COLD RECYCLING ASPHALT PAVEMENT

US RTE 4 SHERBURNE, VT.

INITIAL REPORT 79-1
JANUARY 1979

MENDON-SHERBURNE F 020-2 (16)

STATE OF VERMONT
AGENCY OF TRANSPORTATION

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Date: 3/27/79

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Cold Recycling Asphalt Pavement		5. Report Date January, 1979 6. Performing Organization Code
7. Author(s) Ronald I. Frascoia Donald N. Onusseit		8. Performing Organization Report No. 79-1
9. Performing Organization Name and Address Vermont Agency of Transportation Materials & Research Division, State Admin. Building 133 State Street Montpelier, Vermont 05602		10. Work Unit No. 11. Contract or Grant No. DOT-FH-15-305 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Federal Highway Administration Region 15 1000 North Glebe Road Arlington, Virginia 22201		Initial Report, Construction Phase Oct., 1978 14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

1.5 miles of US Rte. 4 in the Town of Sherburne, Vermont was selected for cold recycling due to a high degree of distress in the existing bituminous concrete pavement. The pavement was pulverized to a four inch depth with a Barber-Greene RX-75 Dynaplane and the material was stabilized with up to 2.9 percent CMS-2 asphalt emulsion using a Koehring Bomag MPH 100 stabilizing unit. The stabilized base course was overlaid with (2) one inch lifts of Type III Bituminous Pavement. The standard maintenance rehabilitation procedure of overlaying the existing pavement was carried out on an adjacent 0.7 mile section of roadway to be considered the control section.

The initial report includes detailed construction records and energy and cost comparisons between the cold recycling process, the standard maintenance procedure, and the estimated cost of removal and replacement of a portion of the base pavement and the riding surface.

Based upon initial observations and test results to date, the procedure and equipment used appears to be practical from the stand point of construction feasibility, conservation of natural resources and end product obtained. A reduction in future maintenance will be required on the recycled section in order to justify the higher cost and amount of energy consumed using the cold recycling procedure when compared with the standard pavement maintenance-rehabilitation procedure.

17. Key Words	18. Distribution Statement
Cold Recycling Pulverized, Asphalt Emulsion, Stabilized Base Course, Rehabilitation, Energy	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENT

This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Region 15 in conjunction with Demonstration Project No. 39, Recycling Asphalt Pavements under Contract No. DOT-FH-15-305.

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Introduction

Vermont's standard pavement maintenance-rehabilitation procedure for the past several years has consisted of routing and filling cracks in the existing pavement, placing a ½± inch leveling course and overlaying with one to two inches of new bituminous concrete pavement. Experience has shown that this procedure does not prevent cracks in the old pavement from reflecting up through the new overlay. In numerous cases, thermal cracks, which are generally transverse to the centerline, were found to reflect up through the new overlay during the first winter of exposure. Such experiences led to the decision to try cold surface recycling as a means of eliminating the cracks. It was also hoped that the cold recycling process would provide secondary benefits by reducing fuel consumption and conserving natural resources, namely aggregates and asphalt. This report covers the construction phase of the first Category III experimental project.

Project Description and Roadway Condition

The roadway selected for recycling consisted of 1½ miles of U.S. Route 4 beginning 0.047 miles east of the intersection of Town Road 41 in Sherburne and extending easterly to the intersection of Vermont Route 100. The Town of Sherburne is located in the west-central part of the State in Rutland County, approximately nine miles east of the City of Rutland.

The existing roadway was constructed as new relocation in 1948 featuring a 32 foot wide surface with a climbing lane in the westbound direction. As additional overlays were placed, the roadway width was increased to approximately

40 feet by widening and paving the shoulder areas. The subbase consisted of gravel which varied from 15 to 24 inches in depth within the limits of the recycle project. The wearing course was 2½ inches of crushed gravel mixed in-place bituminous mix. Additional pavement courses included a 3/4 inch blade mix in 1949, 1½ inches of bituminous concrete in 1961 and a 3/4 inch hot-mix overlay in 1971. Records show a total pavement thickness of 5½ inches while actual field measurements disclosed depths of 5 to 8 inches.

The condition of the pavement varied greatly from stable and crack free to severely cracked with areas of localized heaving and wheel path rutting. The latter was confined almost exclusively to random locations in the outer wheel paths of both the east and westbound lanes adjacent to the shoulders. The failures appeared to be base related with maximum rutting values of 3½ inches recorded.

A 0.71 mile section of U.S. Rte. 4 immediately west of the recycle area was selected as the control area for comparison purposes. This segment of highway was constructed in 1959 and included an 18 inch subbase of gravel and a 1½ inch bituminous concrete wearing course. An additional 3/4 inch hot-mix overlay was placed in 1971.

A condition survey was made at four specific locations within the control section prior to its repair. An average of 679 lineal feet of cracks was recorded per 100 lineal feet of 32 foot wide roadway. Longitudinal cracks made up 80 percent of the total while transverse cracks were all limited to less than one-half of a lane width. The overall condition of the pavement was better than that of the recycle section with no significant amounts of heaving, settlement or wheel path rutting.

Typical pavement distress in recycle area

Typical pavement distress in control area

Climatological data for the area obtained in Rutland, the nearest official weather recording station, shows a freezing index of 842, an average of 113 freeze-thaw cycles and 68 inches of snowfall. However, it should be noted that the recording station is situated at an elevation of 620 feet while the construction project is located at elevations of 1688 to 2150 feet above sea level. Recent unofficial records kept by highway maintenance personnel show an average yearly snowfall of 206 inches in the vicinity of the project.

Average daily traffic volume on this section of Rte. 4 has been recorded at 6390 vehicles with 6 percent consisting of truck traffic.

Preliminary Investigation

Preliminary testing of field recovered cores was carried out in the Materials and Research Laboratory. The results showed an average asphalt content of 6.6 percent and a recovered penetration of 10. The absolute viscosities were too high to measure with available equipment. In-place densities averaged 150 pounds per cubic foot.

A CMS-2 cationic asphalt emulsion was chosen as the binding agent for stabilizing the top four inches of pavement which was to be pulverized. The selection was based upon lab compatibility results and the recommendations of the proposed asphalt supplier. A 2 percent asphalt content was selected as the proper amount of stabilizer. This resulted in an application rate of 1 gallon emulsion per square yard of stabilized base. Compaction of the pulverized pavement samples using AASHTO T 180 (Test Method "C") established a 4 percent moisture content as best suited for aiding in the obtainment of maximum densities and optimum asphalt distribution.

Construction Operation

The cold recycling project which was a part of a larger paving contract was awarded to F. W. Whitcomb Construction Corporation of Bellows Falls, Vermont on August 11, 1978 with a completion date requirement of October 20, 1978. The prime contractor sublet the recycling work to Pike Industries of Tilden, New Hampshire.

A price of $4.50 per square yard was bid on the recycling Item No. 310.15 Bituminous Base Stabilization. The price was later increased an additional $0.60 per square yard to insure that the contractor would provide a self-propelled mixer for the uniform distribution of asphalt. The emulsified asphalt was bid at a price of $5.00 per hundred weight.

The rehabilitation of the control section was completed the last week of September prior to initiating construction on the recycle project. The cracks were not routed and filled as initially planned due to the extensive amount of cracking. The thin leveling course was also omitted from the control section due to the absence of significant deformations in the pavement surface.

The cold recycling process began on October 3, 1978 and was completed 11 working days later on October 21, 1978. Generally poor weather conditions prevailed throughout the construction period although such conditions did not appear to adversely affect the end product. Temperatures during the period ranged from 23^{o} F to 64^{o} F with an average daily temperature of 49^{o} F. The application of water or asphalt was prohibited when air temperatures were below 40^{o} F. Light to moderate and occasionally heavy rain showers occurred during 4 of the 11 work days but did not result in a shutdown in the recycling process.

The construction procedure consisted of preparing areas approximately 1000 feet in length by 18 feet in width or one-half of the 3 lane roadway. Pulverization to the required 4 inch depth was accomplished with a Barber-Greene RX-75 Dynaplane. As the pulverization progressed, a Caterpiller 14G grader was used to level the windrowed material back in place. Moisture tests were then taken and water was sprayed on the pulverized material with a distributor truck to bring the moisture content within the desired range. Following blending with 6 or 8 passes of the grader, additional moisture tests were taken to determine acceptability. The application of the CMS-2 asphalt emulsion was accomplished with a Bomag MPH 100 hydrostatic stabilizer. Immediately following the final leveling and shaping with the grader, the recycled material was compacted with a double axle vibrating steel roller. As soon as test results disclosed that the stabilized base had been compacted to 98 percent of standard density, traffic was allowed on the new surface.

Production rates varied greatly within each work day and with each piece of equipment (see Table 1, page 7). Initially, the Dynaplane was able to pulverize a 10.5 foot wide by 4 inch deep strip at rates up to 11 feet per minute. However, as the project progressed a high percentage of mechanical down time occurred due mainly to the need for replacing the tungsten-carbide teeth on the rotary cutter assembly and the side plates at each end of the drum. The 155 teeth on the cutter were quickly changed as required but wear on the outer plates and their 24 fixed teeth required that they be changed up to 2½ times per 1000 feet of roadway prepared. Approximately 1/3 of the way through the project, the contractor elected to pulverize in two passes at 2 inches of depth per pass. This procedure was

TABLE 1

EQUIPMENT PRODUCTION RATE SUMMARY

	DYNAPLANE	BOMAG	GRADER	WATER TRUCK	ROLLER
Total Days On Job	11	10	12	10	12
Total Hours Of Work	99.0	99.0	99.0	99.0	99.0
Total Operating Time (HRS)	40.5	24.7	40.6	10.3	16.4
Total Mechanical Down Time (HRS)	27.7	1.5	0.6	0	0
% Of Time Equipment Down (Mechanical)	40.6	5.9	1.3	0	0
Total Area Recycled (YD^2)	28,711	28,803	-	-	-
Total Volume Recycled (YD^3)	3190	3200	-	-	-
Total Weight Recycled (Tons)	6460	6480	-	-	-
Overall Rate Of Recycling (YD^2/HR)	709	1168	-	-	-
Overall Rate Of Recycling (YD^3/HR)	79	130	-	-	-
Overall Rate Of Recycling (Tons/HR)	160	263	-	-	-

Pulverizing 2-4 inch depth with Barber-Greene Dynaplane

Windrow of pulverized pavement from Dynaplane

Blending moisture following the addition of water to obtain the optimum 4 percent moisture content

Stabilization of pulverized pavement with CMS-2 asphalt emulsion utilizing a Bomag MPH 100 stabilizing unit

Note smaller particle sizes following additional pulverization with the Bomag

Flow of water on cold planed surface noted following drainage of rain through asphalt stabilized material helpful in extending the tooth life per unit volume of material recycled. It is possible that the tooth wear would have been reduced if pavement temperatures had been higher. The average production rate obtained with the Dynaplane was 160 tons per hour with mechanical down time amounting to 41 percent. Production rates achieved with the Bomag MPH 100 mixing unit ranged up to 35 feet per minute with coverage obtained over a 6½ foot wide area. In areas where stabilization was not required for the full width, spray jets could be shut off to limit the area of coverage. Control of the asphalt application rate was based on a combination of equipment speed and hydrostatic pressure applied. The final application rate was determined by measuring the roadway treated and noting the gallons of asphalt pumped through the accumulative flow meter. The actual application rates varied from a low of 1.5 percent or 0.77 gallons per square yard to a maximum of 2.9 percent or 1.54 gallons per square yard. In all cases a uniform and acceptable distribution of asphalt emulsion was obtained with the Bomag stabilizer. Because the unit is designed to pulverize as well as apply an asphalt product, the average particle size of the previously crushed pavement was further reduced during stabilization (see gradation levels on Table 2, pg. 11). The final average production rate obtained with the Bomag mixing unit was 263 tons per hour with mechanical down time limited to 5.9 percent.

The asphalt emulsion was omitted from a 500 foot test section of full width roadway immediately east of mile marker 0200 for comparison purposes. The contractor was also given permission to suspend the recycling process from the end of the no-asphalt section to the junction of Vermont Rte. 100

TABLE 2

GRADATION OF PULVERIZED PAVEMENT

	Recycled By Dynaplane and Bomag		Recycled By Dynaplane	
Sieve Size	Percent Passing	Range	Percent Passing	Range
1 3/4 in.	100	100 - 100	100	100 - 100
1 1/2 in.	100	100 - 100	100	100 - 100
1 in.	92	87 - 95	92	87 - 96
3/4 in.	86	82 - 87	84	80 - 88
1/2 in.	73	69 - 77	68	66 - 69
3/8 in.	62	57 - 65	52	43 - 59
4	41	37 - 44	32	27 - 37
8	24	22 - 26	21	18 - 24
16	14	11 - 15	13	10 - 15
30	8	6 - 8	8	6 - 9
50	4	3 - 5	5	3 - 5
200	1	1 - 1	1	1 - 1

a distance of 975 feet. The reasons for shortening the length of the project included anticipated difficulties with traffic control, poor weather conditions, and the low production rates which were being attained.

During the course of the project, approximately 5 tons of bituminous mix was used to fill potholes or patch areas where various degrees of surface raveling occurred. The amount of surface area involved was not considered significant.

The stabilized base was overlaid with two 1 inch lifts of Type III bituminous pavement on October 23 and 24, 1978.

Project Testing and Observations

On-project testing was limited to sampling for gradation and asphalt content plus compliance with moisture and density requirements. The gradations obtained following pulverization and mixing can be seen in Table 2 on page 11 .

Moisture contents were determined using a "Speedy" Moisture Tester. Density test results were obtained with a Troxler nuclear gage using the four inch direct transmission mode of operation. The minimum density requirement was for 98 percent of the unit weight obtained using AASHTO T 180 test method "C". The unit weight of the stabilized mixture using the T 180 method ranged from 118 to 130 pounds per cubic foot as compared to an original in-place density of 150 pounds per cubic foot. Cores taken following completion of the project disclosed densities averaging 138.4 pounds per cubic foot.

The addition of the CMS-2 asphalt emulsion gave the pulverized mixture the appearance and feel of a bituminous mix or cold patch. When the loose material was stepped upon, the foot would slowly sink into the mixture pulling adjacent material down with it. No significant differences were noted between the area given the lightest application of 1.5 percent asphalt or the heaviest rate of 2.9 percent.

Occasionally heavy rain showers did not have a detrimental effect due to the excellent draining characteristics of the pulverized material following the addition of the asphalt emulsion. During the period of heaviest precipitation, moisture which had drained through the pulverized material was observed flowing on the planed surface beneath the loose material. Such drainage resulted in a satisfactory moisture content and acceptable stabilities following compaction. Similar results were obtained in laboratory tests. Samples immersed in water and then allowed to drain for 5 minutes retained an average of 6 percent moisture. When drained for 30 minutes, the moisture decreased to 4.4 percent which was only 0.4 percent over the level considered optimum.

Attempts at recovering full depth 4 inch diameter cores of the stabilized base were not successful. Recovery was limited to an average core length of 1 3/4 inches at 6 locations and no recovery at a seventh location. Although differences in moisture and asphalt contents as well as cure times were known for each section treated, the effect of the various conditions was not significant since the recovered core specimens were similar in length and density. (see core data in Table 3 on page 14).

It is interesting to note that the zero recovery location was in the section given the highest asphalt application rate of 2.9 percent. A 1/2 to 1 inch long core was also recovered from one of two locations cored within the area which had been pulverized but not stabilized with asphalt emulsion.

TABLE 3

CORE DATA INFORMATION
CONDITIONS WHEN RECYCLED

CORE #	LOCATION	WEATHER CONDITIONS	MOISTURE CONTENT	ASPHALT CONTENT	CURING TIME	DESCRIPTION OF CORE
1	0090 WB (10' Off Shoulder)	$T = 55^o$ F Clear	5.1%	1.9%	90 Min.	1 - 1 1/2" Core Recovered
2	0140 WB (10' Off Shoulder)	$T = 64^o$ F Cloudy	4.7%	2.9%	80 Min.	No Recovery
3	0142 WB (10' Off Shoulder)	$T = 58^o$ F Heavy Rain	5.4%	2.0%	275 Min.	1 1/2" Core Recovered Density 140.6#/cf
4	0205 WB (15' Off Shoulder)	$T = 56^o$ F Clear	6.1%	0%	No Cure Req.	No Recovery
5	0205 EB (15' Off Shoulder)	$T = 58^o$ F Cloudy	2.6 - 3.1%	0%	No Cure Req.	1/2 - 1" Core Recovered
6	0180 EB (10' Off Shoulder)	$T = 66^o$ F Clear	5.2 - 5.4%	2.0%	115 Min.	1 3/4 - 2 1/4" Core Recovered Density 138.7#/cf
7	0101 EB (10' Off Shoulder)	$T = 54^o$ F Cloudy	2.9 - 4.6%	2.2%	75 Min.	1 1/4 - 1 3/4" Core Recovered Density 134.7#/cf
8	0101 EB (3' Off Shoulder)	$T = 52^o$ F Cloudy	2.9 - 4.6%	2.0%	5 Min.	2 - 2 1/4" Core Recovered Density 138.9#/cf
9	0090 EB (10' Off Shoulder)	$T = 42^o$ F Heavy Rain	3.2 - 3.8%	2.1%	130 Min.	1 1/2 - 2" Core Recovered Density 139.1#/cf

Energy and Cost Analysis

Records were kept of fuel consumption required to carry out the recycling process and the manufacture and application of the bituminous overlay. A total of 4208 gallons of fuel were used to recycle 28,800 square yards or 6480 tons of roadway material. This averaged out to 0.1461 gallons of fuel per square yard or 0.649 gallons per ton of recycled material. Including the energy required to manufacture the asphalt emulsion, this amounted to 22,330 BTU per square yard or 99,230 BTU per ton. The manufacture and placement of two 1 inch lifts of bituminous pavement over the stabilized base used an additional 70,830 BTU per square yard for a total consumption of 93,160 BTU per square yard.

The energy required to carry out the standard pavement maintenance-rehabilitation procedure amounted to 43,060 BTU per square yard or 54 percent less than the recycling process.

Energy consumption was also estimated for an alternate treatment which would insure the elimination of reflective cracking. The method included the removal and disposal of the top 3 inches of existing pavement followed by replacement with 3 inches of plant mixed base course and 1½ inches of pavement. This procedure would have required 150,000 BTU per square yard or 61 percent more than that used with the recycling process. Energy consumption data can be seen on Tables 4, 5, 6, & 7 on pages 19-26.

Based upon bid prices, the actual cost of the treatments used was $7.90 per square yard on the recycled section and $1.83 per square yard on the area treated with the standard pavement maintenance-rehabilitation procedure. In comparison, the cost for the removal, disposal, and replacement of pavement with the alternate method was estimated at $10.11 per square yard or 28 percent more than the recycling process (see Table 8 on page 27).

SUMMARY

A cold recycling process was selected primarily for the purpose of eliminating reflection cracking by pulverizing the top four inches of existing pavement. A CMS-2 cationic asphalt emulsion was selected as the most suitable binding agent when mixed with the pulverized pavement at an application rate of two percent by weight of bituminous mixture.

Generally poor weather conditions prevailed throughout the construction period although such conditions did not appear to adversely affect the end product obtained. This was due in large part to the excellent drainage characteristics of the pulverized and asphalt stabilized material prior to compaction.

The pavement was pulverized with a Barber-Greene RX-75 Dynaplane and the material was further reduced in size when the asphalt was applied with a Bomag MPH 100 stabilizer. The only disadvantage noted with the two pieces of equipment was a high percentage of mechanical down time which occurred with the Dynaplane due mainly to wear on the cutter teeth.

The recovery of 4 inch diameter cores taken from the stabilized base was limited to an average core length of 1 3/4 inches at 6 of 7 locations. Satisfactory densities averaging 138.4 pounds per cubic foot were obtained on the samples.

Total energy consumption on the recycled section including the manufacture and placement of the bituminous pavement amounted to 93,160 BTU per square yard. The cost of the treatment was $7.90 per square yard. The recycling treatment would produce significant savings in energy, cost and conservation of natural resources when compared with the alternate method

of eliminating cracks by removing and disposing of the existing pavement. Energy consumption for the latter treatment was estimated at 150,000 BTU per square yard while the cost would be in the range of $10.00 per square yard.

The standard pavement maintenance-rehabilitation procedure used on the control section was completed at a cost of $1.83 per square yard while energy consumption was 43,060 BTU per square yard. A reduction in future maintenance will be required on the recycled section in order to justify its higher cost and energy consumption when compared to the standard maintenance treatment.

The construction of the stabilized base course was considered successful. However, some problems are anticipated with the new pavement in localized areas where poor subbase conditions resulted in heaving and wheel path rutting in the initial pavement.

The recycled and control sections will be inspected at least once each winter and spring until definite conclusions can be drawn on performance and cost effectiveness.

RECOMMENDATIONS

The following recommendations should be considered prior to initiating future recycling projects.

1. The specification covering the stabilized base course should be modified to insure that a suitable mixer is provided for the application of the asphalt binder.
2. Laboratory studies should be conducted to establish the following procedures:
    a) Establish methods of sampling and testing the pavement to be recycled.
    b) Establish methods of determining the correct binder to be used.
    c) Establish methods of determining the proper asphalt and moisture content to be used.
    d) Establish methods of determining the maximum densities and stabilities which may be obtained in both the laboratory and field.
3. The use of softening agents should be considered as a means of rejuvenating the existing asphalt on future cold recycling projects.

IMPLEMENTATION

The findings of this study are being used to carry out the first two articles stated in the recommendation.

TABLE 4

ENERGY CONSUMED WITH THE RECYCLING PROCESS
ALTERNATE A

	EQUIPMENT	FUEL USED (GAL)	ENERGY USED (BTU)
Recycled Base Course (4")	*Manufacture Asphalt Emulsion		6.44×10^7
	Barber-Greene Dynaplane	1743 (Diesel)	2.42×10^8
	Bomag MPH 100	576 (Diesel)	8.01×10^7
	CAT 14 G Grader	581 (Diesel)	8.08×10^7
	Vibratory Roller	156 (Diesel)	2.17×10^7
	Water Truck	168 (Diesel)	2.34×10^7
	Power Broom	21 (Gasoline)	2.63×10^6
	Supervisory Vehicles	287 (Gasoline)	3.59×10^7
	Asphalt Tanker	590 (Diesel)	8.20×10^7
	Welder (for Dynaplane Teeth)	86 (Gasoline)	1.08×10^7
	Sub-Total Energy Used to recycle 4" course =		6.43×10^8 BTU
	Energy To Recycle 1 Ton = 99,230 BTU	Energy Used =	22,330 BTU/S.Y.
Two 1 Inch Lifts (Type III Bituminous Mix)	*Manufacture & Haul Asphalt Cement		2.01×10^8
	Plant Operations	10,000 (Diesel)	1.39×10^9
	Hauling Mix	1,351 (Diesel)	1.88×10^8
	Paving	262 (Gasoline) 823 (Diesel)	3.28×10^7 1.14×10^8
	Shoulders	5 (Gasoline) 559 (Diesel)	6.25×10^5 7.77×10^7
	Traffic Control	263 (Gasoline)	3.29×10^7
	Sub-Total Energy Used =		2.04×10^9 BTU
	For Two 1" Lifts of Type III Mix, Energy Used =		70,830 BTU/S.Y.

TABLE 5

ENERGY CONSUMED WITH AN ALTERNATE TREATMENT
OF REMOVAL, DISPOSAL, AND REPLACEMENT

ALTERNATE B (STEP 1)
REMOVAL & DISPOSAL OF 3" OF PAVEMENT

REMOVAL:	(With Barber-Greene RX-75 Dynaplane) =	1.82×10^8 BTU
*HAULING:	10 Mi. x 2 x 3,800 BTU/Ton Mile x 4860 Tons =	3.69×10^8 BTU
REPAIR:	(Welder For Dynaplane) =	8.10×10^6 BTU
	Total Energy Used =	5.59×10^8 BTU

Note: Removal and repair based on 75% of energy used in removing 4" of asphalt concrete pavement.

ALTERNATE B (STEP 2)
*ASPHALT CONCRETE (BASE COURSE)

MATERIALS

Manufacture asphalt cement =	587,500	BTU/Ton
Haul 80 Mi. x 2 x 3,270 BTU/Ton Mile =	523,200	BTU/Ton
Total For Asphalt =	*1,110,700	BTU/Ton
Crushed Stone @ 70,000 BTU/Ton (75%) =	52,500	BTU/Ton
Sand @ 15,000 BTU/Ton (25%) =	3,750	BTU/Ton
Total For Aggregate =	*56,250	BTU/Ton

MIX COMPOSITION

Asphalt (5%) @ 1,110,700 BTU/Ton =	55,540	BTU/Ton
Aggregate (95%) @ 56,250 BTU/Ton =	53,440	BTU/Ton
Total For Mix =	*108,980	BTU/Ton

TABLE 5 con't.

PLANT OPERATIONS

Dry Aggregate, 5% @ 28,000 BTU/%, 0.95 Ton =	133,000 BTU/Ton
Heat 230^{o} F @ 470 BTU/ ^{o}F/Ton, 0.95 Ton =	102,700 BTU/Ton
Other Plant Operations =	19,820 BTU/Ton
Total Plant Operations =	*255,520 BTU/Ton

HAUL AND PLACE

Haul Mix 18Mi. x 2 x 3,800 BTU/Ton Mile =	136,800 BTU/Ton
Spread and Compact =	16,700 BTU/Ton
Total For Haul and Place =	*153,500 BTU/Ton

Total For 1 Ton of Plant Mixed
Base Course = 518,000 BTU

ENERGY FOR 3" OF PLANT MIXED BASE COURSE

Area = 28,800 S.Y.

Volume = 2400 C.Y.

@ 150 p.c.f. Unit Weight

Total Weight = 4860 Tons

Total Energy Used = 2.52×10^{9} BTU

For 3" Plant Mixed Base Course (In Place):

Energy Used = 87,500 BTU/S.Y.

TABLE 5 con't.

ALTERNATE B (STEP 3)
*ASPHALT CONCRETE (TYPE II)

MATERIALS

Manufacture Asphalt Cement =	587,500	BTU/Ton
Haul 80 Mi. x 2 x 3,270 BTU/Ton Mile =	523,200	BTU/Ton
Total For Asphalt =	*1,110,700	BTU/Ton
Crushed Stone @ 70,000 BTU/Ton (60%) =	42,000	BTU/Ton
Sand @ 15,000 BTU/Ton (35%) =	5,250	BTU/Ton
Mineral Filler @ 70,000 BTU/Ton (5%) =	3,500	BTU/Ton
Total For Aggregate =	*50,750	BTU/Ton

MIX COMPOSITION

Asphalt (7%) @ 1,110,700 BTU/Ton =	77,750	BTU/Ton
Aggregate (93%) @ 50,750 BTU/Ton =	47,200	BTU/Ton
Total For Mix =	*124,950	BTU/Ton

PLANT OPERATIONS

Dry Aggregate, 5% @ 28,000 BTU/%, 0.93 Ton =	130,200	BTU/Ton
Heat 230^{0} F @ 470 BTU/ ^{0}F/Ton, 0.93 Ton =	100,530	BTU/Ton
Other Plant Operations =	19,820	BTU/Ton
Total Plant Operations =	*250,550	BTU/Ton

HAUL AND PLACE

Haul Mix 18 Mi. x 2 @ 3,800 BTU/Ton Mile =	136,800	BTU/Ton
Spread and Compact =	16,700	BTU/Ton
Total For Haul and Place =	153,500	BTU/Ton

Total For 1 Ton Asphalt Concrete -
Type II = 529,000 BTU

ENERGY FOR 1 1/2" OVERLAY OF A.C. TYPE II

Area = 28,800 S.Y.

Volume = 1,200 C.Y.

@ 145 p.c.f. Unit Weight

Total Weight = 2350 Tons

Total Energy Used = 1.24×10^9 BTU

For 1 1/2" Overlay:

Energy Used = 43,060 BTU/S.Y.

TABLE 6

ENERGY CONSUMED WITH THE
STANDARD MAINTENANCE PROCEDURE

ALTERNATE C

MATERIALS	
Manufacture Asphalt Cement =	587,500 BTU/Ton
Haul 80 Mi. x 2 x 3,270 BTU/Ton Mile =	523,200 BTU/Ton
Total For Asphalt =	*1,110,700 BTU/Ton
Crushed Stone @ 70,000 BTU/Ton (60%) =	42,000 BTU/Ton
Sand @ 15,000 BTU/Ton (35%) =	5,250 BTU/Ton
Mineral Filler @ 70,000 BTU/Ton (5%) =	3,500 BTU/Ton
Total For Aggregate =	*50,750 BTU/Ton
MIX COMPOSITION	
Asphalt (7%) @ 1,110,700 BTU/Ton =	77,750 BTU/Ton
Aggregate (93%) @ 50,750 BTU/Ton =	47,200 BTU/Ton
Total For Mix =	*124,950 BTU/Ton
PLANT OPERATIONS	
Dry Aggregate, 5% @ 28,000 BTU/%, 0.93 Ton =	130,200 BTU/Ton
Heat 230° F @ 470 BTU/ °F/Ton, 0.93 Ton =	100,530 BTU/Ton
Other Plant Operations =	19,820 BTU/Ton
Total Plant Operations =	*250,550 BTU/Ton
HAUL AND PLACE	
Haul Mix 18 Mi. x 2 @ 3,800 BTU/Ton Mile =	136,800 BTU/Ton
Spread and Compact =	16,700 BTU/Ton
Total For Haul and Place =	153,500 BTU/Ton

Total For 1 Ton Asphalt Concrete -
Type II = 529,000 BTU

ENERGY FOR 1 1/2" OVERLAY OF A.C. TYPE II

Area = 28,800 S.Y.

Volume = 1,200 C.Y.

@ 145 p.c.f. Unit Weight

Total Weight = 2350 Tons

Total Energy Used = $\underline{1.24 \times 10^9 \text{ BTU}}$

For 1 1/2" Overlay:

Energy Used = 43,060 BTU/S.Y.

*Information from "Energy Requirements for Roadway Pavements", MISC-75-3, April 1975, by the Asphalt Institute.

TABLE 7

ENERGY CONSUMPTION SUMMARY

ALTERNATE A

	ENERGY USED
Recycle (4")	6.43×10^8 BTU
Overlay (2 - 1" Courses)	2.04×10^9 BTU
Total =	2.68×10^9 BTU

Energy Required = 93,160 BTU/S.Y.

ALTERNATE B

	ENERGY USED
Remove and Disposal (3")	5.59×10^8 BTU
Plant Mixed Base Course (3")	2.52×10^9 BTU
Overlay (1½")	1.24×10^9 BTU
Total =	4.32×10^9 BTU

Energy Required = 150,000 BTU/S.Y.

ALTERNATE C

	ENERGY USED
Overlay (1½")	1.24×10^9 BTU
	(Total)

Energy Required = 43,060 BTU/S.Y.

TABLE 8

COST ANALYSIS

COLD RECYCLE AND OVERLAY

ALTERNATE A

	QUANTITY	COST (PER UNIT)	TOTAL COST
Bituminous Base Stabilization	28,800 S.Y.	5.10	146,880.00
Emulsified Asphalt	2588 CWT	5.00	12,940.00
Bituminous Concrete Pavement	3024 Tons	22.40	67,738.00

Cost For Alternate A = $7.90/S.Y.

REMOVAL, DISPOSAL AND REPLACEMENT

ALTERNATE B

	QUANTITY	COST (PER UNIT)	TOTAL COST
Remove & Haul Pavement	28,800 S.Y.	4.50	129,600.00
Bituminous Concrete Pavement	7210 Tons	22.40	161,504.00

Cost For Alternate B = $10.11/S.Y.

STANDARD MAINTENANCE PROCEDURE

ALTERNATE C

	QUANTITY	COST (PER UNIT)	TOTAL COST
Bituminous Concrete Pavement	2350 Tons	22.40	52,640.00

Cost For Alternate C = $1.83/S.Y.

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/3	10.83	3.08	55.4	2049	228	462	665	74	150
Bomag	10/3	10.83	2.20	3.1	2049	228	462	931	104	210
Grader	10/3	10.83	3.40	0						
Water Truck	10/3	10.83	0.75	0						
Roller	10/3	10.83	1.13	0						
Dynaplane	10/4	9.03	3.20	46.2	2584	287	581	808	90	182
Bomag	10/4	9.03	1.95	32.8	2102	234	474	1078	120	243
Grader	10/4	9.03	2.57	0						
Water Truck	10/4	9.03	0.58	0						
Roller	10/4	9.03	0.45	0						

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/5	11.37	4.42	41.3	2217	246	498	502	56	113
Bomag	10/5	11.37	2.35	0	2715	302	612	1155	129	260
Grader	10/5	11.37	3.95	0						
Water Truck	10/5	11.37	0.75	0						
Roller	10/5	11.37	1.58	0						
Dynaplane	10/10	9.68	4.10	41.7	2767	307	622	675	75	152
Bomag	10/10	9.68	2.55	16.9	2316	257	520	908	101	204
Grader	10/10	9.68	3.42	13.9						
Water Truck	10/10	9.68	0.50	0						
Roller	10/10	9.68	1.12	0						

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/11	9.92	5.05	20.8	3905	434	879	773	86	174
Bomag	10/11	9.92	2.42	0	2253	250	506	931	103	209
Grader	10/11	9.92	5.90	0						
Water Truck	10/11	9.92	2.25	0						
Roller	10/11	9.92	3.32	0						
Dynaplane	10/12	8.55	3.45	40.5	3545	394	798	1028	114	231
Bomag	10/12	8.55	0.95	0	1083	120	243	1140	126	256
Grader	10/12	8.55	3.70	0						
Water Truck	10/12	8.55	1.67	0						
Roller	10/12	8.55	1.95	0						

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/13	8.58	2.65	11.7	1889	210	425	713	79	160
Bomag	10/13	8.58	4.62	0	6502	722	1462	1407	156	316
Grader	10/13	8.58	3.50	0						
Water Truck	10/13	8.58	1.02	0						
Roller	10/13	8.58	1.83	0						
Dynaplane	10/16	6.50	2.72	56.6	2056	228	462	756	84	170
Bomag	10/16	6.50	0	0						
Grader	10/16	6.50	2.00	0						
Water Truck	10/16	6.50	0	0						
Roller	10/16	6.50	0.50	0						

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/17	0.87	0	0						
Bomag	10/17	0.87	0.17	0	76*	3*	6*	447	18	35
Grader	10/17	0.87	0.35	0	*Area redone by Dynaplane and Bomag					
Water Truck	10/17	0.87	0	0						
Roller	10/17	0.87	0.17	0						
Dynaplane	10/19	3.87	1.77	37.5	1568	174	352	886	98	199
Bomag	10/19	3.87	0	0						
Grader	10/19	3.87	1.83	0						
Water Truck	10/19	3.87	0.25	0						
Roller	10/19	3.87	0.67	0						

APPENDIX A

DAILY EQUIPMENT PRODUCTION RATES

	DATE 1978	TOTAL LENGTH OF WORK DAY (HRS)	TOTAL OPERATING TIME (HRS)	% OF TIME EQUIPMENT DOWN (MECH.)	AREA RECYCLED (YD^2)	VOL. RECYCLED (YD^3)	WEIGHT RECYCLED (TONS)	RATE OF RECYCLING (YD^2/HR)	RATE OF RECYCLING (YD^3/HR)	RATE OF RECYCLING (TONS/HR)
Dynaplane	10/20	9.17	4.25	41.9	2807	312	632	660	73	149
Bomag	10/20	9.17	3.30	0	4284	476	964	1298	144	292
Grader	10/20	9.17	4.25	0						
Water Truck	10/20	9.17	0.75	0						
Roller	10/20	9.17	1.72	0						
Dynaplane	10/21	10.63	5.78	36.9	3324	369	747	575	64	129
Bomag	10/21	10.63	4.15	0	5499	611	1237	1325	147	298
Grader	10/21	10.63	5.72	0						
Water Truck	10/21	10.63	1.77	0						
Roller	10/21	10.63	1.92	0						

APPENDIX B

DAILY WEATHER, LOCATION, AND PRODUCTION DATA

	DATE 1978	WEATHER	WORK LOCATION	DIMENSIONS	(S.Y.) AREA	(YD^3) VOLUME
Dynaplane	10/3	$T=37^o - 60^o$ Clear RH=52-56%	1180' west of MM 0100 to 183' west of MM 0100 (WB lane)	Length = 997' Width = 18.5' Depth = 4"	2049	228
Bomag	10/3	$T=51^o - 60^o$ Clear RH=52-56%	1180' west of MM 0100 to 183' west of MM 0100 (WB lane)	Length = 997' Width = 18.5' Depth = 4"	2049	228
Dynaplane	10/4	$T=41^o - 44^o$ Lt. to heavy rain. RH=80-100%	1245' west of MM 0100 to 20' east of MM 0100 for ℄ pass (EB lane) 1180' west of MM 0100 to 20' east of MM 0100 for outside pass (EB lane)	℄ Strip: Length = 1265', Width = 8.5', Depth = 4" Outside strip: Length = 1200', Width = 10'-5", Depth = 4"	2584	287
Bomag	10/4	$T=42^o - 43^o$ Lt. to heavy rain. RH=80-100%	1245' west to 20' east (outside strip) 1245' west to 325' west (middle strip) 1245' west to 325' west (℄ strip (all EB lane; east or west of MM 0100)	Outside / Middle / ℄ Length = 1265' / 920' / 920' Width = 5.5' / 6.5' / 6.5' Depth = 4" / 4" / 4"	2102	234
Dynaplane	10/5	$T=49^o - 58^o$ Partly Cloudy RH=85%	20' east of MM 0100 to 33' west of MM 0120 (EB lane) (MM 0100 to MM 0120 = 1076')	Length = 1023' Width = 19.5' Depth = 4"	2217	246

APPENDIX B

DAILY WEATHER, LOCATION, AND PRODUCTION DATA

	DATE 1978	WEATHER	WORK LOCATION	DIMENSIONS	(S.Y.) AREA	(YD^3) VOLUME
Bomag	10/5	$T=52^0 - 54^0$ Partly Cloudy RH=85%	20' east MM 0100 to 33' west MM 0120 (outside 325' west MM 0100 to 33' west MM 0120 (middle) 325' west MM 0100 to 33' west MM 0120 (C) (all in EB lane)	Outside / Middle / ℄ Length = 1023' / 1368' / 1368' Width = 6.5' / 6.5' / 6.5' Depth = 4" / 4" / 4"	2715	302
Dynaplane	10/10	$T=43^0 - 48^0$ Cloudy to Lt. sprinkle	183' west of MM 0100 to 33' west of MM 0120 (℄ strip of WB lane) 183' west of MM 0100 to 367' east of MM 0120 (outside of WB lane)	℄ Strip / Outside Strip Length = 1226' / 1626' Width = 6.5' / 10'-5" Depth = 4" / 4"	2767	307
Bomag	10/10	$T=48^0 - 49^0$ Cloudy	183' west of MM 0100 to 33' west of MM 0120 (WB lane)	Length = 1226' Width = 17.0' Depth = 4"	2316	257
Dynaplane	10/11	$T=46^0 - 64^0$ Cloudy	33' west of MM 0120 to MM 0160 for ℄ strip (WB lane) 367' east of MM 0120 to MM 0160 for outside strip (WB lane)	Length = 2134' Width = 8.0' Depth = 4" Length = 1734' Width = 10'-5" Depth = 4"	3905	434
Bomag	10/11	$T=52^0 - 64^0$ Cloudy	33' west of MM 0120 to 20' east of MM 0140 (WB lane)	Length = 1096' Width = 18.5' Depth = 4"	2253	250

APPENDIX B

DAILY WEATHER, LOCATION, AND PRODUCTION DATA

	DATE 1978	WEATHER	WORK LOCATION	DIMENSIONS	(S.Y.) AREA	(YD^3) VOLUME
Dynaplane	10/12	T=47° - 60° Partly Cloudy	MM 0160 to MM 0200 (outside strip of WB lane) MM 0200 to 500' east of MM 0200 test section (WB lane)	Length = 2125' Width = 10'-5" Depth = 4" Length = 500' Width = 19.5' Depth = 4"	3544	394
Bomag	10/12	T=56° - 60° Partly Cloudy	MM 0200 to 500' east of MM 0200; test section (WB lane)	Length = 500' Width = 19.5' Depth = 4"	1083	120
Dynaplane	10/13	T=54° - 58° RH=84-100% Cloudy to Heavy Rain	MM 0160 to MM 0200 (℄ strip of WB lane)	Length = 2125' Width = 8.0' Depth = 4"	1889	210
Bomag	10/13	T=54° - 58° RH=84-100%	20' east of MM 0140 to MM 0200 (all of WB lane)	Length = 3163 Width = 18.5 Depth = 4"	6502	722
Dynaplane	10/16	T=23° - 44° Clear Cloudy to Heavy rain	33' west of MM 0120 to 358' west of MM 0160 (outside strip of EB lane)	Length = 1776' Width = 10'-5" Depth = 4"	2056	228
Bomag	10/16	—	—	—	—	—

APPENDIX B

DAILY WEATHER, LOCATION, AND PRODUCTION DATA

	DATE 1978	WEATHER	WORK LOCATION	DIMENSIONS	(S.Y.) AREA	(YD³) VOLUME
Dynaplane	10/17	—	—	—	—	—
Bomag	10/17	T=26° F Clear	33' west of MM 0120 (EB Lane) for length of 105' east on ℄ strip. Attempt was made to pulverize w/Bomag (not successful)	—	—	—
Dynaplane	10/19	T=42° - 47° 100% Cloud To heavy rain	33' west of MM 0120 to MM 0140 (℄ strip of EB lane) 358' west of MM 0160 to 170' east of MM 0160 (outside of EB lane)	1: Length = 1076', Width = 8.0', Depth = 4" 2: 528', 10'-5", 4"	1568	174
Bomag	10/19	—	—	—	—	—
Dynaplane	10/20	T=34° - 42°	MM 0140 to 50' west of MM 0180 (℄ strip of EB lane) 170' east of MM 0160 to 50' west of MM 0180 (outside of EB lane)	1: Length = 2066', Width = 8.0', Depth = 4" 2: 838', 10'-5", 4"	2807	312
Bomag	10/20	T=41° - 42° Clear	33' west of MM 0120 to 50' west of MM 0160 (EB lane)	Length = 2084' Width = 18.5' Depth = 4"	4284	476

APPENDIX B

DAILY WEATHER, LOCATION, AND PRODUCTION DATA

	DATE 1978	WEATHER	WORK LOCATION	DIMENSIONS	(S.Y.) AREA	(YD^3) VOLUME
Dynaplane	10/21	$T=38^{\circ} - 66^{\circ}$ Clear to Partly Cloudy	50' west of MM 0180 to 500' east of MM 0200 (EB lane)	Length = 1617' Width = 18.5' Depth = 4"	3324	369
Bomag	10/21	$T=48^{\circ} - 66^{\circ}$ Clear to partly cloudy	50' west of MM 0160 to 500' east of MM 0200 (EB lane)	Length = 2675' Width = 18.5' Depth = 4"	5499	611