Demonstration Projects Program
Technology Transfer
FHWA-DP-39-23
December 1979

DEMONSTRATION PROJECT NO. 39

RECYCLING ASPHALT PAVEMENTS

Panama City, Florida

Prepared for
and
Distributed by

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
REGION 15
DEMONSTRATION PROJECTS DIVISION
1000 NORTH GLEBE ROAD
ARLINGTON, VIRGINIA 22201

FLORIDA DEPARTMENT OF TRANSPORTATION
Office of Materials and Research
P. O. Box 1029
Gainesville, Florida
32602

INITIAL REPORT

RECYCLING OF ASPHALT CONCRETE PAVEMENTS
(US 98, Panama City, Florida)

by

Charles F. Potts
Principal Investigator
Bituminous Materials and Pavement Performance Engineer

and

Kenneth H. Murphy
Bituminous Engineer

Prepared Under Contract with the U. S. Department of Transportation
Federal Highway Administration
Region 15
Demonstration Projects Division
Contract No. DOT-FH-15-317

November, 197[illegible]

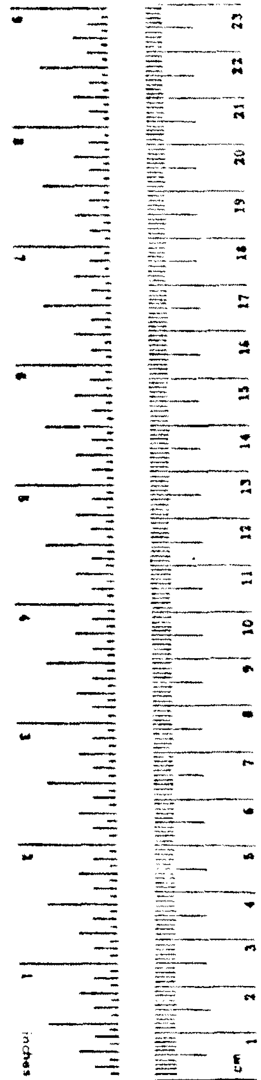
TABLE OF CONTENTS

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

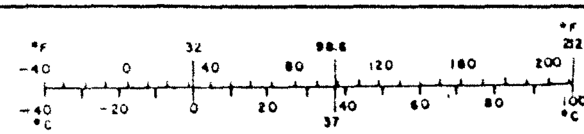
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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	35	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



LIST OF TABLES

(continued)

LIST OF TABLES
(continued)

LIST OF FIGURES

ABSTRACT

This report covers the design and testing of a hot mix recycling process. The process involved the removal of existing pavement by the cold planing process and production of the hot mix recycled paving mixture utilizing a portion of the salvaged material. The mix was produced by the heat transfer method of production.

The field testing includes condition surveys and post construction analyses of the paving mixture and pavement structure.

The initial results indicate an acceptable asphalt concrete mixture can be produced utilizing the heat transfer method of production. Further field evaluations will be necessary in order to draw definite conclusions with regard to long-term pavement performance.

RECYCLING OF ASPHALT CONCRETE PAVEMENT-
US 98, Panama City, Florida

INTRODUCTION

As the cost of highway construction materials continues to increase, highway engineers must seek more cost effective methods of pavement rehabilitation if available funds are to meet current needs. Pavement recycling, which involves reprocessing salvaged materials, is now being considered in Florida and other parts of the country as a potential solution to the problem.

Currently, three methods of recycling asphalt pavements are commonly used -- hot mix recycling, cold mix recycling, and surface recycling. Each of these, when used under proper field conditions, can result in an acceptable finished pavement surface. The equipment and technology exists to produce an asphalt concrete mixture for each of these three processes that will perform in a manner which equals, or in some cases surpasses, that of conventional paving mixtures.

As a standard method of pavement rehabilitation, the Florida Department of Transportation has required the removal of the existing pavement in municipal areas in order to preserve existing drainage facilities. This removal results in the accumulation of rather significant quantities of salvaged materials. As a result, it was the Department's desire to evaluate the potential for using a portion of this material in a conventional asphalt plant modified to accomplish heat transfer to permit the production of an asphalt concrete mixture meeting the design requirements of a standard asphalt concrete leveling course.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the hot mix recycling process by collecting data relative to the quality of construction and performance of the roadway.

The project is located on State Road 30 (US 98) in Panama City, and consists of a four-lane section 3.276 miles in length.

Work on the project included milling the existing asphalt pavement to varying depths (1 to 3.5 inches) to restore the pavement surface to a uniform longitudinal profile and cross-section. The milled surface was then resurfaced with a one-inch leveling course of standard Department of Transportation Type II asphalt concrete which incorporated 30 percent of the material milled from the old pavement. A one-inch asphalt concrete friction course (FC-1) was then placed over the recycled layer. This resulted in a finished riding surface which was not more than one-half inch above the lip of the existing gutter.

PRELIMINARY INVESTIGATION

Description of Existing Pavement

The original roadway, constructed about 1930, consisted of a portland cement concrete pavement 20 feet wide placed on natural subgrade material.

In 1954, the portland cement concrete pavement was removed on the eastern portion (1.608 miles) of the project and replaced with a sand bituminous road mix (SBRM) base and a one-inch Type I asphalt concrete surface. The Type I asphalt concrete surface consists of approximately 56 percent blast furnace slag, 38 percent local sand, and 5.5 percent asphalt cement (penetration grade 85-100). The new construction included expanding the roadway to 49 feet in width and the addition of curb and gutter.

The portland cement concrete pavement was left in place on the western portion (1.688 miles) of the project but was widened to 49 feet using a shell base. This section of roadway was then leveled with a sand asphalt hot mix (SAHM) and resurfaced with a Type II asphalt concrete mixture. The Type II surface was approximately one inch thick and consisted of 56 percent mollusk shell, 38 percent local sand, and 6.0 percent asphalt cement (penetration grade 85-100).

In 1964, the entire project (3.276) was again leveled and resurfaced using a Type II asphalt concrete mixture consisting of mollusk shell and local sand. The asphalt cement used was penetration grade 85-100.

Due to the difference in the construction history of the eastern and western portions of the project, the roadway was divided into two general areas for evaluation purposes. The west end of the project from Milepost 6.332 (Harrison Avenue) to Milepost 8.020 (Sherman Avenue) was designated as one test area containing Section 1A in the eastbound traffic lane (EBTL) and 1B in the westbound traffic lane (WBTL). The east end of the project from Milepost 8.020 (Sherman Avenue) to Milepost 9.628 (Cherry Street) was designated as the other test section area and contains Section 2A in the EBTL and 2B in the WBTL.

Traffic Volumes

Traffic records show the average daily traffic (ADT) to be 12,600.

Friction Numbers

Preliminary friction measurements were made at 40 mph in accordance with ASTM E 274-77. Average friction numbers at 40 mph (FN_{40}) of 34.2

and 34.6 were obtained and considered to be representative of Sections 1A and 1B, respectively. Average values of 39.4 and 39.2 were obtained and considered to be representative of Sections 2A and 2B, respectively (Table 1).

Present Serviceability Index Values

The preliminary Present Serviceability Index values, based on slope variance only ($PSI_{\overline{SV}}$), were determined using the Mays Ride Meter. Results of these tests indicated a rating of 2.38 in Section 1A and 2.24 in Section 1B. A rating of 2.38 was obtained in Section 2A and 2.24 in Section 2B (Table 1). All tests were performed in accordance with Florida Method of Test Designation FM 5-509.

Rut Depth Measurements

Rut depth measurements were made at 200-foot intervals in the outside wheelpath (OWP) of all test sections. Measurements varied from 0.00 inch to 0.90 inch, with the average measurement for each of the four sections being 0.32 inch (Table 1).

Benkelman Beam Deflections

Benkelman Beam deflections measurements were made at 200-foot intervals in both the inside wheelpath (IWP) and OWP of the four test sections.

The deflection measurements varied from .004 to .047 inch in the OWP of Section 1A with an average of .024 inch, and from .012 inch to .042 inch in the IWP with an average of .021 inch. The OWP of Section 1B varied from .008 to .067 inch with an average of .025 inch. The IWP ranged from .005 inch to .051 inch with an average of .020 inch.

The measurements ranged from .007 inch to .047 inch in the OWP of Section 2A with an average of .024 inch, and from .007 to .042 inch in the IWP with an average of .021 inch. The OWP of Section 2B varied from .008 inch to .067 inch with an average of .025 inch. The IWP ranged from .005 inch to .051 inch with an average of .020 inch.

The average deflection measurements are summarized in Table 1.

Cracking

Visual observations indicated 196 square feet per 1,000 square feet of Class II and Class III cracking in Sections 1A and 2A, and 193 square feet per 1,000 square feet in Sections 1B and 2B (Table 1).

Results of Roadway Cores

Prior to recycling, 6-inch cores representative of the four test sections were obtained from the existing pavement for evaluation in the laboratory.

Only the portion of the cores representing the areas to be milled and recycled was used in the laboratory evaluation.

The top 3.5 inches was separated from the cores obtained from Sections 1A and 1B and 1 inch from cores obtained from Sections 2A and 2B.

The average asphalt contents and aggregate gradations determined from the roadway cores are presented in Table 2.

The average asphalt contents and aggregate gradations determined from the milled material are also presented in Table 2 to show the change in gradation after milling.

The Abson method of recovery (FM 1-T 170) was used to recover the asphalt cement from the roadway cores. Penetration at 77°F, viscosity at 140°F and 77°F, and complex flow determinations from the recovered asphalt are shown in Table 3. The higher viscosity and lower penetration values found in Sections 1A and 1B were to be expected since the leveling and surface courses placed in 1954 and 1964 were both included. Only the 1-inch surface course which was placed in 1964 was included in Sections 2A and 2B.

The milled material from the two sections was not handled separately during production of the recylced mix. It was anticipated that the different characteristics of the asphalt cement in the two sections would not cause significant non-uniformity in the recycled mixtures. This assumption was based on the fact that the asphalt in the milled material only comprised about one-third of the total asphalt required in the mixture, and that the milled material from the two sections would also undergo a considerable amount of mixing during handling prior to processing.

Indirect tension tests were performed on 4-inch cores taken from the four sections to determine the tensile strength of the existing pavement. The results of these tests are presented in Table 4.

MIX DESIGN

The design of recycled asphalt mixtures consists of blending new and old materials to provide suitable design properties. The amount of salvaged pavement materials that can be used in a recycled mixture is somewhat limited when processing with a batch plant due to the heat transfer that is required from the uncoated aggregate to the milled material.

Based on previous experience, it was anticipated that the use of 30 percent milled material in the mix would allow an adequate heat transfer during mixing.

Virgin aggregates were then selected and blended with the milled material in the proper proportions to provide a composite gradation within the design range specified for a standard Florida Department of Transportation Type II asphalt concrete mixture.

The hot mix design data was determined using the standard Marshall method of test (FM 1-T 245).

Extraction tests were conducted on specimens that were considered to be at optimum to determine actual asphalt content and aggregate gradations. The asphalt content previously determined in the milled material was subtracted from the extracted value to determine the optimum amount of new asphalt to be added. The aggregate gradation determined from the extraction of the recycled mixture was recorded as the job mix formula.

The design blend and hot mix design data for the Type II recycled asphalt concrete mixture is presented in Table 5. The mixture consists of 30 percent milled pavement material, 32 percent gravel screenings, and 38 percent local sand. The optimum asphalt content for the combination was determined to be 6.4 percent by weight of the total mixture. The amount of new asphalt cement required was found to be 4.5 percent with the remaining 1.9 percent obtained from the salvaged mix.

The design blend and hot mix design data for the asphalt concrete friction course (FC-1) is given in Table 6. The mixture consisted of 60 percent slag screenings and 40 percent local sand. The asphalt cement content was 5.5 percent by weight of the total mixture.

CONSTRUCTION PROCEDURE

Milling of Existing Pavement

A Barber-Greene cold planing machine, equipped with material pick-up and load out conveyors, was used to remove the existing asphalt concrete pavement to a specified grade and slope (Figure 1). A three point vertically adjustable suspension system, automatically controlled by a reference ski, was used to control the depth of cut and transverse slope of the cutter. The carbide-tipped teeth on the 6-foot cutter drum were properly spaced on spiral flights to cut the pavement to a desired gradation for handling. The maximum size of the pieces of milled pavement was controlled by adjustment of the forward speed of the machine and depth of cut.

The machine included a water spray dust control system that performed satisfactorily from an environmental standpoint.

The milled surface provided a good texture for bonding of the overlay and was suitable for immediate traffic use (Figure 2).

Approximately 47,278 square yards of the existing pavement was milled to a depth of 3.5 inches from the western portion of the project, and approximately 16,094 square yards to a depth of 1 inch was milled from the eastern portion of the project. The production rate averaged approximately 1,500 square yards per day during the 33 working days required to complete the milling.

The milled material was transported to a nearby plant site and deposited into truckload size stockpiles. The purpose of the small piles was to prevent further degradation and re-cementation of the material (Figure 3).

Plant Operations

The 8,000 pound capacity Heatherington & Burner (H & B) batch plant used to produce the recycled mixture was owned and operated by Florida Asphalt Paving Company, Panama City, Florida (Figure 4). The necessary attachments needed to handle the milled material were manufactured by the H & B Company and installed on the plant by Florida Asphalt Paving.

As shown in Figures 5 and 6, the attachments included a cold bin, material elevator, surge hopper and drag-out belt. The drag-out belt was controlled by a variable speed motor so that the milled material could be fed from the surge hopper into the weigh box in the proper proportions. The uncoated aggregates were fed through the dryer, heated to approximately 450°F, and processed through the hot bins before being deposited into the weigh box with the milled material.

The combined materials were then moved to the pugmill and dry mixed for approximately 15 seconds. After the asphalt cement (AC-20) was added, mixing was continued for about one minute to complete the mixing cycle. The extended mixing period was required to provide time for adequate heat transfer from the uncoated aggregate to the milled material. This approach resulted in the temperature of the recycled mixture when discharged from the pugmill being approximately 290°F.

A summary of the mix temperatures monitored at the plant during each day's production is included in Table 7.

The dust collection system on this plant, which included a primary collector and bag house (Figure 7), was well suited for the abnormally high temperatures of the uncoated aggregates. The dust temperature was reduced from approximately 450°F to approximately 250°F in the primary collector before entering the bag house, thus protecting the bags from the high heat.

The average production of the plant when producing the recycled mix was approximately 100 tons per hour.

The quality control at the plant was based on results of the extraction tests performed in accordance with FM 1-T 164. Results of the extraction analysis as determined at various intervals of production are included in Table 8.

Samples of the recycled mixture were taken from the trucks and compacted at the plant for Marshall stability, flow, and density determinations in accordance with FM 5-511. Results of these tests, representing each day's production, are included in Table 9.

Samples of the recycled mixture were also compacted at the plant for immersion compression tests to determine the effects of water on cohesion of the compacted mixture. The tests were conducted in accordance with AASHTO T 165-77. As shown in Table 10, the average retained strength was 144 percent after 24-hour immersion in water at 140°F.

Samples of the recycled mixture were also taken each day for recovery of the asphalt cement by the Abson process (FM 1-T 170). The physical characteristics of the recovered asphalt are summarized in Table 11.

The amount of milled material in the mix was increased from 30 to 35 percent for a brief period during the second day of production. This was done in an attempt to establish the maximum amount of milled material that could be processed effectively.

The coating of the mixture was found to be poor at 35 percent. The poor coating was believed to be a result of an insufficient transfer of heat to the milled material. The heat of the uncoated aggregates could not be raised to improve the situation due to the high moisture content of these aggregates. Moisture contents determined from the aggregate stockpiles showed 10.5 percent in the gravel screenings, 15.0 percent in the local sands, and 5.1 percent in the milled material.

It is believed that the amount of milled material could have been increased possibly to as much as 40 percent if the cold materials contained lesser amounts of moisture.

The friction course (FC-1) mixture used on this project was produced using conventional methods in accordance with the Florida Department of Transportation's 1978 Quality Assurance Specifications for Bituminous Mixtures. The quality control and acceptance test results were all within the allowable tolerances.

A summary of the mix temperatures monitored at the plant during each day's production is included in Table 12.

The asphalt contents and gradations of the extracted aggregates are presented in Table 13.

The density, air voids, Marshall stability, and flow values determined from specimens compacted at the plant are included in Table 14.

Characteristics of the asphalt cement (AC-20) recovered from the friction course (FC-1) mixture are recorded in Table 15.

Paving Operations

Prior to placing the recycled pavement, the milled surface was broomed to remove any fine material left by the milling machine. An asphalt emulsion tack coat (RS-2) was then applied at the rate of approximately 0.05 gallon per square yard.

The 1-inch recycled asphalt layer was placed in two one-half inch lifts. The first lift was placed with an asphalt spreader mounted on a motor grader (Figure 8). The second layer of recycled mix was placed with a paving machine (Barber-Greene - SB 140).

A method specification was used for compaction of the recycled mix, in that a standard rolling pattern was adopted for each lift. Breakdown rolling was done in a single pass by a tandem steel-wheel roller. Five passes were then applied with a pneumatic-tired roller. Finish rolling was done with two passes of a steel-wheel roller.

The 1-inch friction course was placed with a paving machine in a single pass. Rolling was accomplished with the same equipment used on the recycled mix. The rolling sequence was established by the control strip method in accordance with the Supplemental Specifications to the 1977 Standard Specifications for Road and Bridge Construction. The in-place density for acceptance was determined by the use of the Nuclear Density Backscatter Method as specified by FM 1-T 238 (Method B).

The control strip density achieved was 99 percent of the laboratory value. The acceptance test values obtained were all above the required minimum of 98 percent of the control strip.

POST-CONSTRUCTION PERFORMANCE

When the project was completed, four one-half mile sections considered to be representative of the total project were selected from the east and westbound lanes of the project for all future in-detph studies. The locations of these sections, designated as Sections 1A, 1B, 2A, and 2B are shown in Figure 9.

Friction Numbers

Friction measurements at 40 mph (FN_{40}) were made following completion of the project. In Section 1A, an average friction value of 41.5 was obtained, and a value of 41.3 was obtained in Section 1B. In Section 2A, an average value of 42.6 was obtained, and 42.7 was obtained in Section 2B. As shown in Table 1, there was an approximate 10 point improvement over the previously existing pavement surface throughout the project.

Present Serviceability Index Values

The $PSI_{\overline{SV}}$ values for the completed pavement were determined using the Mays Ride Meter. The values obtained compared well with those expected for a conventional overlay in a municipal curb and gutter section. As shown in Table 1, there was a substantial improvement in the rideability as compared with the former pavement surface.

Rut Depth Measurements

Rut depth checks were made on the completed pavement after it had been opened to traffic for more than one month. There was no measurable rutting during this period (Table 1).

Benkelman Beam Deflections

Benkelman Beam deflection measurements were also made on the completed pavement after being opened to traffic for approximately one month. The results of these tests are shown in Table 1.

In general, the deflection measurements obtained in Sections 1A and 1B increased, while those obtained from Sections 2A and 2B decreased.

The average values of the deflection measurements in Section 1A and 1B are somewhat higher than those obtained in Sections 2A and 2B. However, all values are within the range considered to be normal for this type of pavement facility.

Cracking

The initial crack survey of the completed pavement was made after the roadway had been opened to traffic for one month. As would be expected, there were no visible cracks at that time.

Results from Roadway Cores

Following completion of the project, 6-inch cores were obatined from all test sections for evaluation in the laboratory.

The 1-inch friction course (FC-1) and the 1-inch recycled mix were separated from the cores and tested separately for evaluation of the asphalt content, gradation, unit weight, air voids, and rheological characteristics of the recovered asphalt.

The asphalt content and gradation results obtained from the recycled mixture are presented in Table 16.

Unit weight measurements and air void contents for the recycled layers are included in Table 17.

Characteristics of the asphalt recovered from the recycled layer, which include the penetration and rheological properties, are shown in comparison to properties in the previously existing pavement (Table 3)

The asphalt content and gradation analysis of the friction course (FC-1) are presented in Table 18.

Unit weight measurements and air void contents are included in Table 19.

The penetration and rheological properties of the asphalt recovered from the friction course are summarized in Table 20.

Indirect tension tests were performed on 4-inch cores taken from the test sections to determine the tensile strength of the combined recycled and friction course layers. Results of the indirect tension tests as compared to the existing pavement are shown in Table 4.

COST ANALYSIS

Conservation of Natural Resources

The 30 percent of recycled material that was incorporated into the Type II mixture on this project was considered to be the only difference between a conventional equivalent method of reconstruction and recycling.

A Type II mixture, which would have been used under a conventional method, would have included 60 percent gravel screenings and 40 percent local sand. Therefore, it was determined that the 30 percent recycled material used replaced 28 percent of the gravel screenings and 2 percent of the local sand. Use of the recycled material also decreased the demand for new asphalt in the mix by 1.9 percent.

The actual quantity of virgin aggregates and asphalt that was replaced by the recycled material is computed in Table 21. Based on these computations, 1,521 tons of gravel screenings, 109 tons of local sand, and 25,953 gallons of asphalt cement were conserved by using the recycling method of construction.

Economic Analysis

The estimated cost of the aggregates and asphalt that was replaced by the recycled material is computed in Table 21. Based on these figures, the recyling project was constructed for $26,776.47 less than estimated for a conventional equivalent method.

Considering that the cost of materials required for a conventional Type II mixture was estimated to be $73,990, there was a reduction in the cost of the recycled layer of approximately 36 percent.

ENERGY REQUIREMENTS

The amount of energy required to produce and haul the aggregates and asphalt that was replaced by the recycled material is computed in Table 22. Based on these computations, a total savings of 712,756,698 BTU's was provided by using the recycling method.

Considering that the energy required to produce and haul the aggregates and asphalt for a conventional Type II mixture was estimated to be 2,107,357,260 BTU's, use of the recycling method provided an energy reduction in the recycled layer of approximately 34 percent.

SUMMARY AND CONCLUSIONS

The overall results of this project proved to be very satisfactory. The milling operation and production of the asphalt concrete mixture utilizing the salvaged material was acceptable, both from an environmental and quality standpoint.

There was a substantial improvement in the ride quality as measured by the Mays Ride Meter. In addition the construction operation did not disrupt the existing drainage system. In fact, the pavement level was reduced in the curb line and resulted in increased drainage capacity.

The friction level increased substantially over the existing pavement. The level of the improvement was approximately 33 percent as compared to the surface prior to reconstruction.

The maintenance of traffic on the milled surface in the municipal areas caused no problems, and because of the ability to maintain traffic on the milled surfaces, the production schedule was actually found to be affected less than is normally the case in planing type operations.

The tonnage production rate for the recycled asphalt concrete mixture was at a level that is consistent with the production rate normally maintained with a conventional mix when similar field leveling operations are conducted by the Department. It was therefore concluded that the production of the recycled mix did not restrict the contractor's field operations.

The reduction in cost of the salvaged layer and the reduction in energy consumption of the salvaged mix production was in the range of 30 to 40 percent which is consistent with the savings found in other studies previously conducted by the Department.

The high moisture content in the various aggregate components restricted the amount of salvaged material that could be used under the heat transfer process. Future studies will be necessary to determine if the 30 percent maximum salvaged material is the limit when using the heat transfer process under conditions existing in Florida.

There were no problems encountered in controlling the uniformity of the recycled asphalt concrete mixture, both from the standpoint of gradation and asphalt content. The contractor was able to meet the standard Quality Assurance Acceptance Specifications used by the Department.

Although the physical properties of the asphalt cement in the recycled layer were improved as compared to the existing material, the resulting rheological properties were not in the range that would normally be expected when using 100 percent virgin asphalt cement.

Performance evaluations in the field will be necessary to determine if there is an effect on the service life as a result of the conditions of the asphalt cement. There was no asphalt cement modifier used in conjunction with the production of the mix, and previous studies have shown that use of an asphalt modifier would restore the properties of the asphalt cement to the range normally obtained with a 100 percent virgin asphalt cement mixture. Further studies are planned in which modifiers will be utilized in conjunction with the heat transfer process in order to compare the performance of a mix with and without the modifier additive.

To date, flexural fatigue test results are not available; however, this testing is scheduled and the results of the tests will be included in future reports.

TABLE 1

SUMMARY OF FIELD EVALUATION

Test	Location	Existing Pavement Before Recycling	Recycled Pavement: After Construction	Six Months	One Year	Two Years	Three Years
FN_{40}	Section 1A - EBTL	34.2	41.5				
	1B - WBTL	34.6	41.3				
	Section 2A - EBTL	39.4	42.6				
	2B - WBTL	39.3	42.7				
$PSI_{\overline{SV}}$	Section 1A - EBTL	2.38	4.18				
	1B - WBTL	2.24	4.03				
	Section 2A - EBTL	2.38	4.31				
	2B - WBTL	2.24	4.33				
Rut Depth (inch)	Section 1A - EBTL - OWP	0.32	0.00				
	1B - WBTL - OWP	0.32	0.00				
	Section 2A - EBTL - OWP	0.32	0.00				
	2B - WBTL - OWP	0.32	0.00				
Benkelman Beam (inch)	Section 1A - EBTL - OWP	.024	.041				
	- IWP	.021	.030				
	1B - WBTL - OWP	.025	.034				
	- IWP	.020	.012				
	Section 2A - EBTL - OWP	.024	.020				
	- IWP	.021	.015				
	2B - WBTL - OWP	.025	.024				
	- IWP	.020	.018				

(continued)

TABLE 1
(continued)

Test	Location	Existing Pavement Before Recycling	Recycled Pavement				
			After Construction	Six Months	One Year	Two Years	Three Years
Cracking (Sq. Ft./1,000 Sq. Ft.)	Section 1A - EBTL	196	0				
	1B - WBTL	199	0				
	Section 2A - EBTL	196	0				
	2B - WBTL	199	0				

TABLE 2

ASPHALT CONTENTS AND AGGREGATE GRADATIONS
(Existing Pavement Before and After Milling)

Sample Description	Section Number	Asphalt Content (%)	Gradation - Percent Passing						
			1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
Roadway Cores (Top 3½ Inches)	1A	7.0	100	98	90	80	61	13	5.2
Milled Material (Top 3½ Inches)	1B	5.6	100	99	88	69	46	24	10.5
Roadway Cores (Top 1 Inch)	2A	5.0	100	98	74	43	30	19	6.7
Milled Material (Top 1 Inch)	2B	5.3	99	85	57	37	22	10	6.3

TABLE 3

PENETRATION, VISCOSITY (140°F and 77°F), AND COMPLEX FLOW DETERMINATIONS FROM ROADWAY CORES

Test	Location	Existing Pavement Before Recycling	Recycled Pavement				
			After Construction	Six Months	One Year	Two Years	Three Years
Penetration, 1/10 mm (77°F)	Section 1A - EBTL	16	35				
	1B - WBTL	15	35				
	Section 2A - EBTL	20	30				
	2B - WBTL	20	32				
Viscosity, poises (140°F)	Section 1A - EBTL	442,895	9,290				
	1B - WBTL	338,086	9,054				
	Section 2A - EBTL	195,611	12,954				
	2B - WBTL	90,575	10,470				
Viscosity, megapoises (77°F)	Section 1A - EBTL	24.67	10.97				
	1B - WBTL	12.94	12.56				
	Section 2A - EBTL	11.07	5.36				
	2B - WBTL	13.10	9.81				
Complex Flow (77°F)	Section 1A - EBTL	0.68	0.75				
	1B - WBTL	0.61	0.74				
	Section 2A - EBTL	0.49	0.76				
	2B - WBTL	0.61	0.74				

TABLE 4

INDIRECT TENSION TEST RESULTS
(Tensile Strength, psi)

Location	Existing Pavement Before Recycling	Recycled Pavement				
		After Construction	Six Months	One Year	Two Years	Three Years
Section 1A - EBTL	162	120				
1B - WBTL	---	100				
Section 2A - EBTL	---	116				
2B - WBTL	140	107				

TABLE 5

TYPE II RECYCLED ASPHALT CONCRETE
(Design Blend and Marshall Design Data)

DESIGN BLEND

Sieve Size	Milled* Pavement Material 30%	Gravel Screenings (Chattahoochee) 32%	Local Sand (Panama City) 38%	Job Mix** Target Value	Specification Range (Percent Passing)
1/2"	77	100	100	100	100
3/8"	71	100	100	100	90-100
No. 4	52	90	100	95	80-100
No. 10	31	76	99	84	64-90
No. 40	12	21	70	48	24-60
No. 80	4	4	33	22	10-40
No. 200	0.7	1.4	12.1	8.8	3-12

MARSHALL DESIGN DATA

Asphalt Content (%)	Air Voids Content (%)	Voids in Mineral Aggregate (%)	Stability (lbs.)	Flow (.01")
6.4***	9.4	16.8	1,040	9

*Actual gradation of milled pavement material.

**Composite gradation determined from extraction of specimens used in design.

***30% Milled Pavement Material @ 6.3% = 1.9%
Additional Asphalt Cement (AC-20) Added = 4.5%
Optimum Asphalt Cement Content = 6.4%

TABLE 6

ASPHALT FRICTION COURSE (FC-1)
(Design Blend and Marshall Design Data)

DESIGN BLEND

Sieve Size	Slag Screenings (Tennessee) 60%	Local Sand (Panama City) 40%	Job Mix Target Value	Specification Range (Percent Passing)
1/2"	100	100	100	100
3/8"	100	100	100	---
No. 4	92	100	95	---
No. 10	55	100	73	55-85
No. 40	16	57	32	---
No. 80	9	27	16	---
No. 200	5.0	9.2	6.7	2-8

MARSHALL DESIGN DATA

Asphalt Content (%)	Air Voids Content (%)	Voids in Mineral Aggregate (%)	Stability (lbs.)	Flow (.01")
5.5	12.0	24.4	617	8

TABLE 7

TYPE II RECYCLED ASPHALT CONCRETE
(Temperature of Mixture)

Date	Tons Produced	Minimum (°F)	Maximum (°F)	Average (°F)
5/30/79	265	250	280	263
5/31/79	661	265	370	286
6/ 1/79	1,024	260	310	291
6/ 4/79	504	275	320	289
6/ 5/79	888	250	330	287
6/ 6/79	955	250	375	299
6/ 7/79	864	270	350	292
6/ 8/79	646	270	350	295
			Target	290

Note: The mix temperature tolerance from the Job Mix Formula was ± 25°F for any single measurement, and ± 15°F for an average of any five consecutive measurements.

TABLE 8

TYPE II RECYCLED ASPHALT CONCRETE
(Asphalt Content and Gradation of Mixture)

Tons Produced	Asphalt Content (%)	Gradation - Percent Passing						
		1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
80	6.4	100	100	95	85	41	19	5.8
280	6.4	100	100	94	83	42	22	7.8
1,026	6.5	100	100	92	82	40	21	6.3
1,350	6.3	100	100	94	84	40	18	6.1
2,120	6.8	100	100	94	86	44	21	7.2
2,323	6.5	100	100	94	85	44	19	5.9
2,534	6.5	100	100	94	86	42	19	6.7
2,620	6.3	100	100	95	87	44	17	6.6
3,441	6.2	100	100	93	85	44	22	7.8
3,819	6.2	100	100	94	83	45	21	6.3
4,059	6.3	100	100	94	85	54	21	8.6
4,396	6.3	100	100	92	82	42	20	6.1
4,703	6.3	100	100	93	84	45	28	11.9
5,220	6.3	100	100	94	85	43	20	6.1
5,360	6.6	100	100	95	86	44	21	6.9
Average	6.4	100	100	94	85	43	21	7.1
Job Mix Formula	6.4	100	100	95	84	48	22	8.8

TABLE 9

TYPE II RECYCLED ASPHALT CONCRETE
(Marshall Properties of Specimens Compacted at the Plant)

Date	Density (pcf)	Air Voids (%)	Stability (lbs.)	Flow (.01")
5/29/79	134.7	10.0	710	9
5/30/79	134.5	10.0	820	11
5/31/79	136.2	8.9	808	11
6/ 1/79	139.1	7.5	970	12
6/ 4/79	137.5	8.5	818	12
6/ 5/79	136.0	9.5	608	12
6/ 6/79	137.6	8.4	878	11
6/ 7/79	138.2	8.0	1,067	11
6/ 8/79	134.2	10.7	663	9
Average	135.4	9.1	816	11
Design	135.5	9.4	1,040	9

TABLE 10

IMMERSION COMPRESSION RESULTS
(Recycled Material Compacted at the Plant)

Sample Number	Marshall Stability (lbs.)		Retained Strength (%)
	Standard	24-Hour Immersion	
1	946	1,341	142
2	790	1,341	170
3	900	1,258	140
4	1,081	1,534	142
5	1,029	1,414	137
6	1,092	1,502	138
Average	973	1,398	144

TABLE 11

TYPE II RECYCLED ASPHALT CONCRETE
(Characteristics of Asphalt Recovered from Mixture During Production)

Date	Penetration, 77°F	Viscosity, 140°F (poises)	Viscosity, 77°F (megapoises)	Complex Flow, 77°F	Viscosity 41°F (megapoises)	Complex Flow, 41°F
5/30/79	45	6,389	3.72	0.78	37.2	0.51
5/31/79	32	12,847	5.94	0.73	35.9	0.70
6/ 1/79	40	7,430	4.49	0.78	66.3	0.59
6/ 4/79	45	6,114	4.25	0.84	64.5	0.62
6/ 5/79	45	6,092	4.29	0.84	100.6	0.68
6/ 6/79	40	7,595	5.83	0.91	123.5	0.67
6/ 7/79	44	6,104	4.21	0.80	132.0	0.73
6/ 8/79	35	11,916	6.09	0.75	184.9	0.70

TABLE 12

ASPHALT FRICTION COURSE (FC-1)
(Temperature of Mixture)

Date	Tons Produced	Minimum (°F)	Maximum (°F)	Average (°F)
8/ 1/79	202	300	325	315
8/ 2/79	1,227	250	350	300
8/ 3/79	1,060	260	325	289
8/ 6/79	814	250	300	283
8/ 7/79	865	275	350	303
			Target	285

Note: The mix temperature tolerance from the Job Mix Formula was ± 25°F for any single measurement, and ± 15°F for an average of any five consecutive measurements.

TABLE 13

ASPHALT FRICTION COURSE (FC-1)
(Asphalt Content and Gradation of Mixture)

Date Tested	Asphalt Content (%)	Gradation - Percent Passing						
		1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
8/1/79	5.6	100	100	95	74	41	20	7.3
8/2/79	5.9	100	100	96	75	40	20	7.9
8/3/79	5.3	100	100	96	75	40	19	7.3
8/6/79	5.8	100	100	96	78	43	21	8.0
8/7/79	5.8	100	100	95	67	34	17	7.3
Average	5.7	100	100	96	74	40	19	7.6
Job Mix Formula	5.5	100	100	95	73	32	16	6.7

TABLE 14

ASPHALT FRICTION COURSE (FC-1)
(Marshall Properties of Specimens Compacted at the Plant)

Date	Density (pcf)	Air Voids (%)	Stability (lbs.)	Flow (.01")
8/ 2/79	134.8	11.7	988	11
8/ 3/79	133.5	12.4	713	11
8/ 6/79	134.6	11.9	737	11
8/ 7/79	133.3	12.6	784	8
Average	134.1	12.2	806	10
Design	132.7	12.0	617	8

TABLE 15

ASPHALT FRICTION COURSE (FC-1)
(Characteristics of Asphalt Recovered from Mixture During Production)

Date	Penetration, 77°F	Viscosity, 140°F (poises)	Viscosity, 77°F (megapoises)	Complex Flow, 77°F	Viscosity 41°F (megapoises)	Complex Flow, 41°F
8/ 1/79	49	4,859	3.35	0.92	63.6	0.68
8/ 2/79	49	4,756	3.14	0.87	71.1	0.73
8/ 3/79	56	4,167	4.27	0.87	84.4	0.73
8/ 6/79	44	5,528	4.89	0.88	175.7	0.81
8/ 7/79	62	2,825	2.47	0.92	46.3	0.61

TABLE 16

ASPHALT CONTENTS AND AGGREGATE GRADATIONS
(Recycled Pavement After Construction)

Location	Asphalt Content (%)	Gradation - Percent Passing						
		1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
Section 1A - EBTL	6.8	100	100	93	80	46	20	7.0
1B - WBTL	6.4	100	99	94	82	47	22	8.0
Section 2A - EBTL	6.5	100	99	93	81	45	21	7.5
2B - WBTL	6.7	100	100	95	85	46	21	9.7

TABLE 17

UNIT WEIGHT AND AIR VOID MEASUREMENTS
DETERMINED FROM ROADWAY CORES

Test	Location	Recycled Pavement: After Construction	Six Months	One Year	Two Years	Three Years
Unit Weight (pcf)	Section 1A - EBTL	136.7				
	1B - WBTL	136.8				
	Section 2A - EBTL	137.3				
	2B - WBTL	136.9				
Air Voids (%)	Section 1A - EBTL	7.6				
	1B - WBTL	8.5				
	Section 2A - EBTL	7.9				
	2B - WBTL	7.9				

TABLE 18

ASPHALT CONTENTS AND AGGREGATE GRADATIONS
(Friction Course (FC-1) Pavement After Construction)

Location	Asphalt Content (%)	Gradation - Percent Passing						
		1/2"	3/8"	No. 4	No. 10	No. 40	No. 80	No. 200
Section 1A - EBTL	5.9	100	100	93	64	33	16	7.2
1B - WBTL	6.1	100	100	97	75	37	18	7.6
Section 2A - EBTL	5.3	100	100	97	73	39	19	7.6
2B - WBTL	5.4	100	100	95	72	37	17	8.7

TABLE 19

UNIT WEIGHT AND AIR VOID MEASUREMENTS
DETERMINED FROM ROADWAY CORES

Test	Location	Friction Course (FC-1) Pavement				
		After Construction	Six Months	One Year	Two Years	Three Years
Unit Weight (pcf)	Section 1A - EBTL	131.4				
	1B - WBTL	133.8				
	Section 2A - EBTL	132.7				
	2B - WBTL	129.4				
Air Voids (%)	Section 1A - EBTL	14.5				
	1B - WBTL	11.9				
	Section 2A - EBTL	13.1				
	2B - WBTL	14.9				

TABLE 20

PENETRATION, VISCOSITY (140°F and 77°F), AND COMPLEX FLOW DETERMINATIONS FROM ROADWAY CORES

Test	Location	Friction Course (FC-1) Pavement				
		After Construction	Six Months	One Year	Two Years	Three Years
Penetration, 1/10 mm (77°F)	Section 1A - EBTL	36				
	1B - WBTL	32				
	Section 2A - EBTL	37				
	2B - WBTL	32				
Viscosity, poises (140°F)	Section 1A - EBTL	8,846				
	1B - WBTL	17,748				
	Section 2A - EBTL	8,862				
	2B - WBTL	10,259				
Viscosity, megapoises (77°F)	Section 1A - EBTL	7.54				
	1B - WBTL	8.76				
	Section 2A - EBTL	6.91				
	2B - WBTL	9.81				
Complex Flow (77°F)	Section 1A - EBTL	0.83				
	1B - WBTL	0.76				
	Section 2A - EBTL	0.86				
	2B - WBTL	0.74				

TABLE 21

SUMMARY OF QUANTITY AND COST OF RECYCLED PAVEMENT

Quantity of Materials that was Replaced by the Recycled Pavement

28.0% Gravel Screenings x 5,433 Tons	=	1,521 Tons
2.0% Local Sand x 5,433 Tons	=	109 Tons
1.9% Asphalt x 5,804 Tons = $\frac{110.3 \text{ Tons} \times 2{,}000}{8.5}$	=	25,593 Gallons

Cost of Materials that were Replaced by the Recycled Pavement

1,521 Tons of Gravel Screenings @ $10.00/Ton	= $15,210.00
109 Tons of Local Sand @ $1.35/Ton	= $ 147.15
25,953 Gallons of Asphalt @ $0.44/Gallon	= $11,419.32
	$26,776.47

TABLE 22

ENERGY REQUIREMENTS OF MATERIALS THAT WERE REPLACED BY THE RECYCLED PAVEMENT

Manufacture Asphalt Cement	=	587,500 BTU/Ton
Haul 120 Miles x 2 @ 1,960 BTU/TM	=	470,400 BTU/Ton
		1,057,900 BTU/Ton

Produce Gravel Screenings	=	70,000 BTU/Ton
Haul 78 Miles x 2 @ 1,960 BTU/TM	=	305,760 BTU/Ton
		375,760 BTU/Ton

Produce Local Sand	=	15,000 BTU/Ton
Haul 18 Miles x 2 @ 5,840 BTU/TM	=	210,240 BTU/Ton
		225,240 BTU/Ton

Asphalt		
1.9% @ 1,057,900 BTU/Ton (5,804 Tons)	=	116,660,980 BTU
Gravel Screenings		
28% @ 375,760 BTU/Ton (5,433 Tons)	=	571,621,140 BTU
Local Sand		
2% @ 225,240 BTU/Ton (5,433 Tons)	=	24,474,578 BTU
		712,756,698 BTU = Total Energy Saved

FIGURE 1

Milling Machine in Operation

FIGURE 2

Milled Surface

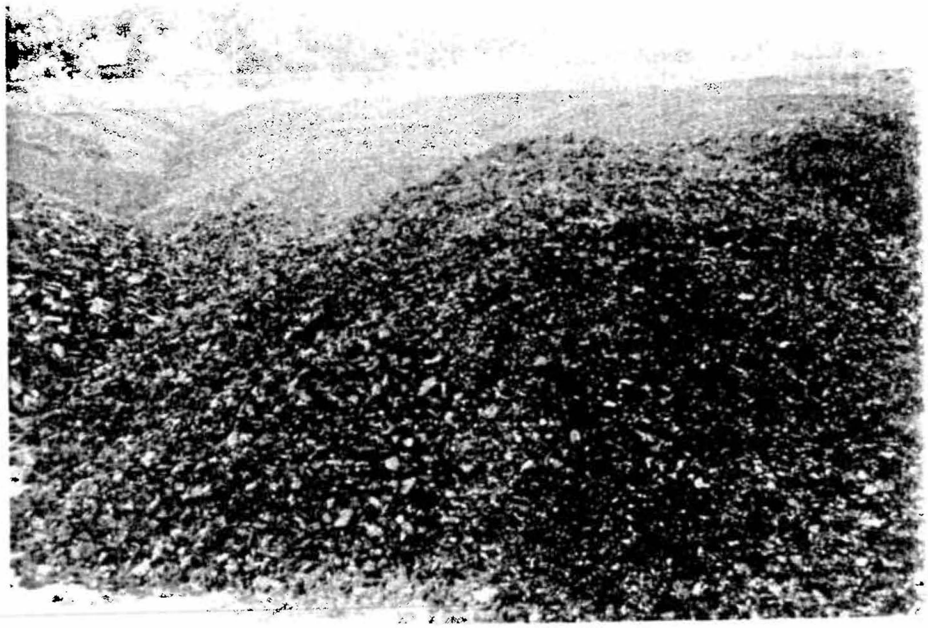


FIGURE 3

Milled Material Stockpile

FIGURE 4

Batch Plant Used to Process Recycled Mixture

FIGURE 5

Attachments Used for Recycling

FIGURE 6

Surge Hopper and Drag-Out Belt

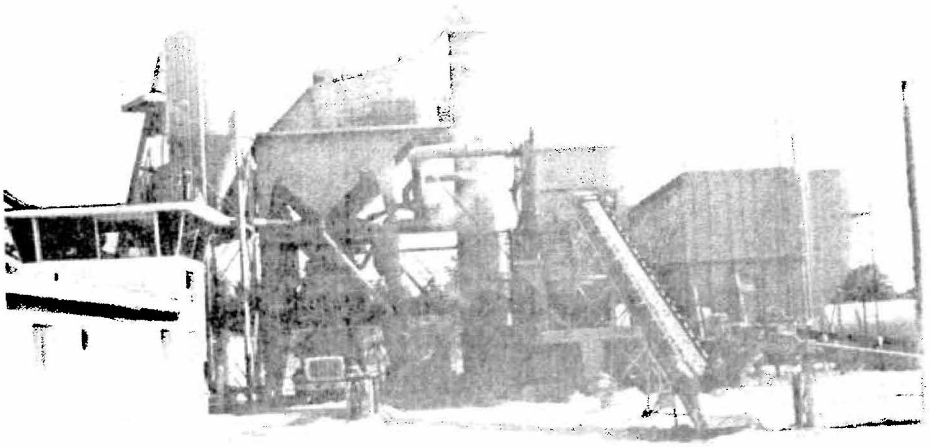


FIGURE 7

Dust Collection System

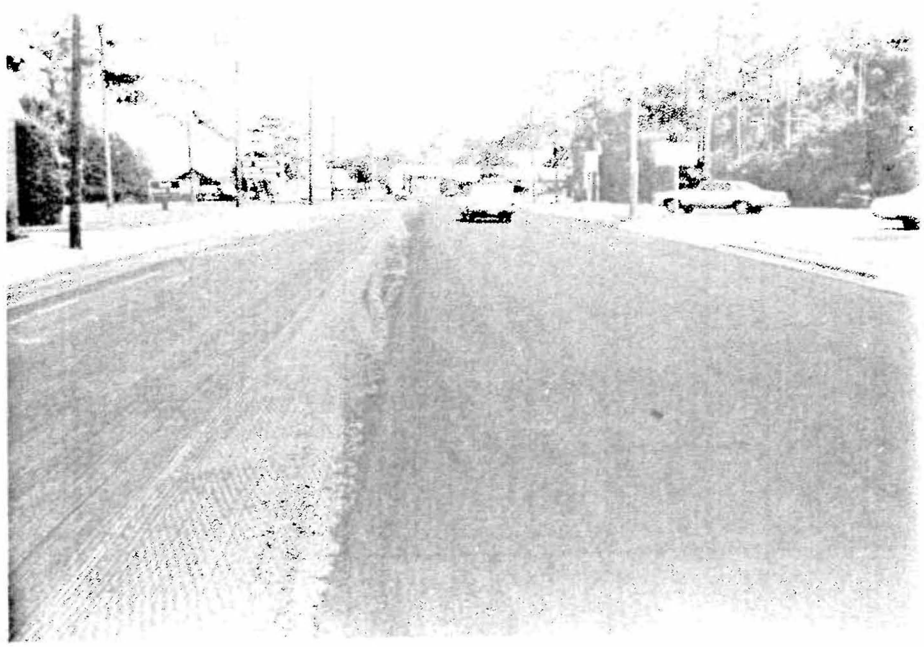
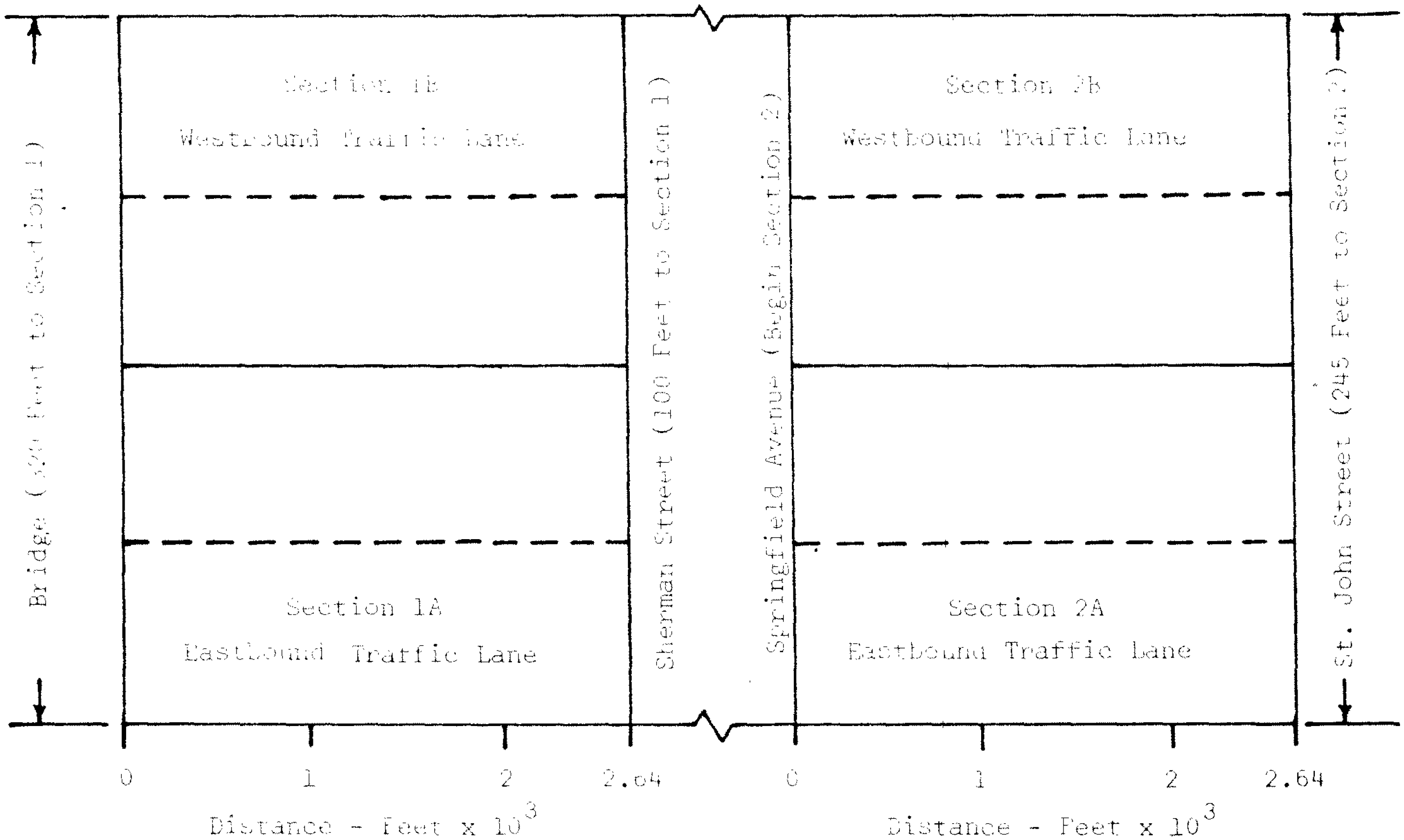


FIGURE 8

View of Contrast of First Course of Recycled Leveling Mixture and Milled Pavement



Sections 1A and 1B

3½" Milling
50 Lbs. Leveling
50 Lbs. Surface
100 Lbs. FC-1

Sections 2A and 2B

1" Milling
50 Lbs. Leveling
50 Lbs. Surface
100 Lbs. FC-1

FIGURE 9

LOCATION OF TEST SECTIONS