TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWATX78204-1F		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Energy Saving Methods of Restoring Pavement Surface Characteristics	5. Report Date: June, 1977 6. Performing Organization Code:
7. Author(s) Underwood, J. P.	8. Performing Organization Report No. 204-1F
9. Performing Organization Name and Address Texas State Department of Highways and Public Transportation P. O. Box 5051 Austin, Texas 78763	10. Work Unit No. 11. Contract or Grant No. 1-10-75-204
12. Sponsoring Agency Name and Address Same as No. 9	13. Type of Report and Period Covered Final Sept. 1975 - Aug. 1976 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with D.O.T. and FHWA
Study Title: "Energy Saving Methods of Restoring Pavement Surface Characteristics"

16. Abstract

The need to conserve natural resources has become a major concern to highway engineers everywhere. This concern has manifested itself in several ways, one of which is the attempt to restore the functional characteristics of a pavement without consuming large amounts of additional resources such as aggregates, asphalts and fuel.

This study investigated several procedures and techniques which were designed to upgrade pavements without the expenditure of large amounts of additional resources. Asphaltic pavements were recycled with both open-flame heating and radiant heating, treated with rejuvenating agents, and sprinkled with skid resistant stones. Resulting structural integrity ranged from dubious to fair. Skid resistance was generally improved but it had a tendency to quickly drop on the sections which had not been treated with skid resistant stones.

The Portland cement concrete pavement test section was blasted with high pressure water sprays in an effort to improve the skid resistance. The technique proved effective but the improvement was short-lived.

17. Key Words	18. Distribution Statement
Heater-Planer, Water-Blasting, Sprinkle Treatment, Skid Resistance, Pavement Recycling	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	35	

Form DOT F 1700.7 (8-69)

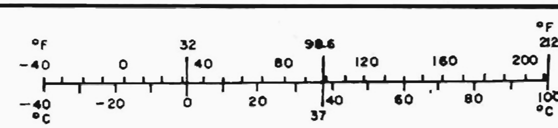
METRIC CONVERSION FACTORS

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

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



ENERGY SAVING METHODS OF RESTORING PAVEMENT SURFACE CHARACTERISTICS

by

Jon P. Underwood

Report No. 204-1F

Research Study 1-10-75-204
ENERGY SAVING METHODS OF RESTORING PAVEMENT SURFACE CHARACTERISTICS

in cooperation with

U.S. Dept. of Transportation
Federal Highway Administration

June 1977

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

TABLE OF CONTENTS

	Page
Metric Conversion Factors	ii
List of Figures	vi
List of Tables	viii
Summary	ix
Implementation Statement	x
Introduction	1
Description of Previous Work in Texas	2
Description of Tests	5
Section #1	5
Section #2	5
Section #3	7
Section #4	7
Section #5	15
Section #6	19
Section #7	26
Section #8	29
Section #9	31
Map Showing Locations of Test Sections	33
Summary of Tests	34
Conclusions and Recommendations	35

LIST OF FIGURES

Figures		Page
1	Open-Flame Heater-Planer	2
2	Example of Aggregate Loss in Wheel Paths	6
3	Comparison of Wheel Path Texture with that of Remaining Roadway	6
4	Close-up of Roadway Texture Between Wheel Paths	7
5	Traffic on Recycled Roadway	8
6	Comparison of Visual Differences Between Sections 3 and 4	9
7	Surface Cracking	10
8	Scarifier Teeth Marks in Pavement	10
9	View of Recycled Pavement Surface After Approximately Five Months in Place	11
10	Edge of Recycled Pavement	11
11	Radiant Heat Surface Recycling Apparatus	12
12	Bottom View of Radiant Heat Elements	13
13	Pavement Scarifier Mechanism	14
14	Mixing Augers	14
15	Close-up of Vibratory Screed	15
16	View of Recycled Pavement Surface Prior to Rolling	16
17	Pavement Corrugations	17
18	Alligator Cracking of Pavement Surface	18
19	Fines Pumped to Surface of Roadway	18
20	Spalled Pavement Surface	19
21	Rejuvenating Agent Spray Bar	20

LIST OF FIGURES (Con't)

Figures		Page
22	Recycled Surface Prior to Sprinkle Treatment Application	21
23	Sprinkle Treatment Application Using Salt Spreaders	21
24	Sprinkle Treated Surface Prior to Rolling	22
25	Rolled Sprinkle Treated Surface	22
26	Recycled Sprinkle Treated Surface After One Year's Exposure to Traffic	25
27	Longitudinal Edge Crack Between Recycled Surface and Shoulder	26
28	Skid Resistant Aggregate on Roadway Prior to Recycling	27
29	Spalling of Blended Recycled Surface	28
30	Transverse Crack over Edge of P.C.C. Pavement	29
31	Narrow Random Surface Cracking	30
32	Wide Random Surface Cracking	31

LIST OF TABLES

Page

Table 1 17

Table 2 23

Table 3 28

Table 4 30

SUMMARY

The "energy crisis" brought about changes in all ways of life. Highway departments were not excluded from the necessity of change, also. New looks at overlaying or surface treating pavements were required. Most existing procedures which did not require overlays involved the use of a heater-planer type machine on flexible pavements. The heater-planer was utilized to shave off a thin portion of the existing surface to expose new aggregate faces to the tire, thereby increasing skid resistance.

The energy crisis emphasized the need to investigate new procedures to improve surface characteristics without additional overlays.

Advancements in technology indicated that heater-planer type equipment could be used to recycle roadway surfaces without transporting the material to a crusher and hot mix plant.

Both open-flame and radiant heat surface recycling machines were used to construct experimental sections for this project.

Both open-flame and radiant heat equipment can recycle asphaltic concrete surfaces in place, but a longer lasting surface is produced if a small amount of new asphaltic concrete is added to the recycled portion prior to replacement on the roadway.

IMPLEMENTATION STATEMENT

Information contained in this report supports the conclusion that "asphaltic pavements can be recycled in place" by heater-planer type equipment if the following suggestions are incorporated into future jobs:

1. A small amount of new hot-mix asphaltic concrete should be mixed with the recycled materials. Observation and investigation of subsequent, non-project related jobs have indicated that the addition of as little as 28 pounds of new material per square yard of surface area may significantly improve the resulting mix.

2. Conscientious inspection should be employed to insure constant depth of scarification.

3. Specifications should be employed for controlling the rate of asphalt distribution applied to the recycled mix.

4. Screed temperature should be specified and checked periodically.

5. Maintenance of sufficient skid resistance should be required.

6. Specifications which regulate the minimum air temperature allowable for surface recycling should be developed.

INTRODUCTION

The energy crisis brought about changes in most life styles. These changes were caused by financial necessity, unavailability of goods and services and many other factors. The highway departments throughout the nation were not excluded from the necessity for changes also.

Inflation and reduced revenue from less driving created a severe monetary crisis in highway agencies everywhere. Second looks at old procedures of overlaying or surface treating to correct pavement surface characteristics or merely skid resistance were required. In some cases, these were only considered. Other cases brought about the trying of new and innovative methods and procedures to correct these surface characteristics without an overlay or surface treatment, especially when the existing surface was structurally sound. It is a known fact that numerous procedures for improving pavement surface characteristics have been tried by various individuals and organizations. Most of this work was done for a particular roadway situation and very little has been reported regardless of the success or failure of the methods or procedures. The literature search conducted under this project revealed that most of the reported attempts to improve pavement surface characteristics have in one way or another involved a form of grooving on rigid pavements and the application of a heater-planer type machine on flexible pavements.

Experience has shown that longitudinal pavement grooving does not, in most cases, improve the stopping coefficient of friction (SN_{40}) as measured by a skid trailer meeting ASTM E-274 specifications. The skid number, or SN_{40}, has actually been decreased in some instances. In almost all cases, the wet pavement accident history of the roadway has been drastically changed. The number of wet weather accidents has decreased due to the grooves allowing passages for water to escape, thereby requiring greater rainfall to achieve a plus water depth, i.e., a water depth over the top of the texture.

The original use of heater-planer type equipment involved open-flame burners to heat the pavement, metal teeth to scarify the heated pavement, and a blade to remove the scarified material from the roadway. Equipment was used to remove bumps or high spots in an asphaltic concrete roadway surface. This equipment was used extensively for this purpose in the beginning. The advent of skid resistance as a concern in design and maintenance of highways brought about a new use for the open-flame heater-planer: the improvement of skid resistance on existing asphaltic concrete roadways. This equipment improves the skid resistance, SN_{40}, to a better and more acceptable level in most cases and eliminates the need for an overlay or seal coat for small and/or isolated situations.

The energy crisis and advancements in technology gave rise to this type of equipment being used to recycle the top portion of an existing asphaltic concrete pavement surface. This recycling is accomplished without removing and transporting the roadway surface to a crusher and hot mix plant, thereby saving the cost of removing, rebatching and hauling the materials.

DESCRIPTION OF PREVIOUS WORK IN TEXAS

Only a limited amount of work has been done in Texas on restoration of surface characteristics for Portland cement concrete pavement. Longitudinal grooving has been used in this State only in spot locations of high wet weather accident frequency. In most cases, the stopping coefficient of friction has not been increased but wet weather accidents have decreased in number each time longitudinal grooving has been employed in these spot locations. However, the cost of this procedure versus a skid resistant overlay has made it almost prohibitive. Additional problems such as pavement structural failures have made the use of overlays mandatory in several cases.

One major longitudinal grooving contract for asphaltic concrete has been performed in Texas. This involved grooving all lanes for a distance of approximately five miles on an Interstate loop which circles one of this State's major cities. This roadway carried traffic in the range of 60,000 to 65,000 vehicles per day in the grooved location. Wet Weather accidents were high, and the decision was made to use longitudinal grooving for the entire length of the project. Approximately four years and many vehicle applications necessitated the placement of a new surface. At the time of the new skid resistant overlay, a small number of the grooves were still present and open to allow water drainage.

One Texas Highway District has recently experienced a condition not unique in that region of the country, but a normal occurrence all over the United States. This is the condition of flushed asphaltic pavement. These pavements had flushed to such an extent that a very small amount of rainfall caused a large increase in the number of skidding incidents. In an attempt to correct this problem, the decision was made to add some additional aggregate, heat the aggregate and the surface of the roadway, and embed this aggregate into the heated surface. An open-flame heater-planer was used to supply the heat (See Figure 1).

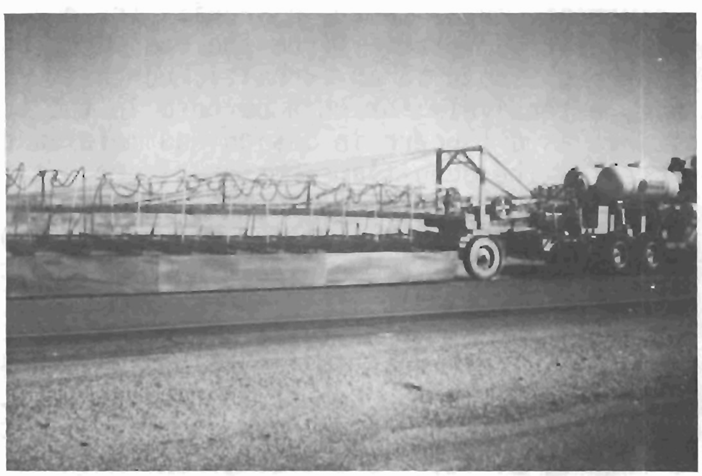


Figure 1
Open-Flame Heater-Planer

The skid resistant aggregate was applied to the roadway at an average rate of one cubic yard to 230 square yards of surface area. Two eight-ton flat wheel rollers followed by two pneumatic rollers supplied the necessary compaction.

Based on 1975 prices, the total costs for this project including equipment, materials and labor was 37 cents per square yard. This cost is comparable with a penetration surface treatment but proved to be effective for a shorter period of time than would normally be expected of a penetration surface treatment.

In late summer of 1975, a South Texas Highway Department District was faced with a potentially dangerous and embarrassing situation. Portions of a recently completed synthetic lightweight asphaltic concrete pavement were flushing and yielding less than desirable skid numbers. This condition existed in lanes in one direction of an Interstate Highway which carried an average of 20,000 vehicles per day with a large amount of trucks.

Two different procedures, both using an open-flame heater-planer, were used. The first method was a modified sprinkle treatment and the second was an attempt to remove the glazed surface by shaving off approximately 1/8" of the surface.

The modified sprinkle treatment was performed by placing a non-precoated skid resistant aggregate with a conventional chip spreader onto the surface of the pavement, heating the aggregate and the surface with a heater-planer, and rolling with an eight ton, three-wheeled roller. Short sections of sprinkle treatment and shaved areas were placed and evaluated. Testing revealed that the sprinkle treatment had skid numbers in the 50's and the shaved sections had skid numbers in the 40's; however, the shaved sections soon lost their good friction qualities while the sprinkle treatment sections continued to be satisfactory.

Based on these results, the decision was made to sprinkle treat the entire flushed section. This work was performed in the summer of 1976 and subsequent skid tests at 40 mph indicated better than acceptable skids. Cost of this project, which was done entirely with State forces, was estimated to be approximately 30 cents per square yard.

A West Texas Highway Department District initiated an experimental project to determine the feasibility of recycling old asphaltic concrete pavement by breaking it down, pulverizing it in place, adding additional asphalt and replacing it without the use of heating equipment. This course was to be used as an asphalt stabilized base.

The purpose of this experiment was to develop a procedure to utilize existing asphalt pavement by crushing the surface in place, and adding additional asphalt and a softening agent to the crushed mixture. This experimental project gave definite proof of the following:

1. Old hot mix can be crushed in place.

2. Asphalt softening agents are available to reestablish the necessary qualities of the old asphalt.

3. Adequate equipment is available to perform the job.

Skid resistance proved to be of no concern in this experimental project, since the recycled surface was to be overlayed with a skid resistant riding surface.

In another Texas Highway Department District, skid resistance was the primary concern of a test. A high pressure water spray was applied to a P.C.C. pavement test section in an effort to improve the skid resistance. The high pressure spray was expected to remove detritus, oil drippings, and small amounts of mortar from between the coarse aggregate particles. Tests confirmed that the skid resistance was improved significantly, but these effects were short-lived.

A sealant and preservative called Gilsabind was tried in another test, but it reduced the skid resistance by approximately 50%. Sand was applied to some sections in an attempt to maintain the skid resistance. It did, but the sand (and apparently the Gilsabind) was worn off by traffic very quickly.

Acid leaching was ruled out as an experimental technique for increasing the skid resistance on Portland cement concrete because of costs, difficulty in handling, and the likelihood of polluting. A "waffle" roller was considered for imparting texture to asphaltic concrete pavement, but such equipment was not readily available, and the level of interest among field personnel was low.

Many other procedures and experiments have been tried, but due to lack of reporting and applicability to more than one situation, only the more documented experiments have been reported as trials in Texas.

DESCRIPTION OF TESTS

The energy shortage and its associated high costs of asphaltic materials occurred about the same time highway designers began to realize that polish resistant aggregate was becoming a scarce commodity in many parts of the State. Therefore, the search began to find equipment to heat and recycle the surface of an asphaltic concrete pavement without removing the asphaltic materials from the roadway surface and also any other methods and/or procedures which can restore a pavement's surface characteristics without an overlay.

Nine test sections were established in order to evaluate the effectiveness of various equipment and several different construction procedures. All test sections were evaluated for skid resistance, and eight of them were evaluated for ride quality. The skid resistance measurements were taken with an automated skid measurement system conforming to the requirements of ASTM E-274. Ride quality was evaluated by use of a trailer-mounted Mays Ride Meter. Test sections #5 through #8 were monitored on a continual basis for approximately one year.

Sections #1 and #2

Test sections #1 and #2 were both located on U.S. 83 north of Abilene. They were evaluated by district personnel prior to construction, and this evaluation revealed extreme asphalt flushing in the wheel paths and slight fatigue cracking of the asphaltic concrete surface. Limited wheel path rutting was occurring in approximately 30% of the two test sections.

Skid testing prior to construction revealed a low skid test value of 14, a high of 28 and an average skid value of 22. These skid tests were performed at 40 mph. No preconstruction ride quality tests were taken.

The experiment consisted of embedding non-precoated limestone aggregate into the roadway surface. An open-flame heater-planer was used to heat the mat, and in both sections two passes were required to sufficiently heat the surface.

In the first test section, the non-precoated limestone aggregate was spread directly behind the heater (second pass) with a conventional surface chip spreader; rolling was then begun immediately. In the second test section, however, the non-precoated limestone was placed on the roadway prior to the two passes of the heater-planer.

Approximately three months after completion of the work, project personnel evaluated the performance of the test sections. This evaluation consisted of photographs, skid resistance testing and ride quality testing.

As shown in Figure 2, aggregate retention in the wheel paths was limited to only a few isolated locations.

Figure 2
Example of Aggregate Loss in Wheel Paths

This lack of aggregate retention recreated the condition of bleeding or flushed wheel paths that existed prior to experimental construction. The surface areas in which the aggregate retention was good showed a considerable increase in surface texture as indicated by Figures 3 and 4.

Figure 3
Comparison of Wheel Path Texture
with that of Remaining Roadway

Figure 4
Close-up of Roadway Texture Between Wheel Paths

Standard 40 mph skid resistance tests revealed a slight increase in the average skid number, when compared to pre-construction skid numbers. The before average skid number of 22 was raised to an after average skid number of 26. The flushed wheel paths again had a low skid number of 14, but due to aggregate retention in some areas, the high skid number was raised to 36.

Mays Ride Meter measurements taken on .05 mile increments averaged 2.6. This 2.6 is a reasonable value for asphaltic concrete surfaces approximately 5 years of age. As no before ride tests were taken, no exact determination of ride effect can be made. However, it is assumed that since no surface reshaping was done, the ride quality was not significantly affected.

Sections #3 and #4

Test sections #3 and #4 were located west of Houston on S.H. 6, and they (like sections #1 and #2) were also evaluated by district personnel prior to the experimental work. The evaluation showed the existing hot mix asphaltic concrete to be extremely rich in asphalt in most areas. Areas with less asphalt exhibited almost total surface cracking.

As was the case with sections #1 and #2, no before ride quality values were measured. Pre-construction skid testing showed a range in values of 26 to 38 with an average of 30.

This roadway had an average daily traffic approaching 5,000 vehicles per day with a large percentage being heavily loaded trucks.

Figure 5
Traffic on Recycled Roadway

The experiment was an attempt at in-place hot recycling of asphaltic concrete pavement using an open flame heater-planer. The asphalt-rich roadway was heated, scarified to approximately 5/8" depth, and relaid without removal of the material from the roadway. Relaying was accomplished by use of a vibratory screed attached to the heater-planer.

Construction of section #4 involved one additional step: an asphalt rejuvenating agent was sprayed on the road surface behind the heater-planer.

An evaluation of these test sections was performed by project personnel approximately 5 months after construction. This evaluation consisted of the same procedures discussed above for sections #1 and #2.

Due to the obvious visual differences between section #3 and section #4, each was evaluated independently. Section #4 (shown in the background of Figure 6) appeared to be much richer in asphalt than section #3. One reason for this difference was the asphalt rejuvenating agent that was added to section #4.

Figure 6
Comparison of Visual Differences
Between Sections 3 and 4

Extreme surface cracking appeared throughout the entire length of section #3. Also, the shallow depth of scarification left teeth marks throughout most of the section.

Figure 7
Surface Cracking

Figure 8
Scarifier Teeth Marks in Pavement

Ride Meter tests showed that ride quality deteriorated below acceptable levels to an average of 2.1. Skid tests at 40 mph revealed a small increase in the average skid number. It was felt that this increase was due largely to the rearranging and exposure to traffic of less polished limestone aggregate faces. The average skid number increased from a 30 to a 36.

Section #4 was considerably more structurally sound than section #3 and exhibited only random surface cracking, smooth texture, and limited edge shelling.

Figure 9
View of Recycled Pavement Surface After
Approximately Five Months in Place

Figure 10
Edge of Recycled Pavement

Sections #5 through #8

Test sections #5 through #8 were placed west of Navasota on S.H. 105; and these were the experimental sections which created the most interest. In these sections, "in-place" or hot surface recycling was performed on a six year old limestone hot mix asphaltic concrete pavement.

The pavement was heated with radiant heat instead of an open flame. It was then scarified, mixed by mixing augers, emulsion added, and the recycled material relaid with a laydown machine vibratory screed. Compaction was achieved with three passes of a ten-ton tandem steel wheel roller. Additional steps or operations were performed on various sections and are explained for each section below.

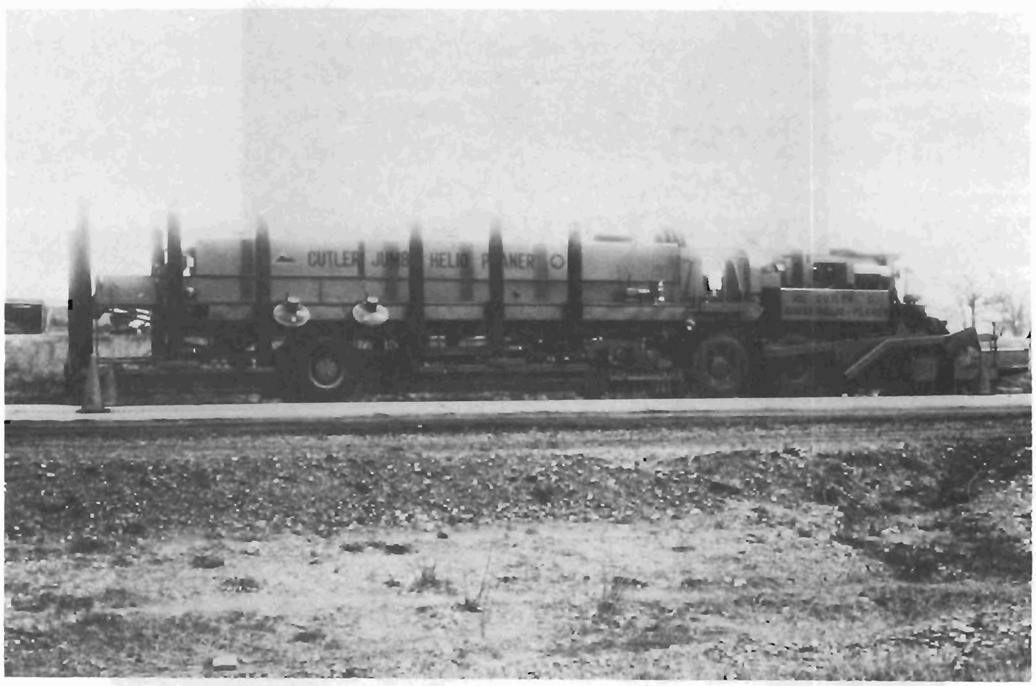


Figure 11
Radiant Heat Surface Recycling Apparatus

Prior to any recycling operations, the material was sampled and the existing residual asphalt was tested and found to be 6.2%. The asphalt penetration of the existing asphalt ranged from 18 to 21 when tested at 77^{o} F. That range in penetration occurred in six tests on all sections to be recycled by this equipment. The original aggregate gradation was also determined as follows:

Sieve Size	% by Weight
1/2" - 3/8"	1.5
3/8" - 4	33.9
4 - 10	23.4
10 - 40	4.0
40 - 80	8.0
80 - 200	17.2
passing 200	5.8

This original gradation and residual asphalt content will serve as the basis for comparison for all test sections performed with this equipment.

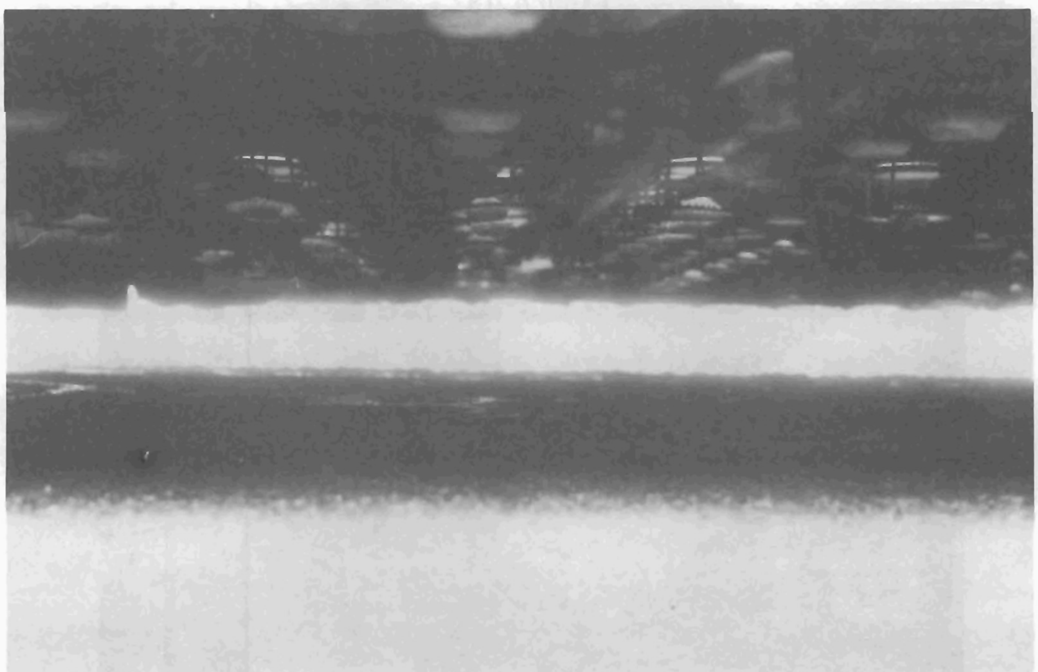


Figure 12
Bottom View of Radiant Heat Elements

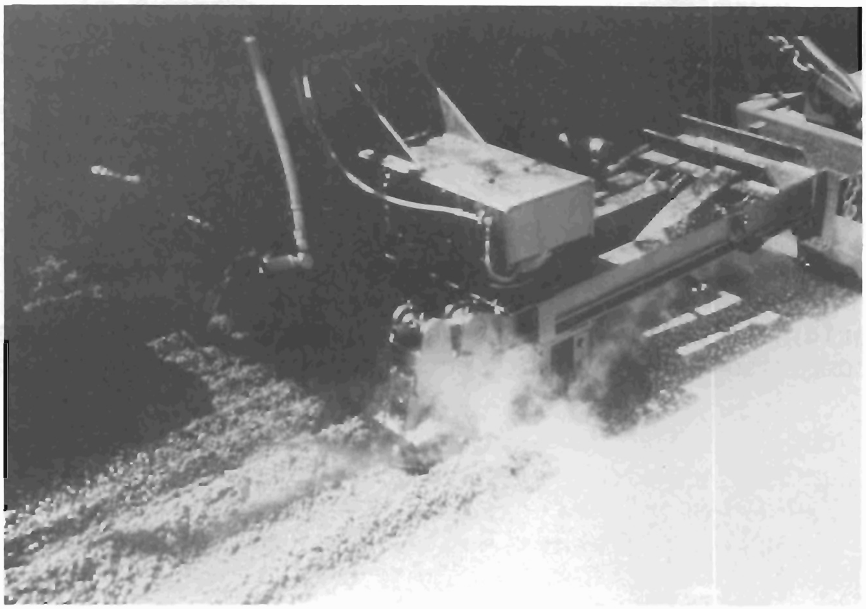


Figure 13
Pavement Scarifier Mechanism

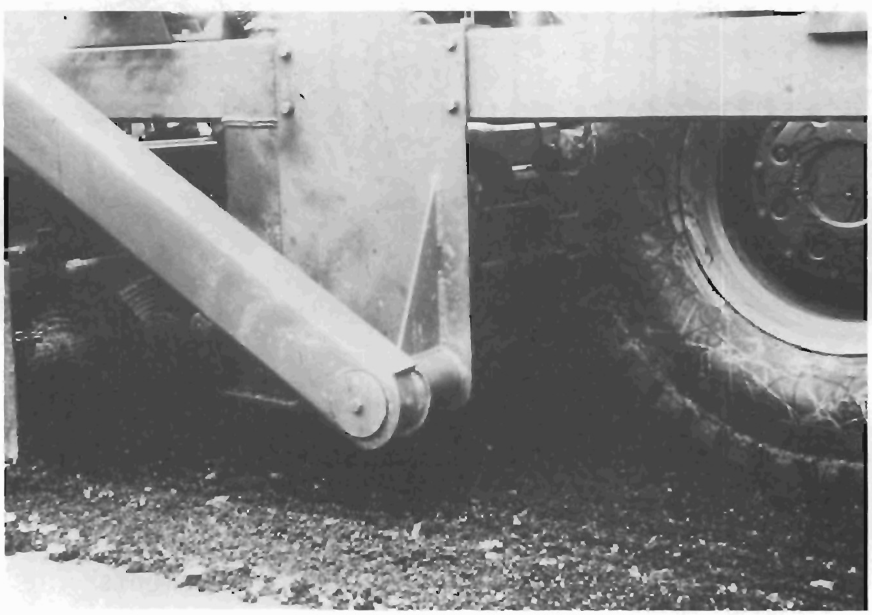


Figure 14
Mixing Augers

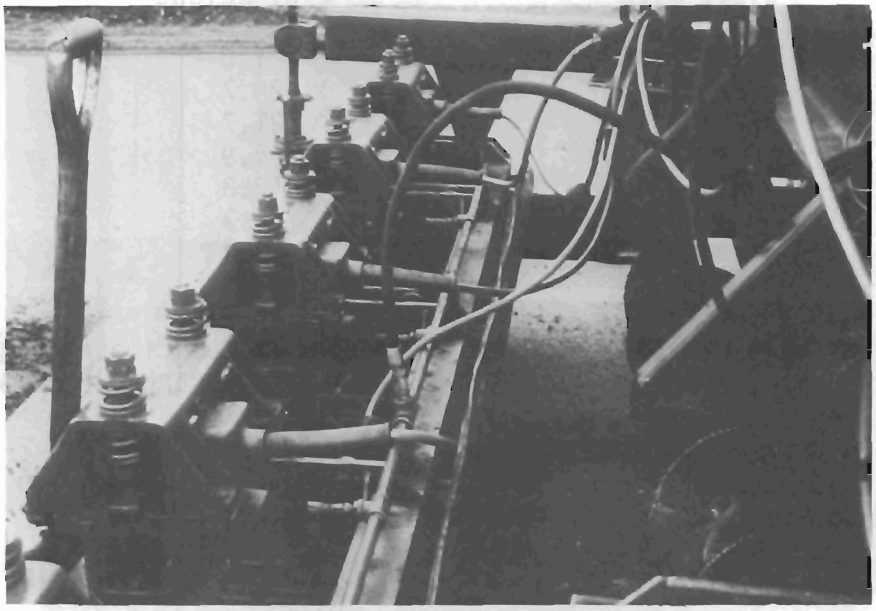


Figure 15
Close-up of Vibratory Screed

Section #5

This section consisted of relaying the recycled surface with only emulsion added to the mixture. No measures were taken to prolong the skid life of the recycled surface. The surface was heated to a temperature in excess of 300° F. and scarified to a depth of approximately 1 inch. 0.07 gallon of emulsion per square yard was added to the mix.

Prior to compaction by the vibratory screed and rolling operation, the asphaltic concrete was sampled and tested in the laboratory. The asphalt was extracted and tested,and a screen analysis was performed. The extraction test showed the recycled surface to have an asphalt content of 6.7 percent. The penetration at 77° F. was measured to be 24. As indicated by the following "after recycling" gradation, a slight aggregate degradation occurred in the process.

Sieve Size	% by Weight
1/2" - 3/8"	1.0
3/8" - 4	29.7
4 - 10	21.7
10 - 40	4.9
40 - 80	12.3
80 - 200	15.3
passing 200	8.4

There was 6.7% residual asphalt in the mixture and the average HVEEM stability of the recycled mix was 38. The stability ranged from 34 to 41.

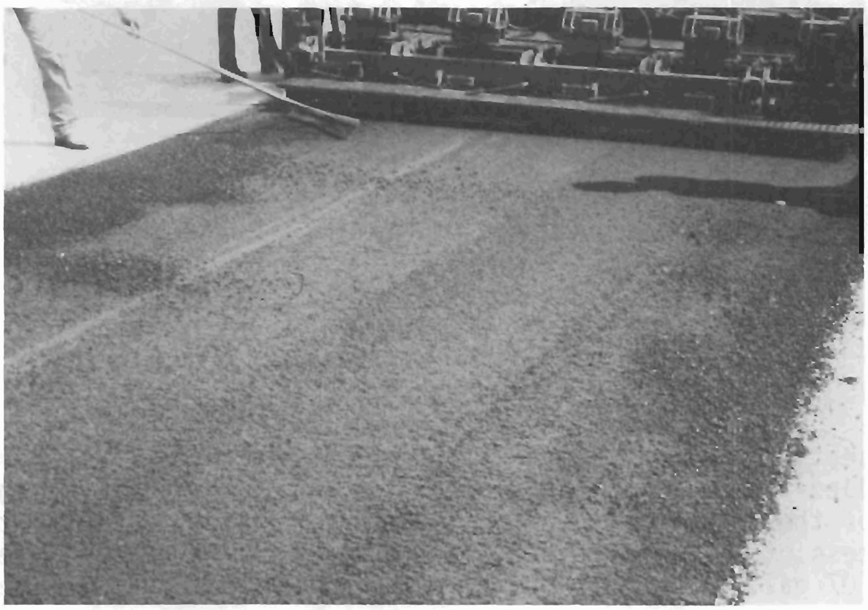


Figure 16
View of Recycled Pavement Surface Prior to Rolling

The testing and evaluation of sections #5 through #8 were performed on a continuing basis for approximately one year after construction. The same evaluation was performed on these sections as on the previously discussed sections.

Table 1

	Before Construction	1 month after	3 months after	9 months after	1 year after
Avg. Skid Numbers	32	50	42	46	32
Avg. Ride Quality	3.1	1.9*	2.0*	1.9*	1.8*

* These average ride quality values were lowered due to approximately 800 feet of this section having been placed with a screed below specified temperature. All screed heaters were lit and working but due to the ambient temperature of 45° F. - 48° F. and a slight northerly breeze, the heaters would not maintain a sufficient temperature to prevent a rubboard effect from occurring at the back north corner of the screed.

The 18 skid number increase which was noted one month after completion was brought about by the rearranging and reorienting of the aggregate particles. Most of the new limestone faces had not previously been exposed to traffic. This particular limestone is a very soft, fast polishing aggregate; and, as noted in Table 1, one year's time and close to 1.75 million vehicles has decreased the skid number to a pre-construction level.

The structural integrity of this recycled roadway section was considered by many highway engineers, as well as the traveling public, to be fair to poor. As discussed earlier extreme roughness (corrugations) occurred on a portion of this section. Note the left lane in Figure 17.

Figure 17
Pavement Corrugations

Approximately 70% of the surface area in this test section contained alligator surface cracks. At some of the cracks, fines were being pumped to the surface.

Figure 18
Alligator Cracking of Pavement Surface

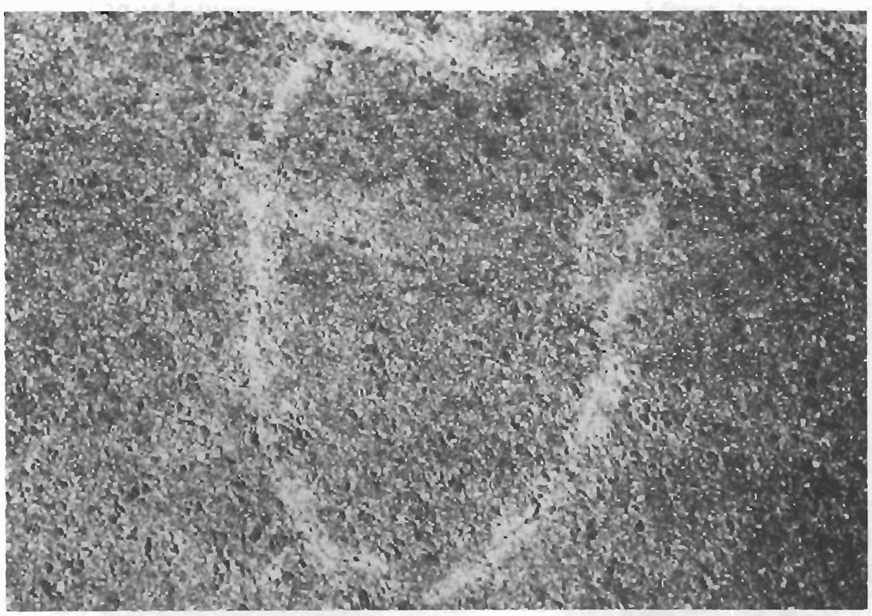


Figure 19
Fines Pumped to Surface of Roadway

After this pumping had occurred for two to four months, the primary area bounded by the pumping cracks spalled out as shown in Figure 20.

Figure 20
Spalled Pavement Surface

Section #6

This section was constructed using the procedures described for section #5 plus two additional operations. An asphalt rejuvenating agent was added to the mix at the approximate rate of 0.05 gallon/square yard. This rejuvenating agent was added during mixing and thoroughly mixed by the augers into the recycled asphaltic concrete.

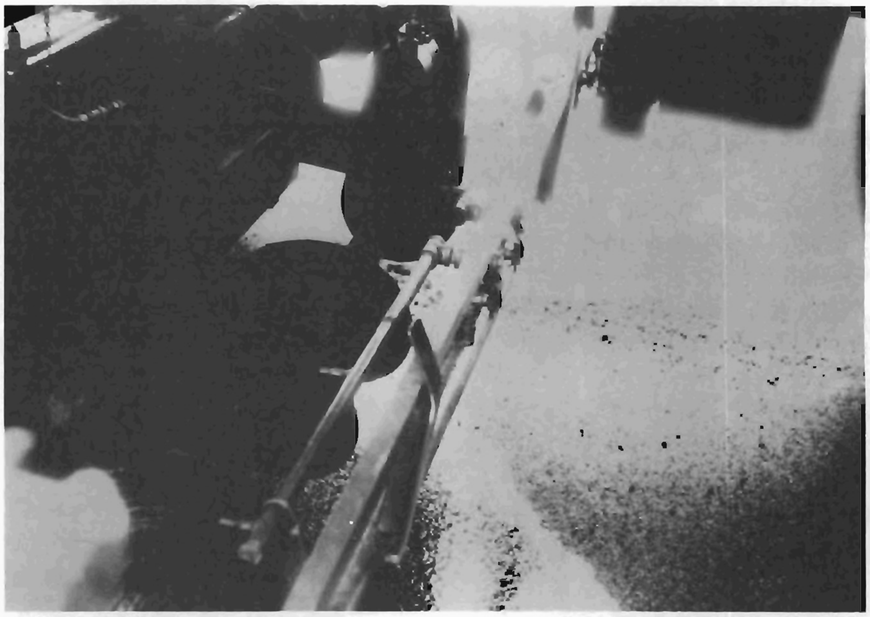


Figure 21
Rejuvenating Agent Spray Bar

Also in an effort to prolong the skid resistant life of the pavement, a sprinkle treatment was added to the roadway surface. This sprinkle treatment involved the placing of asphalt coated synthetic lightweight aggregate to the surface immediately after the passage of the vibratory screed and prior to the commencement of any rolling operations.

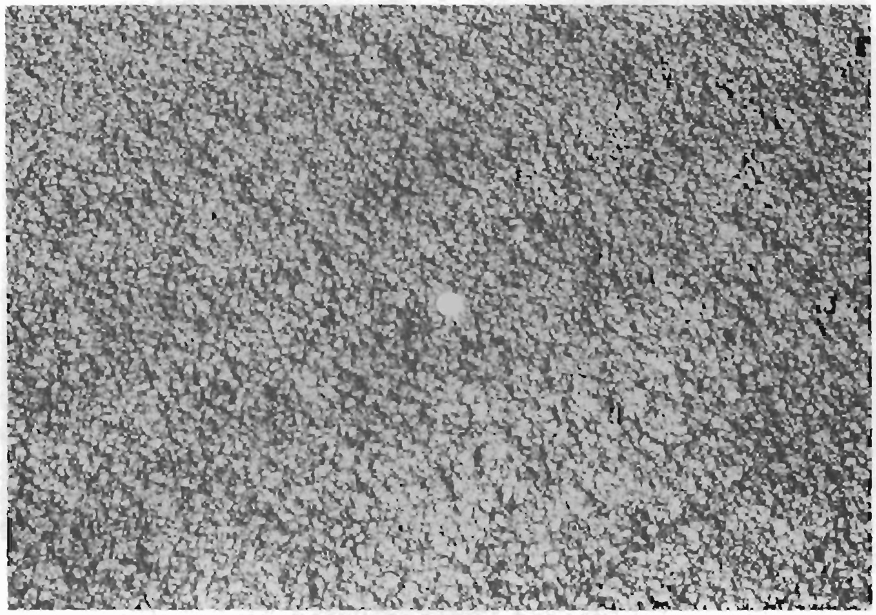


Figure 22
Recycled Surface Prior to Sprinkle Treatment Application

Figure 23
Sprinkle Treatment Application Using Salt Spreaders

Figure 24
Sprinkle Treated Surface Prior to Rolling

Figure 25
Rolled Sprinkle Treated Surface

Laboratory testing of a sample taken prior to laydown showed the following:

Penetration at 77° F. = 32
% Residual Asphalt = 6.7
HVEEM Stability = 37

Aggregate gradation of recycled mix:

Sieve Size	% by Weight
1/2" - 3/8"	1.0
3/8" - 4	29.6
4 - 10	24.7
10 - 40	5.5
40 - 80	15.9
80 - 200	10.7
passing 200	5.9

The skid resistance evaluation showed a drop of eleven skid numbers between the one month test and the three month test. This drop caused concern to project personnel until a close-up examination of this, as well as surrounding sections, was performed.

Table 2

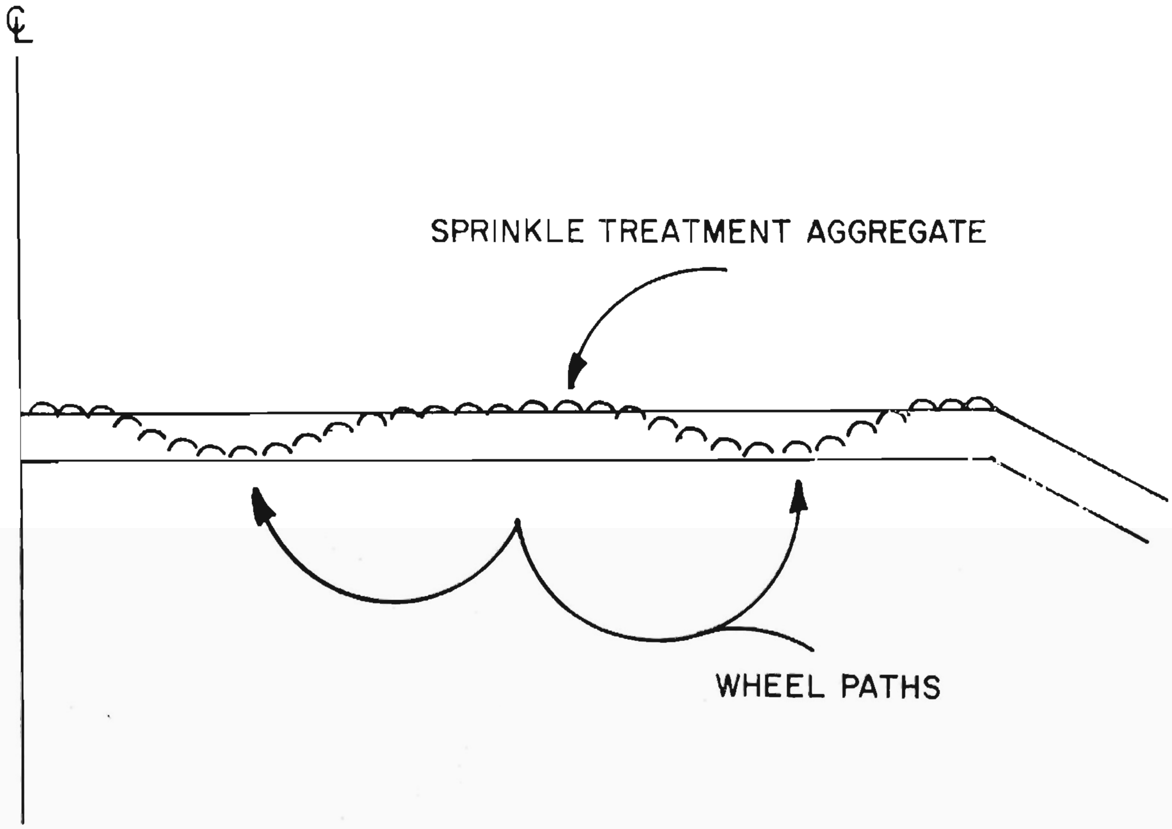
	Before Construction	1 month after	3 months after	9 months after	1 year after
Avg. Skid Numbers	28	49	38	47	50
Avg. Ride Quality	3.1	2.8	3.0	3.0	2.9

The initial feeling was that the sprinkle treatment aggregate had been whipped from the roadway by traffic, but a closer examination of the pavement surface revealed that the unexpected had occurred. The cause of the lowered skid test values was determined to be a combination of the following:

1. The asphalt rejuvenator and July sunshine had made the asphaltic surface very soft.

2. Traffic had pushed the skid resistant sprinkle treatment aggregate into the asphaltic mat, leaving only small tips of the aggregate exposed in some cases.

SCHEMATIC OF HOT MIX ASPHALTIC CONCRETE MAT WITH SPRINKLE TREATMENT AGGREGATE



3. The skid test tire was actually testing, to a large degree, a test section similar to section #5 but one that was richer in asphaltic materials.

A check of Table 2 reveals a nine skid number increase which occurred over the next six month period. Traffic eroded the asphaltic mat from around the aggregate leaving a much larger portion exposed to the tire. One year after construction, skid test results were at a level much higher than the minimum skid number suggested by many.

The structural quality of this experimental section after being in place one year is considered good. Only slight alligator surface cracks have appeared.

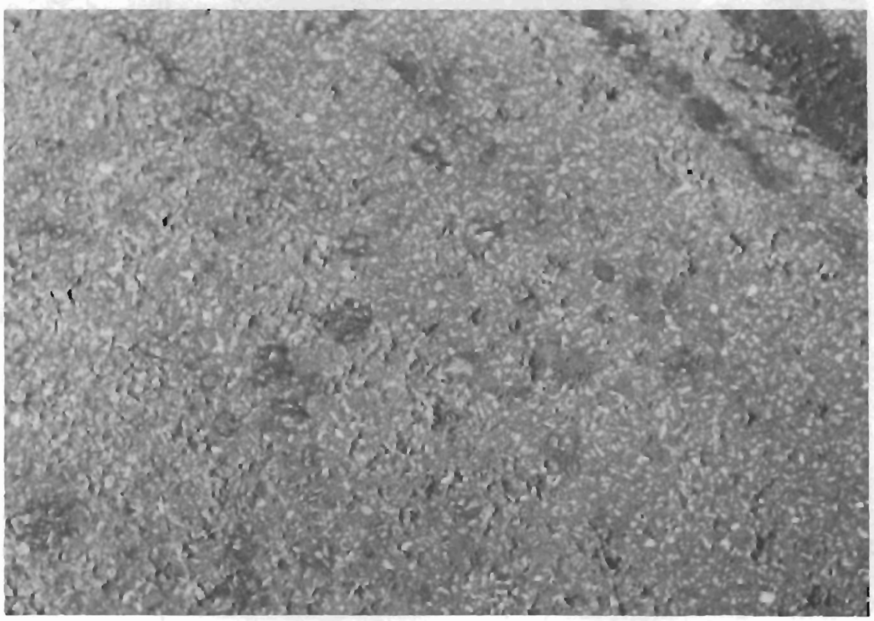


Figure 26
Recycled Sprinkle Treated Surface After
One Year's Exposure to Traffic

Due to the recycled surface being the fourth asphaltic layer above jointed Portland cement concrete pavement, the longitudinal edge crack or joint has occurred along with the associated transverse surface cracks and alligator shoulder cracks. The surface treatment or seal coat shoulder was not recycled in this nor any of the experimental sections, nor was it evaluated in this project.

Figure 27
Longitudinal Edge Crack Between Recycled Surface and Shoulder

Section #7

The construction of this experimental section involved using the same procedures as those utilized in test section #5. A different procedure,however, was used to improve the skid resistant life of the roadway surface. Skid resistant synthetic lightweight aggregate was placed on the existing roadway surface prior to heating and recycling. After a decision was made to increase the coarse aggregate (+10 sieve size) portion of the existing hot mix by 10%, tests were performed to determine the amount of skid resistant aggregate necessary to effect this 10% increase. A spread rate of 1 cubic yard of aggregate per 225 square yards of surface area was used. The skid resistant aggregate was then thoroughly mixed throughout the asphaltic concrete prior to laydown.

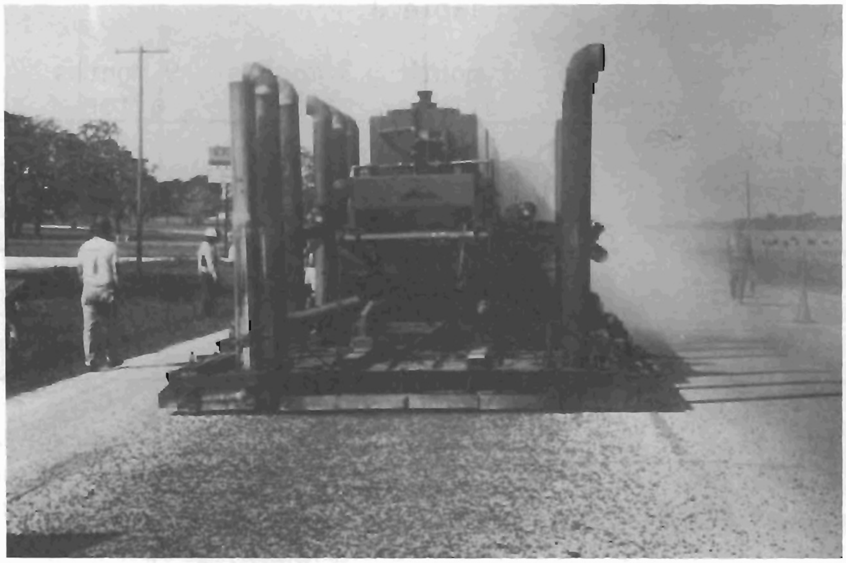


Figure 28
Skid Resistant Aggregate on Roadway Prior to Recycling

Due to an oversight during construction,no attempt was made to increase the amount of emulsion being added to the mix. Therefore a drier mix occurred than had been originally planned.

Penetration at 77° F. = 31
% Residual Asphalt = 5.9
HVEEM Stability = 56

Sieve Size	% by Weight
1/2" - 3/8"	2.5
3/8" - 4	40.2
4 - 10	18.1
10 - 40	4.6
40 - 80	11.3
80 - 200	10.4
passing 200	7.0

As shown in Table 3 below, the skid resistant aggregate (which was placed so that the augers of the recycling machine would blend it into the surface) was sufficient to bring about a small increase in skid resistance. The addition of 5 to 7 percent more skid resistant coarse aggregate could possibly have raised the one year average skid test value to above 40.

Table 3

	Before Construction	1 month after	3 months after	9 months after	1 year after
Avg. Skid Numbers	23	46	41	37	37
Avg. Ride Quality	2.6	2.7	2.7	No Test (Equipment Failed)	2.8

Due to the lack of asphalt content in the mat, extreme surface cracking and spalling occurred. An examination of the spalled areas of this section indicated a depth of recycle of only 3/8" to 1/2". This shallow depth was unintentional.

Figure 29
Spalling of Blended Recycled Surface

A considerable amount of the surface longitudinal cracking was not a result of the recycling process but resulted from the removal of portions of the existing jointed concrete pavement throughout the entire length of the section. This propagated a transverse crack completely across the two roadway lanes.

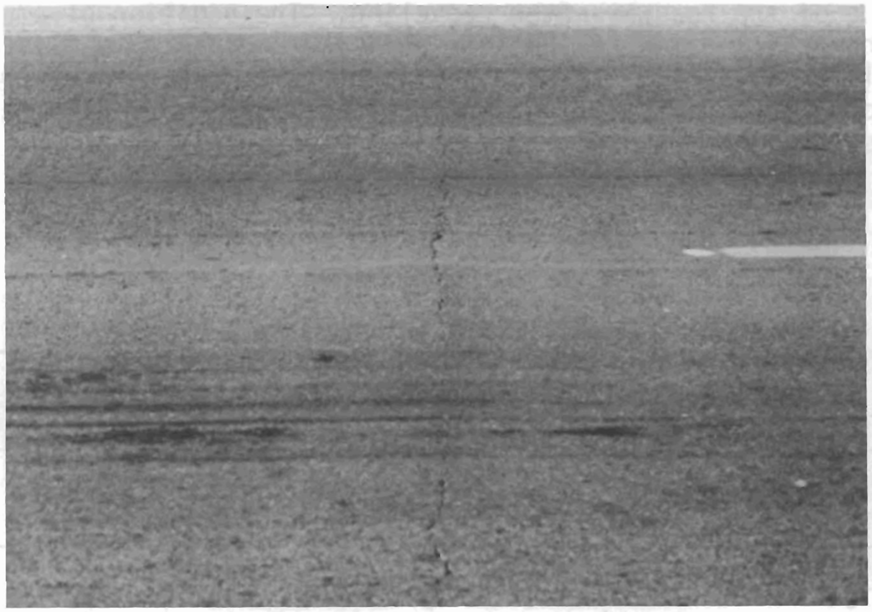


Figure 30
Transverse Crack over Edge of P.C.C. Pavement

Section #8

Test section #8 was constructed in the same manner as section #6 except that the rejuvenating agent was not added. The material was hot recycled using radiant heat, emulsion was added, and it was sprinkle treated with a skid resistant lightweight aggregate.

Penetration at 77^{o} F. = 26
% Residual Asphalt = 6.4
HVEEM Stability = 50

Sieve Size	% by Weight
1/2" - 3/8"	1.6
3/8" - 4	34.1
4 - 10	19.9
10 - 40	4.4
40 - 80	10.2
80 - 200	14.5
passing 200	8.9

An increase in skid numbers,shown in Table 4 below, was attributed to the sprinkle treatment skid resistant aggregate which was applied to the surface of the roadway after recycling. The addition of emulsion only to the recycled mix was not of sufficient quantity to "liven-up" the asphaltic mat for an extended period of time. Therefore, traffic "whipped off" the skid resistant sprinkle aggregate, and all that remained was the limestone hot mix asphaltic concrete.

Table 4

	Before Construction	1 month after	3 months after	9 months after	1 year after
Avg. Skid Numbers	21	50	43	44	37
Avg. Ride Quality	3.1	2.9*	2.8*	3.0*	2.9*

* The slight deterioration in ride quality (S.I. values) arose from the inability of the equipment operator to end testing prior to the end of job.

The structural quality of this section, after a traffic and weather exposure time of nearly twelve months, was fair. Fifty to sixty percent of the surface area exhibited cracking from the narrow width shown in Figure 31 to the wider, shelled areas shown in Figure 32.

Figure 31
Narrow Random Surface Cracking

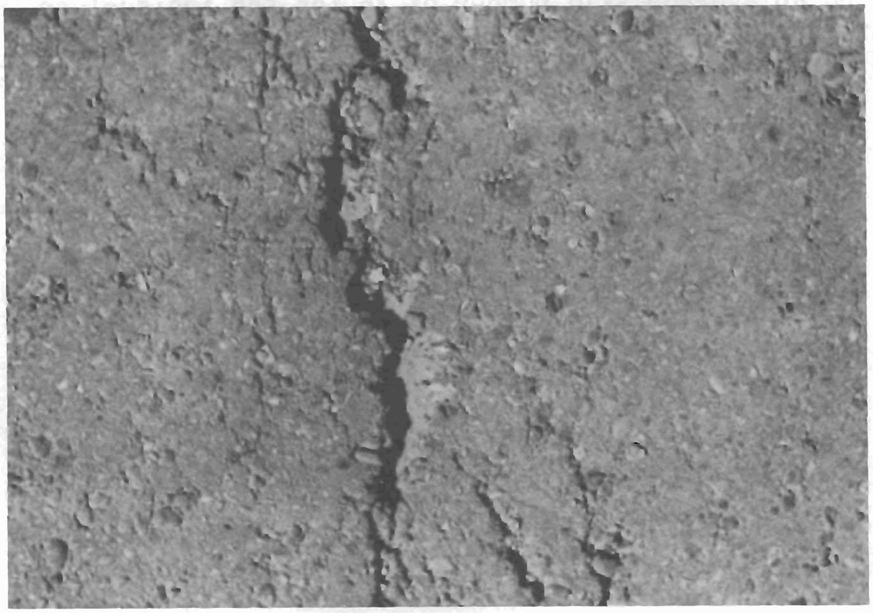


Figure 32
Wide Random Surface Cracking

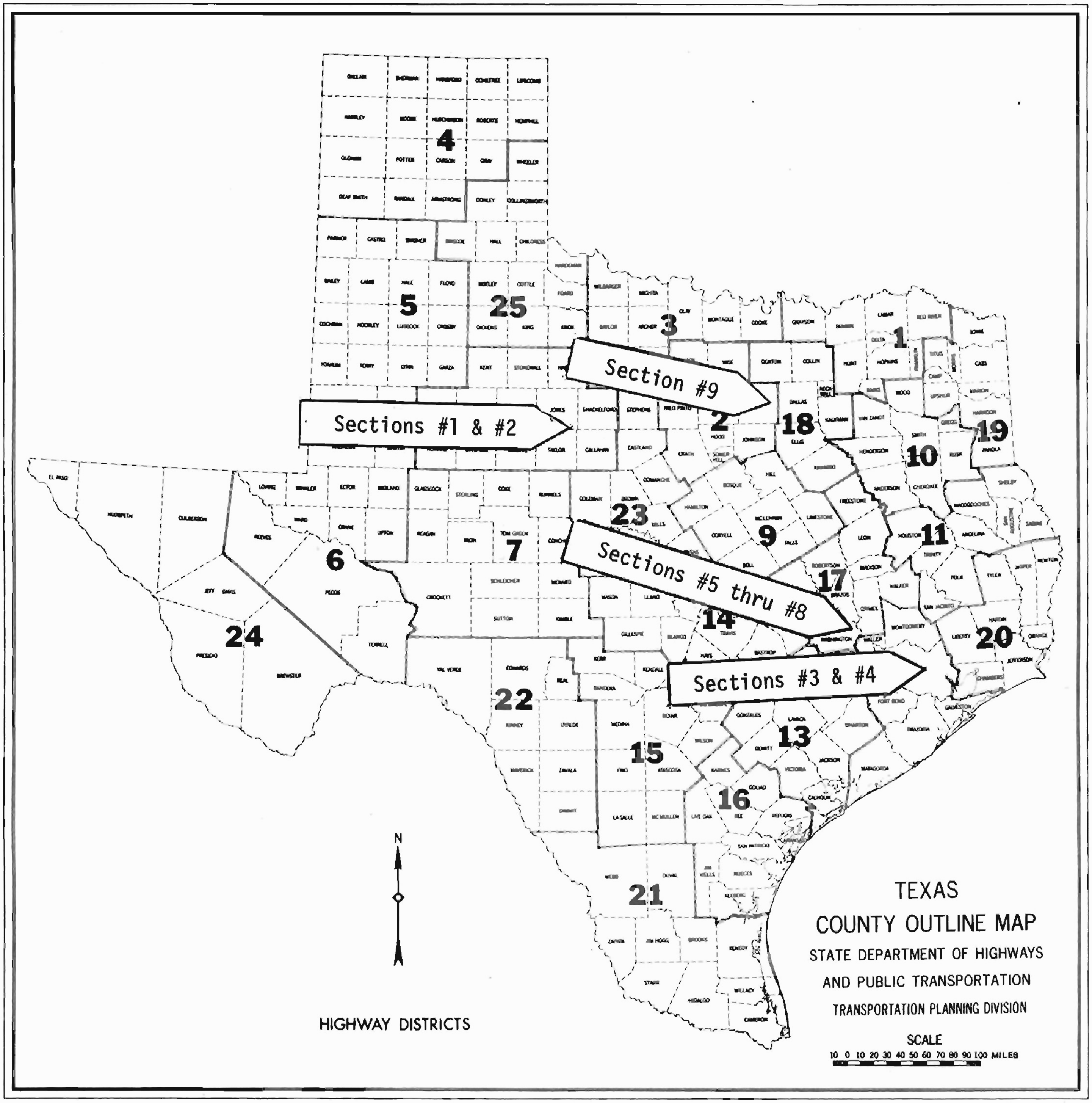
Section #9

Test section #9 was located on I.H. 820 on the east side of Fort Worth. The test was performed on continuously reinforced Portland cement concrete, and its purpose was to improve the skid resistance.

The experiment consisted of blasting the surface with high pressure water sprays. It was felt that the skid resistance would be improved as a result of the removal of debris such as oil and rubber particles and small amounts of cement mortar between coarse aggregate particles.

The test section was 781 feet long and 24 feet wide. The outside lane appeared to be more worn and more contaminated than the inside lane so a slower travel speed was used while spraying the outside lane (3 mph for inside lane and 1 mph for outside lane). Also, a somewhat reduced nozzle pressure was used on the inside lane because two additional nozzles were attached. Water was sprayed at 8,000 to 9,000 psi, and the nozzles were positioned approximately 6" above the surface.

Standard skid tests in the outside lane produced an average skid number of 19 before water blasting and a 32 after. Standard skid tests in the inside lane produced an average skid number of 27 before water blasting and a 36 after. Skid tests were performed three days after the roadway was sprayed. Subsequent testing (about four months later) indicated an average skid number of 26 for the inside lane and 24 for the outside lane. Later tests confirmed the impermanence of improved skid resistance as a result of high pressure water blasting.


Sections #1 & #2
Section #9
Sections #5 thru #8
Sections #3 & #4
HIGHWAY DISTRICTS
TEXAS
COUNTY OUTLINE MAP
STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION
TRANSPORTATION PLANNING DIVISION
SCALE
N

SUMMARY OF TESTS

Section	Location	Type of Pavement	Treatment	Visual Before	Visual After	Skid Before	Skid After	Mays Meter
1	North of Abilene on U.S. 83	HMAC	Pavement was heated in two passes of open flame heater-planer. Non-precoated limestone aggregate was distributed on surface and rolled in.	Extreme flushing in wheel paths. Slight fatigue cracking. Some rutting.	Aggregate retention limited to a few isolated locations. Wheel paths flushed again.	Low - 14 High - 28 Average - 22	Low - 14 High - 36 Average - 26	After (avg.) - 2.6
2	North of Abilene on U.S. 83	HMAC	Non-precoated limestone aggregate was distributed over surface and then heater-planer made two passes over section. Aggregate was rolled in after second pass.	Same as Section 1	Same as Section 1	Same as Sect. 1	Same as Sect. 1	Same as Sect. 1
3	West of Houston on S.H. 6 5,000 ADT	HMAC	Open flame heater-planer heated, scarified to depth approx. 5/8", replaced with vibratory screed attached to heater-planer.	Extremely rich in asphalt in most areas. Almost total surface cracking where there was less asphalt.	Extreme surface cracking throughout entire length of section. Scarification teeth marks remained visible.	Low - 26 High - 38 Average - 30	Average - 36	After (avg.) - 2.1
4	West of Houston on S.H. 6 5,000 ADT	HMAC	Same as Section 3 except that asphalt rejuvenating agent was sprayed on roadway behind heater-planer.	Same as Section 3	Richer in asphalt; more structurally sound than Section 3. Random surface cracking, smooth texture, limited edge shelling.	Same as Sect. 3	Average - 35	After (avg.) - 2.4
5	West of Navasota on S.H. 105	HMAC	Pavement heated with radiant heat, scarified, mixed by augers, emulsion added, relaid with laydown machine vibratory screed, and compacted with 3 passes of 10-ton tandom steel wheel roller.	Surface aggregate (limestone) was polished. Slight rutting. Alligator cracking over approx. 50% of area. Transverse cracks where JCP was removed and longitudinal edge cracks where JCP remained.	Structural integrity appeared poor. Surface corrugated. Approx. 70% of surface area alligator cracked. Some pumping. Some spalling at pumping cracks.	Average - 32	1 Month - 50 3 Months - 42 9 Months - 46 12 Months - 32	Before (avg.) - 3.1 1 Month - 1.9☆ 3 Months - 2.0☆ 9 Months - 1.9☆ 12 Months - 1.8☆
6	West of Navasota on S.H. 105	HMAC	Same as Section 5 except that asphalt rejuvenator added during mixing operation, and synthetic lightweight aggregate was sprinkled on surface behind vibratory screed prior to rolling.	Same as Section 5	Rejuvenator and sunshine made asphalt so soft that sprinkle aggregate was pushed into mat. Slight alligator cracks appeared after one year.	Average - 28	1 Month - 49 3 Months - 38 9 Months - 47 12 Months - 50	Before (avg.) - 3.1 1 Month - 2.8 3 Months - 3.0 9 Months - 3.0 12 Months - 2.9
7	West of Navasota on S.H. 105	HMAC	Same as Section 5 except that skid resistant aggregate was spread on the roadway at the rate of 1 cubic yard per 225 square yards of surface area prior to scarification, mixing and relaying.	Same as Section 5	Due to oversight, no additional emulsion was added. Therefore, extreme surface cracking and spalling occured. Depth of recycle was much less than desired - 3/8" to 1/2".	Average - 23	1 Month - 46 3 Months - 41 9 Months - 37 12 Months - 37	Before (avg.) - 2.6 1 Month - 2.7 3 Months - 2.7 9 Months - No Test 12 Months - 2.8
8	West of Navasota on S.H. 105	HMAC	Same as Section 6 except that rejuvenating agent was not added.	Same as Section 5	Sprinkle treatment aggregate was "whipped off" by traffic. Roadway had significant amount of cracking and after 12 months structural quality was judged to be only fair.	Average - 21	1 Month - 50 3 Months - 43 9 Months - 44 12 Months - 37	Before (avg.)- 3.1 1 Month - 2.9 3 Months - 2.8 9 Months - 3.0 12 Months - 2.9
9	East Side of Fort Worth on I.H. 820	CRCP	Blasted with high pressure water sprays (8,000 - 9,000 psi) at speed of 1 - 3 mph.	Worn fairly smooth. Outside lane appeared to have more oil and detritus than inside lane.	Roadway was lighter color-it appeared to be cleaner.	Outside lane - 19 Inside lane - 27	Outside lane at 3 days - 32 4 months - 24 Inside lane at 3 days - 36 4 months - 26	No Test

☆ These average ride values were lowered due to approximately 800 ft. of this section having been placed with a screed below specified temperature. Rubboard effect occurred.

CONCLUSIONS AND RECOMMENDATIONS

Test sections #5 through #8 have shown that radiant heat surface recycling could be an effective tool in conserving our nation's aggregates and asphaltic products. It is felt that the previously discussed methods and procedures would be greatly improved if the following suggestions were implemented:

1. A small amount of new hot-mix asphaltic concrete should be mixed with the recycled materials. Observation and investigation of subsequent, non-project related jobs have indicated that the addition of as little as 28 pounds of new material per square yard of surface area may significantly improve the resulting mix.

2. Conscientious inspection should be employed to insure constant depth of scarification.

3. Specifications should be employed for controlling the rate of asphalt distribution applied to the recycled mix.

4. Screed temperature should be specified and checked periodically.

5. Maintenance of sufficient skid resistance should be required.

6. Specifications which regulate the minimum air temperature allowable for surface recycling should be developed.

Both open-flame and radiant heat surface recycling equipment increase the skid resistance immediately after placement. Experience has shown that with a few thousand traffic applications, the increased skid resistance soon returns to its original level.