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DEMONSTRATION PROJECT NO. 39

RECYCLING ASPHALT PAVEMENTS

Gila Bend, Arizona

Prepared for
and
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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
REGION 15
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1000 NORTH GLEBE ROAD
ARLINGTON, VIRGINIA 22201

PAVEMENT RECYCLING PROJECT

(DEMO. PROJECT 39, NEEP 22)

I 8-2(76) YUMA COUNTY LINE - GILA BEND

Submitted by
John Ritter - Principal

Under the Direction of
Gene R. Morris - Engineer of Research

And Supervision of
Grant J. Allen - Engineer of Materials

October 1978

Arizona Department of Transportation
Research Division

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The highway construction industry is changing rapidly. With most of the interstate systems completed, the scope of work is now focusing on maintaining the existing systems. Because of the differential time between beginning and completion, many sections are approaching the end of their original design life. Some of these have already had maintenance action and many are presently in need. Many pressures are being brought to bear as to the type of maintenance that should be performed. Fiscal and environmental are probably the most influential pressures being levied. Highway designers are now having to consider many different alternatives and the impact of each of these alternatives.

One of these new alternatives is recycling. Recycling of asphaltic concrete pavements promises to satisfy the concepts of fiscal and environmental savings.

A major recycling project on Interstate 8 was studied to evaluate the savings of this alternative. In addition to this, an extensive evaluation of the recycled asphaltic concrete has been conducted and will continue in the future to determine its long-term characteristics. This paper reports on the findings to date.

I. LOCATION AND HISTORY

Interstate 8 is located in the Sonoran Desert of Southwestern Arizona. The section of highway that was selected for this project is located approximately 90 miles southwest of Phoenix. This desert valley region has an average annual rainfall of 5 inches. The average maximum temperature is 88°F, with temperatures rising to 120°F in the hot summer months.[1]

The original pavement structure was built in 1950 and consisted of 4 inches of select material, 5 inches of aggregate base and 2 inches of mixed bituminous surface. This roadway carried traffic in both directions until 1960 when the westbound roadway was built. The eastbound roadway section was increased by the addition of a 1-1/2 inch overlay at this time. No further work was done until 1970 when the EB roadway was sealed with an emulsified petroleum resin flush. The EB roadway width is 38 feet consisting of a 4-foot shoulder, a 12-foot passing lane, a 12-foot travel lane and a 10-foot distress lane.

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[1] "Arizona Statistical Review", 32 nd Annual Edition, Sept. 1976.

II. PRELIMINARY INVESTIGATION

Preliminary investigation was accomplished in three areas. A visual examination for distress was performed, performance characteristics were measured, and the pavement was sampled for physical properties.

Distress

The pavement was block cracked in the travel lane with some areas at or approaching an alligatored condition. The estimated crack index was 35-40% as determined by a procedure which was presented for the FHWA at the Orientation Session for Pavement Overlay Design on June 24, 1977. See Appendix C. The block cracking occurred at approximately 20 feet spacing, transversely across the roadway. In some areas, cracking had deteriorated to alligator cracking and in the worst areas, popouts were occurring due to the alligatoring. Some minor rutting was evident. All types of distress were greater in the travel lane than in the passing lane.

Performance Characteristics

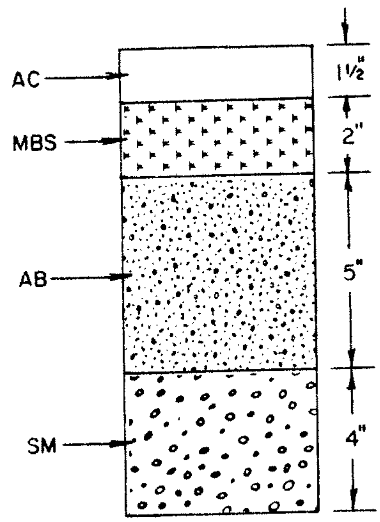
The rideability index as measured by the Mays ride meter averaged 3.1 (see Table 3 p. 30) which indicates a fair ride. The deflection as measured by the Dynaflect indicated an arithmetic mean of .788 mills which is a moderate deflection level (see Table 5 p. 31). The surface friction as measured by the Mu-Meter averaged 58 which is a moderate skid level (see Table 4 p. 30).

Physical Properties

Visual examination of cores coincided with the structural section as shown below:

Figure 1

Original Structural Section



The aggregate was extracted from the bituminous materials and its properties are shown below:

Sieve Size	% Passing
1"	100
3/4"	98
1/2"	87
3/8"	76
#4	57
#8	41
#40	20
#200	7

Oven Dry Specific Gravity 2.520

The asphalt which was extracted yielded the following results:

Average asphalt content	4.9%
Average absolute viscosity (140°F)	300,000 + poises
Rostler Analysis (short)	

Asphaltenes	Nitrogen Bases and 1st Acidiffins	2nd Acidiffins and Paraffins	Chemical Reactivity Ratio
39.3%	32.2%	28.6%	1.15%

The 2 inch mixed bituminous surface and the 1-1/2 inch asphaltic concrete were evaluated for modulus of resilence (M_R) and Marshall stability separately and combined. The average values for the AC were 1,450 KSI for the M_R with a Marshall stability and flow of 5,830 pounds and .15 inches respectively. The average values of the combined were 1,500 KSI for M_R with a Marshall stability and flow of 6,323 pounds and .14 inches respectively.

III. DESIGN CRITERIA/PROCEDURE

Structural Coefficient

Samples of the subgrade were tested. Practically all the subgrade soils fell into an A-2 or A-4 soil (AASHTO SOIL CLASSIFICATION SYSTEM). The test results on the base materials were used to establish the structural coefficients shown below:

Material Type	Coefficient	Thickness	Total
SM	.06	4	.24
AB	.10	5	.50
ABS	.20	2	.40
AC	.28	1.5	.42
		TOTAL	1.56

Referring back to Figure 1, the in-place thicknesses, and using the coefficients given above, the in-place structural number is calculated to be 1.56.

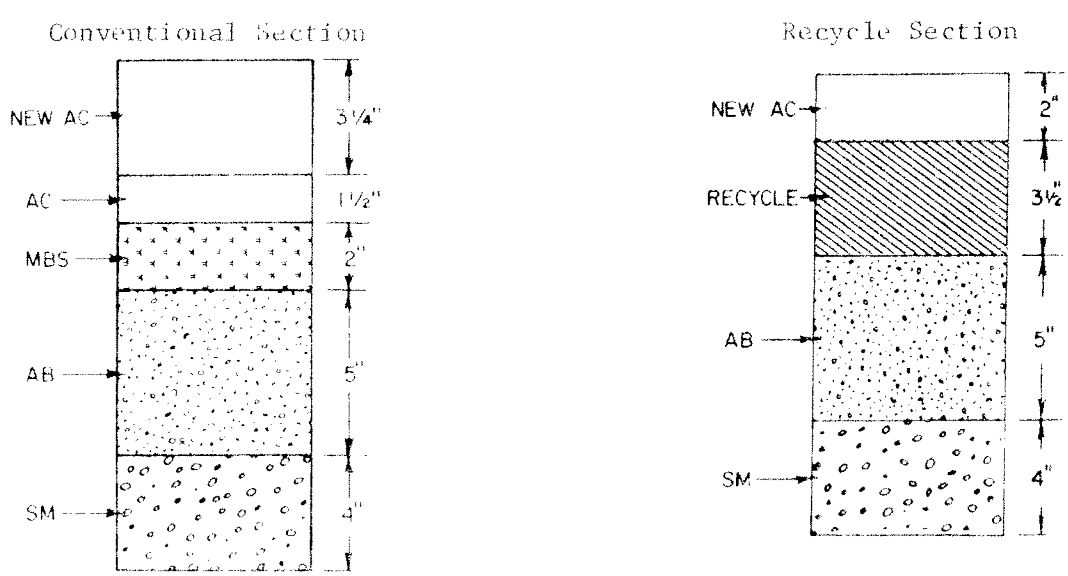
Using an R-value of 39 (which corresponds to a soil support value of 5.42), a regional factor of 0.6 and a traffic value of 2×10^6 18-kip loads (approx. 9-year-design period), the required structural number is 2.90 (see Figure 8 p. 33). The difference is 1.34. Assuming a new AC coefficient of 0.40, the required thickness calculates to be 3.25 inches of new AC. If the required thickness were to be built as a regular overlay by the usual ADOT design policy, heater scarification and application of emulsified petroleum would be needed before overlaying, to eliminate reflective cracking, and the 3.25 inch overlay would have to be full width to achieve a satisfactory cross-slope.

But, if the existing travel lane AC could have its structural number improved by recycling, the passing lane would need only the thin overlay to match its surface with the travel lanes.

In the analysis of this alternate, the first step would be to determine if an acceptable product can be produced. Two options were pursued; first, using only the AC and MBS materials, and second, using 25% AB and 75% AC and MBS materials. Complete mix designs were accomplished on both (see Figs. 9 and 10, p.34-35). On the basis of ARIZ 802, which is a modification of AASHTO T-165 (Immersion Compression), the option of AC and MBS materials was chosen over the option of a combination of AB, AC and MBS materials. A review of the structural analysis of this section follows:

Using the coefficients stated earlier on page 6, the in-place structural number of 4 inch SM and 5 inch AB is 0.74 which leaves a difference of 2.16. By giving the recycled AC the same structural coefficient as new AC (0.40) the required thickness is 5.5 inches or 3-1/2" recycle plus 2 inch new AC overlay. Figure 2 below shows the two sections, conventional and recycle.

Figure 2



Design Selection

A design section of removing and replacing the 3-1/2 inches of bituminous material in the travel lane and placing a 1-1/4" AC and 1/2" ACFC overlay was selected. This design shown below was chosen for the following reasons.

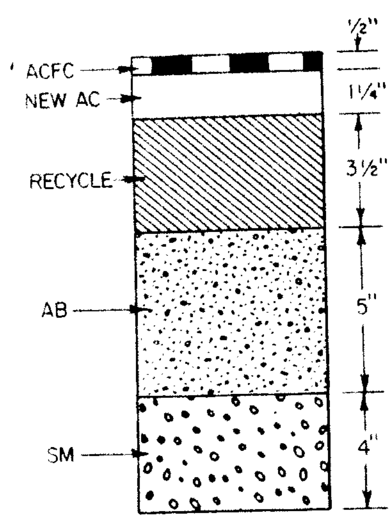
1. The funds were not available for more than 1-1/4" AC and 1/2" AC overlay by FHWA policies and procedures.

2. The major distress was in the travel lane. The passing lane did not justify the same overlay thickness or rehabilitative measures as the travel lane. This design allowed more extensive rehabilitative measures to be performed where they were most needed.

3. It was desired to evaluate the recycling concept.

Figure 3

Design Section



Mix Design

In designing the recycle options, three characteristics were examined: the average gradation, void relationships and effect of water on the mix. First, considering the option of using the AC and MBS materials, the average gradation of the samples indicated a 41% pass #8 and 7% pass #200. The #8 value is approximately what is used for the target value for that screen in a conventional AC design. 4% pass #200 is usually specified as a target value, so 7% is high. A coarse aggregate blend was decided against because of past raveling experience with coarse blends. Secondly, void relationships were examined to determine type and amount of asphalt modifier. At the percentage required, the type needed would be a recycling oil comparable to Cyclogen L_{TM} based on the viscosity of the salvaged materials. (See Figure 11, p. 36). The following is an analysis of the recycling oil.

Average absolute viscosity at 140°F cps	290
Theoretical Chemical Reactivity Ratio	0.38
A, Asphaltenes	0.62 %
N, Nitrogen Bases	14.39 %
A_1 1st Acidiffins	13.28 %
A_2 2nd Acidifins	39.92 %
P, Paraffins	31.78 %

The 3rd characteristic examined was the effect of water on the mix. The mix was tested in accordance with ARIZ 802 (a modification of AASHTO T-165, Immersion Compression). The retention was 35% with a wet strength of 132 psi. The usual requirements for this region are 40% retention and a wet strength of 150 psi. Based on the 5" of annual rainfall, the retention values were accepted.

The second option, using 25% AB and 75% AC and MBS, was evaluated the same way. The average gradation of the composite increased in pass #200's from 7% to 8% due to the addition of the AB. This factor was undesirable. The void relationships were then examined and 2.5% recycling oil was needed to achieve acceptable results. This factor also was undesirable due to the cost of recycling oil. Next immersion compression tests were run and a retention of 28% and a wet strength of 95 psi were recorded. These results were totally unacceptable. Therefore, the option of using AC and MBS materials or 100% recycle was chosen.

IV. CONSTRUCTION CRITERIA/PROCEDURE

Specifications

Appendix A, pages 39-45, is a copy of the specifications for the removal and production of the recycled asphaltic concrete.

The intent of the removal specification was to allow the contractor to have a choice in his removal operation. The width of 12'6' was selected by conversations with milling companies about available equipment. Either the use of milling equipment or the use of conventional equipment for removal was acceptable. Contamination of the removed asphaltic materials by the underlying base was a concern and was so indicated by the specifications.

Reducing the size of the aggregate material to 90-100 percent passing the one-inch sieve was felt to be an adequate specification at the time it was written.

The specifications provided for the contractor to install satisfactory precipitation devices or other adjustment apparatus in order to control excessive emissions.

Mixing temperatures were specified in the range of 210 to 250 degrees Fahrenheit. The temperature prior to rolling was specified to be not less than 170 degrees Fahrenheit.

Contractor's Equipment

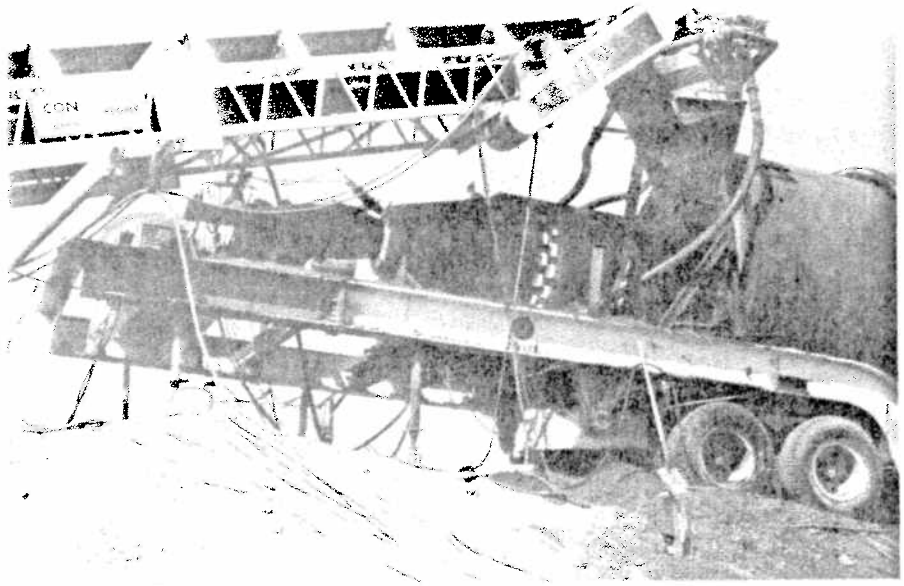
During the removal operation, the contractor used a CMI Rotomill milling machine, type PR-575. The milling machine had a cutting width of 9'2" using a rotary drum with 176 cutting teeth. The contractor initially began cutting the full 3 to 3-1/2" depth in one pass. Because of the crack pattern in the pavement, this full depth milling produced large sized pieces of pavement. The contractor thus began to remove in two lifts, the first 2" deep and the second to the interface of the base and the asphaltic material. Because of the depth restriction and the width, it was necessary to make four passes to get the required depth and width. The milling of the approximately 57,200 sq. yd. was accomplished in 137 working hours for an average of 428 sq. yd./hr. The rotomill was equipped with a conveyor belt which loaded the trucks. The Figures 4 and 5 on the next page show the removal process. The trucks then hauled the material to the plant site and stockpiled it.

The drum mixer was a Shearer Process, 500 TPH, drum mixer. It was equipped with a dry cyclone collector for use as a primary emission control device. The modifications that the contractor made were, 1) to lengthen the frame in front of the drum mixer, 2) move the burner back, and 3) replace the conventional combustion chamber with a Boeing "Pyro-Cone." See Figure 6 page 14.

The "Pyro-Cone" consists of a combustion chamber, an extension sleeve with ventilation slots, and a perforated heat shield. This modification increases the distance from the direct flame to the aggregate material. The shield is used to stop the flame and allow only the hot gasses to pass so as not to ignite the asphalt in the old mix (See Figure 7, p. 14).

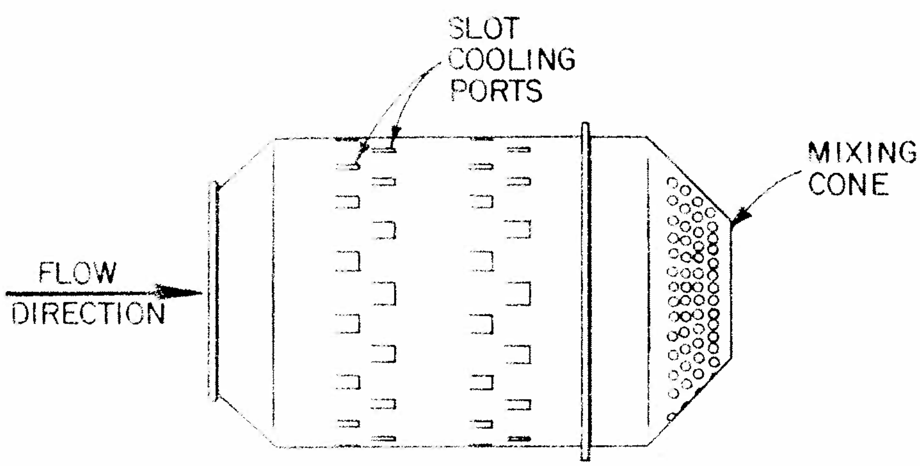
The contractor installed precipitation devices at six different locations, five along the cold feed and one inside the drum. All devices were

Figure 6



DRUM MIXER WITH MODIFICATION

Figure 7



PYRO CONE

fed from one tank and one pump. Later, the stockpile was watered to obtain uniform moisture and the precipitation devices were turned off.

Production

Production rates ranged from 250 to 350 TPH with optimum results at around 275 TPH. Aggregate temperature recorded by the drum dryer pyrometer indicated temperatures ranging from 190 to 275°F. The best product was produced when the plant was running @200°F and 250 or 275 TPH. Table 2, p 29, is a tabulation of hot plant inspection reports. The plant generally produced within the temperature specification. Density was no problem, ranging from 95 to 98% of theoretical maximum density.

Structural and Physical Properties

During construction, the contractor elected to place new AC in the excavated area in order that this area would not be a hazard to the traveling public. When removal of the old AC was completed, the contractor modified his plant and began producing recycled AC. This sequence resulted in the structural sections shown by Figure 12, p. 37.

The performance characteristics were as follows: surface friction 75 (approximate for new friction course), rideability 4.05 (see Table 6, p. 32), and deflection by sections as reported below:

Section	Composition	Deflection
A	New/New	.688
B	Recycle/Old	.723
C	Recycle-New	.771
D	Recycle/Recycle	.999
E	New/Recycle	.702

The physical properties of the structural sections were determined from samples taken at the laydown and from cores taken approximately 30 days after completion of the project. The average properties are listed below:

TABLE 1

		Recycle		New
		Laydown	Core	Core
Modulus of Resilience	@ 73°F	$.520 \times 10^6$	$.407 \times 10^6$	$.696 \times 10^6$
Marshall Stability	@140 F	3704	1274	2958
Marshall Flow	@140 F	20	18	20
Bulk Density	@ 77 F,pcf	143.0	142.8	142.7

Aggregate Gradation (Recycle)

Sieve	% Pass
1"	100
3/4"	94
1/2"	88
3/8"	79
#4	59
#8	43
#40	22
#200	9.1

Asphalt

The asphalt was extracted and its properties are listed below.

	Cores	Laydown
Average % by wt. of mix	5.4	6.9
Average viscosity @ 140°F, poises	8296	5186
Average Rostler		
Asphaltenes		34.8
$N+A_1$ Nitrogen Bases and 1st Acidiffins		29.8
A_2+P 2nd Acidiffins and Paraffins		35.4
CRR Chemical Reactivity Ratio		0.84

V. COST ANALYSIS

The cost analysis of the recycle design versus the conventional is listed below. The overlay thicknesses used are the thicknesses needed to fulfill the structural analysis. The costs are actual bid prices for this job.

RECYCLE

Recycle 3.5" A.C.	(12,750 tons x $8.50/ton)	=	$ 108,375
Recycling Oil	(191 tons x $185/ton)	=	35,335
2" Overlay	(18,860 tons x $10.00/ton)	=	188,600
Asphalt	(1,000 tons x $110/ton)	=	110,000
Anti-Strip	(10 tons x $0.65/lb)	=	13,000
Removal for Recycle	(57,200 sq yd x $1.50/sq yd)	=	85,800
			$ 541,100

Cost per square yard = $3.03

CONVENTIONAL

3.25" Overlay	(30,647 tons x $10.00/ton)	=	$ 306,470
Asphalt	(1,624 tons x $110/tons)	=	178,640
Anti-Strip	(16.24 tons x $0.65/lb)	=	22,880
Heater Scarification	(57,200 sq yd x $0.40/sq yd)	=	21,112
Emulsified Petroleum Resin	(60 ton x $220/ton)	=	13,200
			$ 542,302

Cost per square yard = $3.04

The difference is approximately $1,200 or 1¢ per square yard. This is 0.2% difference which is negligible.

The cost analysis of the recycle design versus the conventional as funding permitted and as-built is listed below.

RECYCLE

Recycle 3.5" AC	(12,750 tons x $8.50/ton)	=	$ 108,375
Recycling Oil	(191 tons x $185/ton)	=	35,335
1-1/4" Overlay	(11,788 tons x $10.00/ton)	=	117,880
Asphalt	(625 tons x $110/ton)	=	68,750
Anti-Strip	(6.25 tons x $0.65/lb)	=	8,125
Removal for Recycle	(57,200 sq yd x $1.50 sq yd)	=	85,800
			$ 424,265

Cost per square yard = $2.38

CONVENTIONAL

1.25" Overlay	(11,788 tons x $10.00/ton)	=	$ 117,880
Asphalt	(625 tons x $110/tons)	=	68,750
Anti-Strip	(6.25 tons x $0.65/lb)	=	8,125
Heater Scarification	(57,200 sq yd x $0.40/sq yd)	=	21,112
Emulsified Petroleum Resin	(60 ton x $220/ton)	=	13,200
			$ 229,067

Cost per square yard = $1.28

The cost is lower for the conventional method. The structural number is 2.64 for the recycle and 2.06 for the conventional. In effect the increase of .50 instructural number cost $1.28 sq/yd and the increase of 1.08 cost $2.38.

VI. ENERGY CONSUMPTION

The energy consumption of the recycling design versus the energy consumption of the conventional design was analyzed by using a calculation procedure similar to those used in the Asphalt Institute's publication "Energy Requirements for Roadway Pavements" (MISC-75-3, April, 1975). Most of the energy values presented in the analysis were calculated from values given in the publication. The analyses are found in Appendix D, p. 53.

For equal structural numbers and from the energy sections, next page, the travel lane for the conventional overlay design would have used 117,003 Btu/yd^2. The rest of the roadway would not have surface rejuvenation (HS+EPR) but would use an additional tack coat. This would give a total of 87,978 Btu/yd^2. The weighted average would be 97,144 Btu/yd^2.

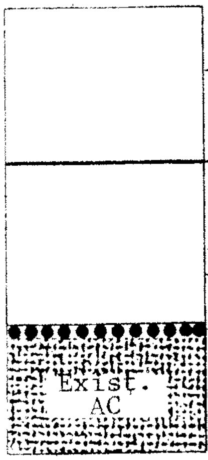
The travel lane for the recycle design would use 123,059 Btu/yd^2. The rest of the roadway would not require recycling so it would use only 53,414 Btu/yd^2. The weighted average is 75,551 Btu/yd^2.

The difference would be 21,593 Btu/yd^2 or (for this job of 181,133 yd^2) 3.91×10^9 Btu. Reporting this in equivalent gallons of gasoline, these values are 0.17 gal/yd^2 or 31,300 gal respectively conserved by recycling.

The energy used for the as-built design (recycle with a 1-1/4" overlay) was 56,698 Btu/yd^2 for the recycling versus 43,730 Btu/yd^2 for the conventional design (surface rejuvenation and a 1-1/4" overlay). Reporting this in equivalent gallons of gasoline, the difference is 0.10 gal/yd^2 or 18,791 gal expended by recycling.

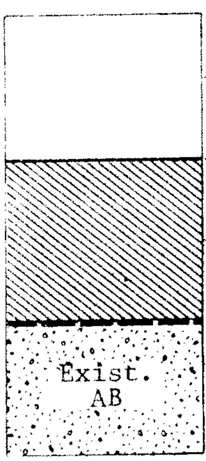
ENERGY REQUIREMENTS FOR ALTERNATIVE PAVEMENT SECTIONS TRAVEL LANE

Overlay Design



surf: 1.25" @ 25,133 Btu/yd^2-in.	=	31,416
tack: .06 gal/yd^2	=	3,148
surf: 2.0" @ 25,133 Btu/yd^2-in.	=	50,266
H.S. + EPR: 0.25 gal/yd^2	=	32,173
Total	=	117,003 Btu/yd^2

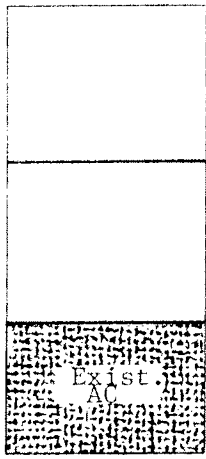
Recycle Design



surf: 2" @ 25,133 Btu/yd^2-in.	=	50,266
tack: .06 gal/yd^2	=	3,148
recycle: 3.5" @ 18,999 Btu/yd^2-in.	=	66,497
prime: .06 gal/yd^2	=	3,148
Total	=	123,059 Btu/yd^2

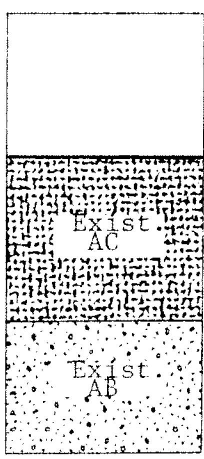
ENERGY REQUIREMENTS FOR ALTERNATIVE PAVEMENT SECTIONS ROADWAY EXCEPT TRAVEL LANE

Overlay Design



surf:	1.25" @ 25,133 Btu/yd^2-in.	=	31,416
tack:	.06 gal/yd^2	=	3,148
surf:	2.0" @ 25,133 Btu/yd^2-in.	=	50,266
tack:	.06 gal/yd^2	=	3,148
	Total	=	87,978 Btu/yd^2

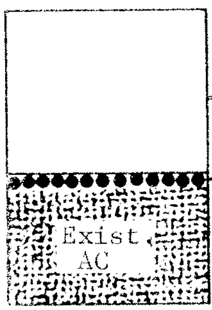
Recycle Design



surf:	2" @ 25,133 Btu/yd^2-in.	=	50,266
tack:	.06 gal/yd^2	=	3,148
	Total	=	53,414 Btu/yd^2

ENERGY REQUIREMENTS FOR ALTERNATIVE PAVEMENT SECTIONS TRAVEL LANE

Overlay Design

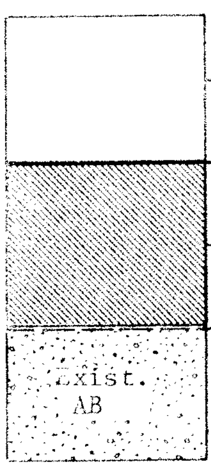


surf: 1.25" @ 25,133 Btu/yd^2-in. = 31,416

H.S. + EPR: 0.25 gal/yd^2 = 32,173

Total = 63,589 Btu/yd^2

Recycle Design



surf: 1.25" @ 25,133 Btu/yd^2-in. = 31,416

tack: .06 gal/yd^2 = 3,148

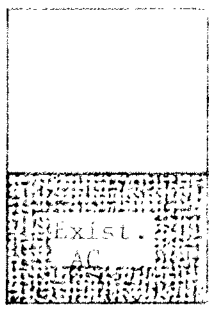
recycle: 3.5" @ 18,999 Btu/yd^2-in. = 66,497

prime: .06 gal/yd^2 = 3,148

Total = 104,209 Btu/yd^2

ENERGY REQUIREMENTS FOR ALTERNATIVE PAVEMENT SECTIONS ROADWAY EXCEPT TRAVEL LANE

Overlay Design

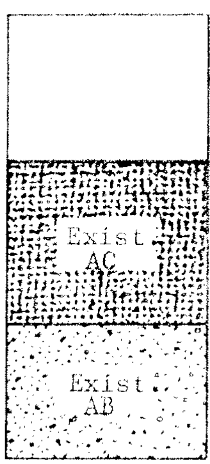


surf: 1.25" @ 25,133 Btu/yd^2-in. = 31,416

tack: .06 gal/yd^2 = 3,148

Total = 34,564 Btu/yd^2

Recycle Design



surf: 1.25 @ 25,133 Btu/yd^2-in. = 31,416

tack: .06 gal/yd^2 = 3,148

Total = 34,564 Btu/yd^2

VII ENVIRONMENTAL CONSIDERATIONS

EMISSION TESTING

A summary of the emission testing performed by the Compliance Section, Bureau of Air Quality Control, Division of Environmental Health Services is found on page 47 in Appendix B. The Air Quality Personnel visited the job site on April 24th and May 3rd and their inspection report is limited to those days.

Following is a description of the emission as seen by the author who does not claim to be an expert and the corrective action applied in the field.

Date	Description	Action
April 24	20-100% opacity Avg. approx. 60% 2 spray bars operating	4 spray bars added to bin belt.
April 25	20-100% opacity Avg. approx. 60% 6 spray bars operating	2" water line fed into drum
April 26	20-100% opacity Avg. approx. 55% 2" water line operating	Stockpile watered and mixed.
April 27	20-70% opacity Avg. approx. 50% Stockpile watering continued 20% of time in compliance	Same as April 26
April 28	20-65% opacity Avg. approx. 40% Stockpile watered. Approx. 85% of time acceptable.	Damper opened full. Suggested removal of collector. No action drum cleaned out.
May 1	20-50% opacity Avg. approx. 30% Stockpile watered. Drum cleaned. 90% of time acceptable.	None
May 2	50-80% opacity Avg. approx. 65% Plant @ 350+ph. Cutback to 250+ph and opacity dropped to approx. 45%. Drum cleanout negated.	Suggested cleanout drum. No action
May 3	40-60% opacity Avg. approx. 45%	None
May 4	Last day 50-80% opacity Avg. approx. 60%	None

Emission control was not a problem when appropriate measures were exercised.

ENVIRONMENTAL BENEFITS

In this particular job, the alternative design would not have called for disposal of material. If indeed the pavement was damaged to the degree that it had to be removed then the 57,200 sq. yd. of 3-1/2" thick old A.C. would have presented a disposal problem.

The recycle design was environmentally favorable because it saved 11,163 tons of aggregate over the conventional design. This equates to 24,800 sq. ft. and when using the material depth of 9 feet, approximately 1/2 acre that was undisturbed as a result of recycling. These values are discussed in the next section.

VIII CONSERVATION OF NATURAL RESOURCES

The natural resources which were conserved by recycling can be represented by the amount of asphaltic concrete which would otherwise have been used.

The 11,788 tons of new AC would be broken down as follows:

Aggregate	11,163 tons
Asphalt	619 tons
Anti-Strip Agent	6.19 tons

The 619 tons of asphalt conserved would be offset somewhat by the use of 191 tons of recycling oil.

The 11,163 tons of aggregate represents conserving approximately 38% of the aggregate that would have been needed.

IX SUMMARY

The analysis of this project would indicate that recycling is feasible and that many of the factors for recycling indeed prove favorable. Following is a summary of the results.

1. The product from recycling was an acceptable product from the standpoint of design and construction properties. A summary table is found on the next page, which attempts to illustrate quantitatively the "before" and "after" effects of recycling.

2. If structural number equivalency is attained, recycling is cost competitive with conventional designs. Bid prices for recycled asphaltic concrete have been steadily decreasing as more experience by the contractors has been gained. Recycled AC costs were $8.50 per ton on this job and $6.00 per ton for jobs bid in late 1978. Also, bid prices decrease when quantity increases.

3. Approximately 20% of the energy required for an equivalent conventional overlay can be conserved by recycling. On this job, where funds were limited, the recycled design expended approximately 30% more energy than the reduced conventional design would have.

4. Approximately 40% of the aggregates can be conserved and approximately 70% of petroleum products can be conserved when structural equivalencies are attained.

5. Emissions can be controlled to acceptable limits with proper care.

6. Removal processes can develop additional fines and should be allowed for in design work.

The most promising aspects of recycling is the possible extension of time before cracking occurs.

The author feels that reflective cracking will occur quicker in an overlay if the cracked pavement's influence is untouched. The time before cracking would probably be shorter than if the pavement had been reconstructed from the select up with new and/or recycled AC. With the different sections constructed on this job, some conclusions can possibly be arrived at in the future because the pavement sections will be monitored and a report given annually.

When structural equivalency is used for design, recycling conserves resources and energy with equal or less cost. With the possible added attraction of longer crack-free life, recycling would definitely have an advantage over conventional overlay designs.

TABLE 2

HOT PLANT INSPECTION

DATE	STORAGE TANK TEMP. (°F)	AGGREGATE TEMP. BY PYOMETER (°F)	TEMP. OF AC IN TRUCKS (°F)	PRODUCTION RATE (TPH)
4 - 24	210	225	200	275
4 - 25	230	230	215	275
4 - 26	195	230	215	260
4 - 27	175	190	190	250
4 - 28	180	205	205	265
5 - 1	175	200	190	250
5 - 2	185	200	195	250
5 - 3	165	195	190	275
5 - 4	210	225	220	300

TABLE 3

MAY'S METER DATA BEFORE RECYCLING
RIDEABILITY INDEX
INTERSTATE 8 EASTBOUND M.P. 88 - 96

DATE: 76-08-11 SPEED: 45 MPH

Milepost	Adjusted Roughness	Rideability Index
88 - 89	167.66	3.08
89 - 90	129.63	3.40
90 - 91	168.99	3.07
92 - 93	187.51	2.95
93 - 94	192.27	2.91
94 - 95	152.41	3.20
95 - 96	166.13	3.09

TABLE 4

MU-METER DATA BEFORE RECYCLING
SURFACE FRICTION INVENTORY
INTERSTATE 8 EASTBOUND M.P. 88 - 96

DATE: 10-26-77 SPEED: 40 MPH

Milepost	High	Average	Low
88	68	54	24
89	73	60	42
90	64	55	40
91	75	70	64
92	64	57	45
93	69	56	41
94	65	54	44
95	65	59	42
96	61	56	51

TABLE 5

DYNAFLECT DATA BEFORE RECYCLING
DEFLECTION INVENTORY
INTERSTATE 8 EASTBOUND M.P. 88-96

DATE: 77-10-4

Milepost	Deflection (Mils)
88.33	1.24
88.66	.62
89.00	.59
89.33	.62
89.66	.64
90.00	.68
90.33	.50
90.66	.67
91.00	.73
91.33	.55
91.66	.79
92.00	.69
92.33	.66
92.66	.67
93.00	.71
93.33	1.00
93.66	.97
94.00	1.34
94.33	1.27
94.66	1.03
95.00	1.08
95.33	.62
95.66	.47

Deflection Mils 0.788 Standard Deviation 0.254

TABLE 6

MAY'S METER DATA AFTER RECYCLING
RIDEABILITY INDEX
INTERSTATE 8 EASTBOUND M.P. 88-96

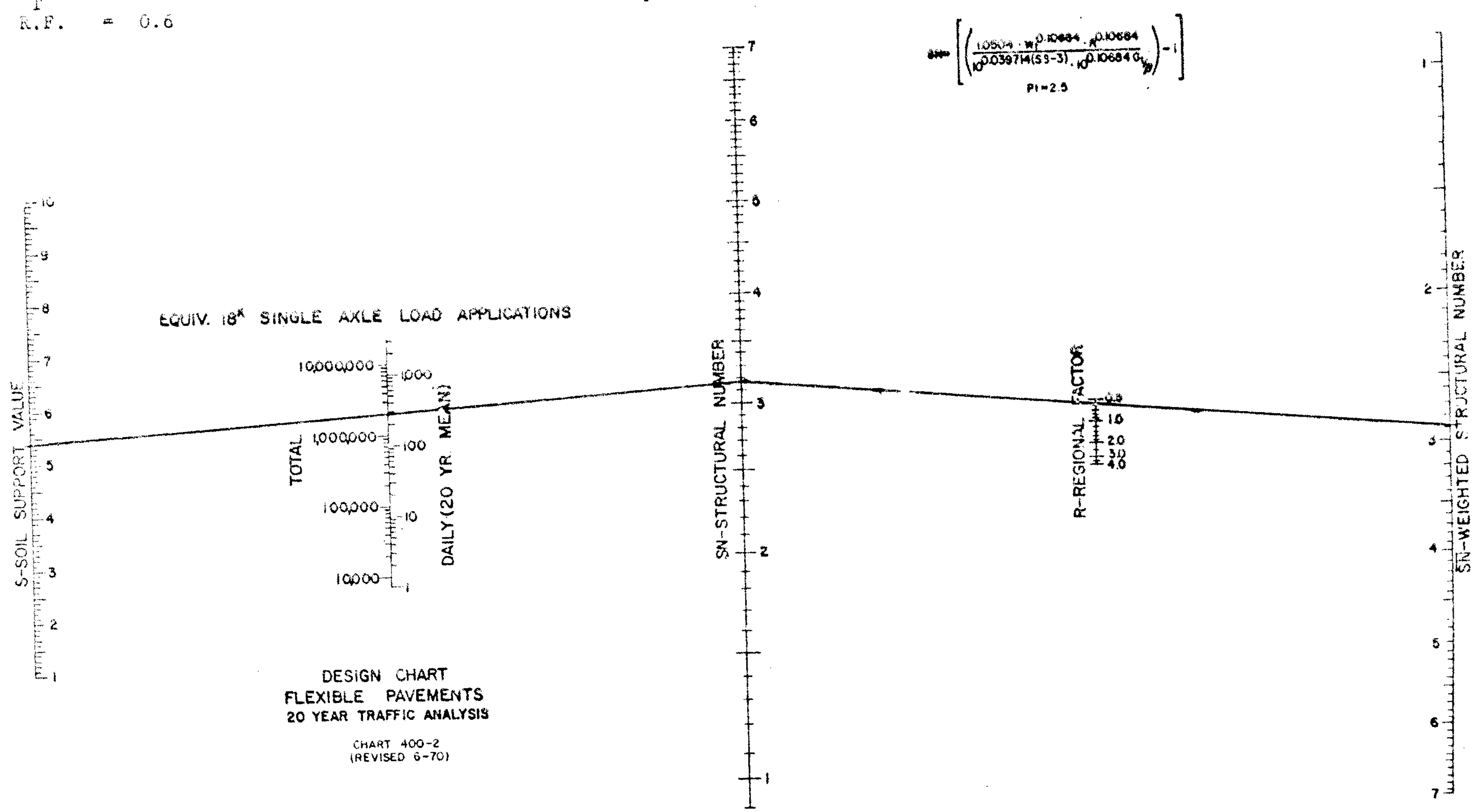
DATE: 78-09-21 SPEED: 45 MPH

Milepost	Adjusted Roughness	Rideability Index
88 - 89	64.4	4.10
89 - 90	60.34	4.15
90 - 91	60.50	4.15
91 - 92	61.12	4.14
92 - 93	66.03	4.08
93 - 94	81.36	3.90
94 - 95	88.55	3.82
95 - 96	64.84	4.10

Figure 8 - Pavement Design Chart

S.S.V = 5.42
W_T = 2 x 10^6
R.F. = 0.6

18-2(49)C
Required SN = 2.90



MATERIALS DIVISION

LABORATORY BITUMINOUS MIXTURE DESIGN

Pit No. RECYCLE AC

Received	Test Commenced	Material
Identification	Sampled	Lab. No. 77- 31662 B
		Project No. I-8-2(56)

Figure 9 - 100% Recycle Mix Design

Quantity

Location of Supply

Contractor

Project Name

Specifications Governing

Sieve	Materials Survey (PE) Preliminary Design Grading: Orig. Pit Average % Ret	Orig. Pit Average % Pass	Crushed Gradation % Ret	Crushed Gradation % Pass	Adj. Crush Gradation % Ret	Adj. Crush Gradation % Pass	As Produced (Construction) Final Adjusted Design Grading: As Crushed on Project Composite	As Adj. in Laboratory Composite	Spec. Limits Sought
3" Slot							%	%	
3"							%	%	
2½"							%	%	
2"							%	%	
1½"							% Ret / % Pass	% Ret / % Pass	
1"	0	100							
¾"	2	98							
½"	11	87							
⅜"	11	76							
¼"	11	65							
No. 4	8	57							
8	16	41							
10	3	38							
16	8	30							
30	8	22							
40	2	20							
50	3	17							
100	6	11							
200	4	7							

SP. GR. Coarse Aggr. SP. GR. Fine Aggr. SP. GR. Comb.

Absorp. Coarse Aggr. % Absorp. Fine Aggr. % Absorp. Comb.

O.D. SP. GR. O.D. SP. GR. O.D. SP. GR. 2.520

	LL	PL	PI	Swell 24 hr.	Swell 48 hr.	S.E.
Natural Fines	%	%		in.	in.	
Crushed Fines	%	%		in.	in.	

ABRASION% Loss 100 Rev. 500 Rev.

REMARKS

Asphalt Content 4.9% 1.2/1.2+4.9 = 20% BLEND

MODULUS OF RESILIENCE 212 KSI

MARSHALL STAB 1583 lb

MARSHALL FLOW 18

DESIGN DATA

Specimen	A	B	C	D	E	F	Design St
Temperature							
Bulk Density Lbs. Per Cu. Ft.		138.0		138.0			
Bit. Grade		1.2 L		1.2 M			
% of Bit. 4.9%		6.1		6.1			
Density Lbs. Per Cu. Ft.							
Stabilometer		52		49			
Cohesiometer		253		263			
Voids		4.4		4.2			
V.M.A.		17.7		17.5			
% Voids Filled		75.1		76.0			
Effective Asphalt Total Mix							

Sample	Air PSI	H_2O PSI	Retention	
No. 1	373	132	35 %	1.1 % Cyclogen L Asphalt
No. 2	373	129	35 %	1.0 % Anti-Strip Agent
No. 3			%	% Dry Lime
No. 4			%	% Dry Cement

Max. Density 144.4 Lbs. Per Cu. Ft. (Rice Method) 1.2

Asphalt — % Absorp. on dry aggregate

Film Strip. (Course Aggr.) =

C.K.E. Values F= C=

Theoretical Bit. Ratio for Grade Bitumen %

Kc= Kf= Km=

Static Density @ psi& % Bit= Lbs. Per Cu. Ft.

Recommended Bitumen Content Considering All Test Data %

Sieve	% Pass	Tol. % Total Wt. Pass
1"	100	
¾"		
½"		
⅜"		
No. 4		
8		
40		
200		

Received | Test Commenced | Material Recycle AC w/AB
Identification | Sampled | Lab. No. 77-31662
Project No. I-8-2(56)

MATERIALS DIVISION

LABORATORY BITUMINOUS MIXTURE DESIGN

Pit No. RECYCLE AC W/ AB

Figure 10 - 75/25 Recycle Mix Design

Quantity

Location of Supply

Project Name | Contractor

Specifications Governing

Sieve	Orig. Pit Average % Ret	Orig. Pit Average % Pass	Crushed Gradation % Ret	Crushed Gradation % Pass	Adj. Crush Gradation % Ret	Adj. Crush Gradation % Pass	As Crushed on Project Composite % Ret	As Crushed on Project Composite % Pass	As Adj. in Laboratory Composite % Ret	As Adj. in Laboratory Composite % Pass	Spec. Limits Sought
3" Slot								%		%	
3"								%	AC	75%	
2½"			EXTRACTED					%	AB	25%	
2"	AB		AC					%		%	
1½"											
1"	0	100	0	100					0	100	
¾"	4	96	2	98					3	97	
½"	11	85	11	87					11	86	
⅜"	10	75	11	76					10	76	
¼"	10	65	11	65					11	65	
No. 4	7	58	8	57					8	57	
8	12	46	16	41					15	42	
10	3	43	3	38					3	39	
16	6	37	8	30					8	31	
30	6	31	8	22					7	24	
40	3	28	2	20					2	22	
50	4	24	3	17					3	19	
100	7	17	6	11					7	12	
200	5	12	4	7					4	8	

SP. GR. Coarse Aggr. 2.527 | SP. GR. Fine Aggr. 2.607 | SP. GR. Comb. 2.573

Absorp. Coarse Aggr. 2.72 % | Absorp. Fine Aggr. 1.75 % | Absorp. Comb. 2.17%

O.D. SP. GR. 2.460 | O.D. SP. GR. 2.562 | O.D. SP. GR. 2.518

	LL	PL	PI	Swell 24 hr.	Swell 48 hr.	S.E.
Natural Fines	%	%		in.	in.	
Crushed Fines	%	%		in.	in.	

ABRASION% Loss | 100 Rev. | 500 Rev.

REMARKS

DESIGN BASED ON CONCEPT OF RECYCLING 3 INCHES OF AC AND 1 INCH OF AB.

AB CKE DEMAND 6.1% X 25% = 1.5 | 2.5-1.5 = 1.0 AVAILABLE FOR SOFTENING

1.0/1.0+3.75 = 20% BLEND

COMPARED TO

2.5/6.25 = 40% BLEND

DESIGN DATA

Specimen	A	B	C	D	E	F	Design Sp
Temperature							
Bulk Density Lbs. Per Cu. Ft.			136.9	139.5			
Bit. Grade Cyclogen M	1.0	1.5	2.0	2.5			
% of Bit. .75 X 5.0 = 3.75	5.75	5.25	5.75	6.25			
Density Lbs. Per Cu. Ft.							
Stabilometer	49	53	52	49			
Cohesiometer	206	174	169	293			
Voids			6.5	4.1			
V.M.A.			17.9	16.8			
% Voids Filled			63.7	75.6			
Effective Asphalt Total Mix							

Sample	Air PSI	H_2O PSI	Retention	
No. 1	334	95	28 %	2.5 % Cyclogen M Asphalt
No. 2			%	% Anti-Strip Agent
No. 3			%	% Dry Lime
No. 4			%	% Dry Cement

Max. Density 145.5 Lbs. Per Cu. Ft. (Rice Method) 6.2

Asphalt 0.50 % Absorp. on dry aggregate ESTIMATED

Film Strip. (Course Aggr.) =

C.K.E. Values | F= | C=

Theoretical Bit. Ratio for Grade | Bitumen %

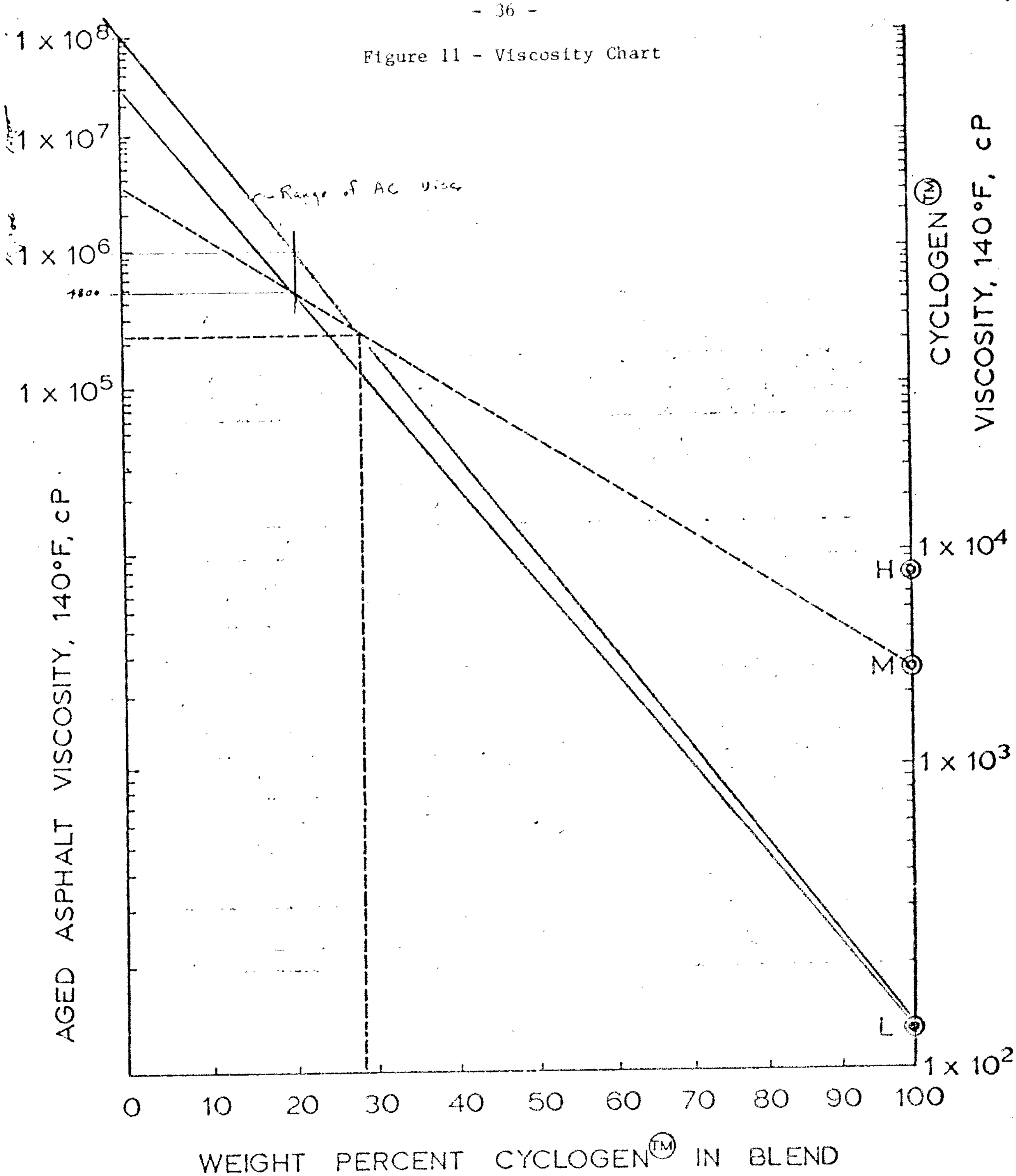
Kc= | Kf= | Km=

Static Density @ psi& | % Bit= | Lbs. Per Cu. Ft.

Recommended Bitumen Content Considering All Test Data %

Sieve	% Pass	Tol. % Total Wt. Pass	
1"	100		
¾"			
½"			
⅜"			
No. 4			
8			
40			
200			

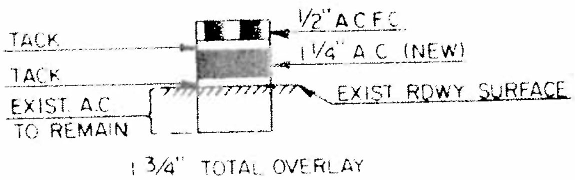
Figure 11 - Viscosity Chart



TO USE: Draw a straight line connecting viscosity of aged asphalt with viscosity of CYCLOGEN(TM). Draw a vertical line up from the percent CYCLOGEN(TM) in blend. The two lines intersect at predicted approximate viscosity of the recycled asphalt.

Fig. 3 - Nomograph for Viscosity.

Figure 12 - Structural Sections



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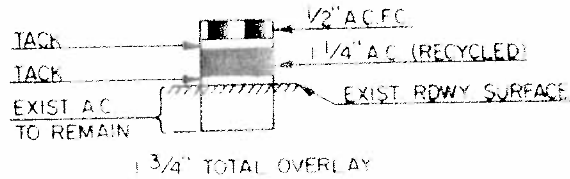

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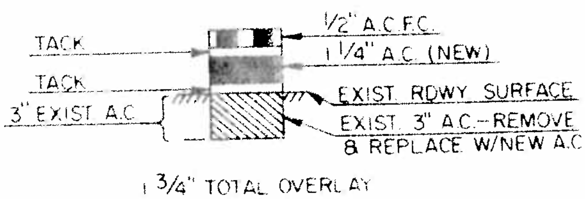

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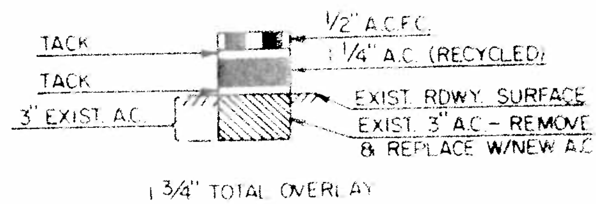

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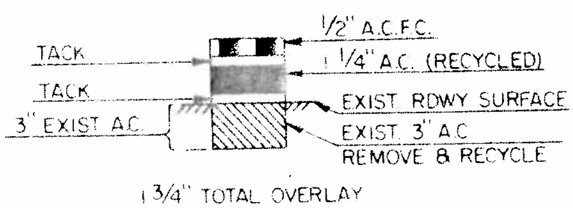

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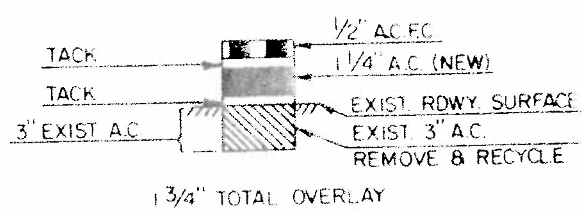


SECTION NO. 6

APPENDIX A

SPECIAL PROVISIONS

ARIZONA PROJECT I 8-2 (76)

YUMA-CASA GRANDE HIGHWAY

(Yuma County Line-East)

RESURFACING

PROPOSED WORK:

The proposed work is located in Maricopa County on Interstate Route 8 beginning at Milepost 79.84, approximately 35 miles west of Gila Bend, and extending easterly to Milepost 95.86 for a distance of approximately 16.02 miles, and consists of heater-scarification of portions of the existing pavement, removal and re-cycling of portions of the existing pavement, furnishing and placing asphaltic concrete and asphaltic concrete friction course and other incidental work.

Rev.: 12/15/77

SPECIFICATIONS:

The work embraced herein shall be done in accordance with the requirements of the following separate documents:

Arizona Highway Department Standard Specifications for Road and Bridge Construction, Edition of 1969,

Supplemental Specifications, July, 1977, which are additional to and supersede portions of the Standard Specifications, Edition of 1969,

Department of Transportation, Division of Highways, Standard Drawings, as follows:

Part 1 - Construction Details, 1974
Part 2 - Structures, August 1976
Part 3 - Traffic Signals and Highway Lighting, 1974
Part 4 - Signing and Marking, 1974

In hauling operations, the contractor shall cross the median only on existing crossovers designated by the engineer. No more than one crossover shall be utilized at any one time unless permitted otherwise by the engineer.

No more than two miles of existing asphaltic concrete shall be removed prior to replacement with recycled asphaltic concrete, or new asphaltic concrete.

ITEM 2020030 - REMOVAL OF ASPHALTIC CONCRETE PAVEMENT:

The work under this item consists of the removal of the existing right travel lane of the eastbound roadway from Station 3575 to Station 3987 and stockpiling for recycling. The width of travel lane to be removed shall be from the center of the paint stripe separating the travel and passing lanes to a line 12-1/2 feet to the right and parallel to the centerline.

The material shall be broken up for the full depth of 4 1/2 inches of existing asphalt, hauled to the hot plant and recycled as called for under ITEM 4060002.

The removal of the existing asphaltic concrete shall be accomplished in a manner which does not destroy the integrity of the left travel lane or the asphaltic concrete shoulder. The contractor may either saw cut, utilize an adequate cutting wheel or use other means approved by the engineer. Care shall be taken in the removal of the asphaltic concrete not to contaminate the asphaltic concrete with the underlying aggregate base material.

After removal of the asphaltic concrete for recycling, the remaining base material shall be proof rolled by three passes of a roller approved by the engineer. Should proof rolling indicate the necessity for re-compaction of the base material, the work shall be accomplished as called for under ITEM 2130002.

Measurement and payment of this work will be made by the square yard of pavement removed and stockpiled, and any minor reshaping of the remaining base material and proof rolling.

Any necessary recompaction of the base materials necessary will be as called for under ITEM 2130002.

ITEM 4060002 - ASPHALTIC CONCRETE (Recycled):

Description:

Asphaltic Concrete (Recycled) shall consist of mixing at a plant the material removed under Item 2020030, and a recycling oil to form a pavement course as called for on the plans and in these Special Provisions.

Material:

Mineral Aggregate Material:

The aggregate material shall consist of the asphaltic concrete removed for recycling reduced to 90-100 percent passing the one inch sieve prior to mixing in the plant.

Bituminous Material:

The recycling oil shall be comparable to Cyclogen (L) and can form to the following:

Viscosity @ 140 Deg. F, CS	80-500
Flash Point, COC, Min.	350
Chemical Fractionation:	
N/P Ratio, Min.	0.5
(N+A1) (P+A2) Ratio	0.4-1.2

Two weeks prior to the beginning of the mixing operations the contractor should submit a sample of his proposed recycling oil for approval by Materials Services.

Construction Details:

Bituminous Mixing Plant Requirements:

The plant shall be designed, equipped, coordinated and operated so the proportioning, heating and mixing will yield a uniform mixture conforming to the requirements of these Specifications. The plant shall be capable of producing a minimum of 150 tons per hour.

The bituminous material shall be introduced into the mixer by a positive displacement metering device. This metering device shall be equipped with a means for varying the delivery rates.

A positive interlocking control shall be provided between the flow of each aggregate feeder, and the flow of bitumen. The interlocking control shall indicate a visible or audible signal when the flow level approaches the strike-off capacity of the feeding devices.

The plant shall include a mixing device which will obtain homogeneity and a uniform coating. The mixing output shall not exceed the manufacturer's capacity rating.

The plant shall be equipped with a approved surge bin at the discharge. The surge bin shall have a capacity in excess of 20 tons and be equipped with an approved surge batcher or other method satisfactory to the engineer that will prevent segregation of the bituminous mixture as it is being discharge into the hauling vehicle.

Armored thermometers of adequate range in temperature reading shall be fixed in the bitumen and aromatic extender oil feed lines. An approved dial scale and electric pyrometer or other approved thermometric instrument for indicating the heated bituminous aggregate shall be installed at the discharge chute of the heat exchanger.

The contractor shall install satisfactory precipitation devices or use other adjustment apparatus which will control excessive emissions during plant mixing operations and meet Local, County, State and Federal environmental protection requirements.

The contractor's attention is directed to the possibilities of the emission of excessive pollutants due to the asphalt coated materials utilized in the mixture.

Mixing:

The mixing temperature of the recycled bituminous mixture shall be in the range of 210 to 250 degrees Farenheit.

The contractor's attention is directed to the possibilities of the emission of excessive pollutants due to the asphalt coated material utilized in the mixture. He shall install satisfactory apparatus to control these so that during plant mixing operations he can meet Local, County, State and Federal environmental protection requirements.

The bituminous material shall be introduced into the plant and mixed with approximately 1.5 percent of recycling oil as a percentage of the total weight of the mixture. The actual percentage will be determined from the job-mix formula.

Sufficient water shall be added to the aggregate immediately prior to mixing to help retard flashing of the recycling oil.

Placing and Finishing:

The temperature of the recycled asphaltic concrete, just prior to rolling shall be not less that 170 degrees F. however, the temperature shall be such that the recycled material can be placed, finished and compacted as required by the engineer.

The recycled asphaltic concrete shall be placed in two courses. The leveling course shall not exceed four inches in compact thickness. The surfacing course, when compacted shall match the grade of the adjacent lanes.

The recycled asphaltic concrete shall be compacted to 95 percent of maximum density as determined by Arizona Test Method 811.

Method of Measurement:

Asphaltic Concrete (Recycled) will be measured by the ton for the mixutre actually used, including the weight of the mineral aggregate and the recycling oil.

Basis of Payment:

The accepted quantities of Asphaltic Concrete (Recycled), measured as provided above, will be paid for at the contract unit price for the bituminous mixture complete in place.

Payment will be made under:

Pay Item	Pay Unit
Asphaltic Concrete (Recycled)	Ton

Payment for the Recycling Oil (For Recycled Asphaltic Concrete) will be made under Item 4012322.

REVISIONS TO THE SPECIAL PROVISION:

ITEM 2020030 - REMOVAL OF ASPHALTIC CONCRETE PAVEMENT:
Additional to the requirements on Sheet 17 of 61:

If the method of asphaltic concrete removal employed by the contractor results in removal in excess of the specified depth, the contractor shall replace the excess with either aggregate base material, mineral aggregate or asphaltic concrete.

Aggregate base or mineral aggregate shall be placed after proof rolling or recompaction of the existing base. Additional base materials required shall be compacted to 100 percent of the maximum dry density as determined in accordance with the requirement of the Materials Testing Manual of the Materials Services.

No measurement or payment will be made for materials utilized for replacement of the excess pavement removed or for the compaction and finishing required.

ITEM 4011701 - ASPHALT FOR TACK COAT (Liquid Asphalt Grade RC-250 or MC-250 or Emulsified Asphalt (Special Type)):

Additional to the first paragraph:

The emulsified asphalt shall be given time to break before paving operations begin. Emulsified Asphalt shall be reheated and reagitated if held overnight.

ITEM 4060002 - ASPHALTIC CONCRETE (Recycled):

Mixing:

Superseding the third paragraph (Sheet 39 of 61):

The asphaltic concrete for recycling shall be introduced into the plant and mixed with 1.5 percent of recycling oil as a percentage of the total weight of the mixture. The actual percentage will be determined by the job-mix formula.

APPENDIX B

CS:DOC-617

ARIZONA DEPARTMENT OF HEALTH SERVICES

Division of Environmental Health Services

Bruce Babbitt
XXXXXXXXXX Governor
SUZANNE DANDOY, M.D., M.P.H., Director

June 9, 1978

Mr. John Ritter
A.D.O.T. - Material Services
1745 W. Madison
Phoenix, Arizona 85007

Dear Mr. Ritter:

RE: Summary of Peter Kiewit and Sons' Pollution Control Performance.

In response to your telephone call to Mr. Wesley Shonerd, Bureau of Air Quality, on June 6, 1978, the following summarizes the inspection results of Peter Kiewit and Sons' Company Boeing Asphalt Plant during recent operations on I-8 utilizing recycled asphalt.

On April 24, 1978, Mike Howeth and Mr. Shonerd of the Bureau inspected the plant. The stack plume was visible at a distance of two to three miles. Official visible emissions readings were not taken because of cloudy skies, but both Mr. Howeth and Mr. Shonerd estimated that the plume opacity ranged between 20 and 100%. It usually appeared to be well over 40% which is the maximum opacity allowed by the State Air Pollution regulations. On May 3, 1978, Mr. Shonerd reinspected the plant. Visible emissions ranged between 60 and 100% with an average value of 95%. The production rate was 275 tons per hour. The process rate was varied to see if there was any change in the opacity of the plume, but at both 250 tons/hour and 300 tons/hour the opacity remained virtually the same. During this inspection, it was observed that the plant would go intermittently into an upset condition. The plume "volume" would increase by a factor of approximately two and change color from white to a grayish-tan. Such conditions lasted approximately 40 seconds. The plant operator theorized that this upset was cause by material igniting inside the drum.

By this time, the portion of the project utilizing recycled asphalt was complete. Unfortunately, the plant was not in compliance with the Air Pollution regulations throughout this project and did not show any trend toward achieving compliance.

On May 9, 1978, Mr. Shonerd inspected the plant again. The plant had been converted back into its normal configuration, using virgin materials.

It still did not comply with State visible emissions standards and a Notice of Violation was issued.

If you need any additional information, please contact Mr. Wesley Shonerd, at telephone (602) 255-1147.

Sincerely,

David O. Chelgren

David O. Chelgren, P.E., Manager
Compliance Section
Bureau of Air Quality Control

DOC:mb

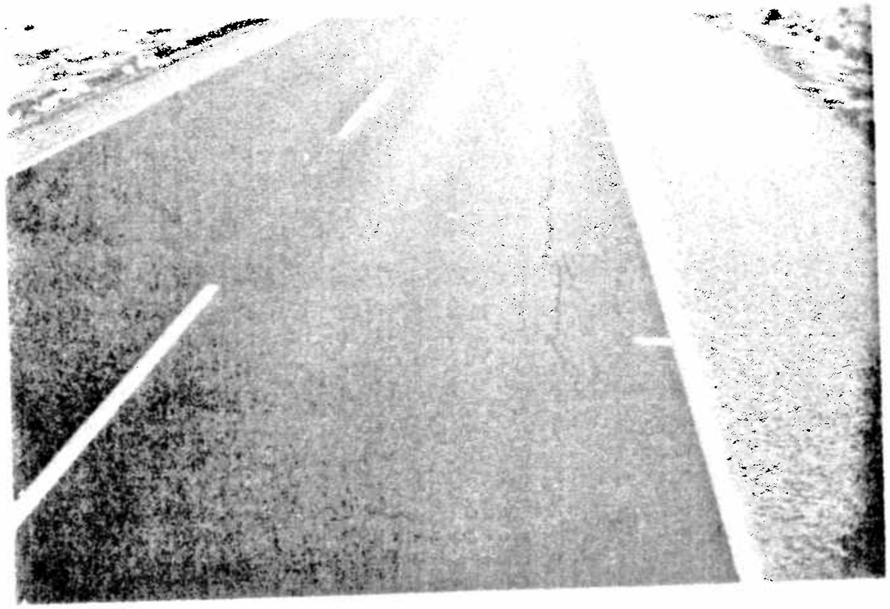
APPENDIX C

FIGURE 1
PERCENT CRACKING

Procedure

Locate a 50' x 20' section of roadway, preferably at a milepost. From the photos and drawings, match the percent cracking. For percentages less than 10, round to nearest 1 percent. For cracking greater than 10 percent, round to the nearest 5 percent.

2.0



5.0

7.4

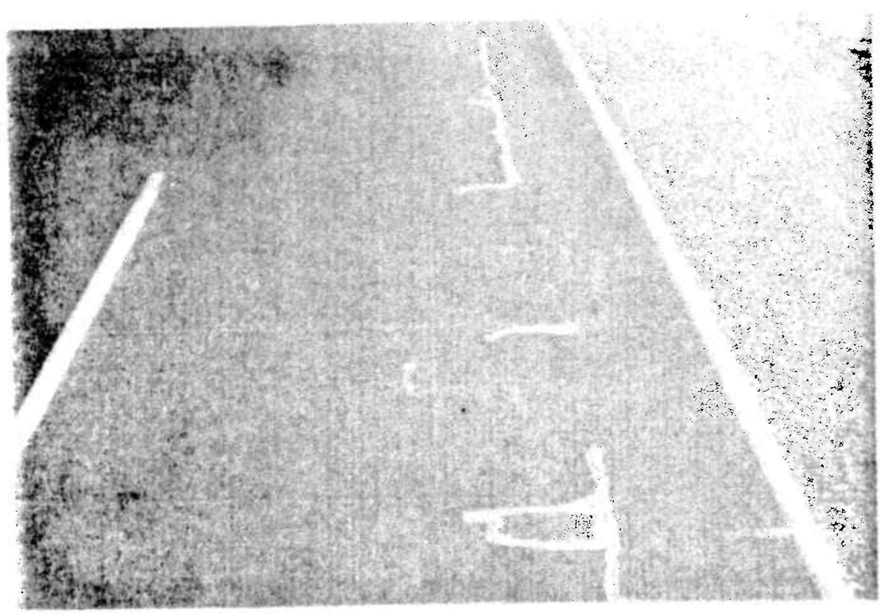
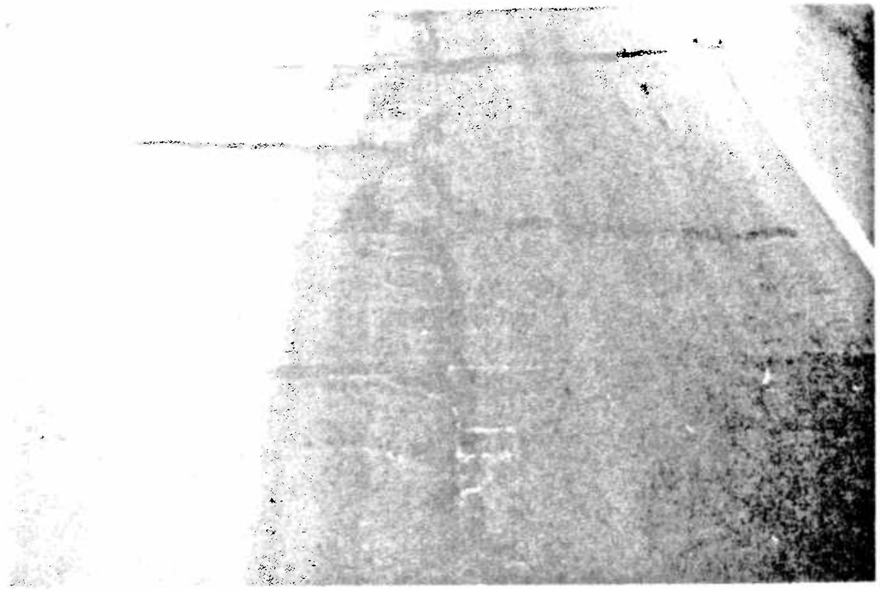


FIGURE 1
PERCENT CRACKING

11



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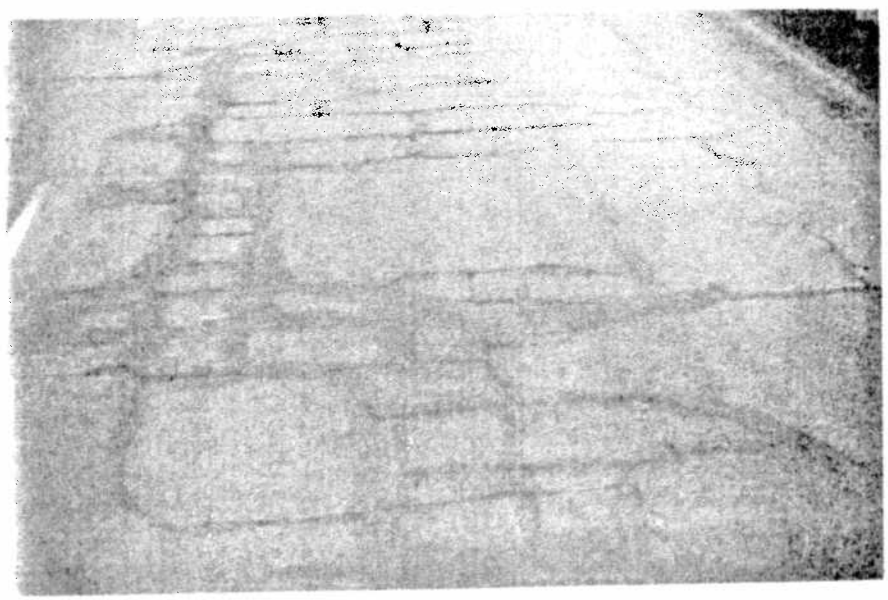

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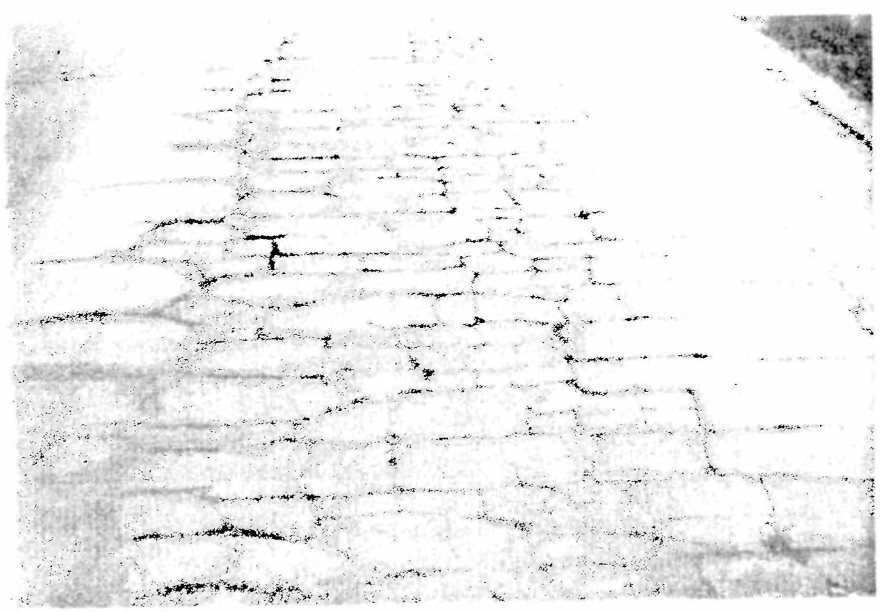

APPENDIX D

Calculations for determining the energy requirements for conventional
ASPHALTIC CONCRETE OVERLAY

Assume the asphalt is freighted from Bakersfield, CA. to Phoenix, AZ. by diesel locomotive. Hauled 94.1 mi in a 4-axle truck to the hot plant. The mix will have 5.3% asphalt content. The aggregate will consist of 50% crushed stone and 50% natural sand hauled 23.8 mi to plant by 4-axle truck. The aggregate has an average moisture content of 1%, and it will be dried and heated from 65°F to 265°F. The mix will have an average haul distance of 7.1 miles in 4-axle trucks. Compacted density of the mix will be 141 lb per cu ft.

Materials			
Manufacture asphalt cement	=	587,500 Btu/t	
Railroad haul 481 mi @ 630 Btu/tm	=	303,183 Btu/t	
Haul 94.1 mix 2 @ 5040 Btu/tm	=	948,528 Btu/t	
Total for Asphalt	=	1,839,211 Btu/t	
Crushed stone @ 70,000 Btu/t, 50%	=	35,000 Btu	
Sand @ 15,000 Btu/t, 50%	=	7,500 Btu	
Haul 23.8 mi x 2 @ 3270 Btu/tm	=	155,682 Btu/t	
Total	=	198,182 Btu/t	
Mix Composition			
Asphalt, 5.3% 1,839,211 Btu/t	=	97,478	
Aggregate 94.7% @ 198,182 Btu/t	=	187,678	
Total for mix	=		285,156 Btu/t
Plant Operations			
Dry Aggregate, 1% @ 28,000 Btu/%, 0.94t	=	26,320 Btu	
Heat 200°F @ 470 Btu/°F/t, 0.94t	=	88,360 Btu	
Other plant operations	=	16,550 Btu	
Total plant operations	=		131,230 Btu
Haul and Place			
Haul mix 7.1 x 2@ 3270 Btu/tm	=	46,434 Btu	
Spread and compact	=	12,510 Btu	
Total for haul and place	=		58,944 Btu
Total for 1 ton asphaltic concrete	=		475,330 Btu/t

@ 141 pcf: $475{,}330 \; \frac{141}{2000} \; 0.75 = 25{,}133$ Btu/yd^2-in.

Calculations for determining the energy requirements for RECYCLED ASPHALT CONCRETE

Assume the recycling oil is freighted from Bakersfield, CA. to Phoenix, AZ. by diesel locomotive. Hauled 94.1 mi to the plant in a 4-axle truck. The mix will have a 1.8% recycling oil content. The aggregate has an average moisture content of 6%, and it will be dried and heated from 65° to 200°F. The mix will have an average haul distance of 7.1 mi in 4-axle trucks. Compacted density of the mix will be 139 lb per cu ft.

Materials			
Manufacture recycling oil	=	400,000 Btu/t	
Railroad haul 481 mi @ 630 Btu/tm	=	303,183 "	
Haul 94.1 mi x 2 @ 5,040 Btu/tm	=	948,528 "	
Total for recycling oil	=	1,651,711 Btu/t	
Salvaging energy 1589 gal @ 139,000 Btu/gal : 10,550t	=	20,936 Btu/t	
Haul (Actual) 2000 gal @ 139,000 Btu/gal : 10,550t	=	26,351 Btu/t	
Haul (Theor) 3270 Btu/tm x 4.5 mi. x 2 = 29,430 Btu/t			
Total	=	47,787 Btu/t	
Mix Composition			
Recycling Oil, 1.8% @ 1,651,711 Btu/t	=	29,731 Btu/t	
Salvaged aggregate 98.2% @ 47,287 Btu/t	=	46,358 Btu/t	
Total for mix	=		76,750 Btu/t
Plant Operations			
Actual (Burner) 15,499 gal @ 139,000 Btu/gal : 10,130t	=	212,671 Btu/t	
Actual (Generator) 2265 gal @ 139,000 Btu/gal : 10,130t	=	31,079 Btu/t	
Total Plant Operations	=		243,750 Btu/t
Theoretical			
Dry, 6% @ 28,000 Btu/1%/t, .92t	=	154,560	
Heat 135°F @ 470 Btu/°F-t, .92t	=	58,374	
Other plant operations	=	16,550	
Total Plant Operations	=	219,474 Btu/t	

Calculations for determining the energy requirements for RECYCLED ASPHALT CONCRETE

Haul and Place

Haul mix (actual) 3002 gal @ 139,000 Btu/gal ÷ 10,130	= 41,192 Btu/t	
Haul mix (theor) 7.1 mi x 2 @ 3270 Btu/tm = 46,434 Btu/t		
Spread and compact	= 12,510	
Total for haul and place =		53,702
Total for 1 ton recycled asphaltic concrete =		374,202 Btu/t

@ 139 pcf: $374{,}202 \frac{139}{2000} 0.75 = 19{,}505$ Btu/yd^2-in.

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