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RECYCLING ASPHALT PAVEMENTS

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NOTICE

RECYCLING OF BITUMINOUS SHOULDERS

Interim Report

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By

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In Cooperation With The

Federal Highway Administration

SUMMARY

OBJECTIVE

The primary objective of this project was to demonstrate the feasibility of constructing a bituminous pavement by the hot recycling process. Secondary to that was the evaluation of the construction procedure and the finished pavement.

PROJECT DESCRIPTION

The project site is on Interstate 94, which is the arterial route through Minnesota, from the West at Fargo, North Dakota to Minnesota's easterly border near the Twin Cities Metropolitan Area. The specific job location is from the north junction of Trunk Highway 59 to the south Otter Tail County line and covers 20 mi. (32 Km) of roadway and, being a divided highway, 40 mi. (64 Km) of outside shoulders were reconstructed. Average daily traffic based on recent counts is 6,300 vehicles with 20 percent heavy commercial.

The project is within the confines of Mn/DOT District Four, which is directly responsible for the design, construction, and administration of the project.

SCOPE

The purpose of this improvement was to restore the outside bituminous surfaced shoulders to a like-new condition.

This project is sponsored by the Federal Highway Administration, Demonstration Projects Division. All aspects of the project have been coordinated with Region 15 and the FHWA Operations Office.

SUMMARY OF FINDINGS AND CONCLUSIONS:

Listed below are the important findings and conclusions of this study:

1. Hot mix recycling, as described in this report, is a viable construction alternative.

2. Recycling through a modified "Drum Mixer" is an acceptable and efficient means of utilizing reclaimed bituminous, and can meet air pollution requirements.

3. An acceptable recycled mixture can be produced at a savings in cost, energy, and materials. It is estimated that 29,413 tons (26,683 metric tons) of virgin aggregate and 1,357 tons (1,231 metric tons) of asphalt were saved on this project. In terms of dollars and energy, the savings were $147,432.00 and 4,630,800,707 BTU's (4,885,754 10^6 J). An energy equivalent of 37,046 gallons (140 m^3) of gasoline.

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INTRODUCTION

Bituminous surface and base materials have generally been disposed of when reconstruction takes place. The bituminous surface that had been constructed contains valuable aggregate that could be salvaged; also a portion of the asphaltic cement may be salvageable. If this material were recycled, the natural supply of these materials could be conserved and haul distance for both the new aggregate and the disposal of the demolition could be reduced. Reduction of haul distances will naturally reduce fuel consumption, and this could prove very beneficial because of the energy crisis. Another item of concern is the disposal of demolition, which often is difficult and expenseive because of environmental restrictions. Considering these factors, both economic and ecological benefits could be derived from recycling.

Recycling would also have advantages on projects where bituminous overlays are proposed. Existing materials could be removed and replaced and established grade lines could be retained. This would be advantageous on projects where bituminous shoulders adjacent to p.c. concrete surfaces have deteriorated and require replacement.

This is an interim report on the Minnesota Department of Transportation's first plant-mix bituminous recycling project. The project involves the restoration of the outside bituminous shoulders along 20 mi. (32 Km) of interstate 94 in rural northwestern Minnesota. The bituminous had developed extensive thermal cracking, it also had separated and dropped away from the p.c. concrete driving lane.

PRELIMINARY INVESTIGATION

Initial Design Characteristics

The old bituminous shoulders were constructed during the period 1962 through 1964. The structure consisted of 7 inches (18 cm.) of gravel base and 2 inches (5 cm.) of plant mix bituminous. The composition of the plant mix bituminous consisted of gravel with 3.5% added mineral filler and 5.3% asphalt penetration grade 120/150. Technical data are listed in the following table:

Table A. Properties of Original Pavement

Bituminous Mix		mm	U.S.	Gradation (% Passing) Gravel	Filler	Composite
		19	3/4	100		100
Asphalt	5.3%	16	5/8	99		99
Mineral Filler	3.5%	9.5	3/8	82		83
M. Stability	1400 lbs.	4.75	#4	62		63
M. Density	143 lbs./cu.ft.	2.00	#10	43		45
Voids in Mix	2.0%	0.425	#40	14	100	17
C.W. Abrasion Loss	12.9%	0.180	#80	6	99	9
		0.075	#200	4.9	82	7.6

1 lb. = .4536 Kg
1 lb./Cu.ft. = 1.602 Kg/m^3

Existing Characteristics of Inplace Bituminous

The old bituminous mat had deteriorated due to thermal cracking and traffic, also along much of the project length there was a 3/4 to 1 in. (19 to 25 mm) drop from the p.c. concrete traffic lane to the bituminous shoulder.

Analysis of Pavement Cores

Cores were taken on the inplace old bituminous. The asphalt was extracted from some of them and tests were run on the constituents. The results of all this testing are tabulated below:

Table B. Properties of Cores of Old Inplace Bituminous

AVERAGE GRADATION

mm	19	16	9.5	4.75	2.00	0.425	0.180	0.075
U.S.	3/4	5/8	3/8	#4	#10	#40	#80	#200
%Passing	100	99	85	62	43	19	11	8.7

Average Results of Recovered Asphalt	
% Asphalt	5.1
Pen at 77 degrees fahren.	21
Ductility, cm at 77 degrees fahrenheit	24
Softening Point °F	146

$$(t°F-32) \div 1.8 = t°c$$

Structural Condition

Structural qualities were also evaluated. The structural ratings (SR)[1] determined for the shoulder pavements were 3.1 for the eastbound and 3.3 for the westbound which fall in the "Good" range.

Frictional Resistance

Friction tests were run according to the ASTM method E274-70 utilizing a towed full scale test wheel trailer. The average friction numbers were 56 for the eastbound and 55 for the westbound shoulder pavement. These values are more than adequate although the variation among individual tests is quite large, as indicated by the standard deviation(s).

Table C. Frictional Resistance of Old Inplace Pavement

July 11, 1977

	EASTBOUND			WESTBOUND		
Test Section	51	58	65	64	59	53
Mile	51to54	54to61	62to70	70to62	61to55	54to51
FN_{40} $\bar{X}$	56.0	56.3	55.3	52.1	59.6	54.6
FN_{40} S	9.31	8.57	7.04	9.23	6.87	7.92

1.Procedure on file in Mn/DOT Materials Office

Deflection Tests

Benkelman Beam deflection tests were run at three locations on the eastbound shoulder and three on the westbound shoulder. Tests were run at 11 points on 50 ft. (15.2 m) intervals covering a 500 ft. (152.4 m) section for each of the six test sites. The avg. results, corrected for 80F (26.7°C) temperature and Spring values are tabulated below:

Table D. Deflection Tests of Old Inplace Pavement

	Eastbound			Westbound	
Mile	Defl.	S	Mile	Defl.	S
51	119	21	53	83	9
58	129	16	59	129	10
65	100	8.7	64	82	9.2

Deflections measured in 1/1000 in. 1 in. = 25.4 mm

DESIGN CRITERIA/PROCEDURE

Ample quantities of inplace bituminous and gravel were forwarded to the Mn/DOT Bituminous Trial Mix Laboratory for mix design. The Marshall Method of mix design ASTM D1559-75 modified was used. The target values or guidelines for the design procedure were those of the Mn/DOT conventional 2331 plant mix bituminous e.g. a minimum stability of 500 lbs. (226.8 Kg), voids in mix of four to six percent, and cold water abrasion (C.W.A.)[1] loss of less than 12 percent. The results of several mixing trials are tabulated below:

Table E. Trial Mix Data

60% Salvage Bituminous — 40% Salvage Gravel
200/300 Penetration Grade Asphalt

%Asphalt added	2.2	2.2	2.5	2.7	3.0
Marshall Density (lbs/cu.ft.)	144.0	144.2	145.6	147.5	145.8
Marshall Stability lbs.	2198	2359	2588	2781	2572
%Voids in Mix	8.9	6.3	5.0	3.4	3.9
C.W.A. % Loss			9.3	6.5	3.9

1. Procedure on file in Mn/DOT Materials Office.

Table E Cont. Trial Mix Data

	50% Salvage Bituminous	50% Salvage Gravel 200/300 Pen Asphalt			120/150 Pen
%Asphalt added	2.8	3.2	3.2	3.5	2.8
Marshall Density (lbs./cu.ft.)	141.9	142.8	143.8	145.3	141.6
Marshall Stability lbs.	2755	2145	2273	2402	2797
%Voids in Mix	7.1	6.9	6.0	3.7	7.1
C.W.A. % Loss	-	9.0	9.3	7.0	-

1 lb/cu.ft. = 1.602 Kg/m^3 1 lb = .4536 Kg.

The recommendations on mix proportions from the trial mix work are listed below, all mixes use 200/300 penetration grade asphalt.

Table F. Bituminous Mixture Recommendations

%Salvage Bituminous	60	60	55	50	
%Salvage Aggregate	40		45	50	
%Virgin BA-2 Agg.		40			100
%Asphalt added to:					
Wear Course	3.0	2.2	3.3	3.5	5.7
Base Course	2.0	1.8	2.2	2.5	4.5

CONSTRUCTION CRITERIA/PROCEDURES

Due to the extensive cracking of the shoulder pavement requiring continual attention, the maintenance force was programming more and more time and money to this section of highway. Also, the separation at the longitudinal joint, between the shoulder and the driving lane, with the resulting drop of 3/4 to 1 inch (19 to 25 mm) appeared to require an extraordinary maintenance operation called "wedge paving". That is, placing a bituminous wedge about 18 inches (46 cm) wide next to the p.c. concrete slab to match the elevation of the driving lane. The wedge tapers away from the slab and the remainder of the shoulder width is covered with a sand seal coat.

At the time that this evaluation was being made the Research Office was looking for a rural project to demonstrate bituminous hot recycling. A proposal was made by the Research Office that complete pavement restoration could be accomplished by the "Minnesota Heat-Transfer Method for Recycling Bituminous Pavement". Because of the success of the Maplewood recycling project in 1976 and the experience that wedge paving was only a temporary solution, the recycling proposal was accepted by the district staff. Specifically, the upper four in. (10 cm) of pavement structure would be recycled. The inplace two in. (5 cm) bituminous mat would be removed and crushed. Two in. (5 cm) of the inplace gravel base would be salvaged and used as the heat-transfer medium.

The estimate of major quantities in this project were as follows:

Salvage bituminous mix	28,000 tons
Salvage aggregate	22,000 tons
Recycled bit. base course	25,000 tons
Recycled bit. wear course	25,000 tons

Also, 500 tons of regular (conventional) bituminous mix was to be produced and placed to aid in the future evaluation of the recycled material.

Prior to the letting, the Federal Highway Administration expressed an interest and through correspondence with FHWA Region 15, it was decided that this project would be a FHWA Demonstration Project.

Because of the relative newness of this type of bituminous production the district arranged for a pre-letting conference in mid-June, this provided an opportunity for interested contractors to familiarize themselves with the heat-transfer method of bituminous production.

The project was let on June 24 and later awarded to the low bidder, Duininck Bros. and Gilchrist of Prinsburg, Minnesota. The pre-construction conference was held in the later part of July. It was learned at this conference that the contractor would be using a Barber-Greene drum-mixing plant, whereas a batch plant had been used on the Maplewood project.

Plant revisions and energy consumption requirement records (See S-2 of appendix A) were discussed at the pre-construction conference. The contractor felt that the mix could be produced without excessive pollution using the heat transfer method and the plant revisions they were planning.

Figure 1 shows the diagram of the plant after revisions. Mix production began the later part of September. Figure 2 shows the typical sections of the old and new shoulder design.

The following is a general description of the construction operations:

a. The old shoulders were scarified using a ripping tooth behind a motor grader, see Figure 3. The most efficient method used was to make two passes, one along the concrete slab and the other down the middle of the shoulder.

b. The broken bituminous mat was then loaded using a front-end bucket loader 10 ft. (3.05 m) wide, same width as the shoulders, and hauled to the plant site.

c. The material was then crushed to the specified gradation, 100 percent passing the 1 in. (2.54 cm) sieve.

d. The existing aggregate shoulder base was then removed to a depth of approximately 2 in. (5 cm) and stockpiled separately at the plant. This removal was done with a CMI finegrader, see Figure 4, and the grade was controlled using the concrete slab. The subgrade was then rolled with two passes of a vibratory roller.

e. The new mix was produced in accordance with Mn/DOT specification 2331 modified, using 50 or 60 percent old crushed bituminous material and 50 or 40 percent aggregate base. The old bituminous material entered the drum-mixer through the outlet end of the drum using a slat conveyor which carried this material about 14 ft. (4.3 m) into the drum.

   The salvaged aggregate base entered the drum at the conventional or burner end. There it was super-heated to act as the heat-transfer agent. Estimated temperature of the aggregate when it reached the old bituminous material, where the mixing began, was 450°F (232°C). Between 3 and 4 percent of new asphalt cement was added. This amount was determined by which bituminous course, base or wearing was being mixed, and also the proportions of old bituminous material and aggregate (see S-16 and s-16.6 of appendix A). The production rate averaged 300 tons (272 metric tons) per hour and no excessive stack emissions were visible, see Figure 5.

f. This mix was placed back onto the roadway in two 2 in. (5 cm) lifts, and again the concrete slab was used for grade control, (see S-16.1, appendix A for compaction requirements). Figure 6 shows the paving operation, which was the same as when a regular mix is being placed.

COST COMPARISON

This project was initially selected for recycling to demonstrate the feasibility of utilizing the inplace material to construct an acceptable bituminous structure of recycled material. Recycling can also be shown to be ecologically and economically beneficial. The following cost estimate compares the cost of recycling to conventional construction. This estimate consists of comparing construction of identical designs, but substituting virgin bituminous material for the recycled bituminous and disposing of the salvaged bituminous and aggregate shoulder base materials. The project basically consists of removing the 2 inch (5 cm) bituminous surface and 2 in. (5 cm) of the aggregate shoulder base of the outside 10 ft. (3.05 m) shoulder and replacing it with a 4 in. (10 cm.) recycled bituminous shoulder consisting of a blend of the salvaged materials.

This cost comparison is based on using the actual pay items, bid prices and final quantities of this project, comparing the actual recycling project to the hypothetical project using a virgin bituminous mixture and disposing of the salvaged bituminous and aggregate base. The items "Remove and Dispose of Inplace Bituminous" and "Remove and Dispose of Inplace Shoulder Aggregate" are added to accommodate the conventional alternate and are estimated at the same respective unit prices as was bid for salvage bituminous and aggregate (in stockpile) for the recycling alternate.

ENERGY CONSUMPTION

Many facets of paving with recycled mix remain the same as paving with conventional mix. The contractor has stated that the laydown procedures and equipment used have not varied significantly from their normal operation and are considered to be the same. Plant operations involving mixing and electrical power generation for conveyors, pumps, etc., was reported by the contractor as 56,670 BTU/ton (65,907 J/Kg) of mix and should be the same for both types of mix. The greatest differences in energy consumption for the two procedures are: the amount of fuel used by the burner for drying and heating; and the fuel used to haul the additional apshalt cement from the refinery; fuel used for aggregate production versus bituminous salvage processing; and fuel used for heated asphalt storage.

Only a small amount of conventional mix was produced (approx. 2,700 tons, 2,449 metric tons) for this job. Therefore, it has been difficult to isolate exact figures for evaluation.

TABLE G. COST COMPARISON

Recycled Versus Conventional Bituminous Mixture

Item	Unit	Unit Price	As-Built Recycled Quantity	As-Built Recycled Amount	Conventional Quantity	Conventional Amount
Mobilization	Lump Sum	$70,450	1	$ 70,450	1	$ 70,450
Field Laboratory	Each	1,000	1	1,000	1	1,000
Remove & Dispose of In-place Bit.	Ton	1.95	-----	-----	32,889	64,134
Salv. Bit. Mixture (Stockpile)	Ton	1.95	32,889	64,134	-----	-----
Remove & Dispose of In-place Shoulder Aggregate	Ton	1.65	-----	-----	12,835	21,178
Salv. Agg. (In Stockpile)	Ton	1.65	12,835	21,178	-----	-----
Shoulder Preparation	Road Sta.	10.00	2,044	20,440	2,044	20,440
Common Laborers	Hr.	10.00	871	8,710	290	2,900
Bit. Material for Mixture	Ton	75.00	1,368	102,600	2,725	204,375
Recycled Bituminous Base	Ton	5.20	26,837	139,552	-----	-----
Conventional Bituminous Base	Ton	6.50	658	4,277	26,202	170,313
Recycled Bit. Shoulder Wear	Ton	5.20	22,864	118,893	-----	-----
Conv. Bit. Shoulder Wear	Ton	6.50	2,044	13,286	26,202	170,313
Bituminous Material for Tack	Gal.	0.20	5,431	1,086	5,431	1,086
Stockpile Agg. for Bit. Mix	Ton	1.77	7,430	13,151	-----	-----
Traffic Control	Lump Sum	20,000	1	20,000	1	20,000
TOTALS				$598,757		$746,189

Cost Difference: $147,432

Percent Savings: 20 percent.

ton x .9072 = metric ton

gal x .37854 10^{-2} = m^3

Rd. Sta. x 30.48 = m

Burner fuel used for the 52,403 tons (47,539 metric tons) of mix on this job amounted to 101,729 gallons, (385 m^3) of #3 fuel oil. It averaged 1.94 gal/ton (.0081 m^3/metric ton) equal to 277,420 BTU/ton (322,640 J/Kg) of mix. These figures have been broken down to approximately 49,701 tons (45,088 metric tons) of recycled mix and 2,702 tons (2,451 metric tons) of conventional mix. From the contractor's daily figures it has been computed that an average of 1.92 gal/ton (.0080 m^3/metric ton) was used for recycled mix at 274,560 BTU/ton (319,313 J/Kg). The conventional mix computed at 2.33 gal/ton (.0097 m^3/metric ton) and 333,190 BTUs per ton (387,500 J/Kg) of mix.

For this job the asphalt transport truck had a one way haul distance of about 220 miles (354 Km). Used for the purpose of analysis was a diesel powered 5 axle truck requiring 1,960 BTU/tm (ton-mile) (1,416 J/Kg/Km) round trip. This job as-built used 1,368 tons (1,241 metric tons) of asphalt cement, paving with only a conventional mix would use 2,725 tons (2,472 metric tons) of asphalt cement. The difference would be 1,357 tons (1,231 metric tons) at 1,960 BTU/tm (1,416 J/Kg/Km).

The amount of #1 fuel oil used to maintain heated asphalt cement at the plant site was 4,008 gal. (15.2 m^3) for 1,368 tons (1,241 metric tons) of asphalt cement. That is 2.93 gal. of fuel oil per ton of asphalt cement (.01223 m^3 per metric ton) the equivalent of 395,550 BTU's per ton of asphalt cement (460,025 J/Kg). Paving with a conventional mix would require 2,725 tons (2,472 metric tons) of asphalt cement. The difference would be 1,357 tons (1,231 metric tons) of asphalt cement. However, a straight line relationship of fuel oil needed to maintain any given amount of hot asphalt cement may not apply here. It can be argued that the energy used for asphalt cement storage is not entirely related to quantity stored but also length of time stored. It can be assumed that the time of storage would be the same, as the two processes are that similar. Since asphalt delivery is geared to use and all asphalt is hot when delivered, any projection of energy needed would be an estimate. An arbitrary figure of 1/3 more energy was assessed, as needed to maintain the additional heated asphalt.

For the preparation of the salvaged bituminous and for the BA-2 aggregate production 43,021 tons (39,028 metric tons) of material were processed through the crushing and screening operation, of that total 2,702 tons (2,451 metric tons) were used on a concurrent maintenance project. The crushing and screening required 6,772 gal. (25.6 m^3) of diesel fuel (#2) and 170 gal. (.64 m^3) of gasoline for an average of 22,380 BTU/ton (26,028 J/Kg). It has been assumed that the wasting of the old bituminous mat had the same energy requirement as that of the salvage operation because the pickup operation was as simple and efficient as could be expected. Also the haul distance was the same because a disposal site was found adjacent to the plant where the surplus salvaged material was wasted. Therefore the difference between the recycling process and a conventional process would be the difference in the amount of material run through the crushing and screening operation. The conventional process would use the 52,403 tons (47,539 metric tons) of mix minus the 2,725 tons (2,472 metric tons) of asphalt cement or 49,678 tons (45,067 metric tons) of aggregate. The difference for this project would be 49,678 tons (45,067 metric tons) of aggregate needed for conventional mix minus 40,319 tons (36,577 metric tons) of salvage mat and aggregate actually used. That amounts to 9,359 tons (8,490 metric tons) at 22,380 BTU's/ton (26,028 J/Kg).

TABLE H. ENERGY SUMMARY

	Recycled	Conventional	Difference
Burner Fuel	274,560	333,190	58,630
Asphalt Transport	22,513	44,846	22,333
Salv. Mat & Agg. Prod.	17,219	21,216	3,997
Asphalt Storage	10,325	13,734	3,409
Plant Operations	56,670	56,670	
TOTALS:	381,287	469,656	88,369

The savings amounts to 88,369 BTUs/ton of mix produced. With a total of 52,403 tons of mix required for the job, 4,630,800,707 BTUs are saved. This energy savings is equivalent to 37,046 gallons of gasoline.

NOTE: Quantities were converted to BTUs with conversions established by the Asphalt Institute Publication MISC-75-3.

Metric conversions according to ASTM E380

Ton = 0.9,072 metric ton
BTU = 1055 joule (J)
gal. = 0.003785 m^3

ENVIRONMENTAL CONSIDERATIONS

A big concern associated with recycling salvaged bituminous products is air pollution. This job was let with the stipulation that "plant emissions, if any, should be similar to the production of a conventional mix". Many photos taken during production verify that this was accomplished. On several occasions trained personnel from the Minnesota Pollution Control Agency had the opportunity to observe the plant emissions. The consensus after these observations was that the opacity of the emissions was consistently less than 15%. On two separate occasions, observations in response to inquiries noted 10% opacity. The standard for compliance is "opacity of less than 20%".

CONSERVATION OF NATURAL RESOURCES

As has been stated, one object of recycling is to conserve natural, finite, resources. The two greatest savings were in the amounts of asphalt cement and virgin aggregate used. The savings of 1,357 tons (1,231 metric tons) of asphalt cement has been documented. The quantity of virgin aggregate saved was a minimum of 29,413 tons (26,683 metric tons)to a maximum of 42,248 tons (38,327 metric tons). The maximum number assumes that all aggregate removed from the base was wasted. The approach taken here is that the contractor had recognized the potential of the 12,835 tons (11,644 metric tons) of gravel contained in the "supplemental pit" of the shoulder base. This material being Class 5 base has a gradation similar to that of aggregate for bituminous mix. Therefore this aggregate could have been hauled off the road and blended in at the crusher-screening operation. The 49,678 tons (45,067 metric tons) of bituminous aggregate needed would then be decreased by that 12,835 tons (11,644 metric tons) with a resultant demand of 29, 413 (26,683 metric tons) of virgin aggregate.

PERFORMANCE AND EVALUATION

Mix Properties.

The hot mix bituminous was sampled at the rate of one sample per 750 tons (680 metric tons) of mix produced. These samples were tested to determine mix characteristics. After extraction the recovered asphalt cement was tested and aggregate gradations were run. The findings are tabulated below:

TABLE I. PROPERTIES OF HOT MIX SAMPLES

	RECYCLED		CONVENTIONAL			
	AC 200/300		AC 200/300		AC 120/150	
Course	Base	Wear	Base	Wear	Base	Wear
Stability lbs.	2560*	2762		452		1343
Density lbs/cu.ft.	146.0	148.5	140.2	141.0	140.6	144.0
% Voids	5.3	2.5	8.1	5.8	8.0	4.8
		Recovered Asphalt				
Course	Base	Wear	Base	Wear	Base	Wear
% AC	4.4	5.3	5.0	6.2	5.1	5.8
Penetration	42	52	150	127	105	88
Ductility cm	120+	120+	120+	120+	150+	120+
Softening Point °F	135	130	114	116	118	121

*One random stability test with Avg. Density, less than Avg. Pen. & Voids
This sample contained more than Avg. % Asphalt.

1 lb = 0.4536 Kg; 1 lb/cu.ft. = 1.602 Kg/m^3; (t°F-32) ÷ 1.8 = t°C

Properties of Extracted Asphalt

When the test results are compared, the penetration, ductility, and softening point of the asphalt in the new recycled mix are better than those of the asphalt in the aged original pavement.

TABLE J. SIEVE ANALYSIS

BASE

Sieve size		60/40 Recyled Mix With Salvage Aggregate		60/40 Recyled Mix With Virgin BA-2 Agg.		Conventional Mix With 100% BA-2 Agg.
mm	U.S.	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$
25	1"	100	-	100	-	100
19	3/4"	100	0.4	100	0.3	100
16	5/8"	97	1.9	98	1.1	99
9.5	3/8"	87	2.6	87	2.5	89
4.75	#4	71	3.5	72	4.3	76
2.00	#10	54	3.5	54	4.5	59
0.425	#40	22	1.9	19	1.3	13
0.075	#200	7.8	0.9	7.2	0.8	4.5

WEAR

Sieve size		60/40 Recycled Mix With Salvage Aggregate		60/40 Recycled Mix With Virgin BA-2 Agg.		Conventional Mix With 100% BA-2 Agg.
mm	U.S.	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$
25	1"	100	-	100	-	100
19	3/4"	100	0.4	100	0.5	100
16	5/8"	96	1.7	98	1.7	99
9.5	3/8"	85	4.5	85	5.1	91
4.75	#4	69	5.9	70	6.2	78
2.00	#10	52	5.5	53	5.9	61
0.425	#40	22	2.1	19	2.2	14
0.075	#200	7.7	0.9	7.2	0.7	4.9

Frictional Resistance

As the following tabulation shows, the frictional resistance of the recycled surface is better than the original surface. The variance is much less, as indicated by the standard deviation(s). Also indicated by the tabulation is that two years after the recycling construction the friction numbers have not changed.

TABLE K. FRICTIONAL RESISTANCE OF RECYCLED PAVEMENT

August 8, 1978

	Eastbound			Westbound		
Test Section	51	58	65	64	59	53
Mile	51to54	54to61	62to70	70to62	61to55	54to51
FN40 $\overline{X}$	59.5	60.1	57.3	59.7	59.7	59.3
FN40 S	1.73	4.34	5.04	3.20	3.72	2.44

TABLE K. CONT. FRICTIONAL RESISTANCE OF RECYCLED PAVEMENT

August 23, 1979

	Eastbound			Westbound		
Test Section	51	58	65	64	59	53
Mile	51to54	54to61	62to70	70to62	61to55	54to51
FN_{40} $\bar{X}$	59.4	58.7	57.8	61.8	60.2	60.6
FN_{40} S	2.59	1.68	2.98	2.63	3.09	1.87

Deflection Tests

Benkelman Beam Deflection Tests were run, initially on the original shoulder pavement, and the Spring following construction on the new recycled shoulder pavement. These tests were run at the same locations each time. The tabulation below lists the average B.B. deflections, corrected for 80°F (26.7°C) and for the Spring equivalent. Also, listed is the co-efficient of variation (V) for the deflections of each test section.

TABLE L. DEFLECTION TESTS COMPARISON

		July 1977 Before		May 1978 After	
Test	Site	Spr. $\overline{BB}_{80}$	V	Spr. $\overline{BB}_{80}$	V
51	EB	119	30%	138	19%
58	EB	129	21%	144	19%
65	EB	100	16%	99	14%
64	WB	82	20%	93	21%
59	WB	129	13%	129	10%
53	WB	83	18%	89	10%

It can be seen that the corrected deflections of the old and the new shoulder pavements are quite similar. However the co-efficient of variation for the new mat is more consistent and generally lower than that for the old mat. In June of 1978, B.B. deflection tests were run on a 1800 ft. (549 m) control section of conventional shoulder pavement constructed at the same time. The average deflection there, corrected for 80°F (26.7°C) and for the Spring equivalent, was 114 with a 20% co-efficient of variation.

In conjunction with the 1978 "Benkelman Beam" testing, strength and deflection testing was also performed with the "Road Rater". The "Road Rater" consists of a trailer mounted ram capable of placing variable loads on the pavement and vibrating the chosen load (force) at a set frequency. Four sensors are mounted on the test equipment to give a read-out of the deflection values from #1 at the center of the force to #4 at 3 ft. (0.9 m) from the center. The four sensors are at one ft. (0.3 m) intervals in a straight line parallel to the direction of travel. Subsequent to 1978 the strength and deflection testing was performed with the "Road Rater" only. A summary of the 1978 and 1979 "Road Rater" test results is tabulated below reporting the average deflection values and their standard deviations. The tests were run at 3 Kips Force and a Frequency of 15 Hz.

TABLE M. ROAD RATER SUMMARY
RECYCLED SECTIONS

	1978 3 Kips Force 15 Hz				1979 3 Kips Force 15 Hz			
SENSOR	1	2	3	4	1	2	3	4
				M.P. 51 E.B.				
DEFL.	20.19	14.90	6.23	3.09	12.22	9.22	5.48	3.09
S	4.14	3.46	1.23	0.40	1.85	1.95	0.90	0.49
				M.P. 58 E.B.				
DEFL.	19.67	14.61	6.02	2.89	12.77	8.11	5.10	2.84
S	3.30	2.97	1.18	0.38	1.33	1.09	1.26	0.55
				M. P. 65 E.B.				
DEFL.	13.13	8.32	3.19	1.52	9.23	7.68	3.29	1.70
S	1.37	0.81	0.31	0.23	0.95	0.82	0.63	0.38
				M.P. 64 W.B.				
DEFL.	14.32	9.66	4.70	2.90	10.16	8.38	5.20	2.92
S	3.38	2.21	0.94	0.68	1.31	0.76	0.55	0.50
				M.P. 59 W.B.				
DEFL.	23.99	17.64	8.73	5.31	14.00	9.96	6.71	4.57
S	3.32	2.72	1.46	0.85	2.17	1.54	0.98	0.82
				M.P. 53 W.B.				
DEFL.	12.53	8.56	3.80	2.07	8.92	7.22	3.85	2.20
S	1.02	0.82	0.42	0.29	0.78	0.81	0.49	0.30

TABLE M. CONT. ROAD RATER SUMMARY
CONTROL SECTION
Sta. 1186-1168+50 WB

	1978	2 Kips Force 15 Hz			1979	3 Kips Force 15 Hz		
SENSOR	1	2	3	4	1	2	3	4
DEFL.	12.52	7.90	3.26	2.08	11.10	7.88	3.81	2.45
S	2.12	2.12	0.55	0.20	1.83	1.09	0.82	0.43

Kip = 4,448.222 N

When the average "Road Rater" test results, for 1978, of the recycled sections are compared against the control section the deflections are greater in the experimental recycled sections. However, the 1978 control section was tested at only 2 Kips. Also, when the characteristics of the deflection basin are studied, the recycled mat seems to spread out the load more evenly.

The average "Road Rater" test results of 1978, when compared to 1979 avg. test results, indicate an evident gain in strength of the new bituminous pavement over the year. The conventional mix section had a slight increase in strength whereas the recycled mix sections had a marked increase. The most dramatic change was at the #1 and #2 sensors which essentially indicate the condition of the mat itself. The change at the #3 and #4 sensors showed slight if any improvements. These sensors indicate the condition of the base and subgrade based on the slope of the deflection basin. The result of the greater improvement in the recycled mat was that after one year the recycled experimental sections show a greater resistance to deflection than the conventional control section. The deflection basin characteristics also indicated an increase in the ability to spread out the load. Here, again, the experimental recycled sections showed up as functioning better than the section of conventional shoulder pavement.

CONCLUSIONS AND RECOMMENDATIONS

The process of hot mix recycling as described in this report was shown to be a viable construction alternative. The process used on this project had some shortcomings but the overall result was quite efficient. The evolution that comes with experience should make the recycling process even more efficient and more predictable.

The typical "Drum-Mixer" can be economically modified to provide an efficient means of utilizing re-claimed bituminous and can meet air pollution requirements.

The testing that has been conducted does indicate that an acceptable mixture equivalent to a conventional mixture, can be produced using recycled material.

The estimated savings realized on this project because of recycling the salvaged materials include the following:

29,413 tons (26,683 metric tons) of virgin aggregate
1,357 tons (1,231 metric tons) of asphalt cement
147,432.00 dollars
4,630,800,707 BTU's (4,885,754$10^6$ J)

The energy savings was equivalent to 37,046 gallons (140 m^3) of gasoline.

The mix proportions of 60% salvage bituminous to 40% aggregate (salvage or virgin) were used almost exclusively in order to utilize all of the salvage material. Because of this, minimal experimenting was done at other proportions. The process was workable at the 60/40 proportions. However, in the future some other combination may be more suitable for a given project because of economics or pollution requirements.

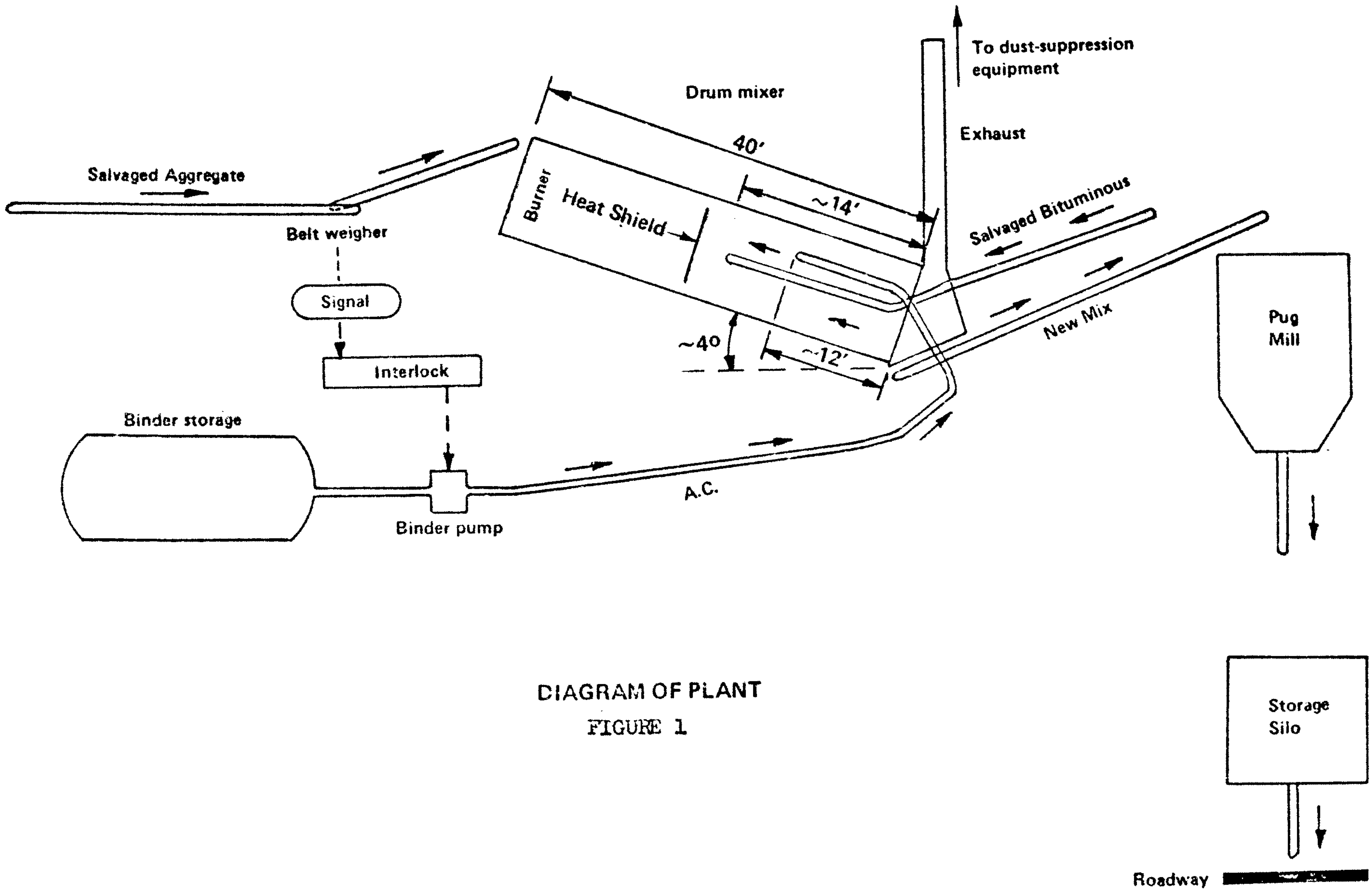
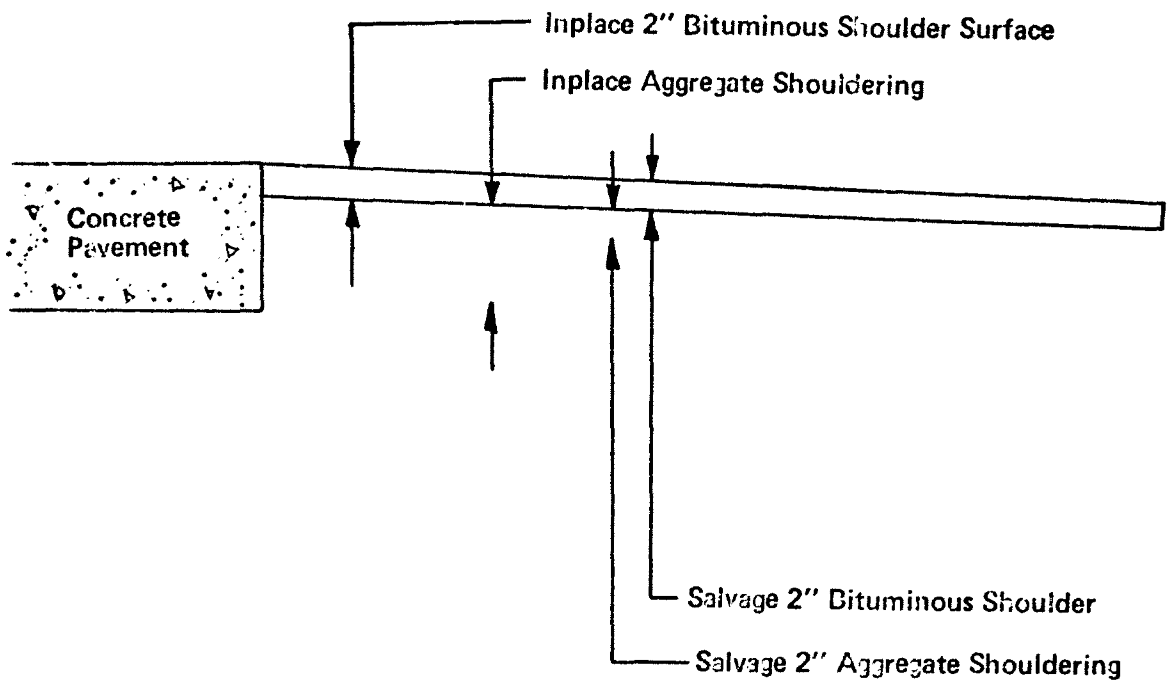


DIAGRAM OF PLANT

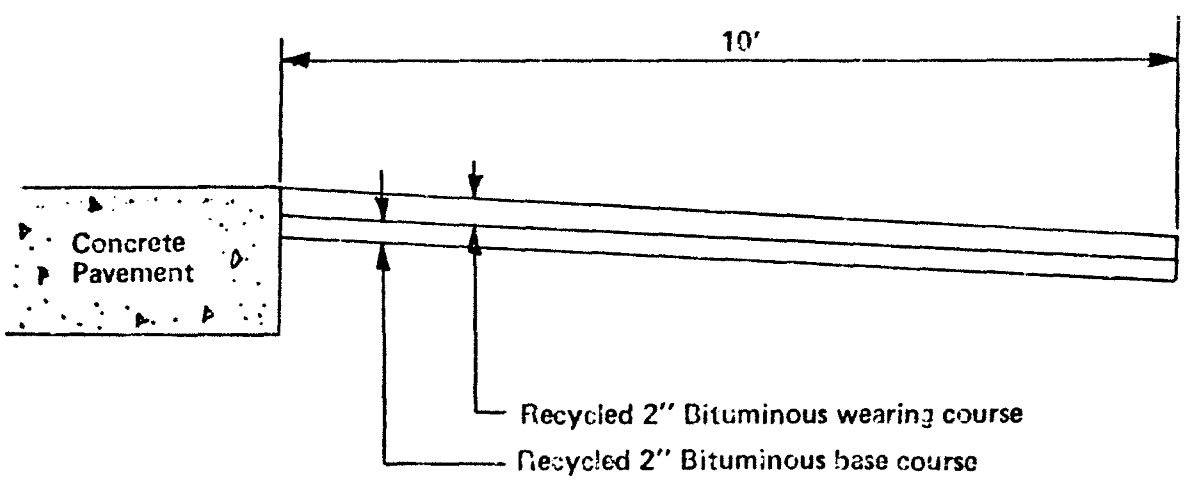
FIGURE 1

Figure 2

OLD



NEW



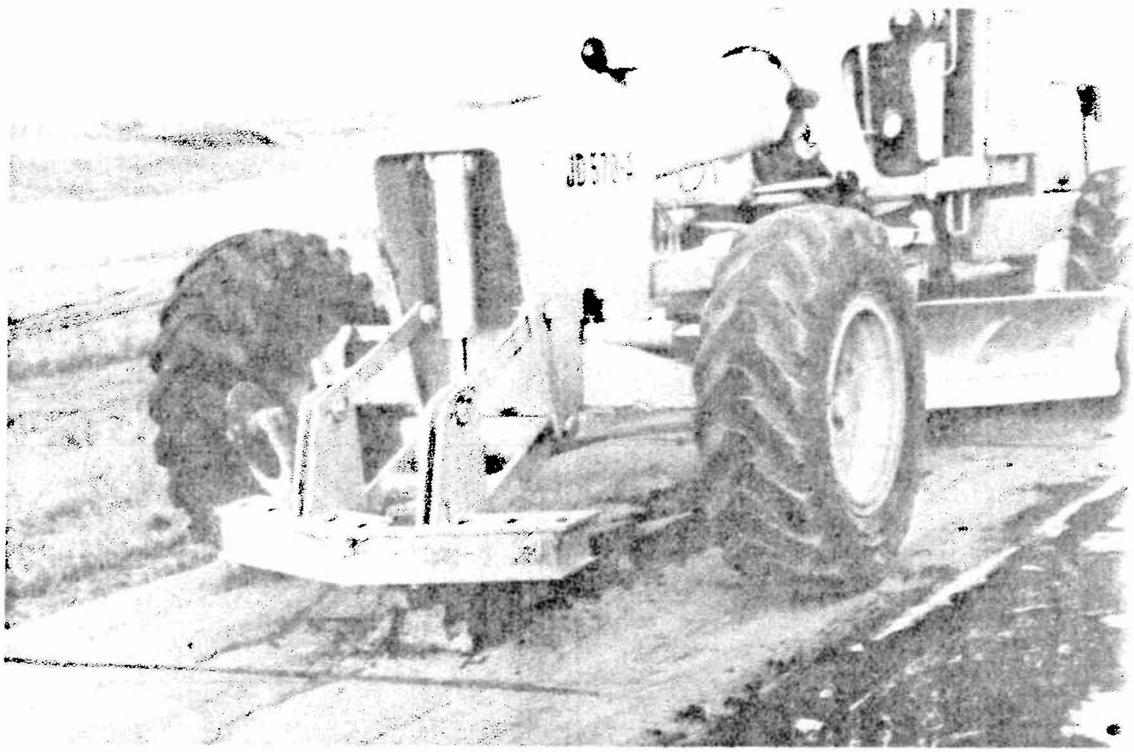


Figure 3 Motor Patrol Ripping the Old Bituminous Shoulder

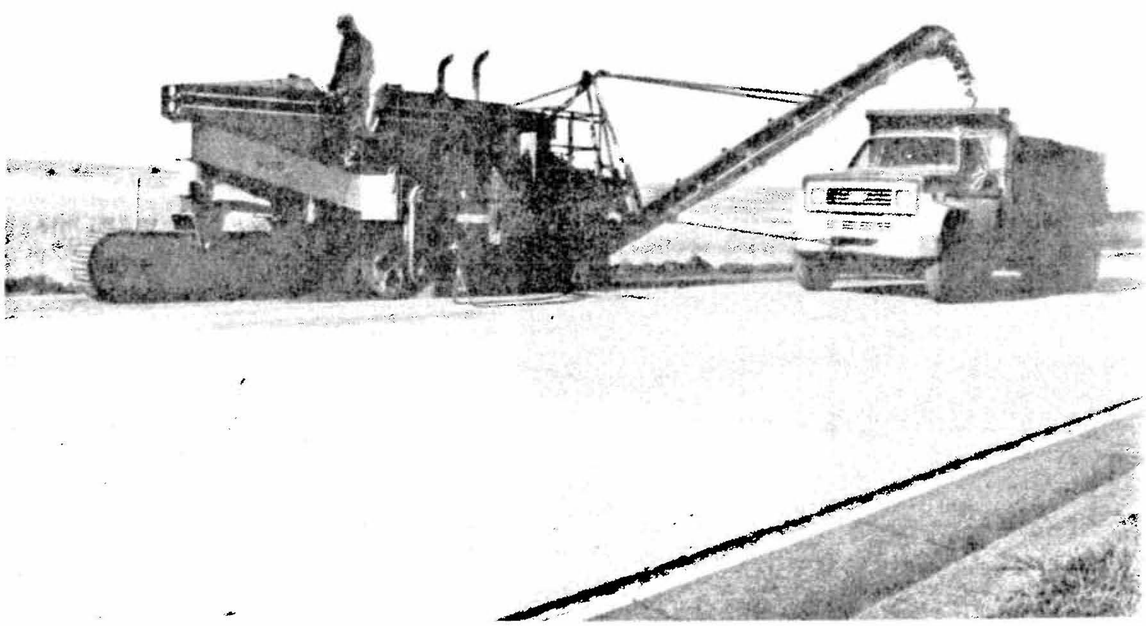


Figure 4 Autograder Picking Up the Excess Shoulder Gravel

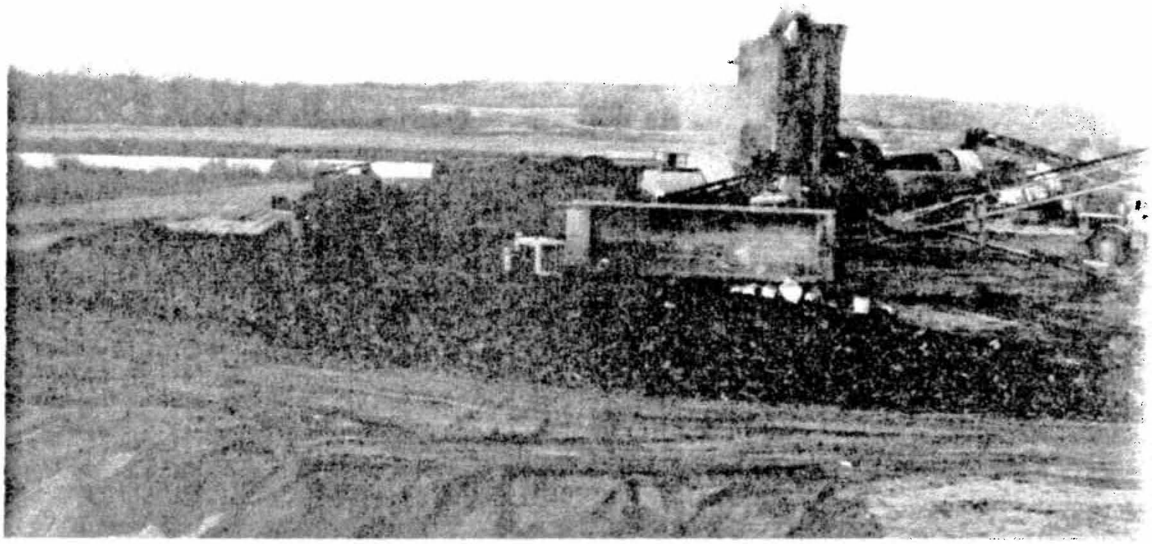


Figure 5 View of Mixing Plant Showing Stack Emissions

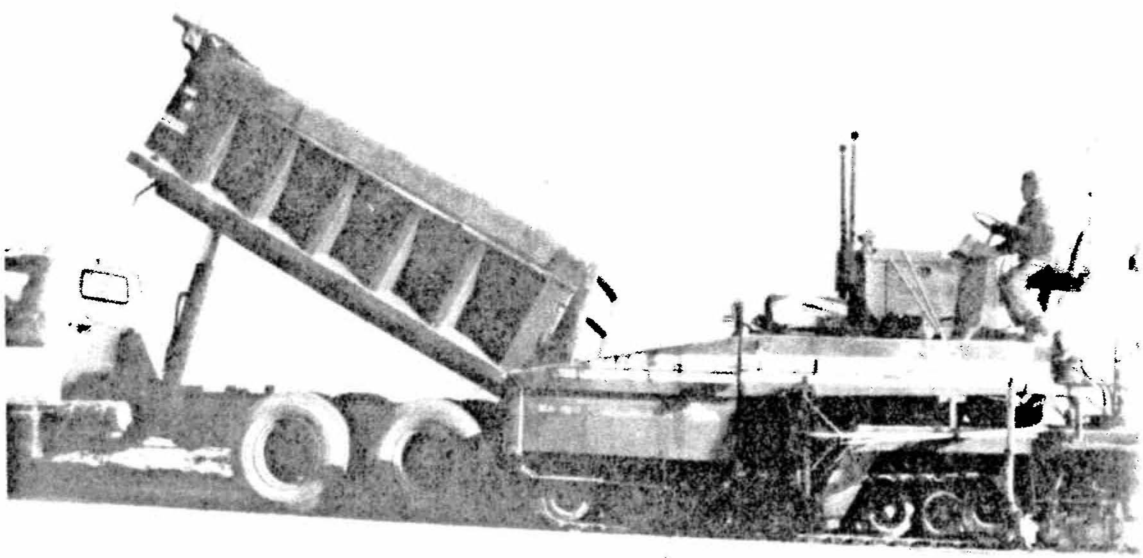


Figure 6 Conventional Paving Operation

APPENDIX A

S-2 ENERGY CONSUMPTION REQUIREMENTS

This project is a "Federal Research Project" which will be used to determine possible energy savings by using reclaimed materials. In conjunction therewith the Contractor shall keep accurate records of all types of energy used to complete the bituminous construction required under this Contract, in accordance with the following requirements.

A. Separate records shall be kept of all energy utilized to produce and place the recycled bituminous mixture and of that energy used for the conventional bituminous construction under this Contract.

B. Energy consumption shall be documented by electrical usage and fuel consumption of the various fuels which may be required to perform the foregoing bituminous construction, such as; (1) gasoline, (2) kerosene, (3) all grades of fuel oil, (4) natural gas, (5) propane gas, (6) butane gas, etc.

C. All equipment shall be documented separately by size, horsepower, etc. The rated production per hour shall be given for each piece of equipment.

D. Upon completion of the project, all energy consumption documentation records shall be submitted to the Engineer.

Compliance with the foregoing "Energy Consumption Requirements" shall be performed, to the satisfaction of the Engineer. Payment therefore shall be construed to be included in the Contract lump sum bid price for Item 2021.501 (Mobilization).

S-16 (2331) PLANT MIXED BITUMINOUS PAVEMENT

A plant mixed bituminous pavement shall be constructed in accordance with the provisions of M.H.D. 2331, except as modified below, using Asphalt Cement 120-150 or 200-300 penetration for producing both the conventional bituminous mixtures and the recycled bituminous mixtures.

S-16.1 Compaction of both the conventional bituminous base and the recycled bituminous base mixtures shall be obtained by the "Ordinary Compaction" method.

Compaction of the conventional bituminous shouldering and the recycled bituminous shouldering mixtures shall be obtained by the "Specified Density" method of compaction.

S-16.2 The exposed side of the concrete pavement shall be cleaned of all loose material prior to applying bituminous tack coat material thereto, as set forth in the Plans.

S-16.3 The following modification shall apply in conjunction with Bituminous Mixture Production:

(A) M.H.D. 2331.4B is revised to read:

"Bituminous material will be measured by weight of the material furnished and used in all mixture."

(B) The third paragraph of M.H.D. 2331.5 is revised to read as follows:

"Payment for the Item of Bituminous Mixture Production at the Contract price per ton of mixture produced shall be compensation in full for all costs of producing the mixture and loading it on board the Department's trucks at the mixing plant, except for the bituminous material for mixture. which will be measured and paid for separately."

S-16.4 In the event the Contractor elects to use taconite tailings in the conventional mixtures such materials shall be obtained only from the sources listed below, unless other sources are given prior approval by the Department's Materials Engineer.

(A) Eveleth Taconite - Forbes, MN

(B) U.S. Steel - Virginia, MN

(C) Butler Taconite (Hannah Mining) - Nashwauk, MN

S-16.5 The 2300 foot Research Sections shall be constructed with conventional bituminous mixtures at the locations designated by the Engineer.

S-16.6 Recycled Bituminous Mixtures:

The following modifications shall apply only to the recycled bituminous mixture construction performed under this Contract.

(A) The provisions of M.H.D. 2331.3B are supplemented with the following: "The Contractor shall submit, prior to the award of the contract, an acceptable proposal for preventing or eliminating excessive air pollutants."

(B) The provisions of M.H.D. 2331.3cla(2) are supplemented with the following:

"Unless another method is approved by the Engineer a means shall be provided for adding the salvaged bituminous mixture, when required, to the heated aggregate after the aggregate has left the drier. This means shall provide for positive control on proportioning the salvaged bituminous material into the mixture."

(C) M.H.D. 2331.3cla(3) is supplemented with the following:

"When it is required to add the salvaged bituminous mixture for the recycled bituminous base and wearing course mixtures it may not be necessary to run the salvaged bituminous mixture through a drier."

(D) The provisions of M.H.D. 2331.3E(1) are supplemented as follows:

"The approximate mixture proportions of salvaged bituminous mixture and salvaged aggregate to be used in the recycled bituminous base and recycled bituminous shoulder wear shall be 1:1 by weight. The Engineer retains the authority to modify the mixture proportions. The recycled bituminous courses shall be placed as shown in the Plans. In addition thereto, "Research Sections" shall be constructed as directed by the Engineer using conventional M.H.D. 2331 bituminous base and bituminous shoulder wear.

(E) The first three sentences of the third paragraph of M.H.D. 2331.3F(1) are deleted and the following is substituted therefore:

"The aggregate shall be heated to a temperature as designated by the Engineer. This temperature may be in excess of 325° F. When the aggregate reaches the mixer, either by itself or in combination with the salvaged bituminous mixture, it will be at a temperature which will not cause damage to the asphalt being added."

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