NEW YORK CITY
DEPARTMENT OF TRANSPORTATION
40 Worth Street
New York, NY 10013

Lucius Riccio, Ph. D., P.E.
Commissioner

Technical Memorandum

NYC-DOT RECYCLED ASPHALT AND GLASSPHALT PAVING MIXTURES

by

Humberto Castedo, Ph.D., P.E. - Director, Office of Pavement Management
Harold Watson - Assistant Commissioner for Asphalt Production, and
Burton Most - General Manager and Assistant Commissioner for Highway Operations
(August 7, 1990)

I.- EXECUTIVE SUMMARY

This Technical Memorandum describes the process followed by the New York City Department of Transportation (NYC-DOT) for the in-house production of high-quality, standard asphalt paving mixtures. This document also summarizes laboratory and field test results performed to evaluate the characteristics of these in-house mixtures, and to assure that these paving mixtures meet the standard specifications set forth by the City and State DOT's.

NYC-DOT is currently producing high-quality asphalt paving mixtures by recycling existing pavement materials and/or by adding crushed glass as substitute for new aggregate. By using crushed glass and reclaimed asphalt pavement (RAP) material (see Section VIII: Glossary of Terms at the end of this document) from pavement reconstruction and resurfacing projects, the NYC-DOT is contributing to the recycling of all potential paving materials that currently are being disposed of in the City landfills. Another reason NYC-DOT decided to use RAP material is because approximately 55% of all City streets need to have their current pavement surface lowered by means of grinding or milling in order to improve the current curb reveal (see Glossary) of the street for safety and drainage purposes.

Paving mixtures produced with RAP and/or glass, as well as all-new materials mixtures produced by the City asphalt plant, meet all the standard specifications and requirements with regard to asphalt content, aggregate gradation, laboratory and field strength, compactability and skid resistance as specified by the City and State DOT's. The only exception that the NYC-DOT is making from State requirements is in the use of recycled paving mixtures as wearing, riding or surface course of City street pavements. The State DOT currently does not recommend the use of recycled mixtures in the surface of pavements until more testing is completed. However; the NYC-DOT believes that as long as the paving material meets all standard requirements for pavement wearing course material (NY State-DOT, Type 6F mixtures), recycled mixtures can be used not only in base and binder layers, but as riding surfaces of City streets.

II.- INTRODUCTION

Our nation is currently generating about 160 million tons of garbage a year, and the landfills have decreased from 18,500 to 6,000 during the past 10 years [Reference 1]. About 2,000 more will close within the next five years. The City of New York as well as the State and the nation in general are coping with the problem of too much garbage and too few places to put it. One of the garbage components that needs to be disposed of in local landfills are the rubble and stripped material obtained from existing city street pavements that have deteriorated to the point that complete reconstruction is necessary. A similar source of garbage from city street pavements are the millings or grindings that need to be removed from the existing pavement surfaces before re-surfacing or overlaying with new asphaltic concrete.

The New York City Department of Transportation (NYC-DOT) believes that the recycling of these and other potential paving materials that are currently being disposed of in landfills, can play a major role in helping the City solve its solid waste problem. All asphalt paving mixtures currently produced by the NYC-DOT are made by recycling existing pavement materials and by adding some crushed waste glass as substitute for new aggregate.

By using crushed glass and reclaimed asphalt pavement (RAP) material from pavement reconstruction and resurfacing projects, the NYC-DOT is contributing to the reduction of the approximately 25,000 tons of trash produced in the City every day [Ref. 2]. This alone will help prolong the service life of the few remaining operating landfill sites. Further more, the use of these materials will reduce the cost of new aggregate materials in paving mixtures, save the City tax-payers for landfill cost and for transporting these recyclables to the landfills.

III.- POTENTIAL QUANTITIES OF RAP FROM NEW YORK CITY STREETS

A city-wide survey was conducted by NYC-DOT in March through May 1990, to evaluate the existing curb reveal of City streets. The survey consisted of determining from a slow moving car the percentage of a given block with curb reveal less than 4 inches. For the analysis of these data it was assumed that a street block with curb reveal less than 4" in more than 1/4 of its total length is a potential candidate for milling (see Glossary) in order to improve the curb's safety and drainage functions. The results of this survey can be summarized as shown in Table 1 [Ref. 3]:

TABLE 1. Number of New York City Blocks Needing Milling

Borough	Total No. of Blocks	To be Milled	
		No. of Blocks	% of Total
Bronx	10,640	6,380	60 %
Brooklyn	21,545	9,695	45 %
Manhattan	7,435	4,090	55 %
Queens	28,780	15,830	55 %
Staten Island	10,120	5,565	55 %
NYC Total:	78,520	41,560	*Avg:* 54 %

Potentially, this many blocks needing milling could generate an estimated 4.7 million tons (see calculations below) of rubble that unless the NYC-DOT recycles them, will need to be discarded in the City landfills. Economic analysis of landfill costs and savings to be achieved from recycling are presented in Section VI of this memorandum.

Estimated Total Amount of RAP from NY City Streets

Assume avg. milling: 4 inches deep x 12 feet wide (curb milling only) x 500 feet long block =
(4/12)ft x 12 ft x 500 ft = 2,000 cu. ft. of RAP/block
2,000 cu. ft./ 27 cu. ft./cu. yd. = 75 cu. yd. of RAP/block
75 cu. yd. x 1.5 ton/cu. yd. = 112.5 tons of RAP/block
112.5 tons/block x 41,560 blocks needing milling = Approx. 4.7 million tons of RAP

IV.- NYC-DOT ASPHALT MIX PRODUCTION

Currently the NYC-DOT operates a continuous mix drum asphalt plant capable of using recycled material up to 50% of the total mix output. The plant is located in Hamilton Ave., Brooklyn and has been in operation since 1981 producing paving mixtures that meet all City and State specifications for new base and surface course materials. This plant has recently been retrofitted with a new center-entry drum that assures the consistency and quality of the asphalt mix produced. The laboratory at the plant has been enlarged and additional personnel has been introduced to cover the testing required for producing consistent recycled paving mixtures; it also meets all environmental requirements regarding emissions.

Table 2 presents a summary of the current and future paving mix production capabilities of the NYC-DOT. For the past two years, an average of 340,000 tons of asphalt mix/year are being produced using 20 to 30% RAP and 0 to 10% glass in all the mixes. In anticipation to the large amounts of RAP to be generated in the coming years (see Section III above), the NYC-DOT is expanding its capabilities for asphalt mix production as shown in Table 2 below. An average of 50% of the total paving material produced by the NYC-DOT is expected to be recycled material.

TABLE 2. In-House Annual Asphalt Mix Production

Current:	Total Tons	Practical % Recycled	Tons Recycled Mat'l. Used Max. Tons	Min. Tons
1. Hamilton Ave. Plant (Bk)	340,000	30 %	102,000	0
Totals:	340,000		102,000	0

Future (by 1991):	Total Tons	Practical % Recycled	Tons Recycled Mat'l. Used Max. Tons	Min. Tons
1. Hamilton Ave. Plant (Bk)	360,000	40 %	140,000	0
2. Queens Asp. Plant (Q)	360,000	40 %	140,000	0
3. 100% Recycling Plant (Bx)	180,000	100 %	180,000	0
Totals:	900,000		460,000	0

Current and future asphalt mix production by NYC-DOT conforms with requirements and specifications from City and State DOT's as summarized in Table 3 below.

TABLE 3. Summary of NY City-DOT and NY STATE-DOT Specifications [Ref. 6]

City and State Specifications for Surface Course Asphalt Mix Type 6F:

Aggregate Gradation:		% Passing	Job Mix Tolerance
	1"	100 %	-
	1/2"	95-100 %	-
	1/4"	65-85 %	+/- 7 %
	1/8"	36-65 %	+/- 7 %
	No. 20	15-39 %	+/- 7 %
	No. 40	8-27 %	+/- 7 %
	No. 80	4-16 %	+/- 4 %
	No. 200	2- 6 %	+/- 2 %
Asphalt Content:		5.8-7.0 %	+/- 0.4 %
Binder:		AC-20	
Min. Marshall (@ 50 blows)			
	- Stability:		1500 lb
	- Flow (.01 in):		8-18
	- Air Voids:		2.0-4.0 %

V.- NYC-DOT QUALITY CONTROL OF RECYCLED MIXTURES

The NYC-DOT is well aware that the production of paving mixtures made with recycled materials of any kind require careful proportioning and control of the mix components. For this purpose, the in-house production plant and personnel are equipped with the latest techniques and equipment for quality control (QC) purposes. Laboratory and field test results presented in this document and obtained daily by NYC-DOT QC personnel shows that in-house paving mixtures meet and/or exceed all the City and State requirements for Type 6F new surface asphalt mixtures.

The use of glass as substitute of aggregate in paving materials is well documented and it is a technique widely used in many States, Canada and Europe since the late 1960's. The use of RAP in paving mixtures is more widespread and common than glassphalt, and it is a technique totally accepted by federal, state, county and local highway agencies.

Quality control procedures generally involve laboratory and/or field evaluation of representative samples of the daily production of in-house asphalt paving mixtures. For example, the evaluation of glassphalt consisted of a mix design procedure performed in the lab that involved various mixes with different proportions of glass, coarse and fine aggregates, and binder (see sample in Table 4).

From studies like these mix designs, NYC-DOT was able to identify the most adequate proportions of mix components (including glass; see gradation in Table 5) for producing glassphalt that meets the standard specifications (Mix #1, #2 and #6 below).

TABLE 4. Representative NYC-DOT Glassphalt Mix Design

	Mix #1	Mix #2	Mix #3	Mix #4	Mix #5	Mix #6
Asphalt Content:	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%
Coarse Aggregate: (Crushed Stone)	63.8%	48.8%	48.8%	63.8%	43.8%	53.8%
Fine Aggregate: (Fine Stone & Nat'l. Sand)	30.0%	25.0%	15.0%	30.0%	30.0%	20.0%
Crushed Glass:	0.0%	20.0%	30.0%	0.0%	20.0%	20.0%
Average(*) Marshall						
- Stability (lbs):	1500	1580	1180	1370	1385	1925
- Flow (.01 in.):	9	11	12	12	13	16

(*) Note: Average of hundreds of Marshall test specimens.

TABLE 5. Gradation of Crushed Glass

Sieve Size	% Passing
3/8"	100.0 %
1/4"	85.0 %
1/8"	53.2 %
No. 20	17.1 %
No. 40	8.8 %
No. 80	3.6 %
No.200	1.2 %

Initial glassphalt production was limited for experimental field sections where tests were performed for skid resistance (see Table 6), and overall pavement performance. Test results showed that the glassphalt produced by the NYC-DOT hot-mix asphalt plant has no different skid properties than regular 6F paving mixtures. Continuous laboratory and field evaluation have demonstrated thus far that waste glass can be used satisfactorily as an asphalt mix aggregate for paving and resurfacing New York City streets. Current evaluation efforts are being concentrated on low speed roads.

TABLE 6. Field Evaluation of Glassphalt

(ASTM E 303: Standard Method for Measuring Surface Frictional Properties Using the British Pendulum Tester - BPN) [Ref. 4]:

Recommended BPN values on wet pavement surfaces [Ref. 4, 5]:

BPN > 65:	"Good" for high speed traffic.
BPN > 55:	"Generally satisfactory".
BPN > 45:	"Fair".
BPN < 45:	"Potentially slippery".

Glassphalt Test Sections:

E. 19th St. & Ave. V:	Avg. BPN = 60, 61, 60
E. 19th St. & Ave. V:	Avg. BPN = 67, 64
E. 19th St. & Ave. V:	Avg. BPN = 56, 58
E. 19th St. & Ave. V:	Avg. BPN = 62, 61

Control Test Section (Regular 6F Mix):

E. 19th St. & Ave. W:	Avg. BPN = 64, 66, 61

For the past year and a half the NYC-DOT asphalt paving mix production consisted (depending of the availability of RAP and/or waste glass), of a combination of RAP that varies from 0 to 30%; waste glass, from 0 to 20%, and virgin aggregate with 5.8 to 6.2% AC-20 binder. Typical laboratory test results for these mixtures are shown in Table 7 below.

TABLE 7. Sample of Typical Laboratory Properties for NYC-DOT Surface Mixtures

Prod'n. Date	RAP Content	Glass Content	Binder Content	Marshall Stability	Flow (.01")	Air Voids	Unit Weight (pcf)
10-89	20 %	10 %	5.8 %	1700 lbs.	10	3.7 %	147
10-89	0 %	0 %	5.8 %	1650 lbs.	9	3.9 %	151
10-89	20 %	10 %	6.0 %	1665 lbs.	10	4.0 %	150
01-90	30 %	0 %	6.0 %	1560 lbs.	9	3.4 %	150
04-90	28 %	7 %	6.5 %	1725 lbs.	12	2.0 %	154
04-90	25 %	10 %	6.2 %	1650 lbs.	11	3.2 %	150
05-90	0 %	10 %	6.0 %	1520 lbs.	10	3.0 %	148
05-90	25 %	10 %	6.2 %	1700 lbs.	9	2.4 %	149
06-90	22 %	10 %	5.9 %	1610 lbs.	10	2.0 %	150
06-90	18 %	10 %	6.1 %	1575 lbs.	9	3.6 %	149
06-90	30 %	10 %	6.5 %	1790 lbs.	10	4.0 %	149
07-90	0 %	7 %	6.1 %	1500 lbs.	10	2.2 %	150

Field Applications of Recycled Asphalt Mixtures

Recycled mixtures are widely used in base, binder and surface layers of asphalt pavements. Many states that have similar climate and traffic conditions than the State of New York allow the use of RAP in surface mixtures (see Table 8 below). For example, Connecticut, Delaware, Illinois, Maryland, Michigan, New Jersey, Ohio and Pennsylvania, to name just a few, allow the use of between 10 to 50% RAP in surface mixtures, depending of the type of central hot-mix plant used (drum or batch plant), the moisture content of the RAP and other similar requirements [Ref. 8]. These requirements for the use of RAP have been developed by these states after many years of monitoring the performance of recycled mixtures in their road networks. Again, recycled paving mixtures properly designed and produced to meet standard mixtures specifications can be used in base, binder and/or surface layers of reconstructed or re-surfaced flexible pavements.

TABLE 8. Summary of Various State Specifications for Use of Recycled Mixes [8]

State	Max. RAP - BATCH Plant			Max. RAP - DRUM Plant			RAP
	Base	Binder	Surface	Base	Binder	Surface	Top Size
Arkansas	70%	70%	70%	70%	70%	70%	NO
Colorado	40%	40%	40%	40%	40%	40%	1 1/2"
Connecticut	40%	40%	40%	40%	40%	40%	2 "
Delaware	30%	30%	25%	50%	50%	30%	2 "
Georgia	40%	40%	40%	40%	40%	40%	< 2 "
Illinois	25%	25%	25%	25%	25%	25%	NO
Kansas	50%	50%	50%	50%	50%	50%	< 2 1/4"
Maryland	50%	50%	30%	50%	50%	30%	NO
Michigan	50%	50%	50%	50%	50%	50%	2 "
New Jersey	50%	50%	10%	50%	50%	10%	2 1/2"
New York	*50%*	*50%*	*NO*	*70%*	*70%*	*NO*	*2 "*
North Carolina	60%	60%	60%	60%	60%	60%	2 "
North Dakota	60%	60%	60%	60%	60%	60%	1 1/2"
Ohio	50%	50%	30%	50%	50%	30%	< 2 "
Pennsylvania	Open	Open	10%	Open	Open	10%	< 2 "
Texas	50%	50%	50%	50%	50%	50%	< 1 1/2"
Utah	70%	70%	70%	70%	70%	70%	< 2 "
Wyoming	50%	50%	50%	50%	50%	50%	2 "

VI.- SAVINGS DUE TO RECYCLING OF EXISTING PAVEMENTS AND GLASS USES IN THE MIX

There are at least two sources of savings being achieved by the current NYC-DOT asphalt mix production practices: (1) savings are being obtained by replacing new aggregate materials with RAP, and (2) landfill costs are being avoided by re-using the RAP instead of landfilling it. It is safe to assume that transportation costs from the milling site to the central recycling plant, are off-set by the transportation cost that would have been incurred by bringing the RAP from the milling site to the landfill.

In average, the cost of the surface asphalt mixture produced by NYC-DOT from all new materials is:

1/4 " Stone Blend	= $ 9.40/ton (@ 44% of mix)	= $4.14
3/8 " Stone	= $11.60/ton (@ 30% of mix)	= $3.48
Sand	= $13.00/ton (@ 20% of mix)	= $2.60
AC-20	= $95.00/ton (@ 6% of mix)	= $5.70
Total:	100%	$16.00/ton

By replacing some of the aggregate (stone and sand above) with RAP and/or crushed waste glass, the following savings can be estimated: 4.7 million tons of RAP (from Section III, Table 1) will substitute those many tons of aggregate costing an average of $10.00/ton = 4,700,000 tons x $10.00/ton = $47 millions in savings on new aggregates.

By avoiding landfill costs, savings can be calculated assuming the current disposal fees in City landfills of $40.00/cu. yd. = 4.7 million tons of RAP/1.5 tons/cu. yd. = 3.2 million cu. yd. of RAP 3,200,000 cu. yd. x $40.00/cu. yd. = $120+ millions in savings on landfill costs (without considering the economic implications of saving landfill space and other environmental considerations).

There are further savings to the environment and to taxpayers dollars by using an average of 10% glass in all asphalt mix production by the NYC-DOT plant, without any sacrifice of quality when compared with paving mixtures produced from all new aggregate and binder materials as described in this technical memorandum.

VII.- GLOSSARY OF TERMS [Ref. 7] AND CONVERSION FACTORS

6F Asphalt Mix: hot-mixed hot-laid asphalt paving mixture with aggregate gradation, asphalt content and other properties as specified by the NY State DOT Standard Specifications [Ref. 6] for Type 6F Mix.

Recycling: the reuse, usually after some processing, of a material that has already served its first intended purpose.

Glassphalt: asphaltic concrete for street paving made from crushed mixed glass as partial substitute for aggregate in the mix.

RAP: (Reclaimed Asphalt Pavement); removed and/or processed pavement materials containing asphalt and aggregates.

Milling: (also "cold milling") is the automatically controlled removal of existing pavement layers by grinding to a desired depth and width with specially designed equipment. This technique is used as an alternative to ripping and crushing the old pavement. Cold milling usually produces RAP of a desired particle size.

Hot-Mix Recycling: a process in which reclaimed asphalt pavement (RAP), reclaimed aggregate material (such as glass), or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as needed, 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.

Curb Reveal: the height of curb showing above the pavement surface. NYC-DOT requirements for curb reveal are, 4" desirable and 2.5" absolute minimum in order to maintain traffic safely away from sidewalk, and to provide proper surface water drainage.

Conversion Factors:

- 27 cu. ft. = 1 cu. yd. = 0.7646 cu. m.
- Compacted asphaltic concrete = 145 pcf = 3,915 lbs/cu. yd. = 2.0 tons/cu. yd.
- Loose RAP = 110 pcf = 3,000 lbs/cu. yd. = 1.5 tons/cu. yd.
- Landfill cost/dumping fee as of 07-90 (Fresh Kills landfill, NY, NY) = $ 40.00/cu. yd.

VIII.- REFERENCES

1. Amoco Chemical, "Recycling - Do it Today for Tomorrow", 1989.

2. The New York Times, "A $600 Million Landfill Cleanup is Set by New York City and State", April 27, 1990.

3. Ocken, R., "Milling Needs", NYC-DOT Internal Memorandum, 07-08-90.

4. 1989 ASTM Book of Standards, Vol. 04.03: "Road and Paving Materials; Traveled Surface Characteristics".

5. Kummer, H. W. and Meyer, W. E, "Tentative Skid Resistance Requirements for Main Rural Highways", NCHRP Report No. 37, Highway Research Board, 1967.

6. New York State - DOT Book of Standards, 1985.

7. The Asphalt Institute, "Asphalt Hot-Mix Recycling", MS-20, 1981.

8. Roads & Bridges Magazine, October 1989.

/hc