Recycling PCC Roadways in Oklahoma

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ABSTRACT

The first portland cement concrete (PCC) pavement recycling project in Oklahoma is described. The project consisted of 7.75 miles of Interstate 40 east of Oklahoma City. The original pavement had passed its design life of 20 years and had experienced moderate D-cracking. The deteriorating 9-in. slab was replaced by a 10-in. slab. As a result of this demonstration project, recycling existing PCC pavements into coarse aggregate was shown to be practical. Sufficient coarse aggregate can be produced to replace old pavements with new pavements. The recycled PCC has the workability and meets the strength requirements of virgin mix PCC. Although a comparison of energy requirements between the recycled PCC alternative and an asphaltic concrete overlay of approximately 9 in. showed no significant difference, the contractors' bids did. The asphaltic concrete overlay was bid at $5.9 million, and the PCC recycle alternative was bid at $5.2 million. Previous research had suggested that the original D-cracking problem had been reduced in two ways. First, the original 1.5-in. coarse aggregate was downsized to 0.75 in. Also, 85 lb of portland cement was replaced with 115 lb of fly ash per cubic yard of concrete.

Emphasis has been on conservation during the last decade. The highway construction industry has used many innovations to conserve both energy and materials. Oklahoma has had several highway improvement projects in which asphaltic concrete roadways were recycled. The Oklahoma Department of Transportation (ODOT) has recently finished the first portland cement concrete (PCC) highway recycling project in the state. Approximately 7.75 miles of I-40 east of Oklahoma City were recycled in 1983.

PAVEMENT DISTRESS

The primary reason for rehabilitation of this highway was moderate D-cracking failure in the joints. This failure can 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 usually originates in the lower and middle levels of the pavement slab and progresses upward to the wearing surface" (1). The Illinois DOT conducted a literature search into D-cracking and summarized their findings as follows (2,p.9):

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 [Portland Concrete Association] 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 9-in.-thick PCC had no steel reinforcement. The original limestone aggregate had a maximum nominal size of 1.5 in. The 15-ft contraction joints were sawed and sealed with conventional asphaltic material. Each direction had a 4-ft inside shoulder, two 12-ft lanes, and a 10-ft outside shoulder. Rebars 0.5 in. in diameter and 30 in. long were placed on 30-in. centers longitudinally to tie the two lanes together. Both the inside and outside shoulders were constructed of soil cement and given a 1-in.-thick "chip and seal" wearing course. The shoulders and roadway both rested on a 6-in. soil asphalt base, which in turn rested on 5 in. of select material.

REHABILITATION

The project was first conceived as a breaking and seating of the existing PCC pavement and overlaying with asphaltic concrete (AC). The original 15-ft-long panels 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 50-ton, pneumatic wheeled roller to seat the fractured pavement. An AC leveling course would be topped with 6 in. 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 in., 2 ft, 4.5 ft, and 8.5 ft diagonally from the corner (Figure 1). Three of the four cores taken 6 in. from the corner crumbled on removal. The fourth core had a compressive strength of 3,223 psi. The following table gives the compressive strength of the cores (psi):

	Slab No.			
Location	1	2	3	4
A	Rubble	Rubble	Rubble	3,223
B	3,836	6,430	2,228	5,292
C	3,501	4,369	4,990	6,915
D	7,074	6,279	4,974	6,549

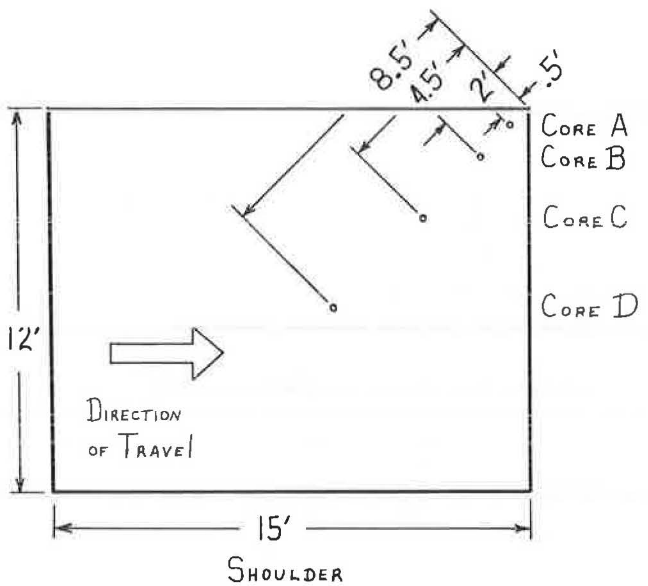

FIGURE 1 Core hole locations.

The alternate design consisted of removing the existing 9-in. PCC pavement and replacing it with 10 in. of new PCC pavement while leaving the shoulders intact. The contractor had the option of using virgin aggregate or recycled aggregate. Pay quantities included provisions for reconstruction of the 6-in. soil asphalt base, if necessary. After the new pavement was placed, plans called for 1 in. of the shoulder to be cold milled and surfaced with 2 in. of hot mix AC material.

The project was let to contract in July 1982. The low bidder, Koss Construction Company of Des Moines, Iowa, chose to recycle the existing PCC pavement. The nearest source of virgin aggregate was a quarry more than 50 miles away. 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 1982, the prime contractor avoided the winter weather by starting work on March 10, 1983. The subcontractor rehabilitated the two bridge decks on the project by December 1982.

A portable aggregate crushing plant and a PCC batch plant were first placed in the median of the west half of the project and then 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 two-way movement on the adjacent roadway.

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-ft centers to keep two-way traffic separated. Because the average daily traffic (ADT) exceeded 20,000 vehicles, traffic maintenance had a never-ending job replacing the plastic delineator devices.

Breaking the existing pavement was the first step in 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 that uses an MKT diesel pile driver. Both pile drivers exert 18,000 ft-lb of energy. Several different breaking patterns were tried. Starting at the centerline and alternately working toward the shoulders 18 in. at a time seemed to disturb the soil cement shoulders the least.

When the pavement had been broken, a crawler loader lifted the rubble into the waiting bucket of a wheeled loader. The more maneuverable wheel loader then placed the rubble in the dump beds of waiting haul trucks. To reduce the amount of soil asphalt picked up by the loader, the crawler made two passes on the rubble with a ripper to dislodge the matrix. Even more efficient production resulted when a backhoe used a ripper tooth (called a "rhino horn") in place of a bucket. The backhoe worked between the loaders providing a continuous supply of loosened rubble.

The broken rubble was delivered to a standard Cedar Rapids crusher plant that uses hammer mills on both the primary and the secondary crushers. The small quantities of steel rebars were removed by an Eriez cross-belt magnet suspended over the conveyor belt between the crushers. Wire cages holding dowel bars, originally used as 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 recyclable, coarse aggregate. Regrettably, the hammer mills produced more fine materials than expected in the crushing process. These fines became the property of the crushing plant subcontractor.

The coarse aggregate met the size requirements; a typical analysis is given in the following table:

Sieve Size	Percentage Passing	Specification
1 in.	100.0	100
3/4 in.	98.5	90-100
1/2 in.	46.5	20-55
3/8 in.	11.2	0-15
No. 4	1.5	0-5

A typical analysis of the fines from the crushing operation is given in the following table:

Sieve Size	Percentage Passing
1/2 in.	100.0
3/8 in.	99.2
No. 4	74.8
No. 10	48.5
No. 40	19.4
No. 80	9.2
No. 200	4.5

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 section. The volume of coarse aggregate produced was not sufficient to pave the section from which it was removed. The first section was 21,954 ft long; the virgin aggregate paved 5,731 ft of that section. The output of the crusher plant was improved to 52 percent on the second section by replacing the secondary hammer mill with a Universal Triple Roller crusher.

To reduce the potential for future D-cracking, the maximum nominal aggregate size allowed was 0.75 in. Also, good results occurred when 15 percent of the portland cement was replaced with 20 percent fly ash (3).

The PCC using recycled aggregate and fly ash would still have to meet the standards for Class A concrete: slump from 1 to 3 in. and a minimum 7-day compressive strength of 3,000 psi. The mix design proposed by the contractor was tested in the laboratory. The design mixes to produce 1 yd^3 of concrete are given in the following table:

	Recycled	Virgin
Portland cement (lb)	479	479
Fly ash (lb)	115	115
Entrained air (%)	5	5
Natural sand (lb)	1,130	1,206
Coarse aggregate (lb)	1,695	1,864
Water (gal)	30	30
Density (lb/ft^3)	136	145

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

The average compressive strength of the five test cylinders of recycled PCC was 3,618 psi after 7 days. The test cylinders using virgin limestone coarse aggregate had an average of 3,856 psi of compressive strength after 7 days.

The pavement-crushing hammer had consolidated the soil asphalt during removal of the existing pavement on the first section. To restore the grade and eliminate the need to mill the shoulders, an average of 3.5 in. of soil asphalt was added to the base. This elevated the surface of the new 10-in. pavement a minimum of 2 in. above the uneven, worn shoulders. A pugmill was used on the site to produce 6,560 yd^3 of soil asphalt. The material was placed, blended with the existing soil asphalt base with a pulvermixer, and compacted. An autograder milled a precision grade before the concrete was placed. Excess soil asphalt was stockpiled for use in the base of the next section.

After the soil asphalt was made for the first section, the pugmill was disassembled and removed. It was found that by combining the fines from the crusher plant with the existing 6-in. soil asphalt base, the necessary profile could be met and sufficient base strength resulted. The remaining sections had fines instead of soil asphalt blended into the base.

Paving began on the first section on May 18, 1983, with a CMI slip form paver. The nonreinforced slab was 10 in. thick and 24 ft wide. The concrete was produced by an 8.5-yd^3, dual-drum central batch plant. However, only 6 yd^3 of concrete were mixed at a time. The contractor used 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 machine to deliver their loads of concrete.

Samples were taken as the concrete was delivered to the paver. Slump averaged 1.5 to 2 in. and air content was 4.6 percent. Test cylinders made of the recycled PCC yielded 7-day compressive strengths in the 3,160 to 4,580 psi range.

The concrete looked as good and handled as well with recycled aggregate as with virgin aggregate. After the paving train placed the concrete, it was tined transversely to enhance skid resistance. The last operation on the paving train was to spray the surface with a curing compound. Joints were sawed (skewed 4 ft from perpendicular) every 15 ft, cleaned, and filled with silicone sealer. While the pavement was curing, the shoulders were paved with an average of 2.7 in. of a dense-graded, hot mix asphaltic concrete. New guardrail was also installed.

This staged construction was continued until the entire 7.75-mile project was completed. The project was opened to traffic in early November 1983, after 247 calendar days of work.

PROJECT EVALUATION

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

With the completion of the construction work, highway engineers have gained new knowledge about concrete recycling techniques. The new pavement looks good and provides a smooth ride. The one question remaining is: How long will it last?

The 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. About $800,000 was saved by recycling the old pavement and thus avoiding the purchase of 63,000 tons of virgin aggregate.

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 freeze-thaw tests conducted on specimens of the recycled concrete. Although not a specification requirement, a factor of 50 or better is used to describe a material as durable.

The original pavement exceeded its design life of 20 years. In the recycled pavement, the coarse aggregate was downsized, and fly ash was used in the design mix. Research indicates that fly ash and downsizing reduce pavement susceptibility to freeze-thaw deterioration; therefore, the recycled pavement should last at least as long as the original pavement.

Another area of interest on the project was energy conservation. Using the Asphalt Institute's "Energy Requirements for Roadway Pavements," and pay quantities on the plans, engineers estimated that the recycling work required the energy equivalent of 1.1 million gal of gasoline (4). Using the same publication, energy requirements were estimated for the overlay alternate. Comparing the PCC to the AC over a 20-year design life has shown that the AC would require two overlays in its life. For the purpose of comparing energy requirements, both overlays were assumed to be AC recycled overlays. Energy requirements for AC were estimated and found to be virtually the same as those for the PCC alternative. Although 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 more than the final bid for PCC recycling.

SUMMARY

As a result of this demonstration project, engineers know that PCC can be recycled. Enough coarse aggregate can be produced to directly replace the old pavement without any new coarse aggregate. No doubt engineers will explore the option of recycling PCC pavements along with other, more traditional methods when designing future rehabilitation projects.

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Curing and Moisture Loss of Grooved Concrete Surfaces

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ABSTRACT

Several tests were conducted to evaluate the curing of grooved concrete surfaces with a liquid membrane-forming compound. The grooves were 1/10 in. (2.5 mm) wide at spacing of 3/4 in. (19 mm) and the depth varied from 1/8 in. (3 mm) to 3/16 in. (5 mm). The curing compound was applied at the rate of 200 ft²/gal as specified by AASHTO and ASTM. In all cases the moisture loss exceeded the allowable amount of 0.55 kg/m² in 72 hr. Moisture loss data were also obtained for concrete surfaces with groove depths of 0.15 in. (3.8 mm). A regression analysis of the data estimated that the moisture loss would be restricted to 0.55 kg/m² when the compound application rate increased by 23 percent of the standard rate. It is suggested that increasing the compound application rate will not be a satisfactory solution because of problems associated with sagging of the curing compound on vertical surfaces. Further investigations on the methods and materials for curing grooved concrete surfaces with liquid membrane-forming compounds are suggested.

Several concerns have been raised in recent years about the adequacy of the methods and materials for curing grooved concrete pavements with liquid membrane-forming compounds. The standard specifications for liquid membrane-forming compounds for curing concrete surfaces [AASHTO M 148-82 and ASTM C 309-81; and AASHTO T 155-82 and ASTM C 156-80a (1-3)] require that the curing compound be applied at the rate of 200 ft²/gal and that the moisture loss be not more than 0.55 kg/m² of surface in 72 hr. Early in 1970 the Transportation Research Board Circular 280 (4,pp.5-6) had indicated that "the trend toward deeply textured pavements such as those textured with a steel wire comb requires a larger quantity of curing membrane than pavements textured with a broom or burlap drag." When the pavement is grooved, the surface area is not only increased, but the vertical sides of the grooves may not receive the same amount of curing as the horizontal surfaces. It is understood that several highway agencies have been using an application rate of 150 ft²/gal for some years, but this rate was not adopted by AASHTO in the new guide specifications published in 1982.

In September 1980 the National Cooperative Highway Research Project (NCHRP) of the Transportation Research Board distributed briefs of research problem statements considered by the Special AASHTO Select Committee on Research for the FY 1982 Program of the NCHRP (5) in the hope that some of the problems might be addressed by other agencies. One of the research problem statements that related to the evaluation of methods and materials to assure adequate curing of grooved concrete pavement received a ranking of 11 on a scale of 1-19. The research described in this paper was motivated, at least in part, by the research problem statement distributed by the NCHRP.

The direction of grooves (transverse or longitudinal) varies from one state to another. A Portland Cement Association publication (6) presents the types and directions of surface textures in various states. A selected groove dimension that would be acceptable to all agencies involved in the design and construction of highway pavements has not been set as a standard. The Federal Highway Administration Technical Advisory (7) recommends the use of grooves 0.095 in. (2.4 mm) wide spaced at 3/4-in. (19-mm) centers. It is recommended that the depth of the grooves range from 1/8 in. (3 mm) to 3/16 in. (5 mm). The FHWA suggests that groove spacing of less than 1/2 in. (13 mm) may not have adequate durability. Similarly, an increase in the groove spacing beyond 3/4 in. (19 mm) cannot be expected to increase durability by a significant amount and may lead to noise problems. The groove dimensions specified by most agencies appear to lie within the limits suggested by the FHWA. For example, the Ohio Department of Transportation (8) specifies that "grooves shall be spaced at approximately 3/4 inch