ILLINOIS' EXPERIENCE WITH A RECYCLED CONCRETE INLAY

Frank R. Van Matre
District Engineer of Construction
Illinois Department of Transportation
District Seven
Effingham, Illinois

Amy M. Schutzbach
Senior Materials Investigation Engineer
Bureau of Materials and Physical Research
Illinois Department of Transportation
Springfield, Illinois

Abstract

This paper describes a research project which evaluated the feasibility of recycling a deteriorated concrete pavement. A cracked and badly faulted 24-foot wide jointed reinforced concrete pavement was selected for the study. Originally constructed in 1964, the pavement cross-section consisted of 10 inches of concrete over six inches of aggregate subbase. A 27-foot wide inlay was constructed to take advantage of the bituminous shoulders that had been reconstructed in 1978.

The two northbound lanes of the four lane project were constructed in 1986, and the two southbound lanes completed in 1987. The construction sequence consisted of removing the inner 1 1/2 feet of each shoulder, breaking the pavement with a diesel pile driver, crushing the broken concrete, cement stabilizing the aggregate subbase in-place to a depth of seven inches, and constructing a new 10-inch continuously reinforced concrete pavement. The recycled concrete mix contained both coarse and fine crushed concrete. Small amounts of natural sand and fly ash were added for workability. The crushed concrete met standard quality requirements with the exception of the sodium sulfate soundness test. The mix properties of the recycled concrete were comparable to those of a conventional concrete mix. The Illinois Department of Transportation is monitoring the long-term performance of the pavement.

The feasibility of the recycling process and the cost savings potentially associated with such a process indicate that recycling deteriorated concrete pavements is yet another viable rehabilitative technique.

The large majority of interstate miles in Illinois were constructed between fifteen and twenty years ago. The emphasis of the Illinois Department of Transportation (IDOT) has thus shifted from new construction to restoring the quality of its aging interstate network. While Illinois has routinely employed a variety of rehabilitative techniques, recycling old Portland cement concrete pavements into new concrete pavements has not been attempted. Other states have found that recycling allows for the optimal use of limited aggregate supplies and the conservation of resources. Such benefits are of great value in these times of declining infrastructure quality and limited funding.

Encouraged by the potential benefits, IDOT developed an experimental feature project to determine the potential of the recycling process. The objective of this project was to evaluate the feasibility of recycling a deteriorated concrete pavement.

SELECTION CRITERIA

In order to ensure a fair test of the recycling operation, IDOT took care in selecting a candidate project. Three main criteria were considered in the selection process. First, the candidate project had to be in need of major rehabilitation. Second, the pavement had to contain aggregate of an acceptable quality. Finally, the project had to be located in an area where two-way traffic control was feasible.

The condition of the pavement to be recycled was of prime concern to the study. For recycling to be both economical and effective, the pavement selected had to be in need of major rehabilitation, since recycling is a long-term measure. Interstate pavements in need only of Illinois' standard three-inch asphalt concrete overlay were not considered. Pavements requiring minimal concrete pavement restoration (CPR) work, such as grinding and pressure grouting, were likewise not selected. Those projects in need of extensive CPR work were considered as candidates for recycling, because costs for the two methods of rehabilitation were thought to be comparable.

Since recycling is one of the more costly rehabilitative techniques in use, IDOT desired to choose a pavement originally constructed of sound, durable materials. Pavements exhibiting signs of D-cracking as well as pavements originally constructed with aggregates known to be susceptible to D-cracking were not considered. Samples from candidate projects were subjected to IDOT's freeze-thaw testing procedure to determine their freeze-thaw rating and their susceptibility to D-cracking. (1)

The final criterion was that the project had to be constructed under two-way traffic. Rather than detour traffic to a nearby existing route or construct a temporary detour, traffic was to be maintained on the project during construction. Illinois has had only limited experience with maintaining two-way traffic on interstate routes under construction. Therefore, it was desired that the project be located in a rural area, well between interchanges, to simplify the traffic control. These three criteria: pavement condition, quality of materials, and feasibility of traffic control, were the main considerations in selecting a pavement for the recycling project.

PROJECT DESCRIPTION

The site chosen for the recycling project met all three of the selection criteria. The 4.14 mile section on Interstate 57, just north of Effingham, Illinois, was located in a rural area. The average daily traffic for 1984 was 10,000, with 2,000 multi-unit trucks. No interchanges were present on the job, so two-way traffic presented no problem. Figure 1 shows the general location of the project.

Originally constructed in 1964, the 10-inch, 100-foot jointed reinforced concrete pavement (JRCP) had been placed over six inches of aggregate subbase. The pavement was reinforced with 612-1/04 style smooth wire fabric reinforcement. Greased dowel bars 18 inches long and 1 1/4 inches in diameter were spaced at 12-inch centers at the contraction joints. In addition, #5 tie bars were placed at 2 1/2 feet centers across the longitudinal centerline joint. The shoulders had been reconstructed in 1978, and consisted of eight inches of bituminous aggregate mixture. Underdrains were also added to the section in 1978. The original pavement cross-section is shown in Figure 2. The aggregates used in the construction of the concrete were of a high quality, and preliminary testing indicated they were not susceptible to D-cracking.

The 100-foot jointed pavement exhibited two to three panel cracks per slab. Virtually every crack and a majority of the joints were badly faulted, thus creating an extremely rough ride. The pavement showed no signs of D-cracking. Spalling was evident at the joints and most mid-panel cracks. Due to the extensive CPR work that would have been required, the project was deemed ideal for recycling. In addition, the previously reconstructed shoulders were in excellent condition. This factor created the possibility of an inlay, thus allowing additional savings since the shoulders did not have to be reconstructed.

PROJECT DESIGN CONSIDERATIONS

Pavement Design

The recycled pavement design analysis was based on a 20-year design life using IDOT's pavement design procedure. (2) The new design called for 10 inches of continuously reinforced concrete pavement (CRCP) over seven inches of cement stabilized subbase. Standard Illinois practice requires a four-inch stabilized subbase. Seven inches were required on this project due to a proposed pavement crown change and a desire to leave only stabilized materials in place over the subgrade. To take advantage of existing features in good condition, both the shoulders and the underdrains were to remain in place. In order to provide good edge support, the pavement and the stabilized subbase were to be built 27 feet wide, with the pavement striped at 24 feet. The extra width later proved useful during the two-way traffic construction phase. Figure 3 illustrates the cross-section of the recycled concrete inlay.

Stabilizing the subbase 27 feet wide with the existing underdrains remaining in place posed a special problem. The original pavement was 24 feet wide, with the underdrains placed directly under the pavement edge-shoulder joint. The new 27-foot wide pavement placed the underdrains 1 1/2 feet in from the pavement edge-shoulder joint. Whether the underdrains would continue to function in their new location was a question that needed to be considered. While an open-graded base was not considered, IDOT felt that the stabilization of the outer 1 1/2 feet of the subbase adjacent to the shoulders would probably be marginal at best. This would provide a more unobstructed path for the water to reach the underdrains. The contractor was required to save all pipe underdrains along the outside shoulder. IDOT anticipated that the underdrains on the median side of the pavement might be damaged due to haul road construction. Therefore, the contract did allow for partial replacement of the median underdrains.

In order to protect the shoulders during construction, unloading and hauling operations were limited to the median and the existing pavement. Trucks were allowed on the median shoulder only to unload cement for the stabilization process and concrete for the actual paving. Any damage to the shoulders was to be repaired at the contractor's expense.

Materials

The use of crushed concrete as an aggregate called for some changes in Illinois' standard specifications. Crushed concrete obtained from the existing pavement was specified to be the primary source of both fine and coarse aggregate. Only a small amount of natural sand was allowed for workability. Standard coarse and fine aggregate gradations, CA-07 and FA-01, similar to AASHTO M 43-82 (1986) size 57 and AASHTO M 6-81 (1986) respectively, were modified to allow for fines produced during the crushing operation. Impact-type aggregate crushers were not allowed due to their tendency to produce excessive amounts of fines. Table 1 details the modified gradations used in the recycling project.

In addition to the gradation modifications necessary to accommodate the crushed concrete, the sodium sulfate soundness test was waived. The crushed concrete met Illinois' one-inch maximum size freeze-thaw requirement, and also the Los Angeles Abrasion and deleterious material requirements. However, the crushed concrete coarse aggregate failed the sodium sulfate soundness test, which is an indicator of an aggregate's resistance to weathering. Apparently the sulfate reacted with the concrete mortar, resulting in the failing tests. For this reason, the sodium sulfate quality requirement was waived for the crushed concrete. Table 2 lists the results of the quality tests on the crushed concrete.

The final material item of concern was the chloride content of the crushed concrete. Excessive chloride contents require expensive chloride control measures such as epoxy-coated steel. The chloride content of the existing concrete pavement was tested. Although slightly high, two points supported the decision to use plain reinforcing steel. First, the fine aggregate was to be washed, which would remove some of the chloride. Second, the crushed concrete would be mixed with other materials and dispersed throughout the recycled concrete, thus minimizing the potential differences that can lead to corrosion.

Mix Design

As mentioned previously, crushed concrete was required to be the primary source of both coarse and fine aggregate. Aside from a small amount of natural sand added for workability, no blending of crushed concrete and virgin material was allowed. The virgin sand, an FA-01 gradation similar to AASHTO M 6-81 (1986), was limited to 20 percent of the total aggregate, including fly ash. IDOT set an initial mix requirement of 600 pounds of cement per cubic yard of concrete. This value could be altered based on strength tests. A minimum of 125 pounds of fly ash was required for workability.

Strength results from preliminary mix designs are shown in Figure 4. Based on satisfactory strength gains, the cement requirement was lowered approximately 15 percent to 515 pounds per cubic yard of concrete, with 125 pounds of fly ash used. The result was a 1.5:1 fly ash to cement replacement ratio, a value currently recommended in federal guidelines. The fly ash was a Type C ash with an R factor of 1.0, indicating a medium-reactive ash. Table 3 outlines the initial mix design quantities.

CONSTRUCTION DETAILS

Work on the recycling project began in April, 1986, with a November 1, 1987 completion date set. Although the contract required two-lane, two-way traffic during reconstruction, all four lanes had to be open for traffic between November 1, 1986 and April 1, 1987. The contractor opted to complete the northbound lanes in 1986 and the southbound lanes in 1987.

Preliminary Work

A haul road was constructed adjacent to the median shoulder of the northbound lanes. Due to a wet spring and a lack of specifications concerning haul road construction, problems developed. Construction equipment operating close to the median shoulder caused the outer part of the shoulder to heave. Modifications to the operation, including benching the earth adjacent to the shoulder and disking and drying the soil before compacting, helped to minimize this condition.

The median and outside bituminous shoulders were then roto-milled to a flat cross-section four inches below the elevation of the existing centerline. A tangent crown replaced the original circular crown of the pavement and resulted in a two-inch grade change in the centerline profile of the new pavement. A 1 1/2-foot wide section of bituminous shoulder was then removed from both sides. This action provided a straight edge "form" for the paver, widened the roadbed to the desired 27-foot width, and minimized damage to the shoulder from the pavement breaker. This bituminous aggregate material was crushed and stockpiled for later use as an aggregate wedge along the outer edge of the shoulders.

The milling and shoulder removal operations did damage the shoulders slightly. The top lift of shoulder material remaining after milling varied from 3/4-inch to 2 1/2 inches. In the areas of the thinner lifts, the top lift had separated from the lower lifts and broken off. Such areas were scattered throughout the length of the project.

Pavement Breaking

The existing 24-foot pavement was broken with a diesel powered pile driver. The weight of the ram was 5,070 pounds and the diesel hammer delivered approximately 60 blows per minute. The degree of pavement breaking was controlled by the speed of the endloader pulling the pile driver. The size of the broken pieces ranged from approximately two feet square on down.

The breaker made two passes per lane and one down the centerline of the pavement. Edge pieces tended to break into long, narrow pieces that caused problems at the crusher. A smaller cable drop pavement breaker was added for the edge breaking to alleviate this problem.

Subbase Stabilization

During the pavement breaking and removal operation, a cone penetrometer was used to check the existing subgrade support. The readings correlated to an average California Bearing Ratio (CBR) value of approximately six. Illinois requires a minimum in-situ CBR of six to eight to ensure adequate subgrade stability, and requires that all interstate concrete pavements be placed over a stabilized subbase. (2, 3)

Two inches of gravel were added to the existing aggregate subbase to attain the raised profile of the new pavement. Tests on the subbase aggregate indicated that a cement content of 7.6 percent by volume of aggregate was required. This translated into 5.4 pounds of cement per square yard per inch of compacted thickness. The cement was blown from a tanker into a spreader, which covered the 27-foot width in three passes.

A mobile mixer was used to process the cement and subbase in place. Since the mixer could not process the material directly adjacent to the shoulders, this material was windrowed out, processed, and then bladed back prior to compaction. A vibratory sheepsfoot roller and a vibratory steel drum roller were used for compaction. Densities checked by a nuclear gauge ranged from 95-100 percent of Standard Proctor, with the moisture content at approximately 90 percent of optimum moisture. After being trimmed to final grade, the stabilized material was cured with white polyethylene sheeting, which was removed prior to placement of the reinforcing steel.

Pavement Crushing

Figure 5 details the primary and secondary crushing system used for breaking up the concrete. A two-inch bar grizzly removed the subbase and fines. The primary jaw crusher reduced the broken concrete to a six-inch size and separated more than 95 percent of the paving mesh from the concrete. After the material left the primary jaw, it was conveyed by belt underneath a magnet to remove the remaining steel. The steel mesh was discarded and the concrete was fed into a surge bin with a reciprocating feeder to ensure a uniform flow to the secondary crusher.

The secondary crusher was a four deck screening unit with a small jaw and roll crusher. The concrete passed over a three-inch screen deck and through a jaw crusher, over a 1.5-inch screen deck and through a roll crusher. Recirculation of material continued until all material was separated on the -#4 screen deck or on the +#4 screen deck. The coarse aggregate, +#4 sieve material, was conveyed by belt to a temporary stockpile. The fine aggregate, -#4 material, was conveyed to a 36-inch diameter sand screw wash system to reduce the -#200 sieve material to four percent.

The crushing operation was finished prior to the start of paving. Allowing the recycled concrete aggregate to drain before paving reduced the fine aggregate moisture content from 25 percent to less than 10 percent. Stockpiling thus ensured more uniform slump control.

The final stockpiles contained 20,145 tons of recycled coarse aggregate and 3,950 tons of recycled fine aggregate, which translated into a 72 percent recovery rate. Three factors prevented a perfect recovery rate. First, 10 percent of the broken concrete was automatically sent to the waste pile since it passed a two-inch sieve. This waste concrete was used as subbase aggregate during the second construction season. Second, long, slender chunks of concrete from the pavement edge could not be crushed due to their irregular shape. Third, some of the concrete was strongly bonded to the reinforcing steel and was not recoverable.

Paving

Mixing was done in a conventional stationary plant adjacent to the crushing operation. The only modification required to accommodate the recycled mix was the addition of a second sand bin since both recycled and virgin fine aggregates were used.

The longitudinal reinforcing steel was tube fed and consisted of #7 bars placed on 8 5/8-inch centers. The transverse steel consisted of 2 1/2-foot long #5 bars placed 2 1/2 feet on center across the longitudinal centerline joint. This amounted to 0.7 percent reinforcing steel. The transverse steel was machine placed behind the belt placer spreader with a wheel. The belt placer spreader, with an attached tube placer, was followed by the slip form paver. The slip form paver featured dual 60-foot skis operating off of the profiled shoulders for grade control.

Special provisions called for an initial test section of 1000 feet to be paved, followed by an evaluation period. This period allowed IDOT to analyze the mix and make any necessary modifications. Aside from some poor profilograph results due to low plant production and frequent start-ups and stops, the test section appeared to be satisfactory, and paving continued.

The general workability of the mix was somewhat poorer than that of conventional concrete. The angularity of the crushed concrete created a harsh mix. The spherical nature of the fly ash and the natural sand softened this effect. Another problem encountered was edge slump of the top portion of the concrete. Since approximately six inches of the 10-inch pavement were being placed in a trench, conventional trailing edge forms could not be used. To combat this problem, the contractor improvised trailing edge forms out of wooden 2 x 4's and sandbags.

Approximately one mile into the 4.14 mile job, the mix proportions were changed. The contract had stipulated that, aside from the natural sand added for workability, no blending of crushed concrete and virgin material would be allowed. However, concerns were raised about a possible shortage of recycled fine aggregate, so an adjustment was made to balance the stockpiled quantities of the coarse and fine aggregates. Also, an additional 25 pounds of fly ash was added, which not only improved the workability of the mix, but also lowered the water to cement and ash ratio. Table 3 lists the revised mix design quantities.

The recycled mix was required to meet standard specifications for slump, entrained air content, and strength. Specifications prohibited slumps in excess of three inches, and required air contents to be between five and eight percent. Field slump tests averaged slightly over two inches, and air contents just over six percent. Fourteen day strengths in both flexure and compression were well above the required minimums. Table 4 details these recycled concrete mix properties.

INTERIM EVALUATION

After paving on the northbound lanes was completed, the bituminous shoulders were capped with an average of 2 1/2 inches of asphalt concrete. The northbound lanes were opened to traffic on November 7, 1986. During the winter that followed, certain tests and evaluations were made.

To evaluate the drainage efficiency of the existing underdrains after subbase stabilization, two test sections had been constructed. One 1500-foot experimental test section had been cement stabilized 24 feet wide. It was adjacent to a 1500-foot control section that had been cement stabilized 27 feet wide. The existing pipe underdrains were in place at a width of 24 feet, 1 1/2 feet in from the pavement edge-shoulder joint of the recycled pavement. Visual inspections of the underdrain outlets made between November 1986 and April 1987 proved that water was reaching the underdrains. The drainage efficiencies of the two sections were judged comparable on the basis of these visual comparisons. However, the decision was made to process the subgrade to a width of 24 feet during the construction of the southbound lanes. Twenty-four foot width stabilization would provide adequate edge support, would eliminate the additional processing necessary to ensure full 27-foot width stabilization, and would provide a less obstructed path to the underdrains.

A second experimental section involved evaluating the effectiveness of sealing the lane-shoulder joint. Two 1,000-foot sections were constructed. The first section featured a 1/2-inch wide by 3/4-inch deep reservoir, sawed mainly into the bituminous shoulder, and filled with a hot-poured joint sealer meeting ASTM D 3405 specifications. The second section had a 1/2-inch wide by 1 3/8-inch deep joint configuration with a 5/8-inch backer rod placed to the bottom of the reservoir. This section was partially sealed with an ASTM D 3405 hot-poured joint sealer, and partially sealed with an ASTM D 1190 hot-poured elastic joint sealer. The outside joint of both sections was sealed and the median joint left open for comparison. After one winter of service, the sealants exhibited good adhesion to both the concrete pavement and the bituminous shoulder. However, an eight-month evaluation period was deemed too short to determine the sealants' long-term ability to withstand traffic and environment. Based on this decision, the lane-shoulder joint of the southbound lanes was not sealed. Monitoring of the joint sealant test sections will continue to evaluate long-term performance.

Total chloride contents were run on the concrete placed during the construction of the northbound lanes. The analysis indicated a total chloride content of 0.186 percent by weight of cement and fly ash for the initial mix design, and 0.181 percent by weight of cement and fly ash for the revised mix design. Chloride corrosion threshold levels quoted in current literature vary, but these test values are in the recommended range necessary to minimize the risk of chloride-induced corrosion. (4,5) The use of non-epoxy-coated reinforcing steel appeared justified, and plain reinforcing steel was again recommended for the southbound lanes.

Testing was also conducted to determine the surface smoothness, the ride quality, and the skid properties of the recycled pavement. Surface smoothness, as measured by a California-type profilograph, averaged approximately six inches per mile. Rough areas in the initial 1000-foot test section were later ground. The Present Serviceability Index was 4.1. The ride quality rated as "very smooth", and the skid properties were judged to be above average. These tests are further discussed in "Post-Construction Evaluation". The results of these tests showed the comparability of newly constructed recycled and conventional CRC pavements.

SECOND SEASON CONSTRUCTION

Construction of the southbound lanes began on April 1, 1987 with all the traffic switched to the previously completed northbound lanes. Based upon the success of the first season of construction, the same procedure was used for the construction of the two remaining lanes, with two exceptions. As mentioned previously, the subbase was cement stabilized in-place to a width of only 24 feet, rather than the full 27-foot width of the northbound lanes. In addition, rather than adding two inches of gravel to the existing aggregate subbase to attain the raised profile of the new pavement, two inches of crushed concrete were used. The concrete used was the minus two-inch material scalped off from the primary crusher. A minor revision was also made to the recycled concrete mix design to adjust for hot weather. The revised 1987 mix quantities are given in Table 5.

Construction of the southbound lanes progressed more smoothly than the construction of the northbound lanes. The learning curve developed during the first season of construction allowed for a more expeditious operation. Rather than completing each task before progressing to the next, the contractor was able to conduct concurrent operations, such as pavement breaking, crushing, and cement stabilizing. Paving went faster and smoother due to better knowledge of the recycled mix characteristics. This practical experience coupled with better weather conditions allowed the recycling operation to be completed well in advance of the November 1, 1987 completion date.

POST-CONSTRUCTION EVALUATION

Performance monitoring is scheduled to continue throughout the pavement's lifetime. Friction testing with a skid trailer in a locked-wheel mode will be conducted three times a year to determine the friction characteristics of the recycled concrete. The ride quality of the pavement will be measured annually with a Roadometer. In addition, deflection testing with a Dynatest 8002 Falling Weight Deflectometer (FWD) will be done annually. The deflection data will provide information on the pavement's load carrying capability, its load transfer efficiency, and the degree of subgrade support provided. Crack surveys will be made periodically to check the crack spacing. This collected data will be used to establish a performance history that can be compared to the performance histories of conventional CRC pavements.

The results of the friction tests are shown in Table 6. To date, the average treaded tire friction number for the section has been 55 and the average smooth tire friction number 51. Compared to statewide transversely tined portland cement concrete pavements tested since 1980, these numbers represent an average to above average treaded tire friction number and an above average smooth tire friction number. The treaded tire friction numbers indicated the pavement has good surface microroughness.

The relatively small differences between the treaded tire and smooth tire friction numbers on an individual test basis indicate that the pavement has good coarse macrotexture. (6) In terms of surface texture and friction characteristics, the recycled pavement is definitely comparable to a conventional CRC pavement.

Data summarizing ride quality are also shown in Table 6. Ride quality was evaluated using a Bureau of Public Roads-type Roadometer. Initial tests on the reconstructed northbound lanes indicated "very smooth" and "slightly rough" pavement by Illinois' standards. Recent tests on both the northbound and southbound lanes resulted in a "smooth" pavement rating. The difference in adjective ratings between the two tests should not be interpreted as a decline in ride quality over the 18-month period. The initial test was actually on the borderline between "very smooth" and "smooth". These results compare favorably with statewide averages for CRC pavements constructed in the last 10 years. (7)

The outside lane in the southbound direction was tested with a Falling Weight Deflectometer in July 1988, approximately one year after its construction. Tests were run at a crack in the pavement every 500 feet and consisted of drops of 4000, 8000, and 12,000 pounds. Six configurations were tested at each location: the center of the lane on the approach and the leave sides of the crack, the outer wheelpath on the approach and the leave sides of the crack, and the edge of the lane on the approach and the leave sides of the crack. In addition, drops of 4000, 8000, and 12,000 pounds were made at locations halfway between those previously mentioned. These tests were made at the edge of the pavement away from any cracks, and were designated as "true edge" tests. The data collected was processed using a void detection analysis program developed by IDOT. This data is summarized and shown in Table 7. The low deflections and high deflection basin "AREA" reflect a sound concrete pavement. As expected, deflections were greater in the wheelpath than in the center of the lane, and higher still at the edge.

The load transfer efficiency of a crack is the ratio of the deflection of the unloaded side to the deflection of the loaded side. The load transfer efficiencies were on the average above 90%, indicating excellent load transfer. At one test site, the load transfer efficiency values dropped to approximately 85% for the center and outer wheelpath locations. The load transfer efficiency of the edge, on the other hand, was greater than 93%. The difference in load transfer efficiencies between the edge and center and outer wheelpath would appear to indicate that the 24-foot width subbase stabilization was indeed adequate to provide edge support. Additional FWD testing will be done annually in both the northbound and southbound lanes to monitor the pavement's load-carrying capability, its load transfer efficiency, and the adequacy of subgrade support. A crack survey of the pavement made 1-2 years after construction showed an average crack spacing of 3 feet, with a minimum spacing of 1 foot. The initial results of the friction, ride quality, and FWD tests and of the crack survey indicate the recycled inlay is a well-constructed, sound concrete pavement.

Field observations were also made of the two experimental sections in the northbound lanes 23 months after construction. Visual inspections of underdrain outlets in both the 24-foot and 27-foot width subbase stabilization sections showed no difference in drainage efficiencies after two years of service. In the experimental lane-shoulder joint sealant section, the unsealed median joint had opened to a width of approximately 1/4 inch and a depth of almost one inch after two years of service. The two reservoir configurations and the two sealants seemed to be performing similarly, with the sealants still pliable. The sealants exhibited relatively good adhesion to both the pavement and the shoulder although 1/4-inch deep gaps were noted in areas along the reservoir walls. The two experimental sections will continue to be monitored to evaluate long-term performance.

CONCLUSIONS

The experience gained from this project has shown that recycling deteriorated concrete pavements is yet another successful procedure that can be added to IDOT's arsenal of rehabilitative techniques. Unlike some of the more common short-term corrective measures, recycling can provide a long lasting solution. The actual cost-effectiveness of the recycling process will be dependent on the life of the project. Recycling would be especially effective in areas of limited supplies of quality aggregates. In addition to conservation of resources, cost savings may be realized since aggregates do not have to be shipped in from great distances. Constructing inlays would allow for additional savings by eliminating the need for shoulder reconstruction.

The recycled concrete inlay project on Interstate 57 at Effingham, Illinois was constructed with a minimum of problems due to careful planning and design. Capping the existing shoulders with a thin bituminous overlay corrected any surface distress due to construction equipment, and proved more economical than complete shoulder reconstruction. Use of existing underdrains also proved economical although care was needed during pavement removal and subbase stabilization to avoid damaging the underdrains. The use of fly ash satisfied federal guidelines and improved the workability of the recycled concrete mix. One minor problem, however, needs to be addressed on future inlay jobs. Specifications concerning haul road construction need to be outlined to minimize the displacement and heaving of shoulders. Despite this minor difficulty, the overall success of the recycled concrete inlay project proved the feasibility of the recycling process. Coupled with the cost savings potentially associated with such a process, recycling deteriorated concrete pavements seems a viable rehabilitative technique.

DISCLAIMER

Administration or the Illinois Department of Transportation. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. Traylor, M.L., "Efforts to Eliminate D-Cracking in Illinois", Transportation Research Record 853, pp. 9-14. Washington, D.C., 1982.

2. Illinois Department of Transportation, "Section 7: Pavement Design", Design Manual, Bureau of Design, Illinois Department of Transportation, Springfield, Illinois. Revised January 1983.

3. Illinois Department of Transportation, "Subgrade Stability Manual", Bureau of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. March 1, 1982.

4. American Concrete Institute Committee 222, "Corrosion of Metals in Concrete", American Concrete Institute Journal, Report No. 82-1, pp. 3-32. January-February, 1985.

5. National Cooperative Highway Research Program Synthesis of Highway Practice, No. 57, "Durability of Concrete Bridge Decks", Transportation Research Board, Washington, D.C. May 1979.

6. LaCroix, John E., "A Summary of the Illinois Skid-Accident Reduction Program: August 1985 to December 1986", Bureau of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. December 1986.

7. LaCroix, John E., "Summary of 1987 Roadometer Tests of New Pavements: Annual Report IHR-504 Riding Quality of New Pavements", Bureau of Materials and Physical Research, Illinois Department of Transportation, Springfield, Illinois. May 1988.

PERCENT PASSING GIVEN SIEVE SIZE

	1.5"	1"	1/2"	3/8"	#4	#16	#50	#100	#200
Coarse Aggregate									
Special Provision	100	90-100	30-60		0-10				0-2.5
1986 (59 tests)	100	93	37		8				1.5
1987 (39 tests)	100	91.5	34		7				1.1
Fine Aggregate									
Special Provision				100	94-100	45-85	3-29	0-10	0-6
1986 (63 tests)				100	100	49	14	6	4.8
1987 (37 tests)				100	100	48	13	5	3.7

TABLE 1: CRUSHED CONCRETE GRADATIONS

	TEST					
Aggregate	Freeze-Thaw	Sodium Sulfate Soundness, % Loss	Los Angeles Abrasion, % Loss	Deleterious Material, % of Sample	Absorption, %	Specific Gravity, Saturated Surface Dry (SSD)
CM-07* (Coarse)	1" Max. -Meets criteria of 0.060% maximum expansion at 350 cycles	25 -Criteria of 15% maximum loss waived	33 -Meets criteria of 45% maximum loss	0.2 -Meets criteria of 5% maximum total deleterious	5.3	2.42
FM-01** (Fine)	---	19 -Criteria of 10% maximum loss waived	---	---	6.6	2.41

*Similar to AASHTO M 43-82 (1986) size 57
**Similar to AASHTO M 6-81 (1986)

---Denotes No Specification For Fine Aggregate

TABLE 2: CRUSHED CONCRETE QUALITY TESTS

	QUANTITY, POUNDS	
INGREDIENT	INITIAL DESIGN	REVISED DESIGN
Cement	515	515
Fly Ash	125	150
Recycled CM-07(1) (SSD)(2)	1,721	1,818
Recycled FM-01(3) (SSD)	369	312
Virgin FA-01(3) (SSD)	554	570
Water (Includes water reducer and air entraining agent)	282	249
Total, Pounds/Cubic Yard	3,566	3,614
Mortar Factor = $\frac{\text{Vol. mortar}}{\text{Vol. dry rodded aggregate}}$	0.80	0.72
Water/(Cement + Ash) Ratio	0.44	0.37
FM-01(3)/CM-07(1) Recycled Use Ratio	0.21	0.17
Fineness Modulus (ASTM C 33-85)	3.1	3.0

(1) Similar to AASHTO M 43-82 (1986) size 57
(2) (SSD) Denotes Saturated Surface Dry Condition
(3) Similar to AASHTO M 6-81 (1986)

TABLE 3: 1986 MIX DESIGN QUANTITIES

	Slump, Inches	Entrained Air Content, %	14 Day Strengths, PSI Flexure	Compression
Field Test Average	2.2	6.3	851	3573
Specification	3 Maximum	5-8	650 Minimum, 620 with Fly Ash	3500 Minimum, 3325 with Fly Ash

TABLE 4: 1986 RECYCLED CONCRETE MIX PROPERTIES
(Initial and Revised Mix Designs)

INGREDIENT	QUANTITY, POUNDS
Cement	515
Fly Ash	150
Recycled CM-07(1) (SSD)(2)	1,789
Recycled FM-01(3) (SSD)	312
Virgin FA-01(3) (SSD)	554
Water (includes water reducer and air-entraining agent)	266
Total	3,586 Pounds/Cubic Yard
Mortar Factor = $\frac{\text{Volume Mortar}}{\text{Vol. dry rodded aggregate}}$	0.74
Water/(Cement + Ash) Ratio	0.40
FM-01(3)/CM-07(1) Use Ratio	0.17
Fineness Modulus (ASTM C 33-85)	3.0

(1) Similar to AASHTO M 43-82 (1986) size 57
(2) (SSD) Denotes Saturated Surface Dry Condition
(3) Similar to AASHTO M 6-81 (1986)

TABLE 5: 1987 MIX DESIGN QUANTITIES

FRICTION TESTING

TEST DATE	SOUTHBOUND AVERAGE FRICTION NO., TREADED TIRE	SOUTHBOUND AVERAGE FRICTION NO., SMOOTH TIRE	NORTHBOUND AVERAGE FRICTION NO., TREADED TIRE	NORTHBOUND AVERAGE FRICTION NO., SMOOTH TIRE
07/13/88	58	51	47	41
04/19/88	58	53	55	49
10/21/87	60	63	54	52
08/03/87	---	---	56	49
04/07/87	---	---	51	52

--- DENOTES LANES NOT RECONSTRUCTED AT TIME OF TEST

SURFACE SMOOTHNESS

TEST DATE	NORTHBOUND ROUGHNESS INDEX	SOUTHBOUND ROUGHNESS INDEX	ROUGNNESS INDEX RATING
08/31/88	80		SMOOTH
08/31/88		92	SLIGHTLY ROUGH
02/23/87	72		VERY SMOOTH

ILLINOIS ROADOMETER ROUGHNESS INDEX FOR PCC PAVEMENT

ROUGHNESS INDEX, INCHES/MILE	ADJECTIVE RATING
75 OR LESS	VERY SMOOTH
76 - 90	SMOOTH
91 - 125	SLIGHTLY ROUGH
126 - 170	ROUGH
171 - 220	VERY ROUGH
221 - 375	UNSATISFACTORY

TABLE 6: PERFORMANCE HISTORY

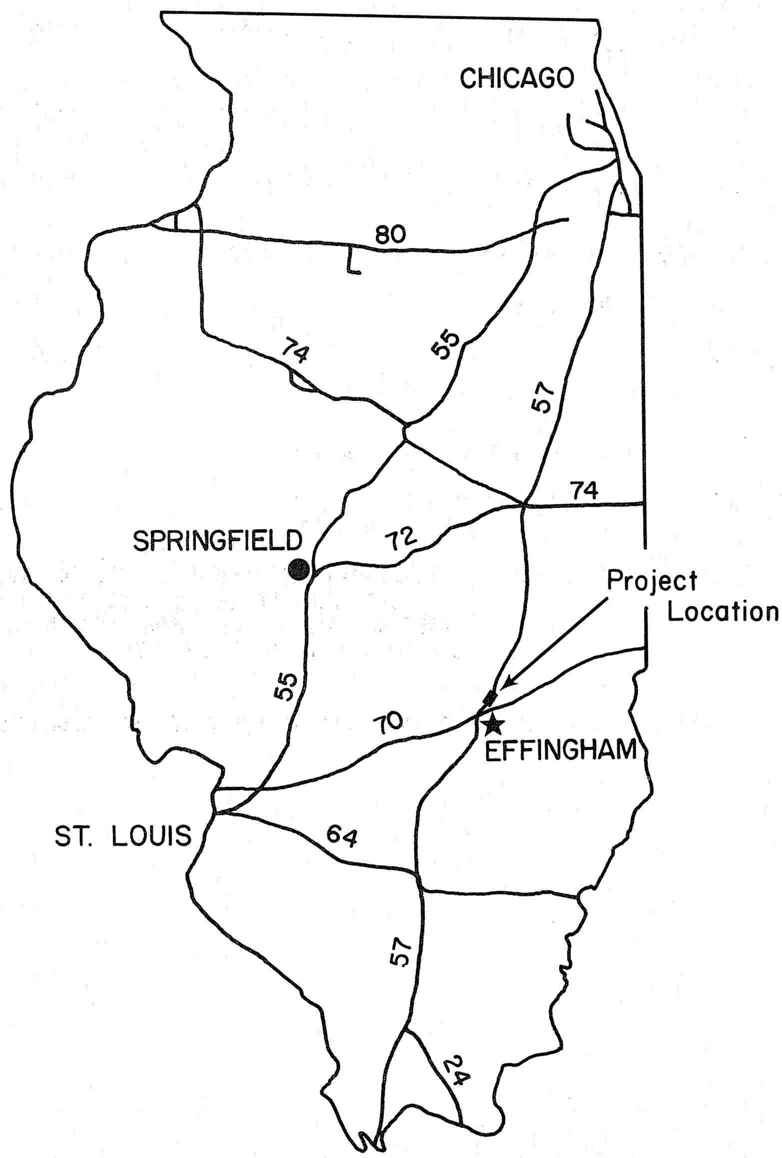
TEST LOCATION	AVERAGE NORMALIZED 9,000 LB. DEFLECTION, MILS	AVERAGE LOAD TRANSFER, %
CENTER OF LANE, APPROACH SIDE OF CRACK	3.6 (n=24)	93.9 (n=72)
CENTER OF LANE, LEAVE SIDE OF CRACK	3.7 (n=24)	92.5 (n=72)
OUTER WHEELPATH, APPROACH SIDE OF CRACK	4.4 (n=24)	93.4 (n=72)
OUTER WHEELPATH, LEAVE SIDE OF CRACK	4.4 (n=24)	92.7 (n=72)
EDGE, APPROACH SIDE OF CRACK	7.7 (n=24)	93.7 (n=71)
EDGE, LEAVE SIDE OF CRACK	7.8 (n=24)	92.8 (n=72)
"TRUE" EDGE	7.9 (n=24)	93.0 (n=72)

AVERAGE DEFLECTION AREA BASIN = 31.2 INCHES

WHERE AREA = $6\left(1 + 2\frac{D1}{D0} + 2\frac{D2}{D0} + 2\frac{D3}{D0} + \frac{D4}{D0}\right)$

AND D0, D1, D2, D3, and D4 = DEFLECTIONS MEASURED AT 0, 12, 24 AND 36 INCHES FORWARD OF THE CENTER OF THE LOADING PLATE AND 12 INCHES BEHIND THE CENTER OF THE LOADING PLATE

TABLE 7: JULY 1988 FWD DATA SUMMARY FOR OUTER SOUTHBOUND LANE



ROUTES SHOWN ARE INTERSTATE ROUTES

FIGURE 1: PROJECT LOCATION MAP

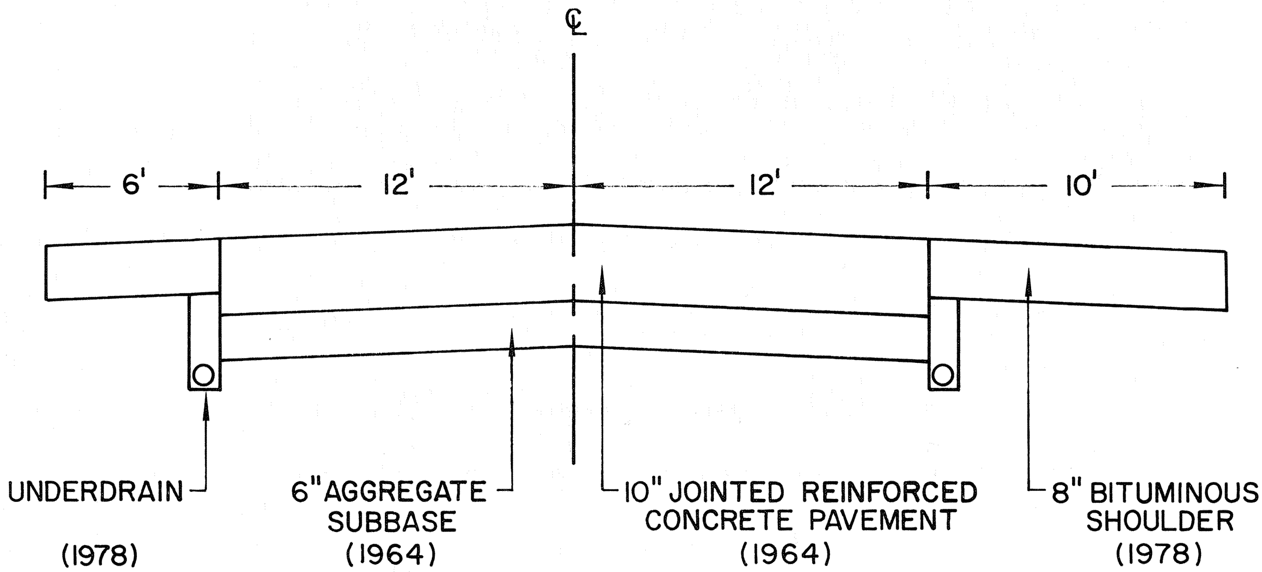


FIGURE 2: CROSS-SECTION OF ORIGINAL PAVEMENT

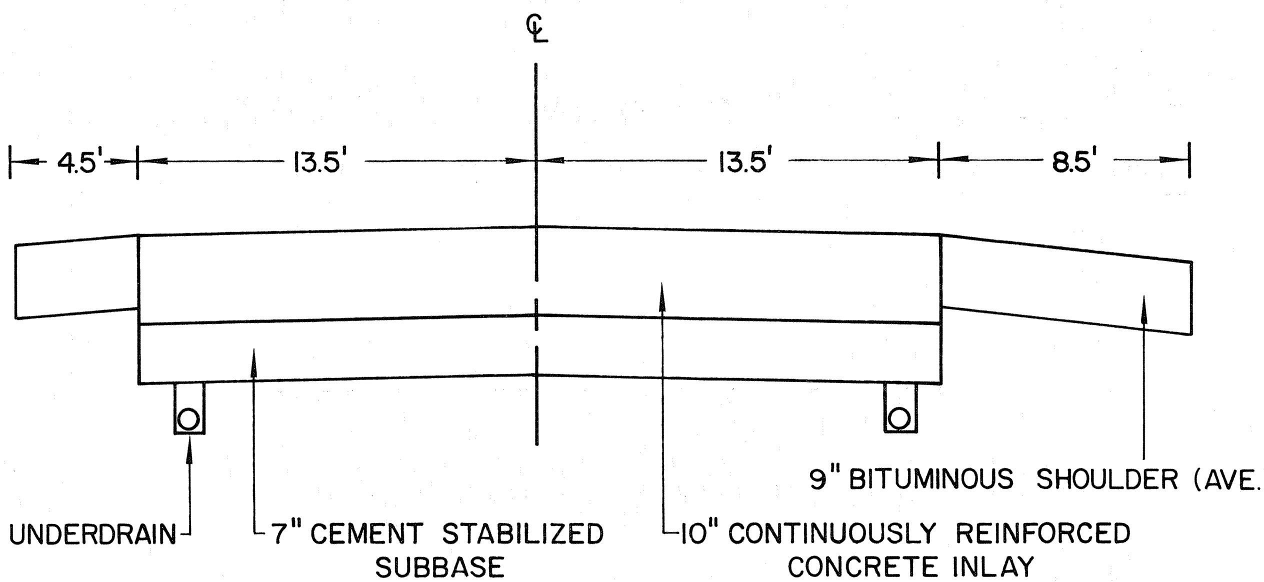


FIGURE 3: CROSS-SECTION OF RECYCLED CONCRETE INLAY

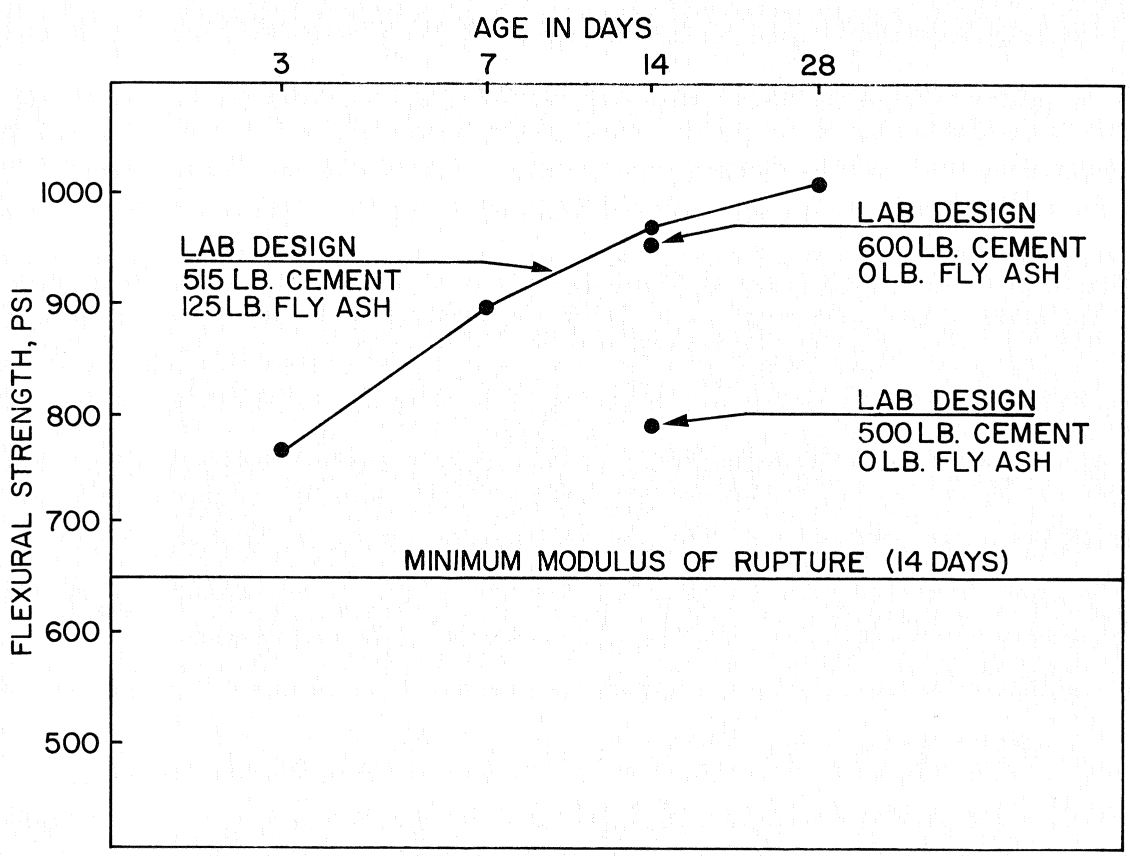


FIGURE 4: LAB DESIGN STRENGTHS - RECYCLED CONCRETE

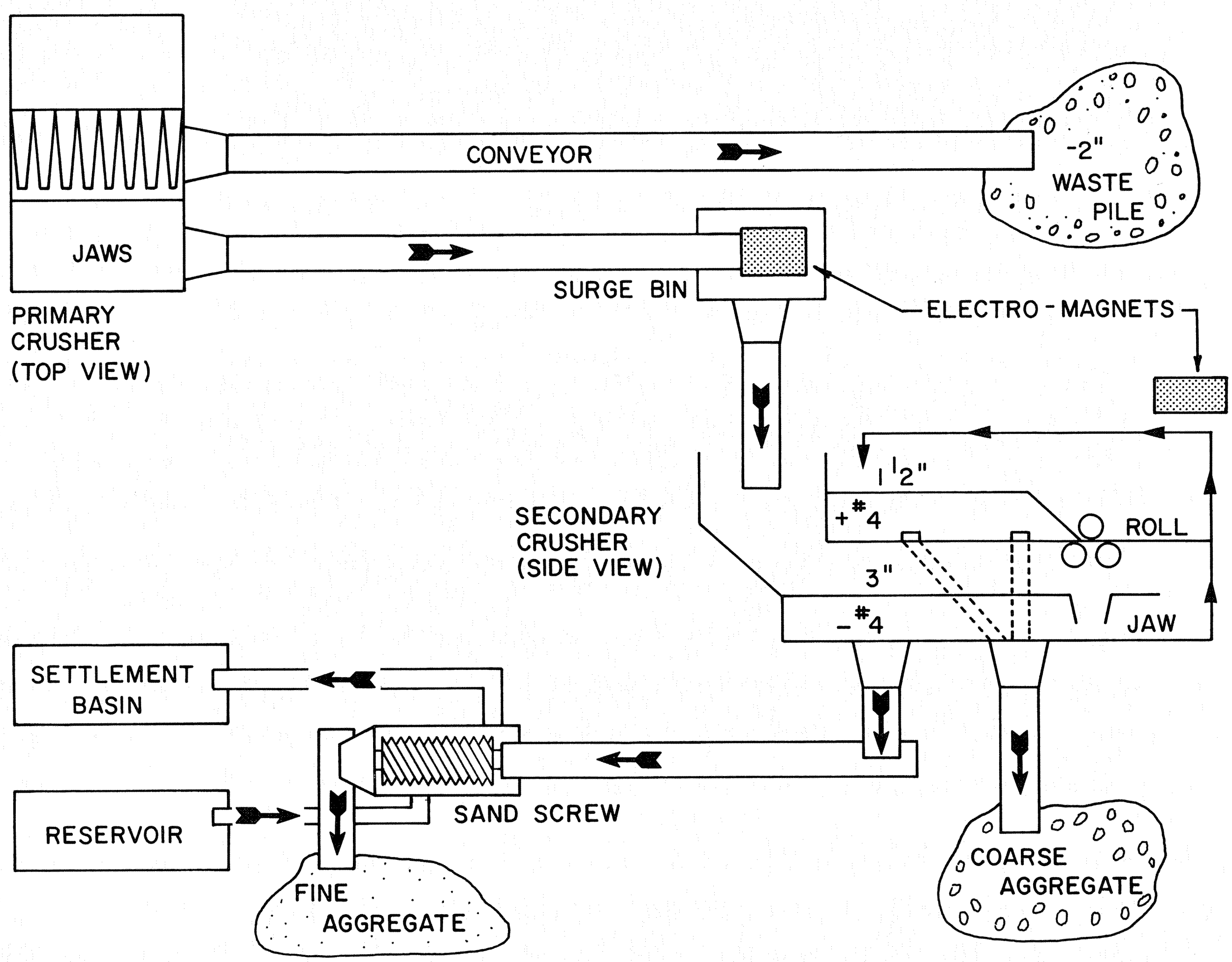


FIGURE 5: PAVEMENT CRUSHING OPERATION