INSTALLATION REPORT

EVALUATION OF RECYCLED HOT MIX ASPHALTIC CONCRETE ON ROUTE 220

by

C. S. Hughes
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

This report describes a project in which the bituminous pavement on an approximately 8-mi. (13-km) section of roadway was removed, recycled through a conventional asphalt batch plant, and relaid. The project was accomplished with little difficulty and proved that recycling is an economical, feasible process. The asphaltic mix relaid consisted of about 40% recycle material and 60% virgin aggregate.

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INTRODUCTION

The energy crisis and the increasing cost of construction materials have heightened the need for efforts in conservation and intensified the search for new methods and processes within the highway construction industry. One result has been the development of several methods for recycling asphaltic concrete pavements. The successful use of these methods will permit—

1. the use of less asphalt binder;
2. the use of less aggregate;
3. a reduction in fuel consumption;
4. retention of original curb elevations;
5. corrective measures to be taken on exposed base or subbase courses; and
6. the removal and reuse of problem mixes such as those showing aging or stripping deficiencies.

The first recycled hot mix asphaltic concrete project in Virginia provided a great deal of insight into the advantages and limitations of recycling through a batch plant.(1) This project, conducted in the central Virginia area, has been followed by two others in the same general vicinity. In the first of these two, the recycled material was used in a cold mix and the second used both hot and cold mix applications. All three projects were sufficiently successful to warrant further experimental work.

The project reported upon here has extended the experience in recycling to the southwest part of the state and is expected to show that hot mix recycling can be both economical and feasible.

The primary reason for selecting the pavement used for the project was the severe cracking (Figure 1) that extended through only the surface and intermediate courses (Figure 2), and the very good condition of the underlying base course.

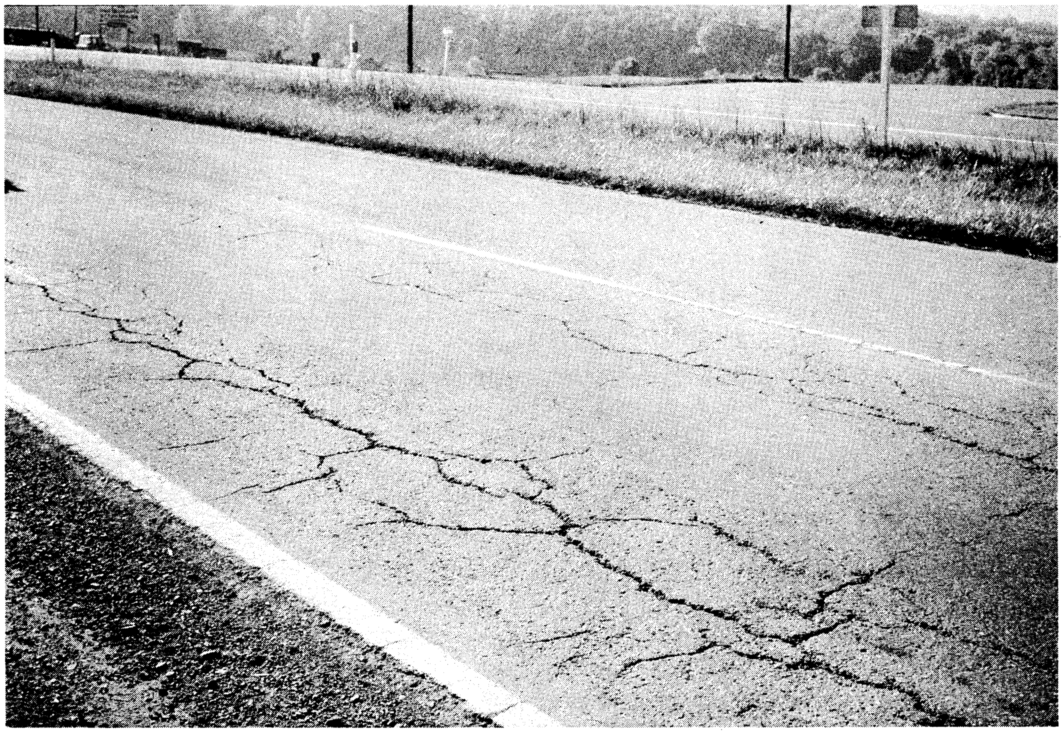

Figure 1. Typical cracking on Route 220.

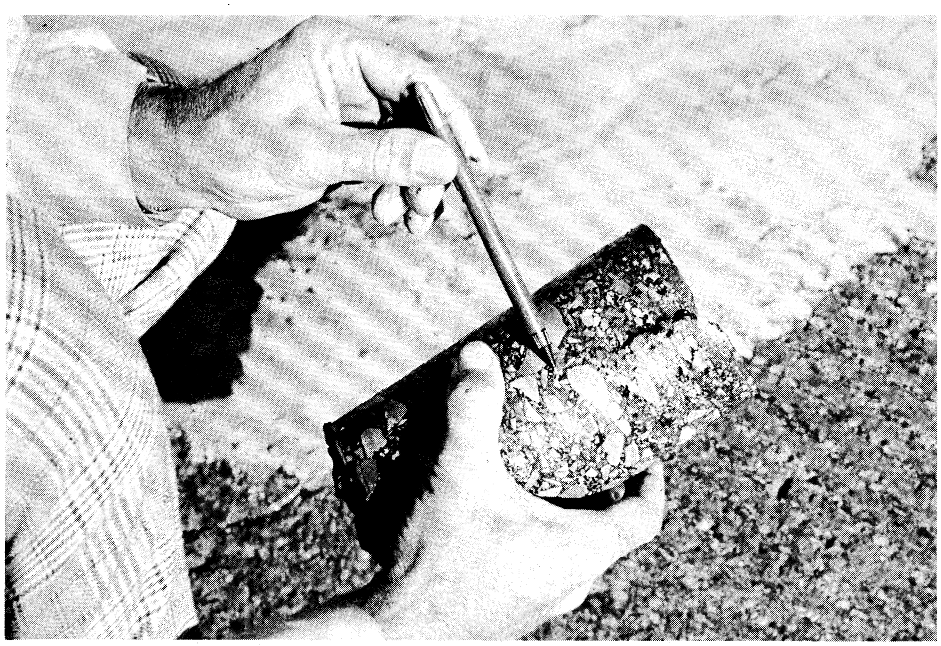

Figure 2. Cracks extending through surface and intermediate courses.

PURPOSE

The purpose of this study was to determine the economics of recycling asphaltic concrete and to demonstrate the feasibility of the process. For the study, observations and tests were made during the production and placement of a recycled asphaltic concrete mix from a plant that had been appropriately modified. Normal quality control specifications and methods were used to analyze the quality of the plant mix.

SCOPE OF STUDY

The asphaltic concrete pavement recycled was a 7.85 mi. (12.6 km) section of U. S. Route 220 in Franklin County. The project included the full width of the two northbound lanes from north of Rocky Mount to south of Boones Mill. A schematic view of the section is shown in Figure 3. The removal of 240 lb./yd.^{2} (130 kg/m^2) of material provided approximately 13,000 tons (11,800 tonnes) of recyclable material. As will be mentioned in more detail later, the use of 40% recycle material provided more mix than was necessary to repave Route 220. Therefore, some adjunct overlay work was done on Route 40 in Franklin County and, for the sake of completeness, that work is also described in this report.

Route 220 carries an ADT of about 6,400 vehicles in one direction, of which about 35% are trucks and busses. The 18-kip (8,000 kg) equivalent is estimated to be 638.

Instead of just replacing the amount of material that was removed, an attempt was made to further strengthen the pavement by applying 300 lb./yd.^{2} (160 kg/m^2) of recycled mix on the roadway. The actual amount replaced on Route 220 was 17,160 tons (15,600 tonnes).

EXISTING PAVEMENT

As mentioned previously, the existing pavement was badly cracked through the surface and intermediate layers.

The construction of the roadway had been completed in October 1969, and the pavement structure was as follows:

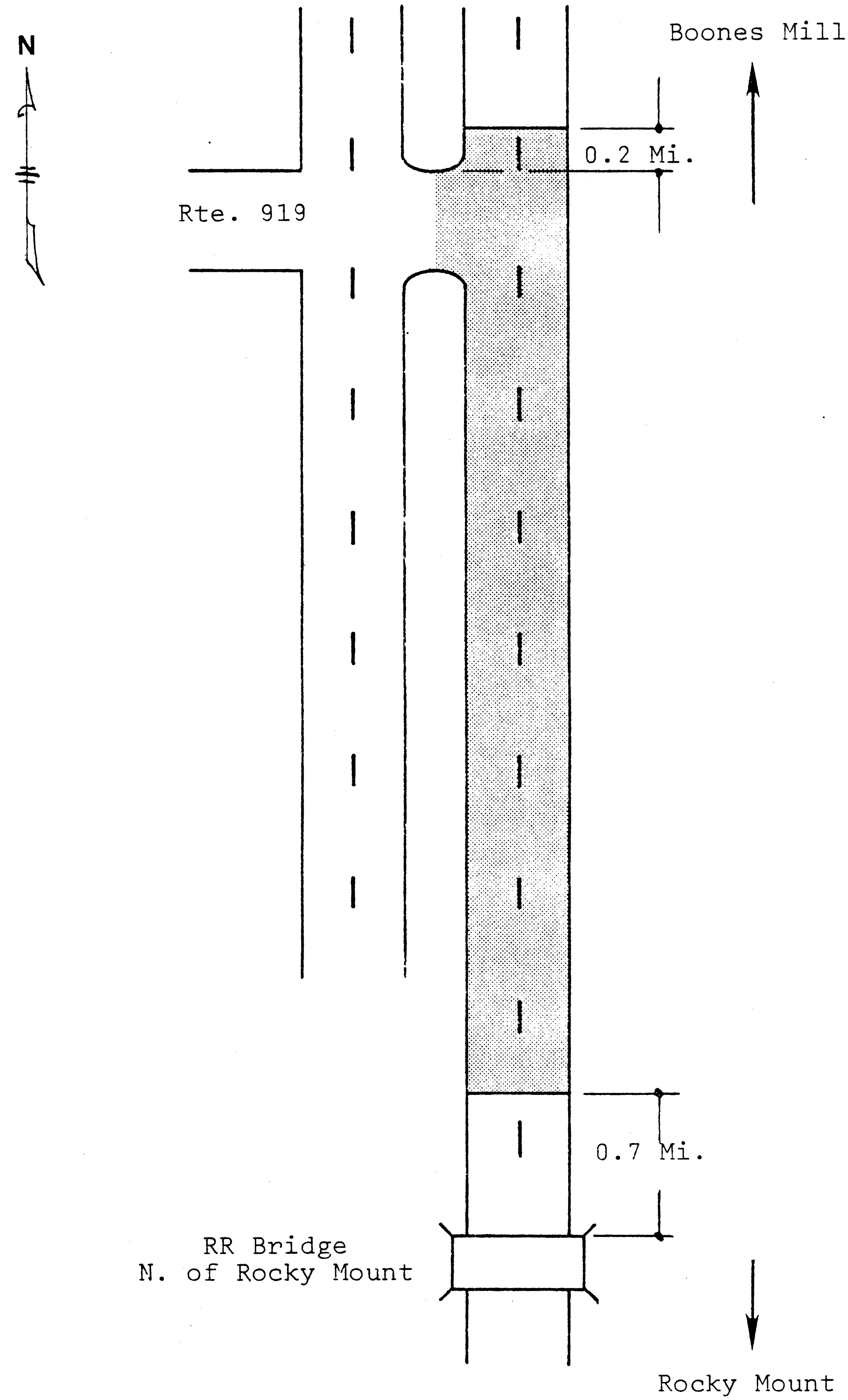

Figure 3. Schematic of project limits Route 220, Franklin County.

Surface— 100 lb./yd.^{2} (55 kg/m^2) S-5 mix
Binder— 140 lb./yd.^{2} (75 kg/m^2) I-2 mix
Base — 5 1/2 in. (14 cm) B-3 mix
Subbase— 6 in. (15 cm) 21-A aggregate
Subgrade stabilization— 6 in. (15 cm) with hydraulic cement

This structure provided a design thickness index of 12.2. Deflection tests made by the Research Council in May 1981 indicated an average thickness index of 10.6, which is less than the 15.5 required under the present traffic conditions.

Thus, it was concluded that the structure had deteriorated slightly more than 1.5 in. (4 cm) in equivalent strength as of May 1981, and that an overlay of almost 5 in. (13 cm) would be needed to bring it up to the desirable strength.

Of course the great advantage of recycling would be to remove the cracked surface and binder layers (negating the probability of reflection cracks), reconstitute the mix by recycling, and relay the material at a heavier application rate than that removed. The choice of a 300 lb./yd.^{2} (160 kg/m^2) repave application instead of 500 lb./yd.^{2} (270 kg/m^2) was dictated by economics.

The gradation, asphalt content, and properties of the recovered asphalt were determined and the results are given in Tables 1 and 2. The average density of the cores was 92.6% of the maximum theoretical (ASTM D-2726 and D-2041).

Table 1

Average Gradation and Asphalt Content of S-5 and I-2 Layers

Sieve Size	Percent Passing
1"	100.0
3/4"	99.9
1/2"	96.6
3/8"	89.6
#4	59.9
#30	19.7
#50	13.9
#200	7.6
A.C., percent	5.57
Percent polishing aggregate +#4	85.0

Table 2

Average Abson Recovery Results

Property	S-5 & I-2	B-3
Penetration	16	40
Softening Pt., °C	66	55
Ductility, cm	10	105+
Viscosity, 140°F. (60°C), poises	47,290	4,230

The gradation and asphalt content results reveal nothing unusual. One concern in recycling the two layers of pavement was that the entire I-2 layer was composed of polish susceptible limestone aggregate and, according to the results of the gradation tests, 85% of the +#4 material in the S-5 and I-2 layers combined was limestone aggregate. The concern was that in recycling, unless special attention was paid to using coarse, nonpolishing virgin aggregate to offset the limestone coarse aggregate, the pavement surface could tend to polish and become slippery.

The Abson recovery results indicated a very brittle asphalt in the two upper layers and a reasonably flexible asphalt in the bituminous base layer. These results indicated that a soft asphalt cement should be added in the recycling process to improve the total asphalt properties. No specific cause was found for the brittleness of the asphalt in the surface layers.

PRELIMINARY MIX DESIGN

The district materials laboratory attempted to simulate the hot mix recycle process in the preliminary mix design. The material from the road was heated to 140°F. (60°C), and 50% of it was combined with 35% of #68 nonpolishing aggregate and 15% of #10 aggregate, both of which had been heated to 425°F. (220°C). The gradation of the three materials is shown in Table 3. This mix design used 2.4% of an AC-10 asphalt with a penetration of 138. This procedure produced a mix having a temperature of 250°F. (120°C). This mix was placed in an oven and heated to 275°F. (135°C) before being compacted into Marshall specimens.

The use of 2.4% AC-10 provided adequate Marshall results, but the properties of the recovered asphalt (penetration of 34 and viscosity at 140°F. (60°C) of 12,000 poises) indicated that a softer grade asphalt would be more beneficial.

Table 3

Gradation of Materials in Preliminary Mix Design

	Percent Passing			
Sieve Size	#68	#10	I-2/S-5 (Recycle)	Blend
1"	100	100	100	100
3/8"	43	100	90	77
#4	9	96	60	50
#50	1	41	14	17
#200	1	12	8	8
A.C., percent	—	—	5.57	

Therefore, a special provision was put in the contract to call for an AC-5, which, because Virginia uses the viscosity grading system, would allow a penetration range of 120-270. To help assure a penetration higher than 138, the special provision allowed the contractor to use an asphalt cement with a penetration of 200±10%.

The 35% of #68 nonpolishing virgin aggregate provided sufficient coarse aggregate to mask the effect of the limestone coarse aggregate in the recycled binder layer.

RECYCLE OPERATION

Milling

On September 8 the contractor (Virginia Asphalt Paving Company, Roanoke, Va.) started milling using a 12-ft. (3.7-m) CMI Rotomill. Because the travel speed on the first few days produced an excess of oversize material, the operation was slowed down and the gradation of the milled material improved. The only other problem encountered was that the 240 lb./yd.^{2} (130 kg/m^2) being removed did not always include all of the binder course. The surface texture was very good (Figure 4). In total, 110,528 yd.^{2} (92.4 km^2) of the surface material were milled.

Several extraction tests were run on the milled material and the results are shown in Table 4.

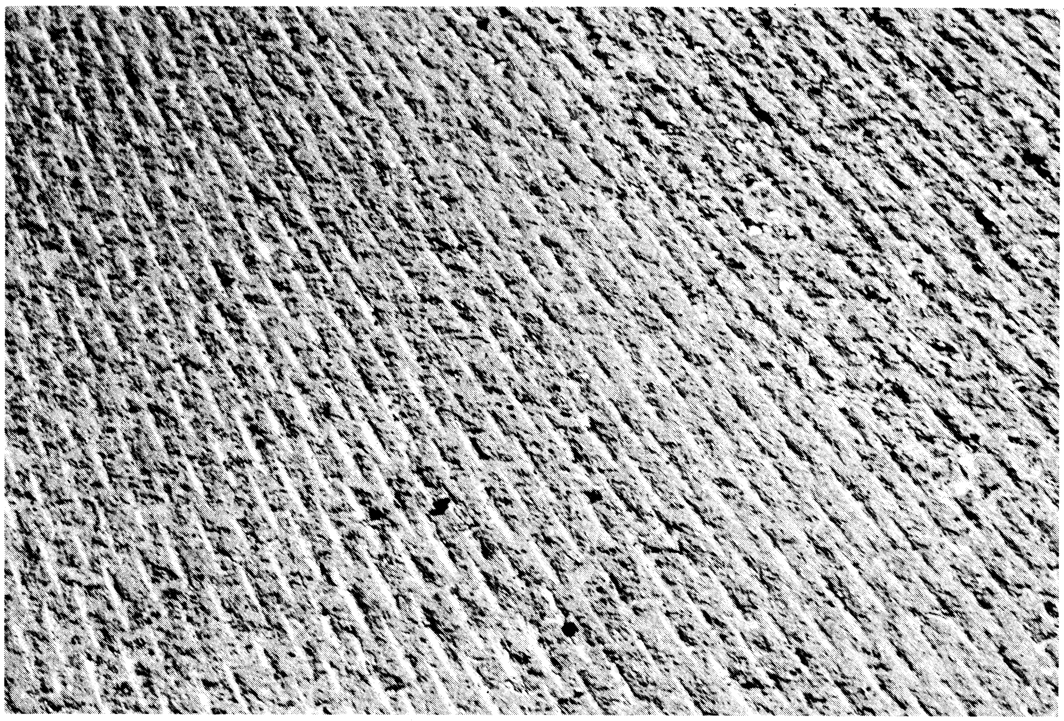

Figure 4. Texture provided by milling.

Table 4

Average Gradation and Asphalt Content of Milled Material

Sieve Size	Percent Passing
3/4"	100
1/2"	99
3/8"	94
#4	69
#8	49
#30	26
#50	18
#100	13
#200	10
A.C., percent	5.39

These results indicate that the recycled material was slightly finer than the mix resulting from the preliminary design; however, there was not sufficient difference to modify the design.

Two additional Abson recovery tests on the milled material produced an average penetration of 15 and viscosity at 140°F. (60°C) of 59,700 poises, verifying that the asphalt cement was very hard.

PLANT MODIFICATION

To handle the recycle material, a bin and elevator were added to the batch plant (Figure 5). The material was then scalped over a 2-in. (5-cm) screen and dropped directly into the #4 bin. This process took less space than using a bin and conveyor, and the elevator was built so that it could be used at another of the contractor's plants. A disadvantage was that some recycle material built up on the sides of the hot bin. This appeared to be caused primarily by the steam release (Figure 6), which occurred when the recycle material met the virgin material that had been superheated to 475°F. (250°C) causing the sides of the hot bin to heat up and the material to stick. This buildup also occurred in the weigh hopper and caused some problem in zeroing the scales after each batch was dropped.

Figure 5. Batch plant modified with additional elevator for recycle material.

Figure 6. Steam released when superheated virgin material was mixed with recycled material.

FINAL MIX DESIGN

Materials

The materials used in the recycled mix were based on the preliminary mix design. The gradations of the virgin materials are given in Table 5 and the properties of the asphalt in Table 6.

The sand had a high sulfate soundness loss and broke down excessively under the high drier temperatures to produce an overabundance of -#200 material. To help alleviate this problem, the sand was pre-blended with equal parts of #8 granite to produce the fine portion of the virgin aggregate.

Table 5

Gradation of Virgin Aggregate

	Percent Passing		
Sieve Size	#68 (36%)	#8 (12%)	Sand (12%)
1"	100		
3/4"	99		
1/2"	65	100	
3/8"	39	96	100
#4	7	11	96
#8	4	3	78
#16	2	3	
#50	2		7
#200	1		1

Table 6

Properties of AC-5 Asphalt Cement

Penetration	200
Viscosity at 140°F. (60°C), poises	472
Viscosity at 275°F. (135°C), Cs	234
T.F.O.T., Residue	
Viscosity at 140°F. (60°C), poises	1,140

PRODUCTION

Once the bugs were worked out of the mix design and the plant became balanced, production averaged about 150 tons/hr. (136 tonnes/hr.). This production rate used dry and wet mixing times of 30 seconds each. This particular sequence was hard on the mixing box, which had to be replaced after the production of about 15,000 tons (13,600 tonnes). (Normally 50,000 tons (45,000 tonnes) of mix can be produced without wearing out the mixing box.) Near the end of the project a 4-second dry and 45-second wet mixing cycle was used with apparent satisfactory results.

Paving on Route 220 was begun on September 30 and completed on October 28. The operation went very smoothly.

MIX TESTS

The normal acceptance tests were run by an inspector at the plant. These included the temperature of the mix in the truck and reflux extraction tests for determining the gradation and asphalt content. Averages and standard deviations of gradations, asphalt contents, and temperatures are shown in Table 6.

The average results from tests on 50-blow Marshall specimens of the recycled mix are given in Table 7.

Table 6

Averages and Standard Deviations of Gradations, Asphalt Contents, and Temperatures

Sieve Size	Percent Passing	σ	JM
1"	100	-	100
3/4"	100	-	95
1/2"	86.4	3.1	-
3/8"	71.6	3.4	70
#4	45.5	3.3	50
#8	32.8	2.9	36
#30	18.3	1.1	-
#50	13.2	0.9	13
#200	7.0	1.0	6
A.C., percent	5.11*	0.34	5
Temperature, °F.**	260	13	2.70

*Based on 5.39% asphalt from milled material, an average of 3.05% AC-5 was added.
**°C = (°F. - 32) 5/9.

Table 7

Average Marshall Results

Max. theoretical density, percent	96.9
Voids mineral aggregate, percent	15.1
Voids filled with asphalt, percent	79.9
Stability, lb.	2,650 (366)
Flow	15

These results all indicate that the mix had a good density. The maximum theoretical density and voids filled with asphalt are slightly higher than normal, but the mix should be able to accommodate the asphalt because over half of the asphalt cement was in the original mix and very likely will not combine totally with the new asphalt.

The properties of the recovered asphalt are shown in Table 8.

Table 8

Average Recovered Asphalt Properties After Recycling

Penetration	46
Ductility, cm	105+
Softening Pt. °C	50
Viscosity at 140°F. (60°C), poises	5,550

These results indicate that the addition of the AC-5 did improve the properties of the aged asphalt cement appreciably.

A stripping test, which was a modification of the Lottman procedure,[2] was also run on the mix. The tensile strength ratio value was 0.87, which compares to a minimum acceptable value of 0.75. The mix incorporated an antistripping agent, Pave Bond Special, in a concentration of 1.0% by weight of new asphalt. This was twice the amount of antistripping agent normally used. The intent was for the additional antistripping agent to compensate for the asphalt already in the mix.

ROAD TESTS

The most important property of the in-place mixture is density, because of the strong influence this property exerts on durability. Thirty samples were sawed from the roadway and density tests run on them. The average density was 95.1 and the standard deviation was 1.5 based on the percent maximum theoretical density, which is considered quite good.

The results of Dynaflect deflection tests, when converted to Benkelman beam values, averaged 0.0174 in. (0.4 mm). This value, combined with a bending factor of 66, produces a thickness index of 11.0. This result was disappointing in that the average thickness index increased only 0.4. However, the variability of the recycled mix was lower than that of the original surface, which indicated that the weaker sections were strengthened.

Skid tests were run approximately one month after completion of the project and, as anticipated, showed the influence of the asphalt film on the surface. The average SN_{40} was 42 with a standard deviation of 4, which is considered adequate.

Road roughness values measured with the Mays meter at 55 mph (88 km/hr.) averaged 85 in./mi. (1.33 mm/m) in the traffic lane and 83 in./mi. (1.33 mm/m) in the passing lane.

ENERGY REQUIREMENTS

An analysis was made to compare the energy requirements for the recycled mix to those for a conventional mix using the Asphalt Institute's procedure.[3] This procedure compares the amounts of energy consumed in producing the two types of mix to the point that they are loaded in the trucks at the plant. Thus, it does not consider the energy used in hauling and placing the mixes, which should be the same for both.

Energy Consumed/Ton Regular Mix

Materials

Manufactured asphalt cement	587,500 Btu/t	
Haul (4-axle truck) 250 mi. (400 km) from source to plant x 2 @ 5,040 Btu/t	2,520,000	
	3,107,500 Btu/t	
Crushed stone	56,000	
Haul (3-axle truck) 30 mi. (48 km) from source to plant x 2 @ 4,270 Btu/t x 1.04	266,450	
	322,450 Btu/t	

Mix Composition

Asphalt 5.2% @ 3,107,500 Btu/t	161,590	
Aggregate 94.8% @ 322,450	305,680	467,270 Btu/t

Plant Operation

Dry aggregate 4% moisture @ 28,000 Btu/% x 94.8%	1,060	
Heat 205°F. (95°C) @ 470 Btu/°F./t x 94.8%	91,340	
Other plant operations	19,800	112,200
Total for Regular Mix		579,470 Btu/t

Energy Consumed/Ton Regular Mix (60/40)

Materials

Manufactured asphalt cement (see above)	3,107,500	
Virgin aggregate Crushed stone (see above)	322,450	
Sand	15,000	
Haul (3-axle truck) 15 mi. (24 km) from source to plant x 2 @ 4,270 x 1.04	161,220	
	176,220	
Recycle aggregate Milling	20,000	
Haul (3-axle truck) 4 mi. (6 km) x 2 @ 4,270 x 1.04	35,530	
	55,530	

Mix Composition

Asphalt 3% @ 3,107,500 Btu/t	93,230	
Virgin aggregate Crushed stone 46% x 322,450 Btu/t	148,330	
Sand 11% x 176,220 Btu/t	19,380	
Recycle aggregate 40% x 55,530 Btu/t	22,200	283,140 Btu/t

Plant Operation

Dry aggregate 4% moisture @ 28,000 Btu/t x 57%	600	
Heat 400°F. (205°C) @ 470 Btu/t x 57%	107,200	
Other plant operations	19,800	127,600 Btu/t
Total for Recycle Mix		410,740 Btu/t

The energy consumed for the recycle mix is approximately 70% of that required for a 100% virgin mix.

COSTS

The unit price for the recycle mix was $22.83/ton ($20.71/tonne), and that for planing was $0.82/yd.^{2} ($0.68/m^2). Converting the milling to a per ton cost gives $7.13/ton ($6.47/tonne). Thus, the total cost of a ton of recycled mix was $29.96. A typical cost for I-2 mix in this area is approximately $28/ton ($25/tonne).

ADJUNCT WORK

With the recycle material left over from Route 220, it was decided to add a CMS-2 emulsion and strengthen several sections of Route 40 in Franklin County. This approach was not satisfactory in that the paver screed could not produce an acceptable surface, and the remainder of the overlay work was done with hot recycle mix. Figure 7 is a schematic sketch of the short section of Route 40 to which 165 lb./yd.^{2} (90 kg/m^2) of the cold recycled mix was applied and the sections that were resurfaced at 145 lb./yd.^{2} (80 kg/m^2) with hot recycle mix. Although the testing for these sections was not as thorough as that on Route 220, the performance will be evaluated visually.

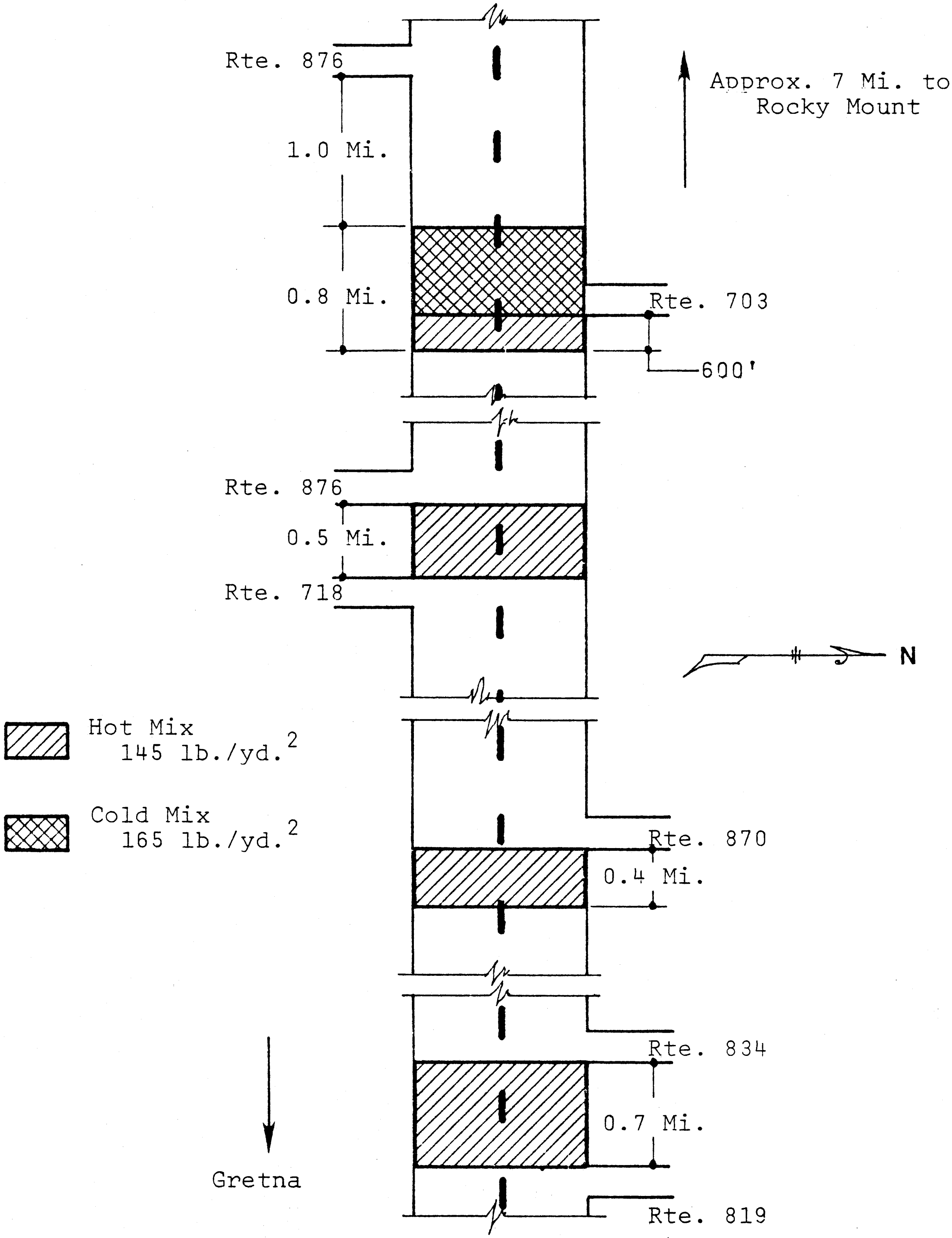

Figure 7. Schematic of recycle mix location Route 40, Franklin County.

ACKNOWLEDGEMENTS

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