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RECYCLING ASPHALT PAVEMENTS

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INTERIM REPORT

Bituminous Concrete Pavement Recycling

Route US 130 From Vicinity of Route US 1 to North of Hickory Corner Road

by

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16. Abstract

This report describes the design, testing and production of a bituminous concrete mixture using the "Minnesota Heat-Transfer Method" of recycling salvaged bituminous material through a conventional asphalt concrete plant. The highly successful project consisted of salvaging approximately 14,000 tons of a milled surface course from Route US 1 and placing it as 27,000 tons of recycled mixture on the shoulder of Route US 130. The salvaged No. 5 FABC Mix was converted to a No. 4 MABC Mix with no significant problems. The addition of an AC-20 asphalt cement changed the lower penetration values of the milled material more dramatically than those having a penetration range of 34-43. In cases where there was little change in penetration, the effect of the AC-20 on the recovered recycled asphalt was shown by a 37% decrease in viscosity and a 127% increase in ductility. Some material was rejected for both high and low temperatures when production was erratic, however, a uniform temperature was maintained on sustained runs. There was no problem in placing the pavement. The energy savings of the recycled mixture over a conventional mix was 3.5 billion BTU or an equivalency of 27,964 gallons of gasoline. The raw material savings amounted to 704 tons (171,707 gallons) of asphalt cement, 12,753 tons of stone aggregate and a dollar savings of $50,346 based on bid prices for a conventional mix.

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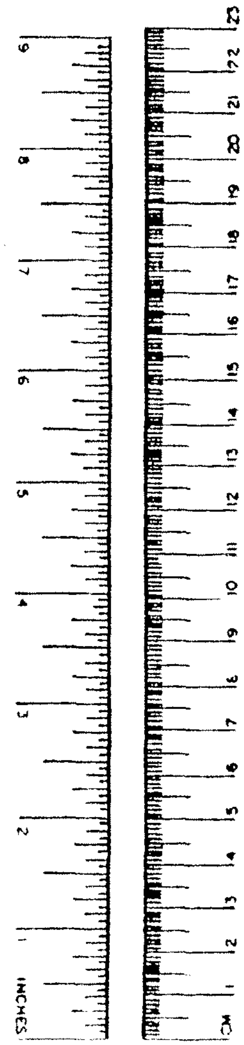
METRIC CONVERSION FACTORS

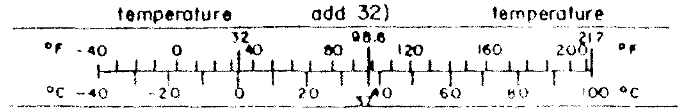
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

This report describes a recycling process using a 50/50 ratio of new material to salvaged bituminous concrete. Approximately 14,000 tons of milled material from U.S. 1 was used to construct 30 miles of inside and outside shoulders on U.S. 130.

The fundamental aim of this project, "to determine the technical and economic feasibility of recycling asphalt pavements through a conventional asphalt plant", was achieved as shown in the following summary of results.

A. The "Minnesota Heat Transfer Method" proved to be a simple, economical method of using existing asphalt plants to recycle bituminous concrete with minimum modifications.

B. The product from recycling was acceptable from the design standpoint as well as those of construction practices.

1) The salvaged No. 5 FABC was easily converted to meet the No. 4 MABC job mix formula.
2) The recycled mixture placed at temperatures between 225^{o} to $330^{o}F$ produced a shoulder pavement comparable to a mixture made with all virgin material.
3) The penetration of the recycled mixture increased an average of three units over the average of the salvaged milled material.
4) The viscosity of the recycled mixture was lowered from that of the milled material an average 4,500 poises from 12,082 to 7,573.
5) The ductility of the recovered asphalt samples of recycled mixture showed an average 127% increase over the corresponding milled material samples going into its respective batch.
6) The Marshall stability samples of the fourteen lots taken at the plant averaged 1,946 lbs.; the flow averaged 10.5 hundredth of an inch.
7) The air voids of 180 cores taken from the finished pavement averaged 6.4%.

C. The net savings in energy on the recycled mix over a conventional mix for the shoulder on U.S. 130 was 3.5 billion BTU (34.7%) or an equivalency of 27,900 gallons of gasoline. If milling was compared to the placement of a conventional leveling course on U.S. 1, the savings for the entire project would have amounted to a savings of 20.7 billion BTU or 165,000 gallons of gasoline.

D. In the conservation of material resources, the U.S. 130 section of the project saved 700 tons of asphalt and 12,700 tons of aggregate. If the benefits of milling versus use of a leveling course are also considered, the combined savings were 2,900 tons of asphalt (712,000) gallons) and 55,700 tons of stone aggregates.

INTRODUCTION

Due to the increasing costs of paving materials, energy shortages and dwindling aggregate supplies, the concept of pavement recycling is being considered by many agencies for the rehabilitation or reconstruction of asphalt concrete pavement. There are three basic types of asphalt pavement recycling and many in-between adaptations thereof; however, for the purpose of this report, the following descriptions should suffice.

(1) Cold recycling, a process which involves removing and crushing the pavement in place or at a central plant and using it for a base course.

(2) Surface recycling, a process where the surface of the pavement is planed, milled hot or cold, or heated in place. In the latter case, the pavement may be scarified, relaid and rolled. Additional asphalt, softening agents, minimal amounts of new asphalt hot mix, aggregates or combinations of these may be added to obtain desirable mixture and surface characteristics.

(3) Hot recycling, a process where the major portion of the existing pavement structure, including in some cases the underlying untreated base material is removed, sized, and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate and/or a softening agent. The finished product is a hot mix asphalt base, binder or surface course.

This study employed the "Minnesota Heat-Transfer Method", an adaptation of hot recycling more commonly referred to as the "Maplewood" process.

A. Project History

In April, 1977 the Federal Highway Administration's Region 15 Demonstration Projects Division gave a presentation before the New Jersey Department of Transportation regarding Demonstration Project No. 39 - Recycling Asphalt Pavements. The interest generated by this presentation prompted the Department to review their construction program and select a project for New Jersey's first trial of recycling.

The project selected was a 17.9 mile section of Route US 1 between Trenton and New Brunswick, New Jersey which was scheduled for rehabilitation through barrier replacement, milling and resurfacing of the pavement. The construction schedule for the project was such that the salvaged (milled) material would have been stockpiled over the better part of two summer seasons. To lessen the possibility of consolidation and moisture pick-up in the stockpile over an extended period of time, it was decided to place the recycled material on a proposed shoulder project on nearby Route US 130. The Route 130 project consisted of a 16 mile rehabilitation of both the north and southbound inside and outside shoulders. By employing the Maplewood process of recycling, the materials balance for both jobs would be just about equal. Consolidating the two projects into one permitted the contractor to start placing the recycled mix within weeks of cessation of the milling operation.

B. Specific Aim

The fundamental aim of this project was to determine the technical and economic feasibility of recycling asphalt pavements through a conventional asphalt plant with the following specific objectives:

1. Develop a proper mix design.
2. Evaluate the method of pavement removal.
3. Evaluate the pavement recycling process.
4. Determine the energy and/or economic savings.
5. Monitor the performance of the recycled mix.

C. Scope of Work

The work performed on this project consisted of the partial removal of the bituminous concrete pavement from US Route 1, recycling the pavement and using the recycled material to pave the shoulders on Route 130. The removal of the bituminous concrete was accomplished by the use of the CMI PR-750 Roto-Mill.

The milling operation consisted of removing 1½ inches of the surface course from 7.5 miles of the northbound outside lane. The 16 miles of the southbound outside lane involved an average 5/8 inch removal of the surface course with an 1½ inch depth for 500 feet before and through each intersection and jughandle. It was estimated that the material removed by the milling operation would total 15,000 tons.

The recycling of the milled material was accomplished by use of the Minnesota Heat Transfer Method for batch type plants more commonly referred to as the Maplewood process. This method was selected because of the desire to use existing plant equipment and avoid air pollution problems. Briefly, the process involved mixing the material to be recycled with super-heated virgin aggregate for 30 seconds in the pugmill. The heat transferred by conduction from the super-heated aggregate to the milled material softened the mixture. The necessary asphalt was added at the pugmill to bring the mix to the design asphalt content. The recycled mixture was then mixed for an additional 20 seconds and dumped into a waiting truck.

The required proportion of the salvaged milled bituminous material to virgin materials was 50/50 ± 5%. The 50/50 blend had to comply with the Department's design requirements for a No. 4 MABC surface course mix. The temperature of the mix was required to be within 225^{O}F- 325^{O}F. It was estimated that approximately 30,000 tons of recycled mix would be produced.

The shoulders on Route 130 were excavated, rolled and a prime coat applied. A two inch thick lift of the recycled bituminous concrete was placed on the five (5) foot inside and ten (10) foot outside shoulders on the northbound side. On the southbound side, three (3) inches of recycled mix was placed on the ten (10) foot outside shoulder. The inside shoulder specified two (2) inches of recycled bituminous concrete and varied in width from five (5) feet in one area to seven (7) feet in another. A 1210 foot control section located on the northbound, outside shoulder was placed with all new material to a depth of two (2) inches using the Department's No. 5 FABC bituminous concrete mix. In order to establish a quicker evaluation of the recycled hot mix, a 1200 foot, 1½ inch overlay was placed full width on a section of the northbound mainline roadway. Conventional equipment and procedures were used for laying and compacting the hot recycled mix (Barber Greene paver, 3-wheel and tandem rollers).

PRELIMINARY INVESTIGATIONS

A. State-of-the-Art

At the start of this investigation there was a sparsity of reports on hot recycling. The equipment list consisted of three basic categories:

1) A heat exchanger
2) Drum-mixers (several)
3) Conventional Plants
    a. single dryer
    b. double dryer

Assessment of the various systems showed that there was a build-up of material in the heat exchanger unit and it had numerous mechanical breakdowns. The drum mixers either had opacity readings of 20% to 40% or could only operate at less than 20% opacity for periods of short duration or at reduced capacity. Of the two types of conventional plants, the single dryer (Maplewood Process) appeared by far the simplest and best suited for meeting the New Jersey Clean Air Standards.

As reported by other researchers, the performance of recycled pavements showed satisfactory results. In most cases, however, there had not been any long-term evaluations of these pavements.

B. Pavement for Recycling

The pavements selected for recycling originally consisted of eight sections placed under several contracts. At the time of placement (1959) mixes were not formally designed and batching was done by experience based, cookbook recipes which delineated the weight percentages of the raw materials. Basically, the mix called for 47% stone retained on the number 10 sieve size with a 5.7% asphalt cement and the sand and filler added to meet the particular gradation specification. The stone portion of the mix was a traprock from three quarries, two diabase and one basalt. The bituminous sand was a natural sand from two sources of supply. The mineral filler was limestone dust from three sources of supply. The asphalt cement OA-4 (85-100 pen) was from two producers.

Prior to the milling operation both four (4) and eight (8) inch cores were taken of the surface course at 24 locations in the 25 lane miles. At two of the locations cores were taken from the binder course to ascertain the condition of the underlying asphalt. One location was dropped since it was in an area that had been resurfaced with a 5/8 inch open graded friction course. The cores were taken from the outside edge of the outer wheelpath and away from any joints or cracks where crankcase drippings or sealing compound could influence the penetration value of the asphalt cement. Figure 1 is a schematic outlining the preliminary testing performed on the cores. Gradation after extraction, Table I, and tests on the Abson recovered asphalt were performed on cores from eighteen of the twenty-three locations. The penetrations at 77^{0}F ranged from 27 to 61 with the average being 41.5 mm. The viscosity at 140^{0}F varied from 5,145 to 36,641 with the average being 12,871 poises. The ductility at 60^{0}F averaged 26.5 cm. The various test values for the individual samples are shown in Table II. From the individual values it appeared that in 6 of the 23 locations a modifier or rejuvenating agent might be beneficial. As a quick test, two of the penetration samples were

PRELIMINARY TESTS PERFORMED ON CORES

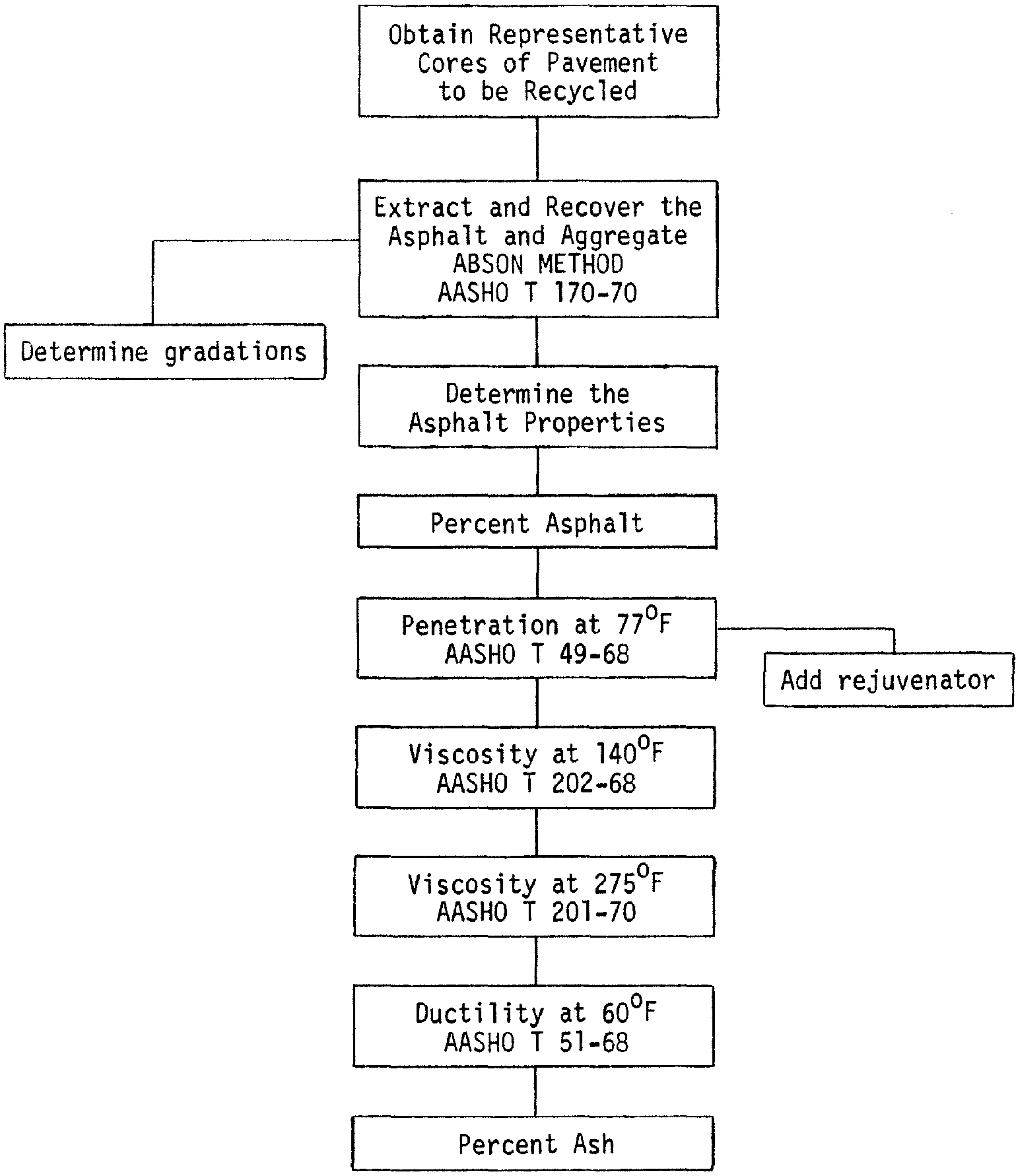


FIGURE 1

COMPOSITION ANALYSIS 23 CORES NO. 5 MIX

Sample	1/2	3/8	#4	* #8	* #50	#200	* % A.C.
1	100	90	61	50	22	4.5	5.5
2	100	93	63	49	23	4.5	5.4
3	100	93	74	55	22	4.8	5.9
4	100	99	65	49	23	5.0	5.6
5	100	94	67	51	26	6.4	5.7
6	100	98	68	55	26	5.3	5.6
7	100	96	70	54	24	5.9	5.8
8	100	94	71	55	28	6.7	5.3
9	100	92	67	53	27	5.0	5.7
10	100	96	69	54	28	5.1	5.8
11	100	97	79	62	29	4.5	6.4
12	100	98	66	51	25	5.1	6.1
13	100	93	65	51	24	3.7	6.5
14	100	98	71	48	22	4.4	5.7
15	100	96	69	52	25	5.3	5.8
16	100	96	66	48	24	3.4	6.3
17	100	95	65	50	24	4.4	6.0
18	100	97	68	52	26	5.3	5.8
19	100	93	64	52	25	5.2	5.7
20	100	96	68	52	26	4.0	5.4
21	100	91	59	48	26	7.6	5.2
22	100	93	63	48	26	6.4	5.7
23	100	90	61	49	23	5.7	5.7

*Rounded off

	Average Composition 23 Cores	Master Composition Band Min.	Master Composition Band Max.
1/2	100	100	
3/8	95	80	100
#4	67	55	75
#8	51.5	30	60
#50	25.0	10	30
#200	5.1	4	10
%AC	5.75	5	10

TABLE I

PERCENT AC, PENETRATION AND VISCOSITY

SAMPLE	DATE RECOVERED	SECTION	A.C.(%)	PENN. @ 77°F	VISC. @ 140°F	VISC. @ 275°F	DUCT. @ 60°F	% ASH
2A	4/28/78	3	5.5	46	6278	711	46.75	2.70
3A	4/28/78	3C-4E	5.4	27	18524	1033	6.75	2.20
4A	5/08/78	3C-4E	5.9	48	9197	744	11.50	2.99
6A	5/04/78	3C-4E	5.7	48	9357	794	10.00	3.32
7A	6/09/78	4D-5C	5.6	44	8231	793	35.00	2.31
9A	6/09/78	4D-5C	5.7	52	5590	628	52.00	2.55
10A	5/01/78	5D	5.3	31	35136	1122	5.25	3.54
11A	4/27/78	5D	5.6	31	18373	993	6.25	2.11
12A	5/01/78	4D-5C	5.8	30	17609	934	8.50	2.10
13A	6/08/78	4D-5C	6.4	40	8678	793	24.00	2.91
15A	5/02/78	4D-5C	6.4	61	5145	628	71.00	1.80
17A	4/26/78	4D-5C	6.3	35	21601	1141	7.00	1.75
18A	6/07/78	4D-5C	6.0	55	5408	669	67.00	2.58
19A	4/26/78	3C-4E	5.8	28	36641	1561	5.00	2.10
20A	6/07/78	3C-4E	5.6	28	15764	1256	7.00	2.55
21A	5/04/78	3C-4E	5.4	42	14081	869	13.00	2.66
22A	6/08/78	3	5.2	45	7233	730	41.00	2.47
24A	4/27/78	3	5.6	56	5229	704	60.00	2.40
Avg.			5.73	41.5	13871	895	26.50	2.50
MIX #2 BINDER								
3A	5/03/78	3C-4E	N.A.	70	2649	497	150+	2.40
14A	5/03/78	4D-5C	N.A.	61	4980	680	94.50	2.30

TABLE II

treated with a 5% and 10% by weight addition of Ashland's "100" asphalt modifier; the penetrations which were originally 35 and 31 increased to 52 and 109 respectively. While the results were interesting, it was preferred for this project to evaluate the effects of a normal production run asphalt cement.

C. Laboratory Testing

The New Jersey Department of Transportation assumed the responsibility for developing the job mix formula to convert the salvaged No. 5 mix material into a No. 4 recycled mix. The supplementary specification called for the contractor to submit to the Department's laboratory representative samples of the salvaged milled material, new aggregates, mineral filler and asphalt cement at least twenty days prior to production of the recycled bituminous concrete. The type and quantities of representative samples to be delivered were as follows:

Type of Materials	Quantities (min.)
Salvaged milled material (U.S. 1)	300 lbs.
New aggregate (each type)	100 lbs.
Mineral filler	25 lbs.
Asphalt cement	5 gallons

Prior to the milling on U.S. Route 1 a surface course material obtained from a milling job on U.S. Route 22 was used for a preliminary laboratory investigation. Figures 2 and 3 are a schematic describing the work performed on the salvaged milled material (U.S. 22) and the testing necessary to establish the job mix formula and a guide to the temperature requirements.

FLOW CHART FOR DEVELOPMENT OF JOB MIX FORMULA

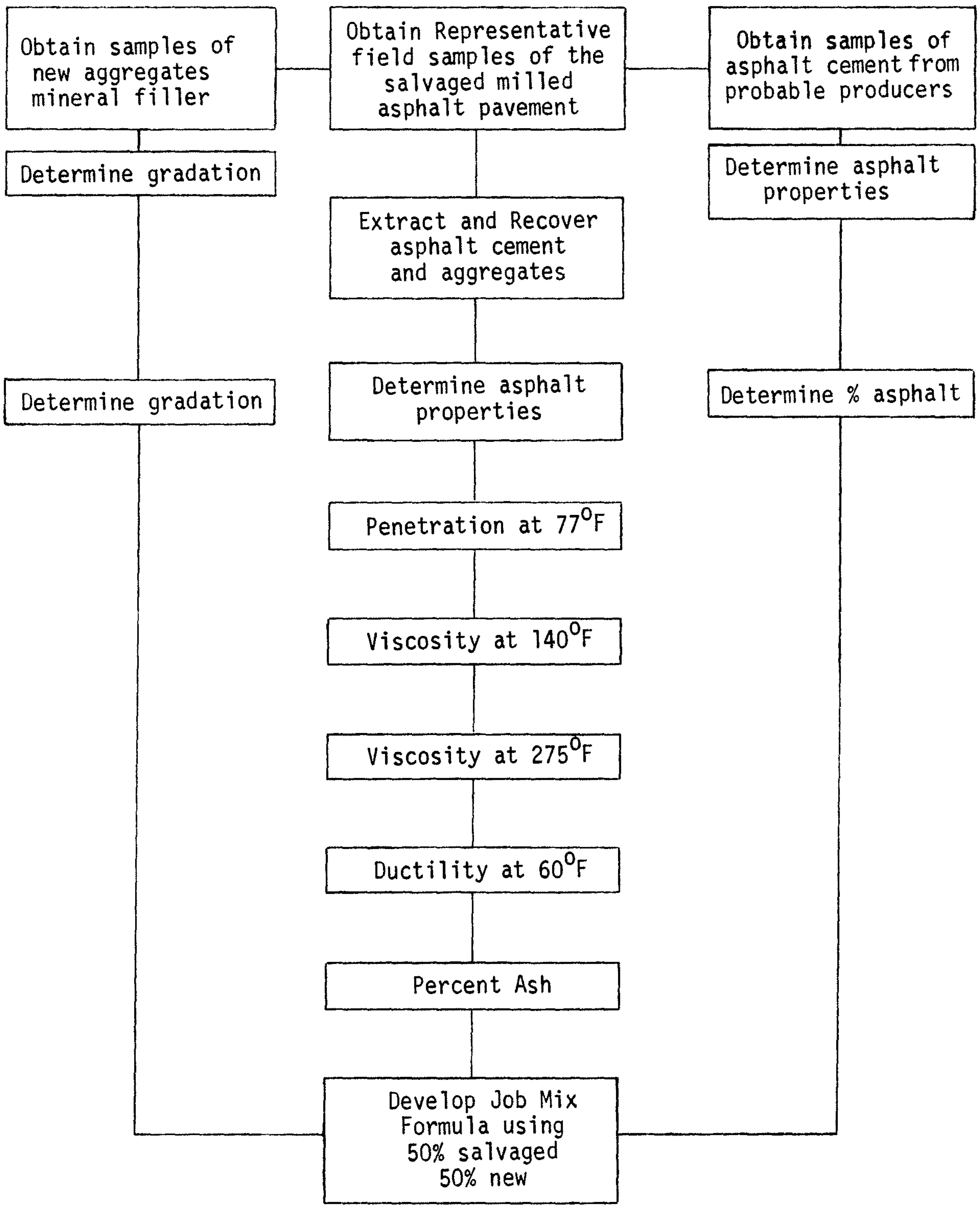


FIGURE 2

FLOW CHART FOR MARSHALL PLUG EVALUATION

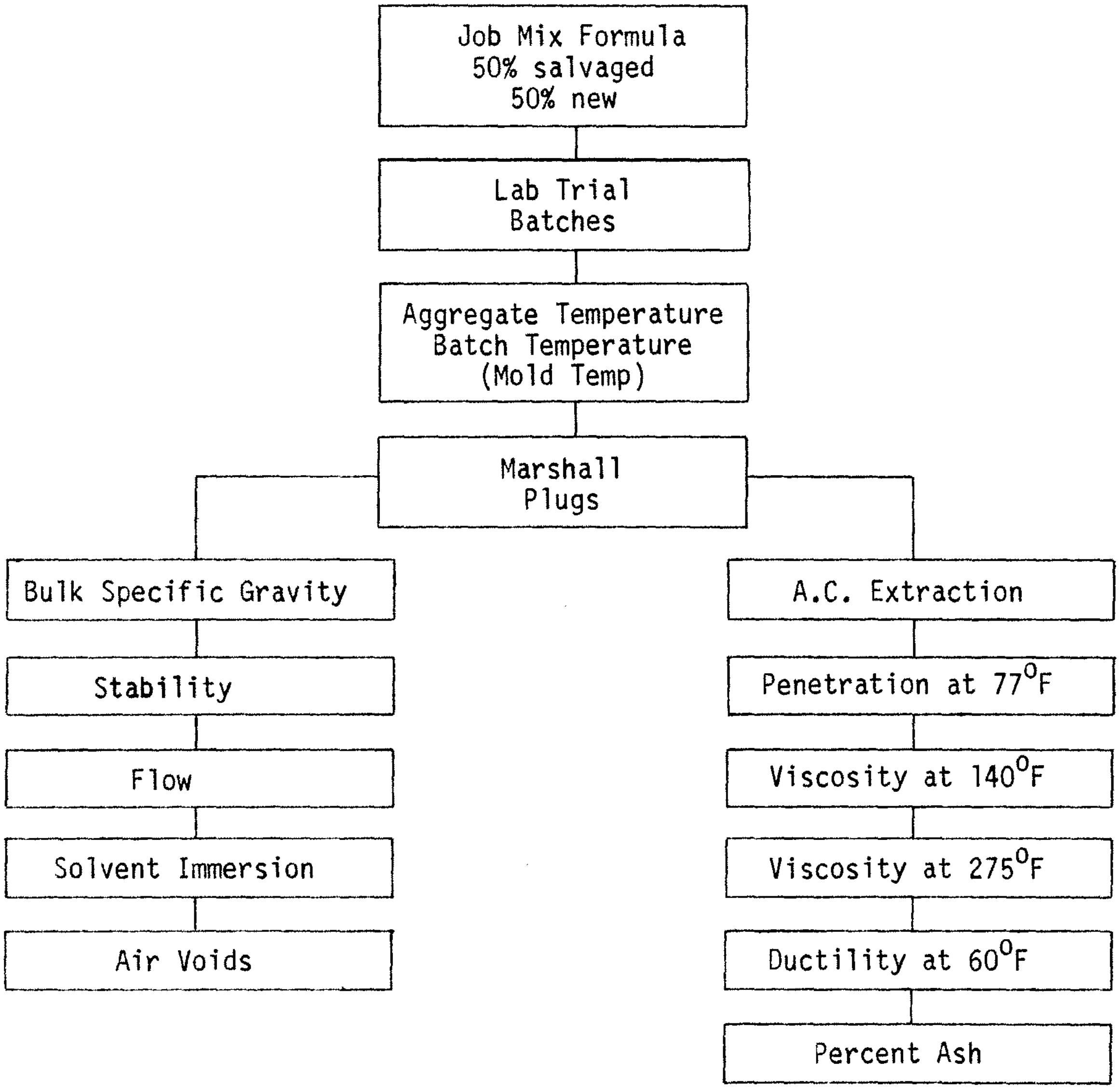


FIGURE 3

The gradation of the new aggregates and of the salvaged milled material (from US Route 22) after extraction along with the physical properties of the asphalt cements are shown in Table III. The mix design for the No. 4 mix became 50% milled material, 50% traprock consisting of 45% (#8), 5% (#10) stone, and 5.5% AC-20.*

1. Mixing Procedure - After establishing the job mix formula, all mixing for the Marshall plugs was performed in the following sequence:

a. the hot aggregate (1100-1300 grms.) was placed in a pre-heated mixing bowl.
b. the milled material was added to the bowl.
c. the combined material was dry mixed for 60 seconds.
d. hot AC at 320^{O}F was then added and mixed for 90 seconds.

2. Heat Transfer Mixing Temperatures - When the virgin aggregate was heated to 450^{O}F, the combined mix temperature dropped to 225^{O}F. There was little coating of the virgin aggregate by the old asphalt cement from the milled material during the dry mixing cycle. At 530^{O}F the recycled mix temperature was 245^{O}F and the coating on the virgin aggregate was better (fair). When the aggregate temperature was raised to 632-640^{O}F, the recycled mix temperature was approximately 280^{O}F and the old asphalt cement uniformly coated the aggregate during the dry

*In some sections of the country the term AC stands for the asphalt concrete mix. In the East and for the purpose of this report, the term AC will stand for asphalt cement.

LABORATORY INVESTIGATION

FOR RECYCLING BITUMINOUS MIXTURE

Materials

A. Milled bituminous pavement material taken from Route 22, Section 10D and 11J.

% Passing	3/4"	100
% Passing	1/2"	99
% Passing	#4	74
% Passing	#8	59.5
% Passing	#50	35.5
% Passing	#200	10.4
% Bitumen		5.5

B. #8 Stone, T.R.I., Kingston, N.J.

% Passing	3/4"	100
% Passing	1/2"	100
% Passing	#4	21.7
% Passing	#8	1.7

#10 Stone, T.R.I, Kingston, N.J.

% Passing	3/4"	100
% Passing	1/2"	100
% Passing	#4	96.8
% Passing	#8	85.6
% Passing	#50	30.6
% Passing	#200	11.0

C.1)AC-20 Arco, Phila., Pa.

Pen. @ 77^{O}F.	60
Visc. @ 140^{O}F.	1726
Visc. @ 275^{O}F.	391
Duct. @ 60^{O}F.	150+
Ash	0.122

C.2)AC-20 Exxon, Bayway, N.J.

	Producer Lot	Plant Samples
Pen. @ 77^{O}F.	73	69
Visc. @ 140^{O}F.	2041	2127
Visc. @ 275^{O}F.	409	379
Duct. @ 60^{O}F.	150+	
Ash	0.016	

TABLE III

mixing stage. After addition of the new AC-20 (2.6%) and subsequent mixing, the recycled mix to the trained eye looked as good as an all-virgin material mix.

In the event that the plant couldn't bring the temperature of the virgin aggregate up to $600^{O}F$ - $650^{O}F$, the milled material was heated to $165^{O}F$. At this same time, to simulate moisture in the stockpile, water additions of 1%, 3% and 5% were added to the milled material before being mixed with the $530^{O}F$ preheated virgin aggregate. There was no discernible difference in the mix temperatures for the three water additions but the combination with the heated milled material elevated the recycled mix (mold) temperature $20^{O}F$ to $265^{O}F$.

3. <u>Penetration</u> - The trial batches of recycled mix were made with an AC-20 from two sources of supply having penetration values of 60 and 73. The penetration values of the salvaged milled material varied from 48 to 57mm. The Abson recovery tests showed penetration values ranging from 41 to 67mm with 5 of the 7 samples lying between 48 and 54mm. As to how much or if any rejuvenation had taken place is a moot point, however, the values were not too much different than those that would be recovered from a pavement core after laydown.

4. <u>Stability, Flow and Air Voids</u> - The stabilities of the recycled laboratory mixture were good, ranging from an average of 1425 lbs. for the low $225^{O}F$ mold temperature to an average of 1661 lbs. for the nominal $277^{O}F$ mold temperature. The flow values ranged from 13 through 17 hundredths of an inch. Voids ranged from 1.5% to 4.0%.

5. Extraction and Ductility - The percentage of asphalt cement extracted averaged 5.34% in comparison to 5.5% target value, the range was 5.2% to 5.6%. The ductilities exceeded the thin film oven test specification requirement of 30, ranging from 34 to 150+cm.

6. Interpretation - The results of the preliminary laboratory tests showed that a 50/50 blend of salvaged bituminous and virgin materials could produce an acceptable mixture with a commercially produced AC-20 asphalt cement. When the virgin aggregates are heated to 600°F-650°F a uniform coating of aggregate is achieved and the temperature of the finished mixture would range from approximately 260°-280° Fahrenheit.

D. Mix Design

The stockpile of the salvaged milled material was sampled, the asphalt extracted and the aggregate gradated. The stockpile gradation was almost identical to that of the average of the cores. Converting the No. 5 salvaged mix to the No. 4 mix using the desired 50/50 blend was accomplished as follows:

50% milled material (by weight)
20% bin #3 (by weight)
17% bin #2 (by weight)
13% bin #1 (by weight)

The approved producer's analysis of material and job mix formula are shown in Appendix A. The Marshall plugs produced with this mix showed a stability of 1880 lbs., a flow of 12 (0.01 inch) and air voids of 4.1%.

PAVEMENT REMOVAL

The milling operation was merely an adjunct to the recycling project serving as the vehicle in preparing the feedstock. While successful as a method of pavement removal, there were some unsatisfactory aspects to the milling which will be discussed in a NJDOT Research report "Second Generation Overlays" to be published next year. Three things noteworthy of mentioning at this time are:

1) the forward speed of the machine has an influence on the size of the milled material and the surface texture,

2) that reflection joints and curbs can cause slabbing of pieces in the range of 4" x 6" x 1½", and

3) there is a need to keep the pavement clean and have personnel refrain from throwing any trash onto the milling machine truck loading conveyor belt. For example, discarded coffee containers and other trash will ultimately be imbedded in the mat behind the paver.

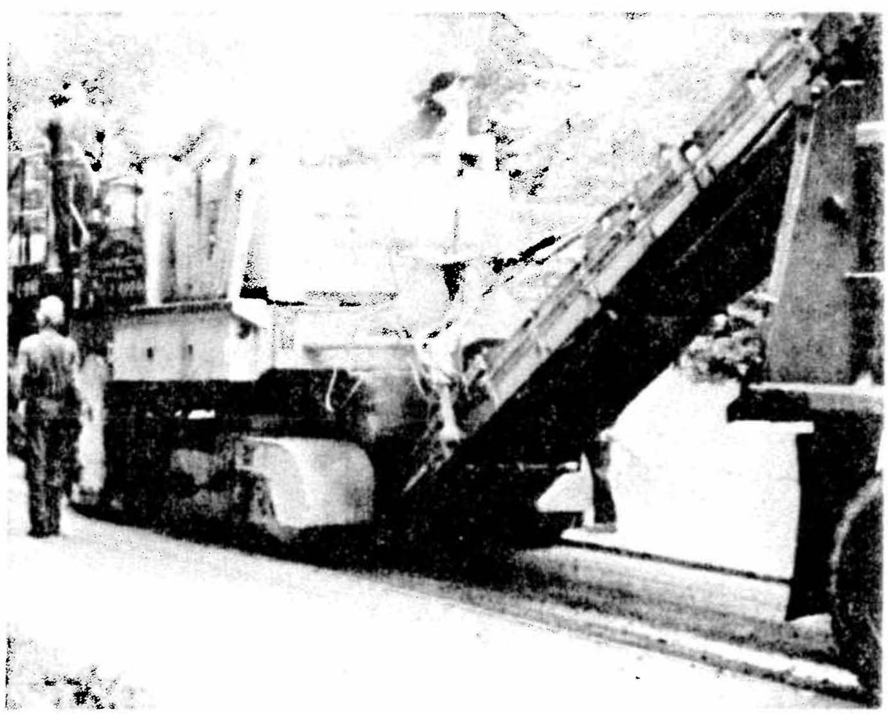


FIGURE 4 CMI Roto-Mill

PLANT OPERATIONS

A. Procedure

As mentioned in the introduction, the Minnesota Heat Transfer method was used to recycle a 50/50 blend of salvaged bituminous concrete and virgin aggregate in a conventional hot-mix batch plant. All of the virgin materials, the sand and both the fine and coarse aggregate were produced from traprock.

Starting from the cold bins, the aggregate was fed by a continuous belt feeder to the dryer. The aggregate was super-heated to a temperature above 600°F and conveyed by elevator to the screening unit and gradated into three bins, the sand bin (Bin #1), the minus No. 4 sieve bin (Bin #2), and the minus 1/2" size bin (Bin #3). The bin pulls were made according to the weights of the batch formula and dropped into the pugmill. The combined hot aggregate and milled material was dry mixed for 30 seconds to effect the heat transfer, the asphalt cement added and wet mixed for an additional 20 seconds. The mix was then dumped into a truck where the temperature was checked and the material sampled.

B. Equipment

A standard Barber Greene 3-ton asphalt batching plant equipped with a scrubber was used to produce the recycled mix. The plant set-up was modified by the addition of a portable concrete bin with weigh hopper and a conveyor belt running up to the access port on the upper side of the pugmill. An earthen ramp was built to permit loading of the salvaged

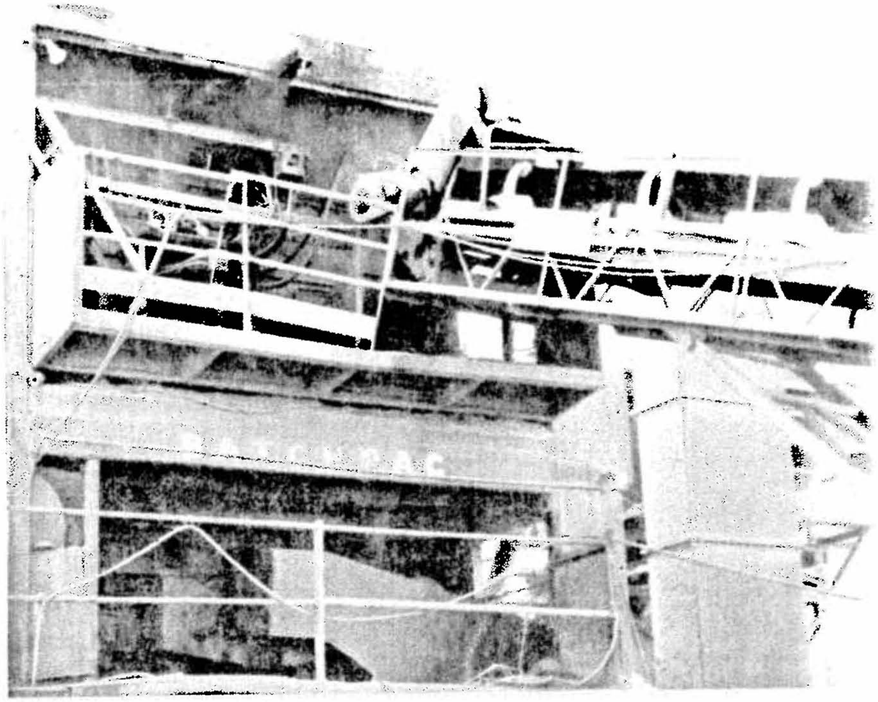


FIGURE 5 Conveyor to Pugmill

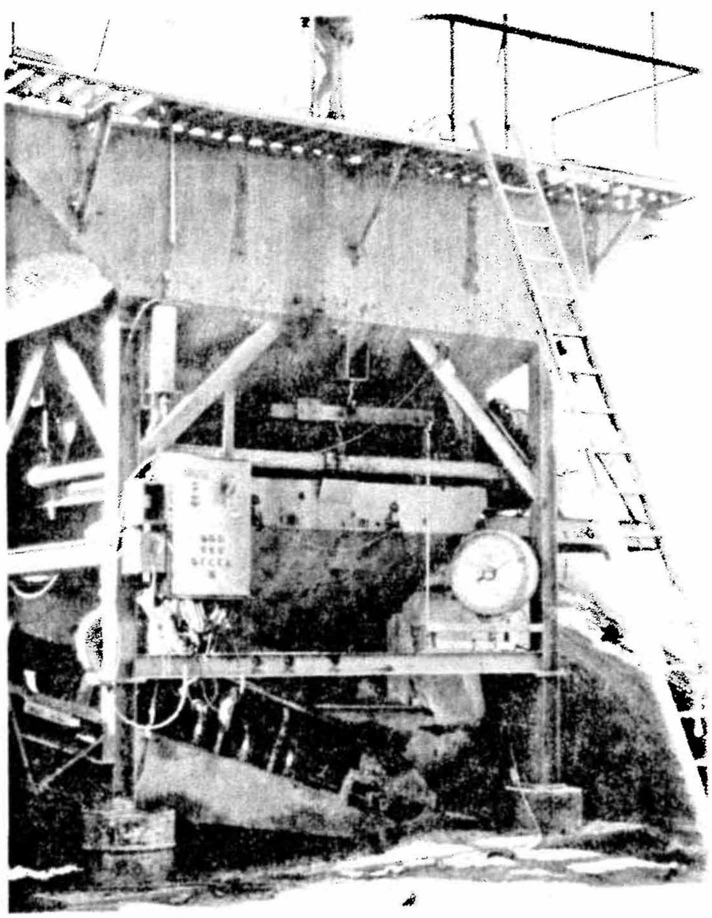


FIGURE 6 Sand Bin and Weigh Hopper

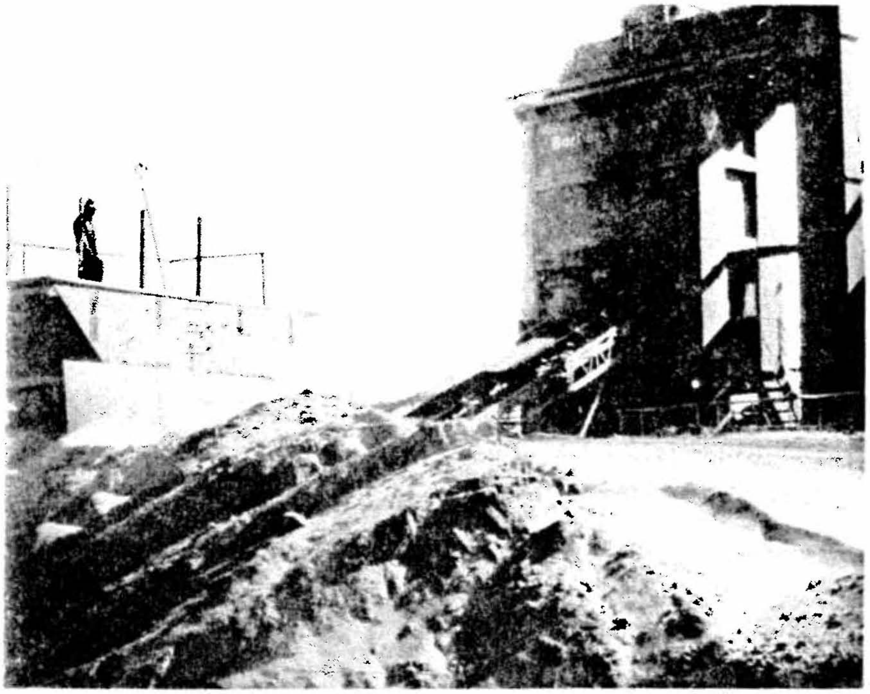


FIGURE 7 Ramp and Bin

FIGURE 8 Stockpile

milled material into the bin by use of a front-end loader. The electrical controls for actuating the weigh hopper and conveyor were set up in the operator's control room. At the beginning of the second paving season, type J thermocouples were installed in the three hot bins. A Northrup Speedmax recorder with an 800°F temperature range was set up in the control room to continuously record the aggregate temperatures. Standard armored thermometers and one electronic thermometer were used to check the recycled mix and mat (lay down) temperatures.

C. Operations

The average production rate was approximately 100 tons/hour. Production rates varied due to the weather, availability of trucks and minor break-downs or interruptions. On occasion, the paving operation caught up with the excavation work and the plant had to be closed down or shifted to commercial work. At the end of the project, a total of 27,068 tons of recycled mix was produced.

Some minor problems persisted during the entire project. The milled feedstock had to pass through a grizzly (6" wide grid the width of the salvaged material bin). This required a man, full time, to break up or roll off the oversized lumps. He also would "rod" the material through the throat of the hopper on blockage.

Due to the higher temperature through the dryer, there was trouble with the bearings losing grease. This problem was alleviated by switching to a higher temperature-rated grease. In other instances, the pugmill discharge gate would hang up causing delays. There also was a loss of pugmill paddles during the first phase of production due to the large lumps forced through the grizzly. After the grizzly openings were halved (nominal 2½"), the problem for all practical purposes disappeared.

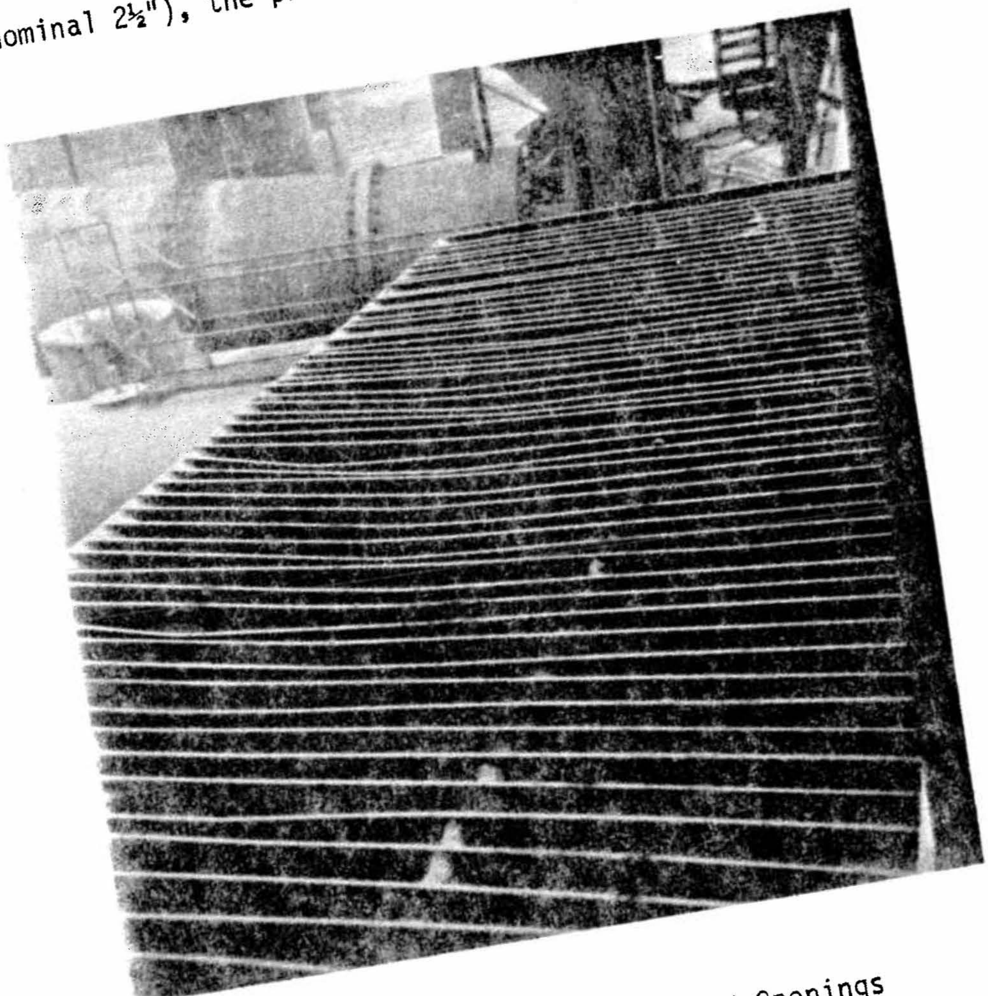


FIGURE 9 Grizzly with Reduced Openings

CONSTRUCTION

The existing shoulder on Route 130, which consisted of a gravel base and successive surface treatment, was excavated to a depth of 2" and 3" as required by the plans. The base was then rolled and checked for grade. A prime coat of MC 30 was applied at an average rate of 0.17 gallons per square yard. The recycled mix was placed utilizing conventional paving equipment and standard paving operations. In order to compare the recycled mix with virgin material, two control sections were established, 1) a section 1210' in length and 2" thick, conforming to a No. 5 mix specification, was placed in the northbound outside shoulder and 2) a 1200' full width, mainline, 1½" recycled overlay pavement section was laid down adjacent to a new material No. 4 maintenance overlay. This would not only permit a comparison of mixes but would afford a more rapid evaluation of the recycled mix. One problem encountered on the mainline test section was escessive tack coat. On rolling, three spots of pavement approximately 1½' wide and 6'-8' long showed signs of bleeding. They were removed and new material hand placed and rerolled. A sample of the removed material showed a 7.8% asphalt content. Another problem was deleterious stone, eight pieces of approximately 4"x7"x2" had to be picked out of the mat. One piece 5"x8"x3½" was caught in front of the tamper bar of the screed unit and tore up 20' of the mat before it was discovered. This small amount of stone came from either the front end loader which worked several stockpiles or had been left in the truck body. Certainly it reinforces the earlier references to keeping the salvaged material clean.

As previously indicated, the total amount of recycled mix produced was 27,068 tons, slightly less than the 30,000 tons projected at the start of the investigation.

FIGURE 10 Shoulder before Recycling

FIGURE 11 Shoulder Excavation

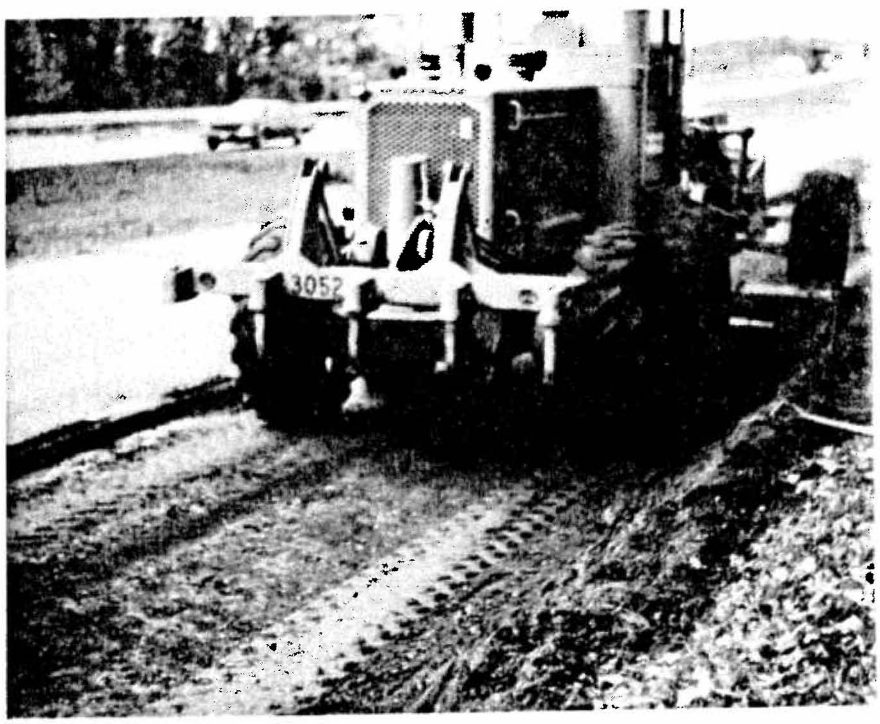


FIGURE 12 Grading

FIGURE 13 Compacting

FIGURE 14 Checking Grade

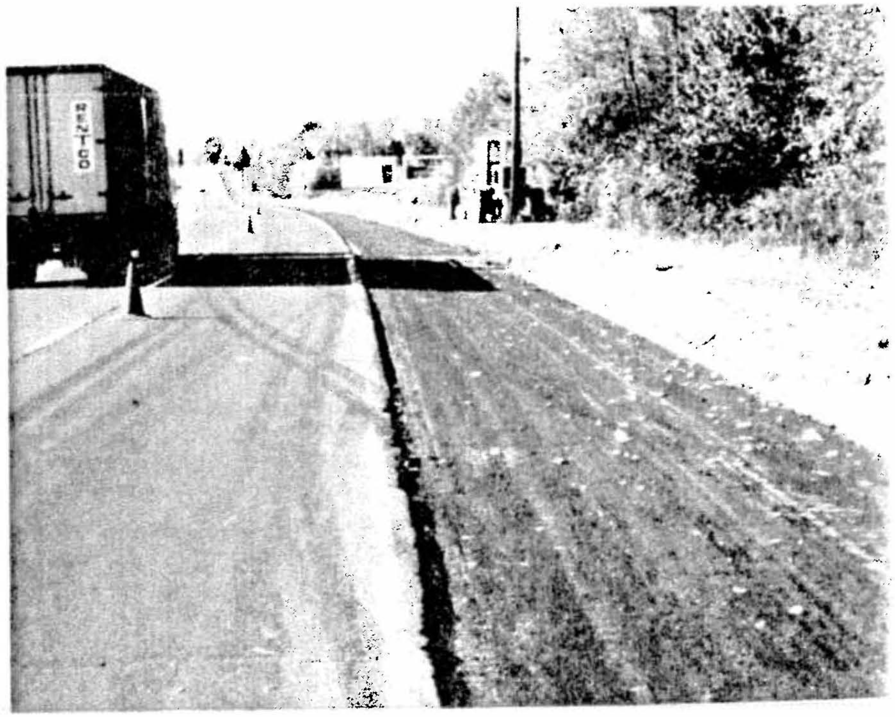


FIGURE 15 Tack Coat

FIGURE 16 Pinching Shoulder to Mainline

FIGURE 17 Finished Shoulder Pavement

FIGURE 18 Tramp Stone

MATERIALS TESTING AND EVALUATION

A. Sampling Procedure

An integral part of this recycling project involved sampling and testing of materials before, during and after the recycling process. Tests on the material were performed in the Department's bituminous laboratory and at the asphalt plant. The test taken included extractions for bitumen content and gradation analysis; recoveries of asphalt cement in which viscosities, ductilities, penetrations, and thin film oven tests were performed; and moisture contents on the milled material.

Previous to milling Route 1, twenty-four cores were taken and tested to establish the initial mix design. During the recycling process, an asphalt cement sample was taken each day. The sampling on the recycled material involved taking a sample of the milled material from the conveyor belt before entering the pugmill for the last batch on a truck. A sample of the recycled mix was then taken from the last batch loaded on the truck. The temperature of the load was checked in two or more locations on the truck. This sampling procedure of the recycled material permitted some insight as to the effect of the new asphalt cement on the old AC in the salvaged milled material. The temperature check permitted identification of a wide range of hot-mix temperatures which were located at the laydown site. Future cored samples could then be taken and evaluated for differences in asphalt hardening and compaction.

B. Test Results

1. Temperature

(a) Recycled Mix - The first recycled mix was produced late in the season on October 20, 1978. This was a short run of 408 tons to permit project personnel familiarization. To prevent a cold load on starting, 50 tons of the virgin aggregate was processed through the dryer, conveyor system, hot bins and emptied out through the pugmill. This was highly successful since the first recycled material came out at 327^{0}F (the dryer was shut off and the second load came out at 270^{0}F). Subsequently, the loads ranged from 300^{0}F-330^{0}F and the 408-ton lot averaged 314^{0}F. One load having a temperature of 345^{0}F was rejected. As each truck dumped its load into the paver, the temperature was checked with an electronic thermometer. The mat temperature for the same load was checked at 8 to 10 points. The average for the first truck was 325^{0}F, a drop of only 2^{0}F. The average mat temperature for the 408 tons was 299^{0}F. The second day was a short run of 255 tons in which the temperatures were extremely high. The third, fourth and fifth truck had temperatures of 350^{0}F, 375^{0}F and 340^{0}F and were rejected. The third day was a full day's run of over 1200 tons and offered the opportunity to exercise better control of the temperature. The average of the truckload temperatures was 267.5^{0}F with a standard deviation of 19.5^{0}F. The average mat temperature was 263.6^{0}F with a standard deviation of 17.7^{0}F. As a frame of reference, samples of the virgin materials yielded the following temperature profiles: sand-520^{0}F, minus 1/4" material 580^{0}F and 590^{0}F for the minus 1/2" material. For the 1979 season, 756 truckload temperatures of accepted material ranged from 225^{0}F to 330^{0}F. A stratified random sampling arranged in groups of six with one random temperature from each group resulted in a mean temperature of 270^{o}F with a standard deviation of 22.5^{o}F.

(b) Virgin Aggregate - The continuous monitoring of the virgin aggregate in the three bins was moderately successful. Two of the thermocouples gave excellent and accurate temperature readings. The third thermocouple well had evidently been placed in a dead spot. The temperature would increase in a slow and steady fashion whereas the other two thermocouples would react quickly and have greater fluctuations due to the burner being on or off and the rapidity of material being loaded into the pugmill. On the third day after the start-up when 1251 tons of material were produced, the temperature of the sand, the minus 1/4" and minus 1/2" aggregate was 520^{o}F, 580^{o}F and 590^{o}F, respectively. This would be representative of the temperatures necessary to produce a mix having an average temperature of approximately 270^{o}F. Elevated temperatures of 620^{o}F, 720^{o}F and 750^{o}F corresponding to the aforementioned virgin materials produced an average batch temperature of 301^{o}F where four truckloads reached temperatures between 330^{o}F and 345^{o}F.

After the rejection of a few loads the contractor cut back on the temperature to avoid being penalized. The temperature of the material was running on the low side of the specification. The viscosity of the recycled asphalt was, of course, higher than a virgin AC-20. It was felt that this combination might compromise the compactive effort and adversely effect the void space. We agreed, therefore, to take an occasional out-of-specification hot load if the contractor would try to keep the temperature of the mix in the range of 270°F - 290°Fahrenheit. For the balance of the project the temperature ranges recorded for the sand, fine aggregate and coarse aggregate were 410°F - 615°F, 400°F - 770°F and 460°F - 795°F with an occasional peak of over 800°F for both the fine and coarse aggregates.

Despite this seemingly wide range of temperatures, especially on the high side, only two truckloads out of 699 were out of specification at 330°F. Unquestionably, the water content of the salvaged milled material had a cooling effect on the super heated virgin material, thus tempering the heating effect of the recycled mix. The moisture content of the salvaged milled material averaged 4.25% and the moisture in the finished recycled mix was 0.5%.

2. Extraction

(a) Gradation - Specifications for this project required that control charts be used as a quality control tool during the production of the recycled bituminous mixture. These charts were required for plotting the results of composition tests on hot bin materials, milled material, and the theoretical composition of the final recycled mixture. The limits to be used with the theoretical composition chart were provided by Research to the Bureau of Plant and Project Inspection. An analysis of the variability of bituminous mixtures from standard production operation had been made and the information was utilized to develop tentative control limits for the recycling project. The following shows the control limits applicable to the #8, #50, and #200 sieve percentages and the percent asphalt content.

Quality Control Limits for Recycled Mixture

Characteristics	Warning Limits (%)	Action Limits (%)
Passing #8 Sieve	4.5	6.5
Passing #50 Sieve	3.5	5.0
Passing #200 Sieve	1.7	2.5
Asphalt Content	0.55	0.75

Two sets of limits were provided, one set called "Action Limits", the other "Warning Limits". These limits were to be applied to the composition of the theoretical combined mixture and, if desired, to the final extraction test results. The plotted composition point in all such applications was the average of two test results (theoretical combination or extraction of finished mixture). The center lines of the charts were the governing job mix formula values.

Using the control charts, three bin pull adjustments were required during the project. The first adjustment was made on May 10, 1979 because the average of the tests on the material passing the #8 sieve fell outside the action limit. The second and third adjustments were made because in each case at least seven consecutive sample results (average of two tests) passing the #200 sieve were above the design formula. There were 14 lots (approximately 21,700 tons) of recycled No. 4 mix in 1979 of which 6 lots would have been non-complying with the NJDOT's normal, new material composition requirements.

Lot #1 - Average passing #200 sieve 7% - spec. 3.9%-6.7%

2 - Average passing #8 sieve 43.5% - spec. 35%-43%

6 - Range between tests #8 sieve 13.5% - spec. 13.0%

Lot #11 - Range between tests #8 sieve 13.5% - spec. 13.0%

12 - Range between tests #200 sieve 1.6% - spec. 1.5%

14 - Range between tests #8 sieve 16.5% - spec. 13.0%

The fineness through the #200 sieve of Lot #1, while fractionally out of specification was readily accounted for. Unknown to State personnel, production was started from the reverse end of the stockpile where the contractor stored 150 tons of sweepings from the milling operation. The minus 200 mesh on two samples of sweepings ran 7.0% and 10% respectively. On Lot 14 the range between tests on the number 8 sieve is questionable. Of 69 split samples the average difference between the percent minus #8 for the field and laboratory was 1.87%; the range was from 0.5% to 6.0%. The one field sample which indicated the lot to be non-complying differed by 10% with the laboratory analysis on the material through the #8 sieve. A rerun of the laboratory sample proved to be identical which makes the writer feel that either a typographical or arithmetical mistake was made on the field analysis. The other four lots were out of specification by 0.1% to 0.5% on one screen.

The control chart system appears to be an excellent prospect as a quality control tool for aiding plant inspectors to affect changes before changes in the mix become a problem. The following compilation of the field and laboratory tests when compared to the job mix formula and theoretical combination (milled material and virgin aggregates) shows what we believe to be very good control.

Sieves	Job Mix Formula %	Avg. Field Results %	Standard Deviation %	Avg. Lab Results %	Standard Deviation %	Theoret. Combo. %
#8	39.0	40.0	4.06	39.0	4.05	38.0
#50	17.5	17.5	1.64	17.5	1.61	16.5
#200	5.3	6.1	0.73	6.0	0.68	5.4
A.C.	5.5	5.5	0.32	5.2	0.27	5.7

(b) Asphalt Content - The asphalt content of the core samples of the original pavement averaged 5.75%. For design purposes, the Department's central laboratory rounded the figure to 5.8% and calculated that the addition of asphalt in the amount of 5.2% of the weight of the virgin aggregate would meet the design figure of 5.5%. In 1978 approximately 5500 tons of recycled material were produced averaging 5.14%. During this same period the extractions of the milled material ranged from 4.8% to 5.4% averaging 5.15% for the six samples taken by the department inspectors.

The asphalt addition was increased to 6% of the weight of the virgin aggregate for the 1979 season to bring the mixture up to the design value. Seventy samples were taken during production of fourteen lots with the following results:

	Job Mix Formula %	Avg. Field Results %	Standard Deviation %	Avg. Lab Results %	Standard Deviation %	Theoret. Combo. %
A.C.	5.5	5.50	0.32	5.2	0.27	5.7

Traditionally, there has always been a 0.1% to 0.2% difference between the field and laboratory analysis which has been attributed to moisture, or the ash and spin corrections or a combination of all three. The laboratory is presently conducting an investigation to determine the specific causes.

3. Recovery

(a) Penetration - The penetration of the milled material was altered only slightly by the AC-20 during the recycling process (see Table IV). The largest change, 8 units, occurred in the milled material having the lowest penetration (25). The penetration of the milled and recycled material appears to be reversed in two of the samples. However, a change of 2 to 3 units in penetration is not significant since this falls within the precision of the test. The effect of the AC-20 is demonstrated more vividly in the viscosity and ductility tests.

(b) Viscosity - The viscosities of the milled material at 140^{O}F ranged from 7,939 to 24,937 poises, the average being 12,082 poises. The viscosity of the recycled mix ranged from 5,926 to 9,912 poises. The average difference was 4,500 poises. As might be suspected, the sample with the highest viscosity was effected the most by the asphalt cement, changing over 15,000 units from 24,937 to 9,912 poises. At 275^{O}F the changes were, of course, minimal. The averages for the recovered asphalt of the milled and recycled mix were 909 poises and 771 poises, respectively.

(c) Ductility - The ductilities of the milled material were improved in every case through the recycling. The average increase was 14.45 cms. The increases ranged from 5 to 30 cms which percentages wise was a 71.4% and 250% increase for their respective corresponding samples. Also, this amounts to a 140% increase over the minimum requirement for an AC-20 residue after the thin film oven test.

PENETRATION AND VISCOSITY OF MILLED AND RECYCLED MIX

Sample	No.	Pen. at 77°F	Vis. at 140°F	Vis. at 275°F	Duct. at 60°F
Milled	(1)	39	10,708	875	11
Remix		44	7,458	795	29
Milled	(2)	40	10,347	830	12
Remix		46	6,051	712	25
Milled	(3)	43	10,491	866	12
Remix		46	6,485	714	29
AC-20	(4)	72	1,836	446	--
TFOT		50	2,915	---	33+
Milled	(5)	37	9,275	891	10
Remix		40	8,277	864	16
Milled	(6)	46	7,939	854	14
Remix		44	7,559	799	39
AC-20	(7)	81	1,917	462	--
TFOT		59	4,020	---	66
Milled	(8)	41	9,592	855	12
Remix		47	5,929	710	42
Milled	(10)	42	10,797	941	12
Remix		48	6,158	731	31
Milled	(11)	43	10,497	913	12
Remix		40	7,627	805	19
AC-20	(9)	76	2,091	465	--
TFOT		51	3,833	---	63
Milled	(12)	34	14,515	986	9
Remix		34	7,963	747	19
AC-20		80	1,923	432	--
Milled	(13)	36	13,808	875	10
Remix		35	9,883	795	19
AC-20		77	1,914	449	--
Milled	(14)	25	24,937	1,112	6
Remix		33	9,912	805	11
AC-20		80	1,943	464	--
Milled Average		38.7	12,082	909	10.9
Remix Average		41.6	7,573	771	25.4

TABLE IV

4. Air Voids - Since this was an experimental project no penalty was to be assessed for air voids in excess of the specifications for a regular mix. The process and inspection for air void control proceeded, however, as if it were a regular mix. The NJDOT's 2% - 8% control air voids requirements apply to an average of five cores as determined from the values of the maximum specific gravity of the mix and the bulk specific gravity of the compacted mixture. The 172,000 square yards of shoulder pavement was broken into 36 uniform pavement lots of approximately 4,850 square yards each. Five air voids cores per lot yielded a total of 180 cores (see Table V).

The recycled mixture met the specifications with an average of 6.4% air voids. No penalty would have been assessed had the normal specification clause been in force. The outside shoulders had an average of 6.1% air voids whereas the average for the inside shoulders was 7.0%. The difference in the averages may be due to the difference in compactive effort. The ten foot outside shoulders had the benefit of a vibrating screed on the paver, a breakdown roller and a tandem roller. On the five foot shoulders only a single auger on the paver was used without vibration of the screed. The breakdown roller made only a single pass to pinch the recycled mix to the mainline pavement. The rest of the mat was finished with the tandem roller.

5. Stability and Flow - There were approximately 21,700 tons of the recycled No. 4 mix placed in 1979. This constituted 14 plus lots of material for stability evaluation. The average Marshall stability for the 14 lots was 1,946 lbs., ranging from a minimum of 1110 to a maximum of 2855 lbs. The flow values ranged from 7 to 14 hundredths of an inch. The average of 10.5 is well within the 6-16 range as set forth in the specification for a regular mix. The individual values of the lots are shown in Table VI.

% AIR VOIDS

927 + 00

LEFT OUTSIDE SHOULDER		LEFT INSIDE SHOULDER		RIGHT INSIDE SHOULDER		RIGHT OUTSIDE SHOULDER	
927+12	4.92						
		921+02	7.78				
883+84	6.32						
833+67	7.22					6.50	851+45
758+24	7.42					7.22	783+93
		746+53	7.78				
				7.08	781+79		
724+73	7.12						
						6.30	740+88
683+39	7.50						
						5.02	594+22
610+00	6.64						
						5.34	544+72
		588+03	6.02				
						6.38	488+85
570+00	7.90						
				5.74	433+07		
513+45	7.10						
						5.54	401+45
		510+30	7.50				
						5.6	348+27
429+35	5.54						
				6.52	293+69		
377+74	6.64						
						4.56	282+67
		342+85	7.30				
						4.12	235+73
319+16	5.74						
				7.42	195+40		
		195+16	7.32				
						4.56	183+38
165+33	7.42						
98+14	7.02						
						4.40	97+95
73 + 32							
GRAND AVERAGE	6.75		7.28	6.69		5.46	

NOTE: Each value is an average of five cores between stations.

TABLE V

STABILITY AND FLOW OF RECYCLED MIX

Lot Sample	Stab./Lbs.	Flow--0.01"	Lot Sample	Stab./Lbs.	Flow--0.01"	Lot Sample	Stab./Lbs.	Flow--0.01"
1A-RM	1620	9	6A-RM	2085	--	11A-RM	1695	8
1B-RM	1785	8	6B-RM	2220	10	11B-RM	1200	9
1C-RM	1770	11	6C-RM	2235	9	11C-RM	1875	11
1D-RM	2010	14	6D-RM	2160	10	11D-RM	1525	11
1E-RM	2355	14	6E-RM	2145	8	11E-RM	2070	9
2A-RM	2410	16	7A-RM	2085	9	12A-RM	2205	7
2B-RM	1875	11	7B-RM	2055	10	12B-RM	2340	6
2C-RM	1620	13	7C-RM	2385	10	12C-RM	1740	11
2D-RM	1665	9	7D-RM	2010	9	12D-RM	1650	11
2E-RM	1455	12	7E-RM	1995	11	12E-RM	1950	7
3A-RM	1330	11	8A-RM	1800	9	13A-RM	1965	8
3B-RM	1225	13	8B-RM	1980	11	13B-RM	1925	8
3C-RM	2855	17	8C-RM	2280	8	13C-RM	2070	10
3D-RM	2190	13	8D-RM	1995	9	13D-RM	1740	11
3E-RM	2280	11	8E-RM	1725	11	13E-RM	1860	8
4A-RM	2355	10	9A-RM	2250	8	14A-RM	2220	11
4B-RM	2070	11	9B-RM	2430	11	14B-RM	1845	10
4C-RM	1965	12	9C-RM	1110	14	14C-RM	1800	11
4D-RM	2040	11	9D-RM	1950	11	14D-RM	1725	9
4E-RM	2145	13	9E-RM	1875	11	14E-RM	2125	11
5A-RM	1740	10	10A-RM	2265	11			
5B-RM	1905	13	10B-RM	1695	10	AVERAGE	1945.9	10.5
5C-RM	1755	12	10C-RM	1845	10			
5D-RM	1875	14	10D-RM	2115	9			
5E-RM	2325	9	10E-RM	1680	10			

TABLE VI

COST COMPARISON

As a result of the 1973 oil embargo, the price of asphalt cement became extremely volatile. In order to remove this hazard to contractors and thus achieve the lowest calculable bid, the State of New Jersey adopted an escalator clause for the price of asphalt cement. When a bid is received, the unit price of the bituminous concrete pavement includes all labor, equipment and materials with the exception of the asphalt cement. Payment for the asphalt cement, measured in tons, is made at an adjusted unit price per ton. This adjusted contract unit price is determined by applying the materials adjustment factor to the original contract unit bid price. The adjusted contract unit price is determined at the beginning of each month for the asphalt cement furnished during the month. The material adjustment factor will be a percentage increase or decrease determined by comparing the basic materials index with the monthly materials index. The basic materials index will be the average of quotations from refineries serving the area in which the project is located. The basic materials index for the asphalt cement at the start of the project was \$81/ton. The following paving season the index increased to \$94/ton. Both of these prices were used in figuring the cost comparison between the recycled mix and the regular mix.

The unit price for the conventional No. 4 mix dry in place was \$14.11/ton versus \$17.52/ton for the recycled mix. When the asphalt cement adjustments were applied, the prices were \$19.81/ton and \$20.51/ton respectively or a difference of \$0.70/ton as shown in the following:

Regular Mix No. 4 AC-20 5.6% Unit Price 14.11/ton

1978

5348.63 tons (14.11)	=	75,469.17
5348.63 tons (.056) ($81)	=	24,261.39

1979

21,719.27 (14.11)	=	306,458.89
21,719.27 (.056) (94)	=	114,330.23
21,719.27 (.056) $\left(\frac{94-81}{81}\right)$ (81)	=	15,811.62
		$536,331.30/27,067.9 tons
		19.81/Ton

Recycled Mix No. 4 AC-20 2.6% 1978 3.0% 1979 Unit Price 17.52/ton

1978

5348.63 tons (17.52)	=	93,707.997
5348.63 tons (.026) (81)	=	1,264.214

1979

21,719.27 tons (17.52)	=	380,521.61
21,719.27 tons (.03) (94)	=	61,248.341
21,719.27 tons (.03) $\left(\frac{94.81}{81}\right)$ (81)	=	8,470.513
		555,212.67
		27,067.9 tons $20.51/ton

Other factors, however, must be considered in establishing the cost differential between the new and recycled mix. First of all, the US 1 project originally called for removal of the surface course without recycling, so the cost of milling and disposal of the material is not germane to the cost comparison.* Secondly, the average haul distance

*However, if milling introduced in New Jersey in June of 1974 had not been available, the normal leveling course would have been an additional $585,000 calculated expense based on the bid prices over the cost of milling.

to US 130 was 10 miles greater than for US 1 on which the price for the regular mix was predicated. Thirdly, the shoulders on US 1 were 10 feet wide, whereas the inside shoulders on US 130 were, for the most part, 5 feet wide. The 5 foot shoulder which required additional waiting time not only increased the trucking and plant production costs but also increased the costs for the labor and equipment forces as well. While it may be argued that the 10 foot shoulders with a two and three inch lift would appear to be a place where a lot of tonnage could be placed in a minimum of time, the production rate, however, was actually blunted due to the great number of equipment moves at intersections. The lower production rate and longer hauling distance would have added an estimated $2.56 per ton to the cost of the regular No. 4 mix. This would have increased the cost to $22.37/ton and changed the differential to $1.86 in favor of the recycled mix. The savings for paving with the recycled over all virgin material was a theoretical $50,346.

It must be noted that the milled material which supplied approximately 50% of the asphalt cement and aggregate might appear to have given the contractor a windfall profit. However, the value of this material merely helped the contractor defray the extra expense for the recycling program. These extras included preparing the stockpile and maintaining it over the winter; moving the material from the pile to the plant; erecting the weigh hopper and conveyor belt; building the ramp to the weigh hopper; modifying the grizzly; using two operators for weighing the batches; using extra manpower to remove the oversize from the grizzly and rod the milled material through the hopper; finally, to repair the burner tile, and replace the flights in the dryer.

ENERGY COMPARISON

An analysis of the energy requirements was made to compare the recycled mix with a conventional mix. While not required for this study, a comparison was also made for the milling operation versus the placement of a leveling course. The energy expended on the various operations was taken from the actual consumption on the project from the contractor's yearly records for the conventional mix. In cases where it was impractical, energy values as derived in the Asphalt Institute's publication "Energy Requirements for Roadway Pavements" were used. In certain phases of the comparisons where particular operations were common to both the recycled and the new mix, the energy value was omitted.

The complete energy analysis for the recycling project is given in Appendix B. For the comparison of the recycled mixture and the all virgin mix, the energy values for all operations through producing the mix were calculated. The hauling and placement of the mixes being a constant were not included in the comparison.

The recycling operation used 1.17 gallons of No. 2 fuel oil for drying and heating per ton of finished mix. The average for a conventional mix was 1.67 gallons per ton. The comparative energy value for the recycled mixture was 6.53 billion BTU and 10.03 billion BTU for the conventional (virgin) mix. The net energy saving was 3.5 billion BTU or an equivalency of 27,964 gallons of gasoline. The conservation of asphalt cement and stone aggregates was 704 tons and 12,753 tons respectively.

In comparing the placement of a leveling course with the milling operation, the energy needed for the leveling course was 20.74 billion BTU. The total energy for the milling and paving of the milled areas was 3.58 billion BTU, a net saving of 17.16 billion BTU or an equivalency of 137,313 gallons of gasoline. The conservation of materials amounted to 2,215 tons (540,150 gallons) of asphalt cement and 42,975 tons of stone aggregates.

An overview of the total energy requirements of three methods available to the design engineers is shown below:

U.S. 1		U.S. 130	
A. New Materials		**New Materials**	
Leveling Course	20.70×10^9 BTU	Shoulder No. 4	10.03×10^9 BTU
Tack Coat	$.25 \times 10^9$ BTU	Mix in Place	
Surface Course	26.03×10^9 BTU	Prime Coat	$.05 \times 10^9$ BTU
	46.98×10^9 BTU		10.08×10^9 BTU
TOTAL: 57.06×10^9 BTU			
B. New Material; Milled Mat'l. Discarded		**New Materials**	
Milling	$.57 \times 10^9$ BTU	Shoulder No. 4	10.03×10^9 BTU
Haul to Dump	2.39×10^9 BTU	Mix in Place	
Tack Coat	$.06 \times 10^9$ BTU	Prime Coat	$.05 \times 10^9$ BTU
Binder	2.72×10^9 BTU		10.08×10^9 BTU
Tack Coat	$.12 \times 10^9$ BTU		
Surface Course	26.03×10^9 BTU		
	31.89×10^9 BTU		
TOTAL: 41.97×10^9 BTU			
C. New Material; Milled Mat'l. Used		**Recycled**	
Milling	$.57 \times 10^9$ BTU	50/50 No. 4 Mix	6.53×10^9 BTU
Haul to Plant	$.28 \times 10^9$ BTU	Mix in Place	
Tack Coat	$.06 \times 10^9$ BTU	Prime Coat	$.05 \times 10^9$ BTU
Binder	2.72×10^9 BTU		6.58×10^9 BTU
Tack Coat	$.12 \times 10^9$ BTU		
Surface Course	26.03×10^9 BTU		
	29.78×10^9 BTU		
TOTAL: 36.36×10^9 BTU			

CONCLUSIONS

A. The results of this study confirm that the heat-transfer method is a simple and economical method of processing salvaged bituminous material through a conventional asphalt concrete production plant.

B. The recycled bituminous concrete pavement appears to be performing extremely well, based on the short term service life to date. Various sections have undergone one or two winter cycles with no adverse effects. There has been no discernable cracking in the 30 lane miles of outside shoulders.

C. This project achieved a $50,000 saving in money and a 34.85% saving in energy when compared with a conventional overlay improvement. While both savings are significant, the latter will become of more increasing importance as the cost of energy and asphalt cement continues to rise.

D. The salvaged bituminous feedstock when passed through a six inch grizzly (scalper) caused a loss of paddles in the pugmill and some tearing of the mat by cold oversized lumps. When the openings were halved, a nominal 2½ inches, both problems disappeared.

E. The milling machine cannot produce a minus one inch material when progressing at a forward speed of 45 to 90 feet per minute.

F. Milling of a surface course of a bituminous overlay will tend to produce slabby pieces at reflection cracks and along vertical curbs.

G. A 12-foot stockpile of milled material stored up to one year will develop an 8 to 10 inch "skull" which broke up very easily when picked up and dropped by a front-end loader.

H. In order to assure good quality control, ample cores should be taken prior to salvaging the bituminous material so that the material may be placed in select locations by penetration or gradation, if necessary. It was not necessary on this project due to the uniformity of gradation of the original mix.

I. The addition of a regular AC-20 asphalt cement can alter the physical properties of the salvaged asphalt such as decreasing the viscosity and increasing the ductility and penetration.

RECOMMENDATIONS

A. It is recommended that the recycling program be continued on maintenance and construction-rehabilitation projects for the conservation of energy and raw materials and for the establishment of the necessary criteria for the various processing methods and types of materials. The extended program should include the following elements of study:

1. A laboratory investigation to:

   (a) Determine the necessary tests and limits to measure the quality of the paving materials for recycling.

   (b) Determine the effects of various asphalt cements and modifiers.

   (c) Determine if the limits of recycled material should be the same or different from virgin materials.

2. Continuation of field studies including construction, observation and evaluation of test sections to:

   (a) Determine what equipment and requirements for each of the recycling processes.

   (b) Develop the specifications and procedures of construction for the various recycling processes.

B. It is recommended that projects calling for removal or milling of bituminous concrete be advertised permitting the contractor the alternative of recycling, or the placement of a conventional mix. This should result in lower bid prices.

C. It is recommended that in cases where the quantity of bituminous concrete to be removed is too small to justify recycling, or when the contractor elects to place new material that ownership of the salvageable material be retained and stored on State property.

D. It is recommended that if softening of a reclaimed asphalt cement is deemed necessary based on the core results, two other alternatives be considered before using a rejuvenator:

1) If a 50/50 mixture is to be used, specify an AC-20 with an 85-90 penetration value.
2) If the aforementioned did not bring the recovered asphalt to a reasonable penetration of 43-47, then change the mixture ratio from 50/50 to 40/60 or 35/65 (salvaged to new aggregate) using a regular asphalt cement.

The increased amount of new asphalt would have greater resolving power and the temperature of the new aggregate could be lowered and still effectively transfer the heat.

Although it may seem apropos to use an AC-10 asphalt cement, it is not recommended. This would necessitate the use of a second storage tank in order for the producer to have the flexibility to service commercial accounts. Furthermore, the specifications for viscosity graded asphalt cements are broad enough to permit an AC-10 to have a lower penetration than an AC-20.

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APPENDIX A

NEW JERSEY DEPARTMENT OF TRANSPORTATION

Form LB-251 A 2/77

PREPARE AND SUBMIT IN DUPLICATE.

PRODUCER'S ANALYSIS OF MATERIALS AND JOB MIX FORMULA

DATE 10/16/78

PRODUCER T.R.I. PLANT LOCATION Kingston

PROJECT Rt. U.S. 130 (1953) Sec. 16C, 15A, 18A, & 14D
Rt. U.S. 1 (1953) Sec. 2C, 3C, 4A, 5B, & 6J
Federal Project #RF-U-33(106), RRS-33(101), RRP-33(101), & RF-U-17(108)

CONTRACTOR Trap Rock Ind., Inc.

MIX NUMBER 4 COURSE Top (Shoulder) BATCH SIZE 6000

JOB MIX FORMULA				
	%	POUNDS	COMPONENTS – PRODUCER AND LOCATION	
BIN 5	These percentages are for the new aggregates and AC.			
BIN 4	This constitutes 50% of the batch weight.			
BIN 3	38.0	1140	Trap Rock, TRI @ Kingston, N.J.	
BIN 2	32.2	966	" "	
BIN 1	24.6	738	" "	
FILLER				
ASPHALT CEMENT	5.2	156	Chevron	AC-20

PI BIN 1	100.0	3000.	REQUIRED: NON-PLASTIC

MARSHALL	DESIGN	REQUIREMENTS	
		MINIMUM	MAXIMUM
STABILITY (lbs.)	1880		
FLOW (0.01 in.)	12		
AIR VOIDS (%)	4.1		

PREPARED BY N.J.D.O.T.	SUBMITTED BY: N.J.D.O.T.
SIGNATURE	SIGNATURE
TITLE Principal Engineer	TITLE Principal Engineer
REPRESENTING (COMPANY) N.J.D.O.T.	REPRESENTING (COMPANY) DATE OF INITIAL SUBMISSION FOR CALENDAR YEAR 19 78

CONTRACTOR CERTIFICATION:

This is to certify that I ______________, Representing ______________ have reviewed the entire Mix Design package consisting of Design forms LB-251 A, B, C, D, E, LB-242 and concur with them.

SIGNATURE ______________ DATE ______________

COMPLIES	DATE	SIGNATURE OF HIGHWAY ENGINEER	MATERIALS REGION NO. ______
DOES NOT COMPLY			Bureau of Inspection, Plant and Project

SEE REVERSE SIDE FOR DEPARTMENT OF TRANSPORTATION COMMENTS

BIN GRADATIONS

SIEVE SIZE	BIN NO. 5 50 %		BIN NO. 4 ___ %		BIN NO. 3 20 %		BIN NO. 2 17 %		BIN NO. 1 13 %		FILLER ___ %		THEOR COMB	SPEC	
	% Pass.	% Batch	% Pass.	% Batch	% Pass	% Batch	% Pass	% Batch	% Pass.	% Batch	% Pass	% Batch		Min.	Max.
2"															
1½"															
1"															
¾"	100	50			100	20	100	17	100	13			100		100
½"	97.5	48.8			100	20	100	17	100	13			98.8	90	100
3/8"															
# 4	65.0	32.5			2.4	.5	69.1	11.7	100	13			57.7	40	70
# 8	51.0	25.5			.8	.2	5.0	.8	96.3	12.5			39.0	25	55
# 16															
# 30															
# 50	25.0	12.5			.4	.1	1.3	.2	37.1	4.8			17.6	10	25
# 100															
# 200	6.8	3.4			.2	--	.6	.1	14.3	1.8			5.3	3	8

Milled

STOCKPILE GRADATIONS

SIEVE SIZE	SIZE NO. ___ 50 %		SIZE NO. ___ ___ %		SIZE NO. 8 37 %		SIZE NO. ___ ___ %		SIZE NO. 10 13 %		FILLER ___ %		THEOR. COMB.	SPEC.	
	% Pass.	% Batch	% Pass.	% Batch	% Pass	% Batch	% Pass	% Batch	% Pass	% Batch	% Pass	% Batch		Min.	Max.
2"															
1½"															
1"															
¾"	100	50			100	37			100	13			100		100
½"	97.5	48.8			100	37			100	13			98.8	90	100
3/8"															
# 4	65.0	32.5			23.6	8.7			100	13			54.2	40	70
# 8	51.0	25.5			4.2	1.6			95.2	12.4			39.5	25	55
# 16															
# 30															
# 50	25.0	12.5			1.9	.7			35.2	4.6			17.8	10	25
# 100															
# 200	6.8	3.4			.9	.3			14.9	1.9			5.6	3	8

APPENDIX A

Form AD-40 5/77

NEW JERSEY DEPARTMENT OF TRANSPORTATION

MEMORANDUM

TO Frank Palise
Project Engineer
Region 3-4

FROM John Archibald

SUBJECT Reclaimed Asphalt Concrete Route 1 DATE 10-13-78 TELEPHONE NO.

Below are listed results of milled material gradations given to me by phone by J. Kujalowicz on October 13, 1978. Samples taken; run on October 13, 1978.

Percent Passing

Sieve	#1	#2
3/4	100	100
1/2	97.5	96.2
4	65.4	69.9
8	51.2	52.9
50	23.0	24.6
200	6.7	7.4
AC	5.44	5.01

John Archibald

cc: File

APPENDIX B

A. ENERGY ANALYSIS FOR CONVENTIONAL NO. 4 MABC MIX

MATERIALS	BTU/TON
Mfg. asphalt cement	587,500
Haul 20 mi x 2 @ 5040 BTU/T-Mi.	201,600
	789,100
Crushed Stone @ 70,000 BTU/T	70,000
Haul 1 mi x 2 @ 4270 BTU/T-Mi, 1.025	8,754
(2.5% moisture 1.025)	78,754

MIX COMPOSITION	
Asphalt cement 5.6% @ 789,100 BTU/T	44,190
Aggregate 94.4% @ 78,754 BTU/T	74,344
Subtotal	118,534

PLANT OPERATIONS	
Heat and dry aggregate @ 1.67 gal*/T	232,130
Store asphalt cement	6,400
Cold feed	4,730
Dryer and exhaust	4,770
Mixing plant	3,920
Subtotal	251,950
TOTAL	370,484

370,484 BTU/T x 27,067.9 = 10.028×10^9 BTU

*139,000 BTU/Gal #2 F.O.

B. ENERGY ANALYSIS FOR RECYCLED MABC MIXTURE

MATERIALS	BTU/TON
Mfg. asphalt cement	587,500
Haul 20 mi x 2 @ 5040 BTU/T-Mi	201,600
	789,100
Crushed stone @ 70,000 BTU/T 50%	35,000
Recycled material @ 0 BTU/T	0
Haul crushed stone 1 mi x 2 @ 4270 BTU/T-Mi (.5125)	4,377
	39,377
MIX COMPOSITION	
Asphalt, 3% @ 789,100 BTU/T	23,673
Aggregate, 97% @ 39,377 BTU/T (50/50 mixture)	38,196
Subtotal	61,869
PLANT OPERATIONS	
Heat and dry aggregate @ 1.17 gal #2 F.O./T	162,630
Store asphalt cement .03/.056 = 0.54 (6400)	3,429
Cold feed	4,730
Dryer and exhaust	4,770
Mixing plant	3,920
Subtotal	179,479
TOTAL	241,348

ENERGY SAVINGS $241{,}348 \text{ BTU/T} \times 27067.9\text{T} = 6.533 \times 10^9 \text{BTU}$

$$\frac{10.028 \times 10^9 - 6.533 \times 10^9}{10.028 \times 10^9} \times 100 = 34.85\%$$

$$\frac{3.495 \times 10^9 \text{BTU}}{125{,}000 \text{ BTU/gal. gas}} = 27{,}964 \text{ gals.}$$

C. ENERGY ANALYSIS FOR LEVELING COURSE

$$25.1 \text{ mi} \times 5280 \text{ ft/mi} \times 30' \times \frac{\text{yd}^2}{9 \text{ ft}^2} \times \frac{120\#}{\text{yd}^2/\text{in}} \times 1\tfrac{1}{2} \text{ in} \times \frac{1 \text{ ton}}{2000\#} = 39{,}758.4 \text{ ton}$$

$$2.8 \text{ mi} \times 5280 \text{ ft/mi} \times 39' \times \frac{\text{yd}^2}{9 \text{ ft}^2} \times \frac{120\#}{\text{yd}^2/\text{in}} \times 1\tfrac{1}{2} \text{ in} \times \frac{1 \text{ ton}}{2000\#} = 5{,}765.8$$

45,524.2 ton

To Mfg. conventional mix	370,484 BTU/ton hot mix*
Haul 8 mi x 2 @ 4270 BTU/ton mile	68,320 "
Spread and Compact	16,700 "
	455,504 BTU/ton hot mix

Calculated Total Energy Needed: 455,504 (45,524.2) = 20,740,000,000 BTU

*See calculations on conventional method.

D. ENERGY CONSUMED IN MILLING

Equipment	Fuel in Gals.	BTU/gal	BTU Consumed
Milling machine	3326.2	139,000	462,397,400
Trucks for hauling	1997.3	139,000	277,624,700
Sweeper	601.0	125,000	75,125,000
Water Wagon I	166.8	139,000	23,185,200
Water Wagon II	77.8	125,000	9,725,000
Front End Loader	31.0	139,000	4,309,000
		Subtotal	852,366,300

$$\frac{852{,}366{,}300 \text{ BTU}}{222{,}045 \text{ yds}^2} = 3839 \text{ BTU/yd}^2$$

Energy consumed in paving 1½ inch milled areas.		BTU Consumed
To mfg. conventional mix		370,484 BTU/T
Haul 8 mi x 2 @ 4270 BTU/T-Mi		68,320 BTU/T
Spread and compact		16,700 BTU/T
	Subtotal	455,504 BTU/T
455,504 BTU/T x 5979 Tons (1½ milled area)	Subtotal	2,723,458,416 BTU
	TOTAL	3,575,824,716 BTU

ENERGY SAVINGS

20,740,000,000 BTU for leveling course
- 3,575,824,716 BTU for milling

17,164,175,284 BTU

$$\frac{17{,}164{,}175{,}284 \text{ BTU}}{125{,}000 \text{ BTU/gal. gasoline}} = 137{,}314 \text{ gals.}$$

$$\frac{20.740 \times 10^9 - 3.576 \times 10^9}{20.740 \times 10^9} = 82.8\%$$

E. NATURAL RESOURCES

Asphalt Cement

Shoulders	27,067.9 Tons BC x 2.6% A.C. =	703.8 Tons
Leveling Course	45,524.2 Tons BC x 5.6% A.C. =	2,549.4
		3,253.2 Tons A.C.

Stone Aggregate

Shoulders	27,067.9 tons x 47.28% stone	12,798.8
Leveling Course	45,524.2 tons x 94.4% stone	42,974.8
		55,772.6 Tons Stone

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