M 57

PRODUCING A BITUMINOUS WEARING COURSE BY DRUM MIX RECYCLING

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
TESTING LABORATORY SECTION

M 57

PRODUCING A BITUMINOUS WEARING COURSE BY DRUM MIX RECYCLING

R. B. Moore
R. A. Welke

Testing and Research Division
Testing Laboratory Section
Bituminous Technical Services Unit
Research Report No. 78 TB-13

Michigan Department of Transportation

Lansing, January 1979

ACKNOWLEDGMENT

The support of G. J. McCarthy, Director of the Bureau of Highways, and K. A. Allemeier, Engineer of Testing and Research, were greatly appreciated especially considering the magnitude of this project and its experimental nature. Appreciation is also due to Roger Vander Meulen, District Construction Engineer, and David Miller, Project Engineer, for their supervision of the construction and S. Castronova for design of the project.

SYNOPSIS

A 7.2 mile section of M 57 east of Greenville, Michigan was recycled as a bituminous wearing course by using a drum mix plant. The original bituminous pavement placed in 1956 was 22 ft wide and approximately 3 in. thick.

The pavement was removed and sized by CMI Rotomills. The salvaged material was then mixed in a Boeing drum plant with various percentages of new aggregate and additional 200-250 penetration grade asphalt cement. The recycled mix was then placed back on the grade at a 30-ft width and 3 in. in thickness. There were no major construction problems on this project. Construction equipment is available to successfully recycle bituminous material by hot mixing.

The appearance and test results of the recycled mix were similar to that of a conventional bituminous wearing course. Control of the asphalt content is not as good as with a conventional mix; however, the difference is not large enough to be considered critical. Variability of the aggregate gradation proved to be similar to that of a conventional mix. A 200-250 penetration grade asphalt cement rejuvenated the old asphalt cement to the viscosity of asphalt in new mix.

The cost of the recycled wearing course was $16.72/ton versus $20.20/ton for conventional wearing course used elsewhere on the project. A minimum of 210,000 gal of petroleum products were saved along with approximately 21,000 tons of aggregate.

Introduction

The need to conserve diminishing natural resources has become apparent in recent years. Conservation of petroleum products is of worldwide significance while the savings of quality aggregate materials used in construction is often of regional importance. Today, any savings in materials can almost certainly be translated into a savings of money. Recycling asphalt pavements is an idea whose time has come, for it promises both an ecological and monetary savings.

There are three basic types of asphalt pavement recycling (1):

1. Hot Recycling,
2. Surface Recycling,
3. Cold Recycling.

It is generally agreed that hot recycling produces a higher quality material than the other two types. Except for a small 500-ton project done last year that produced a wearing course, Michigan's experience had been only with surface and cold recycling, producing base and shoulder materials. However, on M 57 a high quality material was considered desirable since the recycled mix was to be used as a wearing course; thus, hot recycling was considered necessary. To date there are two successful methods of hot recycling (1):

1. Drum Mix Method,
2. Heat-Transfer Method.

For the M 57 project the drum mix method was chosen while on I 94 near the Indiana border the heat-transfer method was employed. It was felt that the experience gathered from both of these hot recycling projects would be instrumental in setting the direction of the Department's recycling program.

Description of Work

The location of the 7.2 mile recycled portion of the project was on M 57 between M 66 and Berridge Rd in Montcalm County, east of Greenville. The work consisted of removal and reduction of the existing 22 ft (two 11-ft lanes) bituminous pavement that was placed in 1956 (Photo 1), recycling through a bituminous drum mix plant with the addition of asphalt cement and virgin aggregate, and replacing the recycled material on a 30-ft roadway (two 12-ft lanes and a 3-ft paved shoulder) at 330 lb/sq yd. Also included in another portion of the project was a conventional bituminous resurfacing.

Preparation of Proposal

A 'Special Provision for Recycling Bituminous Pavement' was included in the proposal (Appendix A). Section B of the Special Provision required that 95 percent of the salvaged material must be reduced so that it can pass the 2-in. sieve. However, it was stated at the prebid meeting that if large chunks of material could be broken down in the mixing process so they would not appear in the mat, then this requirement could be waived.

In Section C, water added to the salvaged bituminous material on the cold feed belt was stipulated. One drum mix manufacturer (Boeing) finds that this improves air quality. However, adding water is not desirable when using other makes of drum mix plants and should not have been specified for all plants. In Section D, it is stated that "... the Contractor shall submit, prior to the award of the contract, an acceptable proposal for preventing excessive air pollutants." This statement along with the preceding one, "... the plant shall at all times conform to local and state air quality standards," is sufficient. Otherwise, the plant equipment section would have to be overly specific or possibly unduly exclusive of certain manufacturer's equipment. The requirement of adding water was discussed at the prebid meeting and was waived for all but the Boeing plant.

Section G describes measurement and payment. On this project virtually everything was paid for separately--removal, 20AA aggregate, asphalt cement, and recycling. It was felt that this would give us more flexibility in changing the percentages of salvaged and virgin material along with the asphalt cement added. Due to our inexperience with hot mix recycling, we wanted to avoid any conflict in payment if the percentages of materials used varied substantially from the estimate in the proposal. The overall percentages for the project in the proposal were 72.1 percent (16,397 tons) salvaged material, 26.3 percent (5,980 tons) 20AA aggregate, 1.6 percent (375 tons) asphalt cement. The 20AA aggregate and asphalt cement quantities were to be paid for based on the mix design percentages. Removing salvaged material was paid for by the square yard; this avoided having to weigh the removed material. Also, removal was paid for depending on the thickness of the pavement. Since only seven cores were taken, there was an amount of uncertainty as to the thickness. One 1/2-mile section had been resurfaced and this was thought to be the only section that was greater than 4 in. in thickness.

On May 11, 1978, a prebid meeting was held to clarify the proposal and answer any questions. The meeting was well attended. Ten different construction companies and two equipment manufacturers were represented. On May 17, the project was let to the low bidder, Spartan Asphalt Co. (see Appendix B for unit prices of items of work).

Mix Design

The design of the mix actually began eight months prior to the start of the project. In January 1978, cores of the existing pavement were taken (Appendix C). After analyzing the existing bituminous concrete it was decided that a 20AA material (dense graded with a minimum of 40 percent crushed retained on No. 4 sieve) would be the best virgin material to add to the salvaged material in order to produce a suitable combined gradation. Based on this, 20AA was required in the proposal. The following is the gradation requirement for 20AA:

Sieve	Total Percent Passing
3/4-in.	100
1/2-in.	95-100
3/8-in.	65- 90
No. 8	45- 65
No. 30	20- 40
Loss-by-Washing	0- 7

Recovered penetrations of the existing pavement averaged 38, ranging between 28 and 45. It was determined that adding a 200-250 penetration grade asphalt cement would sufficiently soften and rejuvenate the old hardened asphalt cement, and thus, it was required in the proposal.

The aggregate base was also considered for it was assumed that in removing the salvaged material some of the aggregate base would also be included. The aggregate base is dense graded with a maximum 1-in. particle size. It was felt that the inclusion of some of this material would not be detrimental to the recycled mix.

As soon as the salvaged material (removed by coldmilling) and 20AA from the source to be used were available, a mix design was run at a 60 percent salvaged-40 percent virgin ratio. It was determined that 2.7 percent new asphalt cement should be added to this recycled mix, making a combined asphalt content of 5.4 percent (Appendix D).

Construction

For the recycled portion of the project there was a suitable detour available. Two weeks prior to the start of construction the contractor notified the Project Engineer who in turn notified local officials, the newspapers, and local radio stations. This detour aided construction considerably.

On July 19, 1978, subcontractor Eisenhour Construction Co. began removing the existing pavement with CMI Rotomills (Photo 2) and stockpiled the material at the asphalt plant site (located at the job). The particular model used can remove 9 ft of pavement per pass at approximately 15 to 20 ft per minute. However, maintenance and repairs of these machines led to a considerable down-time estimated between 40 and 50 percent. The Rotomill did a good job in reducing the material and left the grade in excellent condition. Approximately 1/2-in. of the aggregate base was removed along with the existing pavement. This was done to ensure complete removal of the bituminous surface. Removal of the existing 22-ft pavement was accomplished by using two 9-ft passes and a final 4-ft pass. Where cracking along the edge of the pavement had formed a small disconnected piece, the Rotomill did not reduce the piece to the less than 2-in. requirement. It was, therefore, not uncommon to find pieces up to 8-in. in size in the stockpile (Photo 3).

Before recycling could start the grade had to be approved for density and grade tolerance. There were problems encountered in meeting these requirements.

The contractor on average could only obtain 99 percent density where a minimum of 100 percent was the requirement. The grade appeared to be well compacted since it was left basically undisturbed by the Rotomill operation. The 100 percent density requirement limited production for the first few days of the project and was then later changed to a minimum of 98 percent. It was considered better to do this than to rip up the grade, add water, and then recompact. The aggregate base had originally been compacted to 100 percent density and traffic over 20 years had further compacted it.

There were also problems with grade tolerances. The existing grade was not in exact agreement with the original plan grade. Before the pavement was removed there were long rolls and dips. Since there were no quantities in the contract for grade correction, it was not up to the contractor to make these corrections. Thus, it was decided to try to correct these rolls and dips as much as possible by varying the depth of the pavement when surfacing.

The recycling of bituminous material was done with a Boeing Drum Mix Plant. The key component to recycling with this type of plant is the Pyrocone (Fig. 1). The Pyrocone was designed to minimize the vaporizing and burning of the salvaged bituminous mixture as it entered the drum. For a description of the Pyrocone see Appendix E.

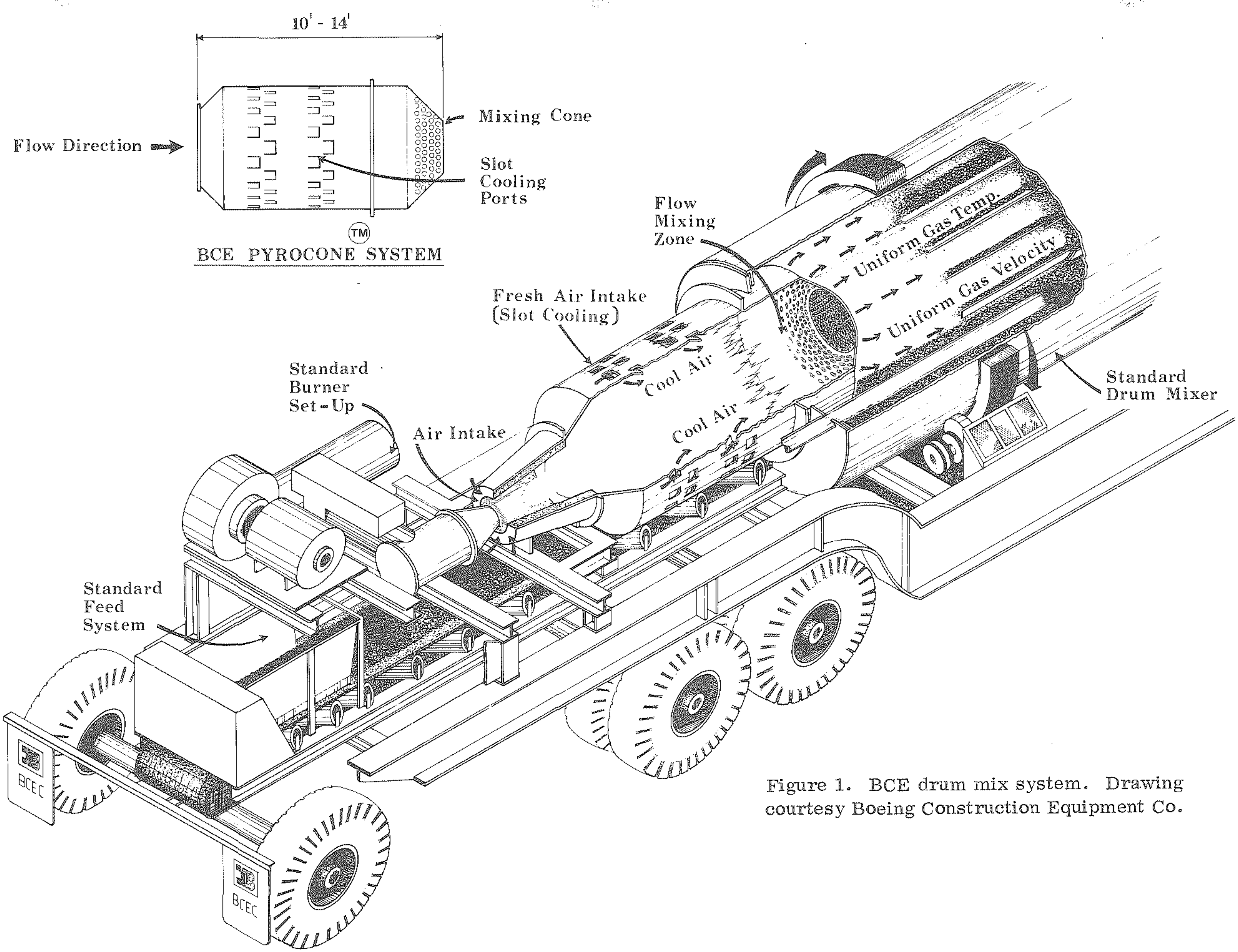


Figure 1. BCE drum mix system. Drawing courtesy Boeing Construction Equipment Co.

The following is a general description of how the plant operated for this project. The salvaged material was proportioned by use of cold feed bins (Photo 4). The gate was fully open and the rpm of the belt under each bin was controlled to give the proper percentage of salvaged and virgin material. The materials then continue on a conveyor belt over a belt weighing scale (which controls the amount of asphalt cement added) and then the material is sprayed with water (Photo 5). The water protects the salvaged bituminous material from high temperatures as it enters the drum. Next, the material enters the drum where it is heated, mixed, and new asphalt cement is added. The drum on this plant is 36 ft in length and at 11 ft from the entrance the asphalt cement is added. The material is mixed in the drum for approximately two minutes. The material then exits the drum and is lifted to a surge bin by conveyors. From the surge bin the material is loaded into trucks and transported to the paver. The entire sequence of the recycling operation is shown in Photos 2 through 12.

On July 25, the recycling began. The initial mix was set up to be 60 percent salvaged-40 percent virgin (by aggregate basis) with an additional 2.7 percent 200-250 penetration grade asphalt cement. The mix looked like a conventional wearing mix and production was 275 tons/hr (normal capacity of plant). It was decided to let some large chunks of salvaged material pass through the plant to see if they would break up. Upon exiting the drum there were still some chunks intact; however, after the material had been in the surge bin, transported in the truck, and delivered to the paver, the chunks had disappeared or were so soft the auger in the paver completely disintegrated them. The chunks were of no problem for the entire job; however, this did lead to a related problem.

Since there was no screen to scalp-off oversized material (in order to utilize chunks of salvaged material), any large stone that had inadvertently gotten into the cold feed bins would be incorporated into the mix. There were three sources of large stones (2 to 6-in. diameter). The first source was the ground around the plant site where, if the loader scooped too low, stones would be picked up. The second source was a similar situation where the virgin aggregate was being produced. The third source was the shoulder adjacent to the existing road where the Rotomill was removing material. The first two sources were eliminated by instructing the loader operators not to scoop so deeply, and the third source was eliminated by instructing the Rotomill operators to stay closer to the edge of the pavement.

Experimentation was done with the mixing temperatures. Excessively high mix temperatures produced a heavy blue smoke from the stack, where at low temperatures the smoke was minimized considerably. The optimum mix temperature would be the lowest temperature where density and workability requirements could be met. The first day the desired discharge temperature at the plant was 270 F. Later it was dropped to 260, 250, 240, and finally to 230 F. The temperature of the mix was approximately 10 to 15 degrees cooler by the time it arrived at the paver. At 230 F the mix became difficult to work with and 95 percent density was hard to obtain. A discharge temperature of 240 F proved to be optimum. This is the identical temperature that the Oregon DOT found to be optimum on a recycling project constructed last year with a similar plant (2).

Experimentation was also conducted on the percentage of salvaged, virgin, and new asphalt cement in the mix. This changing presented no construction problem and could be done almost instantly (see Fig. 2 for strip map showing various mixes). The change of mix percentages did greatly affect air quality and properties of the asphalt cement. These changes are dealt with in more detail in the Test Result and Air Quality sections of this report.

There were a few minor incidents during construction that served as lessons. One lesson learned by the contractor was that the salvaged material should not remain in the cold feed bins overnight. The next morning it took approximately two hours to free the bins, for the material had reset and hardened.

Another lesson learned was to avoid the inclusion of large amounts of patching material in the recycled mix. One section of road had a 200-ft maintenance patch in an area where base settlement had occurred. The material appeared to be a very soft cutback asphalt mix. When going through the drum, the exhaust from the plant turned very dark and the temperature of the mix suddenly increased 20 F. It was suspected that the volatile material in the patching mixture ignited in the drum. It is felt that oil aggregate roads, tar based materials, and multiple seal coats would also produce poor air quality.

A final incident showed the need for complete removal of the existing pavement when a bond coat is not being used. In the area where the thickness of the pavement changed from 3 to 5 in., the Rotomills left a small amount of pavement on the grade. When surfaced with the first of two courses, this area received only 3/4-in. thick pavement (instead of 1-1/2 in.). Photo 13 shows what happened to this area after a large trailer-truck combination (loaded with 40 tons of salvaged material) applied its brakes. A poor bond between the old surface and the thin mat caused the mat to slide. This area was later removed and repaired.

In general, the construction went very well with no major problems. Many lessons were learned from minor problems encountered and some predictions were reinforced.

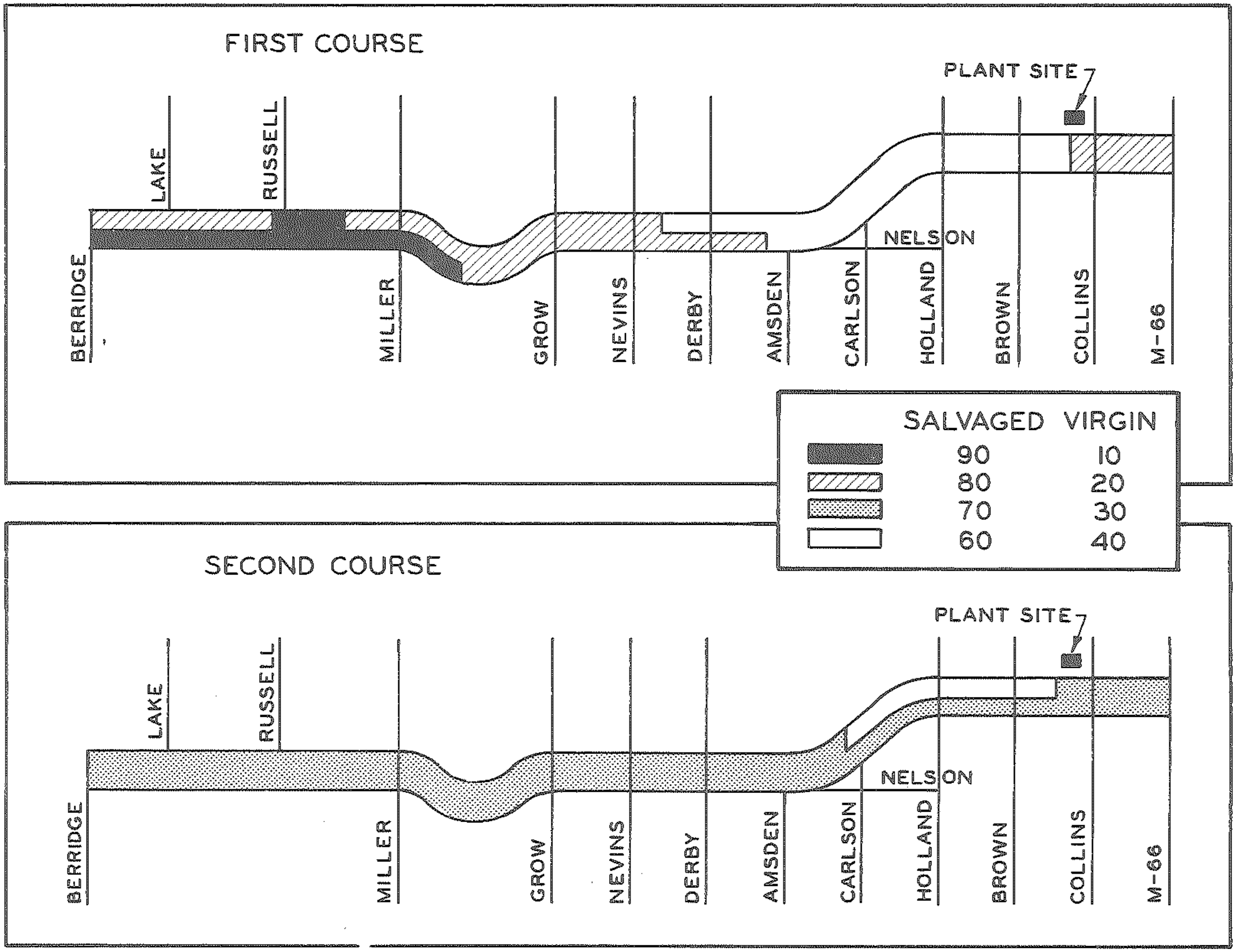


Figure 2. Percentages of salvag d virgin materials in recycled mix.

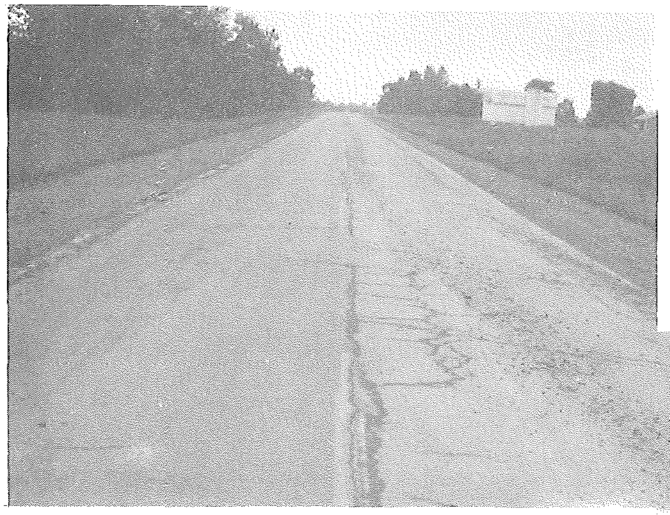


Photo 1. M 57 Before. Transverse thermal cracking, some alligator cracking in wheel-paths, and edge of pavement cracking all in evidence.

Photo 2. Pavement removal by rotary reduction machine.

Photo 3. Large chunk of salvaged material in stockpile.

Photo 4. Loading of cold feed bins.

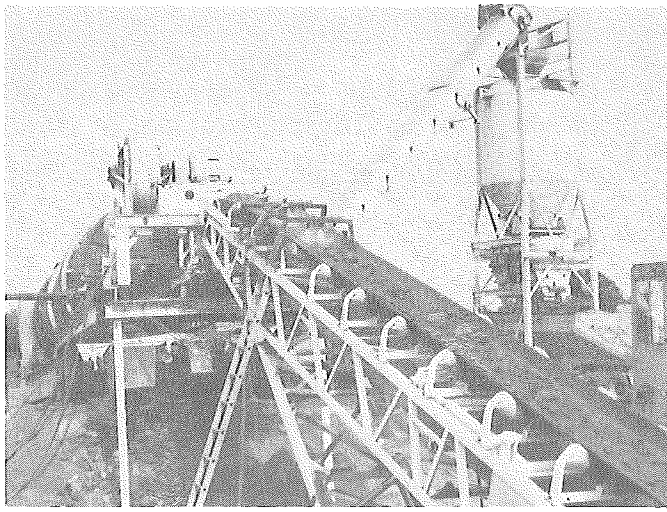
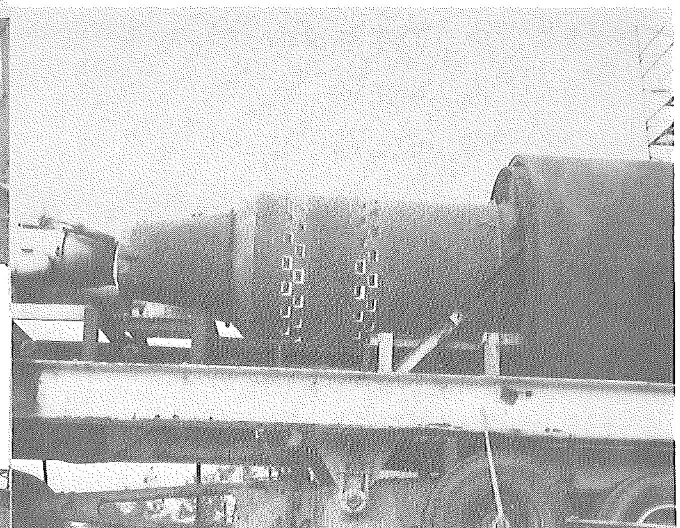


Photo 5. Material transported up conveyor to drum. Note water being sprayed on material.

Photo 6. Pyrocone.



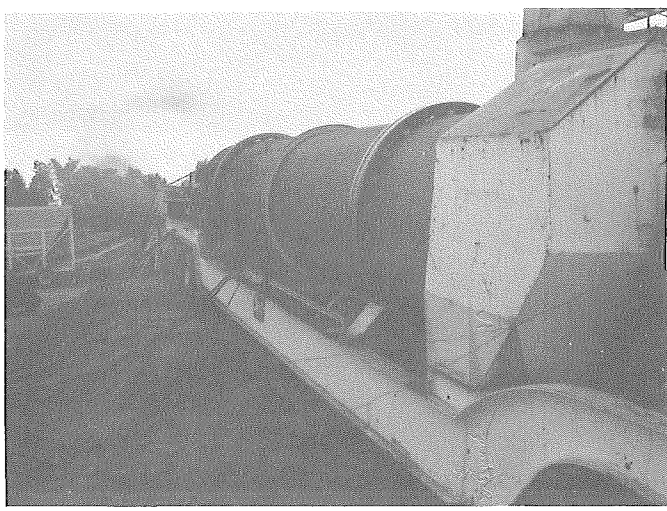


Photo 7. Looking at the drum from discharge end.

Photo 8. Material being discharged from weigh hopper. Eighty ton surge bin is above.

Photo 9. General view of plant site looking westerly.

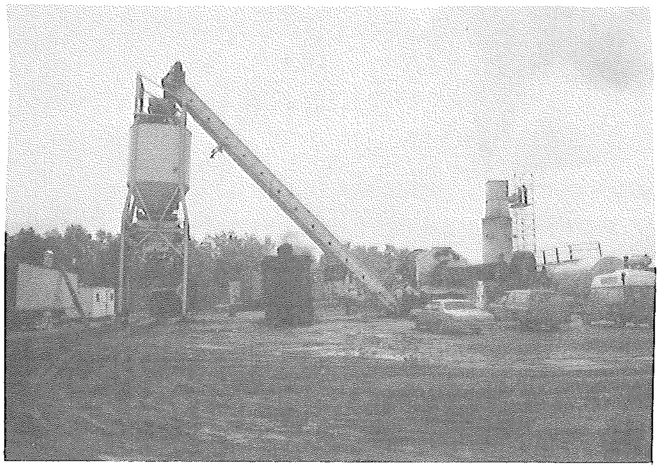


Photo 10. General view of plant site looking easterly.

Photo 11. Taking particulate tests for air quality. The plume is virtually all steam.

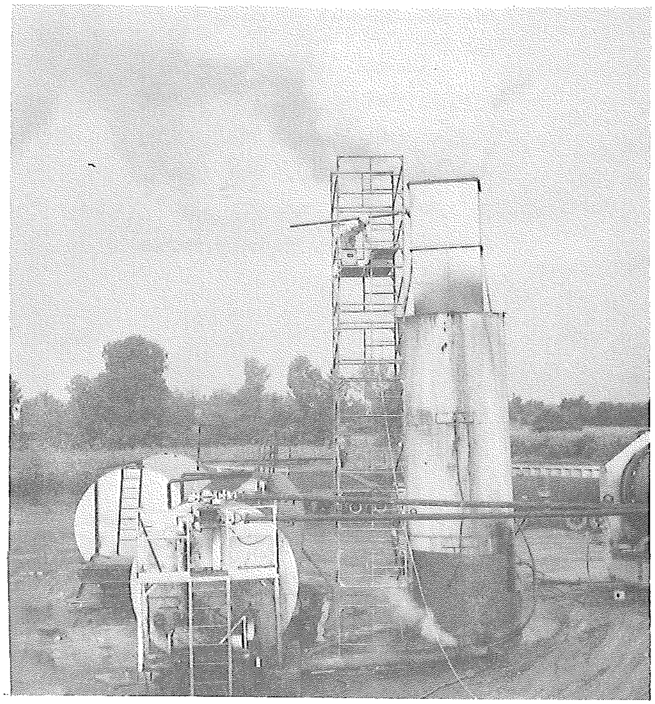


Photo 12. Paving operation.

Photo 13. Valuable lesson--this is what can happen when not all of the old material is removed. The resultant is a poor bond and slippage of thin pavement. This area was removed, repaired, and resurfaced with one more course.

Photo 14. M 57 After. Two 12 ft lanes with 3 ft paved shoulders.

Test Results

Large variations in the asphalt content and gradation test results are undesirable when producing a high quality bituminous paving material. However, it was suspected, even before the project had started, that there would be more fluctuations in the test results than found in conventional mixes. The reason for this was the added variable of the salvaged material. Any of the following factors can cause this added variability:

1. Variability in original bituminous mix,

2. Variable thickness of different courses (wearing, leveling, or binder),

3. Different construction histories (e.g., one area has had a resurfacing with a different composition of mix while another area has not),

4. Fluctuations in depth of aggregate base removed with the bituminous pavement.

Existing bituminous pavements that have wide variances in any of the first three factors should not be considered for hot mix recycling for producing a wearing course. M 57 was chosen as a suitable project for a recycled wearing course because of its uniformity. Except for a 1/2-mile section that received a 2-in. resurfacing, the material was uniform throughout the 7.2-mile project. Factor number four was considered to be the most significant on this project for producing variability in the salvaged material.

As mentioned previously, approximately 1/2 in. of aggregate base was removed along with the existing pavement in order to assure a good bond for the recycled mix. The following table shows the asphalt content of the salvaged material when various depths of aggregate base are included (assuming a 4.8 percent asphalt content in the salvaged mat and a 3-in. pavement thickness):

Inches of Aggregate Base in Salvage	Asphalt Content, percent
0	4.80
1/4	4.43
1/2	4.11
3/4	3.84
1	3.60

Thus, one can see that a minor fluctuation in the coldmilling operation can cause a substantial fluctuation in the asphalt content in the salvaged material.

In Appendix F are the summary sheets for field and laboratory test results. In Appendix G there are quality control charts for four gradation sieves and the extracted asphalt content. The average asphalt content for the entire project was 5.06 percent for the plant and 4.99 percent for the laboratory. At the beginning of the job, 5.4 percent was the target, however, the amount of material passing the 200 sieve was significantly higher in the actual mix than in the mix design. The reason the P200 was higher and the combined asphalt content lower than in the mix design was because more of the aggregate base was removed than had been expected. The laboratory averaged 6.78 percent P200 (plant values are often inaccurate due to less sophisticated equipment). The mix design was based on 5.8 percent P200. A mix design rule of thumb is that for an increase of 1 percent in the P200, the asphalt content should drop 0.3 percent.

Cores were taken from the newly compacted pavement and the air voids were found to be 3.6 percent at 5.2 percent asphalt cement. Air voids will become less with time as traffic further compacts the pavement. From experience, 3.0 percent is the desired air voids after traffic has had a chance to compact the pavement. However, 3.6 percent air voids for newly compacted pavement is low, thus, asphalt content around 5 percent did not seem excessively low. Appearance of the mix was good. However, the percentage of new asphalt added was increased (0.1 percent) to 2.8 percent for a 60-40 percent salvaged-virgin mix in order to keep the combined asphalt content from dropping too low. For a 70-30 mix, 2.3 percent asphalt cement was added; for an 80-20 mix, 1.9 percent asphalt cement was added; and for a 90-10 mix, 1.3 percent asphalt cement was added. The combined asphalt content was approximately 5 percent for all mixes.

In order to analyze the variability found in the control charts, a comparison to conventional mix variability is necessary. Standard deviation is used as the indicator of variability. The following table compares the variabilities for 10 end product (conventional wearing courses) projects done over the past three years in Michigan with the variabilities within the M 57 project.

	Standard Deviations For 10 Projects			Standard Deviation For M-57 Recycle
	Avg.	High	Low	
Plant Asphalt Content	0.20	0.29	0.14	0.37
Lab Asphalt Content	0.21	0.30	0.12	0.29
Plant P200	0.69	0.96	0.38	0.52
Lab P200	0.76	1.14	0.31	0.51
Plant P30	2.1	4.3	0.9	1.9
Lab P30	2.2	3.1	1.1	1.6
Plant P8	2.3	3.7	1.6	3.1
Lab P8	2.3	2.9	1.3	2.7
Plant P3/8	2.3	3.0	1.8	3.3
Lab P3/8	2.6	4.3	1.7	3.0

It should be noted that all the variability of test results is not caused by variation in the mix, but also by sampling and testing errors. Although it is being studied at present, we are not able to separate the mix variation from sampling and testing errors. Thus, overall variability of test results is the only available indicator of mix variation.

Standard deviations of asphalt contents were higher for the recycled project than for conventional mixes. This was expected due to the added variability of the salvaged asphalt cement. Although variability is higher, it is believed that the effects on the wearing course will be insignificant. It should also be noted that a contributing factor to the 0.37 plant asphalt standard deviation was the presence of moisture. Drum mix plants do not fully dry the aggregate, and moisture in the mix appears to be asphalt cement in plant extraction results. Although moisture corrections were used on this project, the added variable undoubtedly increased the standard deviation for the plant results.

In analyzing the variability of the aggregate gradations, it must be remembered that a change in the mix proportion of salvaged and virgin materials caused a small change in the percent passing the various sieves, thus increasing total job variability. Even so, for the No. 200 and No. 30 sieves the standard deviation was slightly lower than average, and for the No. 8 and 3/8-in. sieves it was slightly higher. It was somewhat unexpected that the variability for the aggregate gradations proved to be comparable to that of a conventional mix. It is felt that the reason for this was the fact that the aggregate base, the salvaged material, and the virgin material all have similar gradations.

Recovered penetrations (indicator of viscosity) of asphalt cement from laboratory extractions varied depending upon the percentage of salvaged and virgin used. The following table illustrates this.

	Original Pavement From Cores	Salvaged-Virgin, percent			
		90-10	80-20	70-30	60-40
Average Recovered Penetration	38.4	41.7	53.9	55.0	68.2
High	45	45	83	59	83
Low	28	36	42	48	55
Number of Samples	7	4	11	11	9

As expected the higher the percentage of salvaged material used the lower the recovered penetration (the higher the viscosity). Recovered penetrations in the 50's would be comparable to a typical recovery of a new 85-100 penetration grade pavement where values in the 70's would represent a new 120-150 pavement. Thus, the 80-20 and 70-30 mixes would seem to be similar to a new 85-100 penetration grade mix, and the 60-40 mix would be similar to a new 120-150 mix. Analysis of the old pavement showed an average recovery of 38 which indicates that the original asphalt cement still had some life in it. Recovered penetrations below 25 are thought to be indicators of a crack susceptible material. It is common to find badly cracked areas with recovered penetrations in the teens. Although recovered penetrations are not a fail-safe method of predicting cracking susceptibility, they are an indicator. Thus, it is felt that the 200-250 penetration grade asphalt sufficiently rejuvenated the old asphalt cement to the viscosity of a new cement, except for the 90-10 mix.

There is a widely accepted theory that some of the old hardened asphalt that was absorbed into the aggregate does not become part of the effective asphalt in a recycled mix. Thus, the recovered penetrations in a recycled mix are lower and are not true indicators as to the hardness of the effective asphalt cement. It is felt that a recycled mix may have a greater service life than the recovered penetrations indicate.

Moisture in the mix and stockpiles were monitored. Moisture in the virgin stockpile averaged 2.5 percent on a dry basis, and 2.0 percent in the salvaged pile. Anywhere from 1 to 3 percent water was added on the cold feed belt; however, this moisture had no chance to be absorbed into the stone and evaporated quickly upon entering the drum. Moisture in the mix varied with the temperature. At 270 F, 0.05 percent was in the mix, and at 240 F, 0.15 percent moisture was measured.

Approximately two months after construction, wet friction coefficients of the pavement were measured at 40 mph in accordance with ASTM E274. The average value was 0.54 with a high of 0.57 and a low of 0.49. The statewide average friction coefficient for initial construction is 0.51.

Air Quality

Particulate emissions were measured by Department personnel in order to determine if the plant complied with Federal and Michigan standards. Federal standards require that particulate matter shall not exceed 0.04 gr/DSCF* and the plume shall not exceed 20 percent opacity. Michigan standards require 0.30 lb/1,000 cu ft of gas, approximately equivalent to 0.15 gr/DSCF, and the plume shall not exceed 20 percent opacity.

The following table shows the particulate emissions measured for this project:

Date of Sample	Mix Ratio Salvaged-Virgin	Particulate Emissions gr/DSCF (EPA Method 5)
August 1, 1978	80-20	0.20
August 3, 1978 - #1	90-10	0.21
August 3, 1978 - #2	90-10	0.20
August 4, 1978	80-20	0.19
August 10, 1978 - #1	70-30	0.11
August 10, 1978 - #2	60-40	0.09

All six tests were above the 0.04 Federal requirement but two of the six were below the 0.15 Michigan requirement.

There was no one available trained in measuring opacity; however, at 60-40 salvaged-virgin and 70-30, the plume of the stack appeared as steam only. At 80-20 a light blue smoke appeared and at 90-10 it became heavy.

Particulate emissions were also measured by Department personnel on a Gratiot County drum mix recycling project that was done concurrently with M 57. Three of the four tests passed the Federal requirements (0.09, 0.04, 0.02, and 0.01 gr/DSCF) and all passed Michigan requirements. The Barber-Greene drum mix plant used on this project had a baghouse collection system versus a wet scrubber that was used on the M 57 project. The Gratiot County job was running lower percentages of salvaged material (30 to 50 percent versus 60 to 90 percent on M 57).

* grains/dry standard cubic foot of gas

Over the winter, Spartan Asphalt Co. plans to rebuild the exhaust system on their Boeing plant that was used on M 57 in order to comply with Federal standards for particulate emissions. They presently have little or no problem with opacity (caused by burning and/or vaporizing of asphalt cement--generally the air quality problem associated with recycling).

The interest in recycling and improved air quality are both recent developments, and a great deal of work is being done to improve them. The Gratiot County project proves that both interests can be accomplished concurrently. It is felt that with an improved collection system, the plant used on M 57 would have also complied with Federal standards.

Energy-Resource Savings

It is calculated that 190,000 gal of asphalt cement and 15,600 tons of aggregate were recycled on this project. Use of the drum mixer and low mix temperatures saved an estimated 20,000 gal of dryer fuel oil. It is also calculated that approximately 5,300 tons of shoulder material were saved (because of removal of old pavement the top 3 in. of shoulder material was not paved over but bladed over to the new edge of pavement). Quantities are not known, but it is felt that a considerable amount of fuel was saved by recycling the aggregate from the existing roadway. New aggregate had to be hauled 15 miles one way to the plant site where the salvaged material haul was from 0 to 6 miles.

Costs

The bid prices for the various items of work were as follows:

Removal, transport, and crush bituminous pavement (4-in. or less)	\$ 1.50/sq yd
Removal, transport, and crush bituminous pavement (more than 4-in.)	\$ 1.75/sq yd
Aggregate 20AA	\$ 4.50/ton
Asphalt cement	\$95.00/ton
Recycling bituminous material	\$ 7.20/ton

The final quantities varied somewhat from the estimated quantities. See Appendix B for calculations of costs. Overall, it cost \$16.72/ton for the entire recycling process. This compares very favorably to the 4.12 wearing course price of \$20.20/ton and leveling course price of \$18.95/ton for work elsewhere on the project.

The cost for 90-10 ratios of salvaged-virgin was not significantly different from the cost of a 60-40 ratio ($16.71/ton versus $16.75/ton, respectively). The cost of Rotomilling on this project was relatively high, $8.81/ton of salvaged material. On the I 94 project the Rotomilling cost was $6.60/ton; however, the average thickness of the pavement was greater (6 in. versus 3 in.).

For resurfacing jobs in urban areas where removal of pavement is necessary to maintain curb and gutter effectiveness, recycling is extremely economical. In speaking with officials from the Detroit area, they explained that they pay approximately $8/ton to remove the existing pavement (which becomes property of the contractor) and then pay from $22 to $25/ton for a new resurfacing. Thus, the cost of this type of operation is approximately $30/ton, where the recycling on M 57 was $16.72/ton--a considerable savings.

As mentioned previously, approximately 5,300 tons of shoulder material was saved. At $3.50/ton this would amount to a savings of approximately $18,500.

Recycling has already proven to be economical as far as initial reconstruction costs are concerned. However, long-term durability is still unknown; thus, costs amortized on an annual basis are unknown. If the long-term durability of recycled mixes proves to be similar to that of a new mix, and if the current trend of material costs increasing at a faster rate than the average rate of inflation continues (due to finite resources and environmental concerns this should be true), there is little doubt that recycling pavements will become more attractive in the future.

Conclusions

Major conclusions for this project are as follows:

1. There were no major construction problems on this project. Construction equipment is available to successfully recycle bituminous material by hot mixing.

2. A high quality bituminous wearing course can successfully be produced by hot-mix recycling. Control of the asphalt content is not as good as with a conventional mix; however, this was expected due to the added variability of the salvaged asphalt cement. A standard deviation of approximately 0.3 percent for the asphalt cement was encountered on this project, compared to an average of 0.2 percent for conventional mixes. The difference in control is not felt to be critical. Variability of the aggregate gradation proved to be similar to that of conventional mixes.

3. A 200-250 penetration grade asphalt cement rejuvenated the old asphalt cement to the viscosity of a new mix, except for the 90 percent salvaged-10 percent virgin mix.

4. A considerable savings in energy, resources, and money is realized through recycling. A minimum of 210,000 gal of petroleum products were saved along with approximately 21,000 tons of aggregate. Recycled wearing course material was $16.72/ton versus $20.20 for conventional wearing course used elsewhere on this project.

5. The plant used on this project did not meet Federal air quality requirements for particulate emissions; however, a drum mix plant used on a Gratiot County recycling project met Federal particulate requirements in three of four tests. The interest in recycling and improved air quality are both recent developments, and a great deal of effort is being given toward improving them.

6. Quantities should be set up for grade correction, for complete removal of the existing pavement gives a second chance to correct grade deficiencies.

7. There are certain materials that should be avoided when recycling. The small amounts of patching material encountered on this project caused smoking from the mixer. It is felt that oil aggregate roads, tar based materials, and multiple seal coats would also produce poor air quality. Existing bituminous pavements that have wide variances in gradation and asphalt contents should not be considered for hot mix recycling for use as a wearing course.

Recommendations

Major recommendations for this project are as follows:

1. Recycling material through a drum mix plant for use as a wearing course should be considered a desirable alternative to resurfacing.

2. Guidelines should be developed to aid in the selection, planning, design, and construction of recycling projects. Much of the information and experience gained in this project and others should be incorporated into these guidelines. To date there has been much enthusiasm in the potential for recycling but a general lack of experience in it. Guidelines would help District personnel in selecting and programming projects, Testing and Research personnel in making a recommendation of procedure, Design personnel in preparation of the proposal, and Construction personnel to alert them to the necessary work and inspection required for successful projects.

REFERENCES

1. National Asphalt Pavement Association, Recycling Report, "State-of-the-Art: Hot Recycling," Volume 1 - No. 1, May 1977.

2. Rural and Urban Roads, "Recycling the Hotmix Way: What Texas and Oregon Learned," July 1978.

APPENDIX A

SPECIAL PROVISION FOR RECYCLING

APPENDIX A

FOR M-57 FROM BERRIDGE ROAD TO M-66

SPECIAL PROVISION
FOR
RECYCLING BITUMINOUS PAVEMENT

A. DESCRIPTION: This work shall consist of removing the existing 22' bituminous pavement, crushing and recycling through a bituminous Drum Mix plant. Recycled material shall be replaced on the 30' roadway, as shown in the proposal.

B. CRUSHING: The existing 22' bituminous pavement shall be removed full depth and crushed so that 95% passes the two (2) inch sieve. Oversize pieces that will adversely affect the recycled bituminous mixture shall be removed prior to incorporation in the mix. The salvaged bituminous pavement material shall be stockpiled at the plant site in a uniform mixture. If the existing bituminous pavement is removed in two passes, separate stockpiles shall be maintained and blended through the cold feed as directed by the engineer.

C. COMPOSITION AND QUALITY OF RECYCLED BITUMINOUS MIXTURE: Based on the gradation, existing asphalt content and recovered penetration of the existing asphalt, the Testing Laboratory will prepare a job mix formula for the recycled bituminous mixture. The recycled mixture shall be produced with the addition of 0 to 40 percent of 20AA aggregate and 0.0 to 3.0 percent of 200-250 penetration asphalt cement. Water as directed by the Engineer shall be added to the salvaged bituminous material on the cold feed belt.

D. PLANT EQUIPMENT: All equipment shall meet Section 7.10.08 of the 1976 Standard Specifications except a system to prevent direct burner flame contact with salvaged bituminous material shall be part of the dryer drum. A water spray bar with a flow meter indicating gallons and a delivery pump with an on-off switch in the control room shall be attached to the cold feed conveyor to spray on the salvaged bituminous material as it is being fed to the dryer drum. The plant shall at all times conform to local and state air quality standards. The contractor shall submit, prior to the award of the contract, an acceptable proposal for preventing excessive air pollutants.

E. COMPACTIVE EQUIPMENT: Special Provision for Compacting Bituminous Pavement (See Attachment) will apply.

F. CONSTRUCTION METHODS: Prior to placing of the recycled bituminous material, the existing aggregate base shall be reshaped and compacted to conform to the provisions of 3.01.07a.

G. MEASUREMENT AND PAYMENT: Removing and crushing of the existing bituminous pavement and transporting to the plant site will be measured and paid for by the square yard. Addition of 20AA aggregate to the salvaged bituminous pavement shall be paid for separately. Asphalt cement added to the mixture during the recycling process will be paid for separately as specified under Measurement and Payment Section 1.09. Recycling with the addition of aggregate, hauling, placing and compacting, will be measured and paid for as specified under Section 4.11 of the 1976 Standard Specification. Quantities shall be determined based upon mix design percentage of the resultant recycled material.

PAY ITEM	PAY UNIT
Removing, Crushing, and Transporting Existing Bituminous Pavement	
4" thickness or less	Square Yard
Greater than 4"	Square Yard
Aggregate 20AA	Ton
Asphalt Cement	Ton
Recycling Bituminous Material	Ton

APPENDIX B

CALCULATIONS OF COSTS

APPENDIX B

CALCULATIONS OF COSTS

Item of Work	Unit	Unit Price	Quantities Used	Costs
Remove 4" or less of Bit. Pav't.	Sq.Yd.	$ 1.50	89,011	$133,516.50
Remove more than 4" of Bit. Pav't.	Sq.Yd.	$ 1.75	5,622	$ 9,838.50
Aggregate 20AA	Ton	$ 4.50	6,013	$ 27,058.00
Asphalt Cement	Ton	$95.00	489.1	$ 46,464.50
Recycling Bituminous Material	Ton	$ 7.20	22,773.4	$163,968.48
				$380,846.48

$$\text{Total Cost per ton} = \frac{\$380{,}846.48}{22{,}773.4} = \$16.72/\text{ton}$$

APPENDIX C

ANALYSIS OF CORES -- EXISTING PAVEMENT

REPORT OF TEST
GENERAL

Control Section Identification	Mb 59022
Job No.	12689A
Laboratory No.	78B-667 thru 674
Date	May 10, 1978

Sheet 1 of 2

Report on sample of: BITUMINOUS CONCRETE MIXTURE (Cores)

Date sampled: January 12, 1978 — Date received: April 11, 1978

Source of material: Recycled Existing Pavement

Sampled from: Pavement (M-57) — Quantity represented: Core No. 1 thru 8

Submitted by: R.N. Shean, Testing Laboratory Section

Intended use: Wearing course — Specification: 1976 Std Specs Supp

	Course:					
Lab Number 78B-	668	669	670	671	672	673
Core Number	2	3	4	5	6	7
Average Thickness	3.2	3.1	3.0	3.2	5.1	2.8
Moisture in Sample % by wt.	.25	.25	.20	.30	N/A	N/A
Gradation: Cumulative % Passing ¾ in.	100.0	100.0	100.0	100.0	100.0	100.0
½ in.	96.2	96.5	95.5	94.9	96.1	95.7
⅜ in.	82.8	78.1	82.5	78.8	83.7	81.9
No. 4	51.6	45.1	50.0	45.1	59.2	52.0
No. 8	40.2	35.8	38.9	35.6	47.1	41.1
No. 16	34.0	31.0	33.3	30.8	38.8	35.3
No. 30	29.6	27.8	29.5	27.1	32.0	31.4
No. 50	20.7	20.6	22.5	19.9	19.5	23.1
No. 100	10.2	10.9	11.6	9.5	9.7	11.7
No. 200	5.6	5.3	6.0	5.1	6.0	6.7
Bitumen %	4.8	4.9	4.8	4.4	5.3	5.0
Tests on Recov Asphalt: Penetr, dmm	36	36	45	28	42	45

	Course:					
Lab Number 78B-	674					
Core Number	8					
Average Thickness	3.4					
Moisture in Sample % by wt.	N/A					
Gradation: Cumulative % Passing ¾ in.	99.2					
½ in.	95.7					
⅜ in.	82.4					
No. 4	53.2					
No. 8	42.4					
No. 16	36.6					
No. 30	32.5					
No. 50	23.1					
No. 100	11.9					
No. 200	6.5					
Bitumen %	4.7					
Tests on Recov Asphalt: Penetr, dmm	37					

REMARKS:

See Sheet 2

pbr

Signed: M E Witteveen
Engineer of Testing

REPORT OF TEST

GENERAL

1801 (8/75)

Control Section Identification	Mb 59022
Job No.	12689A
Laboratory No.	78B-667 thru 674
Date	May 10, 1978

Report on sample of BITUMINOUS CONCRETE MIXTURE (Cores)

Date sampled ______ Date received ______

Source of material ______

Sampled from ______ Quantity represented ______

Submitted by ______

Intended use ______ Specification ______

TEST RESULTS

Location: M-57 from M-66 interchange to Greenville City Limits.
All Cores were taken heading easterly from Greenville.

Core Number	Location	Position
1	1,000' East of Greenville	Right Wheel Track
2	500' East of Berridge Road	Right Wheel Track
3	200' East of Russell Road	Right Wheel Track
4	Directly across from Roadside Park	Right Wheel Track
5	1,000' East of Grow Road	Right Wheel Track
6	1,000' East of Derby Road	Right Wheel Track
7	1,000' East of Holland Road	Right Wheel Track
8	500' East of Collins Road	Right Wheel Track

REMARKS: Tested for Information

cc:
File
D.F. Malott
D. Moore
R.N. Sheap (2)

pbr

Signed M E Witteveen
Engineer of Testing

APPENDIX D

MARSHALL MIX DESIGN

1932 (N9/77)

REPORT OF TEST

BITUMINOUS MIXTURE DESIGN DATA

Control Section Identification	Mb 59022
Job No.	12689A
Laboratory No.	78B-3316D
Date	August 4, 1978

Type of Mix BITUMINOUS AGGREGATE Mix Design No. 55 Date Tested July 25, 1978

Intended Use Surfacing Course (Recycle & 20AA) Specification 4.11, 1976 Std Specs Supp

MATERIALS USED

Material	Type	Source	Pit Number	Apparent Specific Gravity	Bulk Specific Gravity	Absorption Percent
Asphalt	200-250	Trumbull Asphalt Co., Detroit		1.020		
Recycled Pav't	Bit Concrete	M-57 Greenville, Michigan		N/A	N/A	N/A
Dense Graded	20AA	Spartan Asphalt Co., Stockpile	N/A	N/A	N/A	N/A

AGGREGATE GRADATION
CUMULATIVE % PASSING

Sieve Size	Dense-Graded Agg	Course Agg	Fine Agg	Extracted Agg
1 inch	100.0	100.0		100.0
3/4 inch	100.0	100.0		100.0
1/2 inch	99.1	98.4		98.6
3/8 inch	86.3	86.8		86.6
No. 4	68.7	55.8		60.9
No. 8	56.7	44.1		49.1
No. 16	45.7	37.0		40.4
No. 30	34.4	32.0		33.2
No. 50	16.3	24.0		20.9
No. 100	6.2	12.1		9.7
No. 200	4.0	7.0		5.8

MIX DESIGN

Asphalt %	2.7
P 8	49.1
P 200	5.8
Marshall Density lb/ft^3	150.3

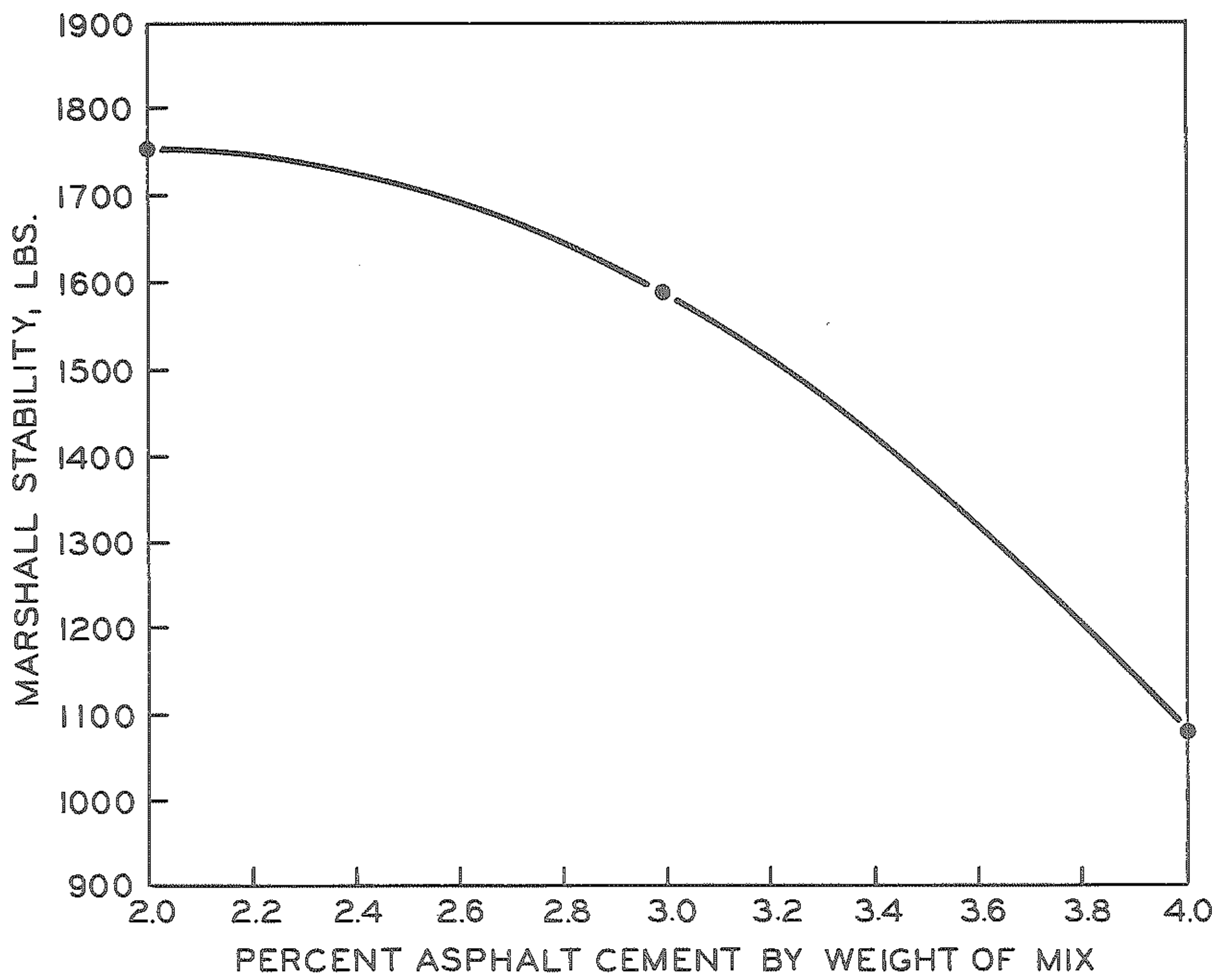
Compactive effort of 50 blows

REMARKS: The above bitumen content and aggregate proportions are based on the samples of materials submitted to the laboratory for mix design as indicated above. Variations in the actual materials and other field conditions may require a field correction in the aggregate proportions and adjustment of the bitumen content not to exceed ±0.2 percent.

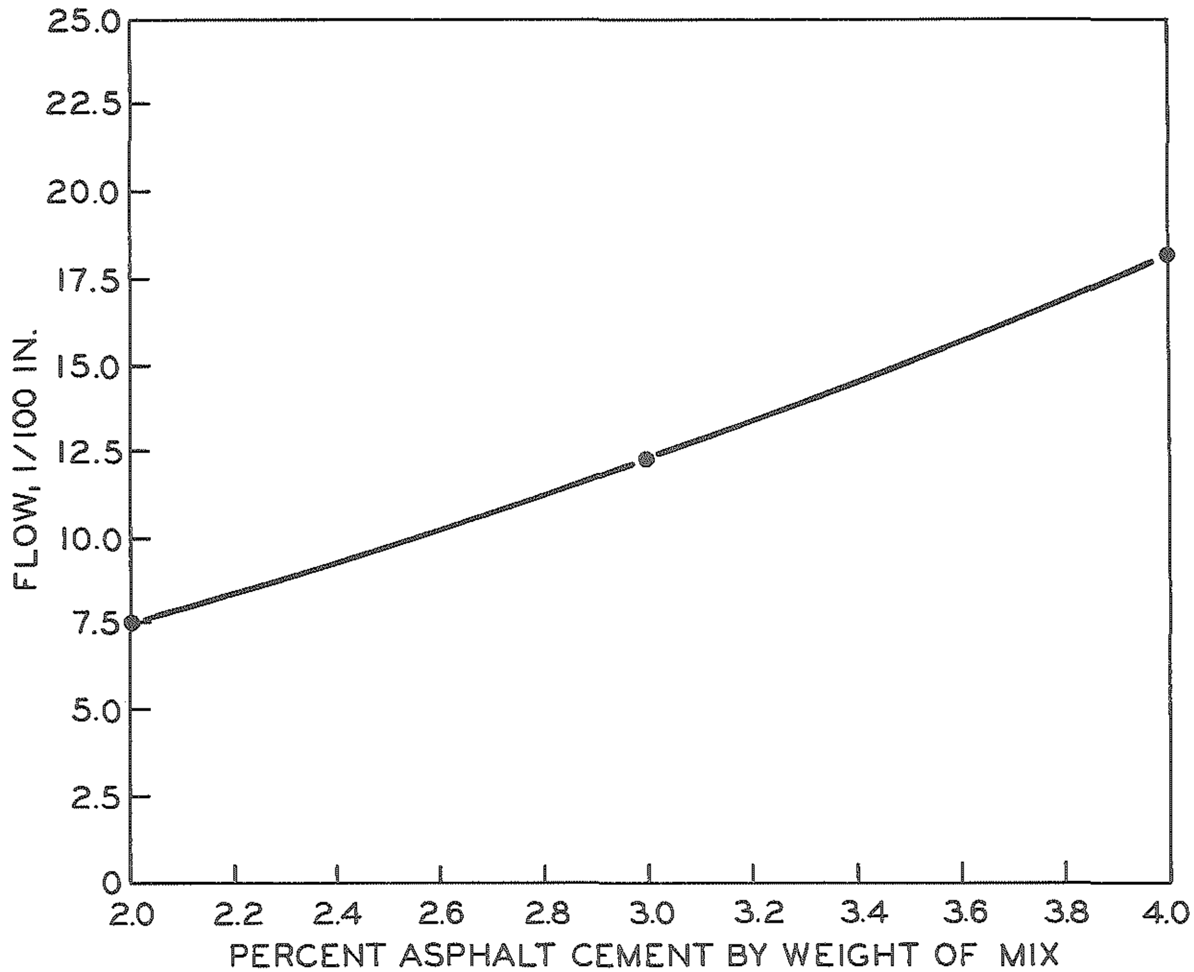
Tested for information

cc:
File
D. F. Malott
J. Norton
J. Marsh
F. Carian (3)

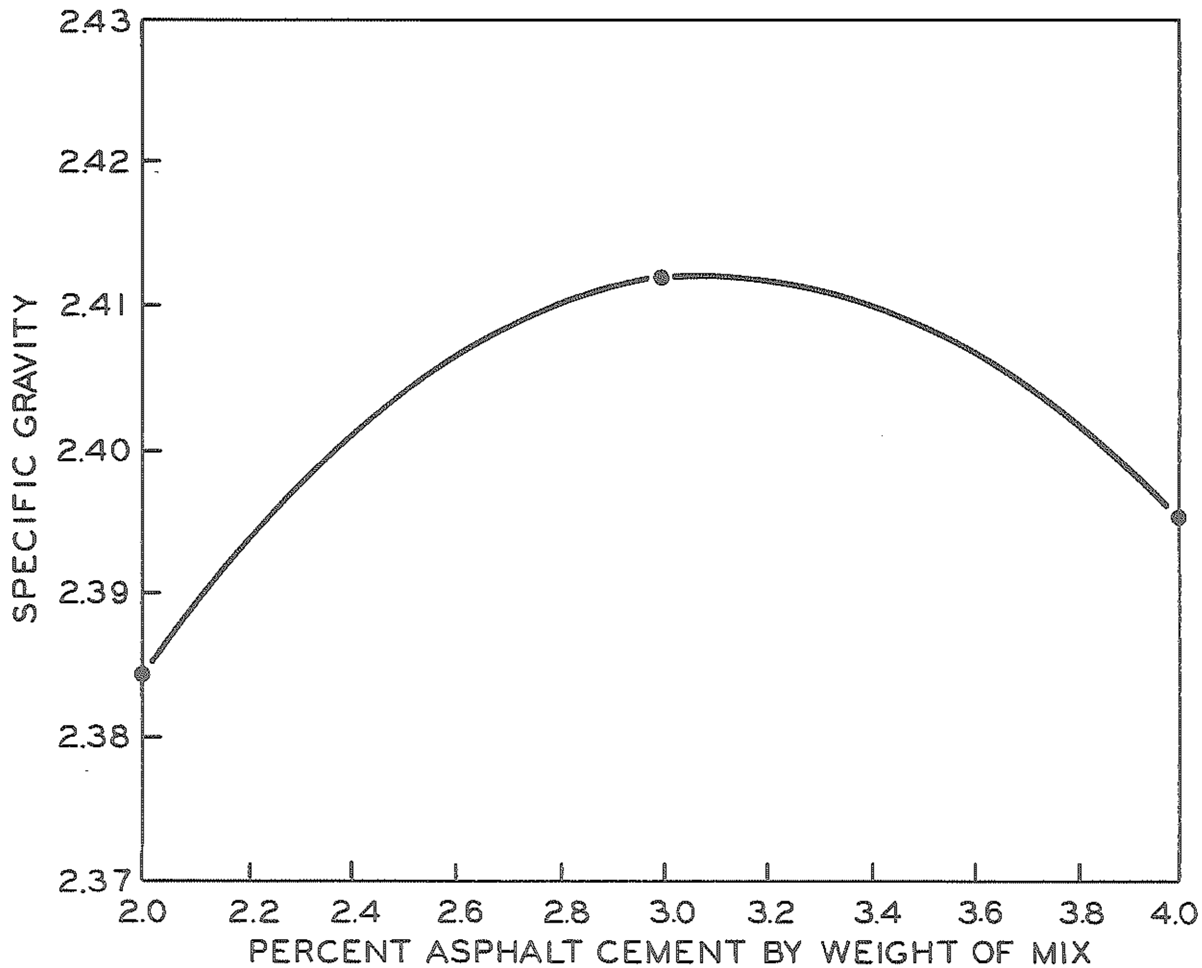
Signed M. E. Witteveen
Engineer of Testing



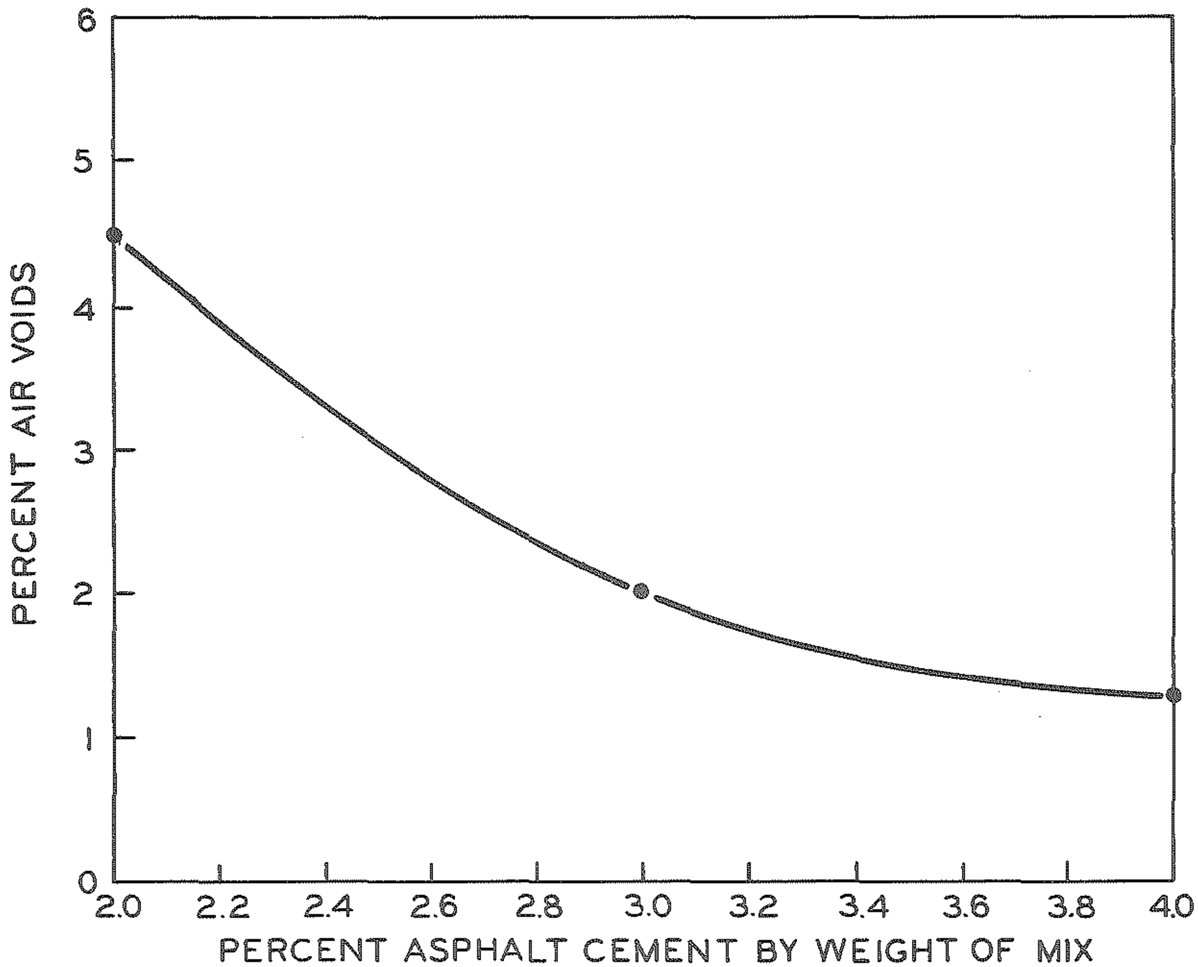
Marshall Mix Design Chart



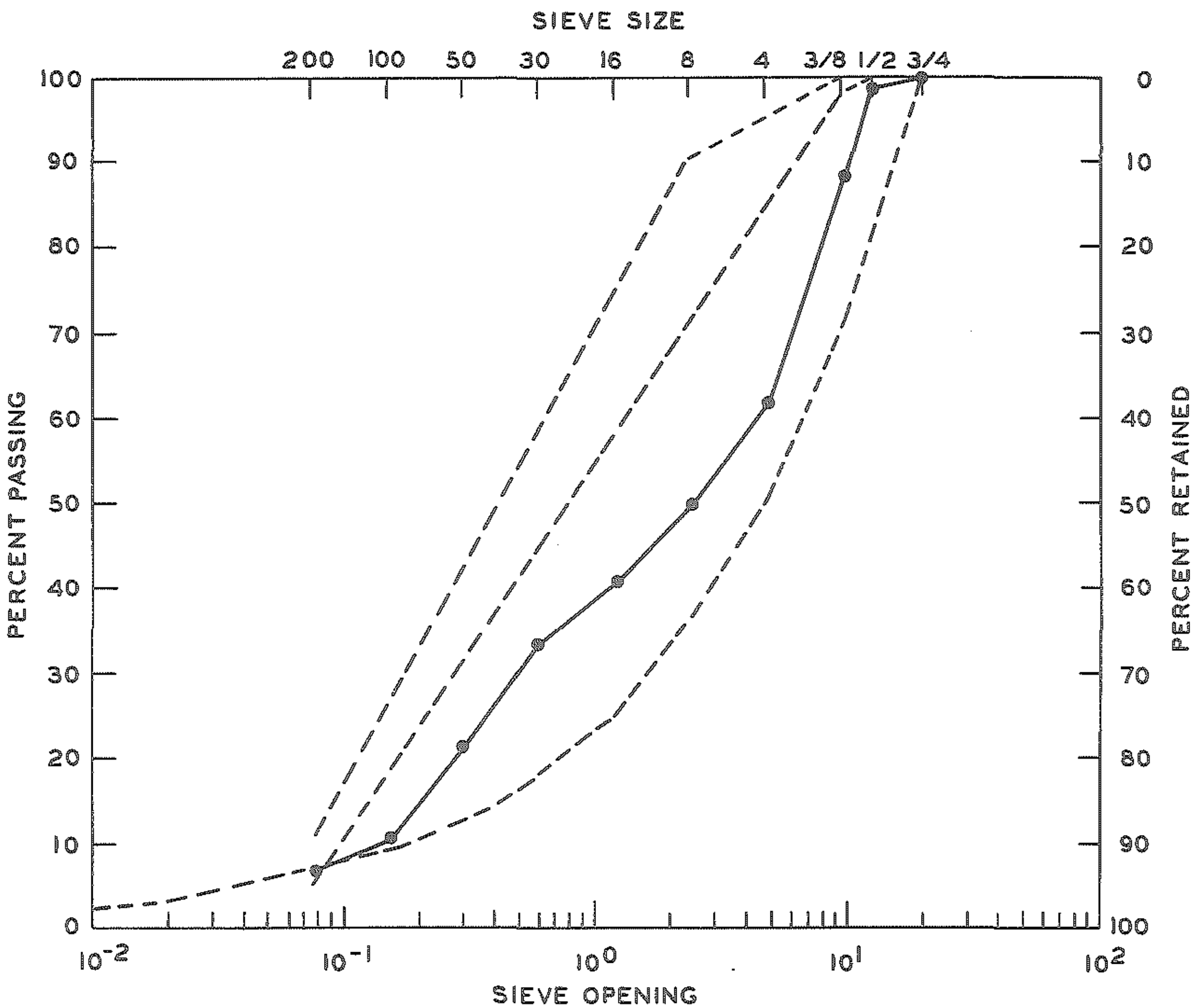
Marshall Mix Design Chart



Marshall Mix Design Chart



Marshall Mix Design Chart


SIEVE SIZE
200
100
50
30
16
8
4
3/8
1/2
3/4
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
PERCENT RETAINED
0
10
20
30
40
50
60
70
80
90
100
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
SIEVE OPENING

APPENDIX E

PYROCONE COMBUSTION CONTROL SYSTEM

APPENDIX E

BOEING CONSTRUCTION EQUIPMENT CO.

PYROCONE^{TM*} - COMBUSTION CONTROL SYSTEM

Boeing Construction Equipment Co. has developed a system to allow the direct processing of old crushed asphalt pavement as recycled hot mix. The development is called the PYROCONE - Combustion Control System. The PYROCONE can be easily adapted to any Boeing drum mixer without requiring significant modifications to the basic plant.

The development of the PYROCONE was started in early 1975 and has progressed through a design evolution leading to the processing of over 170,000 tons of recycle mix during the 1977 paving season. Early in the development of the PYROCONE minimum performance goals were set for the system. These goals are as follows:

1. The system must eliminate the heavy smoke emissions associated with recycle production.

2. The system must adapt to existing drum mix hardware.

3. The system must not upset the basic simplicity of the drum mix process.

4. The system must be able to process high ratio mixes, up to 100% recycle at high production rates.

During 1977 these performance goals were realized. The PYROCONE was used on four separate projects varying from 100% recycle to 70% recycle, 30% new material. Four separate plants were used, three existing units and one new plant.

The PYROCONE makes smoke-free processing of recycled materials possible by controlling the combustion process and burner flame before the flame enters the drum. The PYROCONE design was based on a detailed analysis of the heating process in and around the flame. This analysis shows that the surface temperature of the aggregate at the front end of the drum can reach 1500°F or more due to the extreme heat transfer rates.

* PYROCONE is a trademark of The Boeing Construction Equipment Co.

The extreme heat transfer is the result of high levels of thermal radiation and convection driven by the flame temperature which can be in excess of 3000°F.

When the aggregate surface temperature reaches levels above 700°F the old asphalt cement will vaporize, pyrolize and burn, producing a very dense black smoke.

With the PYROCONE system, the heat transfer rate in the burner end of the drum is controlled to prevent overheating the recycled material, thereby eliminating the heavy exhaust smoke associated with hot-mix recycle.

Physically, the system consists of a cylindrical combustion chamber with a conical heat shield at one end. The unit is installed between the burner and the drum entrance by moving the burner assembly back on the mixer frame. The flame volume is contained within the cylindrical chamber where excess air and combustion gases are mixed to produce a lower temperature, air rich mixture.

The excess air flows into the combustion chamber through slots in the chamber wall which provides wall cooling.

The reduced heating rates with the combustion control system are the result of three interrelated effects. First, the heat shield acts to reduce direct radiation by interrupting the line-of-sight path between the flame volume and the aggregate to be heated. Secondly, the heat energy entering the drum is more uniformly distributed over the drum cross section. And third, the system lowers the temperature of incoming gases from over 2600°F to around 1200°F. The net effect of the system is to lower the heating rate in and around the flame volume to a small fraction of its normal value.

In summary, the PYROCONE system represents a relatively simple modification to the Boeing drum mixer which allows efficient processing of recycled hot mix. The system will accommodate any mixture ratio from all new material to 100% recycled materials. The PYROCONE has been successfully used at production rates over 75% of the normal plant production. The pollution potential and associated problems with recycled will vary from job to job depending upon the mixture ratio, asphalt type, mix temperature and many other variables. However, the PYROCONE system has shown the capability to adequately control pollution over a number of major projects with a wide variation in mix type, mixture ratio, and bituminous additives.

Prepared By

Bernard A. Benson
Director of Product Development
Boeing Construction Equipment Co.
March 10, 1978

APPENDIX F

SUMMARY SHEETS OF TEST RESULTS

1656 (11/75)

SUMMARY OF BITUMINOUS FIELD & LABORATORY TEST RESULTS

PROJECT Mbr 59022 - 12689A	LOCATION M-66 Greenville		BITUMINOUS Recycle COURSE (4.11)
CONTRACTOR Spartan Asphalt Paving Co.	PLANT NUMBER 440-4	PROJECT ENGR. David W. Miller	INSPECTOR David G. Ranson
STONE (20AA Isabela Corp. Buntz Pit Vestaburg		SAND ( )	
MINERAL FILLER ( )		BITUMEN (200-250 Marathon Oil Co. Detroit	1976 STD SPECS

DATE SAMPLED		7-25		7-25		7-26		7-27		7-28		7-28		7-28		7-28		7-31		7-31		7-31		8-1	
1978		LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD
SAMPLE NO.																									
MIX	BIT. %	5.6	5.8	5.1	4.8	5.1	5.1	4.8	5.2	5.1	3.9	5.3		5.0	5.4	5.1	5.2	5.1	5.0	5.0	5.1	5.0		5.0	5.25
AGGREGATE GRADATION PER CENT PASSING	1 1/2																								
	1													100				100				100			
	3/4	100	100	100	98	100	100	100	100	100	100	100		99	100	100	100	99	99.9	100	100	99.9		100	100
	1/2	97	97	96	94	95	94	97	96	96	89	94		92	93	95	96	94	94	94	93	93		97	93
	3/8	86	90	89	85	85	85	85	88	84	76	84		81	81	85	86	83	82	84	84	81		88	85
	4	63		62		61		63		59		62		58		61		59		55		55		63	
	8	51	51	49	49	49	47	51	52	48	43	50		48	47	49	48	45	44	44	45	44		50	49
	16	42		40		41		43		40		42		40		40		38		37		37		42	
	30	35	34	33	30	35	33	35	36	33	31	35		33	33	34	34	33	31	31	32	31		36	34
	50	22		20		21		17		21		22		21		23		22		21		21		25	
	100	11		10		11		10		10		11		11		12		12		11		12		12	
	200	6.6	5.4	5.9	5.4	6.4	5.8	6.3	5.9	6.4	5.3	7.0		6.2	4.8	7.3	6.1	7.0	6.0	6.4	6.3	7.1		7.8	6.7
AVG. HOT BINS CA	P8																								
	P200																								
AVG. HOT BINS FA	P8																								
	P200																								
MIN. FILLER	P8																								
	P200																								
MIX DESIGN	BIT. %	2.7										2.7		1.8								1.8			
	Salvaged	58.4										58.4		78.6								78.6			
	20AA	38.9										38.9		19.6								19.6			
PLANT DATA	BIT. %																								
	CA %																								
	FA %																								
	FILLER %																								
ASPH TESTS PEN	ORIG.	271				348		286						257						256					
	REC.	60		71		64		83		70		73		83		56		53		47		61		52	
MIX TEMP. F		270				260		250		255								250						240	
TONS MIX		342				413		2102		1010								1370						1789	

SUMMARY OF BITUMINOUS FIELD & LABORATORY TEST RESULTS

1856 (11/75)

Sheet 2 of 3

PROJECT Mbr 59022 - 12689A	LOCATION M-66 Greenville		BITUMINOUS Recycle COURSE (4.11)
CONTRACTOR Spartan Asphalt Paving Co.	PLANT NUMBER 440-4	PROJECT ENGR. David W. Miller	INSPECTOR David G. Ranson
STONE (20AA) Isabela Corp. Buntz Pit Vestaburg		SAND ( )	
MINERAL FILLER ( )		BITUMEN (200-250) Marathon Oil Co. Detroit	1976 STD SPECS

DATE SAMPLED		8-1		8-1		8-2		8-2		8-3		8-3		8-4		8-7		8-7		8-9		8-9		8-10	
1978		LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD
SAMPLE NO.																									
MIX BIT. %		4.9	5.05	5.0	4.85	4.2	4.1	5.1	5.0	4.7	4.9	4.7	5.4	4.9	5.4	5.1	5.0	5.1	5.5	5.3	5.3	4.9	5.2	5.4	5.0
AGGREGATE GRADATION PER CENT PASSING	1 1/2																								
	1									100										99					
	3/4	100	99	100	100	100	100	100	100	98	100	100	100	100	100	100	100	100	100	99	100	100	100	100	100
	1/2	96	94	96	93	91	91	92	96	93	96	97	97	94	97	94	97	96	97	91	94	92	95	96	96
	3/8	87	84	84	79	77	78	81	83	82	85	87	88	82	87	84	87	82	86	82	85	80	86	86	87
	4	60		58		51		58		57		63		60		60		56		61		58		63	
	8	47	48	46	41	41	43	46	46	46	46	50	50	48	49	49	50	44	47	48	50	46	48	49	54
	16	40		39		35		39		39		42		40		41		37		41		38		41	
	30	34	34	33	30	30	31	33	33	33	34	35	36	33	34	35	36	32	34	34	34	32	34	34	35
	50	22		23		21		23		23		24		22		24		22		21		21		22	
	100	12		12		10		12		12		13		11		12		12		11		10		11	
	200	7.4	6.1	7.1	6.1	6.5	6.2	7.3	6.5	7.3	6.8	7.4	6.4	7.1	6.5	7.4	6.9	7.1	6.7	7.0	6.4	6.5	6.2	7.0	6.5
AVG. HOT BINS CA	P8																								
	P200																								
AVG. HOT BINS FA	P8																								
	P200																								
MIN. FIL-LER	P8																								
	P200																								
MIX DESIGN	BIT. %					1.3								1.9						2.3					
	Salvaged					88.8								78.5						68.4					
	20AA					9.9								19.6						29.3					
PLANT DATA	BIT. %																								
	CA %																								
	FA %																								
	FILLER %																								
ASPH TESTS PEN	ORIG.	272				280						241		250		231						262			
	REC.	49		50		45		44		36		42		49		42		51		58		49		53	
MIX TEMP. F										230						225				240				225	
TONS MIX						1160				1613				1136		1346				816				2545	

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

1856 (11/75)

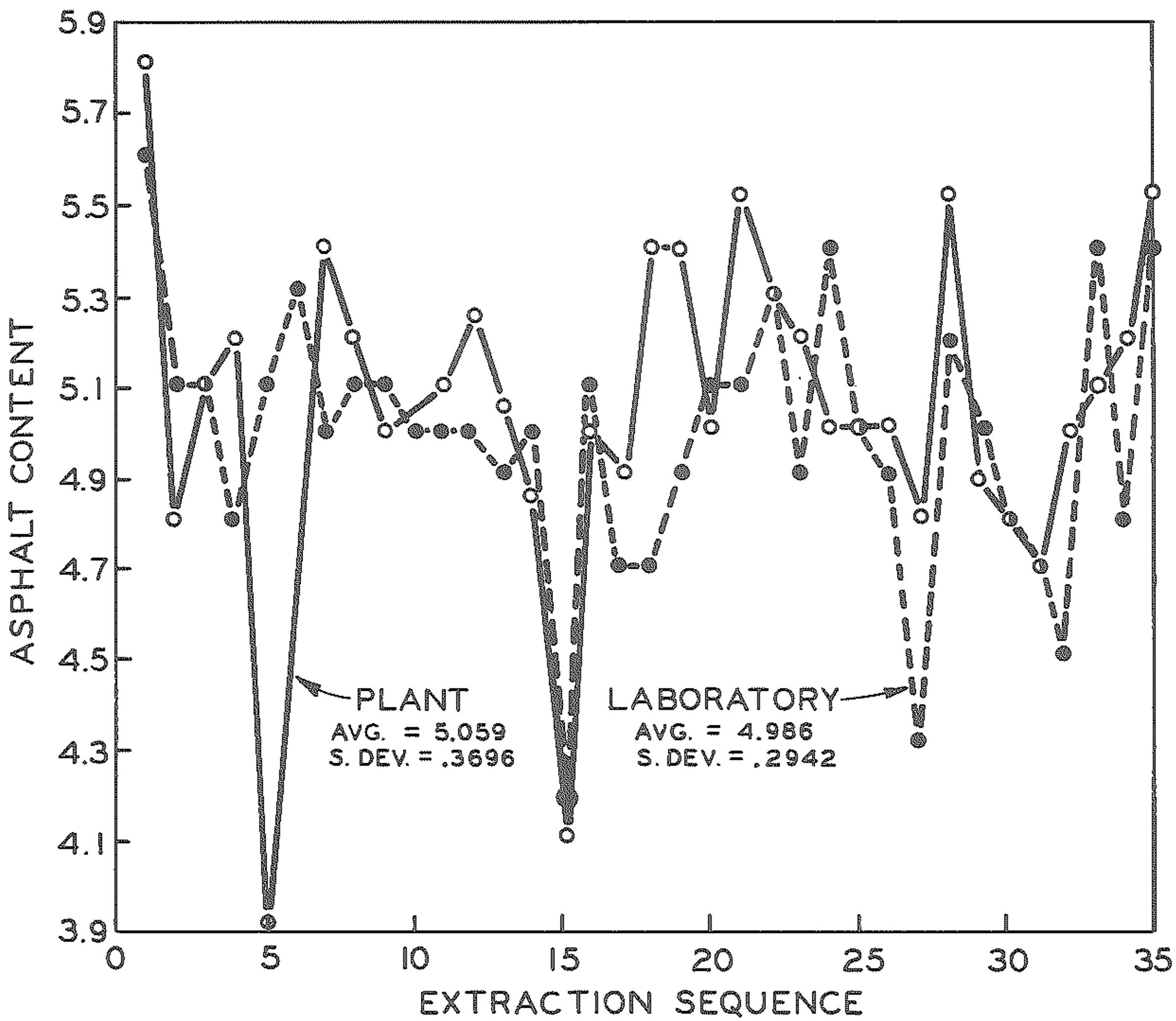
SUMMARY OF BITUMINOUS FIELD & LABORATORY TEST RESULTS

PROJECT Mbr 59022 - 12689A	LOCATION M-66 Greenville	BITUMINOUS Recycle COURSE (4.11)
CONTRACTOR Spartan Asphalt Paving Co.	PLANT NUMBER 440-4 / PROJECT ENGR. David W. Miller	INSPECTOR David G. Ranson
STONE (20AA Isabela Corp. Buntz Pit Vestaburg	SAND ( )	
MINERAL FILLER ( )	BITUMEN (200-250 Marathon Oil Co. Detroit	1976 STD SPECS

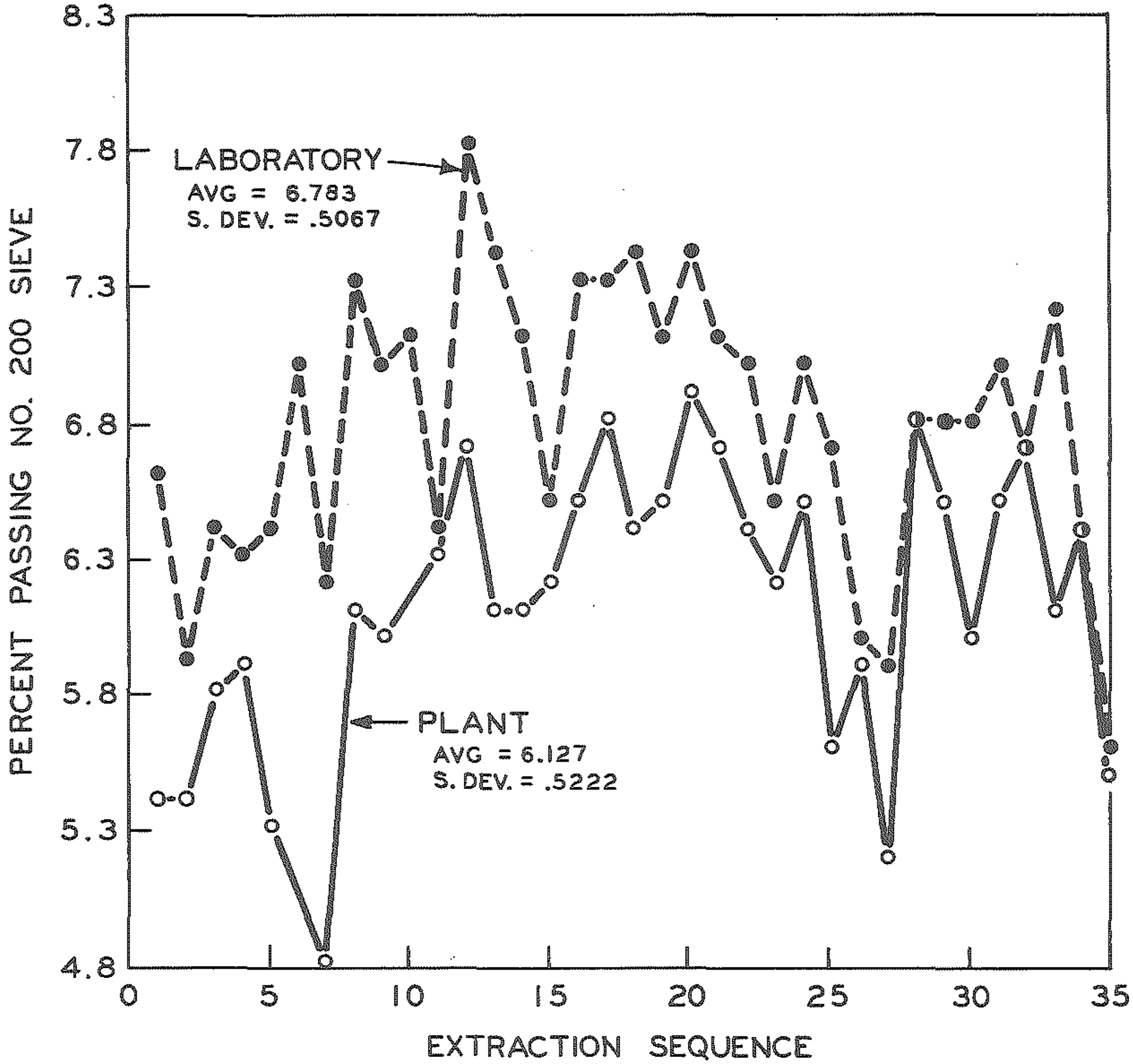
	DATE SAMPLED	8-10		8-10		8-11		8-11		8-14		8-14		8-15		8-15		8-15		8-16		8-17			
		LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD	LAB	FLD
	SAMPLE NO.																								
MIX	BIT. %	5.0	5.0	4.9	5.0	4.3	4.8	5.2	5.5	5.0	4.9	4.8	4.8	4.7	4.7	4.5	5.0	5.4	5.1	4.8	5.2	5.4	5.5		
AGGREGATE GRADATION PER CENT PASSING	1 1/2																								
	1	100				100						100													
	3/4	99	100	100	100	99	100	100	100	100	100	99	100	100	100	100	100	100	100	100	100	100	100		
	1/2	94	96	91	94	85	99	94	96	95	97	92	91	92	95	93	96	97	96	91	95	95	96		
	3/8	84	84	79	82	74	77	84	88	84	85	82	81	80	84	83	87	86	88	81	85	84	86		
	4	60		57		52		60		59		58		57		57		63		56		64			
	8	48	46	46	48	41	42	48	51	48	47	46	46	46	47	46	52	51	50	45	47	52	53		
	16	40		39		35		40		40		39		40		39		43		38		43			
	30	33	33	32	34	29	30	33	35	34	34	33	33	34	34	33	37	36	36	31	33	35	36		
	50	22		21		19		22		22		22		23		22		23		21		20			
	100	11		10		9.3		11		11		11		11		11		12		10		8.7			
	200	6.7	5.6	6.0	5.9	5.9	5.2	6.8	6.0	6.8	6.5	6.8	6.0	7.0	6.5	6.7	6.7	7.2	6.1	6.4	6.4	5.6	5.5		
AVG. HOT BINS CA	P8																								
	P200																								
AVG. HOT BINS FA	P8																								
	P200																								
MIN. FIL-LER	P8																								
	P200																								
MIX DESIGN	BIT. %	2.8				2.3																2.8			
	Salvaged	58.3				68.4																58.3			
	20AA	38.9				29.3																38.9			
PLANT DATA	BIT. %																								
	CA %																								
	FA %																								
	FILLER %																								
ASPH TESTS PEN	ORIG.	285						332				272						286		208		201			
	REC.	59		55		58		59		55		54		57		58		48		56		79			
	MIX TEMP. F					200				215				250						240		270			
	TONS MIX					1111				1729				2346						1985		165			

APPENDIX G

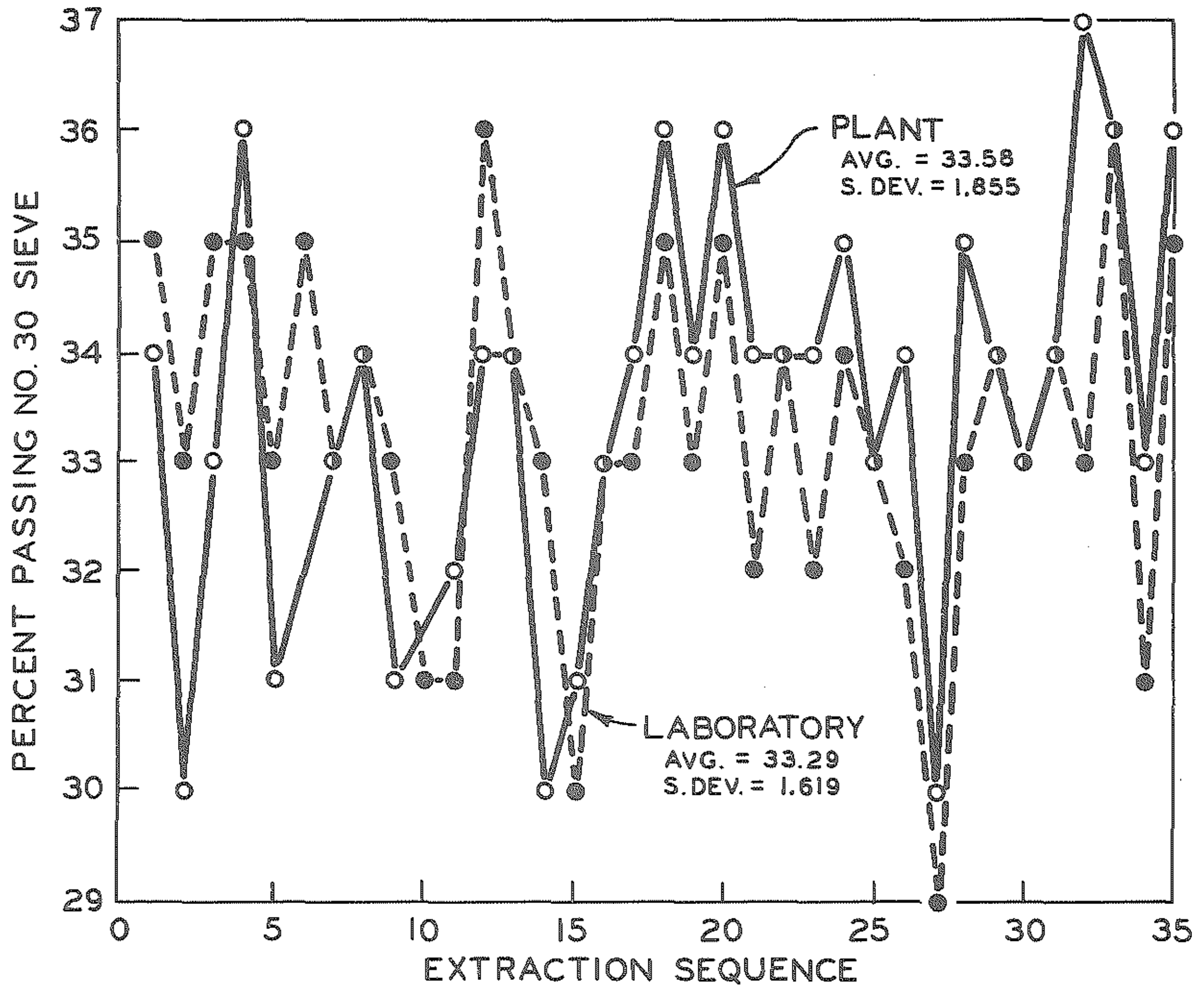
QUALITY CONTROL CHARTS



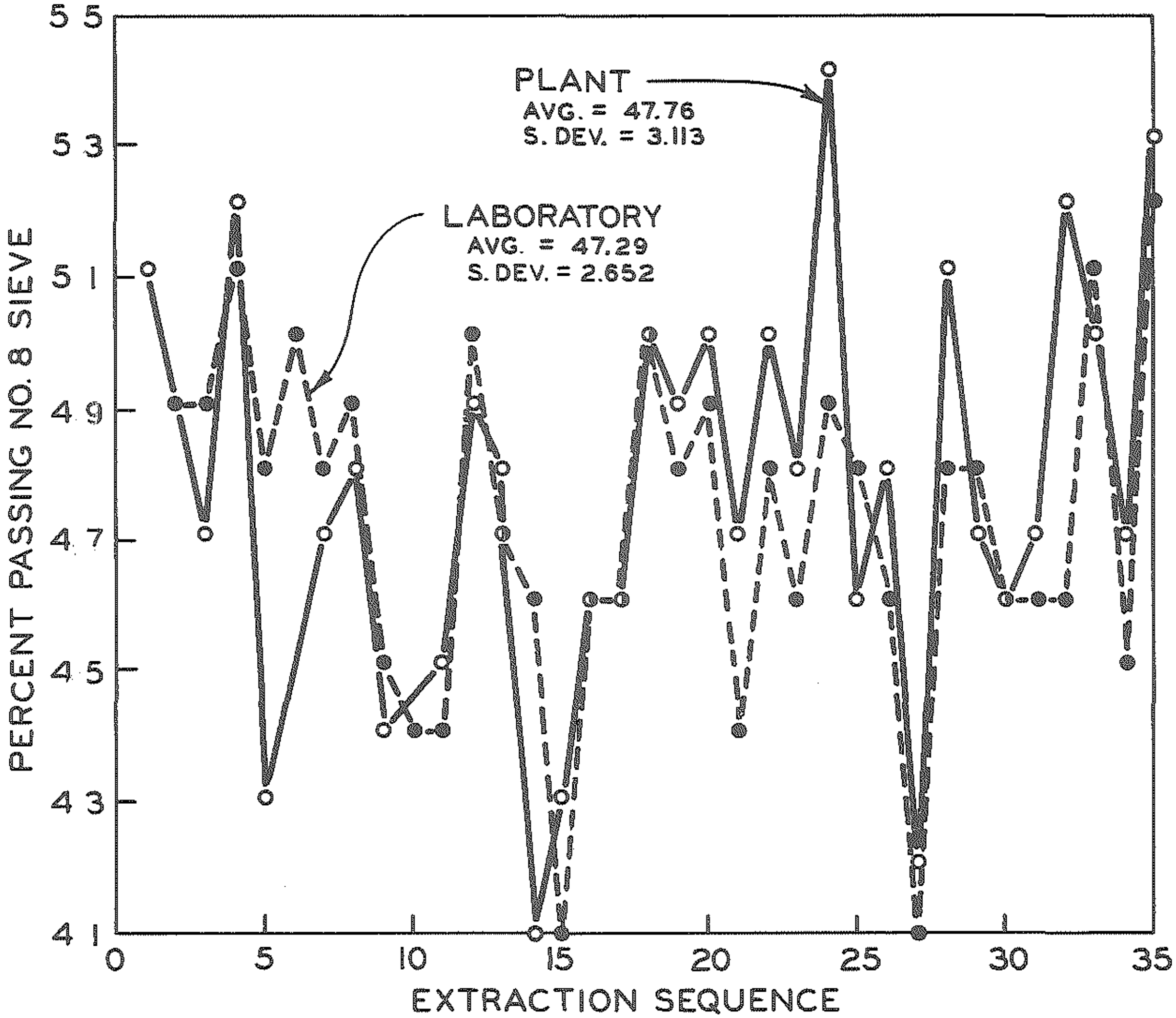
Quality Control Chart



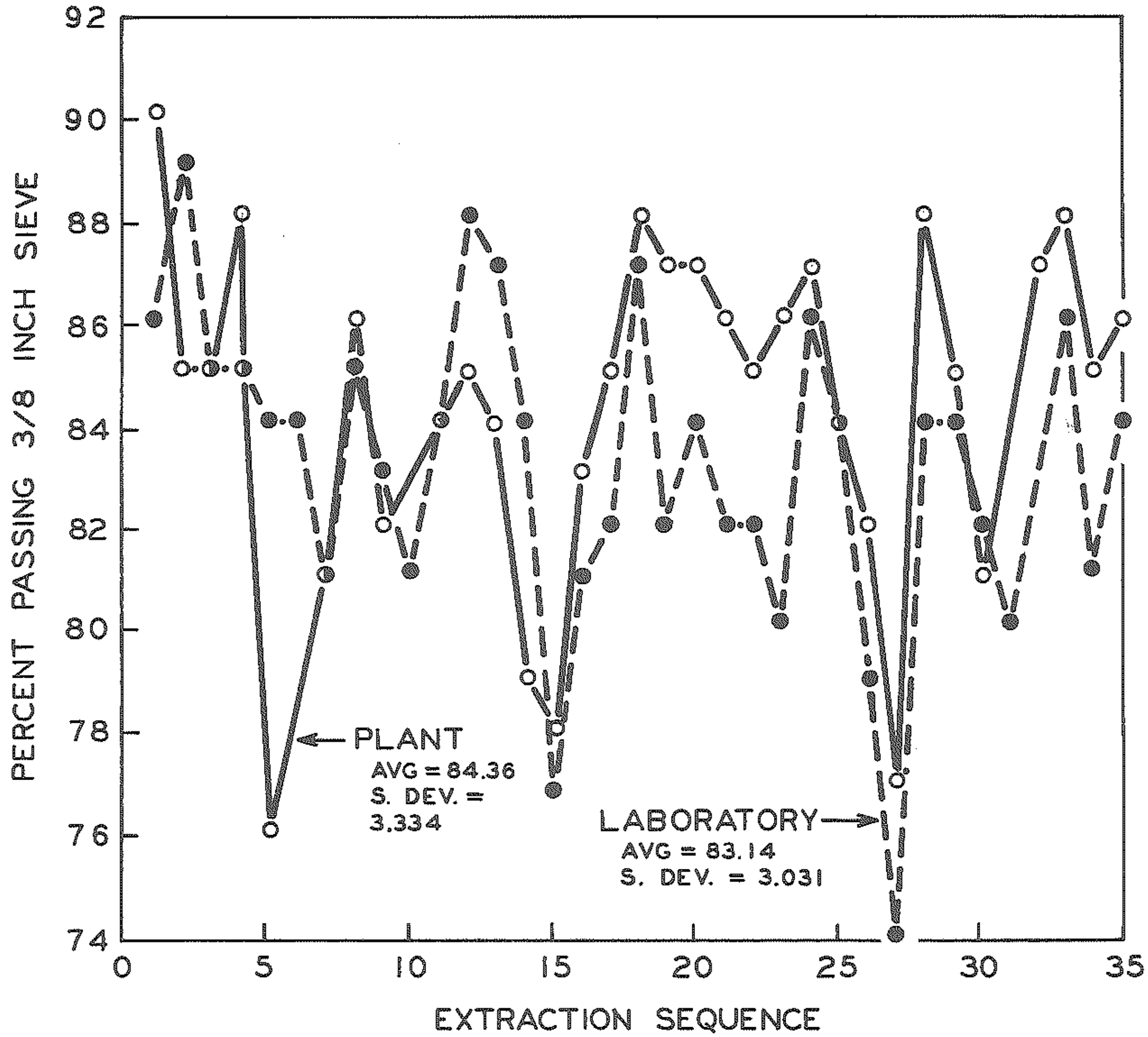
Quality Control Chart



Quality Control Chart



Quality Control Chart



Quality Control Chart