U.S. Department
of Transportation
**Federal Highway
Administration**

Demonstration Projects
Program

Demonstration Project No. 39

# Recycling Asphalt Pavements

## New Hampshire

FHWA-DP-39-33 April 1982

NOTICE



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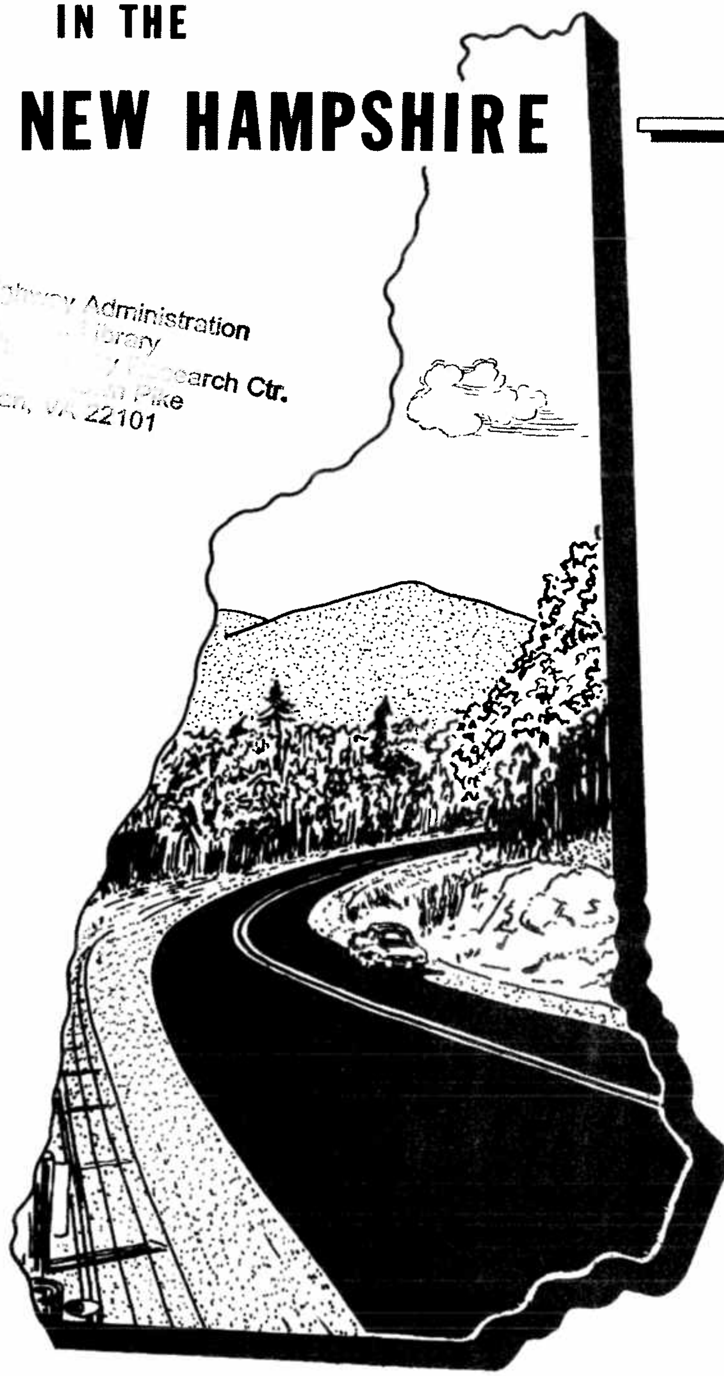
# RECYCLING ASPHALT PAVEMENTS

## IN THE

## STATE OF NEW HAMPSHIRE





## CONSTRUCTION SEASON 1981

# RECYCLING ASPHALT PAVEMENTS

# IN THE

# STATE OF NEW HAMPSHIRE

*Prepared by:*

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Federal Highway Administration
Concord, New Hampshire

*In Cooperation with the:*

New Hampshire Department of Public Works and Highways
Construction Season 1981

ACKNOWLEDGMENT

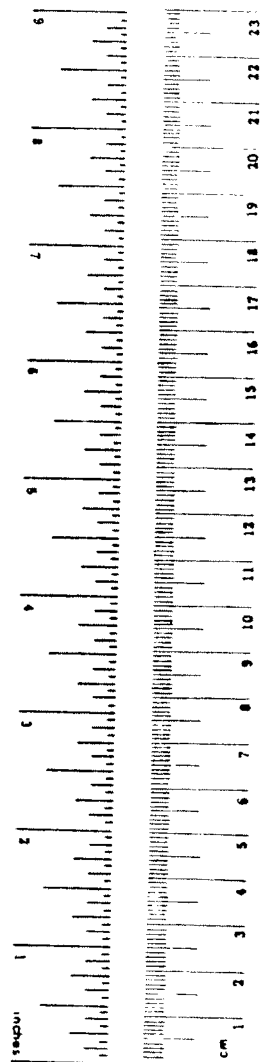
The study reported herein was conducted by Mr. Stephen J. Zywiak of the Federal Highway Administration's New Hampshire Division Office. The author wishes to express his appreciation for the cooperation and assistance of the many people whose efforts contributed to the completion of this report. This includes personnel in the Division Office, the four project engineers and their support staff, plant inspectors and other involved personnel from the Materials Division of the NH Department of Public Works and Highways. In addition, appreciation is extended to Ms. Meg Moran for her patience in the typing of the draft and final reports, and Red Whitcomb for preparation of the cover.

The opinions, findings and conclusions expressed in this report are those of the author and not necessarily those of FHWA or the NH Department of Public Works and Highways.

# METRIC CONVERSION FACTORS

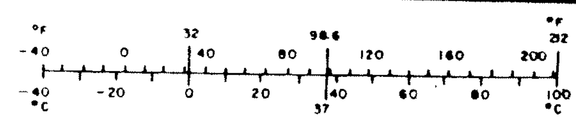
## Approximate Conversions to Metric Measures

| 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 |



RECYCLING ASPHALT PAVEMENTS
STATE OF NEW HAMPSHIRE

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# INTRODUCTION

Spiraling highway construction costs, loss of highway revenues, the uncertain status of energy supplies, and the possible exhaustion of usable aggregate sources are rising concerns being addressed by the highway community. Conservation of available materials, reduction of construction costs, and minimization of energy use are goals that can be accomplished in the reconstruction and rehabilitation of pavements by utilization of the existing pavement in a recycled material.

There are currently three basic methods of recycling which are increasing in common use throughout the Nation:

1. Cold Mix Recycling: A process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents in place, or at a central plant, to produce cold-mix base mixtures. An asphalt surface course is required.

2. Hot Mix Recycling: A process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as necessary, in a central plant to produce hot-mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced.

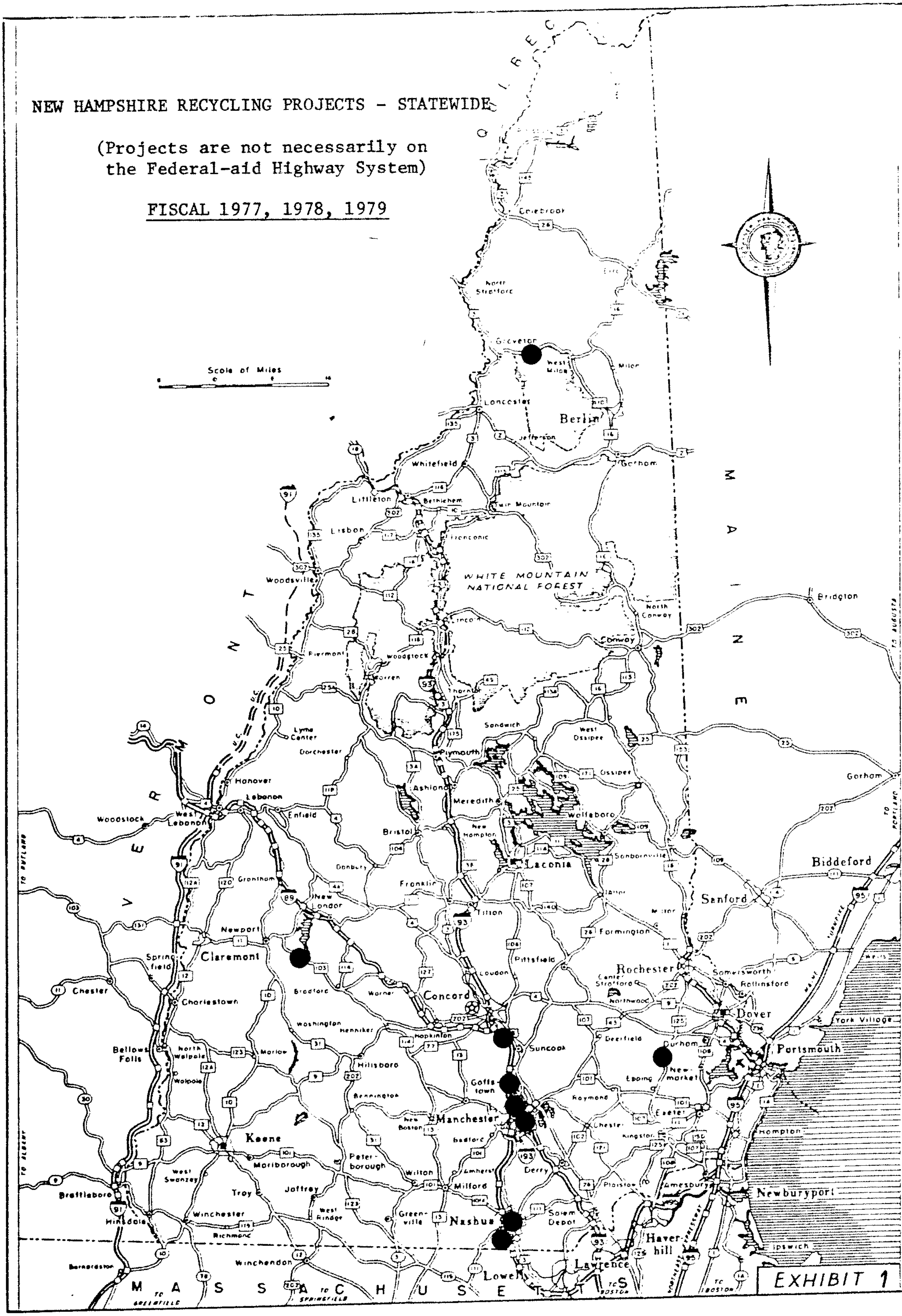
3. Surface Recycling: A process in which an asphalt pavement surface is heated in-place, scarified, remixed, relaid, and rolled. Asphalts, recycling agents, new asphalt hot mix, aggregates, or combinations of these may be added to obtain desirable mixture characteristics. When new asphalt hot mix is added, the finished product may be used as the final surface. Otherwise, an asphalt surface course should be used.

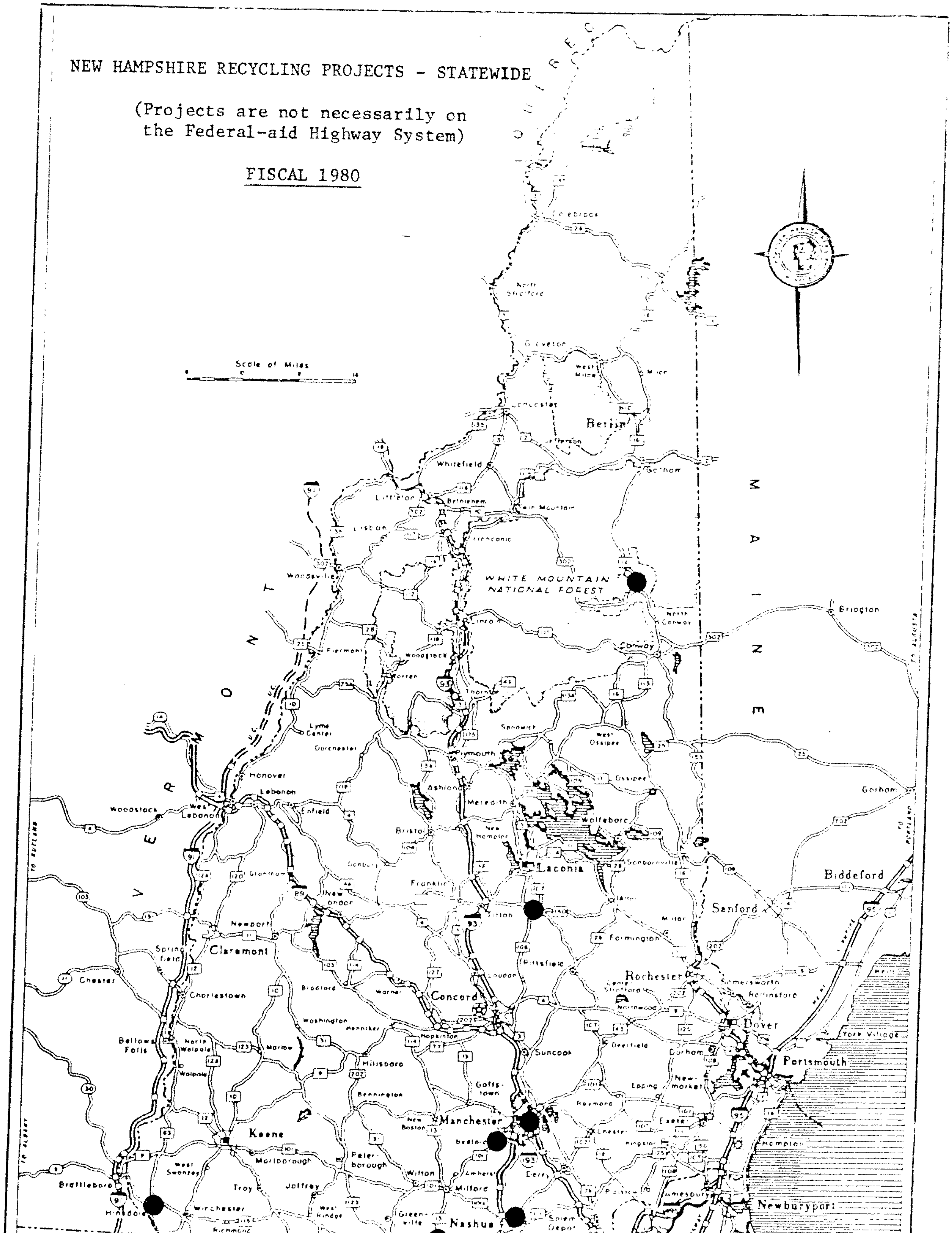
The NH Department of Public Works and Highways emphasizes the use of hot and cold recycling in their current reconstruction and rehabilitation program. As contractors have become more familiar with the various techniques which may be applied to recycling, the number of projects have increased. During FY 1977 through 1979, two hot recycling and seven cold recycling projects were constructed. FY 1980 saw seven additional cold recycling projects. This past fiscal year, 1981, three hot recycling projects and 11 cold recycling projects were initiated. During FY 1982, three additional hot recycling and 11 cold recycling projects are expected to be advertised. Exhibits 1 through 4 show the locations of these recycling projects in the State. It is the policy of the NH Department of Public Works and Highways to review and consider each project for some form of recycling. An early evaluation is performed of the existing pavement and base material, the type and size of project, availability and proximity of material sources, the project's geographic location, waste sites, and other economic considerations. Only those projects where a minimal overlay would meet the project's goals or those which are too small to be cost effective are excluded from the recycling process.

NEW HAMPSHIRE RECYCLING PROJECTS - STATEWIDE

(Projects are not necessarily on the Federal-aid Highway System)

FISCAL 1977, 1978, 1979

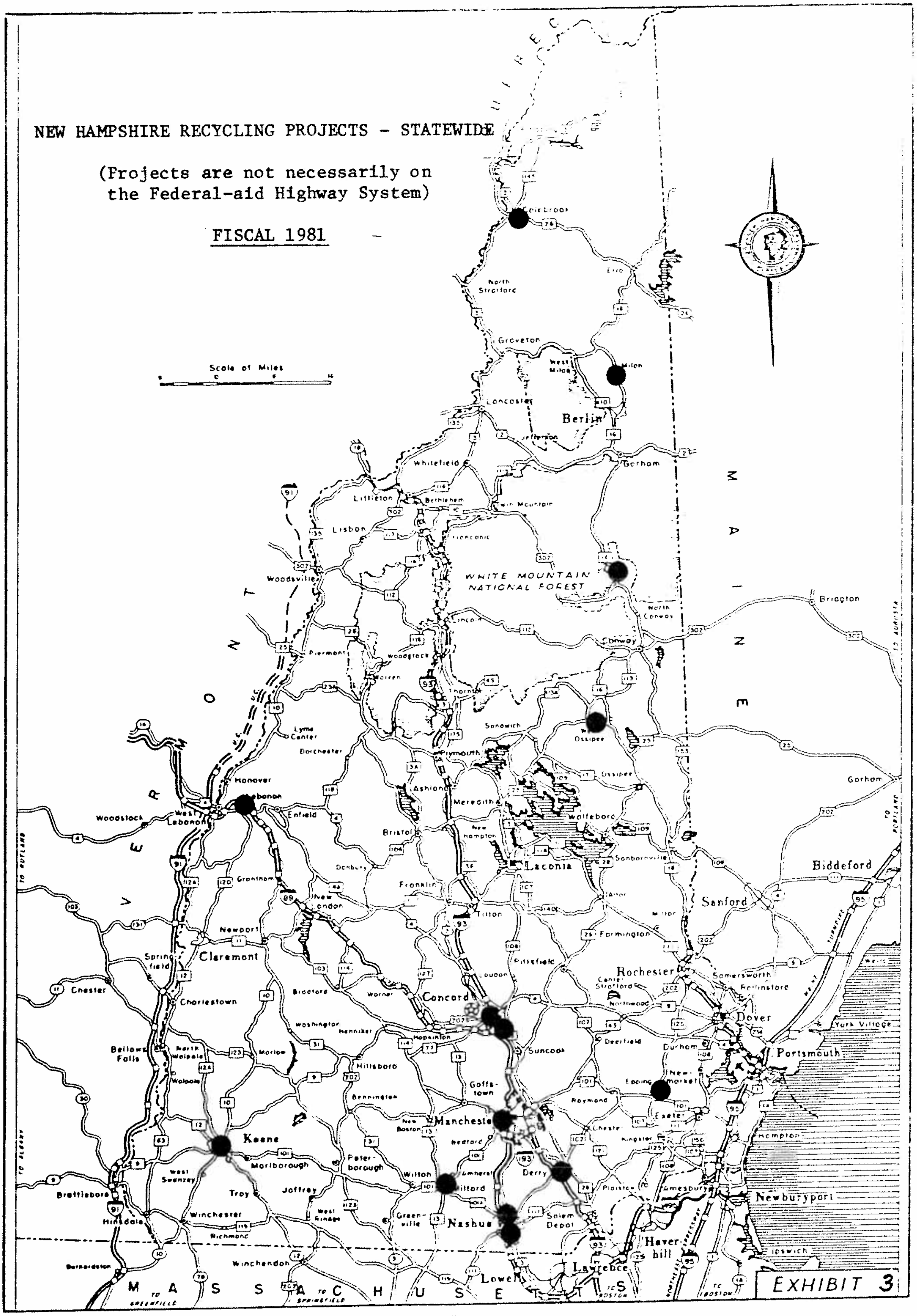


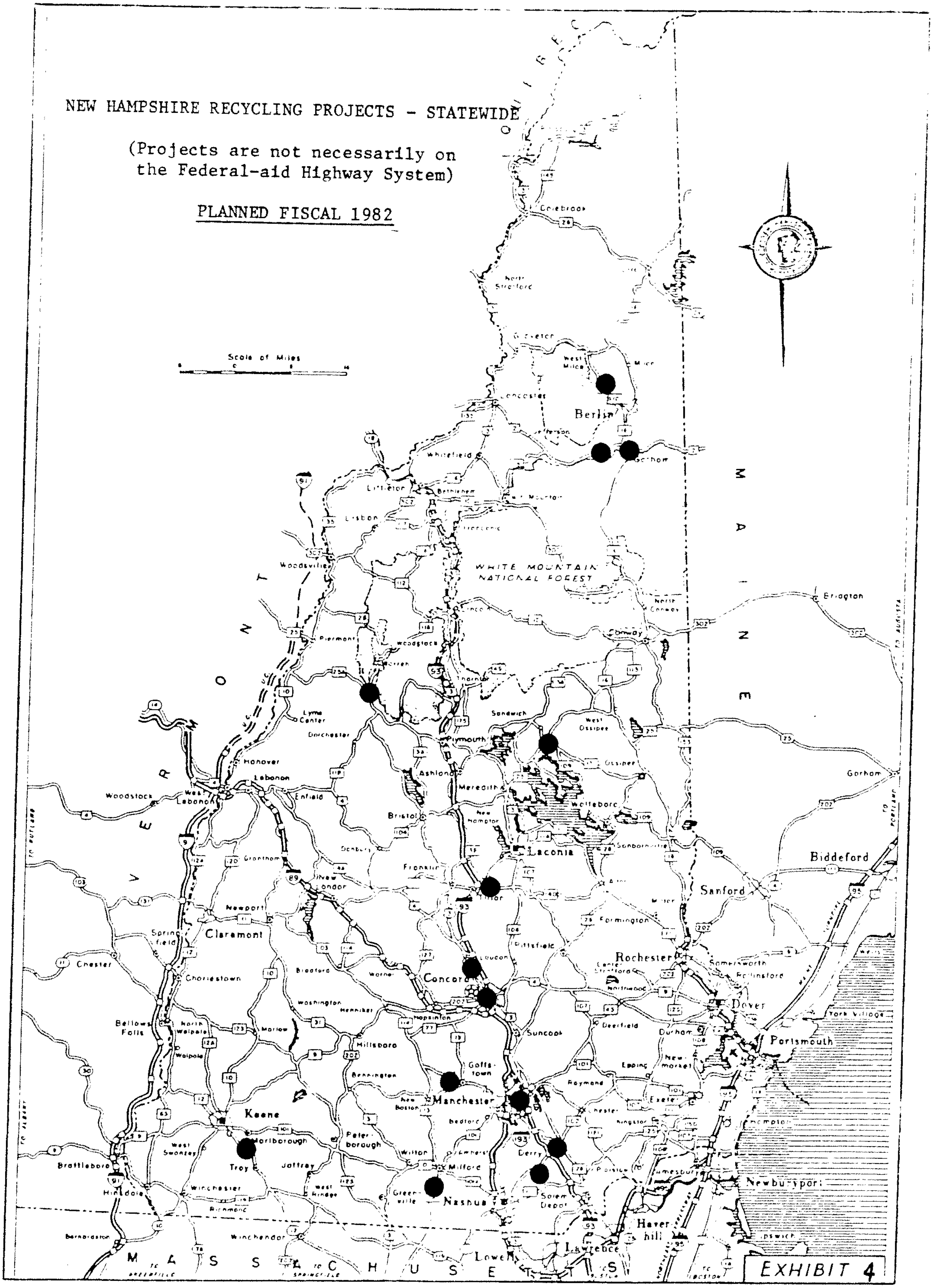

NEW HAMPSHIRE RECYCLING PROJECTS - STATEWIDE
(Projects are not necessarily on the Federal-aid Highway System)
FISCAL 1980
Scale of Miles
WHITE MOUNTAIN NATIONAL FOREST
VERMONT
MAINE
MASSACHUSETTS
Berlin
Gorham
Whitefield
Littleton
Lisbon
Woodsville
North Conway
Conway
Lebanon
Hanover
Claremont
Newport
Charlestown
Laconia
Wolfeboro
Meredith
Plymouth
Tilton
Franklin
Concord
Pittsfield
Farmington
Rochester
Sanford
Biddeford
Dover
Portsmouth
Manchester
Goffstown
Keene
Peterborough
Jaffrey
Milford
Nashua
Derry
Exeter
Hampton
Newburyport
Haverhill
Lawrence
Lowell
Brattleboro
Hinsdale
Winchester
Suncook
EXHIBIT 2

NEW HAMPSHIRE RECYCLING PROJECTS - STATEWIDE

(Projects are not necessarily on the Federal-aid Highway System)

FISCAL 1981




NEW HAMPSHIRE RECYCLING PROJECTS - STATEWIDE
(Projects are not necessarily on the Federal-aid Highway System)
PLANNED FISCAL 1982
Scale of Miles
VERMONT
MAINE
MASSACHUSETTS
WHITE MOUNTAIN NATIONAL FOREST
Berlin
Gorham
Colebrook
Lancaster
Whitefield
Littleton
Lisbon
Woodsville
Conway
North Conway
Plymouth
Ashland
Meredith
Bristol
Laconia
Wolfeboro
Tilton
Franklin
Hanover
Lebanon
West Lebanon
Enfield
New London
Newport
Claremont
Charlestown
Concord
Suncook
Hillsboro
Goffstown
Manchester
Derry
Nashua
Milford
Keene
Marlborough
Troy
Jaffrey
Peterborough
Rochester
Dover
Durham
Portsmouth
Exeter
Newburyport
Haverhill
Lawrence
Lowell
Sanford
Biddeford
Brattleboro
Hinsdale
Bellows Falls
EXHIBIT 4

## PURPOSE AND SCOPE

The purpose of this report was to evaluate the recycling processes presently in use in New Hampshire by collecting data relative to the method and quality of construction, the economic implications of recycling, and determining possible recommendations for future implementation. In addition, the specifications relating to recycling will be reviewed, as many feel the design of specifications is crucial to the recycling concept.

This paper will review four major projects which have implemented recycling this past construction season:

1. Concord IR-I-393-2(90)39: An Interstate reconstruction project using hot recycling of the existing pavement for incorporation into the bituminous base and binder courses.

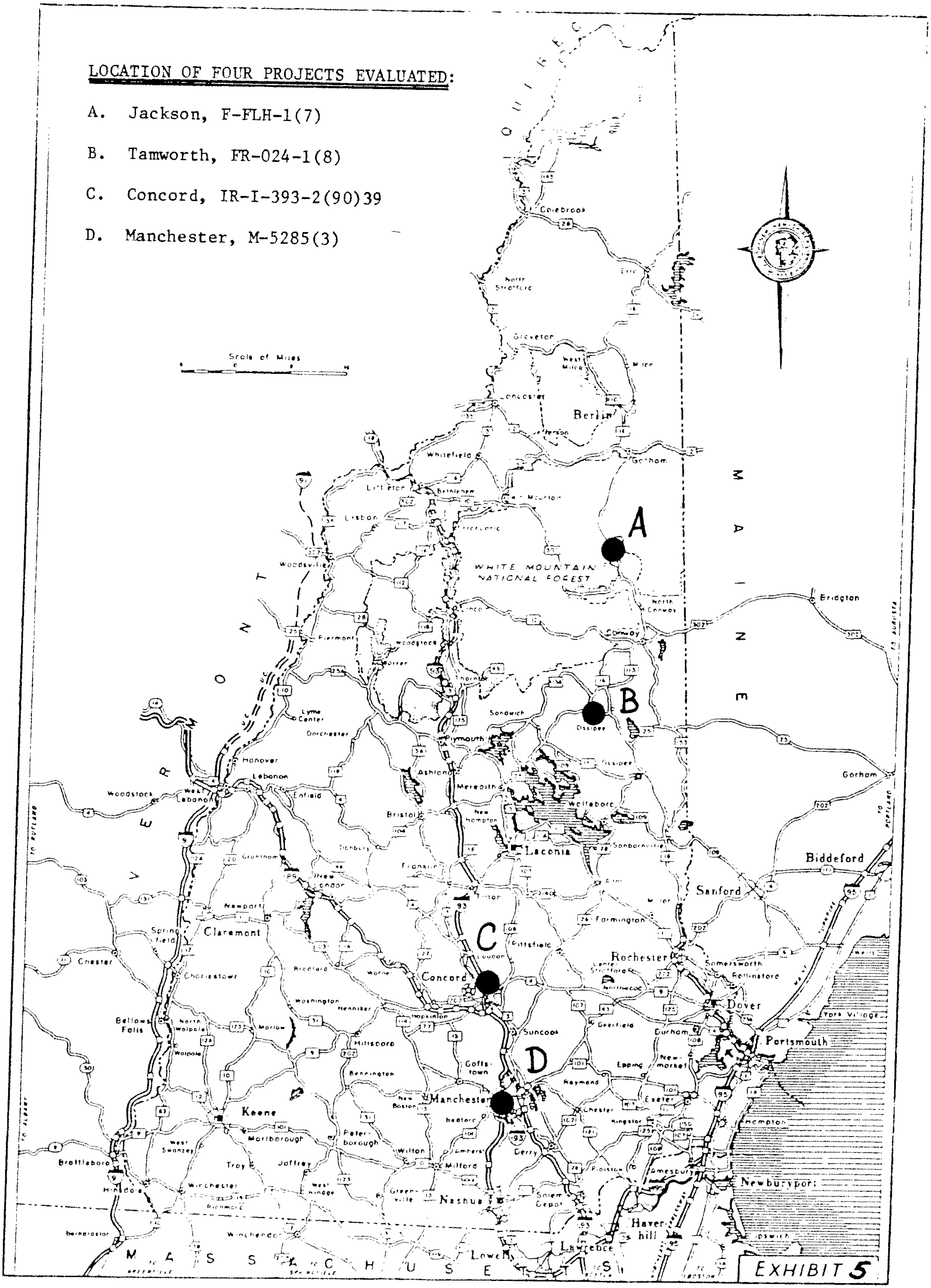
2. Manchester M-5285(3): An urban reconstruction project using hot recycling of the existing pavement for use in the bituminous base and binder courses.

3. Tamworth FR-024-1(8): A primary rural two-lane highway using cold recycling of the existing pavement to construct a reclaimed stabilized base course.

4. Jackson F-FLH-1(7): A primary rural two-lane highway using cold recycling of the existing pavement to construct a reclaimed stabilized base course.

Exhibit 5 shows the location of the four projects in New Hampshire.

Appendix A contains a review of the Annual Report on Energy, Aggregate and Dollar Savings which was recently completed. The report incorporates an estimating procedure for the various factors.


LOCATION OF FOUR PROJECTS EVALUATED:
A. Jackson, F-FLH-1(7)
B. Tamworth, FR-024-1(8)
C. Concord, IR-I-393-2(90)39
D. Manchester, M-5285(3)
Scale of Miles
A
B
C
D
WHITE MOUNTAIN NATIONAL FOREST
Berlin
Laconia
Concord
Manchester
Keene
Claremont
Rochester
Dover
Portsmouth
Nashua
Sanford
Biddeford
Newburyport
MAINE
VERMONT
EXHIBIT 5

CONCORD HOT RECYCLING PROJECT
IR-I-393-2(90)39

## Project Description

Located within the City of Concord, this project consisted of reconstructing the interchange of Interstate 93 and the newly completed Interstate 393 spur. This included partial ramp realignment, asphalt pavement recycling and overlay, Interstate safety improvements and the installation of high mast lighting. Prior to the completion of Interstate 393, this interchange was partially constructed to provide traffic movements to the local streets (refer to Figure C-1).

The project was awarded on September 12, 1980 to Pike Industries, Inc. of Tilton, New Hampshire for the low bid sum of $1,787,487.60. Of this total, approximately $387,000 relates primarily to the recycling effort.

## Preliminary Investigation

The Materials Division of the State Highway Department provides a comprehensive geotechnical report for the proposed project soon after preliminary engineering is initiated. The following description is a summary of their investigations and recommendations for the Concord project.

When this interchange was constructed, the practice of the Department was to reduce the base course and pavement depths on the interchange ramps from those course depths used on the mainline. Problems encountered at this and other interchanges during the post construction period resulted in changing this practice. Typical sections for the interchange ramps are now consistent with mainline typicals.

A review of the typical sections from the original interchange record plans showed the existing ramps to have been constructed with a granular base course consisting of six inches of crushed gravel over 12 inches of gravel and 12 inches of sand. Refering to Figure C-1, all ramps with the exception of

F, G and J had originally been built with three inches of hot bituminous pavement. Prior to construction of the present Interstate 393 spur, ramps F, G, J and L were built to a preliminary stage. Ramps F and G existed as surface treated gravel, while J ramp was composed of one-half inch surface treated gravel and one-half inch of Plant Mix Surface Treatment. A portion of ramp L had been constructed to a three-inch depth of bituminous pavement near the Interstate 93 connection (refer to Figure C-3). These four ramps (F, G, J and L) were open to local traffic and provided access to Fort Eddy Road and the New Hampshire Technical Institute.

The preliminary inspection of this interchange showed problems ranging from moderate to severe pavement cracking, differential pavement settlement in wheel path sections, and bumpy conditions due to frost heaves. The severe sections of pavement distress were located throughout the J ramp and the inner loop ramps where they approach or leave the Interstate mainline. In these sections, the embankment fills were relatively low and the underlying native silty soils did not provide an adequate foundation for the existing base course. The roadway deterioration in the remaining outer ramps and roadways consisted primarily of moderate pavement cracking, although these areas benefited from the high embankment fill and existing drainage systems.

It was recommended that a granular base course consisting of 12 inches each of crushed gravel and gravel, with 24 inches of sand be placed in all reconstructed sections of the project. To improve geometric conditions and the previously mentioned base course inadequacies within the interchange, ramp H in its entirety and portions of the remaining ramps would be reconstructed (refer to Figure C-3). The remaining portions of ramps K, I and Y would involve no change in the existing base course materials. Bituminous pavement which had been previously placed would be removed for future use in a recycling manner. On the remaining portions of inner ramps F and G which did not require reconstruction, the surface treated gravel would be scarified.

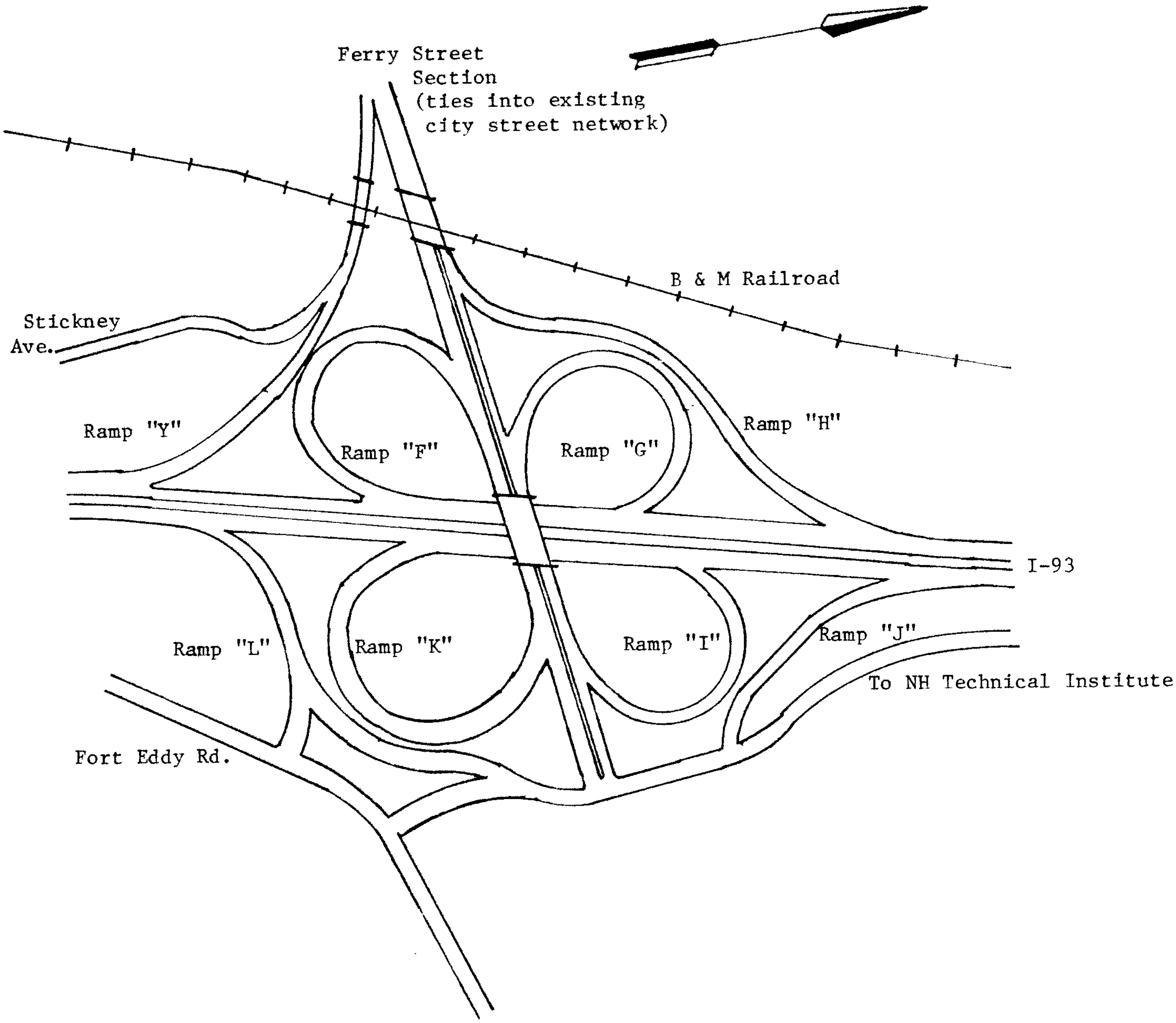



FIGURE C-1: Street Configuration
Prior to Construction

All interchange ramps with the exception of a portion of L would involve the placement of a five and one-half inch nominal bituminous pavement (one-inch wearing course, two-inch binder course and two and one-half inch base course; refer to Figure C-12).

The Ferry Street Interstate 393 section, which was located between the structures above the B&M Railroad and Interstate 93, showed moderate to severe pavement cracking during the preliminary inspection. The existing pavement was approximately five and one-half inches in depth with cracks extending to the base course materials. The granular base course was believed to be composed of 12 inches of surface treated crushed gravel, over a 12-inch gravel course and an undetermined amount of sand (probably 12 inches). This granular base course would be retained in its existing condition. To prevent future pavement cracking, it was recommended the entire bituminous pavement structure be removed and replaced. The placement of an overlay would act only as a temporary cosmetic effect with the existing cracks eventually reflecting through.

The project included safety improvements and a proposed pavement overlay on Interstate 93 between Bridge Street and the Merrimack River for approximately 1.37 miles. This section had previously been overlaid with a leveling course and a three-quarter inch open graded friction course (OGFC) under a project completed in 1975. At that time, the pavement design analysis justified the placement of a future one and one-quarter inch overlay. If a dense graded bituminous overlay was placed on the OGFC during this project, the possibility existed of trapping excess water in the voids between the two layers of dense graded mix. To prevent this from occurring, an overlay should consist of an additional OGFC or the existing OGFC should be removed. In view of these facts, it was recommended the existing wearing surface be planed to a depth of approximately one and one-quarter inches; this would ensure complete removal of the OGFC. The planing operation was then followed by a patching operation to correct any deficiencies. The placement of three inches of hot bituminous pavement would then take place.

With the information available from the record plans and preliminary sub-surface investigations, recycling of the existing pavement was recommended. Further discussion on the location and manner of recycled is located in "Equipment and Construction Procedures."

Specification Section

Although New Hampshire has done extensive work with cold recycling of pavement in the past few years, hot recycling of the existing bituminous pavement is a relatively new experience. The Concord project is the initial project awarded on the Federal-aid Highway System to incorporate the hot recycling method. In the past, the State has implemented this method to a limited extent on turnpike facilities.

This section contains the specification or special provisions included in this contract which dealt with the implementation of the hot recycling method. For review with these provisions, Appendix B contains the appropriate specifications in their entirety. Prior to listing the provisions, several key points located within the text should be identified:

1. The method of removal for all or part of the existing pavement structure was specified to be a cold planing operation.

   a. Where part of the existing pavement was to be removed to a specified depth and grade, Item 417: Cold Planing of Bituminous Surfaces was specified. This material could then be incorporated in the recycled bituminous pavement. Payment of this quantity was to be in square yards of planed pavement.

b. Where the entire depth of the existing pavement structure was to be removed and later used in a recycling mix, Item 404.1: Removal of Hot Bituminous Pavement for Recycling was specified. Payment of the quantity was to be in cubic yards removed.

2. Payment for the placement of recycled hot bituminous pavement was measured by the ton.

3. The stockpiled reclaimed material could be ordered covered by the Engineer with an acceptable waterproof sheeting.

4. There was no alteration in the normally specified job mix formula tolerances.

5. Surplus reclaimed bituminous pavement to be transported and placed in a stockpile for Maintenance Division use was specified under Item 404.9: Placing Surplus Recycled Bituminous Pavement in Stockpiles. Payment of the quantity was to be in cubic yards.

SPECIAL PROVISION

SECTION 404 -- RECYCLED BITUMINOUS PAVEMENT

ITEM 404.1 -- REMOVAL OF HOT BITUMINOUS PAVEMENT FOR RECYCLING

DESCRIPTION

1.1 This work shall consist of the removal and crushing of the entire thickness of existing hot bituminous pavement.

CONSTRUCTION REQUIREMENTS

3.1 The existing bituminous pavement shall be removed in one or more passes by a planing or milling machine. The machine will be operated so as to produce a crushed pavement product, 95 to 100 percent of which will pass a 1½ inch square testing sieve. Other means of pavement removal may be approved by the Engineer provided the removed material is further reduced in size by crushing so as to meet this requirement. The salvaged material shall be processed in such a manner so as to provide a uniform gradation. The bituminous pavement shall be removed in a manner which will prevent unnecessary intermixing with the underlying base course.

3.2 After processing, either on the road or off site, the reduced material will be transported and stockpiled at a designated site to await incorporation into new hot bituminous pavement.

3.3 The stockpiled material may be ordered covered by the Engineer with an acceptable waterproof sheeting.

## METHOD OF MEASUREMENT

4.1 Removed and crushed existing bituminous pavement as shown on the plans or ordered will be measured by the cubic yard as determined by the actual measurements of the lengths, widths and depth of existing bituminous pavement removed.

## BASIS OF PAYMENT

5.1 The accepted quantities of removed bituminous pavement for recycling will be paid for at the contract unit price per cubic yard. Transporting, stockpiling, covering and delivery to an approved bituminous plant for processing will be considered part of this item.

5.2 Existing base courses removed shall be replaced and compacted at the Contractor's expense.

Pay item and unit:

| | | |
|---|---|---|
| 404.1 | Removal of Bituminous Pavement for Recycling | Cubic Yard |

# SPECIAL PROVISION
# SECTION 404 -- RECYCLED BITUMINOUS PAVEMENT

## ITEM 404.9 -- PLACING SURPLUS RECYCLED BITUMINOUS PAVEMENT IN STOCKPILES

## DESCRIPTION

1.1 This work shall consist of transporting and placing surplus crushed recycled bituminous pavement from stockpiles described in 3.2 of 404.1 to a MAINTENANCE DIVISION storage area as directed.

## CONSTRUCTION REQUIREMENTS

3.1 Upon completion of work relating to 404.21, Recycled Bituminous Pavement, the Contractor shall transport all surplus bituminous materials removed under 404 or 417 to the specified patrol shed.

3.2 All material shall meet the sieve size requirements as stated in 404.1.

3.3 Surplus bituminous material shall be placed in neat piles in such a manner as to minimize segregation of the material.

## METHOD OF MEASUREMENT

4.1 Placing surplus recycled bituminous material in stockpiles will be measured by the cubic yard and in accordance with 109.01.

## BASIS OF PAYMENT

5.1 The accepted quantity of surplus recycled bituminous pavement placed in stockpiles will be paid for at the contract unit price per cubic yard.

Pay item and unit:

| | | |
|---|---|---|
| 404.9 | Placing Surplus Recycled Bituminous Pavement In Stockpiles | Cubic Yard |

SPECIAL PROVISION
SECTION 404 -- RECYCLED BITUMINOUS PAVEMENT

ITEM 404.21 -- RECYCLED HOT BITUMINOUS PAVEMENT

DESCRIPTION

1.1 This work shall consist of constructing one or more courses of hot bituminous pavement on a prepared base or an existing pavement using a combination of virgin and salvaged material.

MATERIALS

2.1 The salvaged hot bituminous pavement shall be free from objectionable matter and shall have been reduced in size so that 95-100 percent of the material will pass a 1½ inch laboratory sieve. Salvaged hot bituminous pavements having significantly different gradations shall be stockpiled separately.

2.1.1 Residual moisture content in salvaged hot bituminous pavement shall be held to a practical minimum by covering it with an acceptable waterproof sheeting.

2.1.2 Virgin aggregate material shall meet the requirements of 401.2.1 through 401.2.1.4.

2.2 Bituminous materials shall meet the requirements of AASHTO M 226 except for those values shown in 702 Table 2. The grade to be used shall be designated by the Engineer.

2.3 Sections 2.3, 2.4 of Section 401 shall apply. The job mix formula shall include the proposed proportions of each material including the salvage material, asphalt modifier, if used, and new asphalt cement.

2.4 The asphalt modifier (recycling agent) shall be a softening agent, flux oil, rejuvenator or soft asphalt cement conforming to the following:

| Test | Requirement Minimum | Maximum |
|---|---|---|
| Viscosity, 140 degrees F., centistokes | 5,000 | 10,000 |
| Flash Point, Pensky-Martens | 450 | |
| Saturate, by weight, percent | | 30 |
| Residue, Rolling Thin Film Oven, 325 degrees F., Weight Change Percent | | 2 |
| Viscosity Ratio (Note 1) | | 3 |

(Note 1) Viscosity Ratio - Rolling Thin Film Oven Residue, at 140 degrees F., centistokes; Original Viscosity, at 140 degrees F., centistokes.

## CONSTRUCTION REQUIREMENTS

3.1 The construction requirements shall be the same as those specified under 3.1 through 3.11 of Section 401 except as modified or supplemented hereinafter.

3.1.7 The plant shall be equipped with a separate hopper and conveyor system so as to allow positive control of the feeding of salvaged material directly to the weigh hopper. The feeding system shall have the capability of delivering the exact amount of required material. If automation is used, this system shall be incorporated into the automatic cycle.

3.2 The maximum aggregate temperature as shown in 3.2.1 shall be deleted. The Engineer may require adjustment to the mixing time as shown in 3.2.1.

3.3 The Engineer may approve or require the addition of a modifying or recycling agent to the asphalt prior to delivery of the asphalt to the project or during proportioning or mixing operations.

3.4 Recycled hot bituminous pavement shall not be used as wearing course.

## METHOD OF MEASUREMENT

4.2 Asphalt modifier material will be measured by the nearest gallon.

## BASIS OF PAYMENT

5.1 The requirements of basis of payment shall be the same as stated under 403.5.1. Asphalt modifier material, when used, shall be paid for separately.

Pay items and units:

| | | |
|---|---|---|
| 404.21 | Recycled Hot Bituminous Pavement | Ton |
| 404.211 | Asphalt Modifying Agent | Gallon |

## SPECIAL PROVISION
## SECTION 417 -- COLD PLANING OF BITUMINOUS SURFACES

### DESCRIPTION

1.1 This work shall consist of the removal of existing bituminous pavement, by planing or milling type equipment, to the depth and grade as shown on the plans or ordered.

### EQUIPMENT

2.1 The equipment used for planing of bituminous surfaces shall be a power-operated rotary scarifier capable of uniformly scarifying the existing bituminous surfaces.

## CONSTRUCTION REQUIREMENTS

3.1 The existing bituminous surface shall be removed by a planing or milling machine capable of removing, in one or more passes, bituminous material to the depth specified. The equipment shall be capable of accurately establishing profile grades by referencing from either the existing pavement or from an independent grade control.

3.1.1 The equipment shall have an effective means for controlling dust.

3.2 Material removed during this operation shall be transported and stockpiled for use and incorporation into Item 404.21.

## METHOD OF MEASUREMENT

4.1 Cold planing of bituminous surfaces as shown on the plans or ordered will be measured by the square yard as determined by the actual surface measurements of the lengths and widths of the bituminous areas removed.

4.1.1 The nominal depth of material removed will be as shown on the plans.

## BASIS OF PAYMENT

5.1 The accepted quantities of cold planing bituminous surfaces, to the nominal depth specified, will be paid for at the contract unit price per square yard.

Pay item and unit:

| | | |
|---|---|---|
| 417 | Cold Planing of Bituminous Surfaces | Square Yard |

## Equipment and Construction Procedures

### Pavement Removal

A Barber Greene RX-75 cold planing machine, equipped with material pickup and loadout conveyors, was used to remove the existing bituminous pavement to a specified grade and slope. The depth of cut and transverse slope of the cutter was automatically controlled by the use of the mobile reference skis. The 10'5" wide cutting drum on the machine contained a variable number of replaceable, tungsten carbide tipped teeth. Dust generated by the action of the cutting teeth was controlled by water spray in the cutting area.

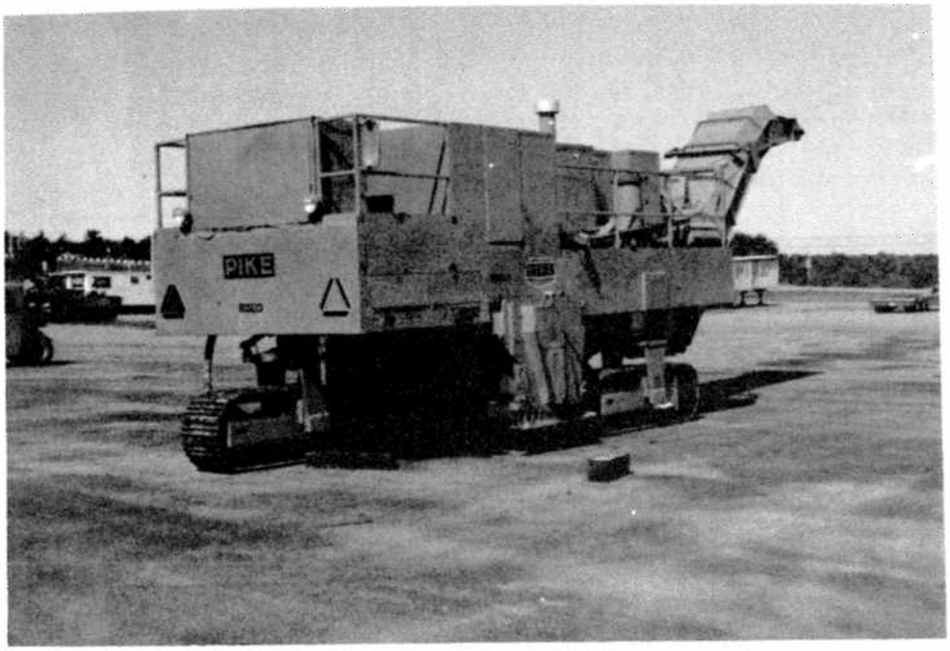



FIGURE C-2: Barber Greene Dynaplane

The productivity of the cold planing machine is a function of the resistance of the existing pavement structure to the penetration of the cutting teeth. The resistance of the pavement may be affected by many factors; among the most prevalent are the material quality, ambient temperature on the date of removal and the depth of cut. A pavement layer which is alligator cracked and in distress will be easier to plane than a section of high structural integrity. The hardness of the aggregate and its gradation in the existing pavement will also affect the rate of productivity. When aggregate hardness increases, the planing productivity will decrease, as will tooth life on the drum.

As the depth of cut increases, the rate at which the material is reclaimed will increase up to a certain thickness. Beyond this optimum depth, the rate of material reclaimed will decrease due to greatly reducing forward speed. The most efficient depth of cut is generally three to four inches in asphalt concrete pavement.

The project involved several methods for pavement removal depending on the existing conditions as discussed in preliminary investigations:

- Item 203.1; Common excavation of those areas which required complete reconstruction due to inadequate base course materials, and the pavement material was of poor quality for incorporation into the recycled mix.
- Item 212.1; Scarifying of the existing surface; this included the scarifying, reshaping and compaction of the surface to form a proper base for the subsequent course.
- Item 404.1; Removal of the existing bituminous pavement for recycling involved the full depth of the existing pavement, whether three or five and one-half inches.
- Item 417; Cold planing of the existing bituminous pavement to a maximum depth of one and one-quarter inches for later use in the recycled material.

Table C-1 contains the type, location and quantity of pavement removal as estimated prior to construction.

| TYPE | LOCATION | APPROXIMATE STATIONS | LENGTH | QUANTITY |
|---|---|---|---|---|
| Item 203.1: Common Excavation | Ramp J | 16+00-23+28 | 728' | -- |
| | G | 7+50-11+42 | 392' | -- |
| | F | 0+00- 2+00 | 200' | -- |
| | | 6+50- 8+92 | 242' | -- |
| Item 212.1: Scarify | Ramp F | 2+00- 6+50 | 450' | 1,000 sy |
| | G | 1+00- 8+86 | 775' | 1,295 sy |
| Item 404.1: Removal of 3" Existing Pavement for Recycling | Ramp Y | 8+95-18+90 | 995' | 265 cy |
| | H | 1+00-13+00 | 1,200' | 290 cy |
| | K | 1+80-14+00 | 1,220' | 270 cy |
| | L | 2+00- 7+00 | 500' | 85 cy |
| | I | 2+00-10+90 | 890' | 190 cy |
| | NB-SB I-93 | Ramps & Shoulders | -- | 215 cy |
| Removal of 5½" Existing Pavement for Recycling | I-393 (Ferry Street Section) | 28+15-21+30 | 685' | 935 cy |
| Item 417: Cold Planing Bituminous Surface | NB I-93 | 58+40-130+85 | 7,245' | 29,500 sy |
| | SB I-93 | 130+85-58+40 | 7,245' | 29,500 sy |

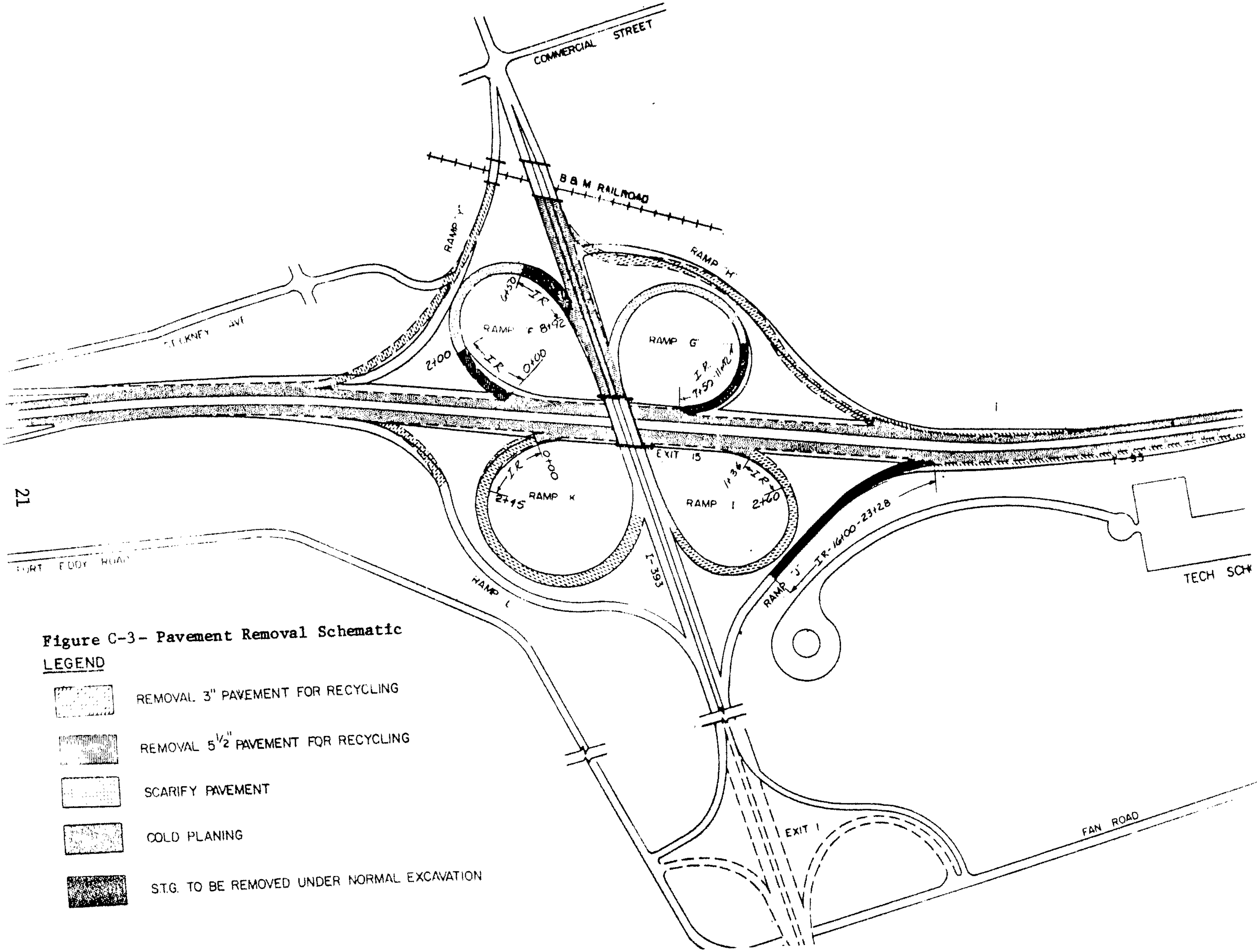



**Figure C-3- Pavement Removal Schematic**

LEGEND

- REMOVAL 3" PAVEMENT FOR RECYCLING
- REMOVAL $5^{1/2}$" PAVEMENT FOR RECYCLING
- SCARIFY PAVEMENT
- COLD PLANING
- S.T.G. TO BE REMOVED UNDER NORMAL EXCAVATION

The removal of the existing pavement by the planer was accomplished in a single pass for the depths of one and one-quarter inches and three inches. The removal of the five and one-half inches of existing pavement on the Ferry Street Interstate 393 section was accomplished in two passes of approximate equal cutting depth. Using two passes not only completed the removal at a high rate of efficiency, but also facilitated the later use of the reclaimed material in different recycled gradations (refer to plant operations). With a cutting width of 10'5" and depth of three inches, the planer removed the pavement at an average rate of 50 feet per minute.

The milled material was transported from the project site to two different locations. The material which was cold planed under Item 417 (this being the I-93 mainline area) was stockpiled at the plant site. Located in Tilton, this was 20± miles north of the project via Interstate route 93. In quantity, this was approximately 1,700 cubic yards. The material reclaimed under Item 404.1 was divided into two portions. That portion which was from the I-393 Ferry Street section (approximately 900 cubic yards) was transported to the plant site. The remaining portion which was from the various ramps and other locations (see Table C-1), was retained by the State of New Hampshire for their use. This was roughly 1,400 cubic yards in quantity.

Under Item 404.9, Placing Surplus Recycled Bituminous Pavement in Stockpiles, the 1,400 cubic yards was transported by the contractor and deposited at an area designated by the Division 5 Maintenance Engineer. This was eight± miles west of the project site via the Interstate and secondary roads. From this location, State maintenance forces transported the material to Maintenance Yard 504 in Henniker. At this site, the existing gravel surface of the storage and parking area was graded, crushed material added, and three to six inches of the reclaimed material placed and compacted. A penetrating oil was expected to be applied to the new surface in the future to prolong the length of service.

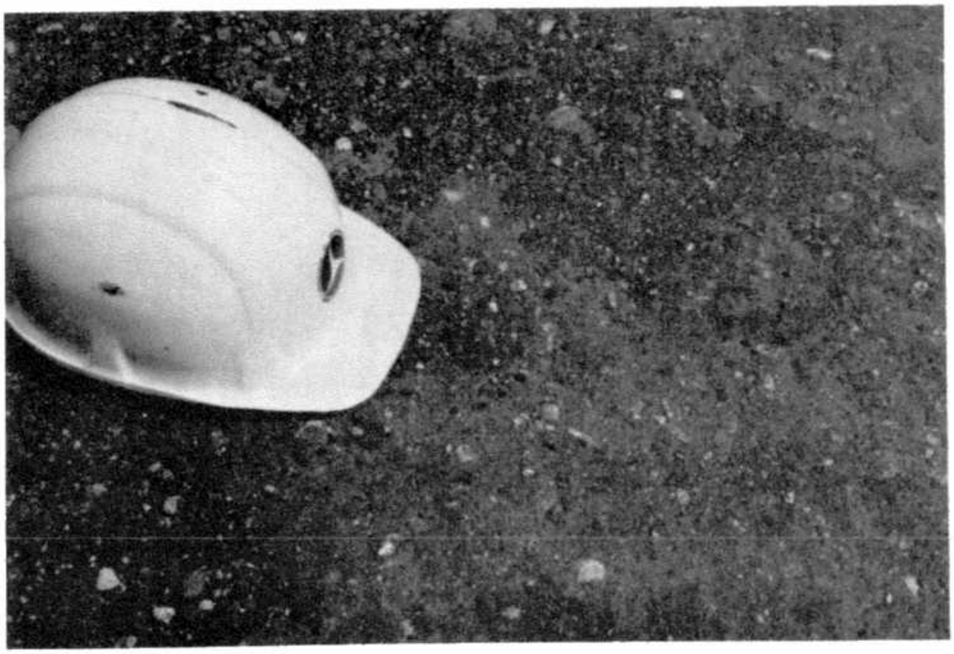


FIGURE C-4: Surface at Maintenance Yard Prior to Application of Penetrating Oil

Plant Operations

The removal of the existing pavement structure by the cold planing machine did not radically alter the gradation of the aggregate. The planing machine cutting tools tended to break the bond between the asphalt cement and the aggregate particles. The existing pavement on the project was removed from three basic sources for use in the recycled mix. To facilitate optimum plant operations, the material was stockpiled in the following manner.

Of the material reclaimed from the I-393 Ferry Street section, the surface wearing course and binder course located in the top three inches of the existing bituminous pavement was incorporated into the three-quarter inch maximum aggregate size recycled binder mix; the base course material located in the lower three inches of the existing bituminous pavement was incorporated into the one and one-quarter inch maximum aggregate size recycled base mix.

The open graded friction course which was cold planed from the I-93 mainline was incorporated into the three-quarter inch maximum aggregate size recycled binder mix. Further processing of the material was not necessitated to meet the requirements for the specified gradation.

FIGURE C-5: Blending of Milled Material Stockpile at Plant Site

Throughout the life of the project, the stockpiles had remained covered with polyurethane sheets. This reduced the likelihood of moisture being retained in the stockpiles and therefore little reconsolidation of the aggregate occurred. The loader operator blended each stockpile to a uniform mixture prior to introduction to the operation. The front-end loader was then used to place the reclaimed material into the recycle bin. This had a relatively small capacity and steep sides to allow for easy discharge to the conveyor system (see Figures C-6 and C-7). The reclaimed material was then fed by the conveyor to a small hopper attached to the plant just above the virgin aggregate hot bins (see Figure C-8).

The virgin aggregates were fed through the dryer and heated to 450-475$^{o}$F (Figures C-9, C-10 and C-11). If the asphalt pavement to be produced was composed of 100 percent virgin materials, the aggregates would normally be heated to 300-325°F. The aggregates were then processed through the gradation control unit and hot bins prior to being deposited in the weigh hopper.

As is the usual practice with batch plant recycling, the reclaimed material was not subject to the gradation control unit or vibratory screens at the plant prior to its introduction to the weigh hopper. From the small hopper, an entrance chute, steep and of constant width was used to introduce the reclaimed material to the center of the weigh hopper.

After depositing the two larger virgin aggregates into the weigh hopper the reclaimed material was introduced and followed by the remaining smaller aggregates. Although together for only a short period, the transfer of heat from the virgin aggregate to the ambient temperature reclaimed aggregate begins here. The combined aggregates were then dropped to the pugmill and dry mixed for approximately 13 seconds. After the asphalt cement (AC-10) was introduced; mixing on the wet cycle for an additional 43 seconds completed the process. The asphalt line at the plant indicated a temperature of 300°F for the additional asphalt required. Upon completion of the mix, the finished product left the plant at 290-300°F.

Rejuvenator was not deemed necessary and thus not used during the recycling process. Each truck hauling to the project carried six batches of material at approximately 36,000 pounds total net weight.

When the reclaimed material is deposited in the weigh hopper with the superheated virgin material and mixed in the pugmill, a significant release of steam and dust particles may occur. With the reclaimed material being adequately covered and containing a moisture content of <u>one to two percent</u>, there existed no real problem in emission control on this project. Had the moisture content been higher, provisions would be required to vent the emissions to the atmosphere or into the plant air pollution system.

The batching quantity had steadily been increased from 2.5 tons to a maximum of 3.6 tons when high production was required at this four-ton batch plant.

On most days, the batching quantity was maintained at three tons. The reclaimed milled material was introduced into the recycled mix at a rate of 25 percent and gradually increased to 35 percent. After consideration of the moisture content of the reclaimed material, the required discharge temperature of the recycled mixture, and the batching quantity, the optimum mix for safe and economic production at the plant was considered to be 30 percent reclaimed and 70 percent virgin material. An increase in any of the factors would have required a dramatic rise in the temperature of the new aggregate, thereby increasing the quantity of fuel expended and the possibility of damage to the dryer. The realistic upper limit for heating the virgin aggregate in most batch plants without reducing the life of the dryer is 575-600$^{\circ}$F. By keeping the reclaimed material covered to minimize moisture, and the amount incorporated in the recycled mix at a relatively low rate (30 percent), the required temperature for the virgin aggregate could be held to a minimum. The plant operator had not evidenced any damage to the dryer during the length of the project. He also stated there had been no problem with the safe operation of the exhaust system baghouse despite the high temperatures of the dryer exhaust gas.

With an additional plant located at the site, there was no change in the rate of output. The main plant produced the recycled material, while the remaining batch plant produced mixes required by various customers.

Information on the 1½-inch maximum aggregate size recycled base material:

| Sieve | % Passing Specs. | Approved Job Mix | Extraction Date of Insp. | (Milled) Reclaimed Material Only |
|---|---|---|---|---|
| 1¼" | 95-100 | 95-100 | 96 | 96 |
| 1" | 75-95 | 87 | 83 | 95 |
| 3/4" | 62-84 | 67 | 66 | 86 |
| 1/2" | 50-70 | 59 | 58 | 79 |
| 3/8" | 42-60 | 52 | 54 | 74 |
| #4 | 28-45 | 36 | 36 | 55 |
| #10 | 18-27 | 23 | 24 | 40 |
| #20 | 10-18 | 17 | 18 | 28 |
| #40 | 5-13 | 12 | 13 | 20 |
| #80 | 1-9 | 7 | 7 | 11 |
| #200 | 0-4 | 3 | 3 | 5 |
| %AC | 3.8-4.8 | 4.5 | 4.8 | 4.0 |

The 6,000 pound batching drops were proportioned by the following mix for the 1½-inch recycled base material:

| | 1 Ton Batch | 3 Ton Batch | |
|---|---|---|---|
| 5/32" | 213 lbs. | 638 lbs. | 11% |
| 3/8" | 271 " | 812 " | 14% |
| Reclaimed | 580 " | 1,741 " | 30% |
| 9/16"-5/8" | 174 " | 522 " | 9% |
| 1 1/2" | 696 " | 2,089 " | 36% |
| | 1,934 lbs. | 5,802 lbs. | |
| Asphalt Cement | + 66 " | + 198 " | |
| | 2,000 lbs. | 6,000 lbs. total drop | |

At the time of batching the recycled base material, the reclaimed milled material had an asphalt content of 4.0 percent. Since it comprised 30 percent of the recycled mix, it contributed 1.5 percent of the asphalt content for the total mix. With the addition of 198 pounds of asphalt cement (AC-10) or 3.3 percent of the job mix, the cumulative asphalt content was 4.8 percent.

Information on the 3/4-inch recycled binder material:

| Sieve | % Passing Specs. | Approved Job Mix | Extraction Date of Insp. | (Milled) Reclaimed Material Only |
|---|---|---|---|---|
| 3/4" | 95-100 | 95-100 | 98 | 97 |
| 1/2" | 70-92 | 79 | 81 | 81 |
| 3/8" | 60-80 | 70 | 70 | 84 |
| #4 | 42-57 | 49 | 45 | 57 |
| #10 | 28-38 | 31 | 30 | 41 |
| #20 | 16-24 | 20 | 21 | 30 |
| #40 | 9-17 | 13 | 15 | 23 |
| #80 | 3-11 | 7 | 9 | 15 |
| #200 | 0-4 | 3 | 4 | 6 |
| %AC | 4.8-6.0 | 5.2 | 5.2 | 5.2 |

The 6,000 pound batching drops were proportioned by the following mix for the 3/4-inch recycled binder material:

| | 1 Ton Batch | 3 Ton Batch | |
|---|---|---|---|
| 5/32" | 385 lbs. | 1,156 lbs. | 20% |
| 3/8" | 328 " | 983 " | 17% |
| Reclaimed | 578 " | 1,735 " | 30% |
| 9/16"-5/8" | 308 " | 925 " | 16% |
| 3/4" | 328 " | 938 " | 17% |
| | 1,927 lbs. | 5,782 lbs. | |
| Asphalt Cement | + 73 " | + 218 " | |
| | 2,000 lbs. | 6,000 lbs. total drop | |

At the time of batching the recycled binder material, the reclaimed milled material was found to have an asphalt content of 5.2 percent. Since it comprised 30 percent of the recycled mix, it contributed 1.6 percent of the asphalt content for the total mix. With the addition of 218 pounds of asphalt cement (AC-10), or 3.6 percent for the job mix, the cumulative asphalt content was 5.2 percent.

The inspector at the plant performed one hot bin aggregate gradation and two extractions per day during production. The quality control and acceptance test results were all within the allowable tolerances. Extraction tests required the use of a stronger solvent to remove the milled asphalt; without careful handling, the solvent could be hazardous to the plant inspector.

The recycled base and binder at the output appeared to be of equal quality as a base and binder mix of entirely virgin material.

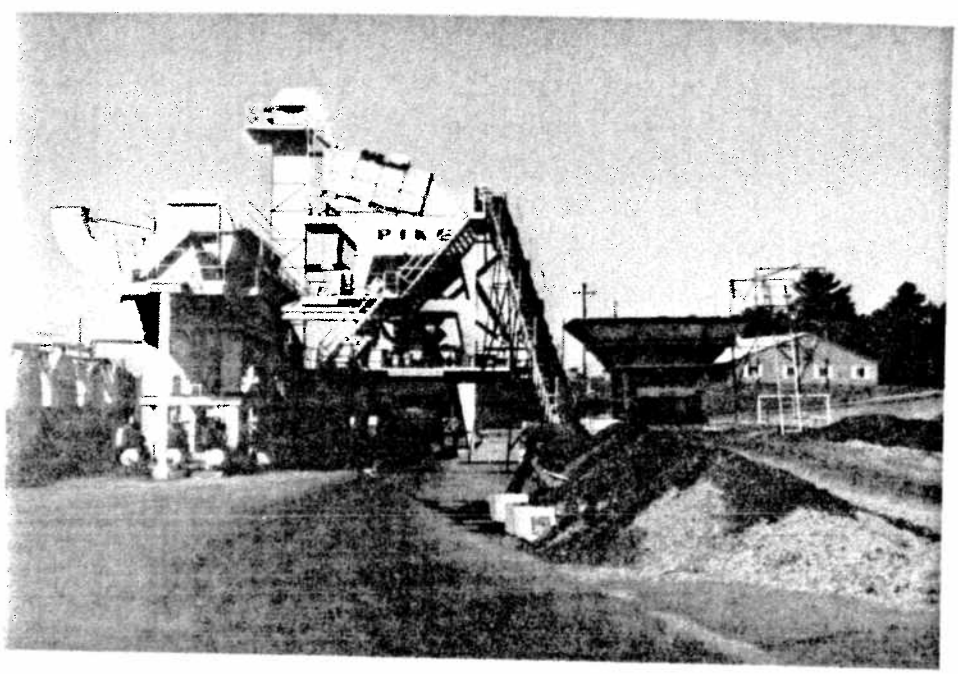


FIGURE C-6: Asphalt Batch Plant With Recycle Bin in Foreground

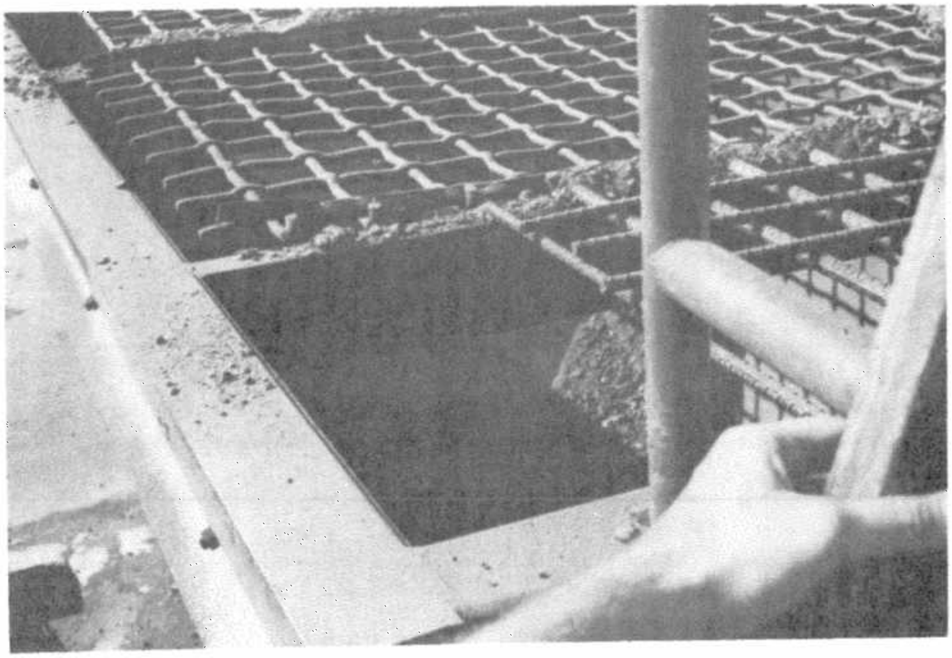


FIGURE C-7: Recycle Bin

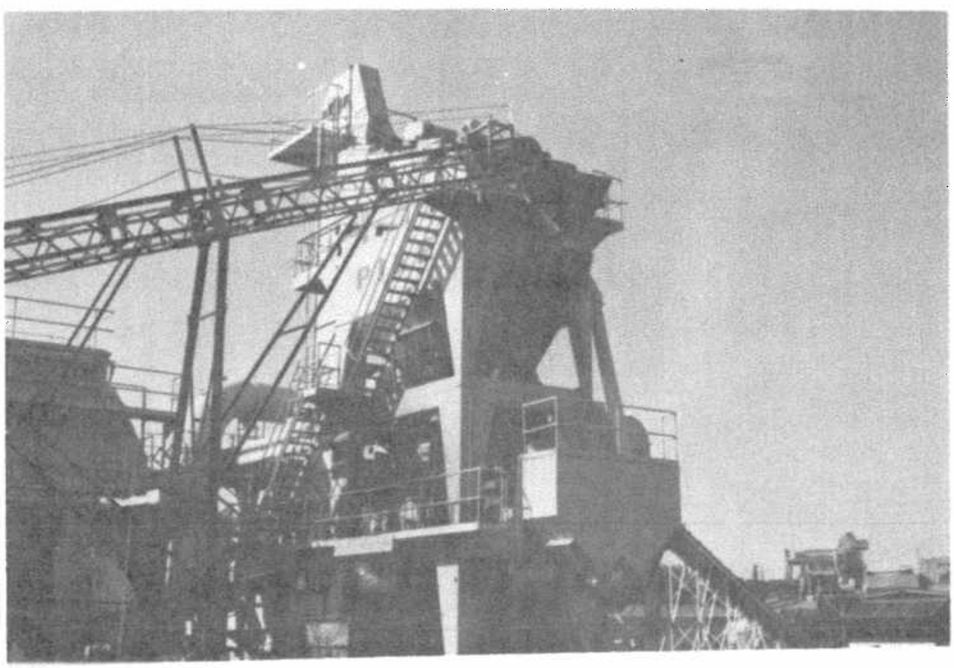


FIGURE C-8: Batch Plant With Small Hopper for Reclaimed Material. Left Foreground: Conveyor from Recycle Bin. Right Background: Conveyor from Virgin Aggregate Storage Bins.

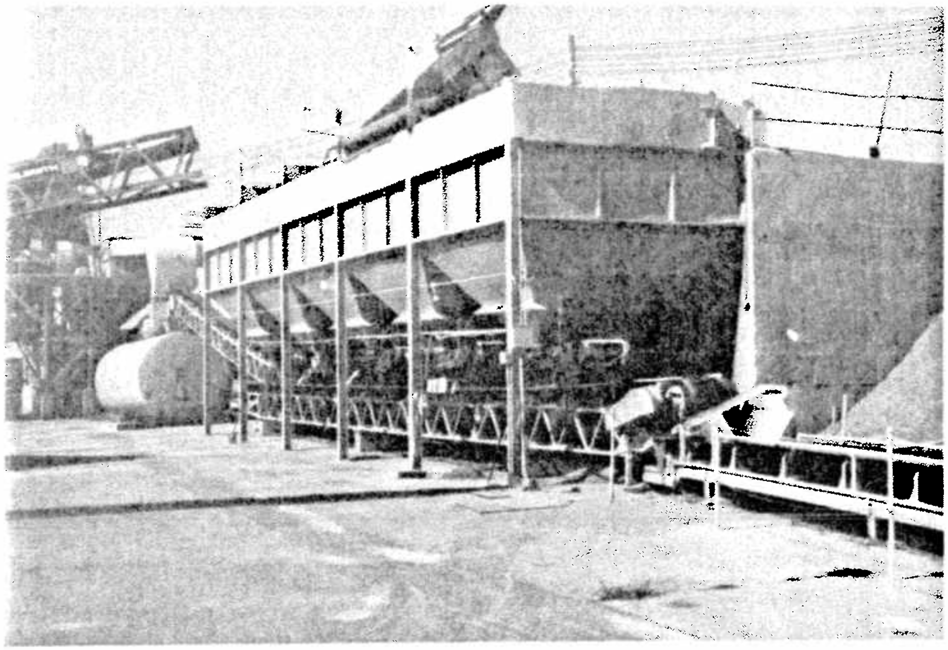


FIGURE C-9: Virgin Aggregate Storage Bins

FIGURE C-10: C. nveyor from Virgin Aggregate Bins to Dryer. Left Background: Control House

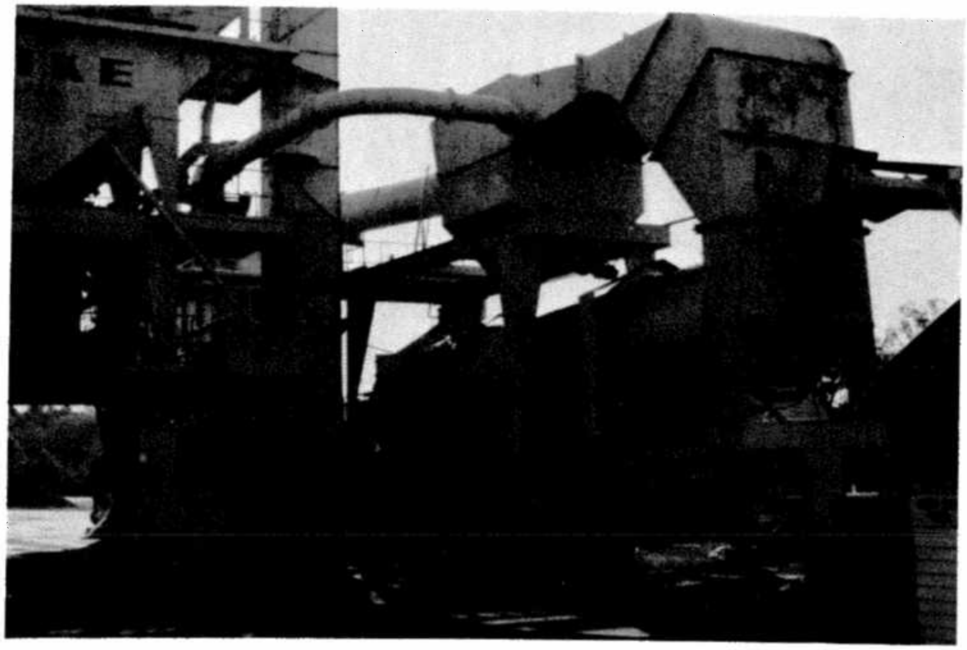


FIGURE:C-11: Dryer Drum and Dust Collection System

## Paving Operations

The recycled base and binder bituminous asphalt was placed throughout the project site; for locations refer to Figure C-12.

Placement of the recycled material was observed on several occasions. The mix was consistent with the characteristics of a virgin material and appeared no different. After the 20± mile journey from the plant, the recorded temperatures during placement were in the 280-300°F range. The material was placed with a conventional paving machine with a variable width screed. The minimum width was 10 feet and could be increased by two and one-half feet on either side for a maximum of 15 feet.

The initial rolling of the base course was accomplished by a two-axle static steel-wheeled roller. This was followed with a pneumatic-tired roller. Final rolling of each course was completed by a three-axle static steel-wheeled roller. These paving and rolling techniques were the same as those utilized for a conventional virgin material.

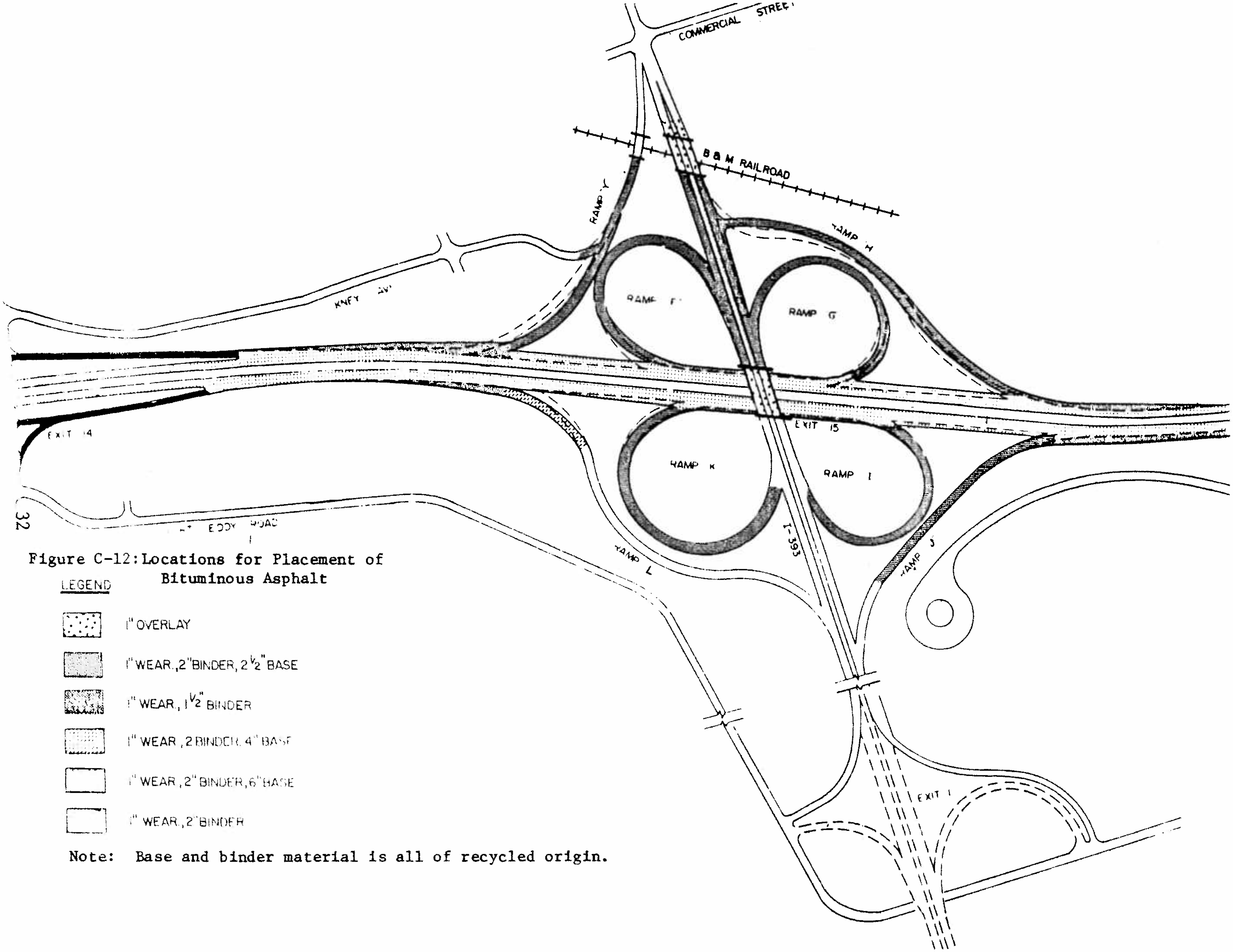



Figure C-12: Locations for Placement of Bituminous Asphalt

Note: Base and binder material is all of recycled origin.

Cost Analysis

This portion of the paper will analyze the costs involved in the construction of the recycle design versus a conventional structural section. This project contained six areas of differing structural sections, due to the existing geometrics, condition of the pavement and prior construction.

Costs are either actual bid prices from the project or weighted average unit prices where noted. These are the items of significance to the paving operation for this project:

| Item | Description | Quantity | Price Per Unit |
|---|---|---|---|
| 203.1 | Common Excavation | 44,000 cy | $ 1.60 |
| 403.11 | Hot Bituminous Pavement Machine Method (100% Virgin Material) | 5,800 ton | 26.60 |
| 404.1 | Removal of Hot Bituminous for Recycling | 2,200 cy | 12.00 |
| 404.21 | Recycled Hot Bituminous Pavement (x% Recycled Material) | 16,400 ton | 18.00 |
| 404.9 | Placing Surplus Recycled Bituminous Pavement in Stockpiles | 1,700 cy | 1.00 |
| 411.1 | Hot Bituminous Concrete Leveling Course (100% Virgin Material) | 1,100 ton | 25.00 |
| 417 | Cold Planing of Bituminous Surfaces | 64,000 sy | 1.00 |

I-93 Northbound-Southbound Mainline

Method: Actual Recycled

Cold plane an average depth of one (1) inch

Place 2" recycled binder and 1" surface wearing course (6" of pavement exist after removal)

Conventional Section (Replacement with 100% Virgin Mix)

Cold plane an average depth of one (1) inch

Place 2" binder and 1" wearing course

Costs: Actual Recycled

1. Cold plane surface = $1.00 per sy

2. Place 2" recycled binder course:

   $18/ton x 0.113 ton/sy = $2.03 per sy

3. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $4.55 per sy

Conventional Section (Replacement with 100% Virgin Mix)

1. Cold plane surface = $1.00 per sy
2. Place 2" binder course:

   $26.60/ton x 0.113 ton/sy = $3.01 per sy

3. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $5.53 per sy

As discussed in the Preliminary Investigation section, the placement of a dense graded bituminous pavement as an overlay for open graded friction course is not recommended. With this in mind, the alternate conventional section incorporates the removal of the OGFC and placement of three inches of virgin bituminous pavement. With removal of the OGFC required in either case (virgin or recycled), the placement of the recycled mix reduced costs by $0.98 per square yard of reconstruction or 17.7 percent.

I-393 - Ferry Street Section

Method: Actual Recycled

Remove the existing 5½" of pavement for recycling

Place 2½" recycled base, 2" recycled binder and 1" wearing course

Conventional Section (Replacement with 100% Virgin Mix)

Remove the existing 5½" of pavement by common excavation

Place 2½" base course, 2" binder course and 1" wearing course

Costs: Actual Recycled

1. Remove existing pavement for recycling:

   $12/cy x 0.15 yd. deep x 1 sy = $1.80 per sy

2. Place 2½" recycled base course:

$18/ton x 0.143 ton/sy = $2.57 per sy

3. Place 2" recycled binder course:

$18/ton x 0.113 ton/sy = $2.03 per sy

4. Place 1" wearing course:

$26.60/ton x 0.057 ton/sy = $1.52 per sy

$7.92 per sy

Conventional Section (Replacement with 100% Virgin Mix)

1. Remove existing pavement by common excavation:

$1.60/cy x 0.15 yd. deep x 1 sy = $ .24 per sy

2. Place 2½" base course:

$26.60/ton x 0.141 ton/sy = $3.80 per sy

3. Place 2" binder course:

$26.60/ton x 0.113 ton/sy = $3.01 per sy

4. Place 1" wearing course:

$26.60/ton x 0.057 ton/sy = $1.52 per sy

$8.57 per sy

As discussed in the Preliminary Investigation section, the existing pavement structure in this area showed moderate to severe pavement cracking. The existing pavement was five and one-half inches thick and the cracks were extended down into the base course. An overlay would have simply delayed the extension of these cracks and provided a cosmetic effect; therefore, an overlay was not recommended. With removal of the pavement required, the placement of the recycled mix rather than virgin materials reduced the cost by $0.65 per square yard of reconstruction or 7.6 percent.

Ramps Y and H

Method: Actual Recycled

Remove 3" pavement for recycling

Place $2\frac{1}{2}$" recycled base course, 2" recycled binder course and 1" wearing course

Conventional Section (Replacement with 100% Virgin Mix)

Remove 3" pavement by common excavation

Place $2\frac{1}{2}$" base course, 2" binder course and 1" wearing course

Costs: Actual Recycled

1. Remove existing pavement for recycling:

   $12/cy x 0.08 yd. deep x 1 sy = $0.96 per sy

2. Place $2\frac{1}{2}$" recycled base course:

   $18/ton x 0.143 ton/sy = $2.57 per sy

3. Place 2" recycled binder course:

   $18/ton x 0.113 ton/sy = $2.30 per sy

4. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $7.08 per sy

Conventional Section (Replacement with 100% Virgin Mix)

1. Remove existing pavement by common excavation:

   $1.60/cy x 0.08 yd. deep x 1 sy = $0.13 per sy

2. Place $2\frac{1}{2}$" base course:

   $26.60/ton x 0.141 ton/sy = $3.75 per sy

3. Place 2" binder course:

   $26.60/ton x 0.113 ton/sy = $3.01 per sy

4. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $8.41 per sy

Due to the realignment of the existing ramps Y and H, an overlay design was not feasible. The three inches of existing pavement was removed and placed in the maintenance division stockpile. With the removal of the existing pavement required, the placement of recycled mix rather than 100 percent virgin aggregate mix reduced the cost by $1.33 per square yard of reconstruction or 15.8 percent.

Ramps K and I

Method: Actual Recycled

Remove 3" existing pavement for recycling

Place 2½" recycled base course, 2" recycled binder course and 1" wearing course

Conventional Section (Replacement with 100% Virgin Mix)

Remove 3" existing pavement by common excavation

Place 2½" base course, 2" binder course and 1" wearing course

Costs: Actual Recycled

1. Remove existing pavement for recycling:

   $12/cy x 0.08 yd. deep x 1 sy = $0.96 per sy

2. Place 2½" recycled base course:

   $18/ton x 0.143 ton/sy = $2.57 per sy

3. Place 2" recycled binder course:

   $18/ton x 0.113 ton/sy = $2.03 per sy

4. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $7.08 per sy

Conventional Section (Replacement with 100% Virgin Mix)

1. Remove existing pavement by common excavation:

   $1.60/cy x 0.08 yd. deep x 1 sy = $0.13 per sy

2. Place 2½" base course:

   $26.60/ton x 0.141 ton/sy = $3.75 per sy

3. Place 2" binder course:

   $26.60/ton x 0.113 ton/sy = $3.01 per sy

4. Place 1" wearing course:

| | |
|---|---|
| $26.60/ton x 0.057 ton/sy | = <u>$1.52</u> per sy |
| | $8.41 per sy |

As discussed in the Preliminary Investigation section, the existing pavement depth on these ramps was three inches in depth. The surface showed moderate to severe cracking, differential settlement in the wheel path sections, and bumpy conditions due to frost heaves. With these conditions in mind, an overlay was not feasible and total reconstruction of the inner ramps was recommended. The existing pavement was removed and placed in the maintenance division stockpile. With removal of the existing pavement required, the placement of the recycled mix rather than a virgin mix reduced the cost by $1.33 per square yard of reconstruction or 15.8 percent.

<u>Ramp L (Connection to Mainline)</u>

<u>Method</u>: <u>Actual Recycled</u>

Remove the existing 3" of pavement for recycling

Place 4" recycled base, 2" recycled binder and 1" wearing course

<u>Conventional Section (Replacement with 100% Virgin Mix)</u>

Remove the existing 3" of pavement by common excavation

Place 4" base course, 2" binder course and 1" wearing course

<u>Costs</u>: <u>Actual Recycled</u>

1. Remove existing pavement for recycling:

| | |
|---|---|
| $12/cy x 0.08 yd. deep x 1 sy | = $0.96 per sy |

2. Place 4" recycled base course:

| | |
|---|---|
| $18/ton x 0.226 ton/sy | = $4.07 per sy |

3. Place 2" recycled binder course:

| | |
|---|---|
| $18/ton x 0.113 ton/sy | = $2.03 per sy |

4. Place 1" wearing course:

| | |
|---|---|
| $26.60/ton x 0.057 ton/sy | = <u>$1.52</u> per sy |
| | $8.58 per sy |

Conventional Section (Replacement with 100% Virgin Mix)

1. Remove existing pavement by common excavation:

   $1.60/cy x 0.08 yd. deep x 1 sy = $0.13 per sy

2. Place 4" base course:

   $26.60/ton x 0.226 ton/sy = $6.02 per sy

3. Place 2" binder course:

   $26.60/ton x 0.113 ton/sy = $3.01 per sy

4. Place 1" wearing course:

   $26.60/ton x 0.057 ton/sy = $1.52 per sy

   $10.68 per sy

This short portion of the L ramp required total reconstruction due to the existing moderate pavement cracking, differential pavement settlement and necessary removal of the underlying foundation soils. The only feasible alternate conventional section was the total reconstruction incorporating 100 percent virgin material. The existing pavement was removed and placed in the maintenance division stockpile. With removal of the existing pavement required in either case (virgin or recycled), the placement of the recycled mix reduced costs by $2.10 per square yard of reconstruction or 19.7 percent.

Ramps F, G and J

As previously discussed in the Preliminary Investigation section, the subject ramps had been built to a preliminary stage. Local traffic used the surface treated gravel ramps to gain access to and from Fort Eddy Road and the New Hampshire Technical Institute. The existing material was either scarified or removed by common excavation; none was incorporated into the recycled mix. After modification to the granular base materials and section, a five and one-half inch nominal section of bituminous pavement was placed, two and one-half inches of recycled base course, two inches of recycled binder and one inch surface wearing course. By using the reclaimed milled material from the I-93 mainline and I-393

Ferry Street section in the recycled mix, these three ramps benefitted from the hot recycling. The placement of the recycled mix rather than a mix of 100 percent virgin material reduced the costs by $2.20 per square yard of reconstruction.

From these calculations, recycling of the existing pavement rather than the placement of entirely virgin materials reduced the cost by $0.65 to $2.30 per square yard of reconstruction or 7.6 to 19.7 percent.

Appendix A includes an estimation technique used in determining the energy, aggregate and dollar savings by incorporation of the hot recycling method.

Tons of Aggregate Saved: 4,675

Equivalent Gallons of Gasoline Saved: 5,550

MANCHESTER HOT RECYCLING PROJECT
M-5285(003), Contract 2

Project Description

This project was located on the west side of the City of Manchester and designed to ease traffic flow in the intersection area of Queen City Avenue, Second Street and Woodbury Street. Queen City Avenue has a high traffic volume and acts as a major thoroughfare across the Merrimack River into the central area of the City. Referring to Figures M-1 and M-2, this project consisted of the following:

1. Widening and reconstruction of Second Street from Arnold Street to West Hancock Street, approximately 1,350 feet in length.
2. Widening and reconstruction of Queen City Avenue from west end of the Queen City Bridge to Second Street, approximately 300 feet in length.
3. Reconstruction and partial relocation of Woodbury Street, an approximate length of 1,150 feet.
4. Widening and reconstruction of the F. E. Everett Turnpike northbound off ramp's exit terminal, an approximate length of 350 feet.
5. Widening and reconstruction of the F. E. Everett Turnpike southbound on and northbound on ramps entrance terminal, an approximate length of 150 feet.
6. Construction of a connector road between Hale Street and Street No. 1, an approximate length of 200 feet.

The project was awarded to Weaver Brothers Construction Company of Bow, New Hampshire on January 19, 1981 for the low bid sum of $1,176,875.00. Of this total, approximately $158,000 relates primarily to the recycling effort.

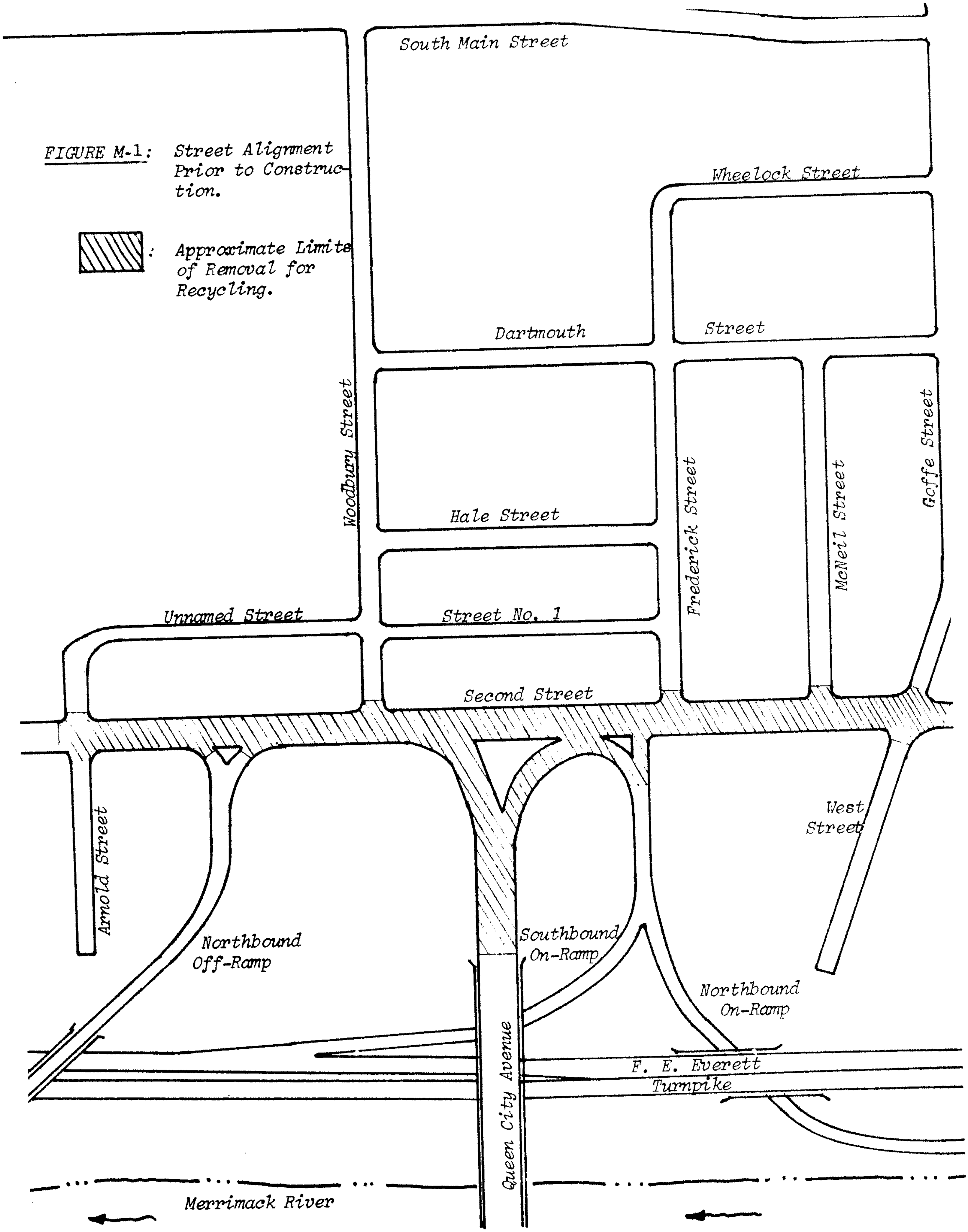
Preliminary Investigation

The Materials Division of the State Highway Department provides a comprehensive geotechnical report for the proposed project soon after preliminary engineering is initiated. The following description is a summary of their investigations and recommendations for the Manchester project.

The areas of investigation included: (1) a 1,700-foot section of Second Street running from the intersection of Arnold Street and continuing northerly to the Piscataquog River Bridge, also including the Queen City Avenue extension; and (2) the proposed Woodbury Street line running between South Main and Second Streets.

Six test borings of the subsurface on Second Street and several test pits along the proposed Woodbury Street were performed. The preliminary investigation reported the present roadway consisted of two or more separate overlays of asphaltic concrete, varying in pavement thickness of three to eight inches. During construction, the pavement was found to vary from two to 12 inches through the project site. It was composed of a mixture of tars, penetrating oils and different grades of asphalt concrete, some up to 30 years old. Included in several areas was a two to three-inch course of Class C-2 Road mix, a large aggregate (two to three-inch) base material (see Figures M-5 and M-6).

A visual inspection of the pavement surface showed minor cracking and several potholes. Most of the rough spots and sags on Second Street appeared to be from past utility construction excavations, which showed settlement as a result of improper backfill and compaction procedures. In general, most of the side streets, business and shopping center driveways in the project area were in poor condition; all showed excessive cracking and differential settlement. These conditions were probably due to a combination of inadequate thickness of base course materials and pavement. On the east side of Second Street in the vicinity


South Main Street
FIGURE M-1: Street Alignment Prior to Construction.
: Approximate Limits of Removal for Recycling.
Wheelock Street
Dartmouth
Street
Woodbury Street
Hale Street
Frederick Street
McNeil Street
Goffe Street
Unnamed Street
Street No. 1
Second Street
West Street
Arnold Street
Northbound Off-Ramp
Southbound On-Ramp
Northbound On-Ramp
F. E. Everett Turnpike
Queen City Avenue
Merrimack River

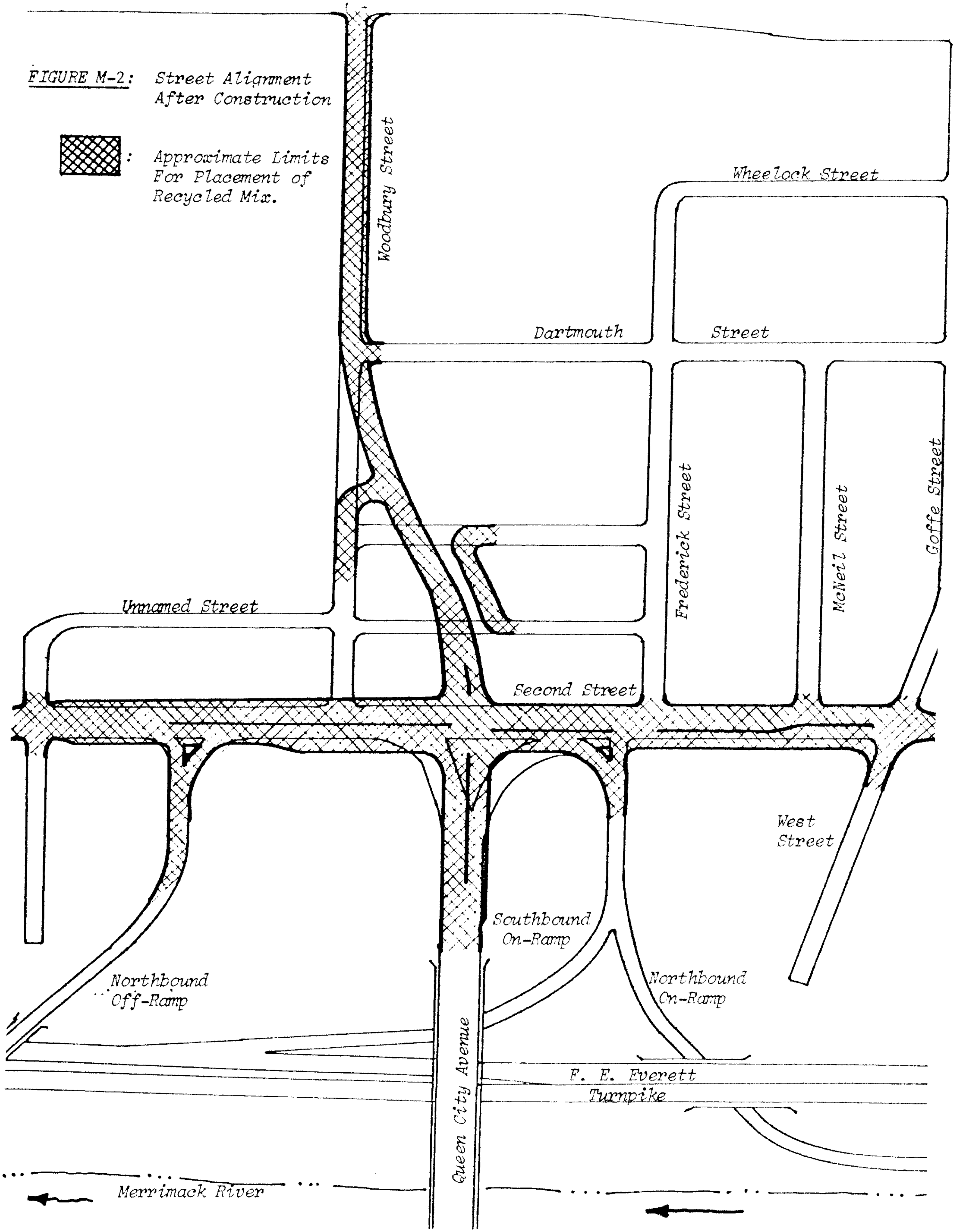


FIGURE M-2: Street Alignment After Construction
: Approximate Limits For Placement of Recycled Mix.
Woodbury Street
Wheelock Street
Dartmouth
Street
Frederick Street
McNeil Street
Goffe Street
Unnamed Street
Second Street
West Street
Southbound On-Ramp
Northbound Off-Ramp
Northbound On-Ramp
Queen City Avenue
F. E. Everett Turnpike
Merrimack River

of the F. E. Everett Turnpike exit, portions of the granite curbing showed both settlement and other distortion which were suspected to be the result of frost heave action.

The natural soil deposits throughout Second Street and the Oueen City Avenue Extension generally consist of stratified fine river sands and silts. The soil types vary from silty sands and sandy silts to silt with thin clay layers. Laboratory gradations of the typical silts showed 70 to 95 percent silt, the remaining being very fine sand. Overlying the natural soils, the existing roadway base course materials varied in depth from two to five feet. The predominant base course materials consisted of a sandy gravel with some silt. The amount of silt in the gravel course ranged from 6 to 20 percent. Ground water was not encountered in the test explorations of this area.

The soil profile in the Woodbury Street realignment generally consisted of variable deposits of granular soils, both manmade and natural deposits, which overlaid deposits of silty sand and silt. The manmade embankments generally consisted of a mixture of loamy and silty fine sand, and some coarse sand with traces of gravel. The native underlying soils generally consisted of silty sand and silts. In some sections the soils were stratified and varied from layers of silty fine sand to sandy silt and included some clayey silts. In the low sections on this profile, wet and swampy conditions existed with traces of organic materials encountered in some of the native soils.

Due to the variable soil and pavement conditions, retaining any portion of the roadway in its existing condition for future use was considered unfeasible (this did not pertain to the practicability of recycling the existing pavement). To achieve the proposed grades and to assure a uniform subgrade condition, it was recommended the project be undertaken with complete reconstruction as a priority. The Soils Engineer recommended the placement of a 36-inch total base course of granular materials be implemented throughout the project. The suggested typical section consisted of 12 inches crushed gravel over 12 inches of gravel and 12 inches of sand. Upon the granular base course materials, a five and one-half inch nominal bituminous pavement would be placed (one-inch wearing surface course, two-inch binder course, and two and one-half inch base course).

Initially, because of the various types and depths of asphalt concrete existing throughout the project, it was believed hot recycling of the pavement material would encounter significant problems. Removal of the existing pavement structure by any method could be difficult due to the variance in depth. Completion of the gradation and extraction analysis determined the existing pavement to be composed of an inconsistent mix.

After further consideration, it was determined the effect of these problems could be reduced through modification of the range of tolerance for gradation control. This range expansion would not diminish the quality of the produced bituminous concrete. By incorporating only that portion of the existing pavement within the project from Queen City Avenue and Second Street into the recycled mix, any inconsistencies in the reclaimed material could be held to a minimum. At the time the project was awarded, the quantity for Removal of Hot Bituminous Pavement for recycling was estimated to be 900 cubic yards. Bituminous pavement removed on streets other than Queen City Avenue and Second Street (refer to Figures M-1 and M-2) was removed under the common excavation item and transported to a site located on Dunbarton Road, approximately three miles from the project. This material was estimated to be 600 cubic yards and became the property of the City of Manchester (see Pavement Removal Section). Any portion of the material removed for recycling which was transported to the asphalt plant and crushed, and remained upon completion of the placement of recycled hot bituminous pavement became the property of the contractor. The contractor would then grant a specified credit of $6.75 per cubic yard for the surplus crushed material to the State.

Upon advertisement of the project for bids, it became apparent that most of the contractors interested in the project were reluctant to incorporate the recycling method. The contractors had requested to bid the project on the basis of crediting the State with $6.75 for each cubic yard of recycleable material and simply place 100 percent virgin material. Since this would, in essence, eliminate the recycling concept on the project, the contractors' requests were denied.

## Specification Section

Although New Hampshire has done extensive work with cold recycling of pavement in the past few years, hot recycling of the existing bituminous pavement is a relatively new experience. The Manchester project is the second project awarded on the Federal-aid Highway System to incorporate the hot recycling method. This method has been implemented in the past on turnpike facilities to a limited extent. With this in mind, several different approaches were utilized.

This section contains the specifications or special provisions included in this contract which dealt with the implementation of the hot recycling method. For review with these provisions, Appendix B contains the appropriate specifications in their entirety. Prior to listing the provisions, several key points located within the text should be identified:

1. The method of removal for the existing pavement structure to be incorporated into the recycled mix was not specified.
2. Payment for the removal and crushing of the existing bituminous pavement for incorporation into the recycled mix was measured in cubic yards.
3. Payment for the placement of recycled hot bituminous pavement was measured by the ton.
4. The stockpiled reclaimed material could be ordered covered by the Engineer with an acceptable waterproof sheeting.

5. The job mix formula tolerances were altered for the incorporation of the reclaimed material from those normally used.

6. The recycled hot bituminous pavement was not to be used in the surface wearing course.

7. A credit was specified for any surplus reclaimed material which was at the asphalt plant upon completion of the placement of hot recycled bituminous pavement on the project. This material then became the property of the contractor for his future use.

8. Existing pavement which was removed for the City of Manchester was accomplished under common excavation. Payment for this quantity was in cubic yards. Transportation of the material to the stockpile was included in this bid price, since the materials would normally have been wasted.

SPECIAL PROVISION

SECTION 404.1 -- RECYCLED BITUMINOUS PAVEMENT

ITEM 404.1 -- REMOVAL OF HOT BITUMINOUS PAVEMENT FOR RECYCLING

DESCRIPTION

1.1 This work shall consist of the removal and crushing of the entire thickness of existing hot bituminous pavement.

CONSTRUCTION REQUIREMENTS

3.1 The existing bituminous pavement shall be removed by ripping, planing or other satisfactory means. The salvaged bituminous pavement shall be removed and transported to a suitable location for further processing. The material shall be reduced in size so that 95 to 100 percent will pass a 1½-inch squares testing sieve. This salvaged material shall be processed in such a manner so as to provide a uniform gradation. The bituminous pavement shall be removed in a manner which will prevent unnecessary intermixing with the underlying base course.

3.2 After processing, either on the road or off site, the reduced material will be transported and stockpiled at a designated site to await incorporation into new hot bituminous pavement.

3.3 The stockpiled material may be ordered covered by the Engineer with an acceptable waterproof sheeting.

METHOD OF MEASUREMENTS

4.1 Removed and crushed existing bituminous pavement as shown on the plans or ordered will be measured by the cubic yard as determined by the actual measurements of the lengths, widths and depth of existing bituminous pavement removed.

BASIS OF PAYMENT

5.1 The accepted quantities of removed bituminous pavement for recycling will be paid for at the contract unit price per cubic yard. Transporting, stockpiling, covering and delivery to an approved bituminous plant for processing will be considered part of this item.

5.2 Existing base courses removed shall be replaced and compacted at the Contractor's expense.

Pay item and unit:

| | | |
|---|---|---|
| 404.1 | Removal of Bituminous Pavement for Recycling | Cubic Yard |

ITEM 404.21 -- RECYCLED HOT BITUMINOUS PAVEMENT

DESCRIPTION

1.1 This work shall consist of constructing one or more courses of hot bituminous pavement on a prepared base or an existing pavement using a combination of virgin and salvaged material.

MATERIALS

2.1 The salvaged hot bituminous pavement shall be free from objectionable matter and shall have been reduced in size so that 95 - 100 percent of the material will pass a 1½-inch laboratory sieve. Salvaged hot bituminous pavements having significantly different gradations shall be stockpiled separately.

2.1.1 Residual moisture content in salvaged hot bituminous pavement shall be held to a practical minimum by covering it with an acceptable waterproof sheeting.

2.1.2 Virgin aggregate material shall meet the requirements of 401.2.1 through 401.2.1.4.

2.2 Bituminous materials shall meet the requirements of AASHTO M 226 except for those values shown in 702 Table 2. The grade to be used shall be as designated by the Engineer.

2.3 Sections 2.3, 2.4 of Section 401 shall apply except that job mix formula tolerances shall be as follows:

| | |
|---|---|
| Passing No. 4 and larger sieves | ± 10 percent |
| Passing No. 10 to No. 80 sieves (inclusive) | ± 6 percent |
| Passing No. 200 sieve | ± 3 percent |
| Bitumen | ± 0.5 percent |
| Temperature of mixture | ± 30 degrees F |

The job mix formula shall include the proposed proportions of each material including the salvage material, asphalt modifier, if used, and new asphalt cement.

2.4 The asphalt modifier (recycling agent) shall be a softening agent, flux oil, rejuvenator or soft asphalt cement conforming to the following:

| Test | Requirement | |
|---|---|---|
| | Minimum | Maximum |
| Viscosity, 140 degrees F., centistokes | 5,000 | 10,000 |
| Flash Point, Pensky-Martens | 450 | |
| Saturate, by weight, percent | | 30 |
| Residue, Rolling Thin Film Oven, 325 degrees F., Weight Change, percent | | 2 |
| Viscosity Ratio (Note 1) | | 3 |

(Note 1) Viscosity Ratio - $\dfrac{\text{Rolling Thin Film Oven Residue, at 140 degrees F., centistokes}}{\text{Original Viscosity, at 140 degrees F., centistokes}}$

CONSTRUCTION REQUIREMENTS

3.1 The construction requirements shall be the same as those specified under 3.1 through 3.11 of section 401 except as modified or supplemented hereinafter.

3.1.7 The plant shall be equipped so as to insure a positive control of the feeding of salvaged material directly to the weigh hopper. The feeding system shall have the capability of delivering the exact amount of required material. If automation is used, this system shall be incorporated into the automatic cycle.

3.2 The maximum aggregate temperature as shown in 3.2.1 shall be deleted. The Engineer may require adjustment to the mixing time as shown in 3.2.1.

3.3 The Engineer may approve or require the addition of a modifying or recycling agent to the asphalt prior to delivery of the asphalt to the project or during proportioning or mixing operations.

3.4 Recycled hot bituminous pavement shall not be used as wearing course.

METHOD OF MEASUREMENT

4.1 The provisions of 401.4.1 shall apply.

4.2 Asphalt modifier material will be measured by the nearest gallon.

BASIS OF PAYMENT

5.1 The requirements of basis of payment shall be the same as stated under 403.5.1. Asphalt modifier material, when used, shall be paid for separately.

Pay items and units:

| | | |
|---|---|---|
| 404.21 | Recycled Hot Bituminous Pavement | Ton |
| 404.211 | Asphalt Modifying Agent | Gallon |

SPECIAL ATTENTION

SECTION 404 -- RECYCLED BITUMINOUS PAVEMENT

It is anticipated that a portion of the bituminous material removed under item 404.1 will remain a surplus after work described in Item 404.21 is complete. The contractor shall become the owner of this material and will therefore grant a credit of $6.75 per cubic yard for the crushed material remaining.

Upon completion of all work relating to Item 404.21, Recycled Hot Bituminous Pavement, the remaining processed bituminous material shall be removed from the stockpiled area and the area cleaned in a satisfactory manner.

The surplus processed bituminous material in the remaining stockpiles will be measured by the cubic yard and in accordance with 109.01.

The credit for the processed material will be applied at the rate of $6.75 per cubic yard as follows.

Pay item and unit:

| | | |
|---|---|---|
| 404.19 | Credit for Stockpiled Bituminous Pavement for Recycling | Cubic Yard |

## Equipment and Construction Procedures

### Pavement Removal

The existing bituminous pavement to be later incorporated into the recycled mix was to be removed in a manner elected by the contractor. This could be done by ripping, planing or other satisfactory means. The method which was utilized ideally should prevent any unnecessary intermixing of the pavement with the underlying granular base material. Several factors known prior to construction influenced the selection of the removal method. Three major factors were: the variable depth of the existing bituminous pavement; utility structures which acted as physical constraints; and economic considerations. With the large variation in pavement depth (from two to 12 inches), cold planing of the entire depth was unrealistic, cost prohibitive, and would have resulted in extensive mixing of the pavement with base materials. Cold planing of the top one to two inches, and removal of the remaining pavement structure by excavation was possible but cost prohibitive.

With this in mind, the contractor removed the entire thickness of the existing pavement structure by initially ripping the pavement with the use of a grader, then removing the material with a large excavator or gradall (refer to Figure M-3). The method of removal and adherence of the gravel to the pavement made it difficult to prevent the unwanted intermixing of gravel and pavement. As a result, there was a slight dilution of the asphalt content in the reclaimed material.

Throughout the project site, pavement depth varied from two to 12 inches with an average removal depth of four to four and one-half inches. The variation in depth resulted in difficulties in establishing a definite payment quantity, since the method of measurement for removal of recycleable material was by cubic yards.

FIGURE M-3: Removal of Existing Pavement for Recycling

After removal of the pavement, the material was transported in large chunks (one to five square feet) to two different sites depending on the subsequent use. The existing pavement from Queen City Avenue and Second Street was hauled and later crushed under Item 404.1 Removal of Hot Bituminous Pavement for Recycling. This resulted in approximately 1,100 cubic yards being stockpiled at the Lane Construction Co. Asphalt Plant. Located on Dunbarton Road, the plant was three miles from the project site. Lane Paving acted as a subcontractor to Weaver Brothers Inc. on this project. Any portion of this material which was surplus upon completion of Item 404.21 Recycled Hot Bituminous Pavement became the property of the contractor. The contractor would then grant a specified credit of $6.75 per cubic yard to the State for the future use of this material. At the time of completion, less than one cubic yard of the reclaimed material remained at the plant site.

Bituminous pavement removed in streets other than Queen City Avenue and Second Street was removed under Item 203.1 Common Excavation. This material was transported to a site located on Dunbarton Road just east of the Lane Asphalt Plant. Estimated to be approximately 500 cubic yards at the time of completion, this material became the property of the City of Manchester.

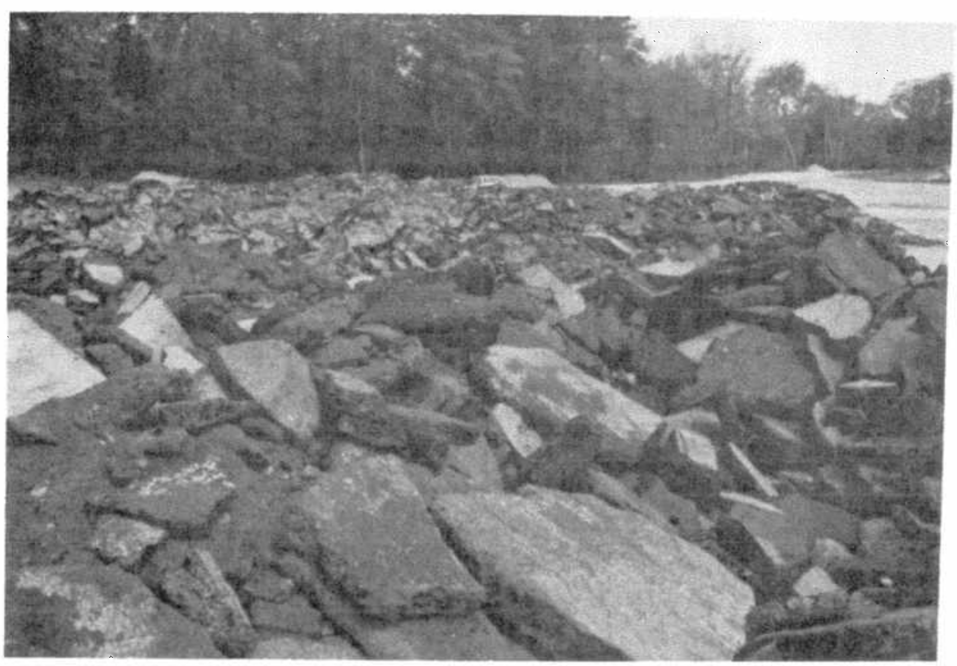


FIGURE M-4: City of Manchester Stockpile

Mr. Theodore S. MacLeod, Public Works Director for the City of Manchester, stated his Department's policy is to stockpile all excavated material from the City's existing bituminous streets. In the future, the stockpiled material would be incorporated into a hot recycled bituminous pavement. The material would be included in a contract with a paving contractor to supply the finished product to the City of Manchester for use in the rehabilitation or reconstruction of City streets.

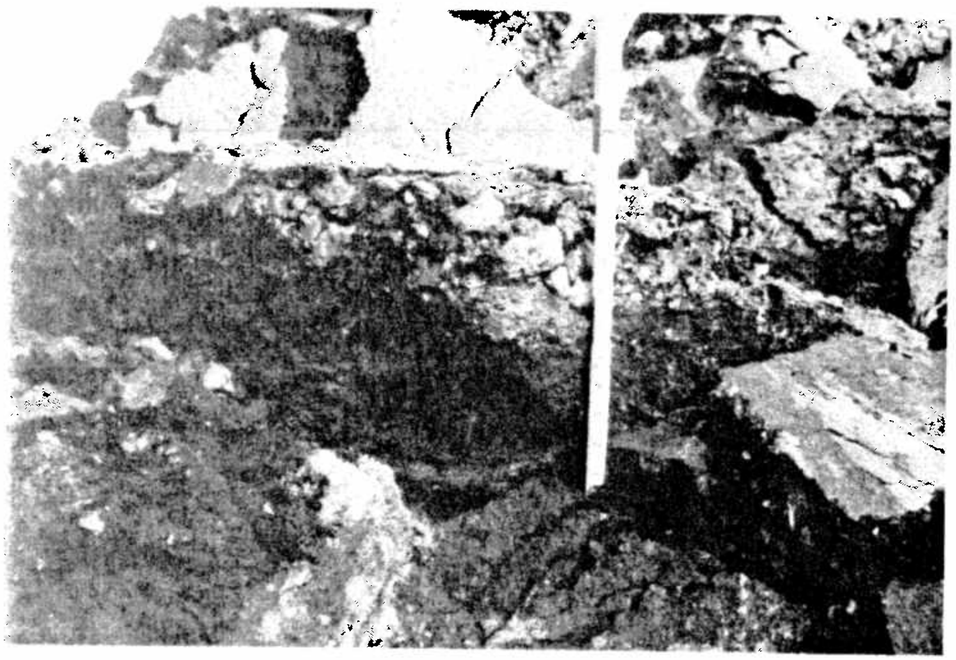


FIGURE M-5: Sample of Existing Pavement Stockpiled for the City of Manchester. Material next to six-foot rule is upside down.

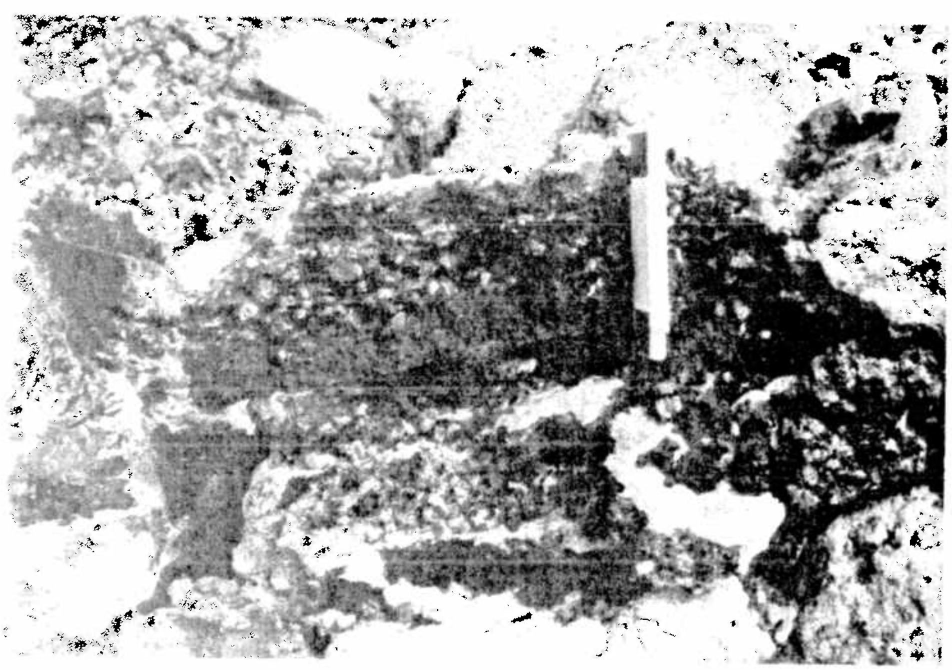


FIGURE M-6: Sample of Existing Pavement Stockpiled for the City of Manchester. Material next to folded six-foot rule is upside down.

## Plant Operations

Once transported to the plant site, the salvaged bituminous pavement from Queen City Avenue and Second Street was reduced in size to allow passage of 95 to 100 percent of the material through a 1½-inch sieve size. This was accomplished by processing the material through a crusher.

To provide flexibility to the contractor on this project, the method of removal was not specifically designated. Whereas planing of the existing one to two inches of surface wearing and binder courses may have resulted in a reclaimed material of proper gradation for incorporation into a 3/4-inch maximum sieve size binder course; ripping and later crushing of the material could not. This was due to the large portion of the existing pavement depth which was composed of Class C-2 Road Mix, a large aggregate (two to three inches) base material with a high ratio of voids (refer to Figures M-5 and M-6). Crushing of the material with a secondary operation beyond the specified 1½-inch maximum sieve size would have probably resulted in a significant increase in fines, due to the fracturing of the existing aggregate. As discussed previously in the pavement removal section, while planing would have been an ideal operation for gradation control, the existing conditions on the project made the operation unrealistic and cost prohibitive.

Prior to construction, the 5½-inch nominal bituminous pavement depth was planned to be composed of a one-inch surface wearing course, a two-inch recycled binder course and a two and one-half inch recycled base course. After consideration of the 1½-inch maximum sieve size aggregate, it was felt the placement of two courses of the 1½-inch maximum aggregate size base mix would not significantly reduce the quality of the pavement structure.

During construction, the project engineer foresaw a potential problem with the 1½-inch maximum aggregate size in the two-inch binder course. He feared the 1½-inch size aggregate would result in excessive surface tearing when the paving screed passed over the mix. For this reason, the course depths were further altered to two 2¼-inch courses of the 1½-inch maximum aggregate size base course material.

Once the material was reduced, the reclaimed pavement material was stockpiled and covered with polyurethane sheets to reduce the infiltration of moisture.

FIGURE M-7: Reclaimed Material Stockpile

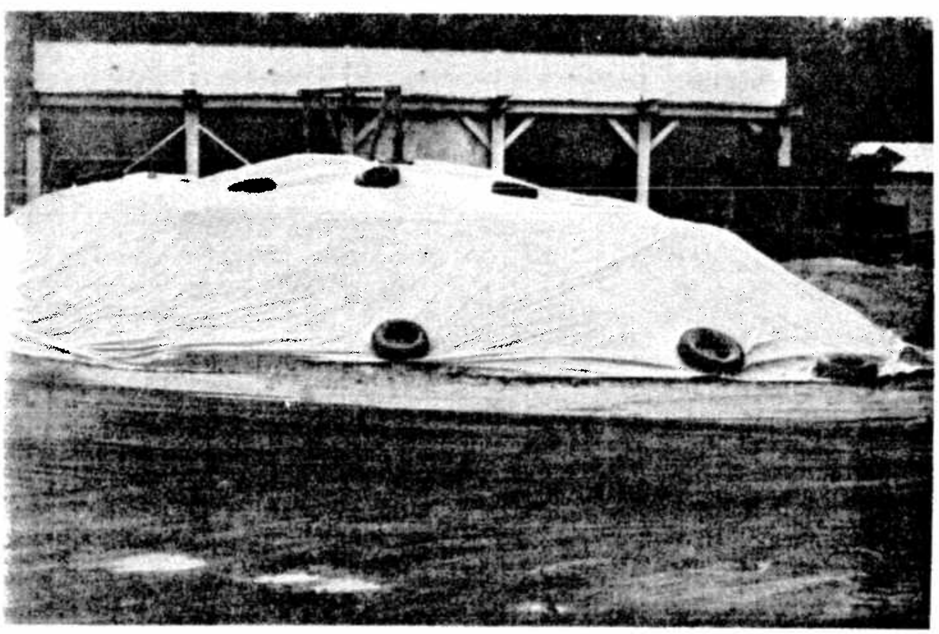


FIGURE M-8: Reclaimed Material with Virgin Aggregate Bins in Background

Although the loader operator blended the material to the extent possible prior to introduction into the operation, it appeared difficult to maintain a homogeneous mixture. The front-end loader was then used to place the material into the recycle bin. This had a relatively small capacity and steep sides to allow for easy discharge to the conveyor system. If the material was dumped quickly and in one movement, the small discharge area to the conveyor tended to become clogged (see Figure M-9). The reclaimed material was then fed by the conveyor to the weigh hopper.

The virgin aggregates were fed by a parallel conveyor system to the plant dryer and heated to 475 - 500°F (see Figure M-9). If the asphalt pavement to be produced was composed of 100 percent virgin material, the aggregates would normally be heated to 300 - 375°F. The aggregates were then processed through the gradation control unit and hot bins prior to being deposited in the weigh hopper.

As is the usual practice with batch plant recycling, the reclaimed material was not subject to the gradation control unit or vibrating screens at the plant prior to its introduction to the weigh hopper. From the conveyor belt, the reclaimed material was dropped directly into the weigh hopper.

FIGURE M-9:
Asphalt Batch Plant. In foreground extreme left, virgin aggregate bins with conveyor. In foreground recycle bin with conveyor; in background, dryer. Off center to the right is the central batch plant with asphalt storage tank.

After depositing the two larger virgin aggregates (1½-inch and ½-inch) into the weigh hopper, the reclaimed material was introduced and followed by the remaining smaller aggregates (3/8-inch and 5/32-inch). The transfer of heat from the superheated virgin aggregate to the ambient temperature reclaimed material begins here in the weigh hopper. The combined aggregates were then dropped into the batch plant pugmill and dry-mixed for approximately 18 seconds. After the asphalt cement (AC-10) was added, mixing on the wet cycle for an additional 43 seconds completed the process. The asphalt line at the plant indicated a temperature of 295°F for any additional asphalt required. Upon completion of the mixing process, the finished product left the plant at 290 - 300°F.

Information on the 1½-inch maximum aggregate size recycled base material:

| Sieve | % Passing Specification | Extraction Date of Inspection | Reclaimed Material Only |
|---|---|---|---|
| 1½" | 95-100 | 100 | 99 |
| 1" | 78-98 | 91 | 95 |
| 3/4" | 64-84 | 71 | 92 |
| 1/2" | 54-74 | 60 | 84 |
| 3/8" | 46-66 | 56 | 74 |
| #4 | 26-46 | 36 | 49 |
| #10 | 17-29 | 25 | 33 |
| #20 | 11-23 | 19 | 23 |
| #40 | 5-17 | 12 | 15 |
| #80 | 0-12 | 6 | 8 |
| #200 | 0-5 | 3 | 3 |
| %AC | 4.0-5.0 | 4.9 | 2.4 |

The 6,000 pound batching drops were proportioned by the following mix for the 1½-inch recycled base material:

| | 3-Ton Batch | |
|---|---|---|
| 5/32" | 809 lbs. | 14% |
| 3/8" | 866 lbs. | 15% |
| Reclaimed | 1,732 lbs. | 30% |
| 1/2" | 347 lbs. | 6% |
| 1½" | 2,021 lbs. | 35% |
| | 5,775 lbs. | |
| Asphalt (AC-10) | + 225 lbs. | |
| | 6,000 lbs. total drop | |

At the time of batching the recycled base material, the reclaimed material was found to have an asphalt content of 2.4 percent. Since it comprised 30 percent of the recycled mix, it contributed 0.725 percent of the asphalt content for the total mix. With the addition of 225 pounds of asphalt cement (AC-10) or 3.775 percent of the job mix, the cumulative asphalt content was 4.5 percent.

The inspector at the plant performed one hot bin aggregate gradation and two extractions per day during production. The quality control and test results were all within allowable tolerances. Extraction tests required the use of a stronger solvent to remove the asphalt from the reclaimed material; without careful handling, the solvent could be hazardous to the plant inspector.

Rejuvenator was not deemed necessary and thus not incorporated into the recycled mix. Each truck hauling to the project carried six batches of material at approximately 36,000 pounds total net weight.

When the reclaimed material is deposited in the weigh hopper with the superheated virgin material and mixed in the pugmill, a significant release of steam and dust particles may occur. Although the reclaimed material stockpile was covered to minimize the effects of moisture, it was found to contain three to four percent moisture. During an inspection at the plant, some steam and other emissions were evidenced venting from the pugmill to the atmosphere. Had this been excessive, the emissions would need to be vented to the plant air pollution system.

The batching quantity had steadily been increased from two to three tons by quarter-ton increments at this three-ton batch plant. The reclaimed milled material was introduced into the recycled mix at a rate of 30 percent with the remaining 70 percent being virgin aggregates. After consideration of the moisture content of the reclaimed material, the required discharge temperature of the recycled mixture and the batching quantity, this ratio was determined to be the optimum mix. The plant operator felt any increase in the percent of reclaimed material introduced into the mix would have increased the potential for problems due to the extra heat required. He stated a dryer had warped at a different plant site in the region due to the intense heat required of the virgin aggregate in a hot recycled mix. The realistic upper limit for heating the virgin aggregate in most batch plants without reducing the life of the dryer is 575 - 600°F. By keeping the amount of reclaimed material incorporated in the mix at the 30 percent level, the required temperature for the virgin aggregate could be held to a minimum. The plant operator had not evidenced any damage to the dryer during the life of the project.

During the production of the recycled material at the plant, other mixes were produced intermittently for other customers. Several remarked the first batch of material after a recycle mix was slightly hotter than normal, although few thought this was detrimental.

Paving Operations

The recycled bituminous pavement was placed as a base and binder course throughout the project site. Placement of the recycled material was observed on several occasions. After the three-mile trip from the plant, the recorded temperatures were in the range of 290 - 305°F. As the material was placed, it appeared consistent with the characteristics of a virgin mix except for a tendency of the screed to occasionally tear at the surface. This was probably due to the 1½-inch maximum aggregate size of the reclaimed material. This characteristic of the paving operation was evidenced only in a small portion of the project. The material was placed with a conventional paving machine of 12-foot paving width.

The initial rolling of the base course was accomplished by a static steel-wheeled roller. This was followed by a pneumatic-tired roller. Final rolling of each course was done by a three-axle steel-wheeled roller. These paving and rolling techniques were the same as those normally utilized for a conventional virgin material. Upon completion of the compaction operation, traffic was restored to its construction phase lane operation. The surface appeared to tighten up significantly under the heavy traffic volume through the project site.

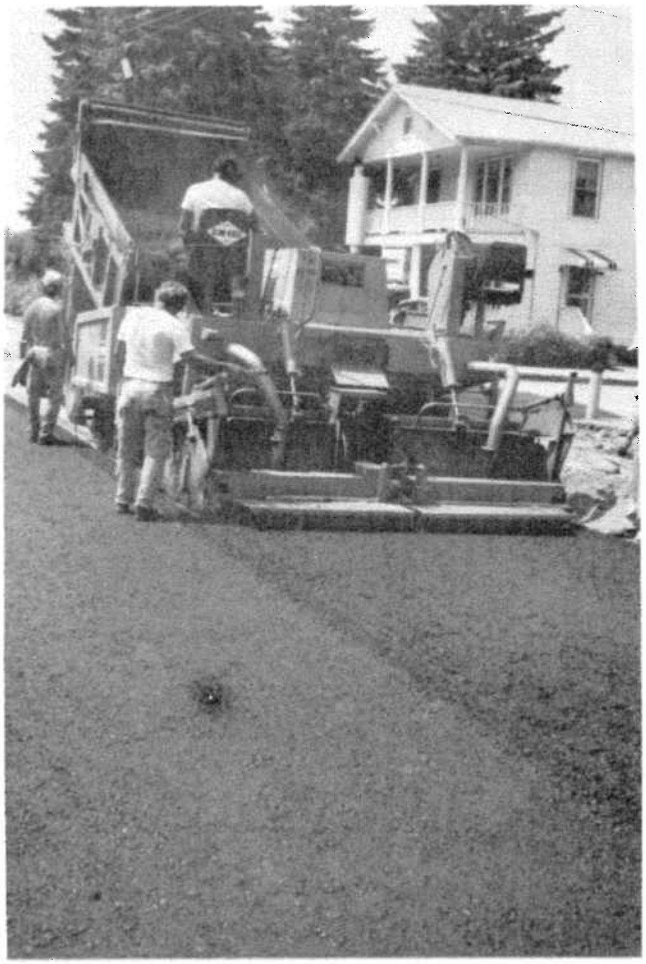


FIGURE M-10: Placement of Recycled Material on Second Street

Cost Analysis

This portion of the paper will analyze the costs involved in the actual recycled mix design versus a conventional mix design for this specific project. As discussed in the preliminary investigation portion, to fulfill the project objectives, total reconstruction was necessitated. Therefore, the placement of a simple overlay was considered inadequate. The costs used in the analysis are actual bid prices. These are the items of significance relating to the paving operations for this project.

| Item | Description | Quantity | Price Per Unit |
|---|---|---|---|
| 203.1 | Common Excavation | 28,000 cy | $ 2.85 |
| 403.11 | Hot Bituminous Pavement Machine Method (100% Virgin Material) | 1,500 tons | $33.50 |
| 404.1 | Removal of Hot Bituminous Pavement for Recycling | 900 cy | $10.00 |
| 404.19 | Credit for Stockpiled Bituminous Pavement for Recycling | x cy | $ 6.75 credit |
| 404.21 | Recycled Hot Bituminous Pavement (30% Reclaimed Material - 70% Virgin Material) | 5,400 tons | $27.50 |

Although all areas of the project were reconstructed to a five and one-half inch nominal pavement section, two sections will be evaluated for the comparison of costs between the recycled and conventional methods at a cost per square yard. The main difference being, on Second Street the existing pavement was incorporated into the recycled mix, while on Woodbury Street the existing pavement was stockpiled. Because removal and replacement of the subbase is common to both reconstruction methods, this portion of the cost will be disregarded*

Second Street: Actual Recycled

Remove existing pavement for recycling

*Remove existing granular base material as common excavation

Place granular base courses

Place 2¼" recycled base, 2¼" recycled base, and 1" surface wearing course

Conventional

Remove existing pavement as common excavation

*Remove existing granular base material as common excavation

Place granular base courses

Place 2½" base course, 2" binder course, and 1" surface wearing course

Costs: Recycled

1. Remove existing bituminous pavement for recycling:

   $10/cy x 0.12 yd. deep x 1 sy = $ 1.20

2. Place 2¼" recycled base course:

   $27.50/ton x 0.127 ton/sy = $ 3.49

3. Place 2¼" recycled base course:

   $27.50/ton x 0.127 ton/sy = $ 3.49

4. Place 1" surface wearing course:

   $33.50/ton x 0.057 ton/sy = $ 1.91

   $10.09 per square yard

Conventional

1. Remove existing bituminous pavement by common excavation:

   $2.85/cy x 0.12 yd. deep x 1 sy = $ 0.34

2. Place 2½" base course:

   $33.50/ton x 0.141 ton/sy = $ 4.72

3. Place 2" binder course:

   $33.50/ton x 0.113 ton/sy = $ 3.79

4. Place 1" surface wearing course:

   $33.50/ton x 0.057 ton/sy = $ 1.91

   $10.76 per square yard

Savings by use of recycling on Second Street and Queen City Avenue:

$10.76 - $10.09 = $0.67 per square yard of reconstruction

or a reduction of 6.2 percent.

Woodbury Street: Actual Recycled

Remove existing pavement by common excavation and stockpile

*Remove existing granular base material as common excavation

Place granular base courses

Place 2¼" recycled base course, 2¼" recycled base course, and 1" surface wearing course

Conventional

Remove existing pavement as common excavation

*Remove existing granular base material as common excavation

Place granular base courses

Place 2½" base course, 2" binder course, and 1" surface wearing course

Costs: Recycled

1. Remove existing bituminous pavement for future recycling:

   $2.85/cy x 0.12 yd. deep x 1 sy = $ 0.34

2. Place 2¼" recycled base course:

   $27.50/ton x 0.127 ton/sy = $ 3.49

3. Place 2¼" recycled base course:

   $27.50/ton x 0.127 ton/sy = $ 3.49

4. Place 1" surface wearing course:

   $33.50/ton x 0.057 ton/sy = $ 1.91

   $ 9.23 per square yard

Conventional

1. Remove existing bituminous pavement by common excavation:

   $2.85/cy x 0.12 yd. deep x 1 sy = $ 0.34

2. Place 2½" base course:

   $33.50/ton x 0.141 ton/sy = $ 4.72

3. Place 2" binder course:

   $33.50/ton x 0.113 ton/sy = $ 3.79

4. Place 1" surface wearing course:

   $33.50/ton x 0.057 ton/sy = $ 1.91

   $10.76 per square yard

Savings by use of recycling on Woodbury Street:

$10.76 - $9.23 = $1.53 per square yard of reconstruction, or a reduction of 14.2 percent.

With total reconstruction required throughout the project, the incorporation of the existing pavement into a recycled bituminous mix resulted in a minimum savings of $0.64 per square yard of reconstruction. On Woodbury Street where the existing pavement was removed for future use by the City of Manchester, $1.53 per square yard of reconstruction was saved by using the reclaimed material from Queen City Avenue and Second Street in the recycled mix.

Appendix A includes an estimation technique used in determining the energy, aggregate and dollar savings by incorporation of the hot recycling method.

Tons of Aggregate Saved: 1,539

Equivalent Gallons of Gasoline Saved: 1,830