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RECYCLING ASPHALT PAVEMENTS

DURANGO, COLORADO

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HOT MIX RECYCLING
DURANGO-HESPERUS
PROJECT C 20-0160-12

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Interim Report
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Prepared in cooperation with the
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16. Abstract

This is an Interim Report covering preliminary mix design, construction experiences and the first post construction evaluation of Colorado's third Hot Mix Recycling Project west of Durango. The report contains extensive mix testing data, air pollution monitoring, and energy, economic, and natural resource analyses. The post construction evaluation contains Dynaflect, PSI, and Skid Resistance Measurements four weeks following construction.

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DURANGO-HESPERUS RECYCLE

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Introduction

Recycling of materials and conservation of energy and natural resources are becoming increasingly important in the highway construction industry because of rising costs, scarcity of new materials, and dwindling energy supplies. The FHWA was encouraging states to construct recycling projects through financial aid in conjunction with demonstration grants. The objectives of these demonstration grants were to encourage states to gain experience and to collect data pertaining to the design, construction, and costs of recycling, as well as energy consumptions and environmental considerations such as air pollution and conservation of natural resources.

Colorado has constructed three hot mix recycling projects. The first project was on US Highway 24, eight miles north of Buena Vista and was constructed during June, 1978. Here 100% recycled pavement was used for the lower coarse and new grading 'E' was placed as a wearing course. The second hot mix recycling project was constructed on Interstate 70 north of Grand Junction, Colorado. The primary mix on this 52,000 ton project consisted of a blend of 60% crushed pavement and 40% virgin aggregate. This report addresses Colorado's third hot mix recycling job, Project C 20—0160—12 on US Highway 160 west of Durango.

EXISTING PAVEMENT CONDITION

This 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 present 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' 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 is 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.

PRELIMINARY TESTING AND DESIGN

A. Preliminary Mix and Road Testing

Prior to requesting demonstration funds for this project, samples of the existing pavement were submitted to the central laboratory for testing to determine the possibility of recycling the old mat.

Appendix A contains the laboratory procedure used to provide a preliminary mix design for the hot mix recycling of the old pavement. Included in the procedure are some of the physical properties of the existing mat, such as aggregate gradation and asphalt cement penetration and viscosity. The final mix design was to be based on tests using the stockpiled pavement, virgin aggregate and modifying agent on the project. Also contained in Appendix A are plan specifications for the modifying agent. These specifications were determined from the preliminary testing on the existing pavement and from previous recycling projects.

Following the determination that hot mix recycling of the old mat was feasible, 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.

Photographs No. 1 and No. 2 show typical pavement conditions for this project.

Figure 1 is a summary of the preconstruction evaluation of the areas to be used for test sections on this project.

Deflections were taken in both the Fall and Spring because some of the cracking problems were believed to be a result of water in the subbase, and data was needed to show that the base was adequate even under saturated conditions found in the spring. These deflections also show that this roadway has an adequate base strength for the traffic volume.

A review of the 1977 Colorado Sufficiency Study shows that the overall PSI for this section of roadway is 3.2 prior to construction.

B. Final Mix Design

Following the approval of this project, final construction plans were developed. Some changes from the original laboratory testing were incorporated into these plans. Appendix B contains the special provisions concerning pavement removal and stockpiling as well as other aspects of recycling. A review of these provisions shows that the size requirement for old pavement to be recycled was passing a two inch screen.

Following the awarding of the construction contract and the start of pavement removal, samples of the reclaimed pavement, virgin aggregate, AC—10, and modifying agent were submitted to the Central Materials Laboratory for a final mix design. The final mix designs were made at this time because a more representative sample of the pavement to be recycled could be obtained from the reclaimed pavement stockpile, and the actual modifying agent (Dutrex), AC—10, and virgin aggregate to be used on the project were available.

Because of the experimental nature of this project, and the unknowns concerning air pollution from the dryer drum plant, mix designs using 70%, 60%, and 50% recycled material were made as well as a mix design for the virgin mix to be used for comparison. Appendix B contains the mix designs for these various blends.

On the project, mixes were produced using 70%, 65%, and 60% reclaimed pavement as well as the virgin mix. The success of these various blends will be discussed later in this report.

Figure 1
Preconstruction Field Data Summary*
Project C 20-0160-12
Durango - Hesperus

	CHLOE PSI	Deflection** (mils) 10-4-78	4-24-79	Avg. Rut Depth (in)	15 Probe Texture	Linear Ft/1000 ft^2	Cracking & Alligator Ft^2/1000 ft^2	F
1-WB	3.0	.673	.899	.06	25			
1-EB	2.6	.758	.875	.15	5	163.0	40.5	
1-P	3.1	.975	--	.05	12			
2-WB	3.1	1.009	1.119	.09	26			
2-EB	2.7	.896	1.083	.10	21	153.6	40.5	
2-P	3.2	1.156	--	.01	22			
2a-WB	2.5	--	1.030	.11	8			
2a-EB	2.6	--	1.054	.23	15	196.6	8.5	
2a-P	2.7	--	--	.05	17			
3a-WB	3.2	--	.834	.13	28			
3a-EB	2.2	--	.782	.23	7	165.8	30.6	
3a-P	3.1	--	--	.05	16			
3-WB	3.0	.835	.866	.19	20			
3-EB	2.5	.869	1.055	.21	13	171.3	17.4	
3-P	3.1	1.065	--	.03	18			
4-WB	2.7	1.041	1.068	.13	32			
4-EB	2.7	.845	.973	.08	30	165.1	19.1	
4-P	3.1	.989	--	.01	22			

*All data except deflections were taken October 11-13, 1978.

**Deflection measurements are for Dynaflect Sensor #1, corrected to 70°F. Fiv readings per section per lane were taken and locations were marked so that readings could be repeated in the same spot.

CONSTRUCTION EXPERIENCES

Pavement removal began on September 20, 1979. Using a Roto-Mill PR750, the top two inches of the old roadway were cold planed from this three lane highway. The Roto-Mill used 5/8" teeth on a 5/8" spacing and removed the entire two inch depth in one pass. The pavement was removed starting with a twelve foot pass in the center lane. The center lane was generally milled until noon, then the other two lanes were completed for that distance on the same day. Using this method, two inches of pavement were removed from a 36 foot width on approximately 3200 lineal feet of roadway per day. Photograph No. 3 shows the Roto-mill operating in the center lane and also some typical roadway cracking. Photo No. 4 shows a typical section of roadway following planing.

Using the conveyer belt on the Roto-Mill the milled pavement was loaded on 5 axle dump trucks to be hauled to the plant site and stockpiled.

At the plant site, the old pavement was screened to remove any plus 2 inch material. The plus two inch material (approximately 2% of the total removed) was used to stabilize haul roads at the plant site and the minus two inch material was stockpiled to be recycled. Photographs No. 5 and No. 6 show the old pavement stockpiles before and after screening.

During the week of September 17, a CMI 9' x 36' dryer drum asphalt plant was set up on the project. Production began on the afternoon of September 27 using a blend of 70% reclaimed pavement and 30% virgin aggregate. At this time, the mix was placed on the road at 240°F using standard laydown equipment; a Blaw Knox paver and 5-axle trucks for haul. Compaction was achieved using a large steel wheeled vibratory roller. Photograph No. 7 shows the start of the paving operation with a 2" x 14' lift being placed over the milled surface. A CSS-1H Tack coat was used for this project. The mix behaved in the same manner as standard Grading E pavement.

In attempts to reduce air pollution from the stack making the 70/30 blend, the mix temperatures at times dropped to 190-200°F. With these low mix temperatures, it was found that one extra vibratory pass was required to obtain the desired compaction.

Because of the experimental nature of this project, mixes using various percentages of reclaimed material were produced, as well as virgin mix using all new material. Plant stack opacities were monitored for blends using 70%, 65%, 60%, and 0% reclaimed material and samples of these various mixes were sent to the Central Materials Laboratory for extensive testing. In add test sections were laid out where these various mixes were placed sc annual evaluations can be conducted for at least the next three yea compare their relative performance.

During the week of October 8, approximately one mile was added t project on the east end. Milling of the top two inches was complet October 9, and paving on this project was finished on October 12, 1979 the project, 131,598 square yards of pavement were removed, and 16,251 t new pavement were placed. Approximately 600 tons of this pavement was v mix, the remainder recycled mix; 1,563 tons of milled pavement were not in the recycled mix. This unused material was taken by District 5 mainte forces to be used in cold mix for roadway repair.

EQUIPMENT MODIFICATIONS

There were no equipment modifications required for the rer screening, and stockpiling of the old pavement. The Roto-Mill d excellent job of maintaining an even profile removing a uniform two down the roadway. The removal of two inches of pavement eliminated irregularities in the pavement surface and the profile both down and a the road was very even as seen in Photograph No. 8.

The loading of the old pavement was facilitated by the conveyer bel the Roto-Mill onto 5 axle diesel dump trucks. The removed pavement was h to the plant site and dumped. Two front end loaders were used to ru milled pavement over a 2 inch scalping screen and stockpile the minus two material for recycling. Since the pavement removed had less than 2% plu inch material, this oversized pavement was used to stabilize haul roads a the plant area instead of requiring further treatment to reduce its siz

A CMI 9' x 36' dryer drum plant specifically modified to process e recycled or virgin mix was used on this project. This asphalt plant has feeds to allow separate entry of the recycled and virgin aggregate. material enters through a standard drum inlet next to the burner reclaimed material is added downstream from the burner, thus elimin contact with the flame. The downstream entry of the reclaimed aggrega permitted by use of a flop gate mechanism shrouded with a metal collar.

gates are opened and closed by gravity as the drum rotates allowing the recycled material to enter at the top of the drum without contacting the flame and also not allowing the hot gasses in the drum to escape. Photograph No. 9 shows the dual aggregate feed system on this plant.

Another special feature of this plant is special flighting designed to maximize the heat transfer from the flame to the virgin aggregate as well as to create a veil of virgin aggregate to prevent the flame from contacting the recycled material. Following entry of the reclaimed material another zone in the drum has special flighting to maximize the mixing of the reclaimed and superheated virgin aggregate so that the reclaimed material is quickly heated and the mix is of uniform temperature. Also in this zone, the liquid asphalt cement and any other fillers are added to the mix. Following this, the material is mixed further before exiting the drum.

The above special recycling kit was purchased from CMI and installed by the contractor at an approximate cost of $128,000.

The only other modification to the plant was done over a weekend following two days of production. In order to reduce air pollution, several baffles were placed in the drum between the virgin aggregate and reclaimed pavement entries so that the virgin aggregate would be retained in front of the flame longer. This helped create a better veil of virgin aggregate to shield the reclaimed pavement from the flame and did significantly reduce opacity from the plant stack.

In addition to these plant modifications, the dryer drum was set up on a slope of 1/2 inch per foot. This flatter than normal slope was incorporated to slow down the flow of material through the drum and help prevent air pollution. Since the slope was not varied during production, the affect of this variation could not be determined.

AIR POLLUTION

A. Stack Opacities

Meeting air pollution standards has been one of the major obstacles in hot mix recycling. This asphalt plant was issued a permit by the Colorado Air Pollution Control Division because of the successful performance of a similar plant on another recycling project (Clifton West) where a predominently 60/40 blend was used. No stack particulate sampling was performed on the asphalt plant used west of Durango.

The plant was equipped with a wet scrubber with venturi, and a 10' x 40' stack. Water was trucked to the plant site and circulated through two ponds during plant operation. For this project, the pressure drop across the venturi was set at 11 inches of water and detergent was added to the water to improve its effectiveness.

Production began on the afternoon of September 27 using a blend of 70% reclaimed pavement and 30% virgin aggregate. During production, opacities were recorded by a member of the Research Section, and certification opacities were recorded by a representative of the Colorado Department of Health, Air Quality Control Division.

Table A of Appendix C lists the opacity readings taken during production as well as mix temperature, production rate, and blend being produced.

Stack opacities during the first two days of production varied from 30 to 55% depending on mix temperature and production rate. With the plant configuration during the first two days of production the major factor in decreasing opacity was increasing production rate. The increase of production rate increased the virgin aggregate input and hence the veil protecting the crushed pavement from the burner flame. The production rate was varied from 400 to 550 tons/hour during those two days. The average opacity at 400 tons per hour was 50% and the average at 550 tons per hour was 30%. Figure 1 of Appendix C shows a graph of opacity versus production rate for these two days. These readings are well above the Colorado Opacity Standard of 20%.

The plant was shut down for the weekend, and during this time some modifications were made to the plant. Baffles were put into the drum to slow the virgin aggregate and help create a denser veil between the burner and the recycled aggregate entry. Additionally, detergent was added to the scrubber water at this time.

Production of 70/30 blend continued on October 1 with a noticeable improvement in opacities which now varied from 25–40% depending primarily on mix temperature. Figure 2 of Appendix C is a graph of the relationship between opacity and mix temperature. As can be seen from this graph, production using a 70% reclaimed pavement-30% virgin aggregate blend never attained the 20% state opacity standard. It was noted in reviewing the data that any relationship between production rate and opacity seemed to be eliminated following the plant modification over the previous weekend.

In addition to the 70% reclaimed/30% virgin aggregate blend, mixes consisting of 65%, 60%, and 0% reclaimed pavement were also produced. The average opacity for the 65/35 blend was 22% with mix temperatures varying from 200^{o}F to 230^{o}F. Producing a mix from 60% reclaimed pavement and 40% virgin material opacities were much more acceptable. Figure 3 of Appendix C shows the results of opacity versus mix temperature for the 60/40 blend. The mix data shows that mix temperature varied from 200^{o}F to 270^{o}F and that acceptable emission rates should be attainable for mix temperatures under 240^{o}F. The virgin aggregate mix had no problems meeting the 20% opacity standard with observed opacity values of 3-10%. The mix temperature for the virgin mix was 275^{o}F.

As can be seen from the above data this plant met air pollution standards producing virgin mix and 60% reclaimed pavement-40% virgin aggregate blend. This plant did not demonstrate that acceptable opacities could be attained with a 65% or a 70% reclaimed pavement mix.

B. Ambient Pollutants

In addition to the opacity monitoring, two Hi-Vol samplers were used to sample ambient particulate concentrations in the plant area. Sampler No. 1 was set up near the dryer drum approximately 30 feet north of the main haul road and also 30 feet east of the virgin aggregate feed belt. Photograph No. 10 shows the sampler No. 1 location relative to the dryer drum and feed belts. Photograph No. 11 shows the location of Sampler No. 2 in a vacant area near the test shack.

Figure 2 lists the particulate concentrations measured at this plant site. As can be seen from this figure, the concentrations at Sampler No. 1 are considerably higher than those measured at Sampler No. 2. The prevailing afternoon wind was from the northwest and dust and particulates generated by the front loader filling the feed bins and also the feed belts were carried past this sampler location. On days of little activity, September 26 and 27, particulate concentrations at the two samplers were comparable. The particulate concentrations measured on this project are typical to those found at similar construction sites.

Figure 2
Ambient Particulate Concentrations during Plant Operation
Durango - Hesperus Hill Recycle

Hi Vol Sampler #1

Date Removed	Number of Hours	Sample Concentration $\mu g/m^3$
9-26-79	23	111
9-27-79	25	127
9-28-79	23	1064
9-28-79	9	2962
10-2-79	23	927
10-3-79	25	2551
10-4-79	23	2394
10-5-79	24	1254

Hi Vol Sampler #2

Date Removed	Number of Hours	Sample Concentration $\mu g/m^3$
9-26-79	23	94
9-28-79	22	194
9-28-79	25	172
10-1-79	6	107
10-3-79	25	579
10-4-79	24	621
10-5-79	23	730

In addition to the ambient particulates, ambient carbon monoxide concentrations were periodically measured in the plant area. An Ecolyzer was used to check CO concentrations when there was activity in the plant area. In general, concentrations were from 0-2 ppm while the plant was in operation. The highest concentration measured was 5 ppm at the scale shack directly downwind from the plant site. On this day the wind was forcing the plume to the ground in the scale shack area. This same strong wind quickly dispersed pollutants generated in the plant area. There did not appear to be any carbon monoxide problems in the plant area.

PHYSICAL TESTING

A. Central Materials Laboratory

Pavement samples of each of the mixes produced on this project were submitted to the Central Materials Laboratory for extensive compliance testing. Specimans 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. Figure 3 lists a summary of the test data and complete test results appear in Table A of Appendix D. A review of this data shows that all four of the pavement mixes are adequate and comparable in strength, R_T value, and Index of Retained Strength.

B. Field Laboratory

Standard acceptance testing was performed in the field laboratory throughout the paving operation. Mix temperatures were recorded at the plant and as placed on the road. Periodic samples of the paving material were taken and analyzed in the field for percent moisture, percent asphalt, and aggregate gradation. Additionally, density and compaction measurements were taken on the roadway to assure proper placement of the pavement. A summary of the field laboratory data is listed on Table B of Appendix D. 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.

C. Post Construction

Following completion of the project, a post construction evaluation was conducted on the test sections established before construction.

Figure 3

Summary of Central Laboratory Mix Testing

Mix	70/30	70/30	70/30	60/40	65/35	Virgin Mix
% Asphalt	5.19	5.17	5.27	5.37	5.19	5.86
% Passing 3/4"	100	100	100	99	100	100
% Passing #4	57	58	70	56	57	44
% Passing #200	9.8	10.6	12.1	10.3	10.5	7.1
Stability Value	44	43	49	45	44	35
R_T Value	106	106	107	104	103	101
Index of Ret. Strength	119	107	104	104	112	100
Pen @ 77^o F	---	128	---	109	110	85
Vis @ 140^o F	---	586	---	717	737	1358
Vis @ 275^o F	---	164	---	220	181	291

Because of the placement of the various mixes in the test areas, the boundaries of the "as constructed" test sections were adjusted and the sections were renumbered to facilitate this and future evaluations. Figure 4 is a map of the test sections evaluated. The stations of the preconstruction test areas are listed so that before and after construction data can be compared.

The post construction evaluation was conducted during the week of October 15, 1979. Included in this evaluation were PSIs using the CHLOE Profilometer, rut depths, and textures as well as deflections from the Dynaflect and skid resistance and PSI measurements from the skid truck. CHLOE PSIs averaged 3.7 following construction, and the deflections using the Dynaflect were approximately 0.2 mils lower than pre-construction data. Visual observations and photographs were also taken to document the condition of the roadway and core samples of the various mixes used on this project were taken and submitted to the Central Materials Laboratory for extensive testing. Figure 5 summarizes the post construction data.

No rut depths or cracking were present in this new project. Photograph No. 12 shows the finished roadway looking west across test sections 1-4.

In addition to the test section data, the Colorado Department of Highways skid test vehicle was used to rate the entire length of the project. However, due to equipment breakdown, only the eastbound driving lane was rated with the skid truck. The skid truck PSI for the length of the project was 4.0 and the average of eight skid resistance tests at 40 mph was 57.

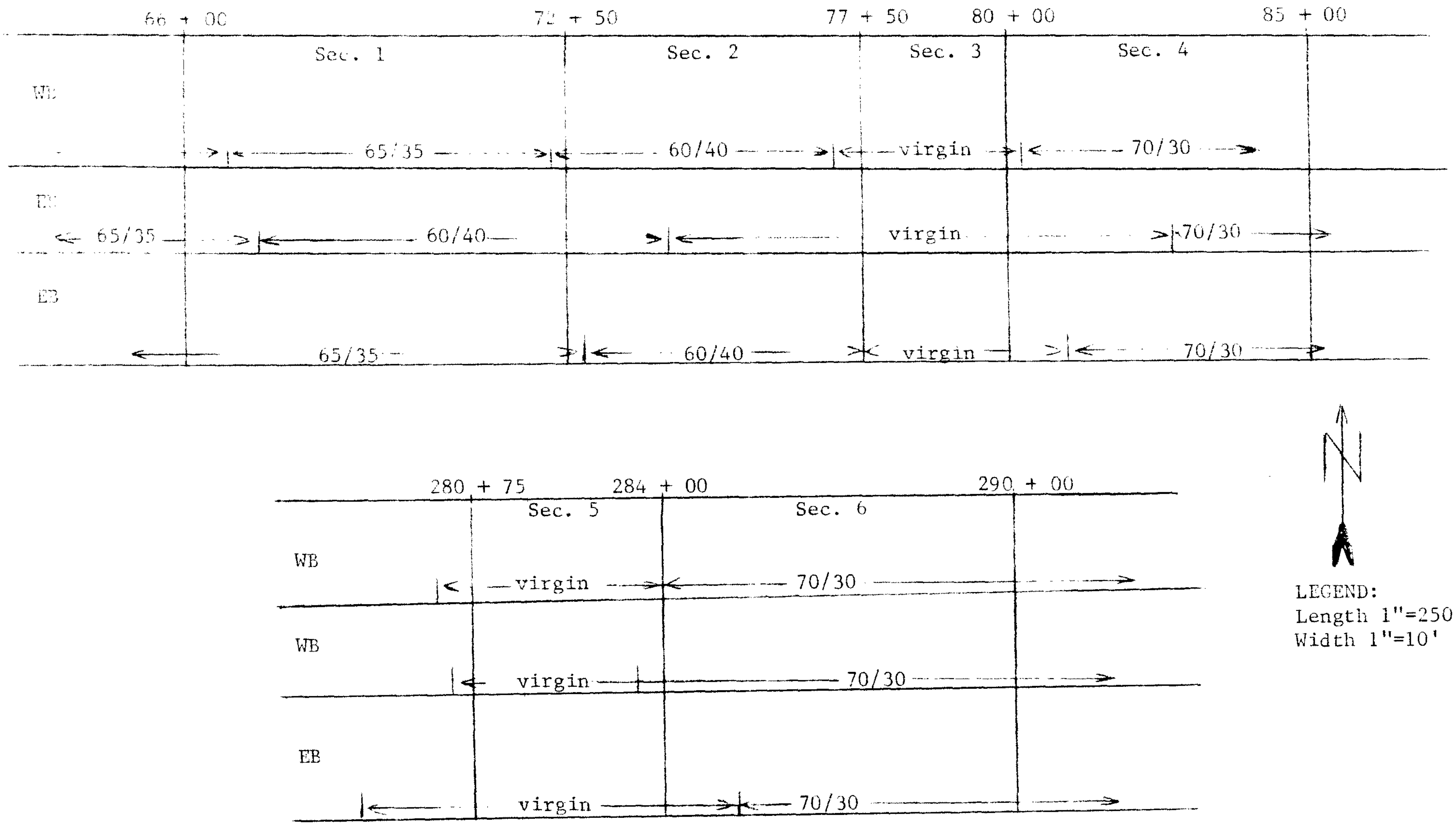
The finished pavement has good ridability and a good skid resistance. Table C of Appendix D shows the test data for core samples from the test sections. In addition, Appendix D Table D shows test results for a 70/30 mix where the modifying agent was limited to 0.3% by weight of the reclaimed pavement instead of the 1.0% called for in the mix design. This sample is much stiffer than the other mixes and will probably be much more susceptible to cracking in the winter. Additional data from these samples is the asphalt composition analysis which shows that the asphalt cement extracted from these cores is both similar and adequate. Table E of Appendix D shows the results of the Asphalt Composition Analysis from the roadway core samples.

Figure 4

Post Construction Test Sections

Project C 20-0160-12

Durango - Hesperus Hill



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. 3a-Sta. 275+00 to 280+00

Sec. 2-Sta. 75+00 to 80+00   Sec. 3-Sta. 280+00 to 285+00

Sec. 2a-Sta. 80+00 to 85+00   [illegible]

Figure 5

Project C 20-0160-12

Durango-Hesperus

Summary of Post Construction Evaluation Data

Section Number	Mix Used	Eastbound Driving Lane*		Westbound Driving Lane*		Passing Lane*	
		PSI	Deflection	PSI	Deflection	PSI	Deflection
1	65/35	3.6	0.705	3.8	0.605	3.6	0.589
2	60/40	3.6	0.750	3.6	0.716	3.7	0.785
3	Virgin Mix	3.8	0.735	3.8	0.767	3.8	0.915
4	70/30	3.7	0.754	3.6	0.746	3.4	0.692
5	Virgin Mix	3.4	0.645	3.8	0.653	3.5	0.796
6	70/30	3.7	0.657	3.9	0.804	3.7	0.880

* Average of 5 readings per lane/section. Sensor #1 deflection in mils, corrected to 70°F (10/23/79)

Post construction evaluations will be done annually for at least the next three years to document how the project performs over time. The laboratory testing will also help determine how recycled mix ages compared to the aging of virgin mix.

NATURAL RESOURCES

The quantities used for this analysis are the actual quantities used on the project and were taken from contractor and highway department records. The total amount of recycled mix produced on this project was 15,638.45 tons. Figure 6 lists the quantities of each type of material used and the quantities that would be required for an equal amount of virgin mix.

A review of Figure 6 shows that a savings of 10,041 tons of virgin aggregate and 811 tons of AC-10 was realized through recycling of the old pavement. The modifying agent, Dutrex, should be subtracted from these savings.

1,563 tons of milled pavement remained following completion of the paving. This material was taken by District 5 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.

ENERGY ANALYSIS

For this analysis, energy consumptions and comparisons are presented in both total quantities and the quantities required to produce one ton of mix. All fuels are converted to BTU's (Brittish Thermal Units) and then to equivalent gallons of gasoline.

A. Process and Delivery of AC-10

For this analysis, asphalt cement is considered as a by-product of the oil refineries and therefore no energy is considered to be inherent in the material itself. However, the energy required to process the asphalt and all transportation is included. Values ranging from 587,500 BTU/ton[1] to 3,150,930 BTU/ton[2] have been reported for the processing of AC-10. From "Energy in Roadway Construction"[3] a value of 1,000,000 BTU/ton will be used in this report.

Figure 6
Savings in Natural Resources
Project C 20-0160-12
Durango - Hesperus

Quantities Used on Recycle Project

10,744.70	ton Crushed Pavement
4,690	tons virgin aggregate
95.88	tons of AC-10
107.87	tons of Dutrex
15,638.45	tons total Mix

Quantities Required for Virgin Mix

14,731.42	Virgin Aggregate
907.03	tons AC-10 (5.8%)
15,638.45	tons total Mix

Quantities saved by recycling

14.731.4 - 4,690 = 10,041.42 tons virgin aggregate
907.03 - 95.88 = 811.15 tons AC-10

The asphalt cement (AC–10) used on this project was manufactured in Sinclair, Wyoming and transported to the project using 5 axle diesel trucks. It is 560 miles from the refinery to the project and including adjustment for dead haul, a 5–axle diesel semi-truck uses 1,960 BTU/ton-mile.(1) Using this estimate for energy consumption of a diesel truck, 560 miles x 1,960 BTU/ton-mile = 1,097,600 BTU/ton was used to deliver AC–10 to the project.

Energy for aspahlt cement (AC-10) at the project

	BTU/ton	Total BTU's
Processing	1,000,000 X 95.88 tons =	95.880×10^6
Truck Transportation	1,097,600 X 95.88 tons =	105.238×10^6
Total	2,097,600	201.118×10^6

B. Process and Delivery of Modifying Agent

Dutrex, the modifying agent used on this project was manufactured in Martinez, California, and transported to the project by diesel truck. Using the same energy consumption as above for diesel trucks, 1054 miles x 1,960 BTU/ton-mile = 2,065,840 BTU/ton was required for the delivery of modifying agent to the project.

For this analysis, it was assumed that the same amount of energy required for processing AC–10 would be required for processing Dutrex; 1,000,000 BTU/ton.

Energy for Dutrex at the project

	BTU/ton	Total BTU's
Processing	1,000,000 X 107.87 =	107.870×10^6
Truck Transportation	2,065,840 X 107.87 =	222.842×10^6
Total	3,065,840	330.712×10^6

C. Pavement Removal

Since the pavement was cold milled from the roadway, no pavement crushing was required on this project. The pavement was removed and loaded onto trucks using the Roto-Mill, and at the plant site, the old pavement was screened to remove any plus 2 inch material. From the contractor's records, 2,271 gallons of #2 diesel fuel was required to removal of 131,615 square yards (16,251 tons) of old pavement. An additional 109 gallons of #2 diesel fuel was used to screen and stockpile this material. Using this information, (2,271 + 109) = 2,380 gallons of #2 diesel fuel were required to remove, screen, and stockpile 16,251 tons of crushed pavement. Thus, 2,380 gal. #2 diesel/16,251 tons = 0.146 gallons of #2 diesel fuel was required to remove, screen, and stockpile one ton of old pavement. The average haul distance on this project was 3.045 miles. Using 1,960 BTU/ton-mile for hauling the reclaimed pavement, 3.045 miles x 1,960 BTU/ton-mile = 5,968 BTU/ton was used for hauling the reclaimed pavement to the plant site.

D. <u>Crushing and Delivery of Virgin Aggregate</u>

The virgin aggregate used for this project was hauled in 5-axle diesel trucks from a pit 13.8 miles from the plant site. Using the same energy consumption as for asphalt haul, 13.8 miles x 1,960 BTU/ton-mile = 27,048 BTU/ton was required to deliver the virgin aggregate to the plant site.

The energy used to crush the virgin aggregate was not available so the estimate from an earlier project was used. This estimate of 0.282 gal. #2 diesel/ton of aggregate was taken from Project TR 70-1(57); Asphalt Pavement Recycling, Clifton-West.

E. <u>Burner Fuel</u>

From the contractors records, 16,537 gallons of #2 diesel fuel were required to produce 15,638.45 tons of recycled mix. This 16,537 gal/15,638.45 tons = 1.057 gallons of #2 diesel fuel were required for each ton of recycled mix.

For the estimate in Figure 7, a blend of [illegible] reclaimed pavement and [illegible] virgin aggregate will be used since it was the proportion mix produced on this project. For a comparison, the energy required to produce an equal amount of virgin mix is also presented. The same quantities as used for the recycle project were used for crushing and haul of the virgin aggregate and for the process and delivery of AC-10. The burner fuel energy was taken from the contractor's estimate for virgin mix from this plant; 1.0 gal. of #2 diesel per ton of virgin mix

Figure 7
Energy for Recycled versus Virgin Aggregate Mix
Project C 20-0160-12
Durango - Hesperus

Energy to produce one ton of 70/30 Blend

	BTU/ton		BTU	Eval Gal. of
Remove, Screen, and Stockpile old mat	20,294 x 0.7 ton	=	14,206	0.1
Crushing of Virgin Aggregate	39,198 x 0.3 ton	=	11,759	0.0
Haul of Virgin aggregate	27,048 x 0.3 ton	=	8,114	0.0
Burner Fuel	146,923 x 1.0 ton	=	146,923	1.1
Process and Delivery of AC-10	2,097,600 x 0.005 ton	=	10,488	0.0
Process and Delivery of Dutrex	3,065,840 x 0.007 ton	=	21,461	0.1
Avg. Haul of old mat	5,968 x 1.0 ton	=	5,968	0.0
			218,919	1.7

Energy to Produce one ton of Virgin Mix

	BTU/ton		BTU	Evalua Gal. of G
Crushing of Virgin Aggregate	39,189 x 1 ton	=	39,198	0.32
Haul of Virgin Aggregate	27,048 x 1 ton	=	27,048	0.22
Process and Delivery of AC-10	2,097,600 x 0.058 ton	=	121,661	0.97
Burner Fuel	139,000 x 1 ton	=	139,000	1.11
			326,907	2.62

Conversions used for Fuels

Diesel Fuel #2 139,000 BTU/gal.
Gasoline 125,000 BTU/gal.

Comparing the results in Figure 7, energy equivalent to 0.87 gallons of gasoline per ton more was required to produce virgin mix. For this project, this represents a saving of energy equivalent to 0.87 x 15,638.45 = 13,605.5 gallons of gasoline.

ECONOMICS

The quantities used in the following analysis were taken from Colorado Highway Department records listing the quantities paid for under the project contract. The prices used for recycled mix in the analysis in Figure 8 were taken from the contract bids awarded in September, 1978. Items such as compaction and priming were not included since they would be required whether recycled or virgin mix was used. Additionally, the $2.00/ton of recycled mix from the FHWA demonstration funds was not considered in this analysis.

The comparison price for HBP (Grading E) was taken from the 1978 Cost Data Book. It represents the average price in the southwest portion of the state for HBP, Grading E, from an undesignated pit with AC—10 and haul included.

As can be seen from a comparison of the costs in Figure 8 recycling cost $4,643 more than a conventional 2 inch overlay or approximately $0.30 per ton of mix produced. However, in a normal overlay, leveling course is often required and the use of only 207 tons of leveling course would make the comparative costs the same for a project of this length.

CONCLUSIONS AND RECOMMENDATIONS

Much was learned from this recycling project. From an air pollution standpoint, the 70% recycled-30% virgin material was never produced with acceptable opacities. 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

Figure 8
Cost for Recycled versus Virgin Mix
Project C 20-0160-12
Durango - Hesperus

<u>Quantities Paid under Project Contract</u>

Pavement Removal	131,615 yd^2	x	$ 1.10	=	$144,776.50
Virgin Aggregate	4,690 tons	x	$ 4.00	=	$ 18,760.00
AC-10	95.88 tons	x	$110.00	=	$ 10,546.80
Dutrex	107.87 tons	x	$200.00	=	$ 21,574.00
HBP (Recycled)	15,638.45 tons	x	$ 9.00	=	$140,746.05
Haul	49,481.0 ton-mile	x	$ 0.40	=	$ 19,792.40
					$356,195.75

<u>Cost for Virgin Mix</u>

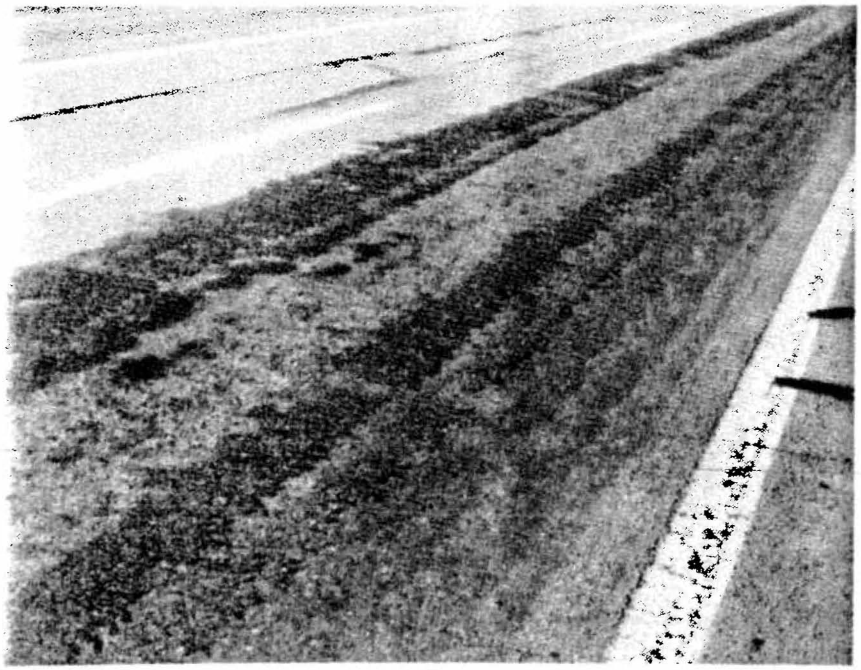
HBP (Grading E)	15,638.45 tons	x	$22.48	=	$351,552.36

this point recycling is still in the experimental stages. In the future both contractors and highway personnel will be more knowledgable about recycling and the savings in energy and virgin materials should be reflected in the cost of future 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. These energy and natural resource savings should help lower the price on future recycling projects.

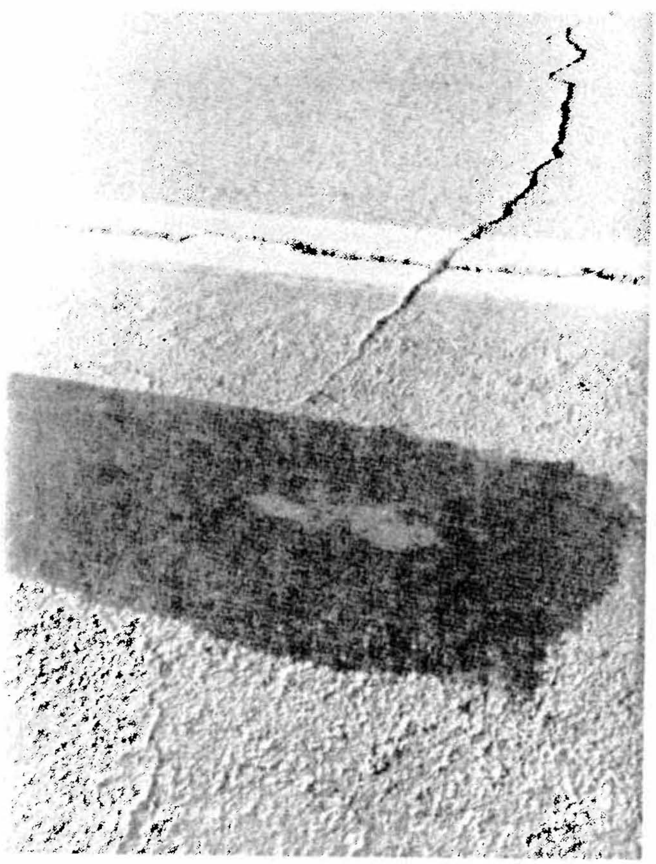
The initial testing of the recycled mixes show that they are comparable to virgin aggregate mix in strength and stability. Evaluations similar to the post construction evaluation will be conducted annually for at least three years. Cores will also be taken annually and analyzed for stability, strength and asphalt composition. Using this data the aging and durability of the recycled pavement will be compared to that of standard pavement. The conclusions on this comparison will be addressed in the project final report.

Asphalt Pavement Recycling
Durango-Hesperus
Project C 20-0160-12



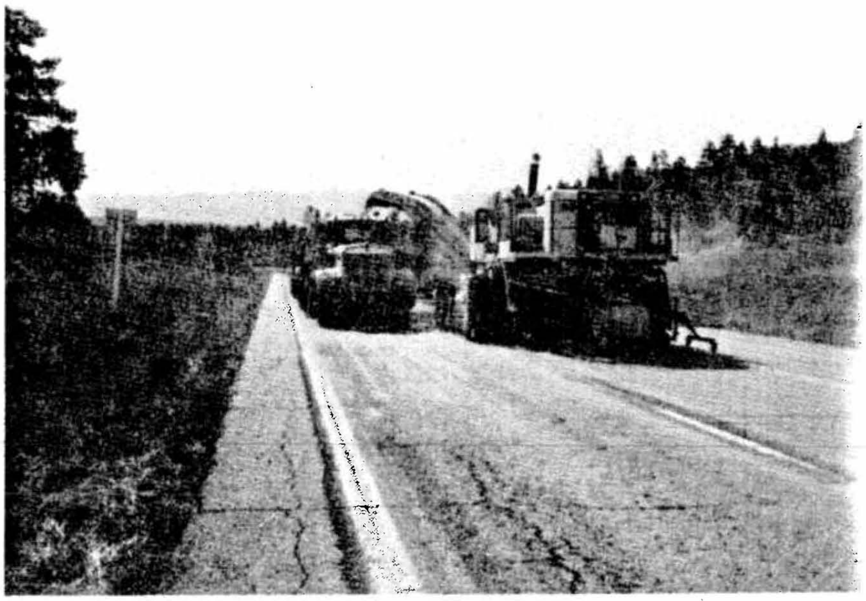
Photograph No. 1

Preconstruction Roadway condition. Note: Rich wheelpaths in the driving lane and numerous transverse and longitudinal cracks.



Photograph No. 2

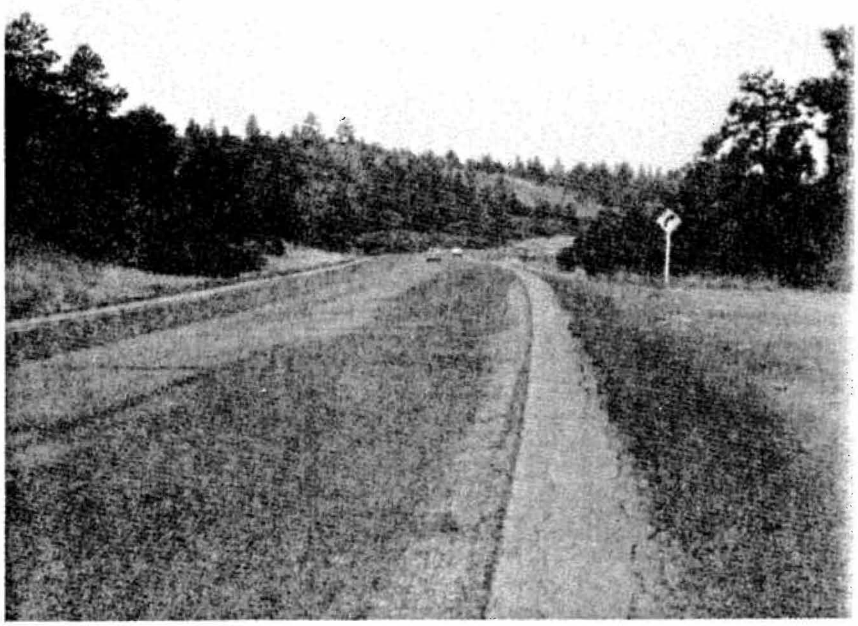
Preconstruction Roadway condition. Large cracks with an extremely rich patch in the wheelpath.



Photograph No. 3

Rotomil planning on center lane.

Note: Cracking and roadway condition in foreground.



Photograph No. 4

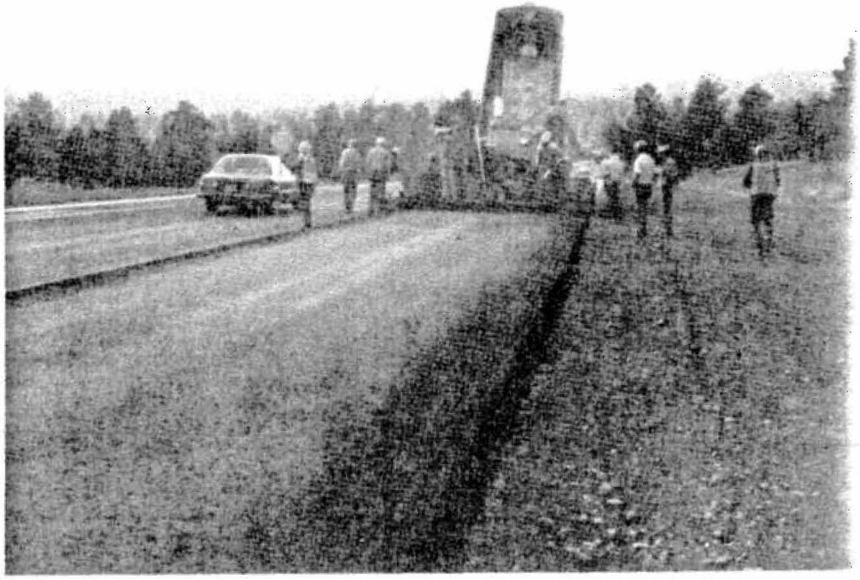
Typical roadway appearance following planing.

Photograph No. 5

Milled pavement stockpile before screening.

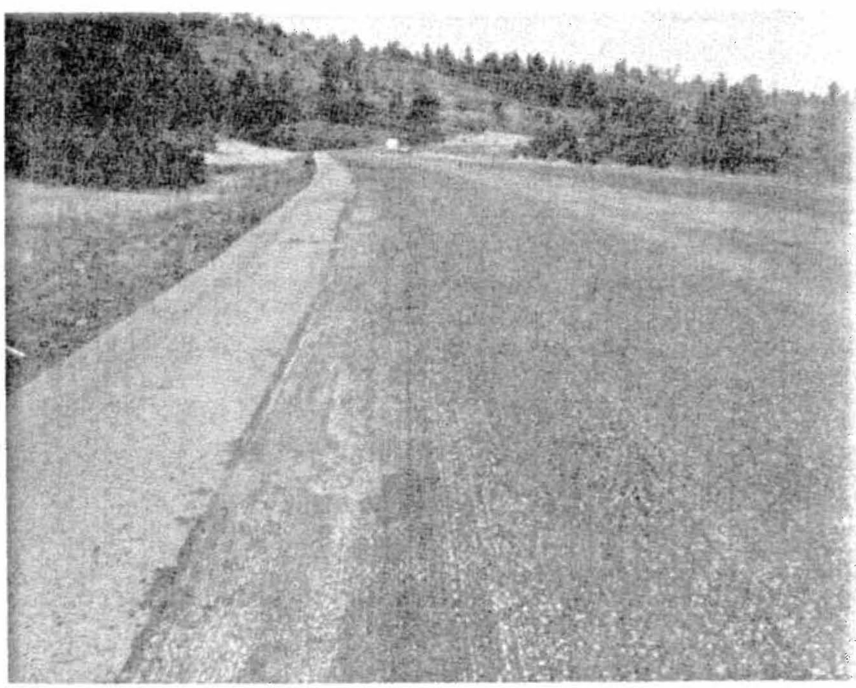
Photograph No. 6

Milled pavement stockpile following screening with 2 inch scalping screen. Samples from stockpile averaged 6.0% asphalt cement.



Photograph No. 7

Beginning of paving operation. Recycled mix behaved similar to standard mix.



Photograph No. 8

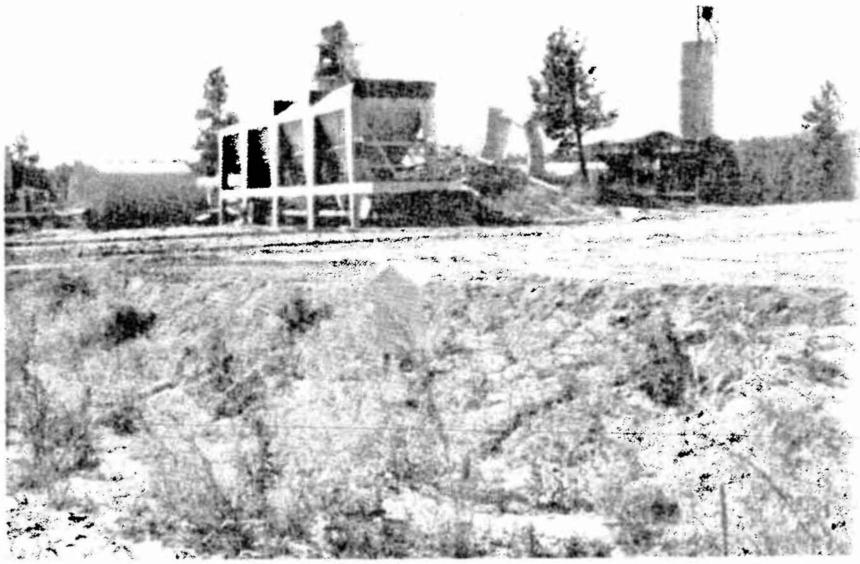
Roadway following milling of top 2 inches. Profile is even both across and down the road.

Photograph No. 9

CMI 9' x 36' dryer drum plant. Note dual feed belts for virgin aggregate and milled pavement.

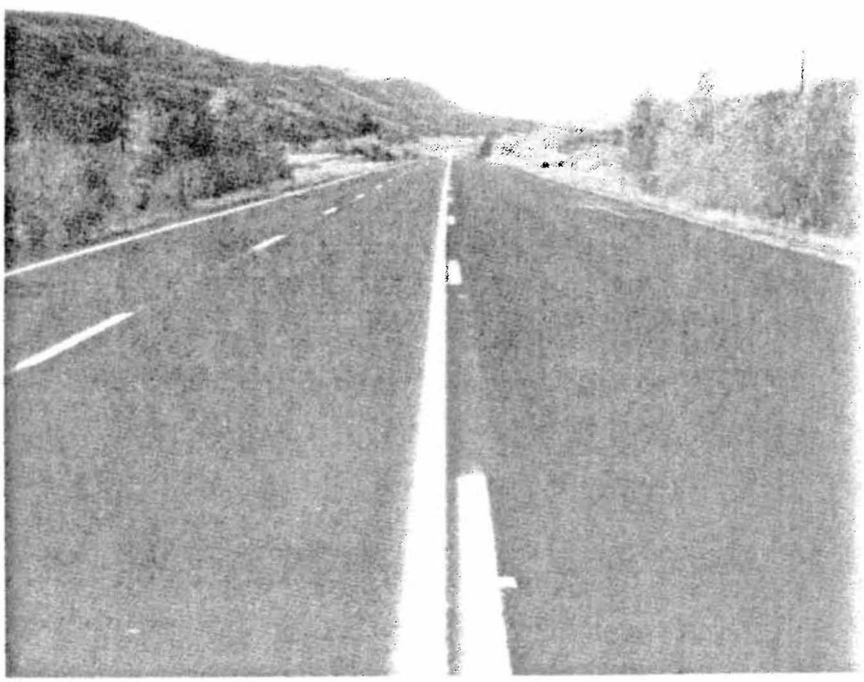
Photograph No. 10

Hi Vol Sampler #1 located near plant. Main haul road is located to left of picture.



Photograph No. 11

Hi Vol Sampler #2 located in vacant area away from plant.

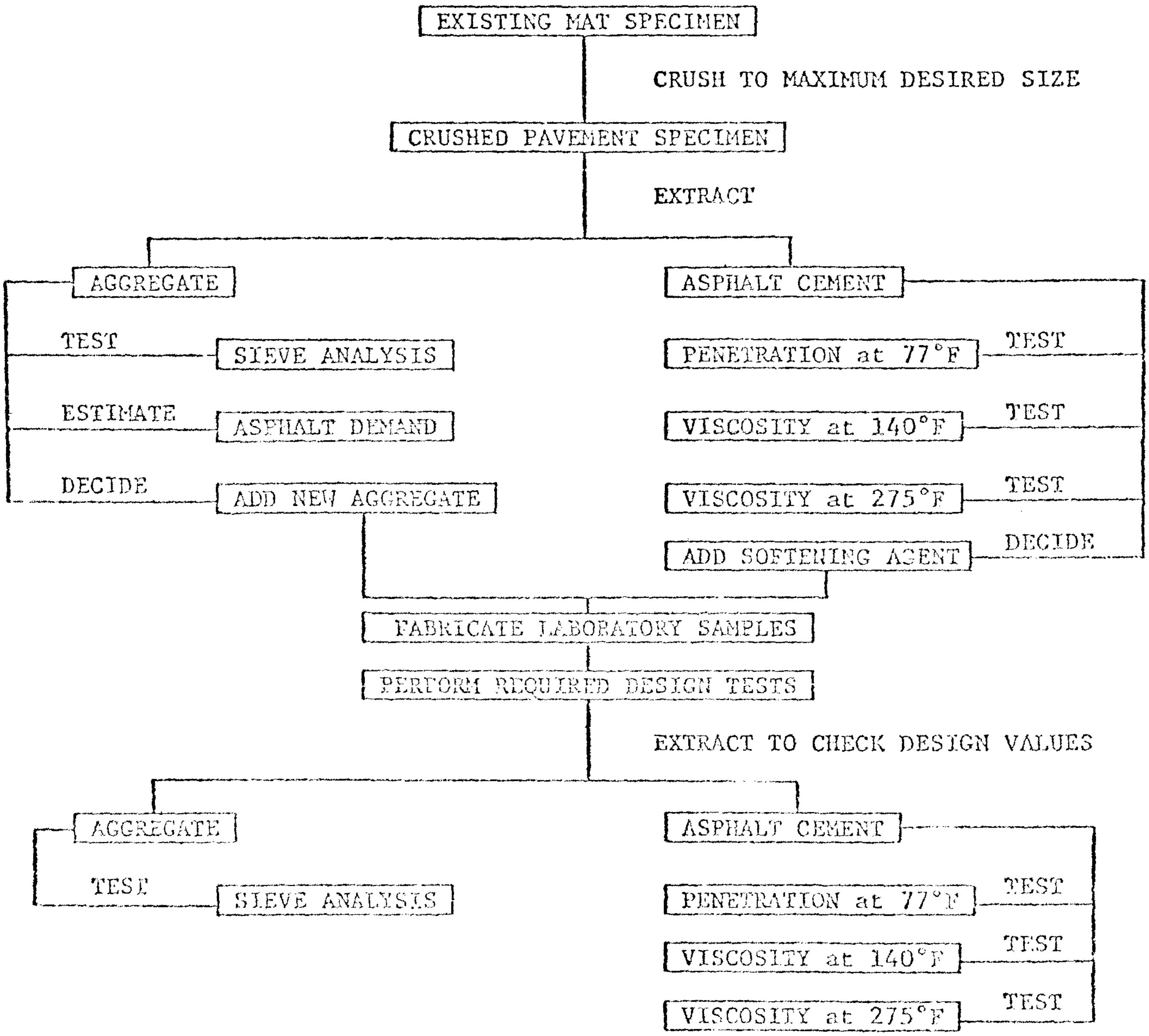


Photograph No. 12

Finished roadway has good appearance, smooth ride, and good skid resistance.

Appendix A

Project C 20-0160-12
Durango-Hesperus



Flow sheet of laboratory procedures for designing recycled asphalt pavements.

Appendix A

Project C 20 160-12
Durango - Hesperus

Samples of old hot bituminous pavement and gravel from the existing roadway were tested to check the suitability for recycling.

The following laboratory procedure was used in determining our recommendations:

Procedure:	Results and/or decisions for this project:
1. Sample received was proportioned by District Lab approximately as it is expected to be when it is picked up and stockpiled.	
2. Reduce old pavement to desired maximum size.	3/4 inch. The 3/4 inch size was used for the convenience of the laboratory. In the field the maximum size of up to 95% - 100% on the one inch and 100% passing the 1½ inch screen.
3. Extract asphalt cement from existing mat. Aggregate: Sieve Analysis	3/4" . . . . 100% 1/2" . . . . 93% 3/8" . . . . 80% #4 . . . . 59% #8 . . . . 48% #16 . . . . 39% #50 . . . . 21% #100 . . . . 15% #200 . . . . 11.7%
Asphalt Cement Percent asphalt cement in existing mat.	5.56 percent
Penetration at 77°F	16
Viscosity at 140°F	13,703
Viscosity at 275°F	382
4. Make decision on how much new aggregate will be added to recycled material.	Add 30 percent new aggregate. 30 percent appears to be the minimum at which air pollution can be controlled. (From existing experiments in other states.) For convenience of Lab, new aggregate used was local Denver Aggregate.
5. Estimate asphalt demand on combination of existing mat and new aggregate for laboratory testing.	a. 5.5% b. 6.0% c. 6.5% d. Run tests on material as crushed with no additions.

Appendix A

6. Make decision if softening agent should be added and how much.

Based on low penetration and high viscosity test results on the existing mat, add softening agent to increase penetration and lower viscosity to approximately AC-10 values.

7. Fabricate samples for laboratory testing.

1 set was made with no additions (100% recycled material)

All other samples were made with:
70% Recycled material
30% New aggregate
1.6% Cyclogen (H) (softening agent)

5.5% Total
70% Recycled Mat
30% New aggregate
1.6% Cyclogen (H)

6.0% Total
70% Recycled mat
30% New aggregate
1.6% Cyclogen (H)
0.5% AC-10

6.5% Total
70% Recycled mat
30% New aggregate
1.6% Cyclogen
1.0% AC-10

With above combinations the addition of new aggregate was kept constant. Also the ratio of old asphalt and Cyclogen was kept constant.

See Form DOH 429 (attached) for Lab results.

8. Run extractions and recovery on samples fabricated for Lab testing to check design values.

5.5%

Pen at 77°F	107
Vis at 140°F	601
Vis at 275°F	121

6.0%

Pen at 77°F	93
Vis at 140°F	763
Vis at 275°F	186

6.5%

Pen at 77°F	85
Vis at 140°F	916
Vis at 275°F	145

Appendix A

Based on the results of the Lab tests, it appears that the material is suitable for recycling.

Final recommendations to be based on material produced and stockpiled.

DIVISION OF HIGHWAYS
STATE OF COLORADO
DOH Form No. 429
Revised: February, 1977

Project C 20-0160-12 Dist. 5
Location Durango-Hesperus
Field Sample No. C 17406
Lab Nos. 77/235-2 236-2 237-2 238-2
Date Rec'd 11-18-77

LABORATORY DESIGN FOR BITUMINOUS MIXTURES

Item 403 Grading or Class E

Preliminary (X) Construction ◯

Asphalt Pavement
Pit Identification Denver area Agg.
70% old pavement-30% new agg.
Contractor
Asphalt Source Used
Conoco AC 10

SIEVE ANALYSIS (Percent Passing)

Test Nos.				As Used	Job Mix Formula
%	70%	30%			
1"					
3/4"	100	100		100	
1/2"	79	90		95	
3/8"	57	70		79	
#4	30	52		58	
#8		44		47	
#16		37		37	
#50		16		20	
#100		9		14	
#200		6.7		10.5	

TEST RESULTS

Percent Bitumen	Plain	5.5	6.0	6.5
Max. Sp. Gr. of Mix		2.43	2.41	2.39
Sp. Gr. of Specimen	2.36	2.35	2.37	2.38
Voids in Specimen		3.29	1.66	0.42
Stability Value	41	48	39	27
Cohesiometer Value	235	252	240	233
R_t Value	101	104	100	92
Resilient Modulus (x 1000)	2632.4	323.4	391.4	372.9
Strength Coefficient	0.44	0.44	0.44	0.44
Item 301 PMBB	0.34	0.34	0.34	0.34

IMMERSION-COMPRESSION

Percent Bitumen		6.0		
Specimen PSI Wet		399		
Specimen PSI Dry		389		
% Absorption by Wt.		0.53		
% Swell by Volume		0.00		
Index of Ret. Strength		103		
% Additive Used				
Asphalt Additive Type				

Laboratory Sp. Gr. = ______ at ______% AC

The recommended asphalt content for the above item is:
5.5 % * grade, total mix basis, with ______% acceptable additive,
including ______% ______ added to the stockpile ◯ to the dry aggregate ◯.
______% ______ emulsified asphalt, dry aggregate basis.

The recommended % asphalt has been adjusted ______% for environmental factors assuming ______ VPD, ______ ft. elev. and construction in ______.

REMARKS: * Addition of 1.6% Cyclogen will result in 5.5% total A.C. content

(30% New Aggregate)

(70% Recycled Mat)

JAN 25,1978

Staff Materials Engineer

REVISION OF SECTION 411
MODIFYING AGENT
COLORADO PROJECT NO. C 20-0160-12

Section 411 of the Standard Specifications is hereby revised to include asphalt cement modifying agent for this project as follows:

Subsection 411.01 shall include the following:

This work shall consist of furnishing an asphalt cement modifying agent and the application of the agent in accordance with these specifications and the details described in the Revision of Section 403, Hot Bituminous Pavement (Recycled) shown elsewhere in these special provisions.

Subsection 411.02 shall include the following:

Modifying agent shall conform to the Revision of Section 702, Modifying Agent shown elsewhere in these special provisions.

Subsection 411.05 shall include the following:

The accepted quantities for modifying agent, as described above, will be paid for at the contract unit price per ton.

Payment will be made under:

Pay Item	Pay Unit
Modifying Agent	Ton

Appendix A

REVISION OF SECTION 702
MODIFYING AGENT
COLORADO PROJECT NO. C 20-0160-12

Section 702 of the Standard Specifications shall include modifying agent for this project as follows:

Subsection 702.04 shall include the following:

(c) Modifying agents used to soften aged asphalts in the recycling process shall conform to the following requirements.

Specification Designation	Test Method	Requirements
Viscosity @ 140°F CS	ASTM D2170	100-300
Viscosity @ 275° CS	ASTM D2170	3-12
Specific Gravity	ASTM D70	0.970-1.040
Flash Point C.O.C., °F	ASTM D92	350 min.
Volatility 22 hrs/225°F % W		1.0 max.
Mixed Aniline PT., °F		75-125
Asphaltenes	ASTM D2006	1% max.
Polar Compounds	ASTM D2006	15 Min.
1st plus 2nd Acidifines	ASTM D2006	60 min.
Saturates	ASTM D2006	20 max.

Appendix B

Durango-Hesperus

REVISION OF SECTION 202
REMOVAL AND STOCKPILING EXISTING BITUMINOUS PAVEMENT
COLORADO PROJECT NO. C 20-0160-12

Section 202 of the Standard Specifications is hereby revised to include removing and stockpiling of existing bituminous pavement for this project as follows:

DESCRIPTION

Subsection 202.01 shall include the following:

This work shall consist of removing a designated depth of existing bituminous pavement, hauling the material to an approved stockpile area as shown on the plans or established.

CONSTRUCTION REQUIREMENTS

Subsection 202.05 shall include the following:

a. Removal of Existing Pavement

The existing bituminous pavement shall be removed by cold planing to a depth shown on the plans. The equipment used for the removal shall have the capability of automatic grade control. The Contractor shall take all necessary precautions in removing the bituminous pavement to prevent damage to the underlying bituminous pavement. The resulting surface of the bituminous pavement shall be reasonably smooth and free of excessive scarification marks or other damage. If any leveling or patching of the pavement is required, as determined by the Engineer, the material will be paid for at the contract unit price for the material used.

b. Stockpiling

Prior to beginning the stockpiling operation, the Contractor shall prepare a base for the stockpile. The base shall consist of a layer of removed existing pavement approximately six inches in depth and an area sufficient to accommodate the stockpile.

The material placed in the stockpile shall pass a 2 inch screen. Any material retained on the 2 inch screen shall be reduced in size by an approved method and used.

The stockpile of removed existing pavement shall be constructed by layer placing or other approved methods which will prevent coning or segregation of the material.

-continued-

-2-

REVISION OF SECTION 202
REMOVAL AND STOCKPILING EXISTING BITUMINOUS PAVEMENT
COLORADO PROJECT NO. C 20-0160-12

Subsection 202.07 shall include the following:

Pay Item	Pay Unit
Removal of Asphalt Mat (Planing)	Square Yard

Haul will not be measured and paid for.

Appendix B

REVISION OF SECTION 304
STOCKPILE AGGREGATE BASE COURSE
COLORADO PROJECT NO. C 20-0160-12

DESCRIPTION AND REQUIREMENTS

This work shall consist of producing, hauling and stockpiling aggregate materials to be used for mixing with recycled bituminous pavement as described in the Special Provision, "Revision of Section 403-Hot Bituminous Pavement (Recycled)."

Aggregate shall be stockpiled by layer placing or other approved methods which will prevent coning or segregation of the material.

MATERIALS

The aggregate to be added to the recycled bituminous pavement shall conform to the requirements of Sections 401 and 703 and meet the following gradation requirements:

Passing 3/4"	Sieve	-	100%	
Passing #4	Sieve	-	52	±8%
Passing #8	Sieve	-	47	±8%
Passing #200	Sieve	-	6	±3%

METHOD OF MEASUREMENT

Stockpile aggregate base course shall be measured by the ton.

BASIS OF PAYMENT

The accepted quantities of stockpiled aggregate base course will be paid for at the contract unit price per ton.

Payment will be made under:

Pay Item	Pay Unit
Stockpile Aggregate Base Course (Class 6)	Ton

Haul will not be paid for separately but will be included in the work.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT (RECYCLED)
COLORADO PROJECT NO. C 20-0160-12

Section 403 of the Standard Specifications is hereby revised to include recycled hot bituminous pavement for this project as follows:

DESCRIPTION

Subsection 403.01 shall include the following:

This work shall consist of combining the recycled pavement with virgin aggregate, asphalt cement, asphalt modifying agent, and heating, mixing, laying and compacting the recycled mixture. The work shall be performed in reasonable close conformity with lines, grades, thicknesses and typical cross sections shown on the plans or established.

MATERIALS

a. Recycled Bituminous Pavement

The recycled bituminous pavement shall be the material in the stockpile as described in Revision of Section 202.

b. Virgin Aggregate

The virgin aggregate to be added to the recycled material shall conform to the requirements of the special provision "Stockpile Aggregate Base Course."

c. Asphalt Cement

The new asphalt cement shall meet the applicable requirements of Section 702-Bituminous Materials.

d. Asphalt Cement Modifying Agent

The modifying agent shall meet the requirements of Revision of Section 411-Modifying Agent and Revision of Section 702-Modifying Agent shown elsewhere in these Special Provisions.

-continued-

Appendix B
-2-
REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT (RECYCLED)
COLORADO PROJECT NO. C 20-0160-12

CONSTRUCTION REQUIREMENTS

The construction requirements shall be in accordance with Subsections 401.07 through 401.20 except as modified herein.

The recycled bituminous pavement mixture shall be processed with dryer-drum equipment modified to process recycled material and meet air pollution regulations. The Contractor shall be responsible for all costs necessary to comply with air pollution regulations. Plant modifications shall be in accordance with the manufacturer's recommendations. The plant used shall be designed, equipped and operated in such a manner that the proportioning, heating and mixing will yield a uniform final mixture with a temperature high enough to meet satisfactory laying and compacting requirements.

The recycled mixture shall consist of a combination of 70 per cent recycled material and 30 percent virgin aggregate. Asphalt cement (AC-10) shall be added at the rate of 7% [± 0.5%] by weight of new aggregate. The asphalt modifying agent shall be added at the rate of 1% [±0.2%] by weight of the Recycled Bituminous Pavement on a daily yield basis. The Asphalt Cement (AC-10) and Modifying Agent feed rates shall be interlocked and synchronized with the system feed rates in a manner to be approved by the Engineer.

A. Modification of the percentages of recycled material, virgin aggregate asphalt cement and modifying agent shall be as directed by the Engineer.

The recommended percentage of asphalt cement and modifying agent will be based on laboratory tests performed on representative samples of the stockpiled material.

The job mix formula specifications for gradation and asphalt content of the recycled mixture will be furnished for information only.

Removal of material from the crushed pavement stockpile shall be accomplished by working a full face of the stockpile, as nearly as practical.

The Contractor shall furnish a detailed description of his recycling methods at the preconstruction conference..

-continued-

-3-

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT (RECYCLED)
COLORADO PROJECT NO. C 20-0160-12

METHOD OF MEASUREMENT

Recycled hot bituminous pavement will be measured as prescribed in subsection 401.21.

BASIS OF PAYMENT

The accepted quantities for recycled hot bituminous pavement will be paid for at the contract unit price per ton, completed and accepted. Payment shall include dryer-drum processing, placing, compacting the recycled mixture on a prepared surface and all other incidentals necessary to complete the item.

Payment will be made under:

Pay Item	Pay Unit
Hot Bituminous Pavement (Recycled)	Ton

Asphalt Cement (AC-10) and Modifying Agent will be measured and paid for in accordance with Section 411.

Haul shall consist of transporting Hot Bituminous Pavement (Recycled) from the plant site to the roadway. Haul will be measured and paid for by the Ton-Mile in accordance with Section 204.

Water that may be used in the mixing plant will not be measured and paid for separately but shall be included in the work.

Virgin aggregate will be paid for in accordance with Section 304.

Appendix B

LABORATORY DESIGN FOR BITUMINOUS MIXTURES

PROJECT C 20-0160-12

DURANGO-HESPERUS

70% Recycled-30% New Aggregate

SEIVE ANALYSIS (% PASSING)

	Recycled Pavement	Large Aggregate	Fine Aggregate	As Used
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	96	52	100	91
3/8"	87	17	100	81
#4	67	4	85	63
#8	53	4	70	50
#16	42	3	60	41
#50	24	2	28	22
#100	17	2	17	15
#200	13.4	1.4	11.2	11.6

TEST RESULTS

Percent Bitumen	4.7	5.2	5.7
Max. Sp. Gr. of Mix	2.46	2.44	2.42
Sp. Gr. of Specimen	2.31	2.35	2.37
Voids in Specimen	5.94	3.56	2.21
Stability Value	50	46	34
Cohesiometer Value	227	226	258
R_T Value	103	102	98
Resilient Mod.(X1000)	659.4	698.5	522.3
Strength Coefficient	.44	.44	.44
Immersion-Compression			
Percent Bitumen		5.2	
Specimen PSI Wet		555	
Specimen PSI Dry		573	
Absorption by Weight		1.31	
Swell by Volume		.16	
Index of Retained Strength		97	

Laboratory Specific Gravity = 2.35 at 5.0%A.C.

* Results of vacuum extraction with 0.0 retention factor used

NOTE: 70/30 Blend with 1% Dutrex added to the recycled material based on the weight of the recycled material and 1.7% new AC-10 based on the weight of the new aggregate.

RECOMMENDED ASPHALT CONTENT 5.0% GRADE AC-10

Appendix B

LABORATORY DESIGN FOR BITUMINOUS MIXTURES

PROJECT C 20-0160-12

DURANGO-HESPERUS

60% Recycled-40% New Aggregate

SIEVE ANALYSIS (% PASSING)

	Recycled Pavement	Large Aggregate	Fine Aggregate	As Used
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	96	52	100	90
3/8"	87	17	100	79
#4	67	4	85	61
#8	53	4	70	49
#16	42	3	60	40
#50	24	2	28	21
#100	17	2	17	15
#200	13.4	1.4	11.2	11.0

TEST RESULTS

Percent Bitumen	4.7	5.2	5.7	6.2
Max. Sp. Gr. of Mix	2.47	2.45	2.43	2.41
Sp. Gr. of Specimen	2.32	2.33	2.35	2.38
Voids in Specimen	5.86	4.57	3.01	1.21
Stability Value	54	52	36	24
Cohesiometer Value	293	281	238	224
R_T Value	107	106	98	89
Resilient Mod.(X1000)	657.2	542.6	516.2	424.8
Strength Coeficient	.44	.44	.44	.35
Immersion Compression				
Percent Bitumen		5.2		
Specimen PSI Wet		499		
Specimen PSI Dry		537		
Absorption by Weight		1.42		
Swell by Volume		.17		
Index of Ret. Strength		93		

Laboratory Specific Gravity = 2.33 at 5.0%* A.C.

* Results of vacuum extraction with 0.0 retention factor used

NOTE: 60/40 Blend with 1% Dutrex added to recycled material based on the weight of the recycled material and 2.8% new AC-10 based on the weight of the new aggregate.

RECOMMENDED ASPHALT CONTENT 5.0% GRADE AC-10

Appendix B

LABORATORY DESIGN FOR BITUMINOUS MIXTURES

PROJECT C 20-0160-12

DURANGO-HESPERUS

50% Recycled-50% New Aggregate

SIEVE ANALYSIS (% PASSING)

	Recycled Pavement	Large Aggregate	Fine Aggregate	As Used
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	98	52	100	88
3/8"	87	17	100	77
#4	67	4	85	60
#8	53	4	70	48
#16	42	3	60	40
#50	24	2	28	21
#100	17	2	17	14
#200	13.4	1.4	11.2	10.3

TEST RESULTS

Percent Bitumen	4.7	5.2	5.7
Max. Sp. Gr. of Mix	2.47	2.45	2.43
Sp. Gr. of Specimen	2.33	2.34	2.38
Voids in Specimen	5.50	4.43	2.19
Stability Value	49	47	37
Cohesiometer Value	259	315	251
R_T Value	104	107	99
Resilient Mod.(X1000)	893.7	687.0	470.5
Strength Coeficient	.44	.44	.44
Immersion-Compression			
Percent Bitumin		5.2	
Specimen PSI Wet		470	
Specimen PSI Dry		520	
Absorption by Weight		1.42	
Swell by Volume		.16	
Index of Ret. Strength		91	

Laboratory Specific Gravity = 2.34 at 5.2%* A.C.

* Results of vacuum extraction with 0.0 retention factor

NOTE: 50/50 Blend with 1% Dutrex added to the recycled material based on the weight of the recycled material and 4.0% new AC-10 based on the the weight of the new aggregate.

RECOMMENDED ASPHALT CONTENT 5.2% GRADE AC-10

DIVISION OF HIGHWAYS
STATE OF COLORADO
DOH Form No. 43
Revised April 1974

JOB-MIX FORMULA MODIFICATION ORDER

Contractor Nielsons, Inc. Project No. C20-0160-12

Date September 17, 1979 Location Hesperus Hill

The Job Mix Formula(s) As Defined In Subsection 401.02 Of The Standard Specifications For Plant Mix Pavements, Based Upon The Following Reason: Revisions based on as-produced aggregate samples.

Is Hereby Modified From That Shown With The Plans To The Following

~~Bottom~~ Top Layer(s), Grading Gr. E (Includes None % Mineral Filler)
For Construction Mix Design, See 157# C6202 Project No.

	Project Provisions	Modification No. 1
Passing ___ Sieve	%	%
Passing ___ Sieve	%	%
Passing 3/4 Sieve	100 %	100 %
Passing Number 4 Sieve	52 %	52 %
Passing Number 8 Sieve	47 %	47 %
Passing Number 50 Sieve	%	%
Passing Number 100 Sieve	%	%
Passing Number 200 Sieve	6 %	6 %
Asphalt % by Wt.	7	5.8 Includes Additive
Asphalt Grade	(AC-10)	(AC-10) Viscosity or Penetration

(Mineral Filler Type, If Any)

Sinclair, Wyoming
Asphalt Source (Refinery)

Asphalt Additive Required
Yes (X) No ( )

0.4 Super Concentrate

Temperature of Mixture When Emptied From Mixer 220-280 °F Spec's. 401.15

Density (Sp. Gr.) of Lab Spec. 234 . Required 93 % Compaction Spec's. 401.17

Top Layer, Grading Recycled (Includes None % Mineral Filler) 70% Recycled Mat'l./30% virgin aggr.
For Construction Mix Design, See 157 # C6202 Project No.

	Project Provisions	Modification No. 1
Passing ___ Sieve	%	%
Passing ___ Sieve	%	%
Passing ___ Sieve	%	%
Passing Number 4 Sieve	%	%
Passing Number 8 Sieve	%	%
Passing Number 50 Sieve	%	%
Passing Number 100 Sieve	%	%
Passing Number 200 Sieve	%	%
Durex Modifying Agent	1.0	1.0
Asphalt % by Wt.	~~7.0~~	~~1.7~~ Include Additive
Asphalt Grade	(AC-10)	(AC-10) Pen.

(Mineral Filler Type, If Any)

~~Sinclair, Wyoming~~
Asphalt Source (Refinery)

Asphalt Additive Required:
Yes (X) No ( )

0.4 Super Concentrate

Temperature of Mixture When Emptied From Mixer 220-280 °F Spec's. 401.15

Density (Sp. Gr.) of Lab. Spec. 235 Required ____ % Compaction Spec's. 401.17

No change

Distribution:

White .... Contractor
Orange .... Staff Construction Division
Pink Copy .... Staff Materials Division
Blue Copy .... District Office
Green Copy ... District Materials Engineer
Canary Copy... Resident Engineer
FHWA .... Photo Copy

CHANGE DISCUSSED WITH CENTRAL LAB Date 9-18-79

Signed [signature] Date 9/17/79
Authorized Project Engineer

Signed [signature] Date 9-18-79
Approved Dist. Materials Engineer

Received [signature] Date 9-18-79
Contractor's Authorized Representative

Appendix C - Table A

Opacities Monitored During Production

Project C 20-0160-12
Durango-Hesperus Hill

DATE	Start Time	OPACITY	Production Rate(tons/hour)	Mix Temp. °F	BLEND
9/27/79	2:30	60	400	225	70/30
9/27/79	4:15	50	400	235	70/30
9/27/79	4:40	42	400	235	70/30
9/27/79	4:45	44	400	235	70/30
9/27/79	5:53	49	400	255	70/30
9/28/79	9:00	55	400	250	70/30
9/28/79	1:20	36	450	220	70/30
9/28/79	1:25	45	450	220	70/30
9/28/79	2:55	31	550	215	70/30
9/28/79	3:00	26	550	215	70/30
9/28/79	3:05	40	450	215	70/30
Plant Modified over Weekend					
10/1/79	12:55	31	400	230	70/30
10/1/79	1:00	35	400	230	70/30
10/1/79	2:00	29	390	210	70/30
10/1/79	3:25	22	400	195	70/30
10/1/79	4:13	25	400	195	70/30
10/2/79	8:31	40	400	240	70/30
10/2/79	8:55	40	400	240	70/30
10/2/79	11:12	21	420	190	70/30
10/2/79	11:17	27	420	225	70/30
10/2/79	11:22	26	420	225	70/30
10/2/79	11:27	27	420	225	70/30
10/2/79	3:34	21	400	195	70/30
10/2/79	3:45	22	400	195	70/30
10/2/79	5:00	26	400	200	70/30
10/3/79	8:54	34	400	235	70/30
10/3/79	9:00	36	400	235	70/30
10/3/79	9:35	35	400	225	70/30
10/3/79	9:47	32	500	220	70/30
10/3/79	9:52	39	500	220	70/30
10/3/79	9:57	35	500	220	70/30
10/3/79	10:02	40	500	220	70/30
10/3/79	10:30	36	400	210	70/30
10/3/79	10:48	36	310	200	70/30

Appendix C - Table A (continued)

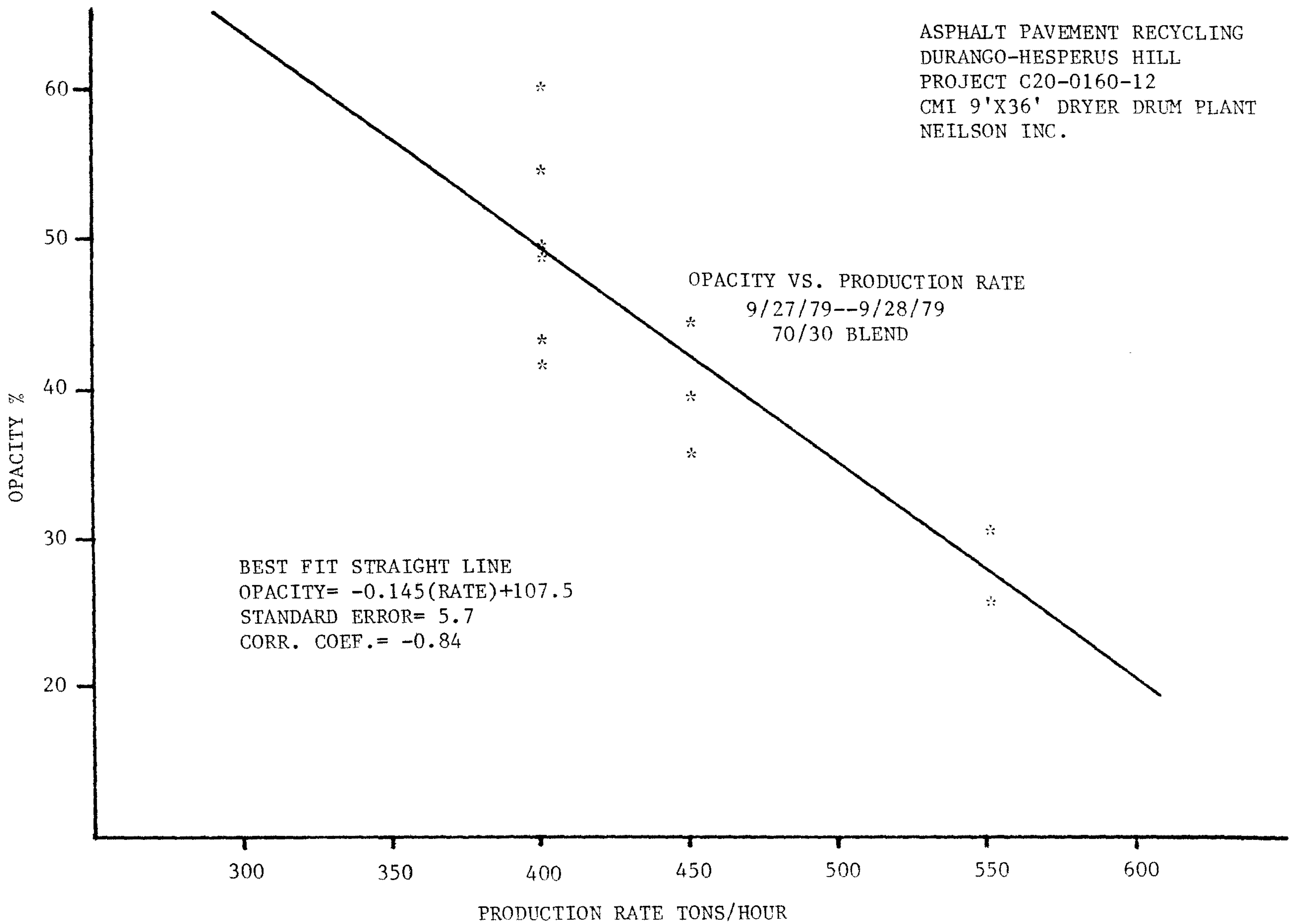
Opacities Monitored During Production

Project C 20-0160-12
Durango-Hesperus Hill

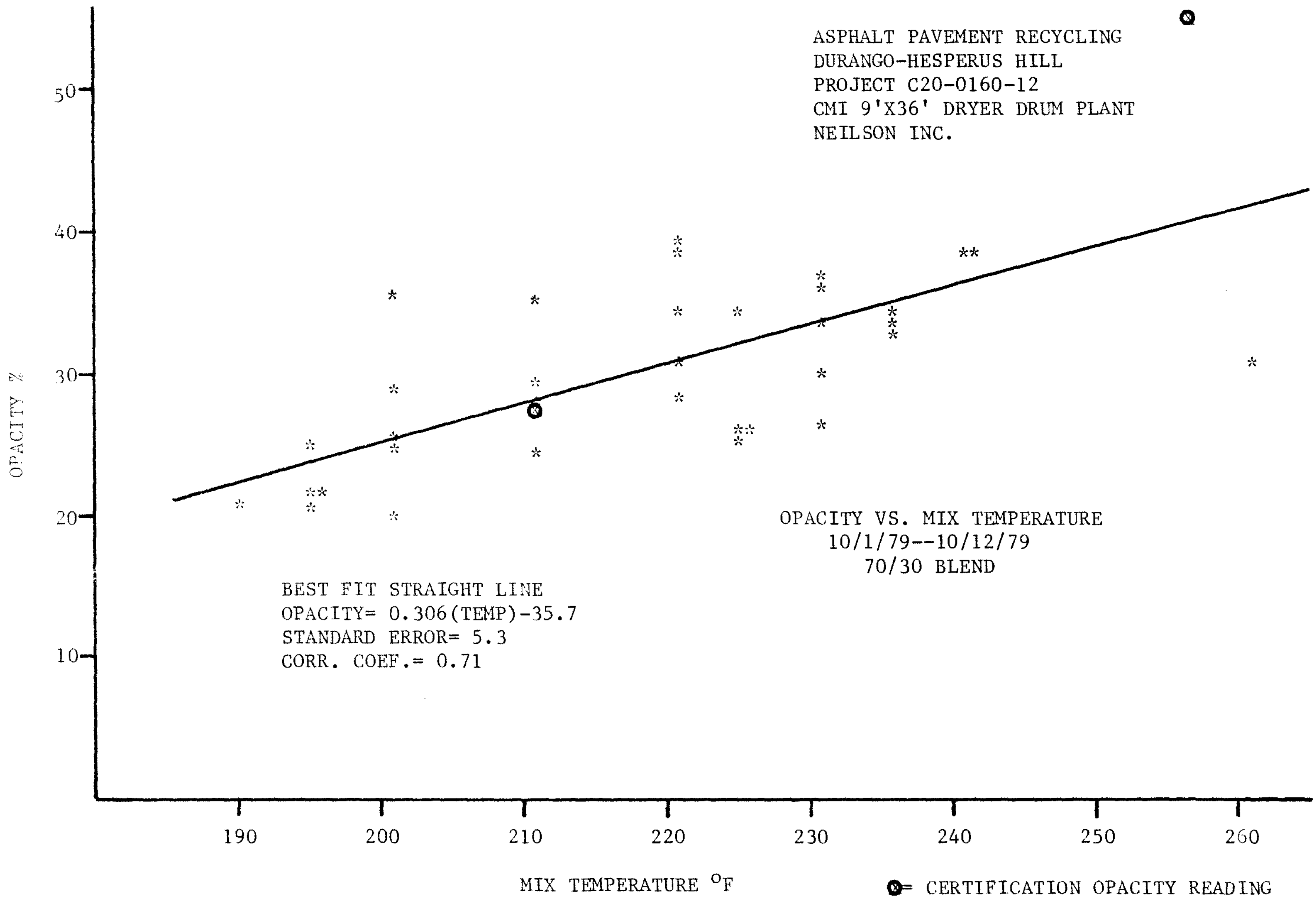
Date	Start Time	OPACITY	Production Rate(tons/hour)	Mix Temp. °F	Blend
10/3/79	12:25	29	400	220	70/30
10/3/79	2:12	7	275	275	Grading E
10/3/79	2:17	9	275	275	Grading E
10/3/79	2:22	22	275	275	Grading E
10/3/79	2:40	17	400	230	60/40
10/3/79	2:45	18	400	230	60/40
10/3/79	2:50	17	400	230	60/40
10/3/79	2:55	22	400	230	65/35
10/3/79	3:08	20	400	230	65/35
10/3/79	3:20	29	400	220	70/30
10/4/79	8:30	37	340	230	70/30
10/4/79	8:50	38	320	230	70/30
10/4/79	10:00	35	320	235	70/30
10/4/79	10:31	7	275	275	Grading E
10/4/79	10:40	9	275	275	Grading E
10/4/79	11:07	15	400	230	60/40
10/4/79	11:14	19	400	245	60/40
10/4/79	11:20	21	400	255	60/40
10/4/79	12:12	23	400	220	65/35
10/4/79	12:20	33	400	260	70/30
10/4/79	2:11	25	310	200	70/30
10/4/79	2:16	20	310	200	70/30
10/4/79	2:45	4	275	250	Grading E
10/4/79	2:52	3	275	250	Grading E
10/4/79	3:17	15	400	200	60/40
10/4/79	3:29	15	400	220	60/40
10/4/79	3:37	21	400	220	65/35
10/4/79	3:45	24	400	200	65/35
10/4/79	4:12	27	340	230	70/30
10/5/79	11:25	30	325	210	70/30
10/5/79	11:45	25	310	210	70/30
10/12/79	8:49	29	415	210	70/30
10/12/79	9:40	57	335	255	70/30
10/12/79	10:36	21	410	220	60/40
10/12/79	11:11	26	330	270	60/40

APPENDIX C

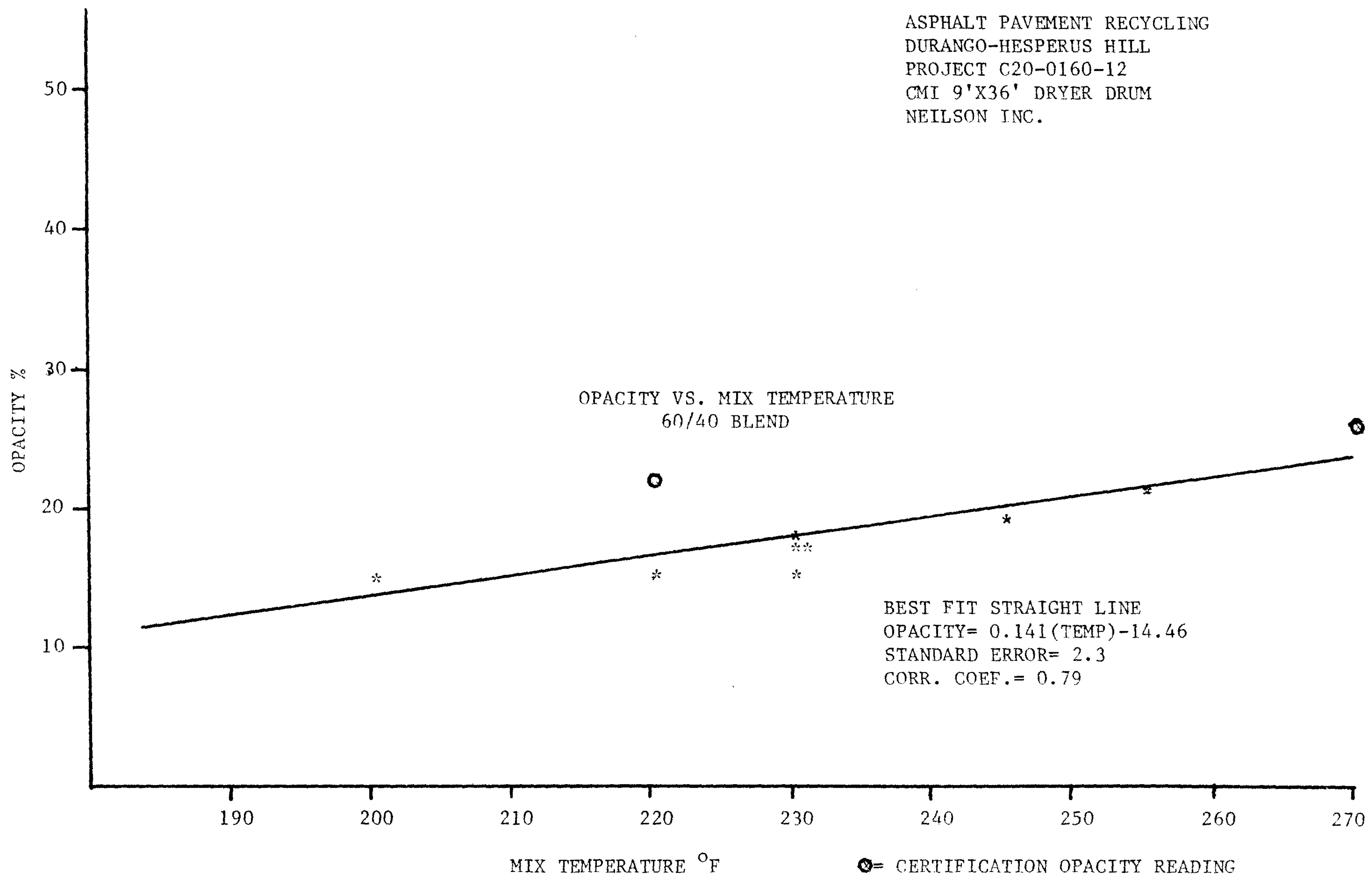
FIGURE 1



APPENDIX C
FIGURE 2



APPENDIX C
FIGURE 3



Appendix D - Table A
Central Laboratory Mix Testing
Project C 20-0160-12
Durango-Hesperus Hill

Blend Tested	1st Rep 70/30	1st 10k 70/30	2nd 10k 70/30	60/40	65/35	Virgin Mix
% Moisture	.22	.28	.26	.14	.15	.14
% Asphalt	5.19	5.17	5.27	5.37	5.19	5.86
Gradation						
% Passing 3/4"	100	100	100	99	100	100
% Passing 1/2"	94	93	97	92	93	84
% Passing 3/8"	84	81	89	82	81	69
% Passing #4	57	58	70	56	57	44
% Passing #8	42	44	54	42	44	35
% Passing #16	34	35	43	33	35	29
% Passing #50	19	20	22	19	20	15
% Passing #100	13	14	16	14	14	10
% Passing #200	9.8	10.6	12.1	10.3	10.5	7.1
Test Results						
Max. Sp. Gr. of Mix	2.44	2.45	2.44	2.44	2.45	2.44
Sp. Gr. of Specimen	2.33	2.35	2.32	2.34	2.33	2.37
Voids in Specimen	4.45	3.80	4.98	3.90	4.79	2.57
Stability Value	44.	43.	49.	45.	44.	35.
Cohesiometer Value	311.	338.	304.	276.	263.	303.
R_T Value	106.	106.	107.	104.	103.	101.
Resilient Mod.(x1000)	605.6	624.3	692.5	491.1	491.5	409.7
Strength Coeficient	44.	44.	44.	44.	44.	44.
Immersion-Compression						
Specimen PSI Wet	622.	497.	528.	462.	511.	455.
Specimen PSI Dry	523.	465.	509.	445.	456.	454.
Absorption by Weight	1.27	1.27	1.78	1.52	1.50	1.01
Swell by Volume	.10	.05	.21	.30	.07	.10
Index of Ret. Strength	119	107	104	104	112	100
Abson Recovery						
Penetration @ 77°F	----	128	----	109	110	85
Viscosity @ 275° F	----	164	---	220	181	291
Viscosity @ 140° F	----	586	----	717	737	1358

Appendix D - Table B

Field Laboratory Test Data

Project C 20-0160-12
Durango-Hesperus Hill

RECYCLED MIX

Sample Number	% AC	Sieve Analysis (% Passing) 3/4"	3/8"	#4	#8	#50	#200
1	4.74	100	80	60	46	22	12.3
2	4.77	100	84	61	46	21	11.6
3	5.03	100	81	58	44	20	10.6
4	5.05	100	81	59	45	21	11.0
5	5.49	100	88	68	53	23	11.6
6	5.01	100	80	57	43	19	10.0
7	5.07	100	77	54	41	18	9.2
8	5.52	100	83	60	45	20	10.2
9	5.51	100	80	60	46	21	10.6
10	5.20	100	80	58	44	20	9.9
11	5.41	100	83	62	47	21	10.8
12	5.16	100	79	59	45	20	9.9
13	5.09	100	76	55	42	19	9.4
14	4.87	100	78	58	43	19	9.0
15	5.19	100	78	56	43	19	9.0
16	4.98	100	80	57	43	19	9.4
17	5.30	100	80	59	45	20	10.0
18	5.92	100	78	56	42	19	9.4
19	5.19	100	78	57	44	20	10.0
20	5.11	100	87	66	51	22	10.9
21	4.96	100	81	58	44	19	9.7
22	5.22	100	83	61	47	21	10.5
23	5.36	100	83	61	46	21	10.7
24	5.53	100	85	63	48	21	10.6
25	5.24	100	84	65	51	23	11.0
26	5.13	100	85	64	49	23	11.7
27	5.16	100	80	59	45	21	10.8
28	5.36	100	79	59	46	21	10.9
29	5.58	100	79	59	45	21	10.8
30	5.06	100	83	59	45	20	10.2
31	5.04	100	79	57	44	20	10.1
32	5.00	100	75	52	39	18	9.9
AVG.	5.20	100	81	59	45	20	10.4

Appendix D - Table B (continued)

Field Laboratory Test Data

Project C 20-0160-12
Durango-Hesperus Hill

Virgin Mix

Sample Number	% AC	Sieve Analysis (% Passing) 3/4"	3/8"	#4	#8	#50	#200
1	6.26	100	69	49	38	16	6.5
2	6.32	100	73	54	42	18	8.8
AVG.	6.29	100	71	52	40	17	7.7
Design	5.8±0.5	100	--	52	47	--	6.0

Appendix D - Table C

Central Laboratory Test Results from Roadway Cores

Project C 20-0160-12

Durango - Hesperus Hill

Blend Tested	70/30	65/35	60/40	Virgin Mix
% Moisture	0.00	0.00	0.00	0.00
% Asphalt	5.75	5.10	5.30	6.46
Gradation				
% Passing 3/4"	100	100	100	100
% Passing 1/2"	93	93	92	90
% Passing 3/8"	82	82	83	74
% Passing #4	59	57	59	50
% Passing #8	45	44	45	40
% Passing #16	36	35	36	33
% Passing #50	20	19	20	17
% Passing #100	14	14	14	11
% Passing #200	11.0	10.1	10.3	8.0
Test Results				
Max. Sp. Gr. of Mix	2.42	2.45	2.44	2.41
Sp. Gr. of Specimen	2.23	2.20	2.25	2.35
Voids in Specimen	7.89	10.17	7.71	2.55
Stability Value	22.	20.	31.	23.
Cohesiometer Value	136.	110.	163.	225.
R_T Value	83.	79.	92.	89.
Resilient Mod.(x1000)	189.4	114.3	183.5	198.9
Strength Coeficient	.25	.25	.40	.35

Appendix D - Table D

Lab Testing on 70/30 Blend with 0.3% Dutrex

Project C 20-0160-12

<u>Blend Tested</u>	Durango-Hesperus Hill
% Moisture	0.00
% Asphalt	4.79
<u>Gradation</u>	
% Passing 3/4"	100
% Passing 1/2"	92
% Passing 3/8"	82
% Passing #4	61
% Passing #8	47
% Passing #16	37
% Passing #50	21
% Passing #100	15
% Passing #200	11.2
<u>Test Results</u>	
Max. Sp. Gr. of Mix	2.46
Sp. Gr. of Specimen	2.17
Voids in Specimen	11.64
Stability Value	29.
Cohesiometer Value	196.
R_T Value	92.
Resilient Mod.(x1000)	591.4
Strength Coeficient	.40

Appendix D - Table E
Asphalt Composition Analysis of Roadway Cores

Project C 20-0160-12

Durango-Hesperus Hill

Blend	70/30	60/40	65/35	Virgin Mix	0.3% Dutrex 70/30
Penetration @ 77° F	63	136	118	86	27
Viscosity @ 275° F	231	172	165	275	395
Viscosity @ 140° F	1377	587	634	1254	5910
Asphalt Composition Analysis					
% Asphaltenes	21.4	22.0	17.6	15.7	24.2
% Saturates	10.5	12.7	11.0	15.7	15.3
% Naphthene-Aromatics	25.1	25.0	11.6	22.4	34.1
% Polar-Aromatics	43.0	40.3	59.8	46.2	26.4

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73-3 Noise Levels Associated with Plant Mix Seals
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73-5 Colorado Tunnel Ventilation Study
73-6 Clifton-Highline Canal Experimental Report
73-7 Seibert Experimental Project

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74-2 Embankments With and Without Moisture Density Control

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75-4 Asphalt Membrane Project at Elk Springs, Colorado
75-5 Treatment of Swelling Soils - West of Agate, Colorado
Project I 70-4(48)347

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76-2 Bridge Deck Deterioration in Colorado
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