as follows:

Subsection 703.04 shall include the following:

Reclaimed asphalt pavement shall be of uniform quality. The material shall not contain clay balls, vegetable matter, or other deleterious substances. The maximum size of the reclaimed asphalt pavement material shall be 1-1/2 inches prior to introduction into the mixer. The maximum aggregate size contained in the combination of reclaimed asphalt pavement and new aggregate shall be the same as the largest size in the job-mix formula.

APPENDIX C

ALTERNATE SPECIFICATIONS

FOR OPTION TO USE

RECYCLED ASPHALT PAVEMENT

REVISION OF SECTION 401 PLANT MIX PAVEMENTS-GENERAL

DRAFT 9/12/83

Section 401 of the Standard Specifications is hereby revised for this project as follows:

Subsection 401.08 shall be deleted and replaced with the following:

401.08 Bituminous Mixing Plant. The bituminous mixing plant shall be capable of producing a uniform material and shall have adequate capacity.

The plant shall be maintained in good mechanical condition. Any defective parts shall be replaced or repaired immediately if, in the opinion of the Engineer, they adversely affect the proper functioning of the plant or plant units, or adversely affect the quality of the hot mix in any manner.

Acceptable safety equipment shall be provided by the contractor to accommodate testing and sampling and shall be subject to approval by the Engineer.

Storage Time of Hot Mix. Hot mix shall not be stored longer than nine hours, unless additional protective measures are used and approved by the Engineer.

Subsection 401.14 shall be deleted and replaced with the following:

401.14 Preparation of Aggregates. Heating and drying of the aggregates shall be accomplished in a manner that does not damage the aggregate.

When hydrated lime is required, it shall be added to the aggregate and the mixture stockpiled to undergo an aging process in accordance with the following:

(a) Dry Hydrated Lime Added to Wet Aggregates. A minimum of one percent hydrated lime (by dry weight of total aggregate) shall be added to the aggregate. Hydrated lime, water and aggregate shall be thoroughly mixed in an approved mechanical mixer and shall then be stockpiled in one or more stockpiles. The mixture shall contain between 5 percent and 8 percent moisture at the time it is stockpiled. If the aggregate contains excess moisture, the excess shall be removed before adding hydrated lime. The mixed material shall remain in the stockpile(s) for a minimum of 5 days before being processed to produce hot mix.

(b) Lime Slurry Added to Aggregate. A minimum of one percent hydrated lime (by dry weight of total aggregate) shall be added to the aggregate. The lime shall be added to the aggregate in the form of a slurry. The lime slurry shall contain a minimum of 70 percent water by weight. The slurry and aggregate shall be thoroughly mixed in an approved mechanical mixer and shall then be stockpiled in one or more stockpiles. The mixed material shall remain in the stockpile(s) for a minimum of 1 day before being processed to produce hot mix.

REVISION OF SECTIONS 401 AND 703 DRAFT 9/12/83
PLANT MIX PAVEMENTS, UNDESIGNATED SOURCE

Sections 401 and 703 of the Standard Specifications are hereby revised for this project as follows:

Subsection 401.02 shall be deleted and replaced with the following:

401.02 Composition of Hot Bituminous Mix. The hot mix shall be composed of aggregate, bituminous material, filler or additives if required, and reclaimed material if used.

Hot mix containing reclaimed material or containing all new material will be accepted on an equal basis provided that all the requirements for hot bituminous pavement are met.

When more than 40% reclaimed material is used in the mix, a modifying agent or softer grade of asphalt shall be added to soften the asphalt cement of the reclaimed material to the consistency of the new asphalt cement specified for the the project. Asphalt modifying agent shall be added at the Laboratory established rate $\pm 0.2\%$. The reclaimed material shall meet the requirements of subsection 703.04. Asphalt cement modifying agent shall meet the requirements of subsection 702.04.

The job-mix formula for each grading to be used will be established by the Laboratory using aggregates and, when applicable, reclaimed material actually produced and stockpiled for use on the project.

The Contractor shall submit the following to the Engineer:

(a) A proposed job-mix gradation which shall be wholly within the Master Range Table, Table 703-1, when the tolerances shown in Table 401-1 are applied.
(b) Source, approximate gradation, and percentage of each element used in producing the final mix.
(c) The name of the refinery which will supply the asphalt cement.
(d) A quantity of each aggregate, mineral filler, reclaimed material, and/or additive proposed for use which is sufficient for the required Laboratory tests.

The Division will process a maximum of three asphalt design mixes at no charge to the Contractor. A charge will be made for the testing and evaluating of each additional design mix submitted by the Contractor.

REVISION OF SECTIONS 401 AND 703 DRAFT 9/12/83
PLANT MIX PAVEMENTS, UNDESIGNATED SOURCE

When Laboratory tests indicate that a proposed job-mix formula meets Table 403-1, as revised for the project, a DOH Form 43 shall be executed between the Engineer and the Contractor. The DOH Form 43 will establish the job-mix formula (gradation, asphalt content, hot mix discharge temperature).

The job-mix formula shown on the DOH Form 43 shall be in effect, unless modified by the Engineer. All hot mix produced for the project shall conform thereto within the following ranges of tolerances:

Table 401-1

* Passing No. 8 and larger sieves	±8%
Passing No. 16 to No. 100 sieve, inclusive	±6%
Passing No. 200 sieve	±3%
Bitumen content	±0.5%
Hot mix discharge temperature	±20 degrees F

* When 100% passing is designated, there shall be no tolerance.

Deviations in excess of the tolerances shown in Table 401-1 for gradation and bitumen content will be subject to the requirements of subsection 105.03.

At the discretion of the Engineer, the job-produced hot mix may be tested for conformance to the criteria shown in Table 403-1 as revised for the project. Failure to meet any of the criteria shall be grounds to require the Contractor, at his expense, to take corrective action before being permitted to continue production.

If proper corrective measures cannot be readily determined, the Engineer will suspend the use of such material until Laboratory tests indicate that the corrective measures taken by the Contractor yield material that is in compliance with Table 403-1. Corrective measures shall be documented on DOH Form 43.

REVISION OF SECTIONS 401 AND 703 DRAFT 9/12/83
PLANT MIX PAVEMENTS, UNDESIGNATED SOURCE

Subsection 703.04 shall be deleted and replaced with the following:

703.04 Aggregate for Hot Bituminous Pavement. Aggregates for hot bituminous pavement shall be of uniform quality, composed of clean, hard, durable particles of crushed stone, crushed gravel, natural gravel, or crushed slag. The material shall not contain clay balls, vegetable matter , and other deleterious substances. Excess of fine material shall be wasted before crushing. The aggregate for gradings C, E, and EX shall have a percentage of wear of not more than 45 when tested in accordance with AASHTO T 96.

Recaimed material shall be of uniform quality. The material shall not contain clay balls, vegetable matter, or other deleterious substances. The maximum size of the reclaimed material shall be 1-1/2 inches prior to introduction into the mixer.

Table 703-1
MASTER RANGE TABLE FOR HOT BITUMINOUS PAVEMENT

Sieve Designation	Percent by Weight Passing Square Mesh Sieves			
	Grading C	Grading E	Grading EX	Grading F
1"				100
3/4"	100	100		
1/2"	70-95		100	
3/8"	60-88			
#4	44-72	44-72	50-78	
#8	30-58	30-58	34-60	45-85
#50	7-27			
#200	3-12	3-12	3-12	5-15

Special provisions
Work Sheet 403-2
Hot Bituminous Pave.
September, 1983
Note: Alter as necessary.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT
UNDESIGNATED SOURCE GRADING ____
COLORADO PROJECT NO. ____________

DRAFT 9/12/83

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.02 shall include the following:

The hot bituminous mix shall conform to the following:

TABLE 403-1

PROPERTY	TEST METHOD	VALUE
Percent voids	CPL 5105	______
Stability, minimum	CPL 5105	______
Strength Coefficient, minimum	CPL 5105	______
Index of Retained Strength, minimum	CPL 5104	75
Accelerated Moisture Susceptibility Tensile Strength Retained, minimum	CPL 5109	______

The asphalt cement for this grading shall be __________.

The top lift of the hot bituminous pavement shall not contain more than ________ percent reclaimed material.

Subsection 403.03 shall include the following:

When ordered by the Engineer, a tack coat shall be applied between pavement courses.

In subsection 403.05, delete the last paragraph and replace with the following:

Haul, asphalt, asphalt cement modifying agent, additives, and all other work necessary to complete the item will not be paid for separately but shall be included in the unit price bid. Material used for tack coat will be measured and paid for as provided in section 411.

****

<u>EXAMPLES OF GENERAL NOTES THAT COULD BE INCLUDED</u>

Hot Bituminous Pavement shall not be laid after October 1, 1983, without approval of the Engineer.

The Contractor shall use an approved anti-stripping additive.

REVISION OF SECTIONS 702 DRAFT 9/12/83
BITUMINOUS MATERIALS (ASPHALT MODIFYING AGENT)

Section 702 of the standard Specifications is hereby revised for this poject as follows:

Subsection 702.04 shall include the following:

(c) Asphalt modifying agents shall conform to the following physical and chemical requirements:

Specification Designation	Test Method	Requirements
Viscosity @ 140 F	ASTM D2170	100-300 cSt
Viscosity @ 275 F	ASTM D2170	3- 12 cSt
Specific Gravity	ASTM D 70	0.970-1.040
Flash Point C.O.C.	ASTM D 92	350 F min.
Oven Weight Change, 5 hrs. @ 325 F	ASTM D1754	4.0% max.
Viscosity Ratio **	ASTM D2170	3.0% max.
Asphaltenes	*	1.0% max.
Polar Aromatics	*	15.0% min.
Naphthene Aromatics	*	60.0% min.
Saturates	*	20.0% max.

* Proposed ASTM Procedure for Asphalt Composition Analysis Part 15,1980 Edition.

$$\text{**Viscosity Ratio} = \frac{\text{Viscoity after oven wt. change test, measured @140 F}}{\text{Original Viscosity @ 140 F}}$$