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DEMONSTRATION PROJECT NO. 39

RECYCLING ASPHALT PAVEMENTS

Gold Run, California

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REPORT NO. FHWA-CA-TL-79-08

RECYCLING ASPHALT CONCRETE ON INTERSTATE 80

INTERIM REPORT

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This report was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report documents the asphalt concrete recycling activity on State Contract No. 03-205404. This was the first "hot mix" asphalt concrete recycling project accomplished by the California Department of Transportation utilizing a central plant. The recycling was confined to the outer shoulders and freeway ramps. The project was located in Placer and Nevada Counties, about 18 miles east of Colfax, and extended from 0.4 mile west of the Gold Run Overcrossing to 0.7 mile west of the Hampshire Rocks Undercrossing, a distance of approximately 24 miles.

A cold planer (Roto-Mill) was used to mill the asphalt concrete from the shoulders for recycling, and a dryer-drum was converted by CMI for preparation of the mix. A total of 43,000 tons of AC was removed and approximately 22,000 tons of this material was combined with approximately 21,000 tons of new aggregate to accomplish the recycling. Although the recycled mix was somewhat difficult to work by hand, its overall handling, appearance, and initial performance characteristics were generally similar to that of a new asphalt concrete and its use resulted in an economic and energy savings when compared with the use of new AC.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Recycled AC, asphalt concrete, salvaged AC, reclaimed AC, cold planer, CMI, dryer-drum, shoulders.	No restrictions.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

April 1979

FHWA No. G-2-14
TL No. 633159

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this interim research project report titled:

RECYCLING ASPHALT CONCRETE ON INTERSTATE 80

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . Donald L. Spellman, P.E.

Principal Investigator . . . . . Robert N. Doty, P.E.

Co-Investigator . . . . Thomas Scrimsher, P.E.

Report Prepared by . . . . Robert N. Doty
and
Thomas Scrimsher

Very truly yours,

Neal Andersen

NEAL ANDERSEN, P.E.
Chief, Office of Transportation Laboratory

Attachment
RND/TS:cj

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Mr. L. J. Trombatore, District Director - District 03 and his staff and particularly to the following personnel for their cooperation in furnishing data and information for this report:

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District Construction Engineer - Tom Lund
Project Resident Engineer - Ken Bousfield
Project Assistant R.E. - Joe Ferron
Project Office Engineer - Lee Roberts
Project Materials Testing - Leo Hogan
Project Plant Inspector - Phil Corbin
District Materials Engineer - Bob Coleman
District Project Engineer - Art Nelson
District Asst. Materials Engineer - Dick Townsend

In addition, appreciation is expressed to the contractor, Bob O'Hair, and his men for their cooperation, and also to the following TransLab personnel who contributed to this project: Joe Palen (who gathered and reported the energy data), John Apostolos, Ken Pinkerman, and Orvis Box of the Environmental/Chemical Branch, TransLab photographer Bob Mortensen of the Engineering, Administration, and Services Branch, and Glenn Kemp, James Cechetini, Jim Matthews, Ron Morrison, Ken Iwasaki and Al Rybicki of the Roadbed & Concrete Branch. In addition, appreciation is extended to Mrs. Carol Johnson and Ms. Eileen Howe for their typing and editorial assistance.

[redacted]

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph)	.4470	metres per second (m/s)
	feet per second(fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs)	4.448	newtons(N)
	kips (1000 lbs)	4.448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1.356	joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds(ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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INTRODUCTION

Inflation, the decreasing availability of good quality aggregate, the possibility of a severe asphalt shortage if another petroleum embargo occurs, and the pressure to use gasoline tax funds for efforts other than roadway construction, rehabilitation, and maintenance have all contributed to the current critical problems regarding highways. If a substantial portion of the existing pavement exhibiting major distress could be recycled, this would alleviate, at least to some extent, these problems in that recycling old worn-out pavements potentially can save money, conserve resources, and reduce energy consumption.

Several processes have been developed and are now being used to recycle asphalt concrete pavement. In an attempt to acquire some experience with hot, central plant recycling of asphalt concrete, the AC shoulders and ramps on a twenty-four mile length of Interstate 80 on the western side of the Sierra Nevada mountain range were recycled during the summer and fall of 1978. This report contains the results of the preliminary laboratory mix design work as well as a description of the actual construction process used and the results thereof.

SUMMARY AND CONCLUSIONS

California's first attempt at "hot mix" asphalt concre recycling appears to have been successful from the star point of production and construction. A few test resul indicated some of the recycled mix had low stabilometer values due to excess asphalt; however, from the standpo of performance, the additional asphalt may eventually prove to be an asset. This mix was placed in the shoul area (some in ramps). Due to a lack of continuous traf the durability and life span may actually be enhanced b higher asphalt contents. Oxidation and hardening of the asphalt film is usually more rapid in shoulders due to the lack of traffic sealing. Also, due to the lack of sustained traffic, it is doubtful that rutting or pushin will occur.

In general, the following observations and conclusions have been drawn from this experimental project:

(1) The C.M.I. method of conversion of the dryer-drum for recycling appeared entirely adequate.

(2) The cost of production compares favorably with a conventional dryer-drum mixing process.

(3) Final mix temperatures of 260-300°F can be obtained without undue air pollution if outside California non-attainment areas.

(4) The hardness of the asphalt in the recycled mix was considerably less than that of the asphalt in the salvage AC (pen. was increased from 16 - 36 with addition of AR2000 with the virgin aggregate).

(5) Placing salvaged asphalt concrete in stockpiles no higher than 10' will prevent consolidation prior to use when fairly hard salvaged AC is stored for a short time in a moderate climate.

(6) The addition of water to the salvaged asphalt concrete during production at the plant appeared to reduce the air pollution slightly.

(7) Both the 50-50 mix and the mix with 70% salvaged asphalt concrete and 30% virgin aggregate mixed and placed well and visually appeared to be identical. The appearance of both was identical to that of conventional mix.

(8) The Roto-Mill cold planer does an excellent job of removing asphalt concrete. The conical shaped tooth proved far superior to the wedge type of tooth. About 10% oversize (+1") material was generated by the Roto-Mill process.

(9) Placing and compacting recycled mix can be accomplished using the same machines and procedures used for a conventional mix.

(10) At temperatures below 250°F, the recycled mix was extremely hard to rake (gummy) and resulted in the occasional formation of poor joints.

(11) The skid properties and density of recycled AC compare favorable with those of conventional mixes.

(12) It appeared that some degradation may have occurred in the field, either in the virgin aggregate or the recycled mix. Most field data indicates more material passing the #200 sieve than was indicated in preliminary design tests.

(13) The amount of "new" materials used can be decreased by recycling. This results in a savings of asphalt, virg aggregate, and the total fuel oil needed to produce and d virgin aggregate.

(14) A construction energy savings of approximately 15% is possible when recycling existing AC as part of a remove-and-replace operation.

(15) There is a need for additional studies comparing lab mixing procedures with actual field test results for recovered asphalt properties.

(16) A requirement of a standard form for fuel supplies and consumption should be included in future contracts involving recycling research to permit more accurate energy calculations.

IMPLEMENTATION

Central plant recycling appeared to be successful. The concept using a dryer-drum appears feasible. With some refinements concerning production and air pollution, it should be considered in future recycling studies as a viable method of recycling. Further experimental use of central plant recycling is recommended.

DISCUSSION

(A) Preliminary Investigation

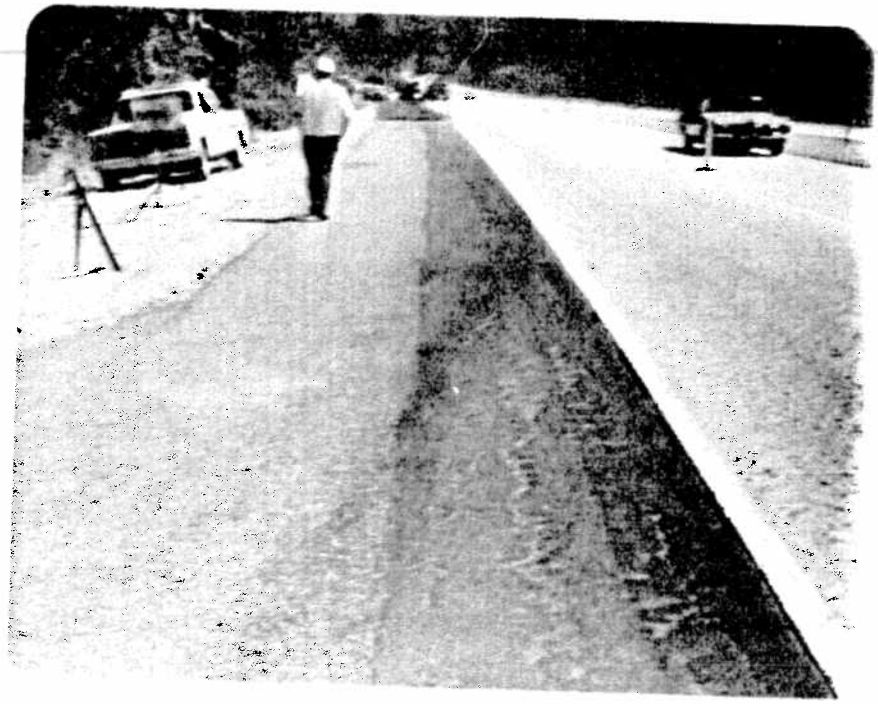
This project (Contract No. 03-205404) was located in Caltrans' District 03 with headquarters in Marysville The existing highway was constructed in the late 1950 and early 1960's under several different contracts. The highway was constructed to freeway standards and generally consists of 4 lanes of PCC pavement with 10-foot outside and 4-foot inside AC shoulders. The median varies in width, and in some areas the roadway is split, forming two roadways. Specifically, it is in Placer and Nevada Counties, about 18 miles east of Colfax, from 0.4 miles west of the Gold Run Overcross to 0.7 miles west of the Hampshire Rocks Undercrossin Interstate 80. The identifying post miles are: Pla-8 41.0/R58.7, Nev-80-R58.7/R62.7, and Pla-80-R62.7/R65. The total length of the project was 24.5 miles.

The project is located in the snow belt of the Sierra Nevada Mountains at an elevation of about 3000' at the lower (west) end and 5000' at the upper (east) end. The pavement is subjected to air temperatures of from 10°F± in the winter to 90°F± during the summer. The m annual snowfall within the limits of this job varies from 24"± at the west end to 200"± at the east end. During the winter months, traffic uses the shoulder ar frequently for applying and removing tire chains. The design traffic for the project was:

1976 ADT = 17,200	Trucks = 3%
1996 ADT = 32,300	

The structural sections consisted generally of 0.67' PCC, 0.33' CTB, and 1.0' of aggregate subbase (ASB) on the traveled way, and 0.25' AC, 0.5' CTB, and 1.25' ASB on the shoulders. Although CTB is not generally used beneath AC shoulders, it was used in this case because it was anticipated that more traffic than usual would be using the shoulders due to frequent chain requirements at this location. The on- and off-ramps were constructed with 0.25' AC, 0.75' AB, and 1.0' ASB.

As of 1977, the shoulders and ramps were suffering from deterioration (Figure 1) and were requiring extensive maintenance efforts. This was due to the adverse environment, loading from snow removal and other maintenance equipment (particularly in wet weather) and age. Major structural damage was occurring which resulted in cracking in the outer shoulder and cracking and wheel-track rutting on the ramps. Pavement deformation was also occurring on the inner shoulders. A PSR rating of 1.9-2.0 was estimated by Mr. Harold Schmitt of the FHWA (California Division). Pavement deflection was measured with a Dynaflect and these measurements then converted to equivalent Deflectometer deflections. The average "equivalent" deflection for the eastbound outside shoulder was 0.011 inch with equivalent values ranging from 0.001 inch to 0.031 inch. Equivalent deflections on the westbound right shoulder averaged 0.007 inch and ranged from 0.001 inch to 0.024 inch (tabulated data is located in the appendix - Table A-1).



Deteriorated Shoulder to be Recycled
Figure 1

A preliminary comparative cost analysis was completed to estimate the potential savings of mandatory recycling of a portion of the distressed AC. For the recycling analysis, it was assumed that 40% of the recycled mix would consist of salvaged AC and 60% would consist of new aggregate and asphalt. This comparison is shown below:

Process or Material	100% New AC (Estimated Cost per sy)	60% New AC and 40% Salvaged AC (Estimated Cost per sy)
Remove and dispose @ $6/cy	$0.50	$0.30
Salvaged AC		
Removal @ $3/cy	-	0.10
Transport to plant @ 15¢/ton mile	-	0.19
Crush @ $2/ton	-	0.13
Mix, haul, & place @ $14/ton	-	0.90
New AC @ $18/ton	2.88	1.73
Tack coat	0.12	0.12
Total	$3.50 per sy	$3.46 per sy

The results of this analysis indicated that no substantial savings would be realized by recycling a portion of the distressed AC. However, the results also indicated that recycling would be competitive, and that if a 50:50 combination of new aggregate and salvaged AC were used, the potential economic advantage of recycling would increase somewhat. Because the results of research reported by other agencies indicated that a 50:50 blend would provide sufficient virgin aggregate for the necessary heat transfer to the salvaged AC in the mixer, the decision was made to require recycling using a (nominal) 50:50 blend.

(B) Project Mix Design Criteria/Procedure

Numerous cores were taken from several locations withi the job limits to encompass all of the six contracts included in the original construction. This asphalt concrete (hereafter referred to as the salvaged AC) was checked for gradation "as received". The asphalt conte of the salvaged AC was measured. Also, some asphalt fr the mix to be recycled was recovered and tested for viscosity.

The use of recycling agents in lieu of or in addition t paving grade asphalt was considered. Due to the additi cost and, in some cases, the additional complexity of using recycling agents, the preliminary mix design work was completed using only paving grade asphalt. Use of the softest conventional AR grade of asphalt (AR-1000) seemed to offer the best possibility of softening and rejuvenating the aged asphalt in the salvaged AC. Howev reports from Oregon and others indicated the lightest grade that could be used without running the risk of excessive smoke and air pollution would be AR-2000. In addition, AR-2000 is sometimes used for fall paving in the Sierra Nevada Mountain region. Thus, the grade of asphalt selected for this project was AR-2000.

Findings from recycling projects in other states such as Washington and Minnesota(1,3) revealed that air pollution problems could probably be minimized if heating of the salvaged AC was done via heat transfer from hot virgin aggregate. Thus, because experience reported by others seemed to indicate that at least 50% virgin aggregate would be required for this heat transfer if a batch plant were used, a recycled mix consisting of 50% salvaged AC and 50% virgin aggregate was selected to permit the use of a batch plant or a drum mixer. The gradation selected for the virgin aggregate was a 1/2" max. medium grading per the January 1978 Standard Specification of the California Department of Transportation. This size was selected because it had been used with success in other (surface) recycling activity and the grading provides the dense surface considered desirable for shoulders. Aggregate complying with this gradation from a source in the Sacramento area was used for the preliminary mix design work.

The asphalt demand of the virgin aggregate was established using standard design methods and then adjusted for the recycled mix in relation to the amount of virgin aggregate proposed for use. It was felt that heating salvaged AC in the lab and mixing this material with hot virgin aggregate in a manner somewhat similar to actual field operation would be the most appropriate mixing procedure so laboratory mechanical mixers (Figure 2) were used. This also made it possible to observe any mixing difficulties. The following laboratory procedure was used for the preliminary mix design work:

(A) Mixing

(1) Heat virgin aggregate to 400°F

(2) Heat asphalt to 300°F

(3) Preheat mechanical mixing pots to 300°F

(4) Maintain salvaged AC at room temperature

(5) Place heated aggregate and salvaged AC in preheated mixing pot.

(6) Add desired amount of new asphalt

(7) Mix for 2 minutes

(8) Place the loose mix in a 1"x7"x11" pan and cure at 140°F overnight (15-20 hrs).

(B) Compaction Procedure

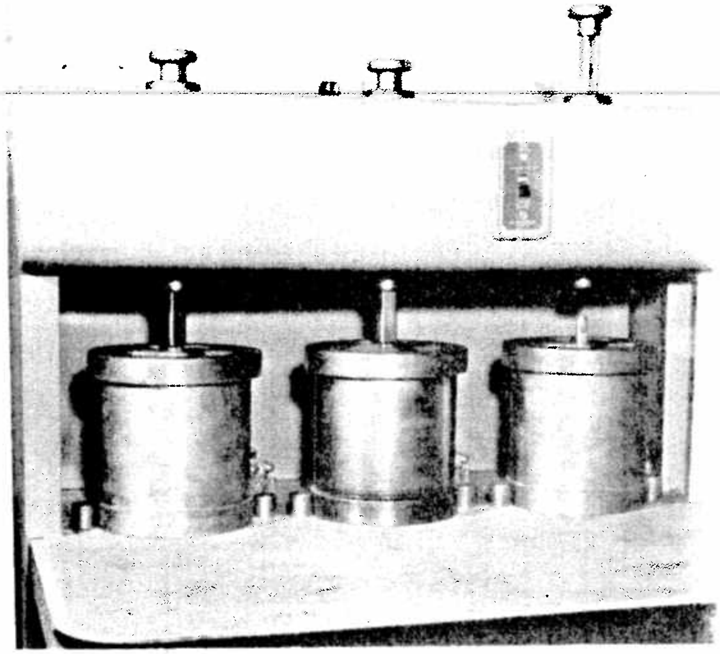
(1) Remove the mix from 140°F oven after the overnight cure and place in a 230°F oven for 1-1/2 hours.

(2) Compact using the kneading compactor- with a foot pressure of 500 psi (150 blows)(Figure 3).

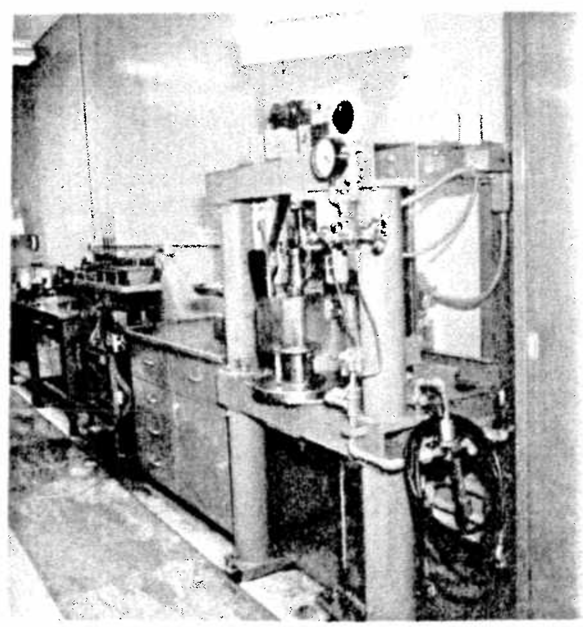
(3) Apply a static 1000 psi load for levelin the specimen.

(C) Testing

Stabilometer and Cohesiometer Tests	-	Heat at 140°F for 2 hours prior to test.
Modulus of Resilience (Mr) & Specific Gravity (sp. gr.)	-	Remove from mold ar set overnight at rc temperature. Test room temperature (78° ±2°F).



Laboratory Mechanical Mixers
Figure 2



California Kneading Compactor
Figure 3

To determine the optimum asphalt content for the recyc mix, several samples were prepared. Having already established the asphalt demand of the virgin aggregate using conventional Caltrans procedures, a starting poi was established for the amount needed for the entire recycled mix. Additional samples containing asphalt contents above and below this starting point in 0.5% increments were prepared and tested. The test results were studied along with visual inspection of each test specimen and the optimum asphalt content then establish

The 50:50 mix worked very well in the laboratory. In general, the laboratory test results indicated that the optimum asphalt content (new asphalt) for the 50:50 mix was 3.7% when using 1/2" max. salvaged AC and 2.7% when using 3/4" max. salvaged AC. This resulted in total asphalt contents of approximately 5.9% and yielded mixes with stabilometer values of 40-41 and void contents of 4.7%±.

The design criteria was based upon the philosophy that the selected process would ultimately be used to design pavements for the traveled way. Thus, although the recycling on this project was confined to ramps and shoulders, the basic requirements, as far as stability and other conventional AC pavement design requirements, were adhered to.

(C) <u>Construction Specifications</u>

Based upon the considerations and test results presented above, contract specifications were prepared containing the following features:

1. The recycled AC shall consist of a mixture of cold salvaged AC, hot 1/2" max. medium Type B AC aggregate, and hot AR-2000 paving grade asphalt.

2. The gradation of the salvaged AC shall be reasonably uniform with 100% passing the 1-inch sieve.

3. The recycled AC shall be mixed in either a batch plant or a dryer-drum type plant.

4. The amount of new aggregate shall be between 45 and 55 percent of the total weight of the combined material.

5. If a batch plant is used, the preheated hot new aggregate shall be mixed dry with the cold salvaged AC for a minimum of 20 seconds followed by the addition of the AR-2000 asphalt and a subsequent mixing period of 30 seconds minimum.

6. If a drum mixer is used, the salvaged AC shall be introduced into the dryer-drum and combined with the new aggregate in such a manner that the salvaged asphalt concrete is protected from direct contact with the burner flame by a positive protective device such as a shield, separator, second drum, or other device acceptable to the engineer.

7. The first breakdown coverage by the roller shall be performed when the temperature of the mixture is not less than 230°F.

See the Appendix for a copy of portions of the actual special provisions for this contract.

A bid summary including the engineer's estimate is presented as Table 1. Analysis of these bids indicat that the cost of using salvaged AC in recycled AC in lieu of 100 percent new mix resulted in a savings of approximately $169,000 for the 43,365 tons of recycle AC placed on this project. This was based on compara costs of $12.91 per ton for recycled AC containing 3. new asphalt (by weight of new aggregate plus salvaged AC) versus $16.81 per ton for new AC containing 6% asphalt. Those values were calculated as follows usi bid item costs from Table 1:

	Cost Per Ton of Mix			
Material	Recycled AC		New AC	
Aggregate	(0.965)($9.75)=	$ 9.41	(0.94)($11.50)=	$1
Asphalt	(0.035)($100.00)=	3.50	(0.06)($100.00)=	
	Total	$12.91		$1

A preconstruction conference with the contractor was on June 13, 1978. Cold planing was started on June 1 1978, and the first mix, a conventional 1/2" max. all virgin aggregate mixture used as a control, was place on August 11, 1978. The first recycled mix was produc and placed on August 15, 1978. Paving for the projec was completed in October 1978.

(D) AC Removal

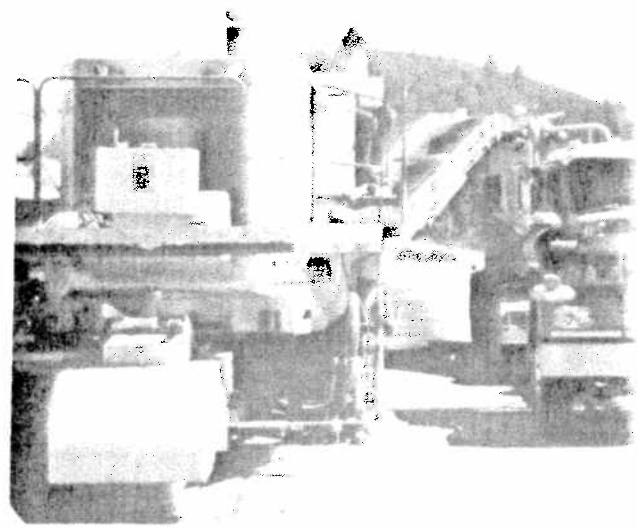
The contractor elected to use the CMI cold planer (Rot Mill) for removal of the top 0.1' of the 10-foot wide shoulder (Figure 4). The Roto-Mill used was a Model PR-750 which has a 12.5' wide mandrel. However, only

TABLE 1

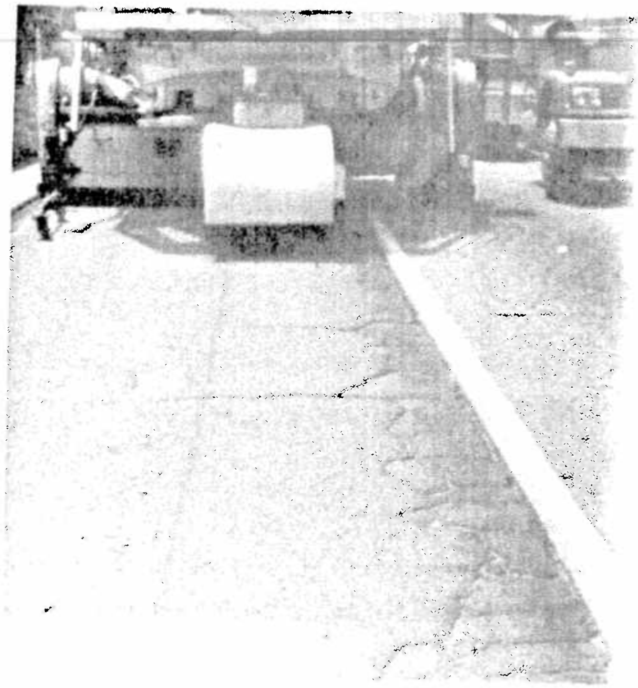
BID SUMMARY

Item No.	Item Description	Unit of Measure	Estimated Quantity	Engineers Estimate	Bid #1	Bid #2	Bid #3
1	Remove asphalt concrete (0.25' thick)	CY	13,500	$ 6.00	$ 18.50	$ 11.80	$ 14.00
2	Remove asphalt concrete (0.10' thick)	SQYD	179,500	0.60	1.35	0.75	0.95
3	Remodel inlet	EA	73	8.00	450.00	900.00	700.00
4	Agg. (Type B-AC-1/2" max. grading)	TON	730	17.00	11.50	17.40	20.00
5	Paving asphalt (asphalt concrete)	TON	1,500	80.00	100.00	119.00	90.00
6	Recycle asphalt concrete	TON	44,000	15.00	9.75	14.70	17.35
7	Paving asphalt (paint binder)	TON	75	150.00	135.00	165.00	135.00
8	Pavement reinforcing fabric	SQYD	57,000	1.00	1.00	0.95	1.20
9	Place asphalt conc. (misc. area)	SQYD	1,122	5.00	11.00	5.00	10.00
10	Place asphalt conc. dike (0.50', Type A)	LF	4,700	1.00	1.50	1.65	1.50
11	Liquid asphalt, SC-250 (prime coat)	TON	172	150.00	120.00	130.00	100.00
12	Asphaltic emulsion (paint binder)	TON	164	150.00	130.00	145.00	160.00
		Total		$1,168,470.00	$1,240,797.00	$1,324,227.00	$1,463,860.00

9' of the 10' wide shoulder was to be processed (remo to within 6"± of the concrete slab to avoid the Petro elastic crack sealant, and to within 6"± of the AC drainage dike). Consequently, to avoid contact with PCC pavement, it was necessary to remove teeth from t mandrel for about a 42-inch width. The toothless are on the mandrel was then permitted to ride over, but n on, the PCC slab in order to facilitate the desired 9 shoulder cut (Figure 5).



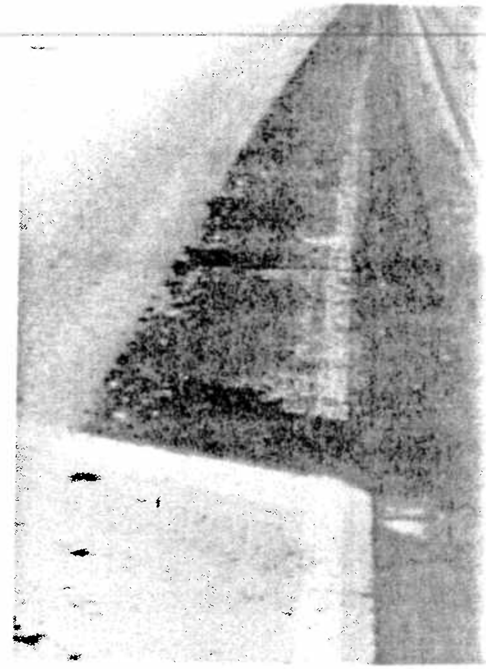
Roto-Mill PR-750 Cold Planer
Figure 4



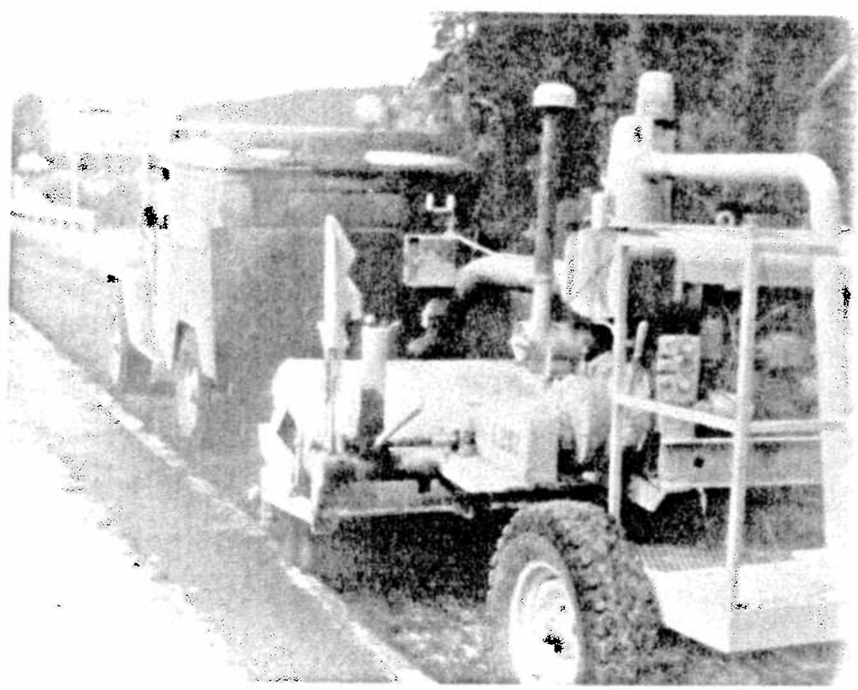
Drum, Minus Teeth, Overhangs P.C.C. Slab
Figure 5

Most of the cuttings were loaded in a continuous operation via a conveyor belt into trucks (bottom dump) for transportation to the plant site for stockpiling (Figure 6). As a result of tooth removal, some fine cuttings were deposited about 1/8 to 1/4 inch deep in the mandrel overhang area on the concrete slab (Figure 7) and also in the processed area behind the Roto-Mill. A power broom was required to sweep the accumulation of cuttings from the concrete slab back into the shoulder area (Figure 8). Water was used to cut down on dust and to cool the teeth. In spite of the added water, however, an occassional odor of burning asphalt was noted due to the heat generated.

Stockpiling Salvaged AC
Figure 6

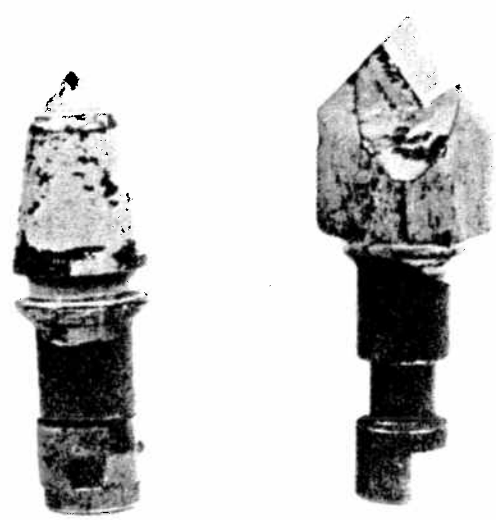


Cutting Deposit on P.C.C.
Figure 7



Pavement Sweeping
Figure 8

The speed of operation varied from 20' to 35' per minute, with the majority of the work performed at or near 35' per minute. In spite of this, however, during the first week of operation a distance of only one mile per day was realized. During this time it was necessary to change cutting teeth as often as twice daily. The cutting teeth had Tungsten-Carbide tips but, unlike the conical teeth previously used with the Roto-Mill, they were wedge or chisel shaped (Figure 9-right). A notch in the shank of the wedge tooth prevented rotation, and thus may have contributed to the accelerated rate of tooth wear. It was necessary to have a complete change of these wedge teeth approximately every 4 hours at an estimated cost per change of $1,400.00 (each tooth cost about $7.00).



Tungsten-Carbide Tipped Teeth for the Roto-Mill.

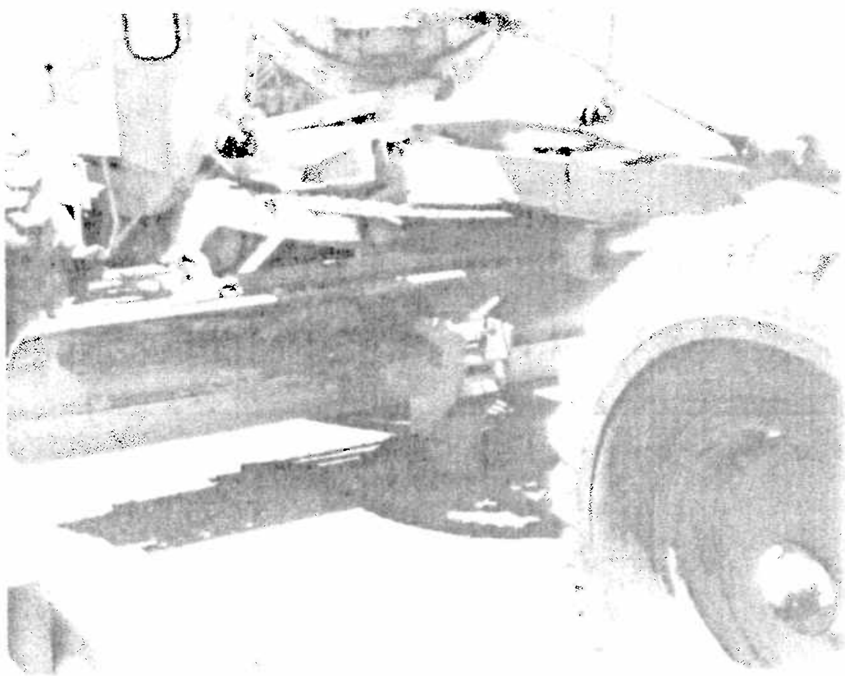
Figure 9

In order to increase efficiency, the wedge teeth an
12.5' mandrel were replaced with conical teeth (C-3
a 9' mandrel. Improvement was immediately realized.
The teeth required replacing only about every 2-3 da
and the shorter mandrel resulted in a cleaner operat

In some areas, delamination occurred where the origi
AC had been placed in a layer only 0.15'± thick. Gr
off 0.1' left only .05' and in some small isolated a
the remaining AC spalled. This resulted in some rat
large pieces (3") being included in the stockpile.
total amount, however, was minimal and no processing
problem with the stockpile occurred.

While the Roto-Mill continued to remove the AC (0.1')
needed for recycling, the second stage of the removal
operation began. This phase consisted of removing
a four-foot wide section adjacent to the edge of the
PCC pavement. The depth of this additional cut was
approximately 0.15'. All the AC in this area (referr
to as the trench section) was removed down to the
underlying cement treated base. A motor grader with
small cutting wheel attached was used to make a clean
longitudinal cut 4-feet from the edge of the PCC
(Figure 10). The AC was then ripped, scooped up, plac
into trucks and hauled away. The chunks thus obtained
were 5" to 15" in size. Because crushing to meet the
job requirements for recycling would have been necessa
this material was discarded. Also, in ripping the
material, it was discovered that considerable damage w
being done to the CTB. Therefore, a smaller model Rot
Mill (Model PR-225) was tried. Although it was now
necessary to get close to the PCC slabs and thus inclu

the removal of the Petroelastic crack sealer, this created no problem for the Roto-Mill and the job was accomplished effectively. Due to the hazard created by the 0.25' drop-off at the edge of the pavement after excavating the trench section, replacement of at least the 0.15' thickness was required during the same shift.

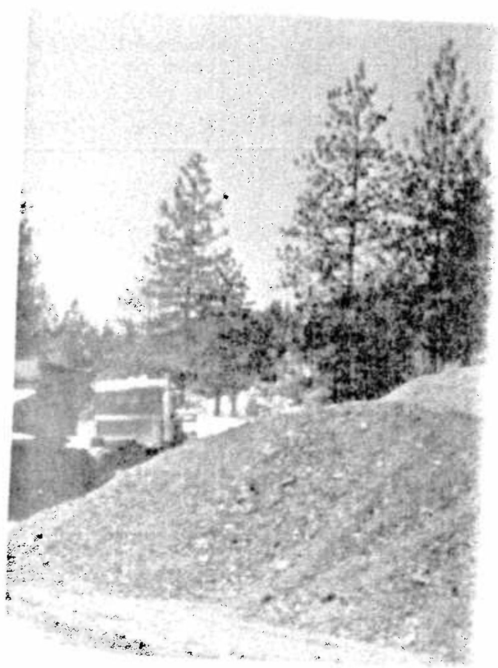


Small Cutting Wheel Used to Scribe Edge for Trench Section

Figure 10

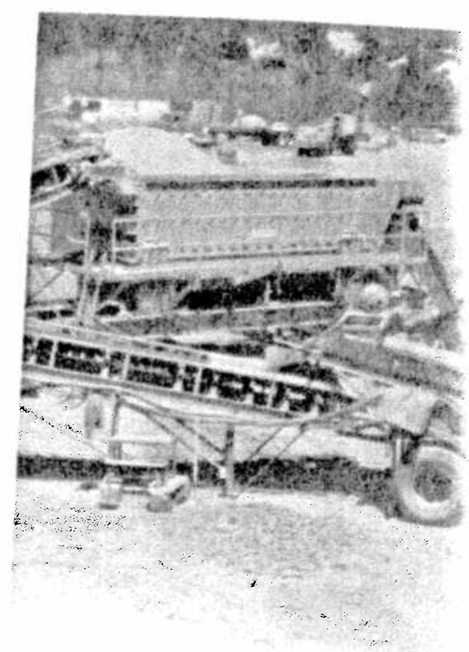
(E) Plant Operations

The hot plant, (a CMI converted dryer-drum), the aggregate crushers for the virgin aggregate, and, of course, the stockpile for the salvaged asphalt concrete were located just off the freeway at the Gold Run Overpass. The salvaged asphalt concrete stockpile was kept to a maximum height of 10' (Figure 11) to avoid segregation and to avoid consolidation during warm weather that may have made removal from the pile difficult. The stockpile formed by first dumping the salvaged AC from bottom (trucks into windrows and then using a front end loade to place this material in the stockpile. The virgin aggregate was hauled 9 miles from the Bear River and was predominately 3"x3/8" quartz although some partic as large as 6" were processed (Table 2). At the crus site, the raw aggregate was stockpiled over a tunnel housing a conveyor, which transported the aggregate t a separator (Hewitt-Robins-Figure 12). The various s were then belt-conveyed to one of two Symons cone crushers (Figure 13) which crushed to a given size. aggregate was then stockpiled according to size.



Stockpile Height Kept to 10' Maximum

Figure 11



Sieve Separator for Remova of Large Aggregate for Crushing

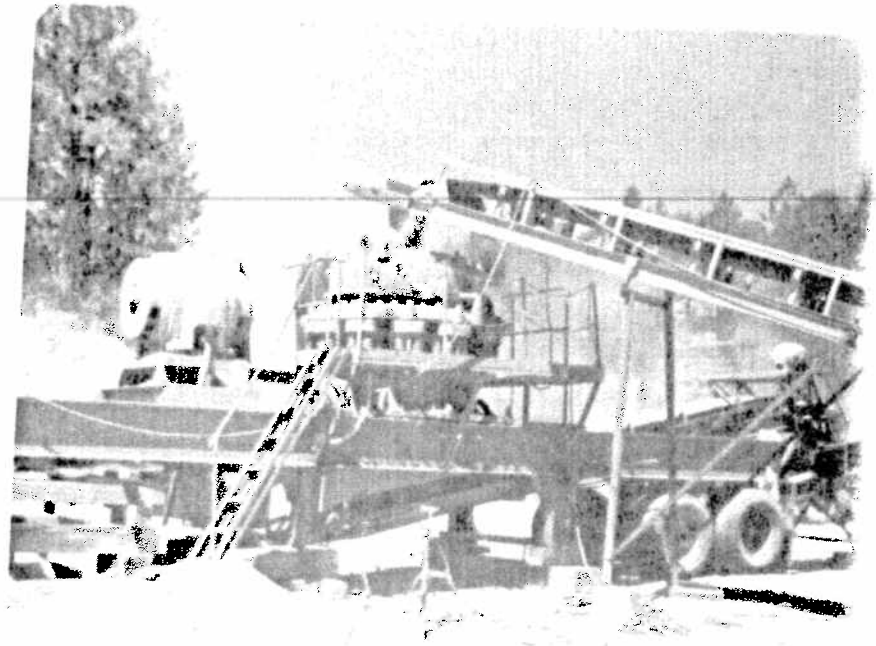
Figure 12

TABLE 2

GRADATIONS

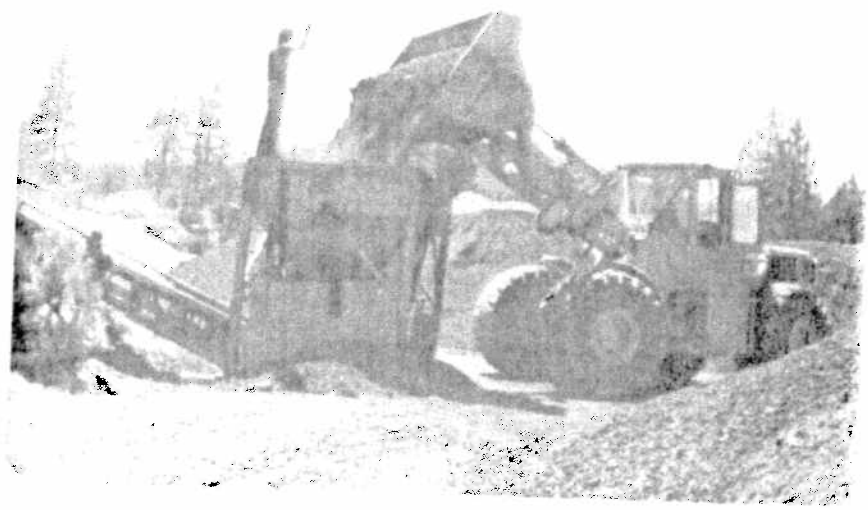
SIEVE SIZE	78-1430 VIRGIN AGGR PIT RUN	78-1355 VIRGIN AGGR. CRUSHED	78-1318A SALV. A.C TYPICAL*	[illegible] REC. A.C. TYPICAL
6"	98			
3	90			
2½"	73			
2	60			
1½"	46			
1"	31		100	
¾"	22	100	99	[illegible]
½	18	97	90	[illegible]
⅜"	16	86	82	[illegible]
4	13	68	64	[illegible]
8	11	47	46	42
16	10	31	37	[illegible]
30	8	21	28	[illegible]
50	6	14	19	[illegible]
100	5	10	12	[illegible]
200	4	7	7.7	[illegible]

*As used for recycled AC



Symons Cone Crusher
Figure 13

With the use of a front end loader (Figure 14), th
processed aggregate was loaded into metal storage
(Figure 15) from which it was transported to the d
mixer using another conveyor belt.



Front End Loader
Figure 14

Cold Storage Bins
Figure 15

The salvaged asphalt concrete was removed from the stockpile with a front end loader and placed into a metal bunker. It was discharged via a bottom slot onto a conveyor belt and transported to a set of sieves for removal of the oversize (Figure 16). (It was estimated that 10% oversize was rejected; however, later some of this oversize was broken down for use by driving over it with a D8-Caterpiller Tractor). The mix was then placed by conveyor belt into a cold storage bin. From the cold storage bins, both the salvaged AC and the virgin aggregate were fed to the plant.

Removing Oversize Salvaged AC
Figure 16

Shortly after the "construction" of these stockpiles began, samples of the new aggregate and salvaged AC were obtained and used for additional mix design wor to provide the basis for final recommendations regar the amount of AR-2000 asphalt to use. Table 3 conta the results of this testing. Based upon these resul the optimum asphalt content for the recycled AC appe to be 3.5%. The design properties agreed quite well with those of the preliminary testing and indicated t a mix having stabilities of 41±, void contents after kneading compaction of 4.5%, and a 67 pen. binder was attainable.

Additional laboratory testing was also completed to determine the effect of increasing the amount of salv AC in the mix to the upper limit of 55%. The results of this testing, which are included in Table 4, indic that the optimum asphalt content would not change.

TABLE 3

I-80 RECYCLE PROJECT

03-205404 (502)

LAB TEST NO. 78-1318 B

ASSUMED 5.0% ASPHALT IN SALV. AC.
USED 1/2" B MED GRADING FOR VIRGIN AGGR.

VIRGIN AGGR	% USED	0		50		50		50		50		50		50		50	
SALV AC	% USED	100		50		50		50		50		50		50		50	
AR-2000 DOH ADDED (%)		0		0		2.0		2.5		3.0		3.5		4.0		4.5	
TOTAL ASPH IN MIX		5.0		2.5		4.5		5.0		5.5		6.0		6.5		7.0	
METHOD OF COMPACTION		CALIFORNIA KNEADING COMPACTOR															
STAB VALUE		44	49	45	47	42	42	41	42	42	42	42	40	30	29	17	18
SPEC GRAVITY		2.26	2.26	2.14	2.13	2.23	2.23	2.24	2.25	2.28	2.28	2.31	2.31	2.32	2.33	2.34	2.34
VOIDS		7.5	7.5	15.7	16.1	9.7	9.7	8.6	8.2	6.2	6.2	4.5	4.5	3.3	2.9	2.1	2.1
COHESION		560	404	186	207	208	199	239	230	298	245	382	466	465	491	466	515
SURF ABRAS (TM 360 B)		—		—		—		—		—		20.4 g		—		—	
M_R X10^5		7.33	7.07	—	—	—	—	—	—	—	—	3.30	3.34	—	—	—	—
MVS	STAB	35	40	—	—	—	—	—	—	—	—	34	34	—	—	—	—
MVS	SP. GR	2.25	2.27	—	—	—	—	—	—	—	—	2.29	2.28	—	—	—	—
MVS	COHES.	1200	1100	—	—	—	—	—	—	—	—	506	548	—	—	—	—
MVS	MOIST. (%)	1.0	1.1	—	—	—	—	—	—	—	—	0.4	0.4	—	—	—	—
RECOV. ASPH. PEN.		14		—		—		—		—		67		—		—	
FLUSH		NONE		NONE		NONE		NONE		NONE		NONE TO SLIGHT		MOD TO HEAVY		HEAVY	
OPTIMUM ASPH %		—		—		—		—		—		X		—		—	

EXTRACTION DATA @ OPT ASPH CONT

SIEVE SIZE	3/4"	1/2"	3/8"	4	8	16	30	50	100	200	% ASPH EXTRACT
% PASSING	100	94	85	68	50	36	27	18	12	8.2	5.9
% THEORETICAL	100	94	84	66	48	34	24	16	11	7	6.0

TABLE 4

I-80 RECYCLE PROJECT

03-205404 (502)

LAB TEST NO. 78-1318C

ASSUMED 5.0% ASPHALT IN SALV. AC.
USED ½ B MED. GRADING FOR VIRGIN AGGR.

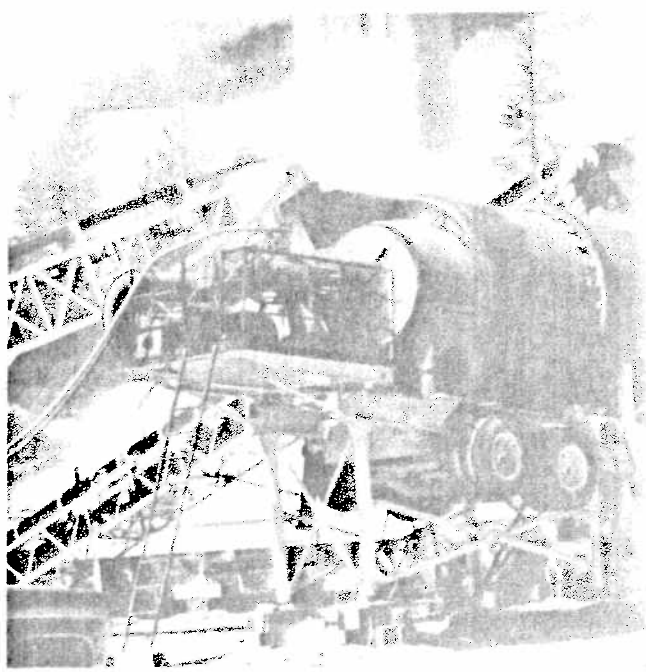
VIRGIN AGGR	% USED	0		45		45		45		45		45		45	
SALV AC	% USED	100		55		55		55		55		55		55	
AR2000 DOH ADDED (%)		0		0		2.0		2.5		3.0		3.5		4.0	
TOTAL ASPH IN MIX		5.0		2.5		4.5		5.0		5.5		6.0		6.5	
METHOD OF COMPACTION		CALIFORNIA KNEADING COMPACTOR													
STAB VALUE		44	49					45	41	42	44	38	38	14	21
SPEC GRAVITY		2.26	2.26					2.27	2.27	2.29	2.30	2.31	2.31	2.33	2.33
VOIDS		7.5	7.5					7.0	7.0	5.8	5.3	4.1	4.1	2.9	2.9
COHESION		560	404					308	276	305	416	489	442	472	460
SURF ABRAS (TM 360B)								—		—		14.7g		—	
M_R X10^5		7.33	7.07					—	—	—	—	2.98	2.76	—	—
MVS	STAB	35	40					—	—	—	—	28	34	—	—
MVS	SP GR	2.25	2.27					—	—	—	—	228	229	—	—
MVS	COHES	1200	1100					—	—	—	—	640	540	—	—
MVS	MOIST. (%)	1.0	1.1					—	—	—	—	0.3	0.4	—	—
RECOV. ASPH. PEN.		14						—		—		268*		—	
FLUSH		NONE						NONE		NONE		SLIGHT TO MOD		MOD. TO HEAVY	
OPTIMUM ASPH %		—						—		—		X		—	

EXTRACTION DATA @ OPT ASPH CONT

SIEVE SIZE	3/4"	1/2"	3/8"	4	8	16	30	50	100	200	% A EXT
% PASSING	98	91	81	65	48	35	26	18	12	8.1	6.1
% THEORETICAL	100	93	84	66	48	34	24	16	11	7	6.0

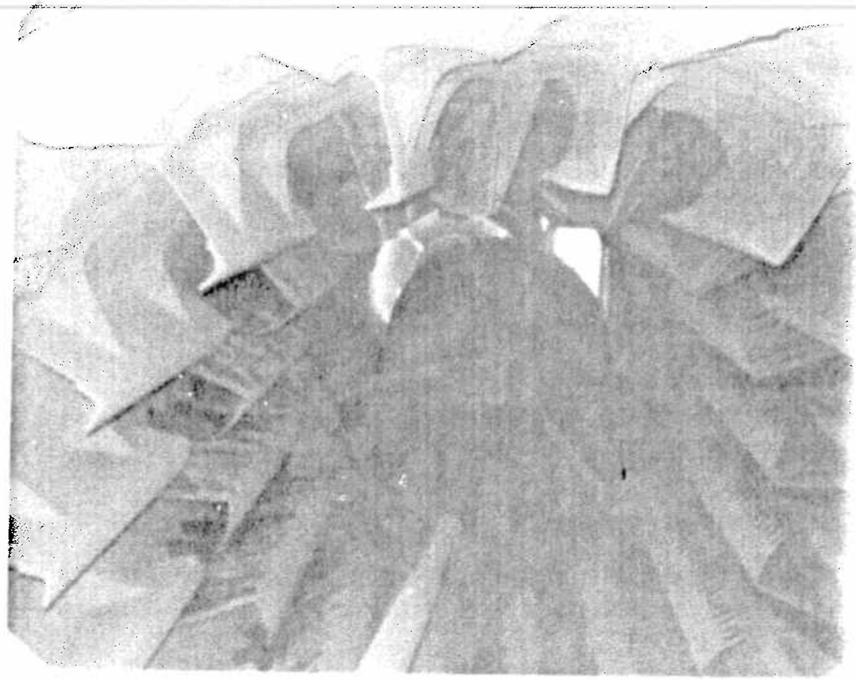
*Questionable

The dryer-drum plant used for the heating and mixing (Figure 17) was converted to provide a heat shield that prevented the flame from coming into direct contact with the salvaged AC (Figure 18). The virgin aggregate entered near the flame in the front of the drum and was heated first. Near the midpoint of the drum, the salvaged AC was introduced and thus was mixed with the heated virgin aggregate. Seconds after this mixing, 3.2-3.5% (by weight of total mix) new asphalt was added via a 2" diameter pipe that entered from the rear or outlet of the drum. The final recycled mix was then discharged into a hot elevator at the rear of the drum and transported up into a storage silo. The temperature of the final mix was monitored by a sensor at the discharge of the mix from the drum.



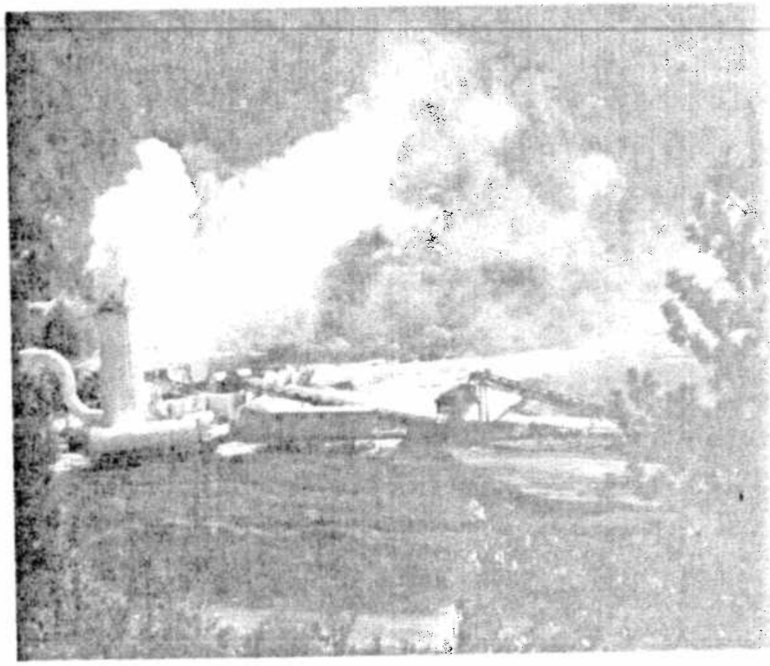
CMI Dryer-Drum Used for Heating and Mixing

Figure 17

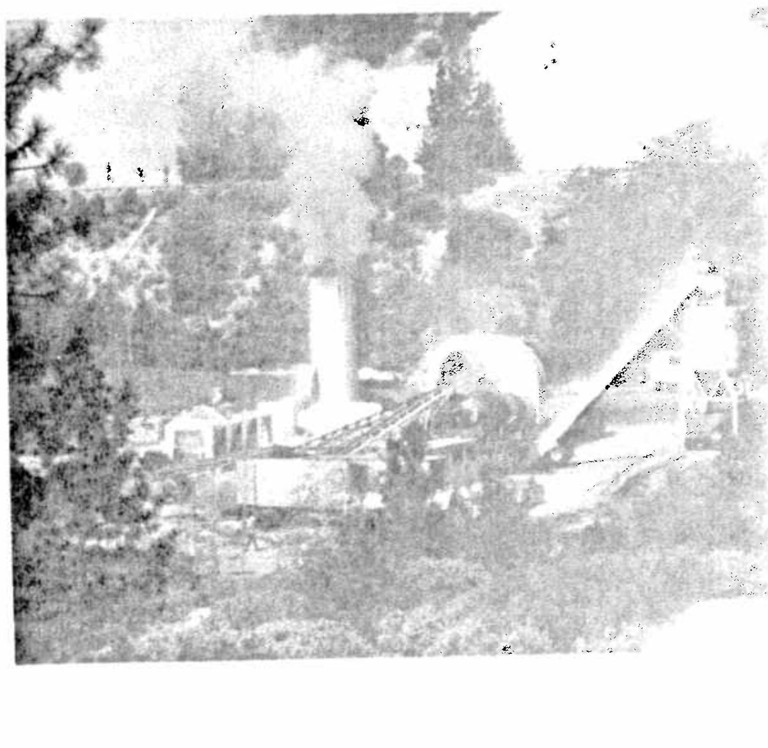


Heat Shield Inside Dryer-Drum
Figure 18

The plant, labeled a "Roto-Cycler", was equipped with a cyclone and a wet tube scrubber to eliminate air pollution. Although considerable steam was in eviden (Figure 19), the pollution standards for Placer Count were reported to have been met. Opacity readings ran from 5-10% were reported. It was also discovered tha a slight amount of water added to the cold salvaged A at its point of entry into the drum mixer reduced pol tion somewhat when, on occasion, dust did appear to b in the steam leaving the stack (Figure 20).



Emission From Dryer-Drum Mixer
Figure 19



Emission After Water Added at Dryer
Figure 20

Although the ambient temperatures seldom exceeded 90°F the temperature in the top 6" of the salvaged AC stock pile reached 120°F. Although no problem with consolid tion was noticed in the stockpile, an attempt to prelo the storage bin the night before operation resulted in consolidation or compaction within the bin. Considera difficulty was encountered loosening the material sufficiently to proceed. Preloading was thus disconti

Sampling devices were provided by the contractor for obtaining samples of the virgin aggregate, salvaged AC and recycled mix. Although somewhat difficult to opera they did meet the requirements.

Samples of the mixture, after extraction, constantly produced a gradation with more material passing the #20 sieve than was present in laboratory prepared samples. The cause was attributed to some aggregate degradation in the dryer-drum.

The recycled mix leaving the plant was generally 270°F or more and appeared to be an excellent mix. However, reports from the street indicated that the recycled mix had a "gummy" characteristic that made hand raking difficult even though mix temperatures were fairly high (Table A-4). Later, when the small spray of water was added to the salvaged AC at the point of entry into the drum, some of the alleged "gumminess" reported on the street appeared to disappear; however, at "street" temperatures less than 250°F, the mix remained very difficult to rake.

(F) Street Operations

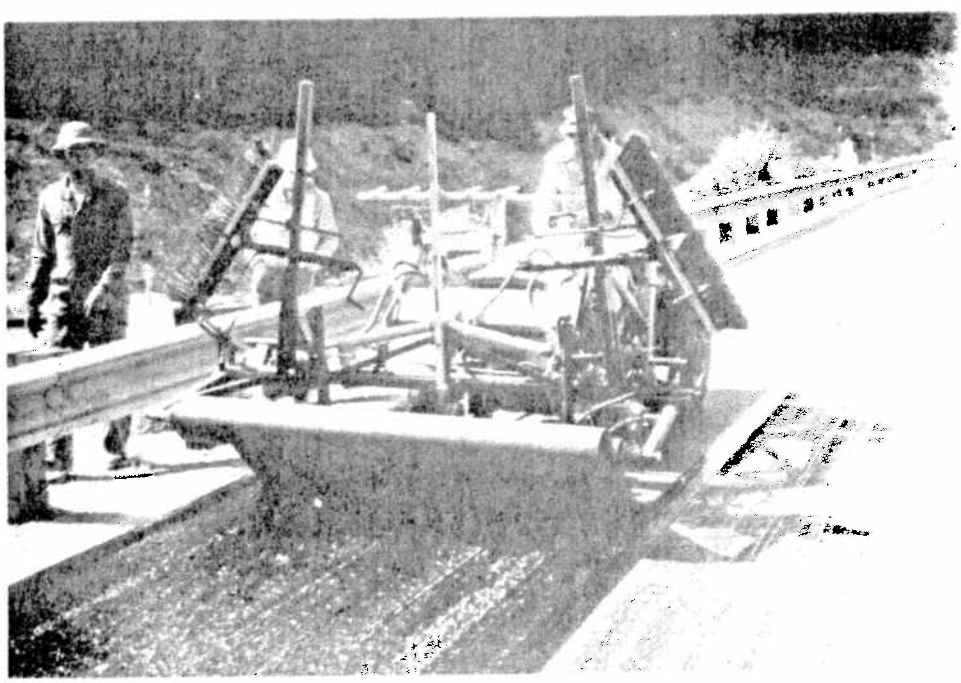
On the street, the project was divided into two general categories:

(1) Conventional Asphaltic Mix

A conventional 1/2" max. (medium grading) mix was placed as a control to compare with the performance of the recycled mix. This was placed in the eastbound shoulder from P.M. 42.50 to P.M. 43.44.

(2) Recycled Asphaltic Mix

(a) Except as noted on (1) above and 2(b) below, a 50/50 recycled mix was placed on the entire project. In addition, Petromat was placed on the shoulders and some ramps prior to paving at the locations shown below in an attempt to retard reflection cracking (Figure 21).



Placing Petromat
Figure 21

The areas selected for Petromat were severly cracked Rather than remove the entire depth, it was decided try fabric reinforcement on an experimental basis to retard or eliminate reflection cracking. Immediatel prior to placing the fabric, a tack coat (0.25 gal/s of AR-2000 paving asphalt was applied.

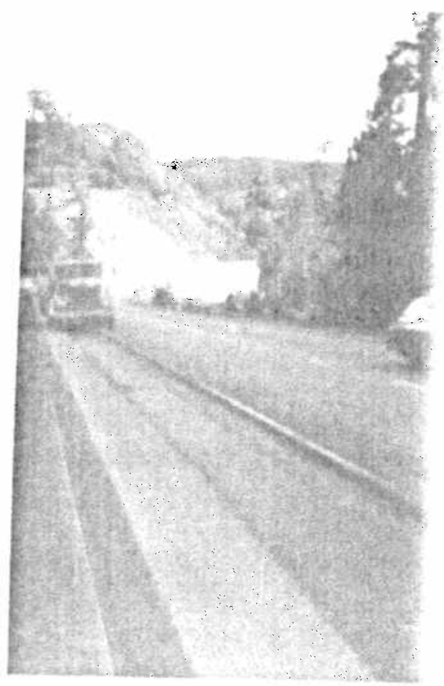
PETROMAT LOCATIONS

PM	to PM	Direction	PM	to PM	Dire
42.50	42.58	EB	42.81	42.96	WE
42.63	42.99	"	43.87	44.02	'
43.33	43.34	"	47.45	48.60	'
43.50	43.54	"	51.91	52.76	'
44.98	45.03	"	52.81	53.00	'
45.19	45.35	"	53.16	53.24	'
45.56	45.71	"	55.93	56.19	'
47.65	47.73	"	60.95	61.20	"
47.91	48.08	"	61.36	61.76	"
50.72	51.03	"	62.43	63.24	"
51.12	51.22	"	64.06	64.20	"
52.38	53.23	"	64.27	64.36	"
53.51	53.61	"	64.55	64.88	"
55.93	56.05	"			
56.79	56.95	"			
57.29	57.42	"			
58.23	60.05	"			
60.16	60.13	"			
62.29	62.70	"			
64.32	64.48	"			

(b) A 70/30 recycled mix was placed from PM 52.40 to PM 52.60 WB.

(c) A "rich" 50/50 recycled mix was placed on the Nyack WB "on" Ramp (3.5% new asphalt for the N. lane and 4.07% for the S. lane)

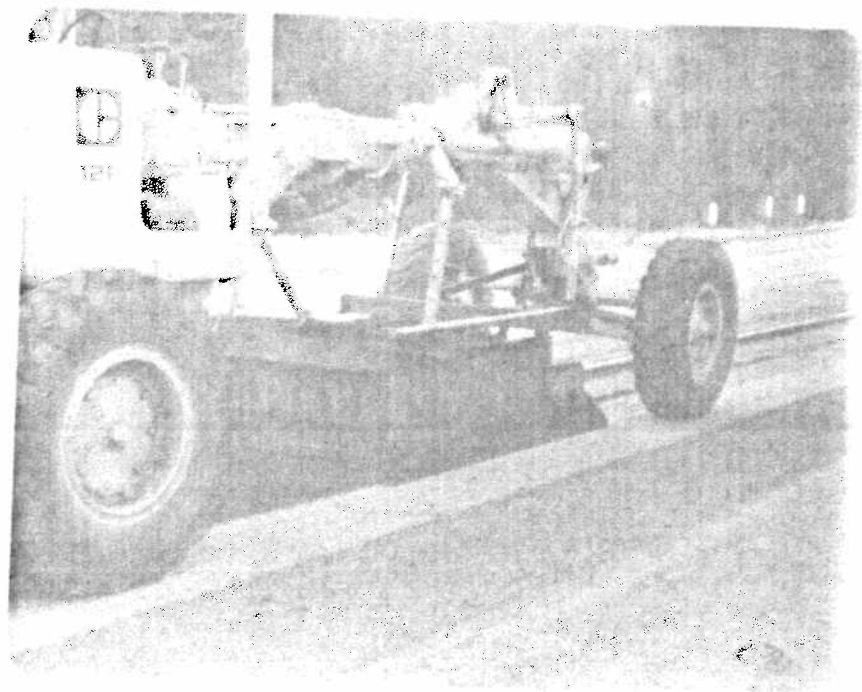
Prior to paving, a prime coat or tack coat was applied (Figure 22). An MC-250 was used for the prime and was placed wherever CTB was exposed. When the CMI Roto-Mill (Model PR-225) was used to excavate the trench, a thin layer of AC was left over the CTB and in these areas an AR-2000 was used for a tack. In both cases, an application rate of .05 gal/sq yd was used.



Tack Coat Prior to
Placing Recycle Mix

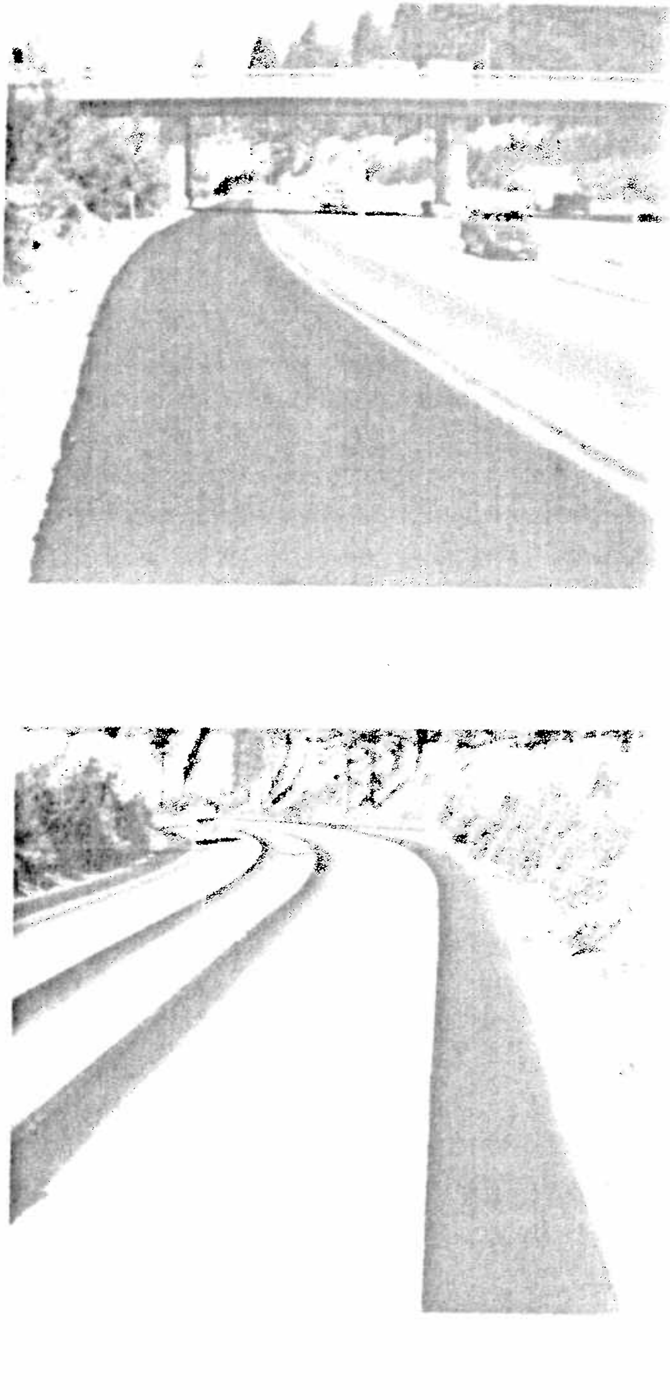
Figure 22

The first mix placed was in the trench section usin
special attachment (Figure 23) and then compacted u
a Hyster Model C-350A roller. Later the trench sec
and the entire shoulder were overlaid with 0.1' thi
recycled AC.



Special Spreader Attachment
Figure 23

Visually, the recycled mix placed in the street appea
excellent (Figure 24). It appeared to be well coated
and to contain the proper asphalt content. There wer
no lumps of old AC visible. No difference between th
conventional mix and the recycled mix could be detect



Completed Recycled AC Shoulders
Figure 24

Upon completion of all paving, a Reclamite construction seal was applied at the rate of .05 gal/sy from the edge of the concrete pavement out 4' with the following exceptions:

(1) All ramps and gores were excluded.

(2) At the following locations, the full 10' wide shoulder was treated:

PM 44.95 to 45.35 WB
PM 45.87 to 46.10 WB

(3) The locations skipped (no Reclamite) for purposes of future field condition evaluation were:

PM	to	PM
43.38		43.80 EB
60.47		60.97 EB
44.30		44.80 WB
62.20		62.70 WB

(G) Testing of the Recycled Mix

A problem extracting the salvaged asphalt concrete using the vacuum extractor (Calif. TM 362) was reported by the project Lab technician almost immediately. It was reported that excessive time was required to complete this extraction because of the aged asphalt in the mix. Testing speed was essential because the use of salvaged AC required approximately twice the testing normally required due to the need to measure the asphalt content of the salvaged AC (in the recycled AC). At each sampling, both recycled mix and salvaged AC (sampled just prior to mixing) were obtained. The asphalt content of the salvaged AC was then subtracted from the amount obtained for the recycled AC. The difference in asphalt was a check on the quantity of new asphalt being added. A minor modification in the rinsing portion of the test procedure resulted in a reduction in the time required per test to that required when testing new AC.

Another problem, however, that was also associated with the extraction testing was not easily resolved. This problem involved attempts to obtain a representative sample of the continually changing salvaged AC. A close inspection of split (quartered) samples often revealed 3/4" size particles that were essentially asphalt and fines, while other pieces of similar size consisted of a single larger aggregate particle. Consequently, it was necessary to perform several extraction tests (as many as possible) and then average the results. Variations of as much as 1.0% in asphalt content were encountered in spite of the efforts to obtain representative duplicate samples for testing on the job and in the Sacramento laboratory. It is anticipated that the recycled mix will thus reflect these variations in asphalt content due to the variables inherent in the salvaged AC (See Table 5).

The Sacramento lab test results in general indicate the overall Hveem stability of the recycled AC to be about 34 as compared to the value of about 40 obtained during design (Tables 6-11). To increase the very low stabilometer values of 14 and 11 that were measured for sample number 782-132 (Table 6), the amount of new asphalt being

TABLE 5

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(Job Control)

VACUUM EXTRACTION TEST (CA-TM-

DATE SAMPLED	EXTRACTED ASPHALT CONTENT (%)			
	SALVAGED ASPH. CONC.	RECYCLED ASPH. CONC.	DESIGNED	ACTU
8-15-78	5.7	6.7	3.5	3.9
8-16-78	6.2	7.0	3.5	3.9
8-17-78	5.7	6.6	3.5	* 3.8
8-21-78	5.7	6.0	3.5	3.2
8-22-78	5.5	7.0	3.5	4.2
8-23-78 AM	6.0	6.4	3.5	3.4
✓ PM	6.0	6.5	3.5	3.5
8-24-78 AM	5.5	6.1	3.5	3.3
8-25-78	6.2	5.8	3.5	2.7
8-28-78	5.0	5.1	3.5	2.6
8-29-78	5.9	6.1	3.5	3.1
8-31-78	5.0	5.9	3.5	3.4
9-7-78	5.1	5.4	3.2	2.8
9-7-78 PM	5.4	5.3	3.2	2.6
9-8-78		5.6		
9-11-78 AM	5.3	5.4	3.2	2.8
9-12-78 AM	5.0	6.2	3.2	3.7
9-13-78	4.9	5.4	3.2	2.9
9-13-78	4.6	5.7	3.2	3.4
9-14-78 AM	6.2	5.4	3.2	2.3

TABLE 5 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(Job Control)

VACUUM EXTRACTION TEST (CA-TM-362)

DATE SAMPLED	EXTRACTED ASPHALT CONTENT (%)			
	SALVAGED ASPH. CONC.	RECYCLED ASPH. CONC.	DESIGNED	ACTUAL
9-14-78 PM	4.3	6.3	3.2	4.1
9-15-78 AM	5.5	5.6	3.2	2.8
9-18-78	5.4	5.2	3.2	2.5
9-18-78 PM	5.1	5.7	3.2	3.1
9-19-78	5.1	5.3	3.2	2.7
9-20-78 NOON	5.6	5.9	3.2	3.1
9-21-78	6.2	5.9	3.2	2.8
9-22-78	6.4	5.75		2.55
9-25-78	6.4	5.9		2.7
9-25-78 PM	5.9	6.3	3.2	3.3
9-26-78 AM	5.5	6.1	3.2	3.3
9-27-78	4.9	6.0	3.2	3.6
9-28-78	5.7	6.0	3.2	3.2
9-29-78	6.1	5.9	3.2	2.9
10-2-78	5.6	5.4	3.2	2.6
10-3-78	5.3	5.8	3.2	3.2
10-4-78	4.8	5.4		3.0
10-5-78		5.9/6.3		
10-6-78		5.8		
10-9-78		5.3/5.2		

TABLE 6

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

SAMPLE NO.	782-103 Control A.C Mix (5.9% AR 2000 DOH)	782-104 Recy. AC	782-106 Recy. A.C.	782-131 Recy A.C.	782-132 Recy A.C	782-139 Recy A.C.	78 Rec
		3.5% AR2000 DOH ADDED					
GRADATION AFTER EXTRACTION							
SIEVE SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	PA
3/4"	100	100	100	100	100	100	
1/2"	98	97	100	98	97	95	
3/8"	86	84	92	89	90	85	
4	64	64	73	69	69	64	
8	44	47	54	51	50	48	
16	30	34	40	37	37	35	
30	21	25	28	27	27	25	
50	14	18	20	19	20	19	
100	10	13	14	14	14	14	
200	7.2	9.1	10.0	9.6	10.0	9.6	
% EXTRACTED ASPHALT	5.0	5.9	6.3	6.3	6.7	6.0	6
TESTS ON MIX							
STABILITY	41/38	28/30	31/33	26/26	14/11	28/26	3
COHESION	235/265	486/482	435/490	360/376	326/250	490/579	54
VOIDS	6.5/5.7	2.8/2.8	2.7/2.7	1.8/1.3	0.8/0.5	1.8/1.8	2
SURF. ABR.	—	19.6 g	17.5 g	17.9 g	15.9 g	18.0 g	1
M_R X10^5	—	4.90/4.93	3.72/3.66	4.30/3.88	4.08/4.22	3.48/3.50	3.8
MVS STAB	—	28/30	28/26	18/26	13/15	24/22	1
MVS MOIST.	—	0.2/0.2	0.2/0.2	0.2/0.2	0.2/0.2	0.3/0.2	0.

TABLE 6 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

SAMPLE NO.	782-103	782-104 Recy A C	782-106 Recy A C	782-131 Recy A C	782-132 Recy A C	782-139 Recy A C	782-140 Recy A C
		35% ARC [illegible] ADDED					
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	2,350 poise	11,485 poise	11,816 poise	10,873 poise	12,757 poise	3,053 poise	8,639 poise
VISC. @275°F	426 cST	906 cST	906 cST	801 cST	1,125 cST	438 cST	741 cST
PEN. @77°F	78	33	32	35	39	76	40
SOFT POINT	121°F	140°F	139°F	137°F	138°F	124°F	140°F
DUCTILITY	100+ cm	95 cm	100+ cm	100+ cm	74 cm	100+ cm	79 cm

TABLE 7

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

3.5% AR-2000 Added

SAMPLE NO.	782-155 Recy AC	782-156 Recy AC	782-157 Recy AC	782-158 Recy AC	782-159 Recy AC	782-160 Recy AC	
GRADATION AFTER EXTRACTION							
SIEVE SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	P
3/4"	100	100	100	100	100	100	
1/2"	98	96	97	96	98	96	
3/8"	88	86	89	88	86	83	
4	66	64	68	68	65	62	
8	49	46	50	50	48	46	
16	36	34	37	36	36	34	
30	26	25	27	26	27	24	
50	19	18	19	18	18	17	
100	13	13	13	12	13	12	
200	8.6	9.0	9.5	8.4	9.6	8.8	
% EXTRACTED ASPHALT	6.1	5.6	5.8	5.8	6.1	5.6	5
TESTS ON MIX							
STABILITY	31/30	29/32	38/35	39/36	29/26	32/30	34/
COHESION	494/570	489/509	483/567	517/463	498/454	502/502	510/
VOIDS	2.5/2.0	3.2/3.2	3.4/3.4	3.7/3.7	2.9/2.9	3.6/3.6	3.7/
SURF. ABR.	17.8 g	21.6 g	19.3 g	20.9 g	—	—	243
$M_R \times 10^5$	3.56/3.09	3.68/3.76	4.30/4.08	4.38/3.98	4.34/4.10	4.02/5.10	4.16/
MVS STAB.	25/28	33/30	34/34	32	—	—	34/3
MVS MOIST	0.3/0.2	0.3/0.3	0.3/0.4	0.3	—	—	0.2/

TABLE 7 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(3.5% AR-2000 Added)

SAMPLE NO.	782-155 Recy AC	782-156 Recy AC	782-157 Recy AC	782-158 Recy AC	782-159 Recy AC	782-160 Recy AC	782-161 Recy AC
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	5631 poise	10,427 poise	15,872 poise	11,282 poise	—	—	11,411 poise
VISC. @275°F	639 cST	745 cST	975 cST	858 cST	—	—	900 cST
PEN. @77°F	50	38	33	38	—	—	41
SOFT POINT	133°F	137°F	142°F	134°F	—	—	140°F
DUCTILITY	100+ cm	68 cm	54 cm	65 cm	—	—	59 cm

[redacted]

TABLE 8

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(3.2% AR-2000 Added)

SAMPLE NO.	782-162 Recy. A.C	782-163 Recy A.C	782-170 Recy. A.C.	782-171 Recy. A.C.	782-172 Recy. A.C.	782-173 Recy A.C	782 Rec
GRADATION AFTER EXTRACTION							
SIEVE SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PAS
3/4"	100	100	100	100	100	100	1
1/2"	96	96	95	95	96	95	9
3/8"	84	82	80	86	83	80	8
4	63	62	61	66	60	59	6
8	45	45	45	48	44	43	4
16	33	33	33	34	32	32	3
30	24	24	25	25	24	23	2
50	18	17	18	18	16	17	2
100	12	12	14	13	12	12	1
200	8.7	8.8	9.0	9.0	8.4	8.6	9.
% EXTRACTED ASPHALT	5.4	5.2	5.5	5.6	5.6	5.5	5.
TESTS ON MIX							
STABILITY	42/40	37/40	39/36	42/39	36/40	37/35	33
COHESION	456/526	556/465	556/568	242/344	582/502	559/588	504
VOIDS	3.8/3.8	3.4/3.7	3.0/3.4	4.0/3.2	2.8/2.0	3.0/3.0	2.9
SURF. ABR.	17.9 g	—	—	20.3 g	20.4 g	19.9 g	19.
$M_R \times 10^5$	4.66/4.22	—	5.33/5.33	4.71/4.82	4.62/4.52	5.07/5.01	5.18
MVS STAB.	36/38	—	—	40/41	31/34	29	3
MVS MOIST.	0.3/0.3	—	—	0.2/0.2	0.3/0.3	0.3	0.

TABLE 8 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(3.2% AR-2000 Added)

SAMPLE NO.	782-162 Recy A.C	782-163 Recy. A.C	782-170 Recy A.C	782-171 Recy. A.C.	782-172 Recy A.C	782-173 Recy A.C.	782-174 Recy A.C
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	11,081 poise	—	11,525 poise	9,200 poise	7,678 poise	12,794 poise	11,678 poise
VISC. @275°F	780 cst	—	828 cst	771 cst	747 cst	882 cst	828 cst
PEN. @77°F	38	—	34	44	42	37	35
SOFT POINT	139°F	—	139°F	136°F	135°F	140°F	140°F
DUCTILITY	83 cm.	—	80 cm	100+ cm	100+ cm	85 cm	85 cm

TABLE 9

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(3.2% AR-2000 Added)

SAMPLE NO.		782-175 Recy AC.	*782 177 Recy A C	*782-193 Recy A C	*782-194 Recy. A C	*782 195 Recy A C.	*782 196 Recy A C	*782 Recy
GRADATION AFTER EXTRACTION								
SIEVE SIZE		% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASS
3/4"		100	100	100	100	100	100	10
1/2"		97	97	97	94	93	94	9
3/8"		84	82	84	86	83	80	8
4		64	61	61	63	65	62	6
8		46	44	44	46	47	45	4
16		34	33	33	34	35	33	35
30		25	24	25	24	25	24	25
50		18	17	17	17	18	17	18
100		13	12	11	12	13	12	13
200		9.3	8.8	8.0	8.2	9.4	8.3	8
% EXTRACTED ASPHALT		5.7	5.4	5.8	5.5	6.0	5.4	5.5
TESTS ON MIX								
STABILITY		42/44	40/42	37	41	32	43	40
COHESION		567/336	523/445	499	424	635	416	375
VOIDS		3.4/4.4	3.8/3.8	3.4	4.1	1.8	4.7	4.1
SURF. ABR.		22.6 g	21.1 g	20.4 g	25.4 g	23.8 g	27.5 g	16.8
M_R X10[5]		5.08/5.65	5.98/4.79	5.60	4.92	5.16	5.96	5.8
MVS	STAB.	37	38/38	36	38	30	37	35
	MOIST	0.2	0.3/0.3	0.3	0.4	0.2	0.3	0.2

*3.2% AR-2000 DOH Added

TABLE 9 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

(3.2% AR-2000 Added)

SAMPLE NO.	782-175 Recy. A.C.	782-177 Recy. A.C.	782-193 Recy. A.C.	782-194 Recy. A.C.	782-195 Recy. A.C.	782-196 Recy. A.C.	782-197 Recy. A.C.
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	12,264 poise	16,030 poise	12,196 poise	20,672 poise	11203 poise	6,670 poise	8497 poise
VISC. @275°F	1137 CST	1,014 CST	855 CST	1,083 CST	828 CST	730 CST	690 CST
PEN. @77°F	39	30	32	27	43	52	40
SOFT POINT	140°F	143°F	141°F	145°F	138°F	132°F	136°F
DUCTILITY	68.5 cm	85.5 cm	79.5 cm	60.0 cm	89.5 cm	100+ cm	100+ cm

TABLE 10

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

SAMPLE NO.	← 3.2% AR 2000	ADDED	→	1.9% AR2000 ADDED 70% SALV./30% VIRGIN AGGR.	← 3.2% AR2000	ADDE[D]	
	782-198 Recy A.C.	782-199 Recy A.C	782 200 Recy A.C	782 201 Recy A.C	782-242 Recy A.C.	782-243 Recy A.C.	7[…] Re[…]

GRADATION AFTER EXTRACTION

SIEVE SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	PAS[…]
3/4"	100	100	100	100	100	100	
1/2"	97	96	98	97	99	95	
3/8"	88	88	87	85	89	88	
4	67	63	65	67	67	65	
8	48	47	48	52	50	48	
16	36	35	36	40	35	36	
30	26	26	26	30	27	26	
50	18	19	18	21	19	18	
100	13	12	13	15	14	13	
200	8.6	8.6	9.0	10.5	10.0	9.0	
% EXTRACTED ASPHALT	5.4	4.9	5.5	6.0	5.8	5.5	

TESTS ON MIX

STABILITY	41	40	32	26	35	34	
COHESION	601	639	564	489	647	702	4[…]
VOIDS	4.7	5.4	3.8	3.0	4.2	3.8	
SURF. ABR.	29.0 g	26.2 g	26.4 g	55.7 g	37.9 g	30.0 g	2[…]
M_R X10^5	5.24	4.85	3.84	—	7.13	8.23	
MVS STAB.	32	34	30	—	34	30	
MVS MOIST.	0.2	0.2	0.2	—	0.6	0.2	

TABLE 10 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

	← 3.2% AR 2000		→	1.9% AR 2000 ADDED 70% SALV. 30% VIRGIN A6	← 3.2% AR 2000	ADDED	→
SAMPLE NO.	782-198 Recy AC	782-199 Recy AC	782-200 Recy AC	782-201 Recy AC	782-242 Recy AC	783-243 Recy AC	783-244 Recy AC
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	13,886 poise	11,604 poise	10,616 poise	21,776 poise	9809 poise	11,001 poise	14,895 poise
VISC. @275°F	840 cST	963 cST	846 cST	1,131 cST	714 cST	723 cST	915 cST
PEN. @77°F	34	33	37	27	26	25	25
SOFT POINT	140°F	140°F	138°F	140°F	136°F	140°F	140°F
DUCTILITY	76.75 cm	77.5 cm	100+ cm	95.0 cm	100+ cm	100+ cm	72.0 cm

TABLE 11

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

SAMPLE NO.	3.2% AR 2000 ADDED 782-245 Recy A.C	4.0% AR2000 ADDED 782-246 Recy A.C	4.5% AR 2000 ADDED 782-247 Recy A.C.	3.5% AR 2000 ADDED 782-248 Recy A.C.			
GRADATION AFTER EXTRACTION							
SIEVE SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
3/4"	100	100	100	100			
1/2"	96	96	99	97			
3/8"	86	89	91	89			
4	65	68	70	67			
8	47	50	52	49			
16	36	37	38	37			
30	27	28	29	27			
50	19	20	21	19			
100	14	15	15	14			
200	9.8	11.0	10.6	9.8			
% EXTRACTED ASPHALT	5.9	6.7	7.5	5.6			
TESTS ON MIX							
STABILITY	35	4	1	32			
COHESION	649	295	270	560			
VOIDS	2.8	0.2	6.0	6.5			
SURF. ABR.	30.7 g	23.6 g	20.4 g	30.4 g			
M_R X10^5	8.46	4.74	4.51	8.10			
MVS STAB.	30	—	6	31			
MVS MOIST.	0.3	—	0.2	0.3			

TABLE 11 (Cont'd)

TEST RESULTS ON RECYCLED ASPHALT CONCRETE

SAMPLE NO.	3.2% AR2000 ADDED 782-245 Recy A.C.	4.0% AR2000 ADDED 782-246 Recy A.C.	4.5% AR 2000 ADDED 782-247 Recy A.C.	3.5% AR 2000 ADDED 782-248 Recy A.C.			
TESTS ON RECOVERED ASPHALT							
VISC. @140°F	5,881 poise	6,794 poise	4452 poise	4,927 poise			
VISC. @275°F	579 cST	600 cST	504 cST	636 cST			
PEN. @77°F	36	30	37	31			
SOFT POINT	133°F	135°F	132°F	136°F			
DUCTILITY	100+ cm	100+ cm	100+ cm	100+ cm			

added was decreased from 3.5 to 3.2%. However, later test results for samples of mix placed just prior to making this change indicated that stabilities in the low 30's had again been achieved even with the continued addition of 3.5% AR-2000. No visual change in the mix was noted when this change in asphalt content from 3.5% to 3.2% was made.

The hardness of the asphalt in the recycled mix will, of course, basically depend on the hardness of the old salvaged asphalt and the amount and type of asphalt or additive used for recycling. The asphalt hardness will also depend upon many other variables, some of which are not easily controllable. One of these variables is the type of field mixing units (an uncontrollable variable at this time) such as pugmills vs. dryer-drums. Production variations will also exist within each method caused by such items as the condition of the mixing equipment, time of mixing, mixing temperatures and character of the asphalt, crack sealers or other bituminous material in the salvaged AC.

Variables in the Laboratory (TransLab) operation may also influence the decision on the amount of new asphalt and/or recycling agent recommended for use. One variable is the procedure used to combine these products with the salvaged AC. One approach involves combining the additive with the salvaged AC. Another approach involves combining the additive with asphalt recovered from the salvaged AC. Using the second procedure decreases the number of recovery tests required. However, this method also relies heavily on the accuracy of the asphalt extraction test results. Thus, an error of 0.2 to 0.3% in extracted asphalt content can influence the final properties of the binder in the recycled AC. Because of this concern, all testing was done by combining the new asphalt or recycling agent with the salvaged AC and virgin aggregate and then recovering the combined asphalt binder.

Another variable it was felt prudent to study was the effect on asphalt hardness of the laboratory mixing equipment used. Thus, a small program to observe which of two laboratory mixing methods currently used by Caltrans most closely correlated with recycled mix obtained from the field was included in this study. The standard method of laboratory mixing at TransLab has been to use the mechanical mixers shown in Figure 2 (page 13 of this report). These units, which are also available in each Caltrans' district, are used to individually mix samples up to 1500 grams. Table 12 contains the results of some initial tests of asphalt recovered from mix prepared in the laboratory using ingredients from the job. The lack of agreement between the results for Nos. 2 and 3 resulted in test number 4. Test No. 4, although closer to the results for the mix from the job, still suggested that the "aging" during laboratory mixing was not hardening the binder as much as the aging occurring in the drum mixer. The asphalt recovered from the field-mixed AC did, however, have a penetration of 33, which indicates an asphalt softer than that in the original salvaged AC (average pen. of 16) was being achieved. This was following the solvation and distillation process that is part of the Abson recovery operation. One significant question arising from this type of recycling in general is that of blending of the new, added asphalt or softening agents and the old, hardened asphalt. Does it actually happen in the mix? Or do results of tests on the recovered asphalt merely show what would happen if they did blend?

Occasionally at TransLab a larger commercial "Hobart" mixer has been used for mixing when samples of 5000 to 7000 grams were desired. Thus, it was decided to compare the Hobart with the conventional mixing units for ability to produce a final mixture with an asphalt hardness comparable to that obtained in the field. The mix prepared for this hardening study consisted of 50% salvaged AC (with an average asphalt penetration of 16), 50% virgin aggregate, and 3.5% new Douglas AR-2000 asphalt. After an Abson Recovery, the asphalt was tested for penetration with the following additional results (Nos. 5-7):

TABLE 12

Test No.	1*	2	3	4	5	6	7
Mixing Unit**	-	Drum Mixer	Pot**	Pot	Pot	Pot	Hobart
Mixing Time(Min)	-	?	2±	2±	2	10	1.5
Penetration	16	33	165	67	57	58	44

*Salvaged AC

**Pot test refers to mechanical mixer used in Calif. Test Method 304, Figure 2.

Again, the hardening in the laboratory with either mixer was not as severe as that in the drum mixer. Thus, it would appear that some additional studies are needed to more closely relate actual lab mixing with field mixing in terms of asphalt hardening. However, the decrease in hardness that was measured (increasing the penetration from about 16 to 33+) indicated that a definite improvement was achieved if similar blending of the new asphalt and the asphalt in the salvaged AC actually occurred in the pavement.

Even though the test results indicated that a satisfactory recycled AC was being produced and that the asphalt recovered from the recycled AC was softer than the asphalt recovered from the salvaged AC, it was felt that additional softening of this aged asphalt might be beneficial. Consequently, some laboratory testing was completed using various amounts of Cyclogen M and Chevron Heavy recycling agents to determine: 1) the optimum amount of each recycling agent using normal mix criteria and 2) the softening effect of these recycling agents on the aged asphalt. Both these recycling agents supposedly contain not only components to soften aged asphalt but also those components required to satisfy the asphalt demand of the new aggregate (and any unsatisfied demand of the salvaged AC). The results of this testing are presented in the Appendix as Tables A-2 and A-3. It can be seen that the optimum amount of these recycling agents, based upon standard mix criteria, was 3.5% (by combined weight of the aggregate and salvaged AC) and that, as expected, use of the recycling agents would soften the aged asphalt more than the same amount of AR-2000. However, the cost of these products was more than that for the paving grade asphalt. In addition, the extreme softening indicated by the use of Cyclogen M seemed questionable. Although this suggested that a lesser amount of Cyclogen M would be appropriate, this would have resulted in undesirably higher design void contents of 5.5% or more (Table A-2). Because the paving was nearing completion and because of the lack of a clearly demonstrated potential for a cheaper and/or superior product if a recycling agent was used, no attempt was made to substitute either recycling agent for the AR-2000 in the field on this project.