HOT PLANT RECYCLING OF ASPHALTIC CONCRETE

FINAL REPORT

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METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
Length		
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4E
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
Volume (Capacity)		
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbm)	kilogram (kg)	907.2
Mass per Volume		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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ABSTRACT

This report covers the design, construction and evaluation of two hot mix recycling projects. One project recycled two inches of existing dense-graded asphaltic concrete through a modified batch plant. The second project recycled a total of five inches of existing asphalt surface treatment and sand-clay-gravel base through a modified dryer-drum plant. Each project was evaluated with respect to construction techniques, recycled mix quality, economics and energy conservation. Results are presented which indicate an acceptable recycled asphaltic concrete mixture was produced in each project.

IMPLEMENTATION STATEMENT

The recommendations of this report call for the Department to consider appropriate means to further the development of the recycling concept. It is believed that specifications can be developed which will permit the substitution of a recycled hot mix for a conventional hot mix.

INTRODUCTION

Conservation of raw materials, along with a need to conserve energy, has prompted the highway industry to examine the possibility of asphaltic concrete recycling. That recycling will be of major importance in the near future is reflected in the efforts of various equipment manufacturers to develop new or modify existing plants to produce recycled asphaltic concrete. Initial attempts in both batch and dryer-drum plants have produced encouraging results. As with any new effort, however, there is a need for gaining knowledge and exposure of the fundamental mechanics of the process.

In an attempt to gain such familiarity with asphaltic concrete recycling in anticipation of its future use in Louisiana, two construction projects were let. One project recycled two inches of existing asphaltic concrete through a modified batch plant. The second project made use of a modified dryer-drum plant to recycle a total of five inches of asphalt surface treatment and sand-clay-gravel base.

This report describes the design, construction and evaluation of both these projects. Each project is presented separately in the body of the report; the batch plant project precedes the dryer-drum plant project. Conclusions and recommendations based upon both projects are then presented.

OBJECTIVE AND SCOPE

The objective of this study was to determine the construction feasibility and to evaluate the quality, the economics and the energy conservation of a recycled asphaltic concrete mix produced through a conventional hot mix plant. The scope of the study is confined to the production of 11,000 tons of a recycled mix in a modified batch plant and 30,000 tons of a recycled mix in a modified dryer-drum plant.

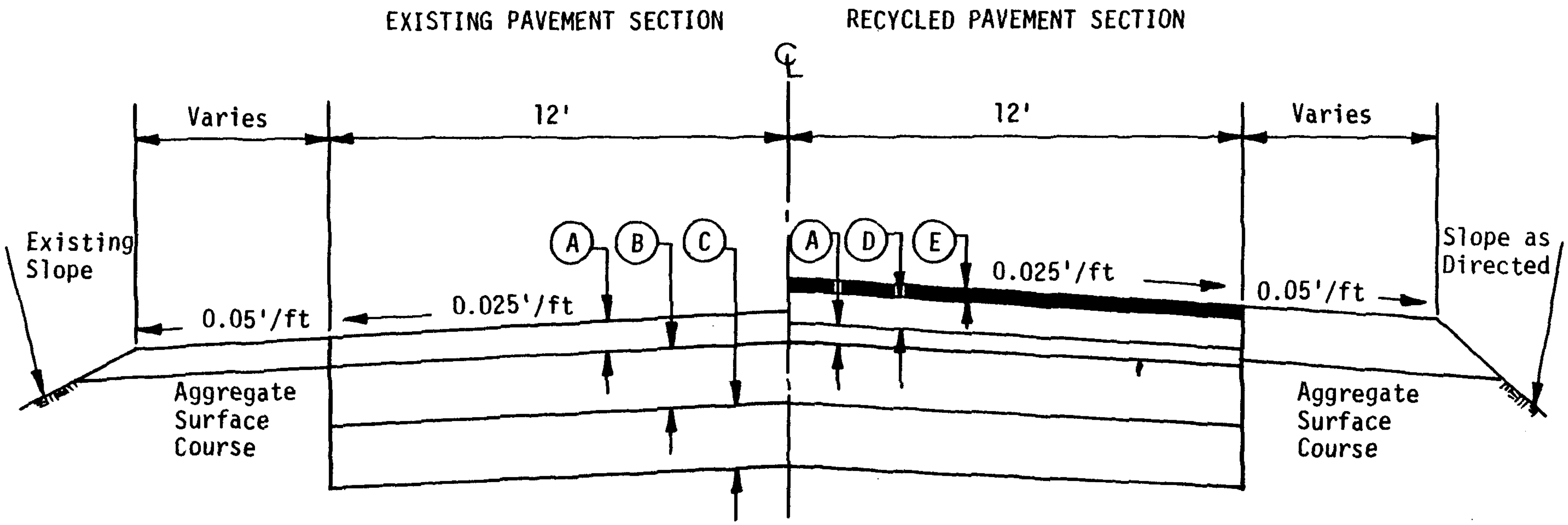
BATCH PLANT PROJECT

PROJECT DESCRIPTION

A 4.8-mile, two-laned section of U.S. 84, located between Clarence and the Winn Parish Line in Natchitoches Parish, was chosen for Louisiana's first hot plant recycling project. The existing pavement consisted of 9 inches of portland cement concrete topped with a 3-1/2-inch asphaltic concrete overlay. This pavement was scheduled for another 4-inch overlay, due to both structural and surface deterioration. Removing 2 inches of the existing asphaltic surface and combining this reclaimed material in a 50/50 blend with virgin materials in a batch plant was proposed as an alternate design to the conventional overlay. Figure A1 presents a typical section of this design. The contract was awarded to Louisiana Paving Company and construction on the project began in June 1978.

PRELIMINARY PROJECT CONSIDERATIONS

Batch plant recycling was first successfully accomplished in Maplewood, Minnesota, and has become known as the "Minnesota Method." The objective was to produce a recycled mixture of reclaimed materials with little plant modification and without the air pollution associated with contemporary dryer-drum recycling operations; the secret of air pollution control was to prevent the reclaimed bituminous material from direct contact with the burner flame. The Maplewood project demonstrated that by mixing superheated, uncoated aggregate and ambient-temperature, reclaimed bituminous material in the weigh box and pugmill of a batch plant, an environmentally clean recycled mix could be produced if enough heat transfer could take place with a reasonable production cycle. It was with this concept of batch plant recycling that Louisiana wished to gain experience in its first attempt at recycling an asphaltic concrete pavement.



(A) Existing Asphaltic Concrete Overlay (2" to be Removed and Reused)
(B) Existing Portland Cement Concrete
(C) Existing Base and Subgrade
(D) Recycled Asphaltic Concrete (4" Thick, to be Placed in Two Lifts)
(E) Asphaltic Concrete Friction Course (5/8" Thick)

Typical Finished Section

FIGURE A1

For this initial recycling project in Louisiana, an examination of the contractor's customary job mix formula showed a gradation which was very close to the mid-point of Louisiana's standard specifications for a Type 1 wearing course. As the existing pavement gradation was quite similar to the customary gradation, it was anticipated that not only could a specification mix be produced, but Minnesota's 50/50 blend of reclaimed-to-virgin materials seemed obtainable with respect to gradation control.

Several questions arose when considering asphalt cement content. Could all of the old, oxidized asphalt cement be used as binder, or would some of this thin-filmed asphalt cement behave as mineral aggregate? If some of the old binder acted as aggregate, would new asphalt cement be needed above the anticipated design quantity? Would a softening agent be necessary?

The contractor's conventional asphaltic concrete job mix formula indicated acceptable mix properties with an asphalt cement (AC-30) content of 5.1 percent by weight. It was felt that 5.1 percent could be used as a target asphalt cement content for the recycled mix, with refinements being made as required to attain a specification mix. An assumption was made that all of the old asphalt cement would behave as binder, so that a blend of 50 percent reclaimed material would contribute 2.4 percent asphalt cement by weight (.50 x 4.8 percent by weight asphalt cement in the existing pavement). Thus, 2.7 percent by weight of additional asphalt cement (AC-30) would be needed.

The use of softening agents for the project was considered as an added variable which could cause confusion should difficulties in maintaining a consistent asphalt cement content occur during production. In order to be able to isolate and identify variations in the asphalt cement content of the recycled mix as caused by fluctuations in the binder content of the reclaimed material, it was decided to eliminate softening agents from consideration. Furthermore, the asphalt cement properties of the existing pavement, as shown in Table A1, did not indicate the need for rejuvenation.

Samples were taken from the U.S. 84 project at 0.10-mile intervals to determine the minimum depth of the existing overlay. The 48 samples showed an average hot-mix thickness of 3.6 inches. Six of these samples were randomly selected and sent to the Research Section where extractions, recoveries and gradations were run. The recovered asphalt cement was tested for penetration at 77°F and absolute viscosity at 140°F. Table A1 presents the mean gradations along with standard deviations, percentage of asphalt cement, penetration and viscosity.

TABLE A1

EXISTING ASPHALTIC CONCRETE PAVEMENT PROPERTIES

U.S. Sieve Size	Gradation (% Passing)	
	$\bar{x}_6$	σ_6
3/4 inch	99	1.6
1/2 inch	88	6.5
No. 4	56	8.5
No. 10	45	6.8
No. 40	28	3.9
No. 80	15	2.4
No. 200	8	1.4
% A.C.	4.8	.47

Absolute Viscosity (140°F)	9813 average (6608, 8820, 14012)
Penetration (77°F)	49 average (58, 52, 37)

Based on these preliminary findings and assumptions, it was believed that, with proper processing, a recycled mix comprised of 2 inches of reclaimed materials (7450 tons), virgin aggregate (7000 tons) and new asphalt cement (450 tons) could be produced in the contractor's batch plant. The special provisions for the project, written to cover the removal of the existing materials and the subsequent processing, are included in the appendix.

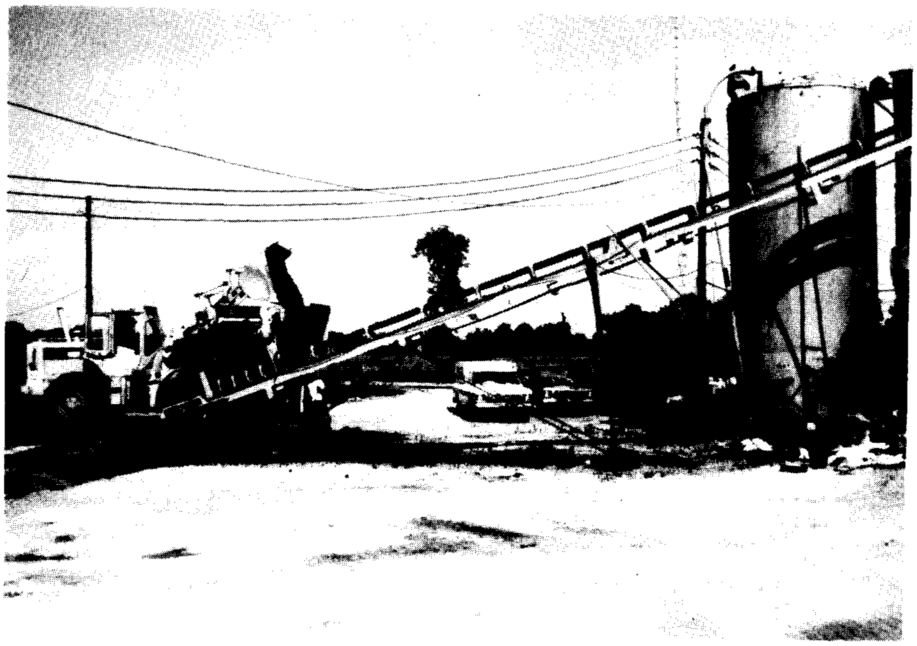
CONSTRUCTION

Plant Modification

In order to obtain the full economic benefits from recycling a minimum amount of plant modification is a prerequisite. For a batch plant operation, the modification consists of charging the weigh bucket with reclaimed material. The contractor on this project accomplished this with the addition of a surge hopper and a belt conveyor (Figure A2). Reclaimed material was deposited in the surge hopper by a front-end loader. The material dropped onto the conveyor which led to a point on the plant superstructure above the weigh box. At this point the material fell into a fabricated chute which distributed the material in the weigh box (Figure A3). The weigh box was charged with reclaimed material on demand through the manual use of a conveyor on/off switch.

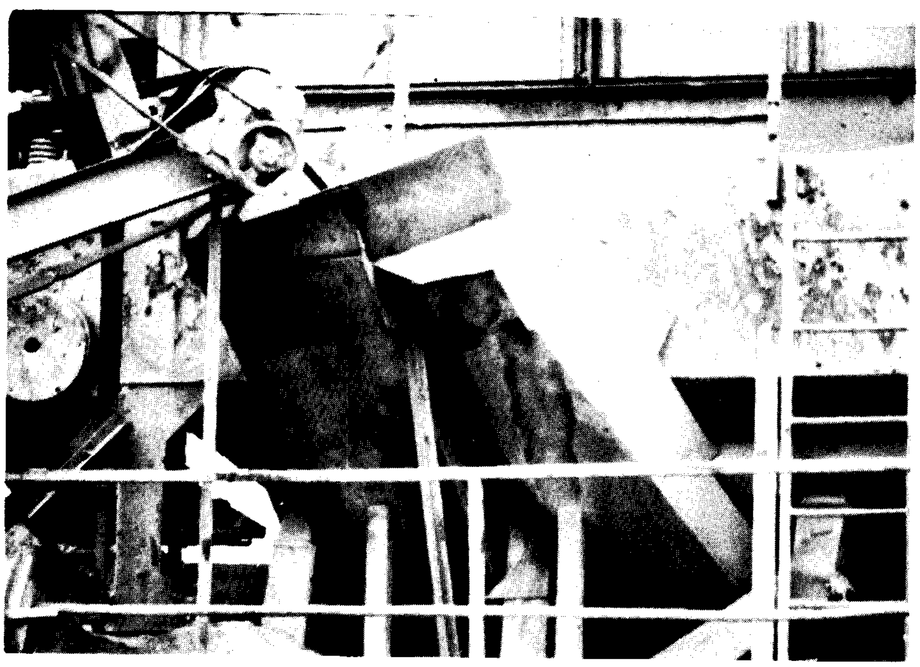
Removal and Processing of Existing Material

The existing asphaltic concrete pavement was milled to an approximately uniform 2-inch depth using a CMI PR-575 Roto-Mill. This machine milled the 2 inches of material across a 9-foot path, picked up the material and placed it into a haul truck by means of a belt conveyor, all in one continuous operation (Figure A4). The pavement was removed at an approximate rate of 250 tons per hour. A prior Louisiana brushfire study had determined that the resulting textured surface (Figure A5) would provide a more than adequate riding surface with regard to rideability and skid for temporary traffic.



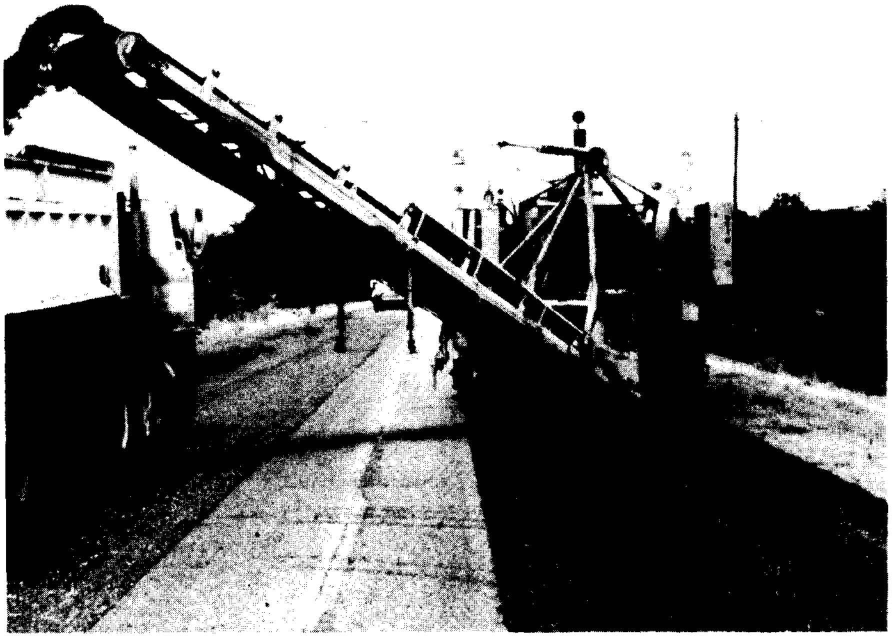
Reclaimed Cold Feed System

FIGURE A2



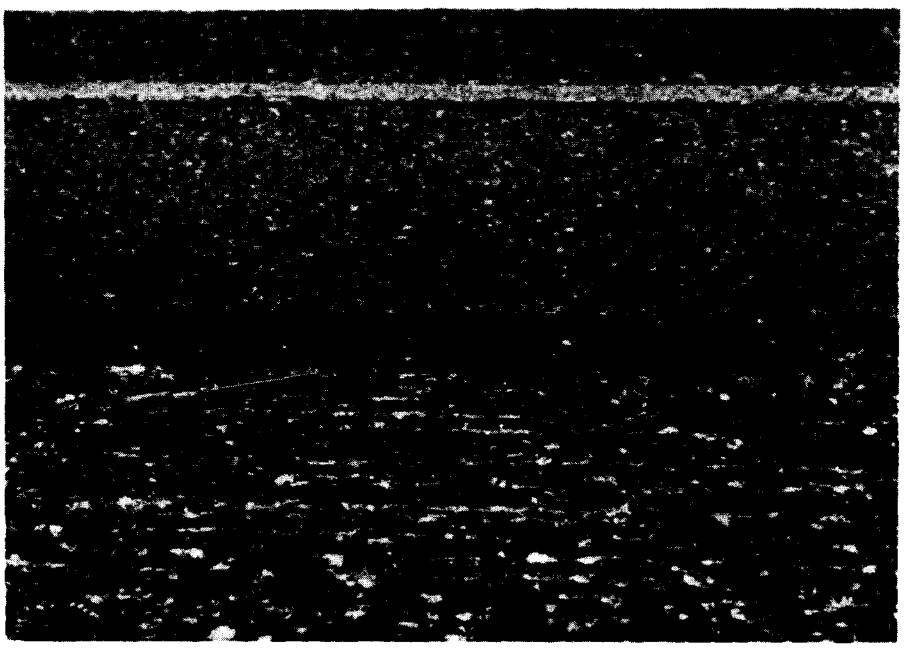
Fabricated Reclaim Distribution Chute

FIGURE A3



Removal Operations

FIGURE A4



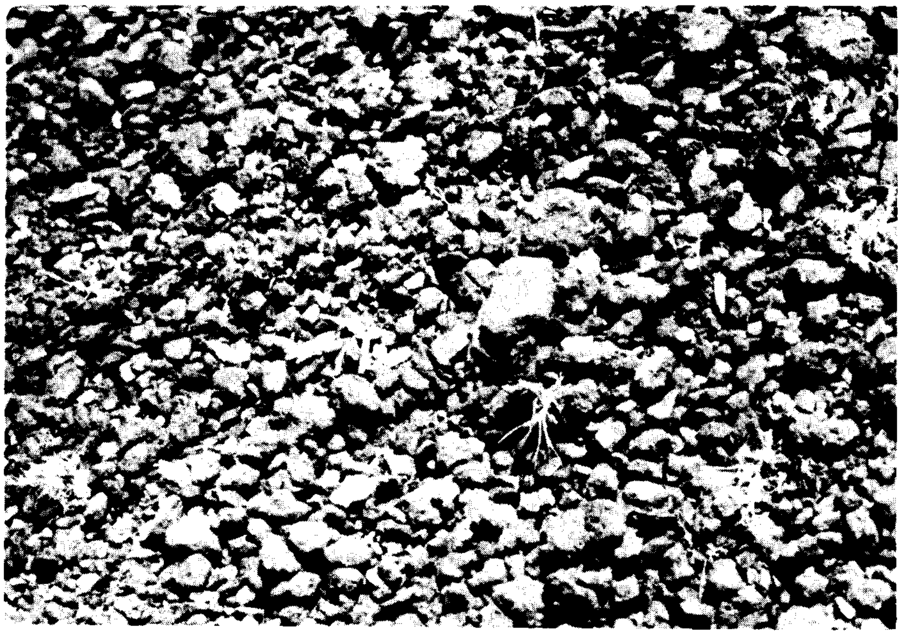
Textured Surface

FIGURE A5

The reclaimed material was hauled to the plant and stockpiled on an unprepared surface (Figure A6). A front-end loader was used to build up the stockpile, but yard equipment was prohibited from running on top of the pile. Most of the reclaimed material fulfilled the specification requirement of being less than 2 inches in size so that no further crushing was necessary (Figure A7). Unused portions of the stockpile were covered to protect the material from the weather (Figure A8).

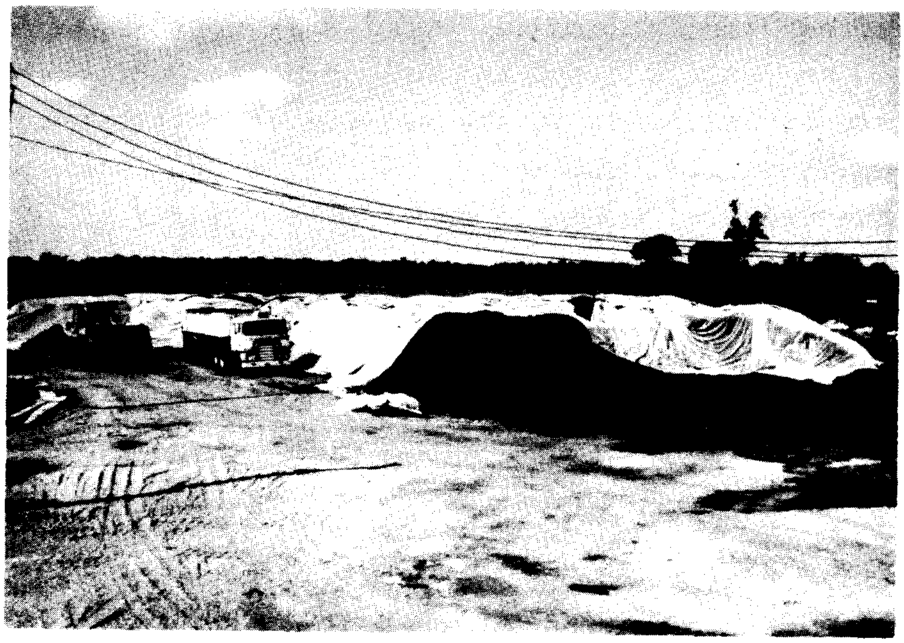
Stockpiling Reclaimed Material

FIGURE A6



Size of Milled Material

FIGURE A7



Stockpile Protected from Weather

FIGURE A8

Plant Production and Laydown

According to the preliminary design considerations, a 50/50 blend of reclaimed-to-virgin materials was attempted with the addition of 2.7 percent by weight of new asphalt cement. The virgin aggregate was proportioned at the cold feed, similar to the contractor's normal operation, and then blended with the reclaimed material to produce a mix near the mid-point of a Type 1 wearing course gradation (Table A2). Virgin aggregate was superheated in the dryer to a temperature between 400°F - 500°F and deposited in the hot bins.

Although the plant capacity was listed as 3000 pounds, the contractor's usual practice was to produce 3500-pound batches. Initial attempts to attain a 3500-pound batch resulted in failure. It was first assumed that the maximum heat transfer would take place if the reclaimed material was placed in the weigh box first with the virgin aggregate hot bin pulls following. However, the reclaimed material "bridged" and the full 3500-pound batch could not be weighed up. Then, the order of addition was reversed so that the reclaimed material would be added last. In this case, the reclaimed material "fluffed" when placed on top of the superheated aggregate and prevented the desired batch weight. Finally, the contractor added some directional vanes to the reclaim chute (thereby distributing the reclaimed material evenly throughout the weigh box) and changed the order of batching to:

1. Hot Bin #1 and Mineral Filler (fines),
2. Reclaimed Material, and
3. Hot Bins #2 and #3 (+4 virgin).

This batching order proved successful and was continued for the entire project.

The total asphalt cement content was increased to 5.2 percent by weight based on Marshall mix properties determined from the first day's production. This was the only deviation made from the preliminary design considerations.

TABLE A2

RECYCLED MIX DESIGN
(% PASSING)

U.S. Sieve Size	Fine Sand	Coarse Sand	Gravel	Reclaim Material	Target Gradation
3/4 inch	100	100	99	99	99
1/2 inch	100	100	93	88	90
No. 4	92	98	59	56	58
No. 10	84	90	35	45	42
No. 40	64	21	20	28	23
No. 80	47	4	16	15	12
No. 200	23	2	9	8	6
% Asphalt				4.8	5.1

The dry mix cycle in the pugmill was increased from 5 to 30 seconds to provide additional time for heat transfer. After the addition of the new asphalt cement (AC-30), a wet cycle of 30 seconds was tried. A wet cycle of 20 seconds was later found acceptable and reduced production time to a total of 50 seconds per batch, which approached the contractor's normal 35-second-per-batch cycle.

The recycled mix temperature was measured in the haul trucks at the plant. A mean temperature of 300°F with a standard deviation of 25°F was attained (based on 55 samples).

Conventional laydown equipment and procedures were used at the roadway. While occasional small lumps of mix were observed in the hopper of the laydown machine, they were completely broken down when screeded. The mix was described by the laydown crew and inspectors as "tough." It was possible for the roller operator to pass very close to the laydown machine (Figure A9). Roadway mix temperatures averaged 285°F. Since the plant was located on the project site, this would appear to be quite a heat loss. It is, however, probably indicative of further heat transfer in the mix.

Laydown Operations

FIGURE A9

The weather conditions were favorable for the length of the project. Ambient air temperatures of approximately 100°F were conducive to reclaim stockpile temperatures of 120°F. A small thunderstorm occurred once during the project. Very little water penetrated the covered reclaim stockpile, as a moisture content of less than 0.5 percent was determined.

Due to the favorable weather conditions and the consistency of the recycled mix during the early portion of the project, limited quantities of 60/40, 65/35 and 70/30 reclaimed-to-virgin blends were successfully produced. Average plant and roadway temperatures were 280°F and 260°F, respectively. These mixes were specification acceptable.

The recycled mix was controlled using normal Department procedures: Marshall mix properties, gradation, asphalt cement content and mix temperature. Roadway cores were taken to determine compactive effort. In addition, to determine reasons for possible recycled mix variations the following items were monitored during plant production:

1. Stockpiles of reclaimed materials and new aggregate,
2. Moisture content of the stockpiled reclaimed materials and the recycled mix, and
3. Cold feed rates of all virgin and reclaimed materials.

Samples of stockpiled reclaimed material, virgin aggregate from the hot bins and recycled mix were obtained daily. These samples were returned to the Research laboratory for asphalt cement content and/or gradation verification. Additionally, asphalt cement properties (Penetration @ 77°F and Viscosity @ 140°F) were run on both the extracted stockpiled material and the final recycled mix.

Records were maintained for each batch, which included the weights of every bin pull and the weight of the new asphalt added.

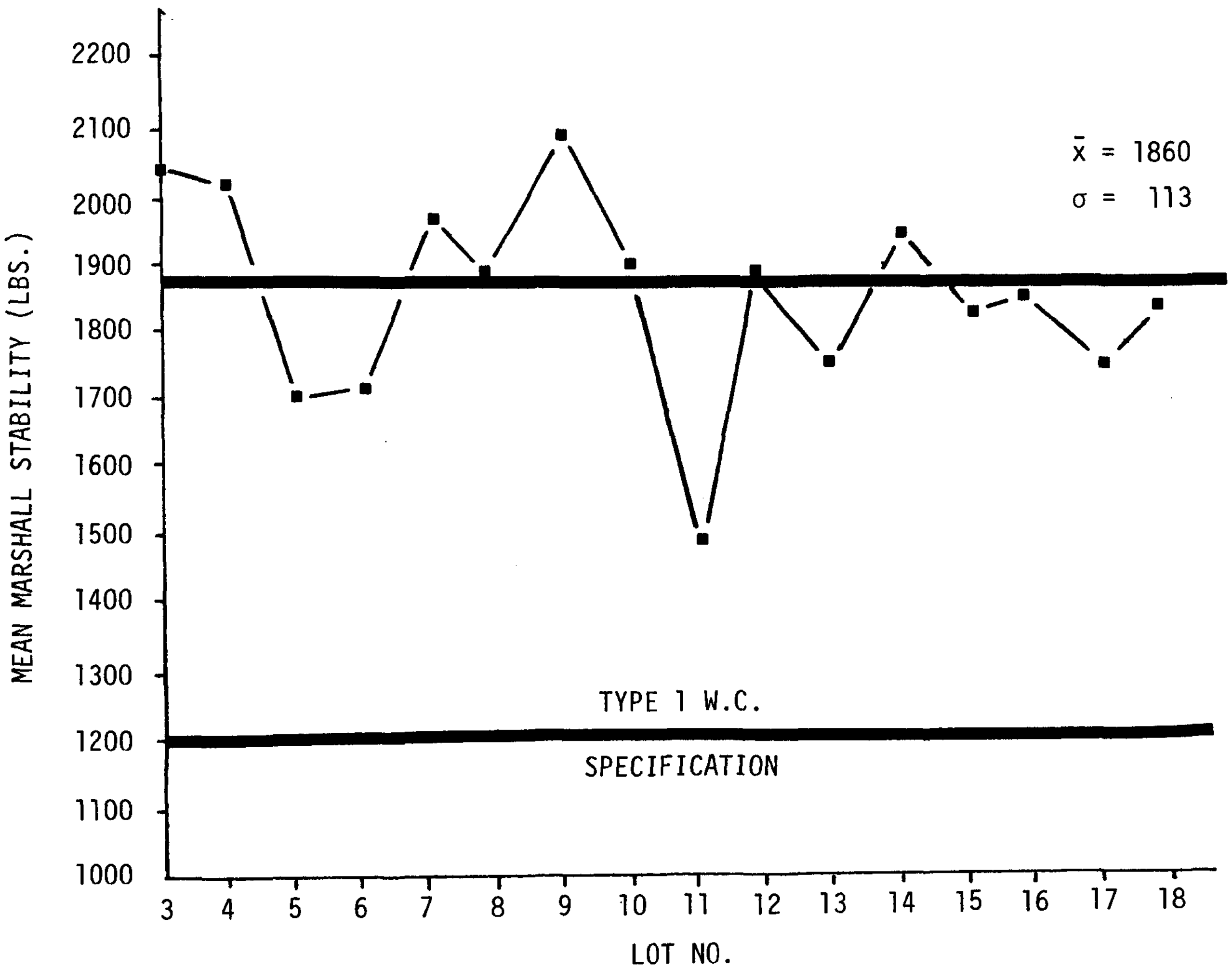
PROJECT EVALUATION

Recycled Mix

Based on all control and acceptance criteria, the recycled mix produced during this project conformed to Louisiana's Type 1 wearing course specification. Mean Marshall stability data for each lot is presented in Figure A10. The overall mean stability of 1860 pounds is well above the specification minimum of 1200 pounds. A smaller than historical standard deviation (150 pounds) shows the consistency of the mix. These briquettes had a mean air void content of 4.3 percent with a standard deviation of 0.53 based on 58 samples.

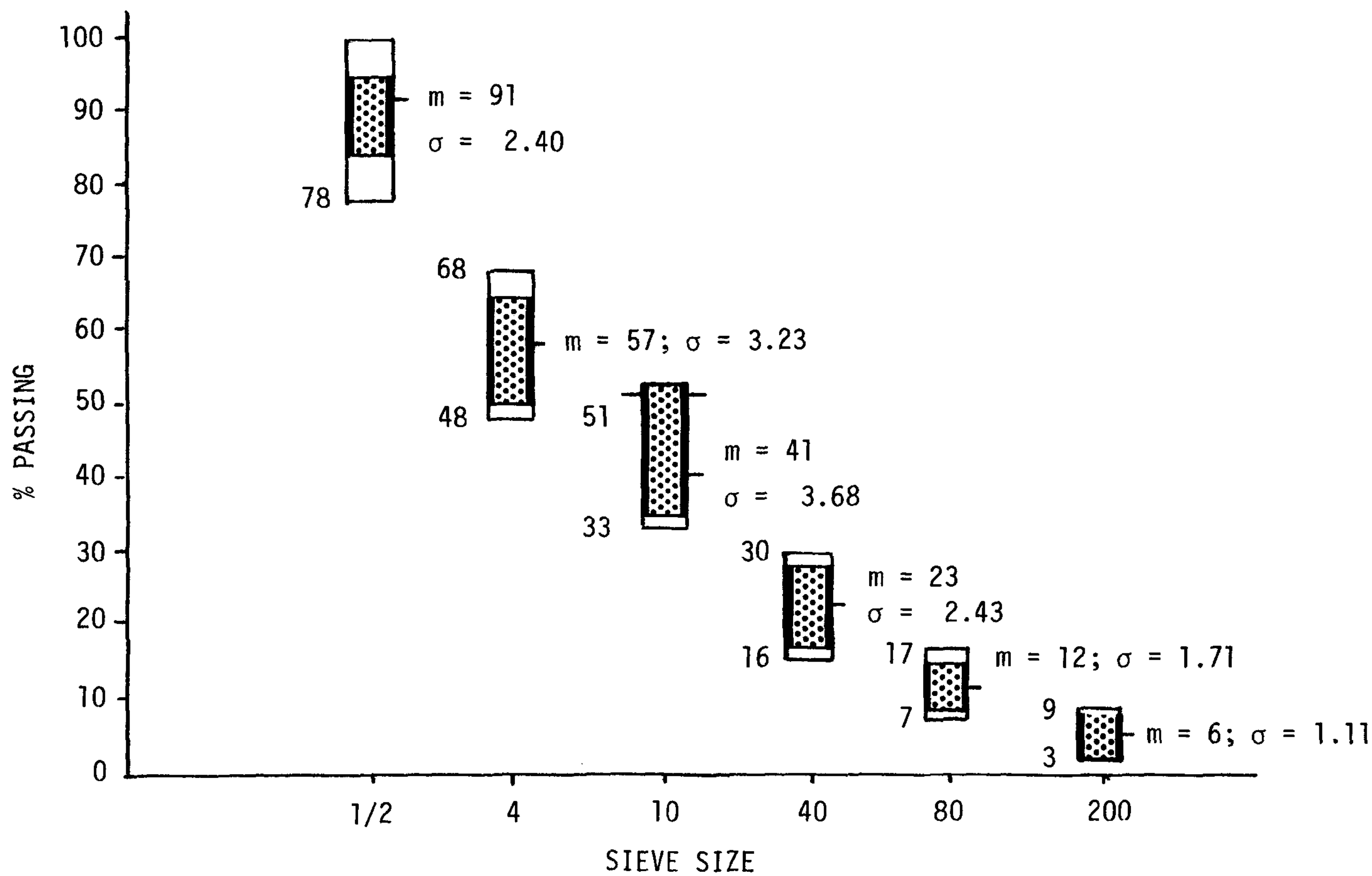
Concern was expressed prior to the project with regard to gradation control. Figure A11 presents the individual plant extractions and the control limits for each sieve size. As can be observed, the recycled mix was within the control limits imposed with the exception of the No. 10 sieve. The percent material passing the No. 10 reached 52 on one extraction of the first day's run. A measure of the uniformity of gradation can be observed in Figure A12. Presented are the variations of conventional Type 1 wearing course mixes and the recycled mix, along with current tolerance limits for each sieve size. This variation is based on a $\pm$ 3 σ level where σ is the standard deviation. The first bar represents present tolerance limits while the second and third bars of each group show conventional mix variation (historically based) and recycled mix variation, respectively. It should be noted that recycled mix variation is more in conformance with present tolerance limits than conventional mixes.

Figure A13 presents mean compactive effort for each lot. The consistency of the recycled mix can again be seen in the small standard deviation.



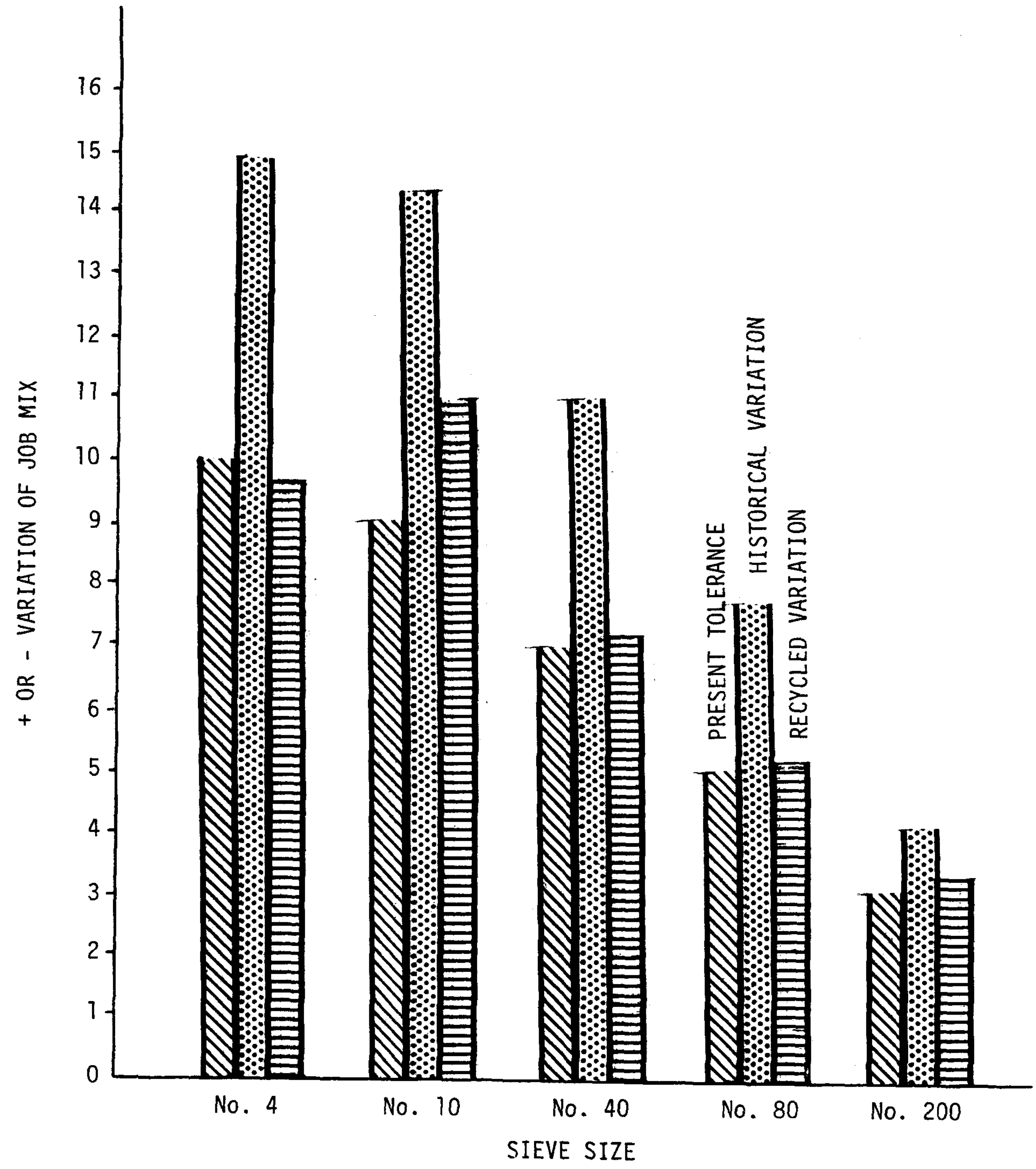
Mean Marshall Stabilities

FIGURE A10



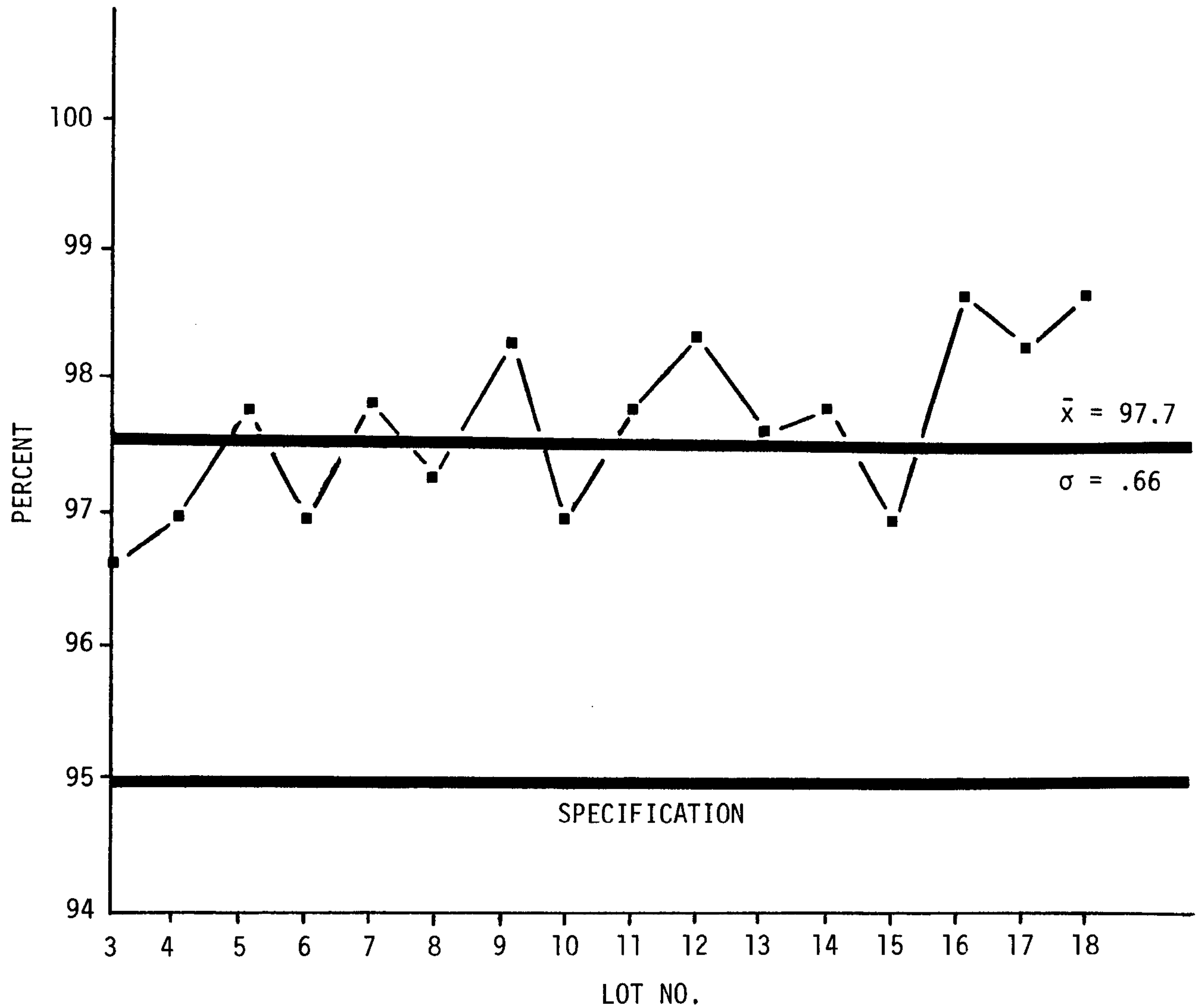
Recycled Mix Gradation Control

FIGURE A11



Recycled Mix - Conventional Mix Gradation Variation

FIGURE A12



Mean Roadway Compaction

FIGURE A13

Asphalt cement properties were tested using material extracted and recovered from the reclaimed and recycled mix samples returned to the laboratory. Unexpectedly, the asphalt cement from the reclaimed material showed a penetration of 28 and an absolute viscosity of 39,000. The initial values from Table A1 were 49 and 9,800, respectively. As should be expected, the milled material taken from near the surface was more oxidized than the asphalt cement from the original full-depth sample. This should be taken into account in future recycling operations.

Penetration and viscosity data for asphalt cement extracted and recovered from recycled mix and the conventional mix used to complete the project are shown in Table A3. The final mix viscosities presented are less than those anticipated by prediction equations but are considered acceptable. The prediction equation may be used as a first approximation in the design of recycled mixes. Penetration values were found to be similar to the 100 percent virgin mix.

According to the design, approximately 7,400 tons of reclaimed material should have been removed from the existing pavement. With a 50 percent rate of addition and almost 11,000 tons of recycled mix produced, a computation shows that only 5,500 tons of reclaimed material were utilized during the project. This represents a material loss of 25 percent. It is estimated that this loss can be traced to the following areas:

1. Loss due to stockpile placement on an unprepared surface - reclaimed material was left on the ground so that the recycled mix would not be contaminated;

2. Loss due to improper cut during the milling operation - the inspector was not familiar with the capabilities of the milling machine and did not insure that the roadway was cut to meet slope requirements;

3. Several bridges on the project were not milled - this tonnage should have been subtracted from the design tonnage milled.

TABLE A3

RECOVERED ASPHALT CEMENT PROPERTIES

	50/50	60/40	100% Virgin
Penetration (77°F)	36	36	39
Absolute Viscosity (140°F) Poises	11,699	14,026	5,182

Quantity of Blended Asphalts

$$50/50 : 100 \times \frac{\%\ \text{new asphalt}}{\%\ \text{recycled mix asphalt}} = 100 \times \frac{2.8}{5.1} = 55$$

$$60/40 : 100 \times \frac{2.2}{5.1} = 44$$

Quality of Blended Asphalts

Viscosity of reclaimed asphalt cement = 39,000 poises
Viscosity of new AC-30 asphalt cement = 3,000 poises

Prediction Equation (1)*

$\text{Log}(\text{Log } V) = a + bp$ where V = viscosity, in centipoises
p = % of lower viscosity material in final blend

$\text{Log}(\text{Log } 3{,}900{,}000) = a + b(o) = .819$

$\text{Log}(\text{Log } 300{,}000) = .819 + 100\,b = .739$
$b = -.0008$

$50/50 : \text{Log}(\text{Log } V) = .819 + (-.0008)(55)$
$V = 9{,}049$ poises

$60/40 : \text{Log}(\text{Log } V) = .819 + (-.0008)(44)$
$V = 11{,}983$ poises

If the aging index for the 100% virgin mix (5182/3000 = 1.73) is assumed consistent for the recycled mixes, then the associated predicted viscosities would be 1.73 x 9049 = 15,655 and 1.73 x 11,983 = 20,730 for the 50/50 and 60/40 blends, respectively.

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*Underlined numbers in parentheses refer to list of references.

The Dynamic Deflection Determination System (Dynaflect), Mays Ride Meter and visual inspections were used as references for field performance on this recycling project. Dynaflect measurements were performed in June 1978, prior to construction, and subsequently in February 1979, August 1979 and March 1980 (Table A4). The structural numbers (SN's) were determined from the average maximum deflection (corrected to 60°F) and the percent spread, according to methods examined in Reference (2). The before readings were taken after milling. There appears to be a less-than-anticipated gain in SN after the completion of the overlay, which would indicate little structural contribution from the recycled mix. It must be noted, though, that the original deflection was small and that a dependency of SN on the maximum deflection is inherent in the analysis employed. A better indicator of performance in this case is the percent spread. The increased values demonstrate that the new pavement system is better able to distribute loads.

The Mays Ride Meter was run in March 1980. An average present serviceability index of 4.35 was obtained. A visual inspection shows the pavement system to be performing well.

TABLE A6

ECONOMIC ANALYSIS
(TON BASIS)

Item	Conventional	Recycled
Asphalt Cement	$ 5.00	$ 2.76
Aggregate	7.36	3.75
Mineral Filler	.51	.27
Milling Costs		2.97
Difference in Production Time-Costs		1.60
Fuel Savings	______	- 1.34
Balance	$12.87	$10.01

TABLE A7

AGGREGATE DIFFERENTIAL COSTS:
MILLED VERSUS VIRGIN

Milled	Virgin		
	$4.00**	$8.00**	$16.00**
$.67*	-2.41***	1.59	9.59
$.46*	- .40	3.60	11.60
$.25*	1.61	5.61	13.61

*Milling cost per square yard per 2 inches of cut.

**Virgin aggregate cost per ton.

***Differential cost per ton--being unfavorable to milling.

Energy Conservation

In addition to a savings in materials cost, recycling conserves energy, as demonstrated in the following energy evaluation. The component percentages and total tonnages in Table A5 were used as the basis for this evaluation. Reference (3) was used as a guide for all energy calculations and equivalencies. All numbers shown are in terms of equivalent gallons of gasoline.

Virgin material energy requirements are shown in Table A8. The gallons of gasoline for each material in each category take into account the amount of energy spent to produce the material and haul it to the contractor's plant. As should be expected, the energy requirement for the recycled design alternative--16,446.1 gallons of gas--is roughly half of that for the conventional mix, whose typical design would require 31,366.4 gallons of gas. The amount of energy actually expended was about two thirds of the requirement for a 100 percent conventional mix.

The energy requirements for the plant include separate entries for the dryer, plant operations, hauling of mix to the roadway and the placement of mix. Table A9 presents the equivalent gallons of gasoline for each process. The figures for dryer operations are based on the rate of fuel consumed per ton of heated virgin aggregate and the total tons of virgin aggregate utilized. Plant operation and laydown operation data were generated from average BTU expenditures and the tonnage produced. Hauling requirements are based on a ton-mile per gallon factor. Similar to the material requirements, the plant energy actually consumed was about 60 percent of the requirement for a 100 percent conventional mix.

Before totalling the energy requirements, the amount of energy expended for removing the existing pavement must be considered. The factor accounting for this requirement is the fuel used by the Roto-Mill and the trucks hauling the material to the plant.

The amount of energy expended for the reclamation operation is relatively small, principally due to the short haul and efficiency of the milling machine. As shown in Table A10, the gallons of gasoline expended for reclamation leaves the ratio between the recycling and conventional operation relatively the same. An energy savings of almost 40 percent was realized during this recycling project.

TABLE A8

VIRGIN MATERIAL ENERGY REQUIREMENTS
(EQUIVALENT GALLONS OF GASOLINE)

	Design Alternatives		Actual	
	Recycled	Conventional	Recycled	Conventional
Asphalt Cement	4,462.4*	7,436.3	3,022.9	1,955.6
Aggregate	10,950.9	22,897.3	8,602.9	6,020.5
Mineral Filler	1,032.8	1,032.8	396.8	271.5
Total	16,446.1	31,366.4	20,270.2	

$$*\frac{14{,}868.5 \text{ tons} \times .03 \text{ (from Table A5)} \times 587{,}500 \text{ BTU/ton (Ref. 3)}}{125{,}000 \text{ BTU/gallon (Ref. 3)}}$$

TABLE A9

PLANT ENERGY REQUIREMENTS
(EQUIVALENT GALLONS OF GASOLINE)

	Design Alternatives		Actual	
	Recycled	Conventional	Recycled	Conventional
Dryer	21,948.9	56,740.6	17,240.4	14,918.9
Operations	2.357.5	2,357.5	1,737.7	619.9
Haul	1,126.4	1,126.4	830.2	296.2
Placement	1,986.4	1,986.4	1,464.1	522.3
Total	27,419.2	62,210.9	37,629.7	

TABLE A10

TOTAL ENERGY REQUIREMENTS
(EQUIVALENT GALLONS OF GASOLINE)

	Design Alternatives		Actual	
	Recycled	Conventional	Recycled	Conventional
Materials	16,446.1	31,366.4	12,022.6	8,247.6
Plant	27,419.2	62,210.9	21,272.4	16,357.3
Reclamation	1,503.8	--	1,503.8	--
Total	45,369.1	93,577.3	59,403.7	

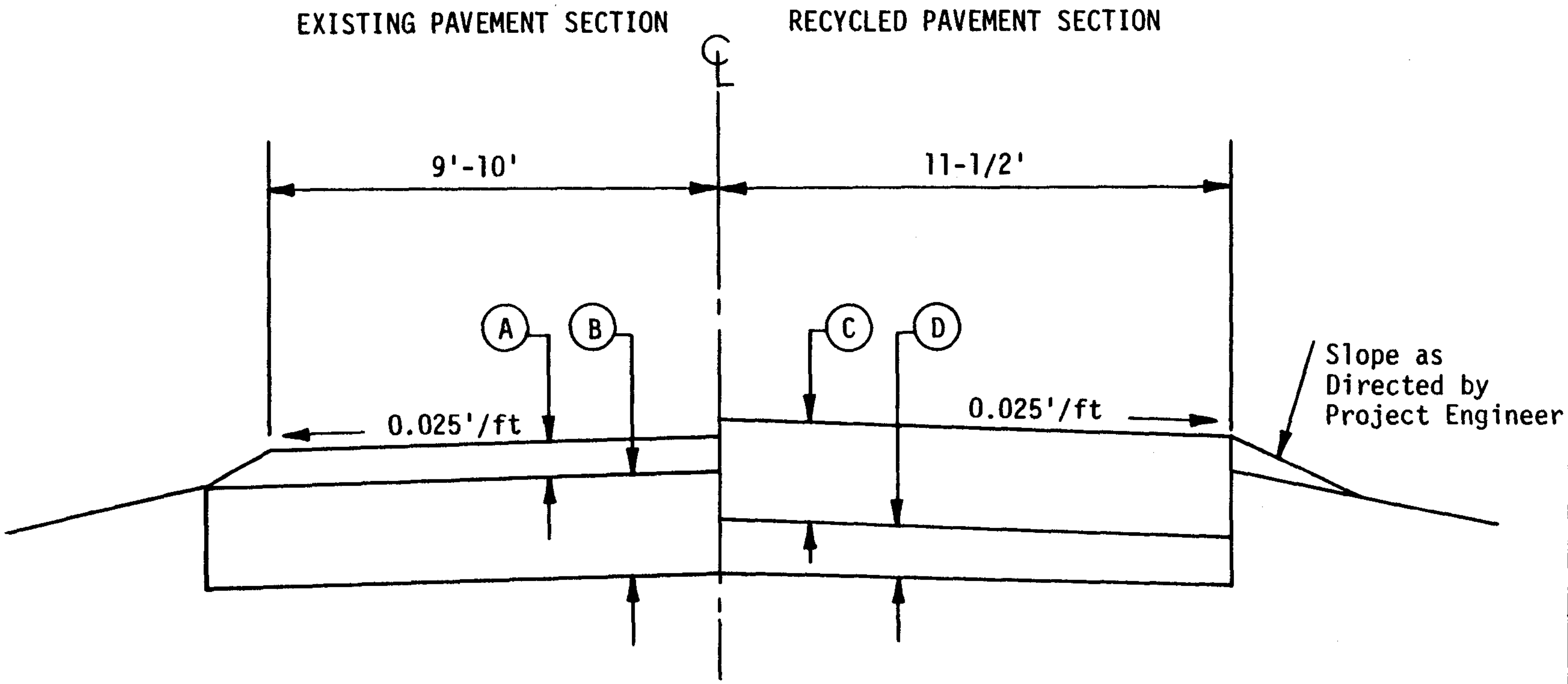
DRYER-DRUM PLANT PROJECT

PROJECT DESCRIPTION

A 6.87-mile, two-laned roadway (La. 621) in Ascension Parish was chosen for Louisiana's second hot plant recycling project. The existing pavement consisted of a sand-clay-gravel base topped with a multiple application asphalt surface treatment. In January of 1978, bids were accepted to separately remove the asphalt surface and 3 inches of the sand-clay-gravel base material; these materials were to be combined with a limited quantity of new aggregate and asphalt cement to produce 6 inches of a recycled asphaltic concrete mixture which was to be placed in two equal lifts on the remaining base material. Figure B1 shows a typical section of the project. Actual construction on the project took place from October, 1978 through March, 1979.

PRELIMINARY PROJECT CONSIDERATIONS

Prior to working up plans and estimates for the project, borings were taken of the existing roadway to verify quantity (width and thickness) and quality of the existing materials. Depths of both the asphalt surface treatment and the base were checked for the entire 6.87-mile project at 0.2-mile increments; results averaged 1.5 inches of surface treatment and 6 inches of base. At 1-mile increments, the widths of both surface and base material were checked; results were as shown on the previously mentioned typical section. At 1-mile increments, the gradation of the existing sand-clay-gravel base was determined along with the gradation, asphalt content and asphalt properties of the surface treatment material. The primary concern for this preliminary data (depths, widths, gradations, asphalt content and asphalt properties) was to develop appropriate bid item quantities for anticipated new aggregate and asphalt cement. Based on these preliminary findings it was believed that, with proper processing, the full tonnage of



(A) 2" Avg. Existing Surface Treatment (2" Avg. to be Removed and Reused)

(B) 6" Avg. Existing Sand-Clay-Gravel Base Course (3" Avg. to be Removed and Reused)

(C) Recycled Asphaltic Concrete (6" Thick, to be Placed in Two Lifts)

(D) Remaining Sand-Clay-Gravel Base Course to be Shaped and Compacted as Directed by the Project Engineer

Typical Finished Section

FIGURE B1

3 inches of removed sand-clay-gravel base (13,500 tons) could be completely combined with the full tonnage of 1.5 inches of removed asphalt surfacing (7,500 tons)* and new aggregate (9,000 tons) and new asphalt cement (1,100 tons) to produce a 6-inch recycled asphaltic concrete pavement (31,100 tons).

No provision (bid item) was included for the use of an asphalt rejuvenating agent based upon the recovered properties of the existing asphalt:

Viscosity @ 140°F = 28,296 poises
Penetration @ 77°F = 33

The belief was that the properties of the asphalt cement in the final recycled product would be acceptable considering it would be a blend of a large quantity of new AC-20 grade asphalt cement (1,100 tons) with a small quantity of aged asphalt (7,500 tons @ 5.4% = 405 tons) from the recovered surface treatment material.

A copy of the special provisions for the project, which take into account the proper processing felt necessary based on the preliminary sampling data, is included in the appendix. A discussion of this processing will be included under the Construction section of this report.

CONSTRUCTION

Plant Modification

The low bidder, Vicon Inc., modified its AESCO dryer-drum plant to provide recycling capability by the addition of a separate cold feed system for the asphalt surface treatment material (Figures B2 and B3). Such a system (feed hopper, belt conveyor, and load cell)

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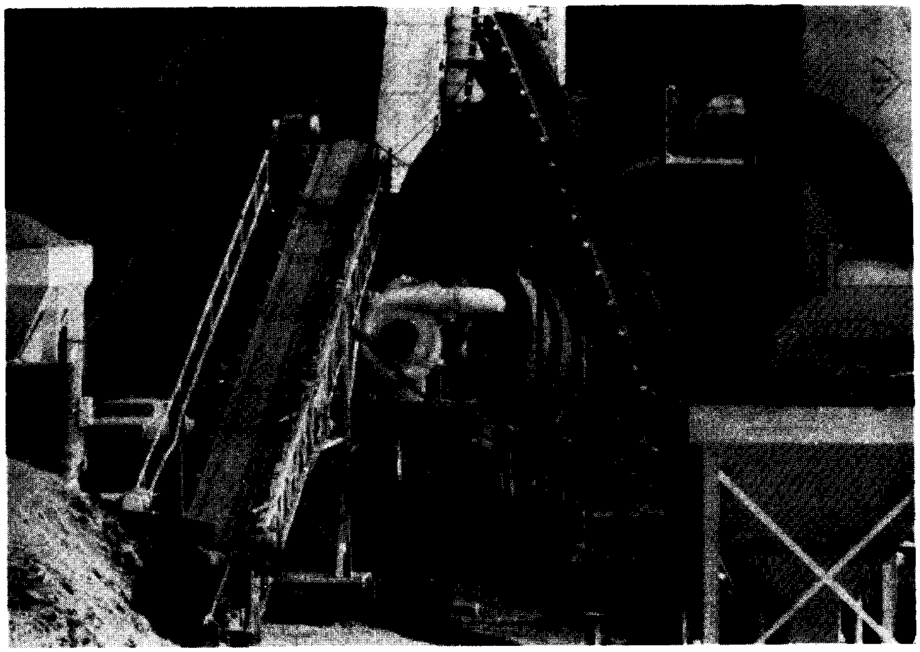
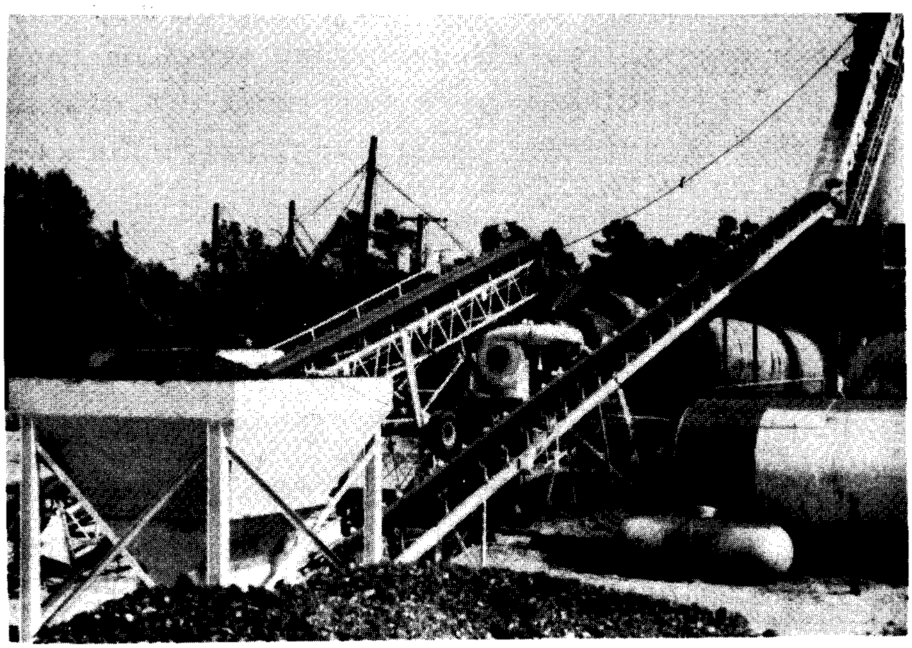
*Asphalt content of existing surface treatment was 5.4%.



Plant Modification

FIGURE B2



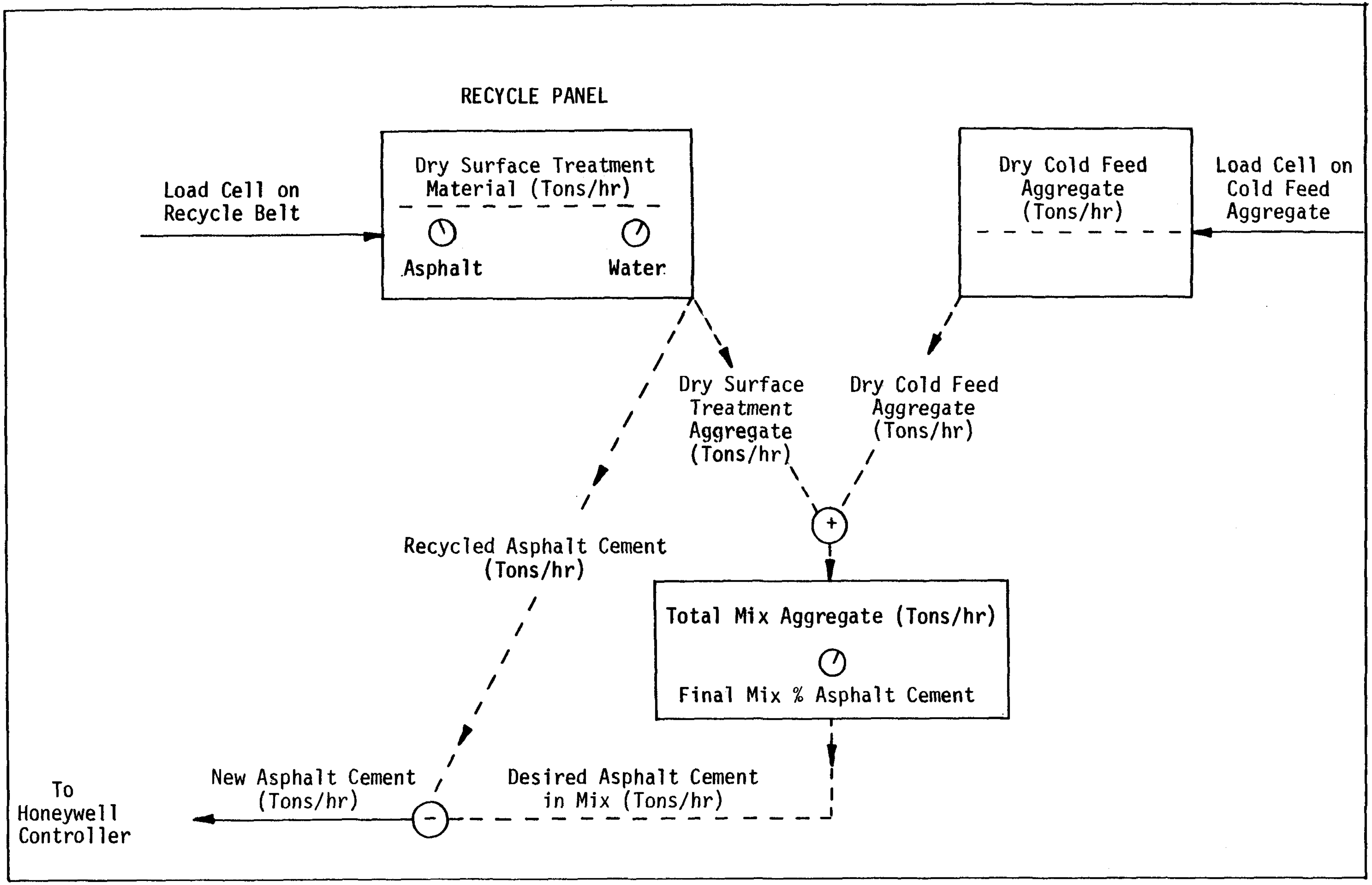
Plant Modification

FIGURE B3

delivered the asphalt surface treatment to an auger at the rear of the drum; the auger discharged the material approximately one third of the way into the drum, where heat transfer and blending occurred with the virgin material (new aggregate and asphalt cement). A load cell was located on the recycle belt conveyor, and its tonnage was displayed on a separate panel board in the plant control room. A set-point controller on this recycle panel board was used to dial in the known asphalt content of the recycled material. The electronics of the main panel board was modified so that the desired asphalt content of the final mix would be based upon the sum of both virgin and recycled aggregate weights. The quantity of new asphalt cement would be automatically calculated and controlled as the difference between the desired final mix asphalt quantity and the asphalt quantity in the recycled material. Figure B4 describes these electronic control modifications accomplished on the plant. The proper operation of this control network was easily verified by setting the asphalt percentage controller on the recycled feed to zero and observing that the panel-displayed tonnage of new asphalt cement increased to the desired level. An example (Table B1), developed from an actual plant verification, describes this procedure.

Removal and Processing of Existing Material

A CMI PR-575 Roto-Mill was used to remove, in two distinct operations, both the asphalt surface treatment and the sand-clay-gravel base. A limiting factor to the length of removal per day's operation was that local traffic would be driving on a structurally unsound roadway; after the removal of the surfacing and 3 inches of the base, only 1 to 3 inches of sand-clay-gravel base remained over a silty clay loam subbase. Additionally, although the contract called for priming the remaining base material, there existed concern that rainfall on this reduced section, prior to receiving the first lift (3 inches) of recycled hot mix, would result in extensive base failures. Consequently, the milling



Modification to Dryer-Drum Automatic Control Panel

FIGURE B4

TABLE B1

VERIFICATION OF ASPHALT CONTENT CONTROL

Control Room Panel Displays

	Surface Treatment Load Cell (Tons/hour, dry)	Set Point (%)	Cold Feed Aggregate Load Cell (Tons/hour, dry)	Final Mix Asphalt Controller (%)	New Asphalt (Tons/hour)
Condition 1*	44	3.6	131	4.8	7.18
Condition 2**	44	0	131	4.8	8.82

*Normal Operation

Total aggregate in mix = 131 + 44(.964) = 173.4 tons/hour

Total desired asphalt $= \frac{173.4}{.952} - 173.4 = 8.76$ tons/hour

Asphalt in recycled mix = 44(.036) = 1.58 tons/hour

New asphalt = 8.76 - 1.58 = 7.18 tons/hour

**Verification (Dial Recycled Set-point to Zero)

Total aggregate in mix = 131 + 44 = 175 tons/hour

Total desired asphalt $= \frac{175}{.952} - 175 = 8.82$ tons/hour

Asphalt in recycled mix (assumed) = 0

New asphalt = 8.82 - 0 = 8.82 tons/hour

operation was confined to approximately a 1/2-mile cut per day (the length of full-width roadway that could be covered with recycled mix in one day's operation). For both ease of traffic control and feasibility of construction, the milling operation remained one day's operation (1/2 mile) ahead of the recycled mix paving operation.

The first pass of the CMI machine over these 1/2-mile lengths removed approximately 2 inches of material (1.5 inches of asphalt surface treatment and 0.5 inches of sand-clay-gravel). This asphalt surfacing was hauled to the plant and stockpiled without further processing, most of the material being less than 2 inches in size (Figures B5 and B6).

Stockpiled Asphalt Surface Treatment

FIGURE B5

TABLE B1

VERIFICATION OF ASPHALT CONTENT CONTROL

Control Room Panel Displays

	Surface Treatment Load Cell (Tons/hour, dry)	Set Point (%)	Cold Feed Aggregate Load Cell (Tons/hour, dry)	Final Mix Asphalt Controller (%)	New Asphalt (Tons/hour)
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Stockpiled Asphalt Surface Treatment

FIGURE B5

Plant Production and Laydown

The initial tonnage (1,178 tons) produced on this project contained no recycled material; the length of roadway from which the first material had been removed needed to be protected by overlay while the necessary information needed to develop a recycled mix design was compiled. Once the sand-clay-gravel material was crushed and separated, samples of the +4 and -4 stockpiles were tested for gradation and percent crushed. Samples of the stockpiled asphalt surface treatment were extracted to determine asphalt content and gradation. The results are given in Table B2, along with the proportions of each cold feed material comprising the recycled mix. The binder content of the stockpiled asphalt material was found to be 3.6 percent; the difference between this and the 5.4 percent found from preliminary roadway core samples is attributed to the addition of 1/2 inch of sand-clay-gravel in the milling process. It is important to point out that the final proportions of each feed were arrived at not only because their combination yielded a satisfactory gradation, but also because their combination was able to utilize nearly all the quantity of removed material.

This combination of materials was used to produce 5,763 tons of recycled asphaltic concrete. On November 14, 1978, the recycled mix design was changed; the sand-clay-gravel material, which had become unusable due to frequent heavy rains. was eliminated. The remainder of the project (24,154 tons) was constructed using a blend of 75 percent virgin aggregate and 25 percent recycled asphalt surface treatment. The appearance of the plant's stack gases did not indicate any burning of the reclaimed material (Figure B9) for the entire production (29,917 tons) which contained the recycled asphalt surface treatment. No air pollution tests were actually conducted during the project to verify this.

Unfortunately, during the construction of this project, a significant quantity of plant production had to be used for the repair of base failures. The efforts to coordinate the operations of base removal and recycled mix replacement were not sufficient to prevent local traffic and heavy rains from damaging sections of the exposed base.

TABLE B2

RECYCLED MIX DESIGN

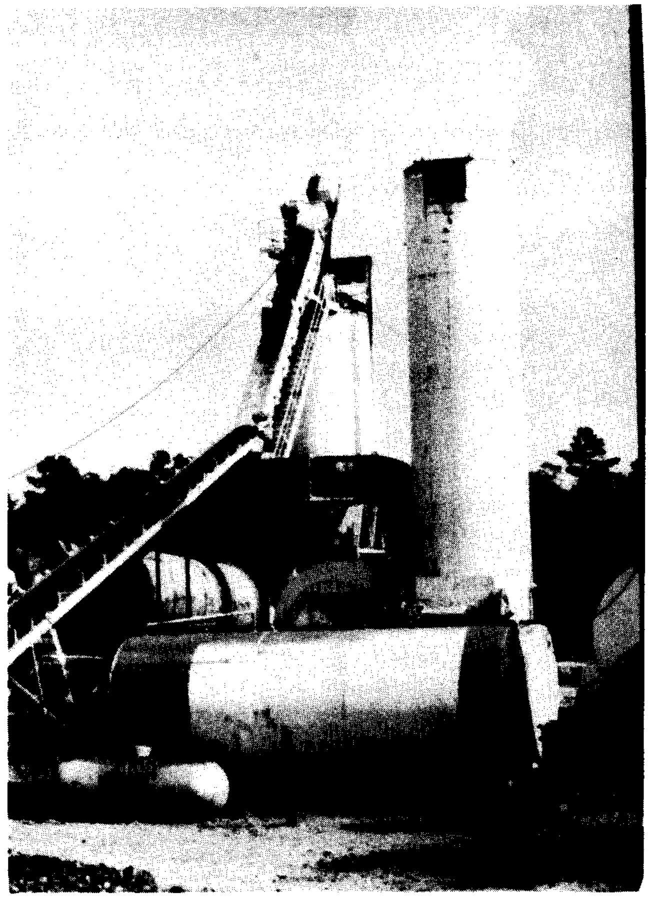
Gradation (% Passing)	Asphalt Surface Treatment (25%)*	+4 Base (15%)	-4 Base (30%)	New Gravel (30%)	Final Mix
1 inch	100				100
3/4 inch	94	100		100	98
1/2 inch	78	97	100	90	91
No. 4	48	6	87	41	50
No. 10	34	0	66	18	34
No. 40	13		44	6	18
No. 80	4		25	3	9
No. 200	2		17	1	6
% Crushed		41		63	46 to 50
% Asphalt	3.6				4.8

Mix Temperature = 300°F

Theoretical Mix Gravity = 2.41**

*Percent of final mix total aggregate.

**Determined by combining the four cold feed materials at design percentages, extracting the asphalt, and testing both the +4 and -4 material for apparent specific gravity.



Visually Clean Dryer-Drum Exhaust Gases

FIGURE B9

PROJECT EVALUATION

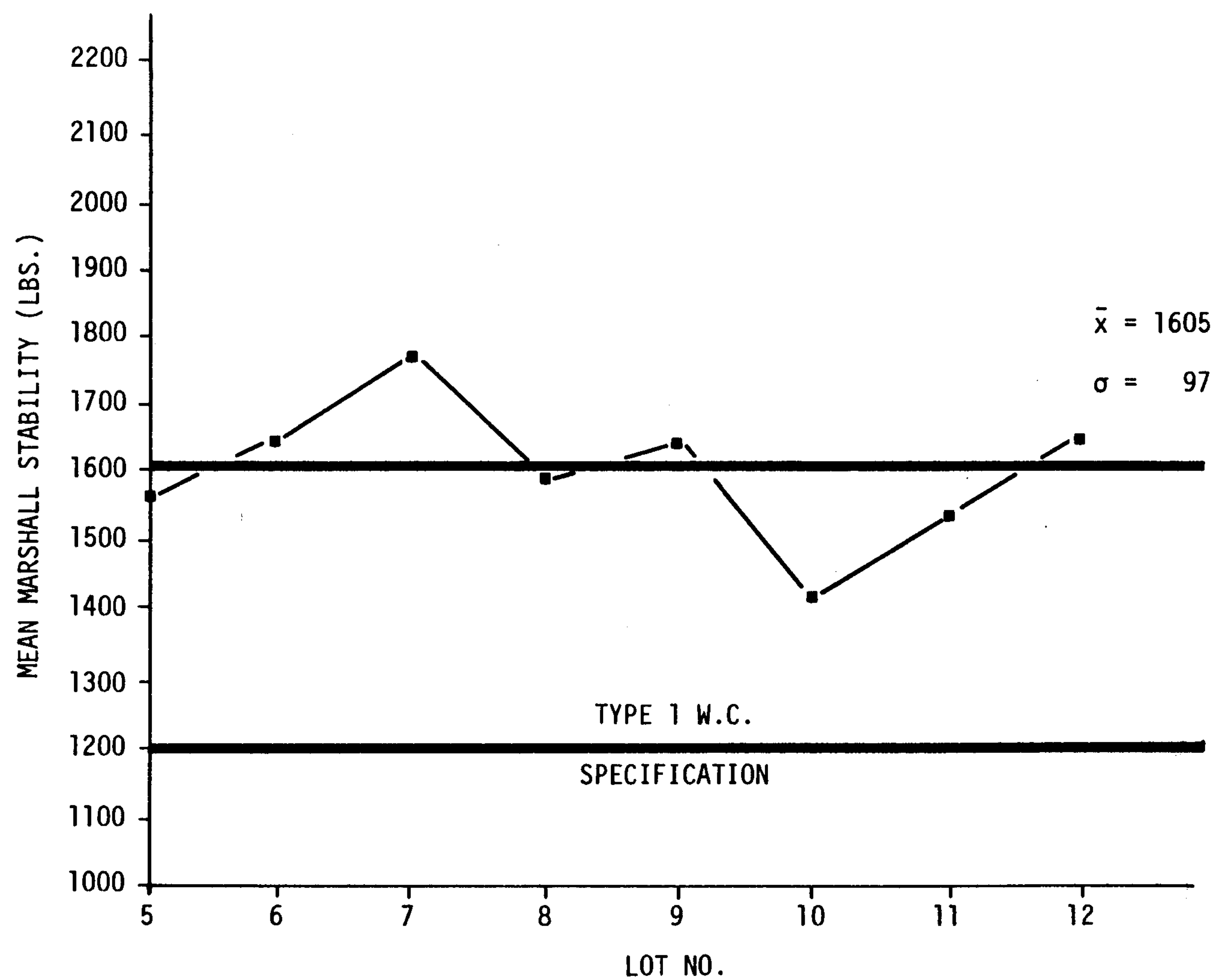
Recycled Mix

Based on all control testing done during the production of a recycled mix which contained both the asphalt surface treatment and the sand-clay-gravel base (5,763 tons), the quality of the mix was found to be acceptable. Marshall stabilities, percent air voids and mix temperatures for each lot are presented in Figure B10. The overall mean data for each lot is presented in Figure B10. The overall mean stability of 1,605 pounds is well above Louisiana's Type 1 minimum of 1,200 pounds; the standard deviation of 97 pounds is smaller than Louisiana's historical value (150 pounds) for asphaltic concrete.

TABLE B3

BASE/ASPHALT SURFACE TREATMENT MIX PROPERTIES

Date	Production (Tons)	Individual Stability	Daily Mean Stability	Daily Mean Air Voids (%)	Daily Mean Temperature (°F)
10-30-78	488	1443			
		1721	1582	4.6	316
11-1-78	779	1686			
		1912			
		1505			
		1393	1624	4.6	306
11-2-78	958	2253			
		1643			
		1608			
		1611	1779	4.6	304
11-3-78	286	1670			
		1509	1590	4.6	300
11-6-78	504	1849			
		1443	1646	4.6	300
11-8-78	566	1576			
		1293			
		1371			
		1416	1414	4.2	319
11-9-78	753	1347			
		1546			
		1588			
		1723	1551	4.6	307
11-10-78	1013	1718			
		1582			
		1569			
		1765	1658	4.6	306
Overall Mean		1605	1605		
Overall Deviation		199	97		



Mean Marshall Stabilities

FIGURE B10

This same acceptable quality was found for gradation and asphalt content (Table B4). The relatively small standard deviation of 0.23 for the asphalt content is quite good. Figure B11 shows all gradation sieve sizes to be within the job mix control limits.

Roadway laydown and compaction were also acceptable. Figure B12 presents mean compaction results for each lot.

As previously mentioned, the sand-clay-gravel recycled material became unusable and the project was completed with a mix comprised of 75 percent virgin aggregate and 25 percent recycled asphalt surface treatment. Although the properties of this recycled mix were quite good initially, internal problems within the contracting firm created a situation which affected quality control. The project was completed with a mix that, although meeting specifications, was produced without the normal level of contractual quality control. It is felt important, however, for this report to document that, before such problems developed, a blend of 25 percent asphalt surface treatment and 75 percent virgin material produced approximately 6,000 tons of good recycled asphaltic concrete. Table B5 lists Marshall stabilities, percent air voids, and mix temperatures for this tonnage. As presented, the overall mean stability was 1,374 pounds with a standard deviation between lots of 65. This is considered to be very good control; the lower stability of this recycled mix, when compared to the sand-clay-gravel recycled mix, is attributed to a reduction in gravel "screening" material when virgin coarse and fine sand replaced the -4 feed of crushed sand-clay-gravel. Table B6 presents the individual plant extracted gradation results which, when compared to the previously presented Table B4, show this recycled mix to be even less variable than the acceptable sand-clay-gravel mix.

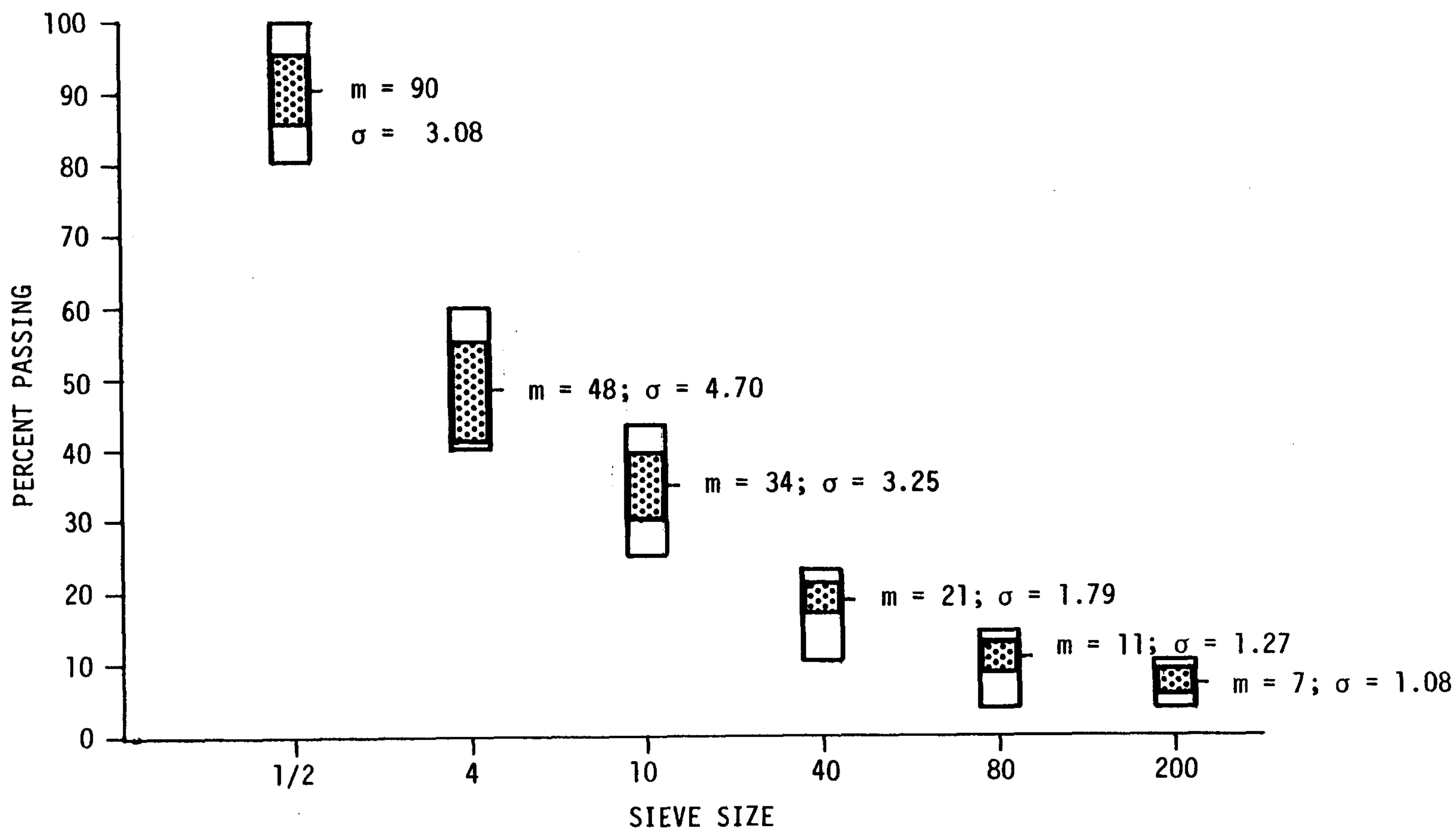
TABLE B4

BASE/ASPHALT SURFACE TREATMENT GRADATION AND ASPHALT CONTENT

Date	Gradation (% Passing)* 3/4	1/2	4	10	40	80	200	Asphalt Content (%)
10-30-78	100	89	50	34	21	11	8	5.3
11-1-78	96, 96	86, 87	41, 42	29, 29	18, 18	9, 9	6, 6	4.6, 4.6
11-2-78	100, 98	94, 87	56, 52	39, 38	23, 23	12, 12	8, 9	5.1, 4.7
11-3-78	100	93	49	34	21	10	7	4.8
11-6-78	100	92	48	36	23	11	8	4.5
11-8-78	98, 100	95, 86	49, 41	35, 30	21, 18	12, 9	9, 6	4.7, 4.9
11-9-78	100, 99	90, 87	49, 44	36, 31	22, 20	11, 11	7, 6	5.0, 5.0
11-10-78	100, 98	93, 89	54, 44	37, 32	22, 21	12, 13	8, 8	5.0, 5.1
Overall Mean	99	90	48	34	21	11	7	4.87**
Overall Deviation		3.08	4.70	3.25	1.79	1.27	1.08	0.23

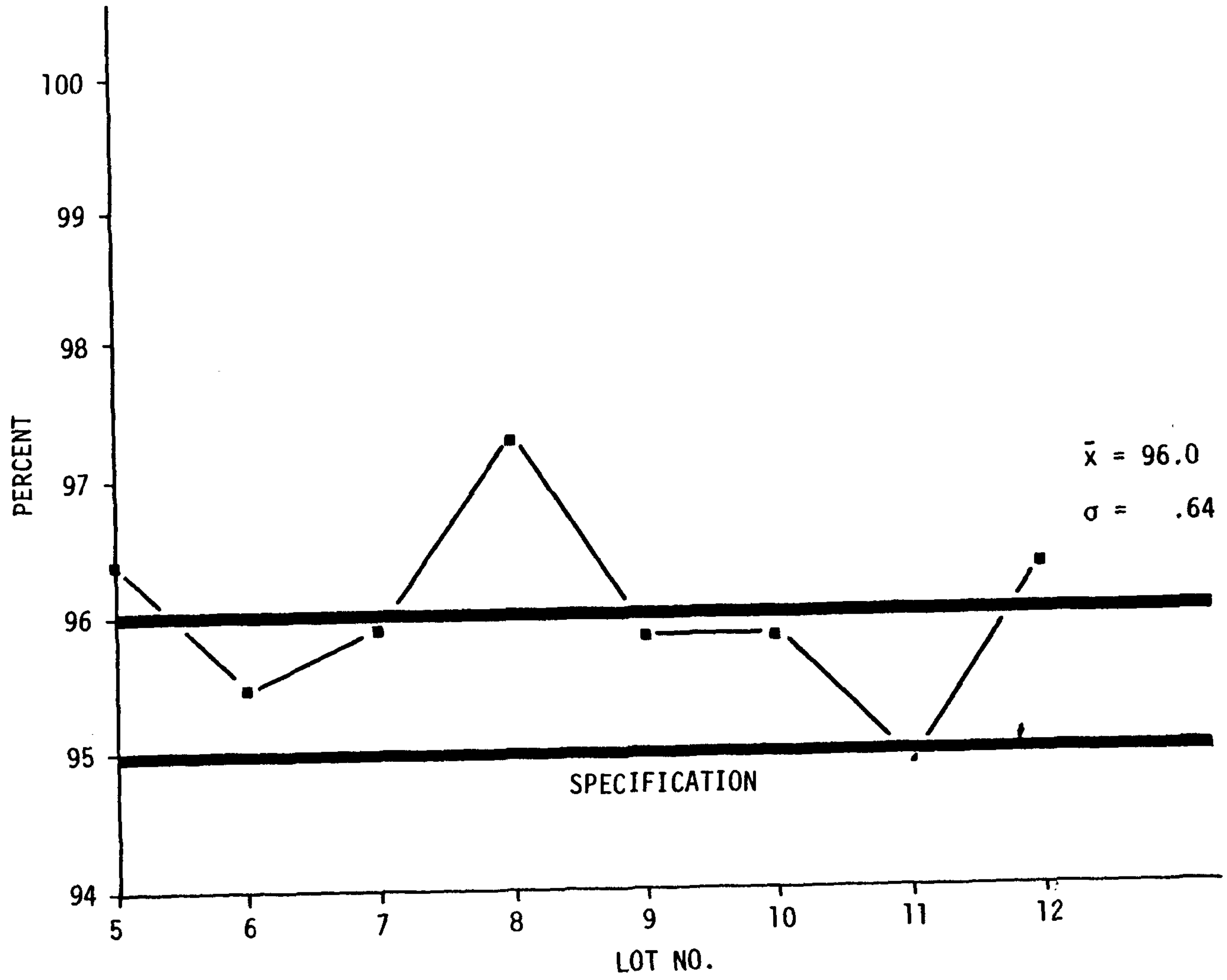
*One or two extraction results are shown per day.

**Design asphalt content was 4.80%.



Recycled Mix Gradation Control

FIGURE B11



Mean Roadway Compaction

FIGURE B12

TABLE B5

NEW AGGREGATE/ASPHALT SURFACE TREATMENT MIX PROPERTIES

Date	Production (Tons)	Individual Stability	Daily Mean Stability	Daily Mean Air Voids (%)	Daily Mean Temperature (°F)
11-14-78	625	1546			
		1289			
		1386	1407	3.7	314
11-20-78	772	1491			
		1582			
		1414			
		1349	1459	4.1	314
11-24-78	1500	1213			
		1205			
		1115			
		1445	1244	4.9	292
12-6-78	1019	1468			
		1560			
		1096			
		1457	1395	4.1	313
12-13-78	756	1275			
		1492			
		1289			
		1415	1368	4.1	307
12-18-78	909	1415			
		1541			
		1097			
		1443	1374	5.0	308
Overall Mean		1373	1374		
Overall Deviation		147	65		

TABLE B6

NEW AGGREGATE/ASPHALT SURFACE TREATMENT GRADATION AND ASPHALT CONTENT

	Gradation (% Passing)*							
Date	3/4	1/2	4	10	40	80	200	Asphalt Content (%)
11-14-78	100	91	55	42	29	13	6	4.8
11-20-78	100, 95	88, 85	50, 46	41, 37	28, 26	12, 12	8, 6	5.4, 4.8
11-24-78	100, 100	89, 88	49, 46	38, 34	25, 26	12, 13	7, 9	4.8, 5.5
12-6-78	99, 100	84, 87	51, 51	37, 38	23, 25	12, 14	7, 9	5.0, 5.4
12-13-78	98, 98	83, 89	44, 44	34, 39	22, 23	13, 14	7, 9	4.9, 5.4
12-18-78	100, 100	93, 92	55, 51	38, 36	20, 20	11, 10	6, 6	4.8, 4.5
Overall Mean	99	88	49	38	24	12	7	5.03**
Overall Deviation		3.06	3.72	2.38	2.83	1.15	1.21	0.32

*One or two extraction results are shown per day.

**Design asphalt content was 4.8%.

Penetration and viscosity data for asphalt cement which was extracted and recovered from the recycled mix is shown in Table B7. The viscosities of the final mix were approximately that which had been anticipated, as shown by the calculations in the table. The viscosity and penetration values show the asphalt cement to be similar to that found in the production of conventional asphaltic concrete in Louisiana.

Field performance of the recycled mix has been performed periodically since the construction was completed in March, 1979. Table B8 contains deflection data taken in May and August of 1979 and, most recently, in April of 1980. The theory behind the analysis shown is discussed in another report (2). Although all discussion previously presented in this report depicts a recycled asphaltic concrete of acceptable quality, based upon these measured system deflections and corresponding calculated structural numbers, it is anticipated that the roadway will need an overlay within 10 years. It is the authors' belief that poor subbase support and drainage is the primary cause of these less than desirable indicators of performance. Visual performance to date of the finished roadway shows the recycled pavement to be performing well.

TABLE B7

RECOVERED ASPHALT CEMENT PROPERTIES*

Asphalt Surface Treatment

	Viscosity @ 140°F, poises	Penetration @ 77°F
	24,062	34
	25,376	34
	35,449	30
Ave. =	28,296	

Final Recycled Mix

	Viscosity @ 140°F, poises	Penetration @ 77°F
	7,898	48
	8,198	48
	9,802	43
Ave. =	8,632	

*Average viscosity of final recycled mix is very close to a value capable of being predicted from a beforehand knowledge of the quantity and quality of the blended asphalts. For this project, the predicted value is shown below:

Quantity of Blended Asphalts

Basis: 100 lbs. of final mix
Total asphalt in final mix = 100 x 4.8% = 4.8 lbs.
Total aggregate in final mix = 100 - 4.8 = 95.2 lbs.
Asphalt surface treatment in mix = 95.2 x 25% = 23.8 lbs.
Asphalt in surface treatment = 23.8 x 3.6% = 0.86 lbs.
New asphalt in final mix = 4.8 - 0.86 = 3.94 lbs.

Quality of Blended Asphalts

Viscosity of asphalt surface treatment asphalt = 28,296 poises
Viscosity of new AC-30 asphalt = 3,000 poises

Prediction Based on Referenced (1) Formula

Log(Log V) = a + bp where V = viscosity, in centipoises and p = % of lower viscosity material in final blend

Log(Log 2,829,600) = a + b(o)
a = .81
Log(Log 300,000) = .81 + b(100)
b = -.0007

for our project, with $p = \frac{3.94}{4.80} = 82\%$

Log(Log V) = .81 - .0007(82)
V = 4,383 poises

This predicted viscosity is before any aging associated with plant mixing. Thus, assuming an aging index of 2, the final predicted mix viscosity would be 2(4,383) = 8,766 poises.

TABLE B8

DEFLECTION READINGS ON LA. 621

Date	DMD*	% Spread	SN
May, 1979	1.54	57	1.10
August, 1979	1.23	54	1.17
April, 1980	1.36	56	1.17

*Dynaflect Maximum Deflection, inches x 10^{-3}; corrected to 60°F.

Economic Analysis

No economic evaluation is presented to cover the recycled mix produced using both the existing asphalt surface treatment and the existing sand-clay-gravel base. This combination was discontinued during the project as the sand-clay-gravel became unsuitable for use after frequent heavy rains. The use of sand-clay-gravel in the future in the hot plant recycling mode would probably be restricted due to the experience gained through this project. An economic evaluation of materials is presented in Table B9 for the removal of 2 inches of asphalt surface treatment on a project of this quantity, using this project's actual bid prices. As shown, there exists an overall savings of $23,445 or $0.75 per ton. This savings, using current prices, would be over $1.00 per ton for a dryer-drum plant, assuming no reduction in plant operating capacity. The overall production cost savings for a batch plant would be slightly less than $1.00 per ton, considering the increased production cost associated with a longer batch cycle.

TABLE B9

MATERIAL ECONOMIC ANALYSIS

	Conventional	Recycled
Tons of Production	31,094	31,094
Tons of Asphalt @ 4.8%	1,493	1,493
Tons of Aggregate	29,601	29,601
Tons of Surface Treatment Aggregate (25% of 29,601)		7,400
Tons of Asphalt in Surface Treatment (3.6% of 7,400)		266
Tons of New Asphalt	1,493	1,227
Tons of New Aggregate	29,601	22,201

COST*

Item	Conventional	Recycled
Asphalt Cement	$134,370	$110,430
Aggregate	192,406	144,306
Milling	0	48,595
Balance	$326,776	$303,331
Savings		$ 23,445

*Asphalt @ $90/ton
Aggregate @ $6.50/ton
Milling @ $0.65/yd^2 (74,762 yd^2 milled)

Energy Conservation

The amount of energy required to produce and haul the aggregates and asphalt that were replaced by the asphalt surface treatment material is computed in Table B10. The energy required for the milling operation is not included in these calculations as it has been previously shown, in this report's batch plant discussion, to be insignificant. As shown in the table, a total savings of 1.9×10^8 BTU's is provided. This savings is equivalent to 15,310 gallons of gasoline.

TABLE B10

ENERGY SAVINGS OF SURFACE TREATMENT RECYCLED MIX

Quantity of Material That Was Replaced by Reclaimed Material*

Aggregate:	7,400 tons
	Gravel = 4,440 tons**
	Sand = 2,960 tons
Asphalt:	266 tons

Energy Required to Produce and Haul These Materials***

Produce gravel	35,700 BTU/ton
Haul 50 miles x 2 @ 1,960 BTU/ton	196,000 BTU/ton
	231,700 BTU/ton
Produce sand	15,000 BTU/ton
Haul 50 miles x 2 @ 1,960 BTU/ton	196,000 BTU/ton
	211,000 BTU/ton
Manufacture asphalt cement	587,000 BTU/ton
Haul 100 miles x 2 @ 1,960 BTU/ton	392,000 BTU/ton
	979,000 BTU/ton

Energy Savings

Gravel:	4,440 tons @ 231,700 BTU/ton	1,028,748,000 BTU
Sand:	2,960 tons @ 211,000 BTU/ton	624,560,000 BTU
Asphalt:	266 tons @ 979,000 BTU/ton	260,414,000 BTU
		1,913,722,000 BTU
	or (@ 125,000 BTU/gal.)	15,310 gals. gas

*From Table B9.

**Assume 60% gravel, 40% sand mix.

***Source of BTU/ton information (3).

SUMMARY AND CONCLUSIONS

The technological feasibility of producing a recycled asphaltic concrete in both a batch plant and a dryer-drum plant has been verified by the two projects evaluated in this study. Material test results for both projects indicated that the final recycled mixtures exhibited properties similar to conventional paving mixtures. The economics and material and energy conservation aspects for both projects were favorable.

The following specific conclusions are warranted based on the results of this study:

1. A recycled mix comprised of up to 70 percent old asphaltic material can be produced in a batch plant modified to permit the necessary heat transfer process.

2. A slight decrease in production capability is experienced when a recycled mix is produced in a modified batch plant. Batch cycle lengths must be increased to allow for heat transfer between virgin and reclaimed material; such increases will vary depending on the ratio of reclaimed to virgin materials.

3. A "sandwiching" of the reclaimed asphalt material in a batch plant's weigh bin can reduce "bridging" or "fluffing" thus assuring rated plant capacity (pounds per batch).

4. The use of a cold milling machine for removal of existing asphaltic material produces material that is suitable for hot plant recycling without further size reduction.

5. The viscosity of the asphalt cement in a recycled mix can be closely approximated from a knowledge of the quantity and viscosity of both the reclaimed asphalt cement and the virgin asphalt cement.

6. The viscosity of a limited quantity of an aged asphalt cement can be adequately modified through the addition of new asphalt cement without the use of a rejuvenating agent.

7. The removal and hot plant recycling of a sand-clay-gravel base material is not structurally or technically feasible.

RECOMMENDATIONS

Based upon the shown capability of both a batch plant and a dryer-drum plant to produce an acceptable quality recycled mix, it is recommended that the Department consider appropriate means to further the development of the recycling concept. It is believed that specifications can be developed which will permit the substitution of a recycled hot mix for a conventional hot mix. With the development of such specifications, it would additionally seem appropriate that on those projects where a leveling operation is necessary, and where anticipated haul costs will not be excessive, removal to slope and grade by cold milling be specified with the removed material being the property of the contractor. The assumption being that with a specification allowing the use of this removed material in hot mix construction, the salvage value of milled material will eventually be realized by the Department in more competitive, lower bid prices for asphaltic concrete. It may, however, be necessary for the Department to design a number of specific hot plant recycling projects to insure initial acceptance of and confidence in the recycling process by a cross section of our contractors.

REFERENCES

1. Davidson, D. D., Canessa, W., Escobar, S. J., "Practical Aspects of Reconstituting Deteriorated Bituminous Pavements," STP662, ASTM, November, 1978.

2. Kinchen, R. W., and Temple, W. H., Asphaltic Concrete Overlays of Rigid and Flexible Pavements "Interim Report No. 1," Louisiana Department of Transportation and Development, Research Report No. 109, April, 1977.

3. "Energy Requirements for Roadway Pavements," The Asphalt Institute, MISC-75-3, April, 1975.

APPENDIX

U.S. 84
STATE PROJECT NO. 22-01-06
SPECIAL PROVISIONS

ITEMS S-1 THROUGH S-5, RECYCLING OPERATIONS: These items consist of removing existing asphaltic concrete surfacing, grading the removed materials, furnishing additional materials as required, mixing the removed materials and new materials in either a dryer-drum or batch plant, and placing the recycled asphaltic concrete mixture on the roadway.

Removal of Asphaltic Concrete Surfacing: The existing asphaltic concrete surfacing shall be removed by approved methods to the required depth and cross slope, crushed as required to pass a 2" sieve (or as otherwise directed by the engineer), and stockpiled separate from other materials at the hot mix plant.

Additional Materials: The contractor shall furnish additional aggregates, asphalt and mineral filler as required for the recycled mixture. The quantities of additional materials required will be determined by the engineer.

(a) Asphalt: The asphalt used in the mixture shall be asphalt cement Grade AC 30 conforming to Section 1002 of the Standard Specifications.

(b) Aggregates: Additional aggregates shall conform to Subsection 1003.07(a) and shall consist of crushed gravel and sand. These aggregates shall be stockpiled separate from other materials at the plant.

(c) Mineral Filler: Mineral filler shall conform to Subsection 1003.07(f).

Recycled Asphaltic Concrete: The mixing and placement of the recycled materials on the roadway shall conform to Section 501 with the following modifications. Mixing shall be performed in either a batch plant or a dryer-drum plant; however, the plant shall be modified as required to permit recycling operations in conformance with all air pollution standards. Both plants shall be equipped with an approved printer system which will print separately the weight of heated aggregates, mineral filler and asphalt used. For dryer-drum plants, a separate cold feed system, including weight indicating apparatus, shall be provided for the recycled material.

It is anticipated that equal proportions of removed materials and new materials will produce the recycled mixture required. The new aggregates shall be dried and heated to a sufficiently high temperature to produce a recycled mixture with a discharge temperature of at least 225°F or as approved by the engineer. The asphaltic surfacing materials to be recycled shall be added to the heated aggregates in the weigh bin at a rate that will minimize heat loss and provide for efficient plant operation. The surfacing materials to be recycled shall not be preheated prior to being added to the weigh bin. In a batch plant, the combined aggregates shall be mixed in the pugmill for approximately 20 seconds, after which the aggregates shall be sprayed with the asphalt and mixed for approximately 30 seconds more.

The recycled mixture shall be delivered to the project and placed with conventional self-powered spreading and finishing machines equipped with automatic screed and slope control devices used with a 30-foot traveling stringline. Asphaltic tack coat shall be applied to the pavement surface prior to placing the recycled mix and also between lifts of recycled mix.

The recycled mixture shall conform to the control requirements for Type 1 Wearing Course. Price adjustments as specified in Subsection 501.25 for deficiencies in stability, density, surface tolerance and aggregate gradation will not be applied to the recycled asphaltic concrete mixtures.

Recycled mixtures that are deemed by the engineer to be unusable shall be disposed of by the contractor and full payment will be made for the wasted quantity of recycled asphaltic concrete, provided the mixture was not rendered unusable due to the contractor's negligence. No payment will be made under Items S-2 through S-5 for recycled mixtures that are wasted due to the contractor's negligence. Any removed materials not recycled shall become the property of the contractor and shall be disposed of by him at his own expense.

Measurement:

(a) Removal of Asphaltic Concrete: Measurement will be made by the square yard of existing asphaltic concrete surfacing removed. Payment will include removing and delivering the asphaltic concrete materials to the plant, and crushing the materials as required.

(b) Additional Materials: Asphalt cement, mineral filler and additional aggregates used in the recycled mix will each be measured by the ton (2,000 pounds). The quantities of additional aggregates will be based upon cold feed measurements for dryer-drum plants and printed weights for batch plants.

(c) Recycled Asphaltic Concrete: Measurement will be made by the ton (2,000 pounds) of recycled asphaltic mix. Payment will include all required plant operations, delivering the mix to the job site, furnishing and applying asphaltic tack coat, and spreading and compaction operations.

Payment: Payment for the accepted quantities of the various items comprising the recycling work will be made at the contract unit prices under:

Item S-1, Removal of Asphaltic Concrete, per square yard.
Item S-2, Asphalt Cement (AC 30), per ton.
Item S-3, Additional Aggregates, per ton.
Item S-4, Mineral Filler, per ton.
Item S-5, Recycled Asphaltic Concrete, per ton.

ITEMS S-1 THRU S-6, RECYCLING OPERATIONS: These items consist of removing existing surfacing and base course materials; grading the removed materials; furnishing additional materials as required; mixing the removed materials and new materials in either a dryer-drum or batch plant; shaping and compacting the roadbed; and placing the recycled asphaltic concrete mixture on the roadbed.

Removing Surfacing and Base Course: The existing asphaltic surfacing materials shall be removed by approved methods, crushed as required to pass a 2" sieve (or as otherwise directed by the engineer), and stockpiled separate from other materials at the hot mix plant.

After removal of the asphaltic surfacing, the sand clay gravel base course materials shall be removed to the required depth. All removed base course materials shall be screened on a No. 4 sieve at the cold feed. Material retained on the No. 4 sieve (+4 material) shall be crushed to approximate the gradation shown in Table A herein. Batch plants will be permitted to crush the base course materials first and screen the crushed material on the No. 4 sieve at the top of the hot bins.

Base course materials remaining on the roadbed shall be shaped to the required section, uniformly compacted by approved methods to the satisfaction of the engineer and primed (if deemed necessary by the engineer) in accordance with Section 504 of the Standard Specifications.

After start-up of plant recycling operations, the contractor will be permitted to use the same trucks for hauling the recycled mix to the job site and hauling the removed base course materials from the job site on the return trip to the plant.

Any existing materials that cannot be satisfactorily recycled shall be removed and disposed of outside the right of way by the contractor.

Additional Materials: The contractor shall furnish additional aggregates, asphalt and mineral filler as required for the recycled mixture. The quantities of additional materials required will be determined by the engineer.

(a) Asphalt: The asphalt used in the mixture shall be asphalt cement Grade AC 20 conforming to Section 1002.

(b) Aggregates: Additional aggregates shall conform to Subsection 1003.07(a) and shall consist of crushed gravel and (if required) sand. These aggregates shall be stockpiled separate from other materials at the plant.

(c) Mineral Filler: Mineral filler shall conform to Subsection 1003.07(f).

Recycled Asphaltic Concrete: The mixing and placement of the recycled materials on the roadbed shall conform to Section 501 with the following modifications. Mixing shall be performed in either a batch plant or a dryer-drum plant; however, the plant shall be modified as required to permit recycling operations in conformance with all air pollution standards. Batch plants shall be equipped with an approved printer system which will print separately the weight of heated aggregates, mineral filler and asphalt used. For dryer-drum plants, a separate cold feed system, including weight indicating apparatus, shall be provided for the recycled material.

The anticipated gradations and recommended mix percentages of the aggregates to be used in the recycled mix are shown in Table A herein and are based on preliminary sampling.

TABLE A - AGGREGATE GRADATION
(% Passing by Weight)

U.S. Sieve	Asphaltic Surfacing	Crushed +4 Base Course	-4 Base Course	New Aggregate	Recycled Mix
1"	100	100	100	100	100
3/4"	99	98	100	99	99
1/2"	89	82	100	91	90
3/8"	76	65	100	74	77
No. 4	53	20	100	37	48
No. 10	34	10	87	19	32
No. 40	20	5	58	7	19
No. 80	11	2	44	3	12
No. 200	8	0	37	2	9
Mix Design:	33%	22%	15%	30%	

The base course materials and additional aggregates shall be dried and heated to a sufficiently high temperature to produce a recycled mixture with a discharge temperature of at least 225°F or as approved by the engineer. The asphaltic surfacing materials to be recycled shall be added to the heated aggregates in the weight bin at a rate that will minimize heat loss and provide for efficient plant operation. The surfacing materials to be recycled shall not be preheated prior to being added to the weigh bin. In a batch plant, the combined aggregates shall be mixed in the pugmill for approximately 20 seconds, after which the aggregates shall be sprayed with the asphalt cement and mixed for approximately 30 seconds more.

The recycled mixture shall be delivered to the project and placed with conventional self-powered spreading and finishing machines equipped with automatic screed and slope control devices used with a 30-foot traveling stringline. Asphaltic tack coat shall be applied to the pavement surface prior to placing the recycled mix and also between lifts of recycled mix.

For control purposes, the recycled mix shall meet the gradation requirements for Type 1 Wearing Course. Other mix requirements such as mineral filler content, percent crushed, voids, VFA, etc. will be subject to the engineer's approval. Price adjustments as specified in Subsection 501.25 for deficiencies in stability, density, surface tolerance and aggregate gradation will not be applied to the recycled asphaltic concrete mixtures.

Recycled mixtures that are deemed by the engineer to be unusable shall be disposed of by the contractor and full payment will be made for the wasted quantity of recycled asphaltic concrete, provided the mixture was not rendered unusable due to the contractor's negligence. No payment will be made under Item S-3 thru S-6 for recycled mixtures that are wasted due to the contractor's negligence. Any removed materials not recycled shall become the property of the contractor and shall be disposed of by him at his own expense.

Measurement:

(a) Removal of Surfacing: Measurement will be made by the square yard of existing surfacing removed. Payment will include removing and delivering the surfacing materials to the plant, and crushing the materials as required.

(b) Removal of Base Course: Measurement will be made by the square yard of existing base course removed. Payment will include removing and delivering the materials to the plant, screening and crushing the materials as required, and shaping and compacting the roadbed as required after removal of the base course materials.

(c) Asphalt Cement: Measurement will be made by the ton (2,000 pounds) of asphalt used in the recycled mix.

(d) Additional Aggregates: Measurement will be made by the ton (2,000 pounds) of additional aggregates used in the recycled mix. For dryer-drum plants, measurement will be based on cold feed percentages; for batch plants, measurement will be based on the percentage of new aggregates (determined at the cold feed) in the total printed weight of heated aggregates.

(e) Mineral Filler: Measurement will be made by the ton (2,000 pounds) of mineral filler used in the recycled mix.

(f) Recycled Asphaltic Concrete: Measurement will be made by the ton (2,000 pounds) of recycled asphaltic mix and payment will include all required plant operations, delivering the mix to the job site, furnishing and applying asphaltic tack coat, and spreading and compaction operations.

Payment: Payment for the accepted quantities of the various items comprising the recycling work will be made at the contract unit prices under:

Item S-1, Removal of Surfacing, per square yard.
Item S-2, Removal of Base Course, per square yard.
Item S-3, Asphalt Cement (AC 20), per ton.
Item S-4, Additional Aggregates, per ton.
Item S-5, Mineral Filler, per ton.
Item S-6, Recycled Asphaltic Concrete, per ton.