OKLAHOMA DEPARTMENT OF TRANSPORTATION
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RECYCLING PORTLAND CEMENT CONCRETE PAVEMENTS IN OKLAHOMA

Final Report

by

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Project Manager

State of Oklahoma
Department of Transportation
Research & Development Division

Under the Supervision of

C. Dwight Hixon, P.E.
Research & Development Engineer

In cooperation with the

Federal Highway Administration
Under
Demonstration Project No. 47

July, 1987

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
FHWA/OK DP-47-06

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
"Recycling PCC Pavements in Oklahoma"

5. REPORT DATE
July, 1987

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Tim M. Borg, P.E.

8. PERFORMING ORGANIZATION REPORT

9. PERFORMING ORGANIZATION AND ADDRESS
Oklahoma Department of Transportation
Research & Development Division
200 N.E. 21st, 2A2
Oklahoma City, OK 73105

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.
DTFH71-82-47-OK-04

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT AND PERIOD COVERED
Final Report
7-82 - 7- 87

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
In cooperation with the Federal Highway Administration, U.S. Department of Transportation

16. ABSTRACT

This report describes the first Portland cement concrete (PCC) pavement recycling project in Oklahoma. A 7.755 mile section of I-40 in eastern Oklahoma County was recycled. It had passed its original 20 year design life and was experiencing "D-cracking" to a point that maintenance costs were becoming excessive. The nine inch thick plain slab was recycled into a ten inch plain slab.

Included in the final report is a description of the construction activities, energy conservation estimates, construction cost comparisons and measures of pavement performance.

A professionally narrated video tape documenting the complete construction effort is available.

17. KEY WORDS
pavement, Portland cement concrete, recycling

18. DISTRIBUTION STATEMENT
unrestricted

19. SECURITY CLASSIF. (OF THIS REPORT)
None

20. SECURITY CLASSIF. (OF THIS PAGE)
None

21. NO. OF PAGES
·65

22. PRICE

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Project 82-07-1, Item 2414

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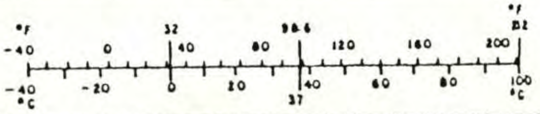
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

This publication was printed and issued by the Oklahoma Department of Transportation as authorized by , Neal A. McCaleb, Director. 125 copies have been prepared and distributed at a cost of $278.00.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Oklahoma Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENT

This paper reports the objectives and results of a research effort conducted in cooperation with the Demonstration Projects Division of the Federal Highway Administration, U.S. Department of Transportation. Most of the data collected has been with the assistance of Denver Jackson, Darrel Heppel and Jesse Casey in the Stillwater Residency, Oklahoma Department of Transportation.

EXECUTIVE SUMMARY

In 1976, Iowa was the first state to conduct a full-scale Portland cement concrete (PCC) recycling project on a highway pavement in the United States. Potential conservation of materials and energy were attractive benefits.

A 7.755 mile long PCC section of I-40 east of Oklahoma City, needed improvement. The Oklahoma DOT allowed recycling as an alternative to a full depth asphalt concrete (AC) overlay.

After providing traffic detours for more than 20,000 vehicles per day, the contractor used 18,000 foot-pound diesel pile drivers to break the existing nine inch PCC pavement. The broken pavement was processed by a conventional crusher plant on the site. The only significant modification to the plant was an electromagnet to remove random steel from the unreinforced pavement. A concrete batch plant next to the crusher provided the PCC for paving. The design mix consisted of coarse aggregate, natural sand, Portland cement, "Class C" fly ash, air entraining agent, and water. Skewed contraction joints were sawed and filled with a silicone sealer. The shoulders were paved with a hot mixed, hot laid asphalt concrete. Thermoplastic traffic stripe, new guardrail, and new signs were added. The project was opened to traffic in late November of 1983 after 247 calendar days of work.

The PCC recycling project was bid at $5.2 million, compared to an AC overlay bid of $5.9 million. It is estimated that

63,000 tons of virgin aggregate were saved because the contractor chose to recycle the existing pavement to provide a major portion of the needed coarse aggregate. Approximately $650,000 was saved by recycling rather than using the AC overlay alternative.

Energy consumption comparisons were made between the recycled PCC alternative and the AC overlay showing little difference in energy used. The addition of fly ash to the Portland cement and reduction of the original 1 1/2 inch coarse aggregate to a maximum of one inch should reduce its susceptibility to freeze-thaw deterioration.

A narrated video tape of the recycling project was prepared by Oklahoma State University. Contact the author for details to acquire a copy of this video tape.

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INTRODUCTION

Purpose

This project was undertaken in conjunction with the Federal Highway Administration's Demonstration Project No. 47, "Recycling Portland Cement Concrete Pavements". The objective was to demonstrate the feasibility of recycling Portland cement concrete (PCC) and to evaluate its performance over a period of time. While several rehabilitation projects in Oklahoma have included recycling asphalt pavements, this was Oklahoma's first PCC recycling effort.

Scope

The eastmost 7.755 miles of I-40 in Oklahoma County had deteriorated severely. The PCC pavement was in immediate need of replacement; maintenance costs were becoming unacceptably high. The project was begun in March of 1983 and opened to traffic in November of 1983. An area map is shown in Figure 1.

Background

The primary reason for the rehabilitation of this highway was D-cracking failure at the joints. This failure could be described as a series of closely spaced cracks that appear on the surface adjacent and roughly parallel to transverse and longitudinal joints and cracks. Research has found that "D-cracking is a surface manifestation of deterioration that

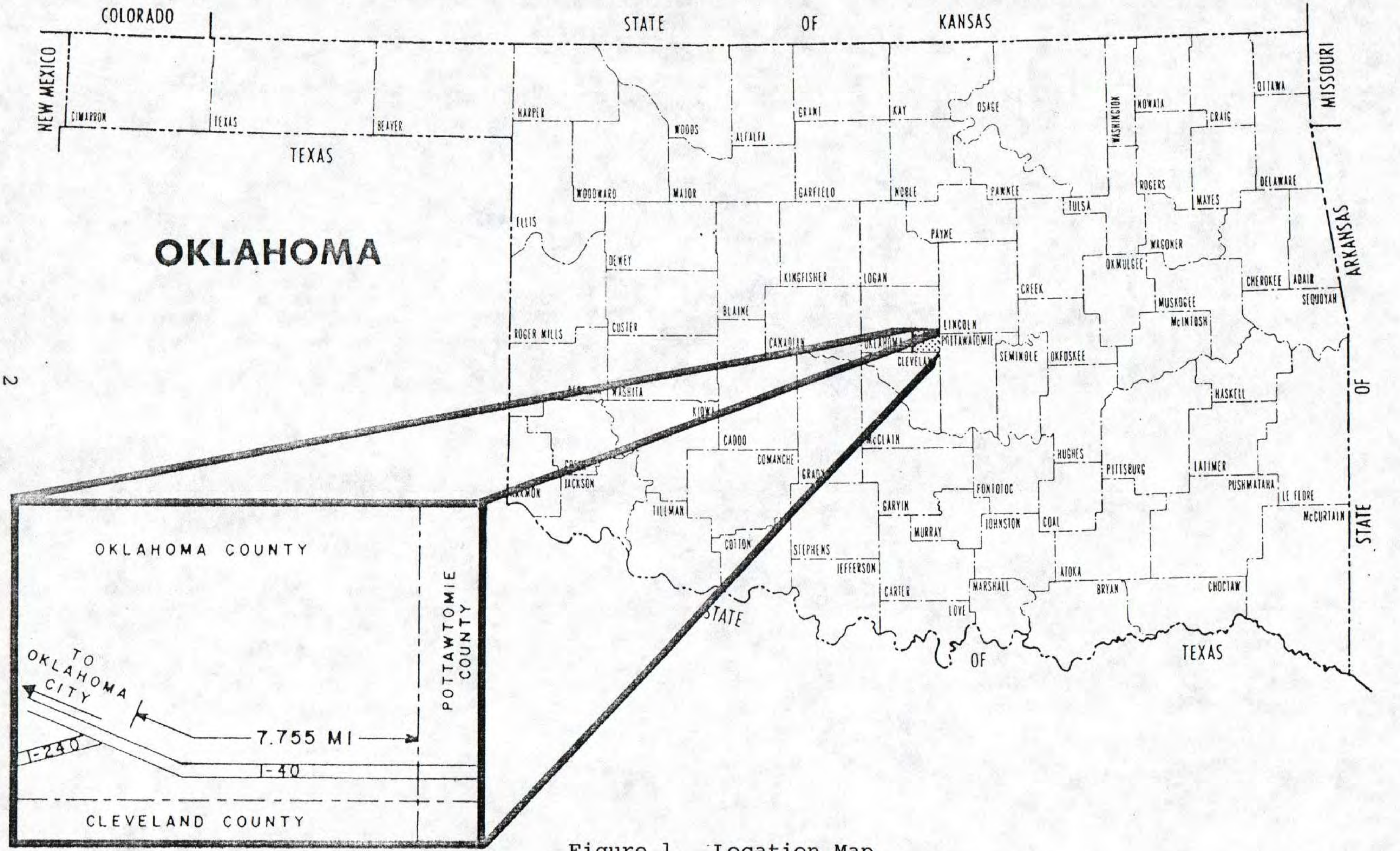


Figure 1. Location Map.

usually originates in the lower and middle levels of the pavement slab and progresses upward to the wearing surface" (1). The Illinois Department of Transportation conducted a literature search into D-cracking and summarized their findings (2):

1. The coarse aggregate is responsible for D-cracking, and sedimentary aggregates are the most susceptible. Once the distress is initiated, it cannot be stopped.
2. Fine aggregates, cement type, drainage systems, and type of subbase have no significant effect on the occurrence of D-cracking.
3. The distress is a result of freeze-thaw stresses, and serious deterioration may occur even without traffic loading.
4. The pore structure of the aggregate is thought to be the characteristic that determines the degree of susceptibility.
5. Removal of moisture or prevention of freezing and thawing would eliminate D-cracking. Neither has been accomplished economically in the field.
6. Reducing the top size of the coarse aggregate lessens the rate of D-cracking and may eliminate the problem altogether with marginal aggregate.
7. A laboratory freeze-thaw test developed by PCA has been successful in predicting the susceptibility of aggregate to D-cracking.

Original Pavement

The roadway had reached the end of its design life. Originally constructed in 1961, the nine inch thick PCC pavement had no steel reinforcement. The original limestone aggregate had a maximum nominal size of 1.5 inch. The contraction joints were sawed at 15 foot spacings and sealed with conventional asphaltic material. Each direction had a four foot inside shoulder, two driving lanes twelve feet wide, and a ten foot outside shoulder. Number four reinforcing bars, 30 inches long, were placed on three foot centers longitudinally to tie the two lanes together. Both the inside and outside shoulders were constructed of soil cement and given a one inch thick double bituminous surface treatment for a wearing course. The shoulders and pavement both rested on a six inch soil asphalt base, which in turn rests on five inches of select material.

Climatological Data

Weather records were reviewed for the project area (3). The average annual rainfall for this area was 32 inches per year. Winter season saw an average of 25 freeze/thaw cycles. Temperature characteristics, in degrees Fahrenheit, were:

AVG/MAX	AVG/MIN	AVG	HIGH	LOW	AVG./NO.DAYS
95	69	82	119	43	Greater than 90^{O}F = 26
52	30	41	89	-9	Less than 32^{O}F = 20

RECONSTRUCTION

Initial Plan

The project was first conceived as a breaking and seating of the existing PCC pavement and overlaying with asphalt concrete (AC). The original 15 foot long slabs were to be mechanically fractured transversely at approximately the 1/2 and 1/4 points. The fractured pavement would then be cleared of loose, spalled concrete, and rolled with a fifty ton, pneumatic wheeled roller to seat the fractured pavement. An AC leveling course would be topped with six inches of hot mix AC and an open graded friction wearing course.

Cores were taken from four selected slabs on the project. One core each was taken at 6 inches, 2 feet, 4.5 feet, and 8.5 feet diagonally from the corner of each slab (see Figure 2). Three of the four cores taken 6 inches from the corner crumbled upon removal. The fourth core had a compressive strength of 3,223 pounds per square inch. Table 1 shows the compressive strength of each core.

Alternate Design

The alternate design consisted of removing the existing nine inch PCC pavement and replacing it with ten inches of new PCC pavement while leaving the shoulders intact. Typical cross-sections can be seen in Figures 3 and 4. The contractor had the option of using virgin aggregate or recycled aggregate.

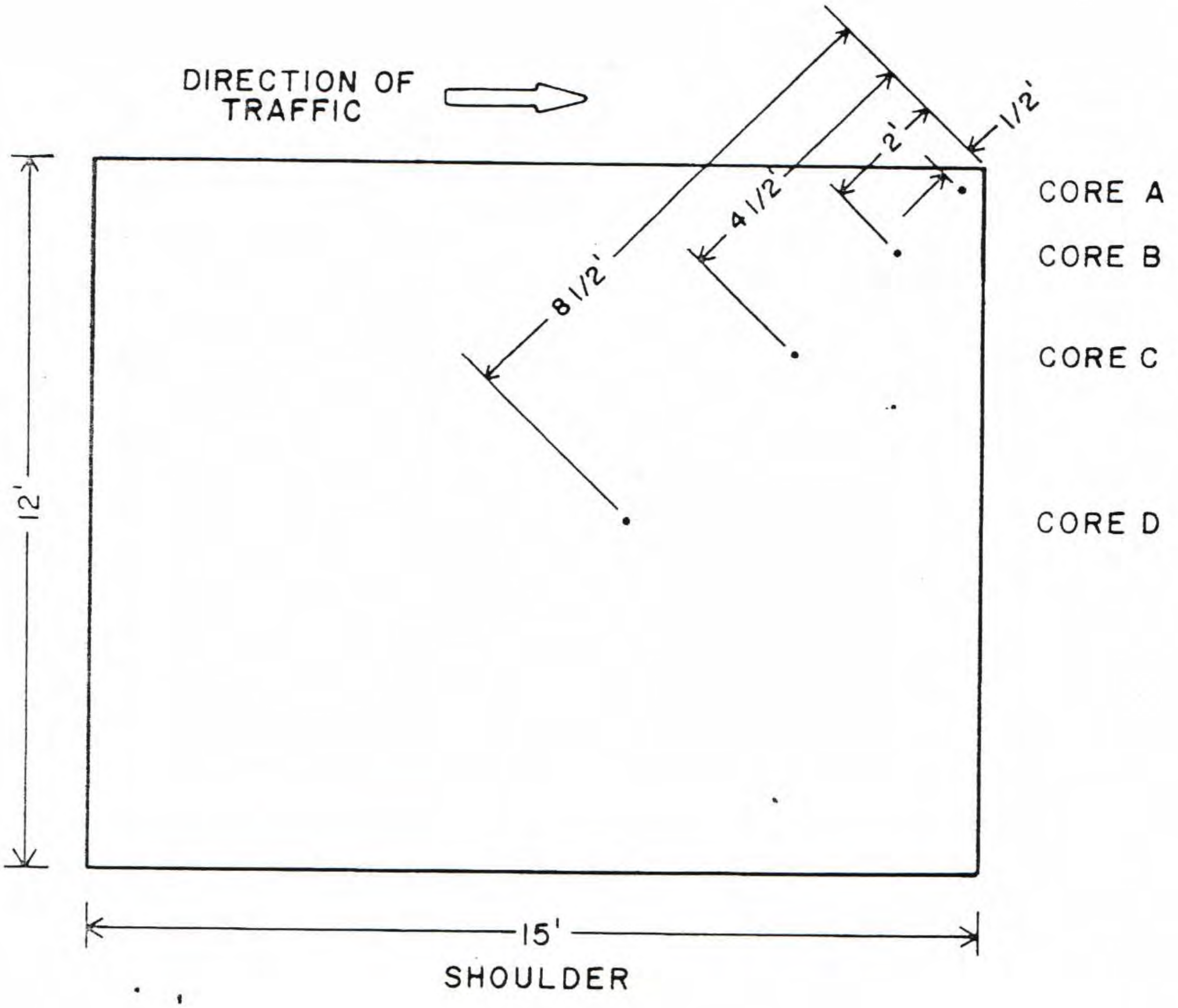


Figure 2. Core Hole Locations

Table. 1

Cylinder Strengths

Core Hole	Test Slab #1	 #2	 #3	 #4
A	Rubble	Rubble	Rubble	3223
B	3836	6430	2228	5292
C	3501	4369	4990	6915
D	7074	6279	4974	6549

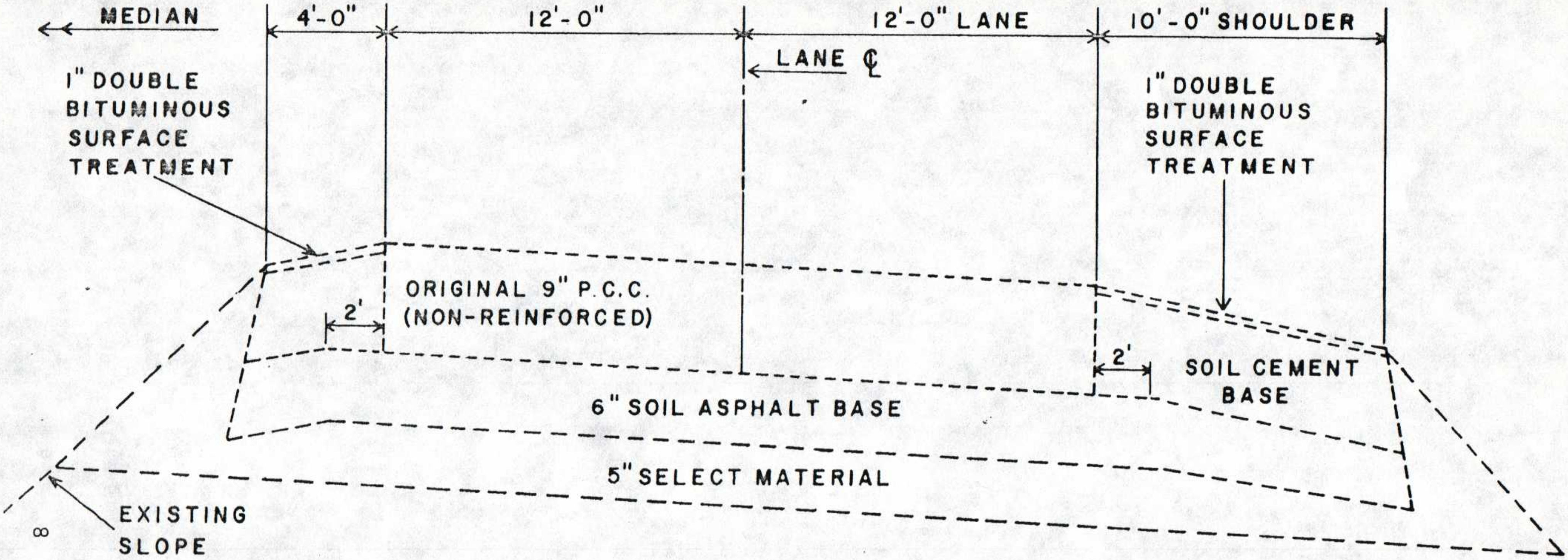


Figure 3. Original Nine Inch Pavement

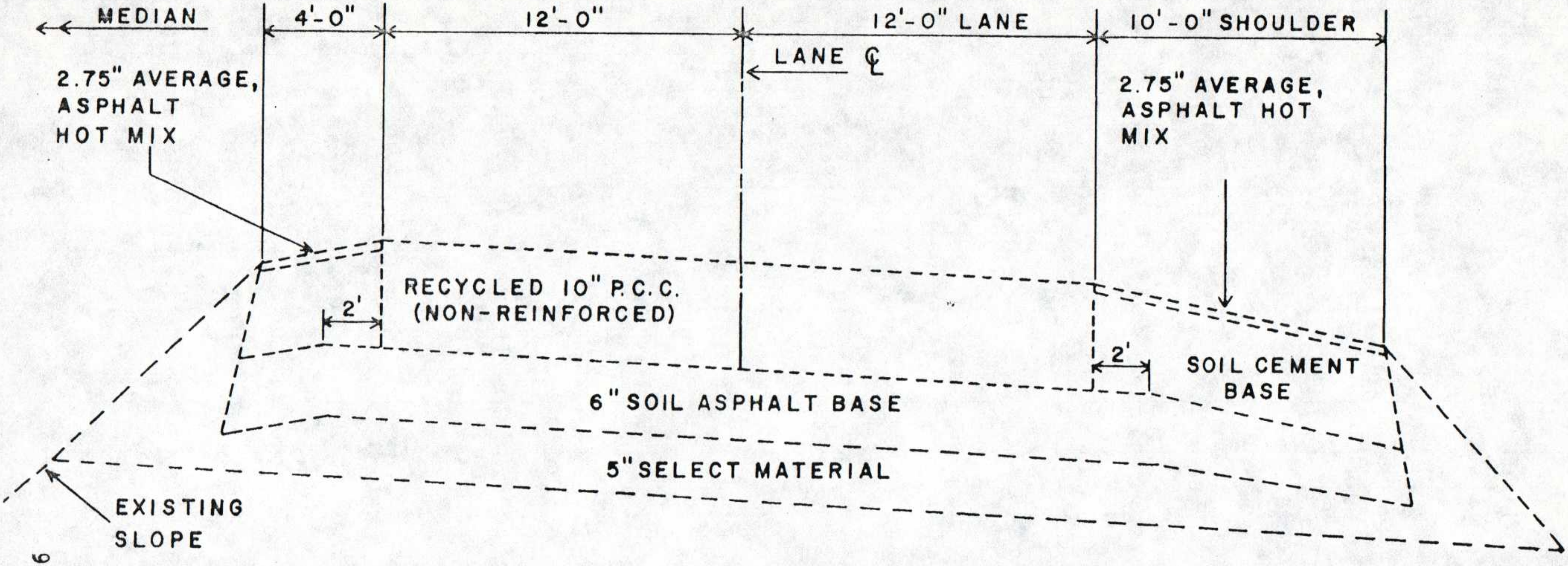


Figure 4. Recycled Ten Inch Pavement

Pay quantities included provisions for reconstruction of the six inch soil asphalt base, if necessary. After the new pavement was placed, plans called for one inch of the shoulder to be cold milled and surfaced with two inches of hot mix AC material.

Construction

The project was let to contract in July of 1982. The low bidder, Koss Construction Company of Des Moines, Iowa, opted to recycle the existing PCC pavement. The nearest virgin aggregate was in a quarry over 50 miles south of the project. The contract amount of $5.2 million to recycle the PCC pavement was $700,000 less than the AC overlay alternative.

Although the work order was issued in August of 1982, the prime contractor avoided the winter weather by starting on March 10, 1983. The sub-contractor had already rehabilitated the two bridge decks on the project by December of 1982.

A portable aggregate crushing plant and a PCC batch plant were placed first in the median of the west half of the project and later moved to the east half of the project. In both cases, the eastbound lanes were constructed, then the westbound lanes. Traffic was detoured from the roadway under replacement onto a two-lane, two-way movement on the adjacent roadway. Figure 5 shows the west half of the project staging; Figure 6 shows the east half.

Traffic jams resulted, as expected, during the morning and evening rush hours. However, traffic flow was seriously hampered

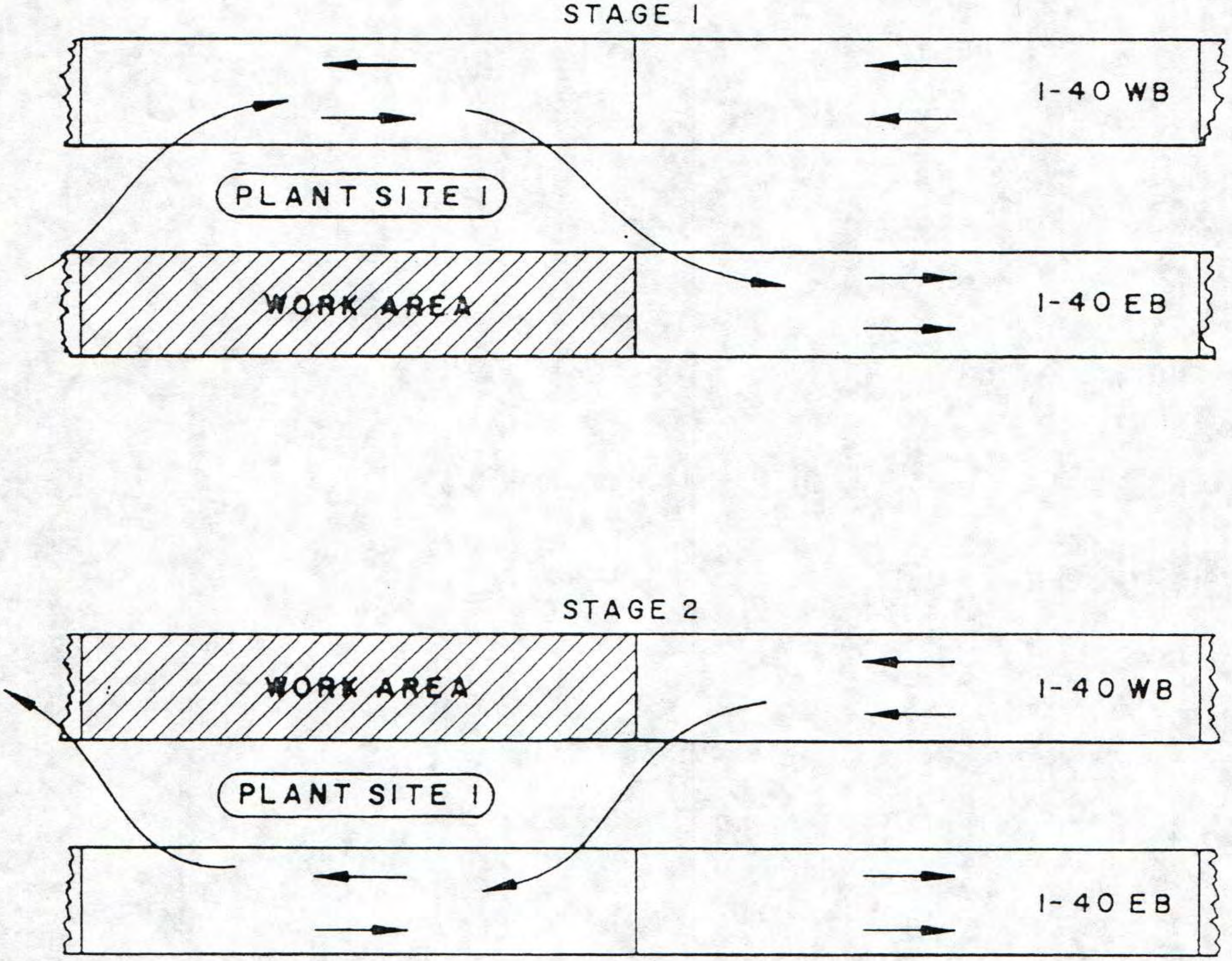
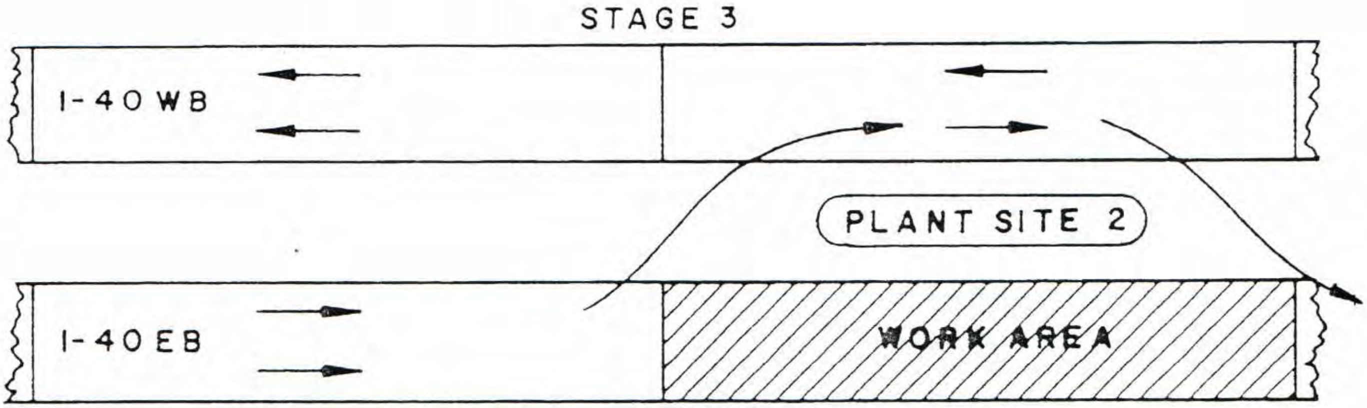
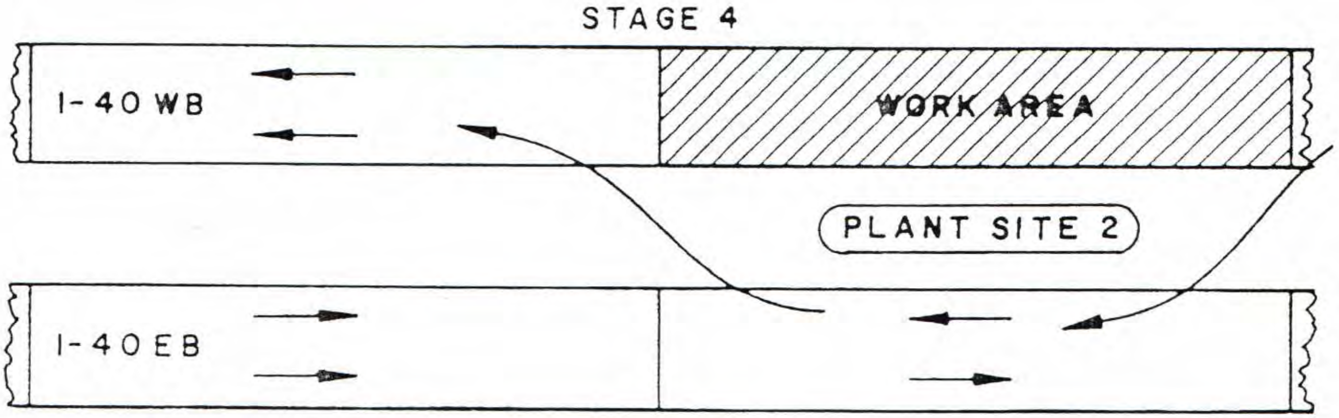


Figure 5. Staging of the West Half of the Project.



STAGE 3



STAGE 4

Figure 6. Staging of the East Half of the Project.

midday by the delivery of materials to the concrete batch plant. At the first plant site, where the median was not nearly as wide as the second site, delivery trucks frequently stopped on the two-way, two lane detour trying to gain access to the plant. At one point, the Research Division project manager observed a massive traffic jam consisting of: dump trucks returning on the detour to the batch plant for more loads of concrete, and large trucks delivering semi-trailer loads of sand, bulk Portland cement, bulk fly ash and coarse aggregate.

The traffic jam observed that day at the first plant was not an isolated, infrequent event. Apparently, the contractor made no attempt to coordinate the delivery of materials or to avoid the afternoon rush hour.

Obstruction to the flow of traffic at the second plant site was minimized by having generous waiting areas for delivery vehicles in the median.

Paved crossovers used portable concrete barriers to provide positive guidance. The ends of the barriers were protected by impact attenuators. Flexible delineator posts with rubber mat bases were placed on 200 foot centers to clearly mark the centerline. With an average daily traffic (ADT) exceeding 20,000 vehicles, the traffic maintenance sub-contractor had a never ending job of repositioning the flexible delineator devices back on the centerline between opposing traffic while the detour was being used.

Removing the old guardrail and cold milling all asphalt patches and spot overlays was the first step. The asphalt would contaminate the coarse aggregate if not removed before breaking. The cold milled asphalt was used as fill on the backslopes of some bridge approaches to widen the shoulders.

Breaking the existing pavement was the next step in the pavement removal. The contractor used two breaking hammers: a Link-Belt diesel pile driver on a shop built frame and a Pettibone-Universal Pavement Crusher which uses an MKT diesel pile driver. Both pile drivers exerted 18,000 foot-pounds of energy thru a steel shoe that contacted the pavement. Several different breaking patterns were tried. Starting at the centerline and alternately working toward the shoulder 18 inches at a time seemed to disturb the soil cement shoulders the least.

With the pavement broken, a crawler loader lifted the rubble into the waiting bucket of a wheeled loader. The more maneuverable wheel loader then placed the rubble into the dump beds of waiting haul trucks. To reduce the amount of soil asphalt being picked up by the loader, the crawler made two passes on the rubble with a ripper to dislodge the matrix. A more efficient production resulted when a back-hoe used a ripper tooth (called a "rhino horn") in place of a bucket. The back-hoe worked between the loaders providing a continuous supply of loosened rubble. The back-hoe also could move broken pavement away from the soil cement shoulder with less damage to the shoulders than the crawler could alone.

The broken rubble was delivered to a standard Cedar Rapids crusher plant that used hammer mills on both the primary and secondary crushers. The small quantities of steel tie bars in the broken rubble were removed by an Eriez cross-belt magnet suspended over the conveyor belt between crushers. Wire cages holding dowel bars, originally used at construction joints, were skillfully extracted by the front end loader operator as he loaded the primary crusher bin. The plant was able to produce 42 percent (by weight) of the broken rubble as recycled, coarse aggregate. Regrettably, the hammer mills produced more fine materials than was expected in the crushing process. These fines became the property of the crushing plant sub-contractor. He then sold these excess fines to local County Commissioners. Some asphalt batch plant operators also purchased the fines as mineral filler.

The coarse aggregate met the size requirements. Typical analysis is shown in Table 2. The fines from the crushing operation had a typical analysis shown in Table 3.

After crushing the pavement in the first of the four sections of the project, an additional 4,871 tons of virgin aggregate were needed to finish paving that first section. The volume of coarse aggregate produced was not sufficient to pave the section from which it was removed. The first 24 foot wide section was 21,954 feet long; the virgin aggregate paved 5,731 feet of that first section. The coarse aggregate output of the crusher plant was improved on the second section to 52 percent by replacing the

Table. 2

Gradation of Coarse Aggregate
From First Section

Sieve Size	Percent Passing	Specification
1"	100	100
3/4"	98.5	90-100
1/2"	46.5	20-55
3/8"	11.2	0-15
No. 4	1.5	0-5

Table. 3

Gradation of Fine Aggregate

Sieve Size	Percent Passing
1/2"	100
3/8"	99.2
No. 4	74.8
No. 10	48.5
No. 40	19.4
No. 80	9.2
No. 200	4.5

secondary hammer mill with a Universal Triple Roller crusher. Also, the specification was changed to allow more material in the low end of the size range as shown in Table 4.

To reduce the potential for future D-cracking, the maximum nominal aggregate size allowed was 3/4 inch. Also, good results have occurred when 15 percent of the Portland cement was replaced with 20 percent "Class C" fly ash by volume (4).

The PCC using recycled aggregate and fly ash still had to meet the standards for Class "A" concrete: slump from one to three inches, and a minimum seven day compressive strength of 3,000 pounds per square inch. The mix design proposed by the contractor was tested in the lab. Attempts to include fine material from the recycled aggregate in the mix resulted in a harsh mix that was not as workable as mixes that used natural sand. To produce one cubic yard of concrete, the design mixes are shown in Table 5.

It was interesting to note that the density of the recycled PCC is not quite as great as PCC using virgin aggregate. That was because mortar clung to the limestone aggregate of the recycled coarse material and the mortar was not as dense as the original stone.

The average compressive strength of the five test cylinders of recycled PCC was 3,618 pounds per square inch after seven days. The test cylinders using virgin limestone coarse aggregate had an average of 3,856 pounds per square inch of compressive strength after seven days.

Table. 4

Gradation Specifications for Coarse Recycled Aggregate

Size	Section 1	Sections 2,3&4
1"	100	100
3/4"	90-100	90-100
1/2"	20-55	25-60
3/8"	0-15	0-25
1/4"	0-15	0-10
1/8"		0-5

Table. 5

Design Mix of PCC

	Recycled	Virgin
Portland Cement	479 lbs	479 lbs
"Class C" Fly Ash	115 lbs	115 lbs
Entrained Air	5 percent	5 percent
Natural Sand	1130 lbs	1206 lbs
Coarse Aggregate	1695 lbs	1864 lbs
Water	30 gallons	30 gallons
Density	136 lbs/ft^3	145 lbs/ft^3

After removing the existing pavement on the first section, it was found that the pavement breaking hammer had consolidated the soil asphalt base. To restore the grade and eliminate the need to mill the shoulders, an average of 3.5 inches of soil asphalt was added to the base. This elevated the surface of the new ten inch thick pavement a minimum of two inches above the uneven, worn shoulders. A pugmill was used on the site to produce 6,560 cubic yards of soil asphalt. The material was placed, blended with the existing soil asphalt base with a pulver-mixer and compacted. An autograder milled a precision grade prior to placing the concrete. Excess soil asphalt was stockpiled for use in the base of the next section.

After the soil asphalt was added to the existing base in the first section, the pugmill was disassembled and removed. It was decided that by combining the recycled aggregate fines from the crusher plant with the existing six inch soil asphalt base, the necessary profile could be met and sufficient base strength was maintained without adding any liquid asphalts. The remaining sections would have recycled aggregate fines blended into the base rather than soil asphalt.

Paving began on the first section on May 18, 1983 with a CMI slip form paver. The non-reinforced slab was ten inches thick and 24 feet wide. The concrete was produced by an 8.5 cubic yard, dual drum central batch plant. However, only six cubic yards of concrete were mixed at a time. The contractor was using the outside shoulder as a haul road to the paving operation and wanted to minimize damage. Steel wedges protected the shoulder edge as loaded dump trucks turned off the shoulder down onto the prepared base. The end-dump, single unit trucks then backed to the slip form paving machine to deliver their loads of concrete.

The continuous delivery of fresh concrete to the slipform paver was critical. When the slipform paver stopped and started repeatedly because of sporadic delivery of concrete, a smooth finished pavement was more difficult to produce.

The flow of concrete delivery trucks was hampered by three constraints in the vicinity of the paver. First, trucks had to take turns individually to drop their load of concrete in front of the paver. The 24 foot wide base was not sufficiently wide for the single unit trucks to turn around. Secondly, as the trucks used the steel wedges to get off the outside shoulder onto the base and then get back up onto the inside shoulder, delays occurred as crewmen continually dragged the wedges in front of the paver. Thirdly, since the inside shoulder was insufficiently wide for the trucks to return to the batch plant, the empty trucks sat in the median trying to find a gap in the flow of detoured traffic. Considerable congestion occurred several times a day.

Workmen had to fill the irregular voids between the slipformed PCC slab and the shoulder by hand. Wet concrete was shoveled into place and hand compacted. The voids occurred when the contractor cleaned the deteriorated soil cement that had been beneath the longitudinal joint between the PCC pavement and the

AC shoulder. The soil cement had deteriorated due to salt water leaking through the joint in winter.

Number four rebars, 30 inches long were placed in the concrete every three feet perpendicular to the centerline to tie the two lanes together. A 2.75 inch wide strip of plastic film was placed vertically 0.25 of an inch below the pavement surface between the two lanes to form a bond breaker. A contraction joint between the two lanes formed later through this plane of weakness.

Test cylinders were made as the concrete was delivered to the paver. Slump measurements averaged 1.5 to 2 inches, while air content in the concrete was almost five percent. These test cylinders yielded seven day compressive strengths in the 3,160 to 4,580 pounds per square inch range for the recycled PCC.

The concrete looked and handled as well with recycled aggregate as with virgin aggregate. After the paving train placed the concrete, it was tined transversely to enhance the skid resistance. The last operation on the paving train was to spray the surface with a white, resin based, curing compound. After the pavement had cured from five to seven days, joints were sawed every 15 feet skewed four feet from perpendicular, cleaned and filled with a backer rod and silicone joint sealer. While the pavement was curing, both the inside and outside shoulders were paved with an average of 2.75 inches of dense graded, hot mix asphaltic concrete. New guardrail of the current design and new signs were installed.

This staged construction was continued until the entire project was completed. The project was opened to traffic in early November of 1983, after 247 calendar days.

POST CONSTRUCTION

Immediate Evaluation

When the project was finished, about 3,000 tons of coarse aggregate were left over, and became the property of the crusher plant sub-contractor. About 25 tons of scrap iron had been salvaged from the crushing operation. However, the steel was wasted because of the concrete still clinging to it.

With the construction work complete, Oklahoma DOT engineers have gained a great deal of new knowledge about concrete recycling techniques. The new pavement looked good and provided a smooth ride. But one question remained: how long would it last?

Low bid on the project, using recycled aggregate, was $5.2 million. Engineers estimated that the work would have cost $6 million, if virgin aggregate had been used. Thus, about $800,000 was saved by recycling the old pavement. The saving was based on an estimated 63,000 tons of virgin aggregate not being needed due to recycling.

But in order to be cost-effective, the recycled pavement must remain serviceable for nearly as many years as pavement produced with virgin aggregate. Durability factors of 9.7 and 14.2 resulted from the ASTM freeze-thaw test C666 method A conducted on specimens of the recycled concrete made during construction. While not a specification requirement on this project, a factor of 50 or more is used to describe a material as durable after 350 cycles by the ODOT Materials Division.

However, the original pavement exceeded its design life of 20 years, and in the recycled concrete, the coarse aggregate was downsized, and fly ash was used in the mix design. Since research indicated that fly ash and down sizing reduces pavement susceptibility to freeze-thaw deterioration (5), the recycled concrete should be at least as resistant to D-cracking as the original pavement which lasted over 20 years.

Another area of interest on the project was energy conservation. Using the Asphalt Institutes "Energy Requirements for Roadway Pavements"(6), and pay quantities on the plans, engineers estimated that the recycling work required the energy equivalent of 1.1 million gallons of gasoline. Using the same publication, energy requirements were estimated assuming the overlay alternative had been chosen. In comparing the PCC to the AC over a 20 year design life, experience has shown the AC would require two overlays in its life. For the purpose of comparing energy requirements, both 1.5 inch overlays were assumed to be AC recycled overlays. Energy requirements for AC were estimated and found to be virtually the same as the PCC alternative. While recycling may not have saved any significant amount of energy, it must be acknowledged that the AC overlay bid of $5.9 million was $700,000 over the PCC recycling final bid.

To reduce overall project costs, it was decided to save the soil cement shoulders. After paving, the shoulders were brought up to grade by an asphaltic overlay. Four factors must be considered when deciding if saving the shoulders was a good idea on this project.

First, salt intrusion from winter snowstorm removal deteriorated the integral strength of the shoulders. The longitudinal joint between the PCC slab and the AC shoulder wearing surface let saltwater down into the soil cement. Random transverse cracks in the soil cement shoulders allow the salt water to migrate to the drainage ditches. The salt destroyed the cohesiveness the Portland cement imparted to the sandy soil along these cracks. The deteriorated soil cement under the longitudinal joint varied from one inch to three inches. Transverse cracks were seldom over an inch wide. They occurred very randomly from a few feet to a few yards between cracks.

Second, the pavement breaking operation would occasionally displace the soil cement shoulder as it neared the shoulder. Where the more closely spaced transverse cracks extended across the shoulders, soil cement slabs were more likely to be sheared from their select soil base.

Third, as the front end loader picked up the pavement rubble, the shoulder was sometimes disturbed. The loader tried to move rubble away from the shoulder before scooping it into the bucket. While the track-mounted back-hoe used a rhino horn to move rubble away from the shoulder, the heavy machine had to drive on the shoulders it was trying to protect.

Fourth, the shoulders were further disturbed by using them as haul roads for the concrete trucks. The contractor tried to reduce the wear on the shoulders by limiting the trucks to six cubic yards of concrete instead of eight and one half.

Performance

One year after opening the project to traffic, 12 sequential slabs cracked longitudinally but not thru the plastic film weakened seam as intended. The location was westbound about two miles west of the Pottawatomie County line on a fill section.

At the same time, water was noticed running out of the seam between the pavement and the shoulder of the eastbound lanes between the exit and entrance ramps of the Harrah/Newalla Road interchange. This seepage continued without interruption, even thru the dry summer months.

In the fall of 1984, a core was taken from the pavement. The original 28 day compressive strength of the recycled PCC core was 4,250 pounds per square inch and had increased to 6,940 pounds per square inch at age one year.

Approximately two years after completion, two slabs in the right lane of the eastbound roadway were found to have broken. Maintenance forces stabilized the slabs by drilling holes thru the slabs and pumping material between the slab and the base. The material filled the voids under the slabs and raised the low portions closer to grade.

About this time, staining of the asphalt shoulder was becoming more apparent after each rainfall. The fines from beneath the PCC slabs were being pumped out thru the seam between the slab and the asphalt shoulder. No pattern seemed to develop. Pumping occurred in cuts as well as on fills, and in vertical sags as well as crests. No joint sealer was used between the shoulder and the PCC pavement. A hot applied, asphaltic tack coat was shot down on the shoulder and against the vertical face of the PCC pavement. This tack coat served as a seal between the AC shoulder and PCC pavement.

Slab fault measurements were taken annually for three years. Specific joints were marked on the shoulder every 200 feet to consistently measure those same joints throughout the evaluation period. Table 6 shows how the proportion of joints faulted 0.25 inch or greater continued to increase each year from zero to one to ten percent. The faulting did not develop uniformly throughout the project. Localized areas of severe faulting occurred regardless of whether the road section was in a cut, fill or transition area. As would be expected, some correlation seems to exist between the fines being pumped out onto the shoulders and areas of more severe faulting.

An Illinois study proposed that reducing the original coarse aggregate maximum size "to avoid D-cracking may be accompanied by increased frequency of intermediate transverse cracks and increased severity of faulting" (7).

The measure of the ride quality of the pavement can be seen in Figure 7. A Mays Ride Meter mounted in a trailer was pulled over the project to evaluate its smoothness. A Present Serviceability Index (PSI) of zero to five described the ride quality. Zero meant impossibly rough, while five related to an absolutely smooth ride. The tabulated data show a deterioration of the ride quality. However, Figure 7 shows the relationship

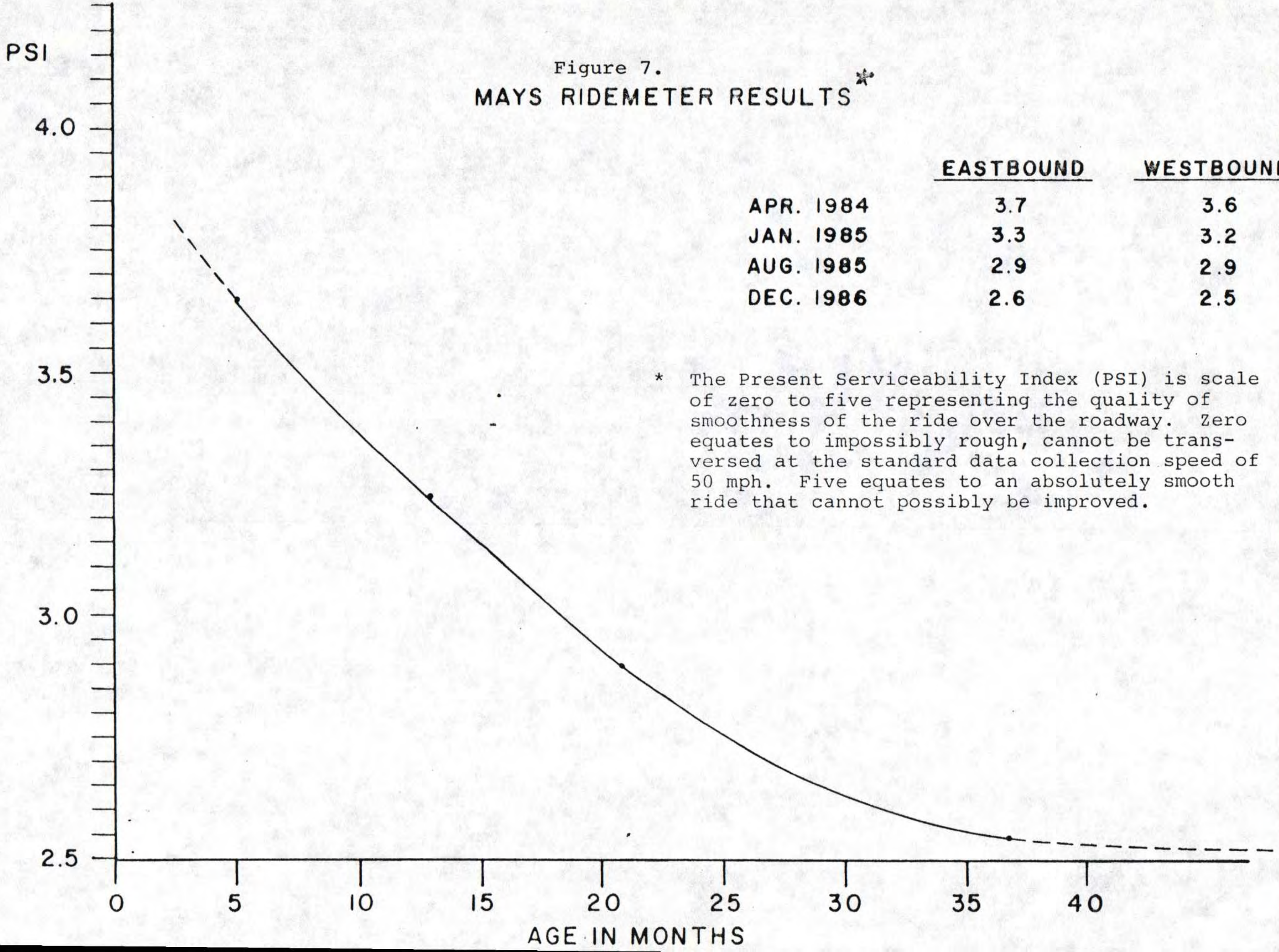
Table. 6

Joint Faulting

Inches of Faulting	Percent of Joints					
	Eastbound			Westbound		
	9/84	8/85	7/86	9/84	8/85	7/86
.00	24	12	4	10	9	1
.05	35	22	10	41	28	8
.10	36	36	27	40	34	25
.15	6	18	30	8	20	32
.20		10	21	1	9	22
.25		1	6			10
.30		1	2			2

Figure 7.

MAYS RIDEMETER RESULTS*



	EASTBOUND	WESTBOUND
APR. 1984	3.7	3.6
JAN. 1985	3.3	3.2
AUG. 1985	2.9	2.9
DEC. 1986	2.6	2.5

* The Present Serviceability Index (PSI) is scale of zero to five representing the quality of smoothness of the ride over the roadway. Zero equates to impossibly rough, cannot be transversed at the standard data collection speed of 50 mph. Five equates to an absolutely smooth ride that cannot possibly be improved.

time had to the quality of the ride. While the quality of the ride has decreased, it did so at a lessening rate.

In the fall of 1985, the silicone joint sealing material in the westbound lanes at the east end of the project began to fail noticeably. Table 7 shows the results of a field survey. While an infrequent joint failure could be found anywhere on the project, this severe, localized failure could not be considered typical. Since this section was built to the same standards and with the same materials as the rest of the project, the reason for this localized failure eluded engineers.

Future Work

Design engineers have been observing the performance of the recycled PCC pavement closely. A project will be designed in 1987 to put edge drains between the pavement and the right shoulder to vent water from beneath the slab. Underdrains will be installed in areas where high or perched water tables are suspected. Underdrains placed during the original construction in 1961 will be located, cleaned and restored to operation, if possible. New joint sealing material will be placed in the more severely deteriorated areas. Six inch thick, tied PCC shoulders are being considered as replacement for the existing shoulders.

Table. 7

Joint Sealer Failures

	Percent of Failed Joints*	
	Nov. 85	May 86
Pottawatomie County line west to Harrah/Newalla Rd.	20	26
Harrah/Newalla Rd. west for 1 mile	41	55
Next one mile segment	30	40

* A joint was described as 'failed' if six inches or more of the joint sealer material had been displaced sufficiently to allow water into the joint.

CONCLUSIONS

1. This project has shown that recycling unreinforced Portland cement concrete is technically feasible using conventional equipment.
2. Recycling PCC pavements can be an economically reasonable concept and can compete favorably with other alternatives on a low bid basis.
3. The recycling effort was successful in conserving natural stone resources.
4. When replacement of the pavement is necessary, recycling reduces the problem of disposing of old pavement. Disposal could be more of a problem in urban areas.
5. The fines were not used as sand in the concrete mix for this project. The highly angular crushed material would have required an excess of Portland cement and water if used in place of natural sand.
6. Design engineers will have to consider dust control at the crusher plant on future jobs in urban areas.
7. The steel tie-bars and construction joint reinforcement steel were removed without great problem. Projects in other states are reported to have removed even greater amounts of steel successfully.
8. A roller crusher proved to produce more coarse aggregate than when hammer mills were used to break the rubble.

RECOMMENDATIONS

1. Tests should be performed on any PCC pavement that is being considered for recycling. Depending on how well the material performs when measured against the current specifications, it could then be directed for its best engineering use in either Portland cement or bituminous layers.
2. When designing future construction projects, more consideration should be given to accommodating the truck traffic generated by the contractor.
3. Interim recommendations were made during the follow-up evaluation of this project. Action was taken to slow or correct the damage that occurred primarily as a result of inadequate subsurface drainage. Plans were prepared to let a project that would:
   a. install edge drains throughout the project length,
   b. add underdrains in other areas subject to infiltration of subsurface water,
   c. repair the existing broken slabs,
   d. replace the present shoulders with six inch, tied concrete shoulders, and
   e. replace sections of failed joint seal material.
4. Monitoring of the performance of the recycled PCC pavement should be continued in order to accurately evaluate the overall effectiveness of the recycling alternative.

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1. Klieger, Monfore, Stark and Teske, "D-Cracking of Concrete Pavements in Ohio", PCA, October 1974.

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3. Climatological Data, Oklahoma, U.S. Department of Commerce, Weather Bureau, 1971.

4. Halverson, A.D., "Recycling Portland Cement Concrete Pavements", Interim Report, Minnesota Department of Transportation, May 1981.

5. Yrjanson, W.A., "Recycling Portland Cement Concrete", Purdue University, West Lafayette, Indiana, April, 1981.

6. "Energy Requirements for Roadway Pavements", The Asphalt Institute, College Park, Maryland, November, 1979.

7. Stark, David, "The Significance of Pavement Design and Materials in D-Cracking", Ohio Department of Transportation, December, 1986.

APPENDIX

Photographs

Figure 1. Deteriorated Joints

Figure 2. Completed Crossovers

Figure 3. Cold Milling Asphalt Patches

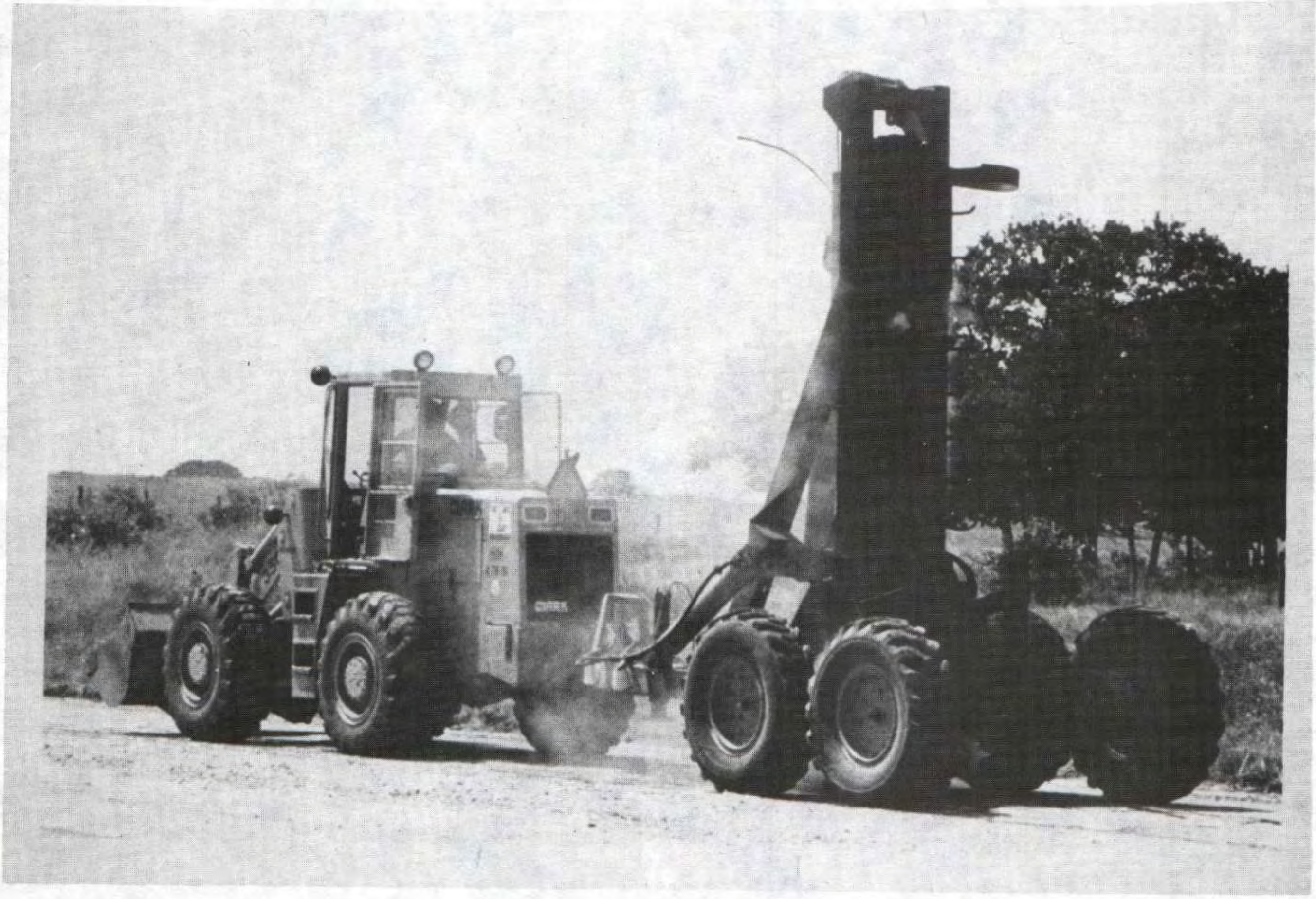

Figure 4. Breaking the Pavement

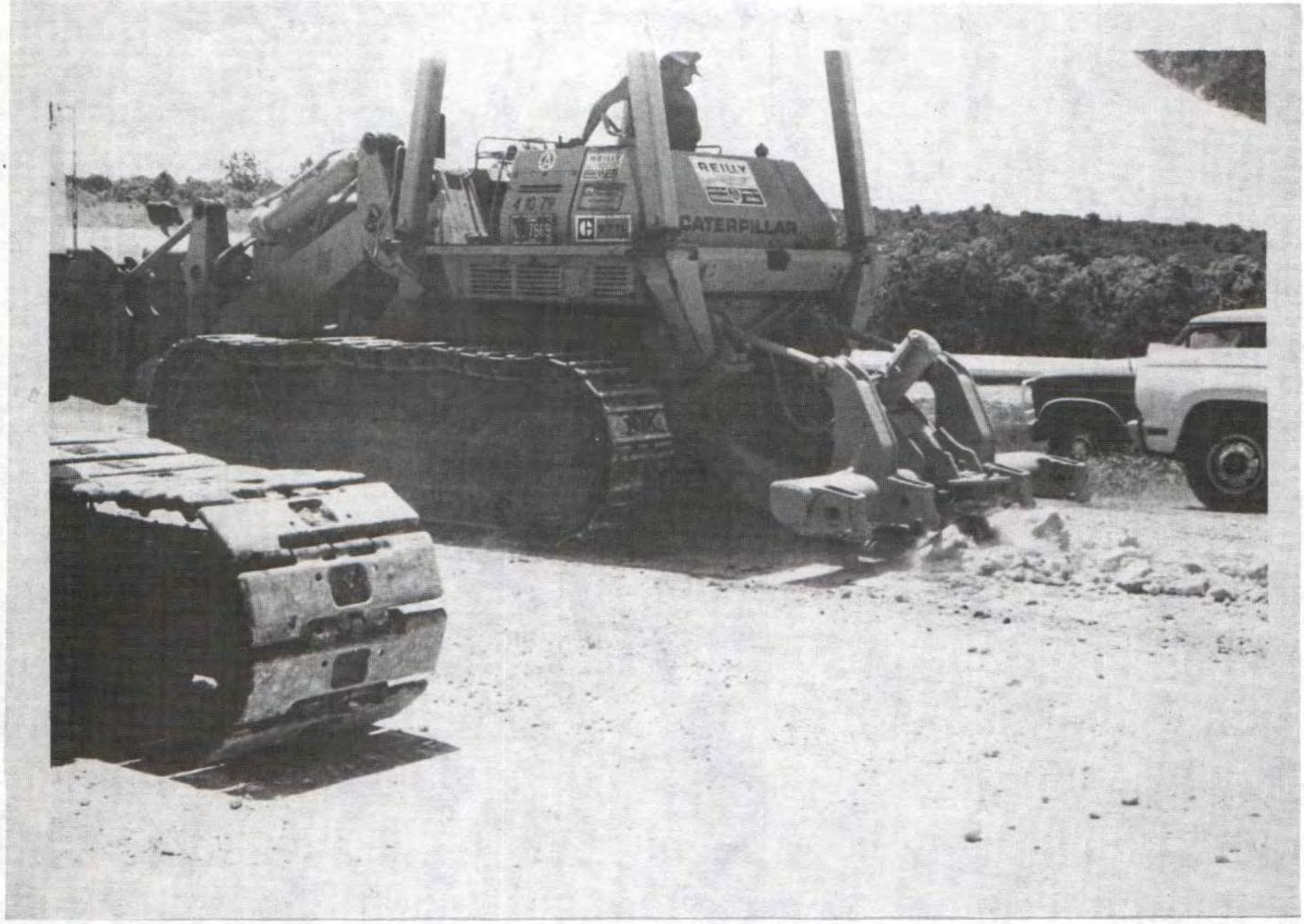

Figure 5. Ripping the Pavement Matrix

Figure 6. Back-hoe with "Rhino Horn"

Figure 7. Loading the Rubble

Figure 8. Crushing Plant

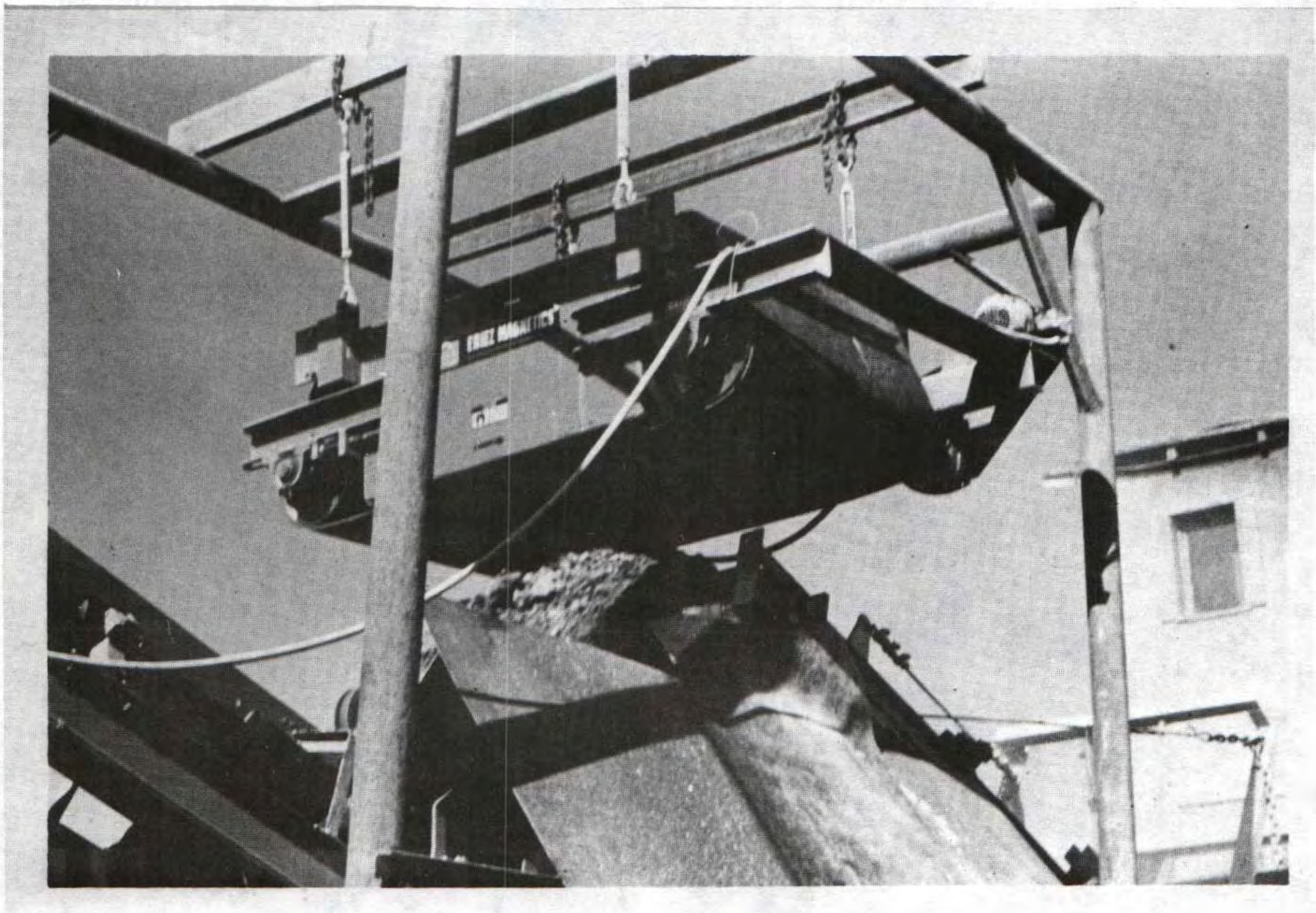

Figure 9. Cross-belt Magnet

Figure 10. Dual Drum Concrete Batch Plant

Figure 11. Deteriorated Soil Cement

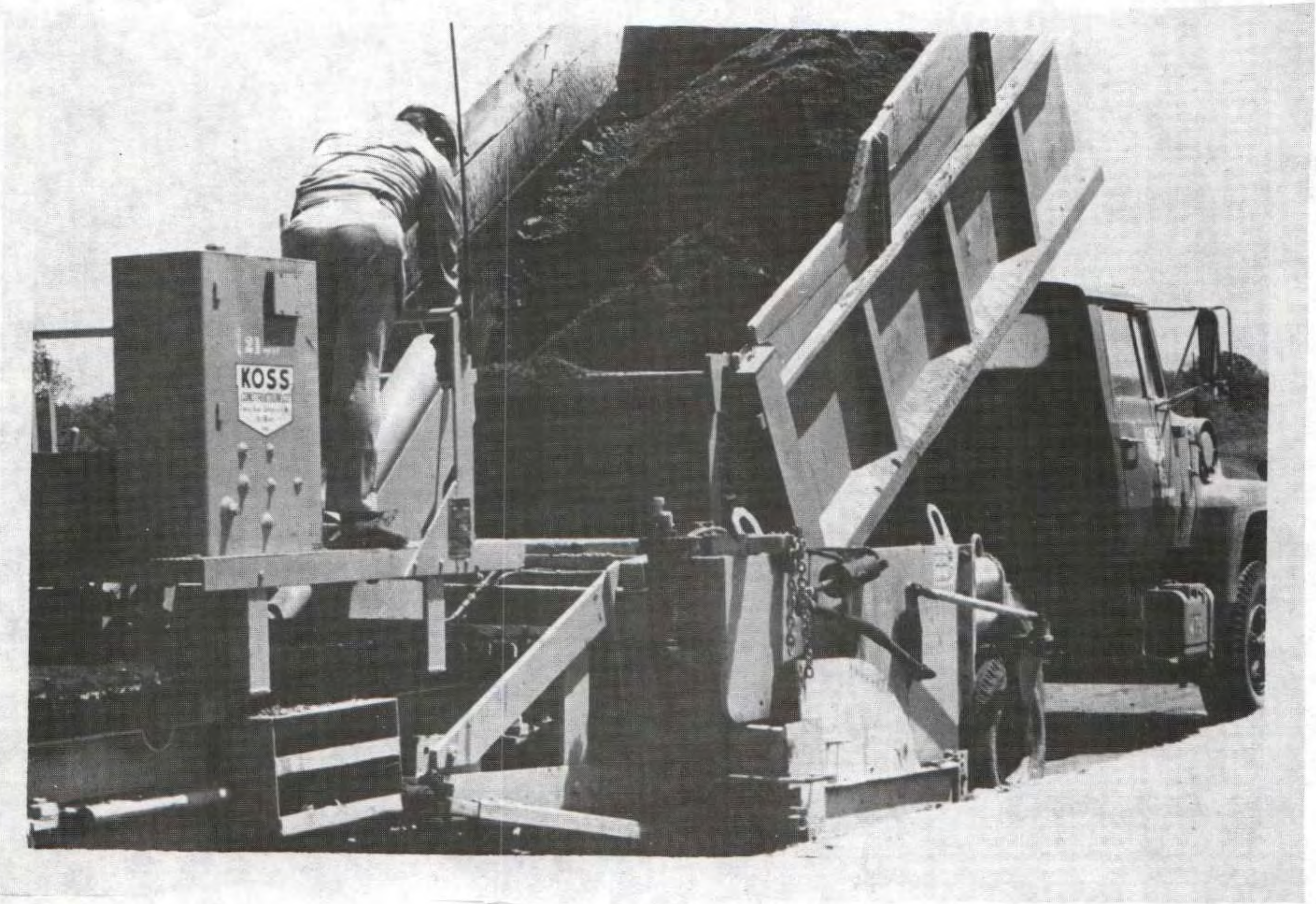

Figure 12. Adding Soil Asphalt to Base

Figure 13. Paving Train

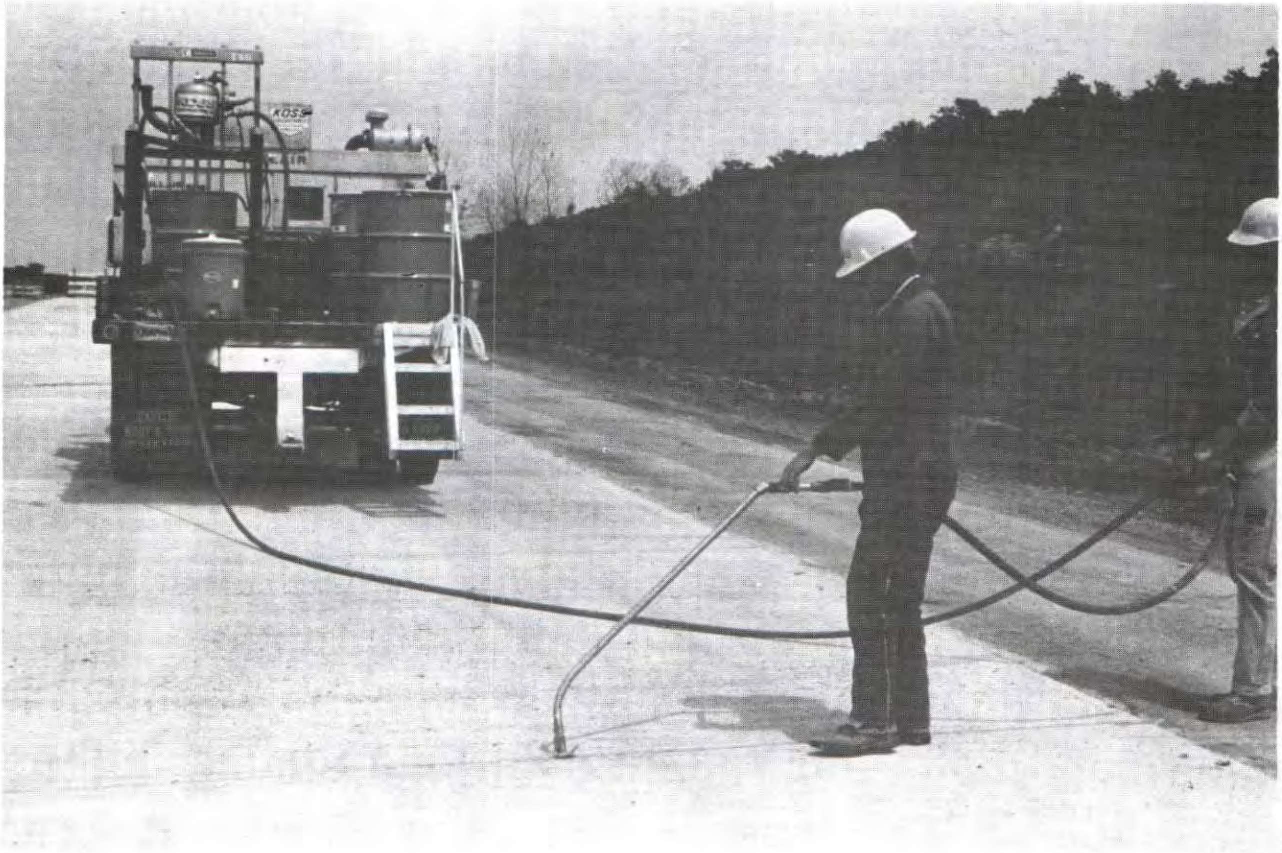

Figure 14. Filling Sawed Joints

Figure 15. Paving the Shoulder

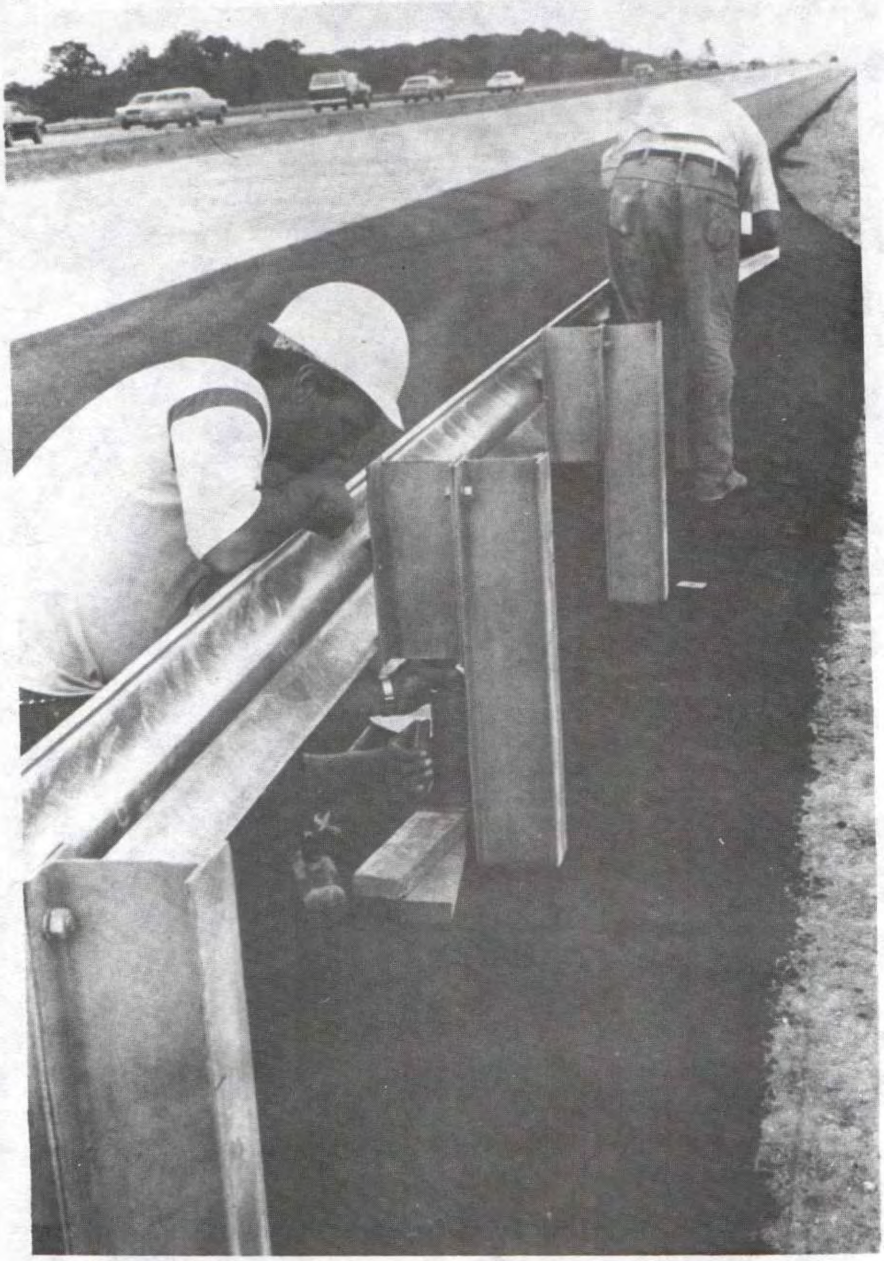

Figure 16. New Guardrail

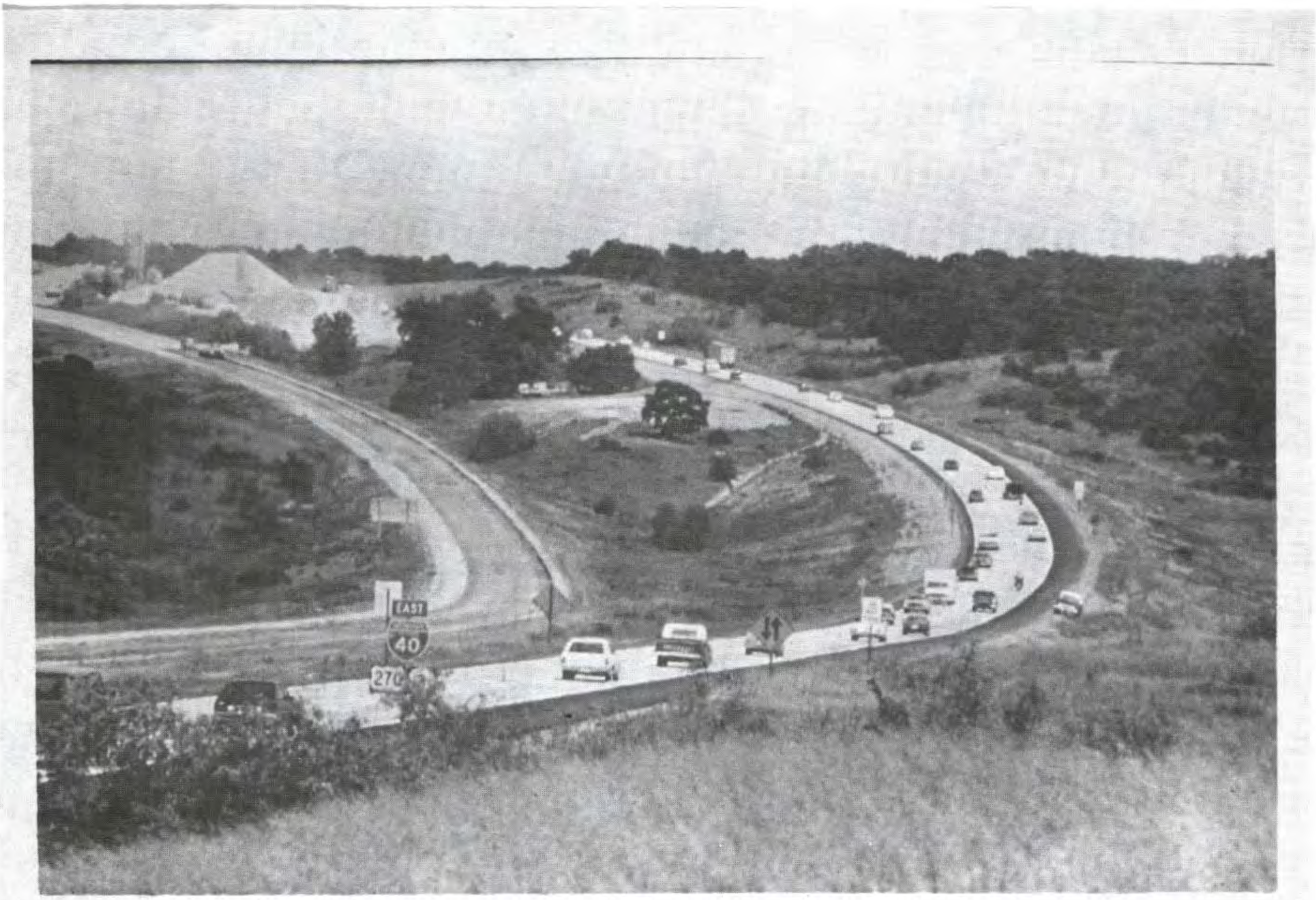

Figure 17. First Section Completed, under Traffic

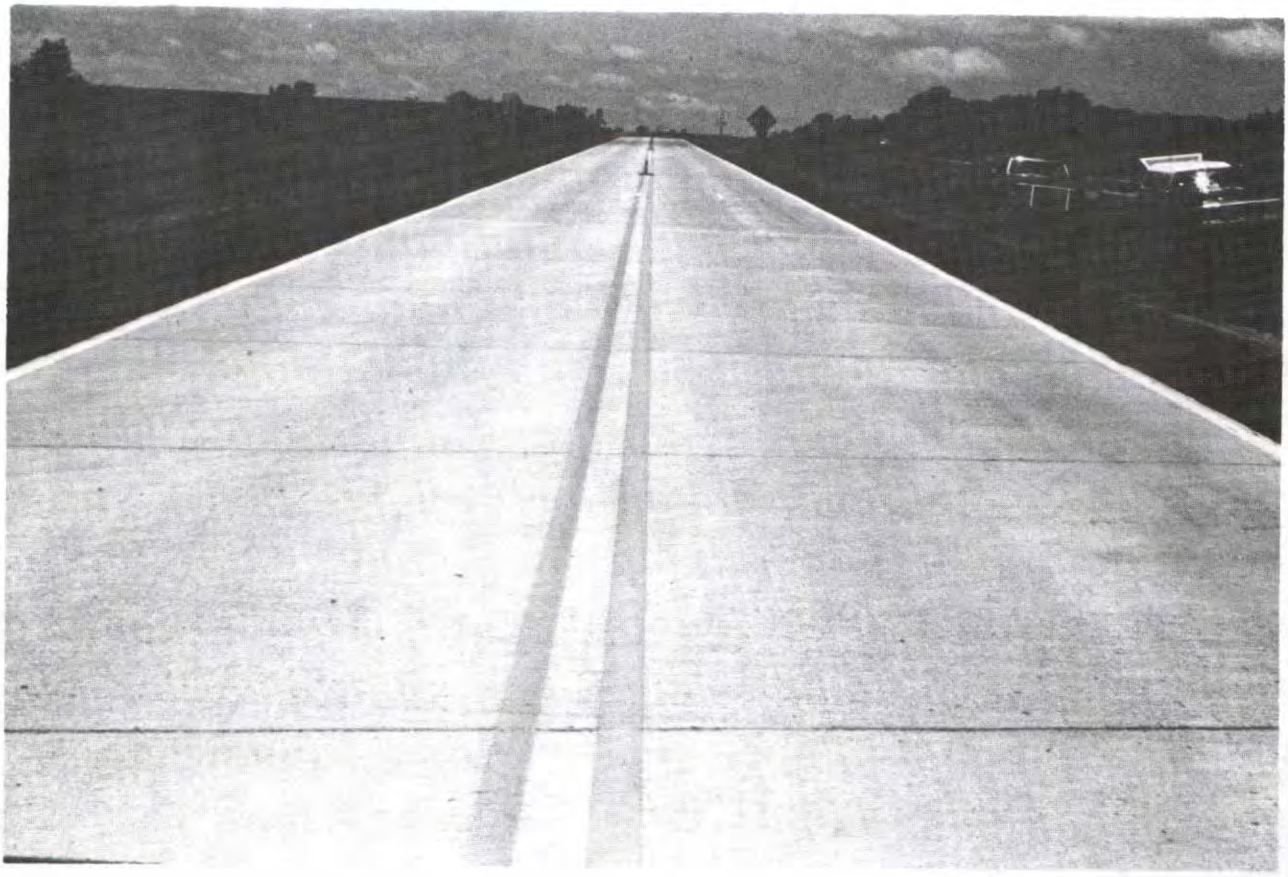

Figure 18. New Pavement (Two-way Traffic in Detour)