Recycling Old PCC Pavement - Performance Evaluation Of FAI 57 Inlays

Physical Research Report No. 113
February 1993

Illinois Department of Transportation
Bureau of Materials and Physical Research

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IL/PR-113		

4. Title and Subtitle	5. Report Date
RECYCLING OLD PCC PAVEMENT - PERFORMANCE EVALUATION OF FAI 57 INLAYS	FEBRUARY 1993
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
AMY M. SCHUTZBACH	PHYSICAL RESEARCH No. 113
9. Performing Organization Name and Address	10. Work Unit No.
ILLINOIS DEPARTMENT OF TRANSPORTATION BUREAU OF MATERIALS AND PHYSICAL RESEARCH 126 EAST ASH STREET SPRINGFIELD, ILLINOIS 62704-4766	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
ILLINOIS DEPARTMENT OF TRANSPORTATION BUREAU OF MATERIALS AND PHYSICAL RESEARCH 126 EAST STREET SPRINGFIELD, ILLINOIS 62704-4766	FINAL REPORT MAY 1986 - FEBRUARY 1993
	14. Sponsoring Agency Code

15. Supplementary Notes

IL 85-06A and B: RECYCLING OLD PCC PAVEMENTS. This study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

This report details the construction and performance monitoring efforts of two demonstration projects proposed in an experimental features work plan entitled "Recycling Old PCC Pavement". The objectives of this experimental feature were to evaluate the viability of recycling old PCC pavements into new inlays and to determine the subsequent performance of the recycled pavements. Two demonstration projects were undertaken to make this evaluation. On one project, an old, badly faulted, jointed reinforced concrete (JRC) pavement containing high quality aggregates was recycled into a new continuously reinforced concrete (CRC) inlay. On the second project, a deteriorated CRC pavement containing D-cracking susceptible aggregates was recycled into a full-depth asphalt concrete (AC) inlay. Inlays were constructed because the existing shoulders were in good condition.

Both demonstration projects were constructed in a two-year phase, beginning in 1986. The construction of both projects was monitored. Performance monitoring of the recycled pavement began in 1987, and included friction testing, ride quality testing, visual distress surveys, and deflection testing with a Falling Weight Deflectometer. After five to six years in service, no major maintenance has been required and both pavements are performing well.

17. Key Words	18. Distribution Statement
Recycling, CRC inlay, full-depth asphalt concrete inlay, recycled concrete aggregate	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	55	

Form DOT F 1700.7 (8-69)

RECYCLING OLD PCC PAVEMENT - PERFORMANCE EVALUATION OF FAI 57 INLAYS

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FEBRUARY 1993

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EXECUTIVE SUMMARY

In this day and age of increased environmental awareness, recycling has taken on new significance in the highway industry. In the summer of 1986, the Illinois Department of Transportation began the construction of two demonstration projects. At that time, Illinois allowed the use of recycled asphalt pavement in asphalt concrete mixtures, but had little experience incorporating recycled Portland cement concrete (PCC) pavement into new PCC or asphalt concrete (AC) pavements. The demonstration projects were designed to evaluate the viability of recycling deteriorated PCC pavements into new PCC and AC pavements and to determine the recycled pavements' subsequent performance. These demonstration projects were proposed in an experimental features work plan entitled, "Recycling Old PCC Pavement".

On one project, an old, badly faulted, jointed reinforced concrete (JRC) pavement containing high quality aggregates was recycled into a new continuously reinforced concrete (CRC) inlay. On the second project, a deteriorated CRC pavement containing D-cracking susceptible aggregates was recycled into a full-depth AC inlay. Inlays were constructed because the existing shoulders were in good condition. This report details the construction and performance monitoring of these two demonstration projects, in accordance with the experimental features work plan.

The construction section of this report discusses material properties of recycled concrete aggregate and project construction details with a special emphasis on the impact of recycled concrete aggregate use. The performance monitoring section of this report discusses the results of friction and ride quality testing, condition surveys, and deflection testing. After five to six years in service, no major maintenance has been required on the demonstration projects, and both projects are performing well.

INTRODUCTION

In the summer of 1986, the Illinois Department of Transportation (IDOT) began the construction of two demonstration projects. The demonstration projects were designed to evaluate the viability of recycling deteriorated Portland cement concrete (PCC) pavements into new PCC and asphalt concrete (AC) pavements and to determine the recycled pavements' subsequent performance. These demonstration projects were proposed in an experimental features work plan entitled, "Recycling Old PCC Pavement". This report details the construction and performance monitoring of these two demonstration projects, in accordance with the experimental features work plan.

Objectives

The objectives of this experimental feature were to evaluate the viability of recycling old PCC pavements into new inlays and to determine the subsequent performance of the recycled pavements. Two demonstration projects were undertaken to make this evaluation. On one project, an old, badly faulted, jointed reinforced concrete (JRC) pavement containing high quality aggregates was recycled into a new continuously reinforced concrete (CRC) inlay. On the second project, a deteriorated CRC pavement containing D-cracking susceptible aggregates was recycled into a full-depth AC inlay. Inlays were constructed because the existing shoulders were in good condition.

Historical Perspective

In this day and age of increased environmental awareness, recycling has taken on new significance in the highway industry. In 1986, Illinois allowed the use of recycled asphalt pavement (RAP) in asphalt concrete mixtures. Until this research was begun, however, Illinois had little experience incorporating recycled PCC pavements into new PCC or AC pavements. Recycling would be advantageous in areas with limited sources of quality aggregates. Recycling could also become an increasingly attractive rehabilitation alternative in light of landfill capacity limitations and material acceptance restrictions.

An economic analysis of recycling was not conducted as part of this study. The main thrust of this project was to determine if recycling was a viable option. However, for recycling to be a cost-effective option, the pavement had to be in need of major rehabilitation. When choosing projects for this study, IDOT considered only those pavements in need of extensive repair or reconstruction. Both projects selected had shoulders in excellent condition as compared to the mainline pavement, allowing the cost-saving concept of inlays to be considered. Furthermore, both sites were interstate pavements located in rural areas. The construction contracts required two-lane, two-way traffic during reconstruction, enabling the contractors to complete the work in a safe, efficient, and timely manner. These features combined to make recycling a reasonably cost-competitive rehabilitation alternative on these demonstration projects.

Both demonstration projects were constructed in a two-year phase, beginning in 1986. The construction of both projects was monitored. Performance monitoring of the recycled pavements began in 1987 after construction was complete, and has continued to this date. Reports detailing the design, construction, and performance of the recycled pavements have been previously published (1, 2).

DESIGN DETAILS

Location

CRC Inlay

On the first demonstration project, the viability of recycling old, deteriorated PCC pavement into new PCC pavement was evaluated. A badly faulted JRC pavement with 100-foot joint spacing was recycled into a CRC inlay. The demonstration project was located on FAI 57 just north of Effingham, Illinois, in Effingham County. The 4.14-mile long section was constructed under Contract 40442 and designated Section (25-8)R. The average daily traffic for 1984 was 10,000, with 2,000 multiple-unit trucks. Figure 1 gives the location of this project.

Full-Depth AC Inlay

The second demonstration project investigated the viability of recycling a PCC pavement into an AC pavement. A badly D-cracked CRC pavement was recycled into a full-depth AC inlay. Durability cracking, or D-cracking, is a form of distress in PCC pavements characterized by closely spaced, hairline cracks which parallel joints and cracks. This project was located on FAI 57 south of Ullin, Illinois, in the southernmost part of the state. The 4.14-mile long section in Pulaski County was built under Contract 40406 and designated Section 77(2,3)-1. The average daily traffic for 1985 was 6,700 with 1,500 multiple-unit trucks. Figure 1 gives the location of this project.

Cross Section

CRC Inlay

The existing 24-foot wide pavement at the CRC inlay site was constructed in 1964. The 10-inch thick, 100-foot JRC pavement was placed on top of 6 inches of aggregate subbase. The aggregates used in the construction of the existing concrete pavement were of a high quality, and preliminary testing indicated they were not susceptible to D-cracking. The shoulders had been reconstructed in 1978 and consisted of 8 inches of bituminous aggregate mixture (BAM). Underdrains had been added in 1978 as part of the shoulder reconstruction. The original pavement cross section is shown in Figure 2.

The 100-foot jointed pavement exhibited 2 to 3 panel cracks per slab at the time of recycling. 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 concrete pavement restoration work that would have been required, the project was an ideal candidate for recycling. The previously reconstructed shoulders, however, were in excellent condition.

The recycled pavement design analysis was based on a 20-year design life using Illinois' American Association of State Highway Officials (AASHO)-based empirical pavement design procedure (3). The new design cross section consisted of 10 inches of CRC pavement on 7 inches of cement-stabilized subbase. Standard IDOT practice required a 4-inch stabilized subbase. Because of a proposed pavement crown change, however, a 7-inch stabilized subbase was placed. To take advantage of existing features in good condition, an inlay was constructed, and the existing shoulders and underdrains remained in place. In order to provide good edge support, the pavement and stabilized subbase were designed 27 feet wide, with the pavement striped at 24 feet. Figure 3 illustrates the cross section of the recycled CRC inlay.

Full-Depth AC Inlay

At the full-depth AC inlay site, the existing 24-foot wide pavement had been built in 1969. The 7-inch CRC pavement was constructed on a 4-inch BAM subbase on top of a predominantly silty clay loam subgrade. The shoulders were constructed of 11 inches of BAM. No underdrains were present. The original pavement cross section is shown in Figure 4.

The original PCC pavement had met the 14-day center-point loading, minimum 650 psi modulus of rupture specification. However, the CRC pavement was badly D-cracked at the time of reconstruction. The outer edges of both the passing and driving lanes had the closely spaced cracks and dark staining characteristic of D-cracking. "Bird's nests", small, localized, round areas of rubblized concrete, were evident at the edge of the pavement throughout the project. The pavement had deteriorated to the point that the cost of patching, where patching was feasible, was prohibitive. The shoulders were still structurally sound. These conditions made a recycled inlay an ideal rehabilitation strategy.

To prevent the existing D-cracked limestone aggregate from possibly deteriorating further if incorporated into a new PCC pavement, IDOT chose to recycle the existing CRC pavement into a full-depth AC inlay. The new design cross section consisted of 1.5 inches of AC surface over 14.5 inches of AC binder, on top of a minimum of 12 inches of lime-modified subgrade. The surface, binder, and lime-modified subgrade were designed and constructed 27 feet wide, with the pavement striped at 24 feet. Underdrains were also included in the design. The cross section of the full-depth AC inlay can be found in Figure 5.

Widening the roadway from 24 to 27 feet required the removal of a 1.5-foot wide strip from the existing 4-foot wide median shoulder and the existing 10-foot wide outside shoulder. It was anticipated that the remaining 2.5-foot wide portion of the median shoulder might experience significant damage during construction. For this reason, construction equipment was allowed on the median shoulder, and funds allotted for its reconstruction. Construction traffic was prohibited from using the outside shoulder, however, and all damage to the outside shoulder was repaired or replaced at the contractor's expense. The full-depth AC recycling project was thus only a partial inlay.

CONSTRUCTION MONITORING

Material Properties

CRC Inlay

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 IDOT CA-07 and FA-01 gradations, similar to AASHTO M43 size 57 and AASHTO M6 respectively (4), 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 crushed concrete aggregate gradations used on the CRC inlay project.

No special quality requirements were set for the crushed concrete. The crushed concrete did meet Illinois' 1-inch maximum size freeze-thaw requirement, and also the Los Angeles Abrasion and deleterious material requirements. However, the recycled concrete aggregate failed IDOT's sodium sulfate soundness test (5), similar to AASHTO T104 (6), which is used as 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; since this time, IDOT has waived the sodium sulfate quality requirement for all crushed concrete. The results of the quality tests on the crushed concrete aggregate are listed in Table 2.

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 total chloride content of the existing concrete pavement was tested and found to average 0.05 percent by weight of concrete. Plain reinforcing steel was chosen for two reasons. 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. Prior to the second construction season, total chloride content tests were run on the recycled concrete aggregate mix. The analysis indicated an average total chloride content between 0.181 and 0.186 percent by weight of cement and fly ash. Chloride corrosion threshold levels quoted in current literature vary, but these test values were in the recommended range necessary to minimize the risk of chloride-induced corrosion (7, 8).

The general workability of the mix was somewhat poorer than that of conventional concrete. The angularity of the crushed concrete created a harsh mix. A minimum of 125 pounds of fly ash per cubic yard of concrete was required, and up to 20 percent natural sand was allowed. The spherical nature of these particles improved the workability of the mix. The fly ash also supplemented the cement, and was used at a minimum 1.5:1 fly ash to cement replacement ratio on a weight basis. A maximum 15 percent cement reduction was allowed from the required minimum initial cement content of 600 pounds per cubic yard. Aside from the natural sand, no blending of crushed concrete and virgin material was allowed. Information on the mix designs can be found in Tables 3 and 4. The mix designs were changed during construction in an effort to improve the workability of the mix and to balance the stockpiled quantities of coarse and fine aggregates.

Full-Depth AC Inlay

Provisions were made regarding the use of the recycled concrete aggregate. The recycled concrete aggregate was crushed into both coarse and fine aggregate, but its use was limited to binder courses only. Recycled concrete aggregate was not allowed in the asphalt concrete surface course due to questions about its durability under traffic. Recycled concrete aggregate was used as the sole source of coarse aggregate in the binder lifts until the supply was exhausted. Before the crushing operation was functional, and when the supply of recycled concrete aggregate was exhausted, newly quarried material (virgin aggregate) meeting all standard specifications was used instead.

Table 5 lists aggregate gradation and quality specifications and the recycled concrete aggregate test results. The recycled concrete aggregate was required to meet IDOT's standard gradations: CA-11, CA-16, and FA-20, similar to AASHTO M43, sizes 67 and 89, and AASHTO M29 Grading #1, respectively (4). However, the standard asphalt concrete paving aggregate quality requirements were waived for the recycled concrete aggregate. Preliminary tests indicated that the recycled concrete aggregate met IDOT's standard Los Angeles Abrasion and deleterious material requirements. As was the case on the CRC inlay project, however, the recycled concrete aggregate could not meet the sodium sulfate quality requirement.

Following standard IDOT practice, mix designs were developed for: the virgin aggregate asphalt concrete mix (virgin asphalt concrete mix), the recycled concrete aggregate asphalt concrete mix (recycled asphalt concrete mix), and later, the recycled concrete aggregate/virgin aggregate blend asphalt concrete mix (recycled/virgin blend asphalt concrete mix). The source of the virgin aggregate was the same quarry that produced the D-cracking susceptible limestone used in the original CRC pavement. An AC-20 grade of asphalt cement was specified.

Although IDOT now specifies 75-blow compaction efforts for interstate overlay and full-depth AC mix designs, a 50-blow compaction effort was used for these mix designs. At the time, it was thought that the 50-blow compaction effort would more closely simulate the final density in the field under traffic.

The results of the preliminary binder and surface mix designs are shown in Tables 6 and 7. The recycled asphalt concrete, recycled/virgin blend asphalt concrete, and virgin asphalt concrete mixtures met the specifications with one exception. The recycled asphalt concrete and recycled/virgin blend asphalt concrete binder mixes did not meet IDOT's 14.0 percent minimum voids in the mineral aggregate (VMA) criterion for binder mixes. Because of variable mortar contents of the recycled concrete aggregate samples, it was difficult to obtain a consistent bulk specific gravity. This in turn made the results of the VMA calculation questionable. However, the design asphalt content of the recycled asphalt concrete binder mix appeared reasonable, being 0.2 percent higher than the design asphalt content of the virgin asphalt concrete mix. The additional asphalt cement was required to compensate for the higher absorption values of the recycled concrete aggregate. In addition, testing with a gyratory compactor indicated that the recycled asphalt concrete mix was stable; gyratory shear indices for the recycled asphalt concrete mix and the recycled/virgin blend asphalt concrete mixes were 1.000 at 90 revolutions and 100 psi ram pressure. For these reasons, the VMA criterion was waived for mixtures containing recycled concrete aggregate.

The moisture susceptibility of the asphalt concrete mixtures was checked by an IDOT procedure similar to the AASHTO T283 test method without freeze-thaw conditioning (6,9). The Tensile Strength Ratio (TSR) was calculated by dividing the tensile strength of a conditioned sample by the tensile strength of an unconditioned sample. The virgin asphalt concrete binder mix design had a design TSR of 0.60, the recycled asphalt concrete binder mix design had a TSR of 0.82, and the recycled/virgin blend asphalt concrete binder mix design had a TSR of 0.84. At the time this project was constructed, IDOT had no definite TSR criterion requiring the use of anti-stripping additives. Consequently, no anti-stripping additives were added to any of the mixes. Additional materials information on the full-depth AC inlay can be found elsewhere (2).

Construction Details

CRC Inlay

Construction of the CRC inlay has been previously documented (1), and will only be briefly summarized here. Work began on the recycling project in April 1986. A November 1, 1987 completion date was specified by contract. 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.

Since the project was to be an inlay, a haul road was constructed adjacent to the median shoulder of the northbound lanes. The bituminous shoulders were roto-milled to the appropriate elevation. A 1.5-foot wide section of bituminous shoulder was removed from both sides to create the desired 27-foot pavement width. This BAM was crushed and stockpiled for later use as an aggregate shoulder wedge. The existing 24-foot wide pavement was broken with a diesel-powered pile driver and a smaller, cable-drop pavement breaker.

During the pavement breaking and removal operation, a cone penetrometer was used to check the subgrade support. The readings correlated to an average California Bearing Ratio (CBR) value of approximately 6. Two inches of gravel were added to the existing aggregate subbase to reach the raised profile of the new pavement. The subbase was stabilized in place with cement to ensure a uniform construction platform.

The recycled concrete was crushed with jaw and roll crushers at a site adjacent to the project. Electromagnets were used to remove the steel reinforcing mesh. The fine aggregate was conveyed to a sand screw wash system to reduce the amount of minus #200 sieve material. Crushing was completed prior to the start of paving. By allowing the stockpiled material to drain, more uniform slump control was achieved.

Mixing and paving required no deviations from standard practice to accommodate the recycled concrete mix. The recycled mix was required to meet standard specifications for slump, entrained air content, and strength. Field slump tests averaged slightly over 2 inches, and air contents just over 6 percent. Fourteen-day compressive strengths averaged over 3,500 psi, and 14-day flexural strengths averaged approximately 850 psi. The results of daily material property tests for 1986 and 1987 are shown in Tables 8 and 9.

After the mainline paving was completed, the shoulders were capped with an average thickness of 2.5 inches of asphalt concrete. The shoulders had been slightly damaged due to the milling and shoulder removal operations. A combination of wet spring weather and heavy construction equipment operating adjacent to the median shoulder resulted in shoulder heave. The top lift of shoulder material remaining after milling varied in thickness from 0.75 inch to 2.5 inches. In scattered areas, the top lift had separated from the lower lifts and broken off. Capping the existing shoulders with a thin asphalt concrete overlay corrected these deficiencies and was more economical than complete shoulder reconstruction. For future inlay construction, however, specifications regarding haul road construction should be outlined so as to minimize damage to the existing shoulders.

Full-Depth AC Inlay

Construction of the full-depth AC inlay has been previously documented (2), and will only be briefly discussed here. Construction began in April 1986 and was completed in advance of the November 1, 1987 specification date. Two-lane, two-way traffic was allowed during construction, but all four lanes had to be open to traffic between November 1, 1986 and April 1, 1987. The construction sequence is summarized below.

All traffic was switched to the northbound lanes. The inner 9 inches of both southbound shoulders were removed to provide expansion room during the pavement breaking operation. A high frequency, low amplitude, resonant breaker was used to lubblize the existing D-cracked concrete. The bulk of the reinforcing steel was removed in the field, and an electromagnet at the crushing plant removed the remainder.

The BAM subbase was milled off and the material used to construct a haul road adjacent to the median shoulder. The subgrade was modified with approximately 4 percent Code "L", a lime kiln dust from a plant producing high quality lime, to a minimum depth of 12 inches. Cone penetrometer tests were taken prior to subgrade modification. Areas with CBR's less than 6 were either treated with additional lime and/or processed greater than 12 inches deep to ensure a uniform construction platform.

The contractor elected to crush the recycled concrete aggregate in the fall of 1986 and the spring of 1987 with a hammer mill impact crusher. Since the crushing operation was not started until the fall of 1986, virgin aggregate was used in the southbound lanes, and recycled concrete aggregate reserved for the northbound lanes. Due to an insufficient quantity of recycled concrete aggregate, only approximately 13 percent of the northbound lanes contained the full 14.5 inches of recycled asphalt concrete binder. As the recycled concrete aggregate supplies ran out, virgin aggregates were substituted. Mix designs for 2 recycled concrete aggregate/ virgin aggregate blend asphalt concrete binder mixes (recycled/virgin blend asphalt concrete mixes) were developed: Mix 1 contained CA-11 virgin aggregate and CA-16 and FA-20 recycled concrete aggregate, and Mix 2 contained CA-11 and CA-16 virgin aggregate and FA-20 recycled concrete aggregate. The results of these mix designs are shown in Table 6. For research purposes, the southbound lanes constructed with virgin asphalt concrete binder were designated Section A; the portion of the northbound lanes constructed with recycled/virgin blend asphalt concrete binder was designated Section B; and the portion of the northbound lanes containing all recycled asphalt concrete binder was designated Section C. All three sections received virgin asphalt concrete surface. Figure 6 details the boundaries of the different binder mixtures.

After the full 14.5 inches of binder were placed, underdrains were installed and the southbound lanes opened to traffic. Southbound traffic ran on the top lift of binder course throughout the winter of 1986 until the spring of 1987, at which time all two-way traffic was switched to the southbound lanes while the northbound lanes were reconstructed. The same construction procedure was used on the northbound lanes. A 1.5-inch virgin asphalt concrete surface course and a 1.5-inch virgin asphalt concrete surface shoulder capping were constructed on all lanes and shoulders during 1987.

Although the full-depth AC inlay presented no construction problems, certain materials problems were noted. The asphalt contents of mixes containing recycled concrete aggregate were difficult to determine. Nuclear gauges produced highly variable and questionable asphalt contents, probably due to the variable mortar contents of the recycled concrete aggregate. Nuclear gauges determine asphalt content by monitoring the amount of chemically-bound hydrogen in the sample. Typical virgin aggregates in Illinois are comprised of calcium carbonate or calcium-magnesium carbonate, so in a typical asphalt concrete mix, the only hydrogen present is in the asphalt cement. Fully hydrated Portland cement, however, can contain approximately 26 percent chemically-bound water (10). The presence of hydrogen in the recycled concrete aggregate mortar thus apparently affected the nuclear gauge readings. Extractions were run instead to determine asphalt content, but they took longer than normal due to the pore structure and high absorption of the recycled concrete aggregate. Aside from asphalt content determination, the recycled concrete aggregate presented no other material problems during construction.

PERFORMANCE MONITORING

Post-Construction Maintenance Activities

Neither the CRC inlay nor the full-depth AC inlay have required specialized maintenance since their construction.

Friction Testing

CRC Inlay

Friction testing with both treaded and smooth tires has been conducted since construction was completed. The results are shown in Table 10. The average treaded tire friction number has been 55, and the average smooth tire friction number 50. These numbers compare favorably with conventional CRC pavements of similar age constructed between 1980 and 1986 (11).

Full-Depth AC Inlay

Friction testing with both treaded and smooth tires has been conducted annually since 1988. The results are shown in Table 10. The average treaded tire friction number has been 60, and the average smooth tire friction number 40. These numbers indicate that the pavement has good surface microtexture and medium to fine macrotexture. These numbers compared favorably with other asphalt concrete surfaces constructed in the same time frame (11). These results were not surprising since the surface of the full-depth AC inlay was constructed with virgin aggregate to the same specifications as any other conventionally constructed asphalt concrete surface.

Ride Quality

CRC Inlay

Surface roughness testing has been conducted annually since construction, and the results are summarized in Table 11. Early tests were taken using a Bureau of

Public Roads-type Roadometer. More recent tests were taken with Illinois' road profiler, modeled after South Dakota's prototype. Both devices measure surface roughness in inches per mile, but they use different scales to determine adjective ratings. In general, CRC inlay test results indicate a smooth to marginally slightly rough pavement. The results immediately after construction compare favorably with statewide averages for CRC pavements constructed between 1977 and 1987 (12). This finding would appear to indicate that the harshness of the recycled concrete mixture did not have an adverse effect on surface smoothness.

Full-Depth AC Inlay

Surface roughness testing has been conducted periodically since construction and the results are summarized in Table 11. Surface roughness was measured using both a Bureau of Public Roads-type Roadometer and Illinois' road profiler. The full-depth AC inlay has consistently been in the very smooth to smooth category, depending upon the chosen method of measurement. A recent statewide road profiler survey showed the full-depth AC inlay to be one of the overall smoothest sections in the state (13). This result is not surprising, since the lime-modified subgrade provided an excellent construction platform, and the multiple lift construction allowed additional opportunities to correct surface irregularities.

Condition Surveys

CRC Inlay

Pavement

Pavement condition surveys of the entire CRC inlay project were made in March 1990 and April 1992. In addition, a windshield survey, conducted by driving at slow speeds on the outside shoulder, was completed in September 1991. The result of the pavement condition surveys are summarized in Tables 12 and 13. At the time of the March 1990 survey, the northbound driving lane had received approximately 2.2×10^6 18-kip equivalent single axle loads (ESALs). The southbound driving lane had received approximately 1.6×10^6 ESALs. The March 1990 survey showed little distress. Five small localized areas of distress were found, along with some low severity deterioration at three construction joints. The primary form of distress noted was low severity random longitudinal cracking. This distress was found over approximately 2.5 percent of the length of the southbound lanes. The distress was clustered together, and was the result of late centerline joint sawing during construction. At the time of construction, the contractor was allowed up to four days to saw the centerline joint. However, hot weather caused random longitudinal cracking before the joint could be saw cut. A policy change was enacted as a result that required centerline joint sawing be completed before uncontrolled shrinkage cracking occurs. In general, the pavement was in excellent condition. The average crack spacing was found to be 3 feet, with a minimum spacing of 1 foot.

The September 1991 windshield survey revealed little change. Wide flange beam joints in need of sealing were observed, but no additional distress was readily discernible. The April 1992 survey was a detailed pavement condition survey similar to the March 1990 survey. By the time of the April 1992 survey, the northbound driving lane had received approximately 3.0 x 10^6 ESALs. Localized areas of distress and low severity longitudinal cracking were the primary forms of distress noted. A total of 14 localized areas of distress were observed. The low severity random longitudinal cracking was limited to 3.6 percent of the length of the southbound lanes. One punchout was found that had formed off of the random longitudinal crack. After 5 to 6 years in service, the CRC inlay was still in excellent condition.

Shoulders

Shoulder condition surveys were made during construction since the project was an inlay. At the start of construction, the shoulders were observed to be in good condition. Minor longitudinal and transverse cracking were observed, but no structural failures were apparent. Construction of the haul road immediately adjacent to the median shoulder did result in heaving of the outside 1.5 feet of the shoulder. The shoulders were milled to achieve the desired pavement grade, and the milling alleviated the heaving shoulder problem. The milling operation did cause some of the thin surface lift material to break off. Some shoulder cracking due to construction did occur. An average 2.5-inch thick asphalt concrete surface shoulder capping effectively covered this construction damage. The variable thickness shoulder capping was a result of a change from a circular crown to a tangent crown, as well as a 2-inch grade change. To date, the shoulders are performing well, supporting the idea of an inlay as a valid concept.

Underdrains

The original pavement was 24 feet wide with the underdrains placed under the shoulder and adjacent to the pavement edge-shoulder joint, as shown in Figure 2. The 27-foot wide CRC inlay placed the underdrains 1.5 feet in from the pavement edge-shoulder joint, as shown in Figure 3. Whether the underdrains would continue to function efficiently in their new location was a question that had to be considered. It was assumed that stabilization of the outer 1.5 feet of the subbase adjacent to the shoulders would probably be marginal at best. Theoretically this would provide a relatively unobstructed path for the water to reach the underdrains.

To evaluate this hypothesis, during the first construction season a 1,500-foot long, 24-foot wide cement-stabilized experimental test section was constructed. The drainage efficiency of this test section was compared to the drainage efficiency of an adjacent 27-foot wide cement-stabilized control section. Figure 7 shows the location of the experimental stabilization width sections. Visual inspections of the underdrain outlets made between November 1986 and April 1987 proved that water was reaching the underdrains in both the experimental and control sections. The drainage efficiencies of the two sections were judged comparable on the basis of these visual comparisons.

The decision was made to process the subbase to a width of 24 feet during the 1987 construction of the southbound lanes. Twenty-four-foot width stabilization would still provide adequate edge support for the 27-foot wide CRC inlay, would eliminate the additional processing necessary to ensure full 27-foot width stabilization, and would provide water a less obstructed path to the underdrains. Subsequent visual surveys have shown the underdrains to be functional. Deflection testing with the Falling Weight Deflectometer (FWD) has also shown that the 24-foot width cement-stabilized southbound lanes are providing adequate edge support, as will be discussed later.

Lane/Shoulder Joint Sealing

A second experimental section on the CRC inlay evaluated the effectiveness of sealing the pavement edge-shoulder joint. Two 1,000-foot sections located in the northbound lanes were constructed in 1986. The first section featured a 0.5-inch wide by 0.75-inch deep reservoir, sawed mainly into the bituminous shoulder and filled with a hot-poured joint sealant meeting ASTM D 3405 specifications. The second section had a 0.5-inch wide by 1.375-inch deep joint configuration with a 0.625-inch diameter backer rod placed to the bottom of the reservoir. Part of this section was sealed with an ASTM D 3405 hot-poured joint sealant, and part was sealed with an ASTM D 1190 hot-poured, elastic-type joint sealant. The outside shoulder joint of both sections was sealed and the median shoulder joint left open. Figure 7 shows the location of the sealant test sections.

After one winter of service, both sealants exhibited good adhesion to both the PCC pavement and the bituminous shoulder. However, an 8-month evaluation period was deemed too short to determine the sealants' long-term ability to withstand traffic and environment. Based on this decision, the pavement edge-shoulder joint of the southbound lanes was not sealed during the 1987 construction season.

Visual inspections of the sealant sections were conducted periodically between April 1987 and October 1991. The latest survey showed both sealants to be pliable and performing moderately well. The ASTM D 3405 sealant in the 0.5-inch wide by 0.75-inch deep reservoir was 50 to 75 percent effective, i.e., still adhered to the sides of the reservoir. Both the ASTM D 3405 and ASTM D 1190 sealants in the 0.5-inch wide by 1.375-inch deep reservoir with a 0.625-inch diameter backer rod were 75 percent effective. The sealants adhered to the PCC pavement in some areas and to the asphalt concrete shoulders in others. Even where the sealant appeared to be adhered to the sides of the reservoir, it was possible to peel the sealant away and view intruded fines. In approximately 5 percent of each of the sections, the sealant reservoir was cut into the PCC pavement only. Without a fresh cut into the asphalt concrete shoulder for the sealant to adhere to, there was little bonding between the sealant and the shoulder.

Based on these visual observations, it appeared that the deeper reservoir, used in conjunction with the backer rod, provided a marginally better reservoir configuration for the sealant. After 6 winters in service, however, the sealants seemed to have lost their effectiveness. Fines were noted in the joint reservoirs, and the lack of adhesion between sealant and pavement and sealant and shoulder obviously provided an entry point for water infiltration.

Full-Depth AC Inlay

Pavement

Pavement condition surveys of the entire full-depth AC inlay were made in March 1990 and March 1992. In addition, a windshield survey, conducted by driving at slow speeds on the outside shoulder, was made in September 1991. The results of the pavement condition surveys are summarized in Tables 14 and 15. At the time of the March 1990 survey, the northbound driving lane had received approximately 0.9×10^6 ESALs and the southbound driving lane approximately 1.3×10^6 ESALs.

The March 1990 survey showed the pavement to be performing well. The only distresses noted were some isolated "fat" spots, pockets of asphalt cement in the asphalt concrete surface, and 3 tight transverse cracks. No thermal cracking or fatigue cracking was noted.

Little change was evident between the March 1990 survey and the September 1991 windshield survey. Approximately 10 "fat" spots, 1 foot wide by 10 to 15 feet long, were found throughout the project, with the majority occurring in Section B. These "fat" spots were not limited to the wheelpaths. Other smaller, isolated "fat" spots were noticed throughout the project. These "fat" spots could have been the result of isolated pockets of aggregate containing excess moisture. No thermal cracking or fatigue cracking was noted, and the only transverse cracks found were the transverse paving joints.

The March 1992 survey was also a detailed condition survey. As of March 1992, the northbound driving lane had received approximately 1.6×10^6 ESALs and the southbound driving lane approximately 2.0×10^6 ESALs. "Fat" spots were again observed to be the primary form of distress. This distress was found throughout less than 2 percent of the inlay's length. No thermal cracking or fatigue cracking was observed. A total of 2 transverse cracks and 100 feet of low severity longitudinal cracking was found. As of the survey date, the centerline paving joint had been routed and sealed for the entire length of Sections B and C, and approximately one-half the length of Section A. Based on a visual distress survey, the full-depth AC inlay was in excellent condition.

Rut Depths

Rut depths have been measured annually on the full-depth AC inlay since construction. The data are summarized in Table 16. Initial differences between the northbound and southbound lanes can be attributed to the construction sequence. Traffic ran on the top binder lift of the southbound lanes for approximately one year before the surface was placed. The initial mat densification under traffic thus occurred in the binder before the surface was placed. Traffic was not allowed on the northbound lanes, however, until after the surface had been placed. The July 1988 northbound driving lane's average 0.12-inch rut depth thus reflected the effect of initial mat densification due to traffic. Table 16 shows similar 0.26-inch rut-depths in both the northbound (March 1992) and southbound (April 1991) driving lanes for comparable levels of ESALs. Some of the variability in rut depths over time can be attributed to the different measurement methods used. The manual rut gauge and the automated road profiler "read" rut depths differently, but can be expected to illustrate the same general trends, if not the same measurements (14). A comparison of the March 1990 manual measurements and the May 1990 road profiler measurements shows the relative similarity of the two methods.

Shoulders

The condition of the shoulders during construction was of prime importance, since the project was a partial inlay. Condition surveys were made of the shoulders at the start of construction. Both the median and transverse shoulders were in good condition, with no structural failures, and only a minimal amount of low severity transverse and longitudinal cracking. No signs of thermal cracking or fatigue cracking were observed. A small amount of weathering and raveling was observed.

During the construction sequence, the condition of the shoulders was observed. Construction equipment was prohibited from using the outside shoulder. Some construction damage to the inner edge of the outside shoulder did occur, but this material was removed as the roadbed was widened from 24 to 27 feet. The 1.5-inch asphalt concrete surface shoulder capping placed in 1987 effectively covered whatever minor damage may have occurred to the outside shoulder during construction. To date, the shoulders are performing well, with no signs of distress.

Deflection Testing

CRC Inlay

Deflection testing was conducted annually with IDOT's Dynatest 8002 Falling Weight Deflectometer (FWD) to provide information on the CRC inlay's load carrying capability, its load transfer efficiency (LTE), and the degree of subgrade support provided. The FWD is a non-destructive loading device capable of exerting a load impulse comparable in magnitude and duration to moving truck loads. The load is applied to a loading plate by dropping a weight package on a damping system and is measured by a load cell. The resulting pavement deflection is measured by 5 seismic deflection sensors spaced at pre-determined intervals from the loading plate. A series of 3 drops of 4,000, 8,000 and 12,000 pounds were made in the driving lane in both the northbound and southbound directions. These drops were normalized to a standard 9,000-pound load during analysis. Tests were taken in the center of the lane, away from any cracks, and at the edge of the pavement away from any cracks. Tests taken in the center of the pavement were designated as center panel tests, while the tests at the edge of pavement were designated "true edge" tests. Center panel and true edge tests were used to provide information on the CRC inlay's load carrying capability and the degree of subgrade support provided.

In addition, tests were made at the leave sides of cracks at the edge of pavement and in the outer wheelpath. Use of a trailing sensor on the approach side of the crack allowed the LTE of the crack to be calculated. The LTE of a crack or joint is calculated by dividing the deflection on the unloaded side of the crack or joint by the deflection directly beneath the loading plate.

The data were processed using a void detection analysis program developed by IDOT. The data are summarized and shown in Table 17. The results of the center panel tests show that average deflections under the load ranged between 3.0 and 4.6 mils (0.001 inch), and average deflection basin areas between 30.4 and 31.6 inches. Area values are an indication of the pavement's structural integrity, and are calculated by determining the area of the deflection basin, as shown in Figure 8. These area values are indicative of a sound concrete pavement. As expected due to slab geometry, deflections under the load were higher for the true edge tests, averaging 5.0 to 10.3 mils. Average subgrade resilient modulus (E_{Ri}) values calculated from center panel tests ranged from 7,970 to 12,708 psi, indicating adequate subgrade support. The E_{Ri} values backcalculated from FWD testing are a function of D3, the deflection under the sensor 36 inches from the center of the load. The LTEs of the cracks ranged from 91.0 to 93.4 percent in the outer wheelpath and from 91.4 to 94.4 percent at the edge of pavement. These values reflect excellent load transfer, which is to be expected of a CRC pavement that is performing well. The LTEs at the edge of the pavement were comparable to the LTEs obtained in the outer wheelpath. In addition, little variation was found between the northbound and southbound values. These findings indicate that both the 24-foot width subbase stabilization of the southbound lanes and the 27-foot width subbase stabilization of the northbound lanes are providing adequate edge support.

Full-Depth AC Inlay

Deflection testing with the FWD has been conducted since construction. Tests were taken every 200 feet in the outer wheelpath of the driving lane in each direction. The data were normalized to a 9,000-pound load. Deflection basin areas and E_{Ri} values were backcalculated using concepts and algorithms developed by Dr. Marshall Thompson of the University of Illinois (15). Asphalt concrete modulus (E_{AC}) values were also backcalculated using an algorithm developed at the University of Illinois (M. R. Thompson, unpublished data).

The E_{Ri} and E_{AC} algorithms were developed from a matrix of computer runs using ILLI-PAVE, a stress-dependent, finite element pavement model (16). The E_{Ri} algorithm is valid for full-depth AC thicknesses ranging from 4 to 16 inches, E_{Ri} values ranging from 1 to 12.3 ksi, and E_{AC} values ranging from 200 to 2,000 ksi (15). The E_{AC} algorithm is valid for full-depth asphalt concrete thicknesses ranging from 9.5 to 18 inches, E_{Ri} values ranging from 1 to 12.3 ksi, and E_{AC} values ranging from 100 to 1,100 ksi (M. R. Thompson, unpublished data).

Since asphalt concrete's material properties are a function of the testing temperature, temperatures were recorded during FWD testing. Initially, pavement temperatures were measured at a nominal 6-inch depth by drilling a hole at the edge of the pavement, filling it with oil, and inserting a thermometer. In April 1990, copper constantan thermocouples were installed, allowing for continuous temperature monitoring throughout the depth of the pavement structure. The temperature at the mid-depth of the pavement was used for backcalculation purposes.

The FWD data and pavement test temperatures are averaged by test date and summarized in Tables 18A and 18B. Average deflections under the load ranged from 3.3 to 8.3 mils for Section A, and from from 3.0 to 6.4 mils for Sections B and C. Average deflection basin areas ranged from 20.7 to 27.0 inches in Section A, and from 22.0 to 28.0 inches in Sections B and C. These relatively low deflections and high deflection basin areas are representative of sound, full-depth AC pavements; however, the data showed Section A to be marginally lower in stiffness than Sections B and C. The average E_{Ri} values, which ranged from 11.5 to 15.9 ksi in Section A and from 12.5 to 15.9 ksi in Sections B and C, reflected the beneficial effect of the lime modification process. The E_{Ri} values were considered effective E_{Ri} values, since they were a composite value of the minimum 12-inch lime-modified subgrade and the untreated subgrade below. The lime-modified subgrade provided excellent support and a solid construction platform to compact against. The average E_{AC} values ranged between approximately 215 and 800 ksi in Section A, and between 270 and 1350 ksi in Sections B and C. Given the range of FWD test temperatures, the backcalculated E_{AC} values in Section A and Sections B and C appeared reasonable and representative of well-constructed asphalt concrete mixtures. However, the E_{AC} values in Sections B and C were considerably higher than the E_{AC} values in Section A.

The modulus of an asphalt concrete mixture is a function of the test frequency, the test temperature, and the mix composition (17). The variability of backcalculated E_{AC} with pavement temperature for the various sections is shown graphically in Figure 9. A complete analysis of these variables and their potential effect on the variable E_{AC} values that were backcalculated from FWD testing has been presented elsewhere (2). The analysis showed that test frequency and test temperature were not the cause of the variable E_{AC} values. Differences between design and production asphalt concrete binder mixture composition were investigated, but could not explain the variability in E_{AC} values between Section A and Sections B and C.

In 1989, the full-depth asphalt concrete inlay was cored to determine if moisture damage had occurred. The cores were split into binder lifts. Moisture contents of the lifts were determined, and indirect split-tensile tests at 77^{o}F were run on unconditioned cores. The split cores were then visually surveyed for signs of moisture damage. The testing procedure used was the same as the one currently specified by IDOT for evaluating the effectiveness of anti-strip additives (9).

Despite no visual signs of distress on the pavement surface, cores from Section A consistently showed visual signs of moderate to severe moisture damage in both the coarse and fine virgin aggregate. The cores from Sections B and C, which contained at least some recycled concrete aggregate, showed little visual signs of moisture damage. None of the binder mixtures contained an anti-strip additive. The lack of moisture damage in Sections B and C may be attributed to the recycled concrete aggregate. The high alkalinity of the newly crushed faces of the recycled concrete aggregate may have provided some resistance to moisture damage. The highly absorbtive nature of the recycled concrete aggregate may have decreased the moisture susceptibility of the mix as well, since additional asphalt cement may have been absorbed into the pores of the concrete mortar. The design TSR values of the binder mixes - 0.60 for the virgin asphalt concrete binder, 0.84 for the recycled/virgin blend asphalt concrete binder, and 0.82 for the recycled asphalt concrete binder - thus presented an accurate picture of moisture susceptibility.

Moisture contents averaged 0.98 percent for Section A, 2.23 percent for Section B, and 2.90 percent for Section C. The higher moisture contents of Sections B and C seemed to reflect the higher absorptive properties of the recycled concrete aggregate rather than the presence of moisture damage. Tensile strengths of cores taken from Section A averaged 82.0 psi, from Section B averaged 163.6 psi, and from Section C averaged 154.0 psi. The lower average tensile strength of the cores taken from Section A appeared to be a direct result of moisture damage. The presence of moisture damage in Section A, coupled with the lower tensile strengths, seemed to indicate that the differences in backcalculated E_{AC} on this project were attributable to moisture damage. After 5 to 6 years of service, all pavement sections appear to be performing well, with no visual signs of moisture damage-related distress apparent on the pavement surface. In spite of the apparent effect of moisture damage on the E_{AC} values in Section A, the backcalculated E_{AC} values were still representative of a sound full-depth AC pavement.

COSTS

CRC Inlay

The final cost of the CRC inlay was $6,377,506, which translates to a cost of $1,540,460 per 4-lane mile. An economic analysis of recycling was not conducted as part of this study, as the main thrust of this project was to determine the viability of recycling. Since the project was an inlay, cost savings over complete reconstruction were realized since the shoulders and underdrains were left intact. To date, the performance of the CRC inlay has been comparable to any conventionally constructed CRC pavement. After 5 to 6 years in service, the CRC inlay is performing well, with no major maintenance required so far, and none anticipated.

Full-Depth AC Inlay

The final cost of the full-depth AC inlay was $6,193,589, which translated to a cost of $1,496,036 per 4-lane mile. This project demonstrated that recycling a deteriorated PCC pavement into a new full-depth AC inlay was viable. To date the performance of the recycled asphalt concrete mix has been as good as, if not better than, the performance of the virgin asphalt concrete mix. Both the recycled and virgin asphalt concrete mixes are performing well, however, with no major maintenance required, and none anticipated. Although the actual cost-effectiveness of the recycling process was not determined, some cost savings were realized because the outside shoulder was not reconstructed.

FUTURE MONITORING

This report concludes the work required by the experimental features work plan. Currently, IDOT plans to continue performance monitoring efforts throughout the pavements' lives. Surface response, structural response, visual distress survey, and maintenance data will provide a better understanding of both the recycling processes and the performance of CRC and full-depth AC pavements.

SUMMARY AND RECOMMENDATIONS

The objectives of this experimental feature were to evaluate the viability of recycling old PCC pavements into new inlays and to determine the subsequent performance of the recycled pavements. One project proved the viability of recycling a badly cracked and faulted JRC pavement into a CRC inlay. After 5 to 6 years in service, no major maintenance has been required, and the performance of the CRC inlay has been comparable to any conventionally constructed CRC pavement. The other project proved the viability of recycling a badly D-cracked CRC pavement into a full-depth AC inlay. No major maintenance has been performed to date, and the pavement is performing well. In addition, the performance of the recycled asphalt concrete mix has been as good as, if not better than, the performance of the virgin asphalt concrete mix.

Based on the experience gained from the experimental features projects, the following recommendations are offered:

- Recycling should be considered as a rehabilitation strategy, but the cost-effectiveness of all the alternatives should be weighed. The cost-effectiveness evaluation should consider project location, proximity of quality aggregates, project life, and potential user costs connected with the construction staging sequence.

- The condition of the existing shoulders should be investigated to determine if an inlay is viable.

- Specifications concerning haul road construction need to be strengthened so as to minimize the displacement and heaving of shoulders on an inlay job.

- Although using the existing, functioning underdrains can be a cost-saving measure, extra care is required during pavement removal and subbase stabilization to avoid damaging them.

- The use of fly ash and natural sand can improve the workability of a PCC mix containing recycled concrete aggregate.

- Additional research is needed to determine if standard tests and specifications for aggregates and asphalt concrete mixtures need to be modified or adapted to account for the pore structure and chemical composition of recycled concrete aggregate. Specific items that need to be addressed include:

  - An aggregate soundness test that can be used with recycled concrete aggregate.

  - An accurate method to determine the bulk specific gravity of recycled concrete aggregate.

  - A fast and reliable method to determine the asphalt content of an asphalt concrete mix containing recycled concrete aggregate.

- The moisture susceptibility of asphalt concrete mixes containing recycled concrete aggregate should be carefully investigated. The moisture susceptibility of stockpiled recycled concrete aggregate and the combined effectiveness of recycled concrete aggregate and anti-strip additives require further study.

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DISCLAIMER

This paper is based on the results of an experimental features project entitled, "Recycling Old PCC Pavement." This project was sponsored by the Illinois Department of Transportation (Division of Highways) and the U. S. Department of Transportation (Federal Highway Administration).

The contents of this paper reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation nor the Federal Highway Administration.

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ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions of the following people without whose help and support this report would not have been possible; Brenda Miller and Becky Hermes, manuscript preparation; Tom Courtney, illustrations; Audrey Lyons, Joe Vespa, Mary Milcic, Paul Jenkins, and LaDonna Blecha, data collection and review; and Christine Reed, David Lippert, Eric Harm, Ernest Barenberg, and Marshall Thompson, manuscript review.

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 Test Results (59 tests)	100	93	37		8				1.5
1987 Test Results (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 Test Results (63 tests)				100	100	49	14	6	4.8
1987 Test Results (37 tests)				100	100	48	13	5	3.7

TABLE 1: RECYCLED CONCRETE AGGREGATE GRADATIONS FOR CRC INLAY

			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	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	---	19 -Criteria of 10% maximum loss waived	---	---	6.6	2.41

---Denotes No Specification For Fine Aggregate

TABLE 2: RECYCLED CONCRETE AGGREGATE QUALITY TESTS FOR CRC INLAY

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

(1) (SSD) Denotes Saturated Surface Dry Condition

TABLE 3: 1986 MIX DESIGN QUANTITIES FOR CRC INLAY

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

(1) (SSD) Denotes Saturated Surface Dry Condition

TABLE 4: 1987 MIX DESIGN QUANTITIES FOR CRC INLAY

TABLE 5: RECYCLED CONCRETE AGGREGATE GRADATION AND QUALITY DATA FOR FULL-DEPTH AC INLAY

TEST	CA-11		CA-16		FA-20	
	SPECIFICATION	AVG. TEST RESULT	SPECIFICATION	AVG. TEST RESULT	SPECIFICATION	AVG. TEST RESULT
Gradation, % Passing						
1"	100	100				
3/4"	84-100	86.0				
1/2"	30-60	41.1	100	100		
3/8"	---[a]	---	94-100	95.6	100	100
#4	0-12	3.4	15-45	28.0	94-100	98.9
#8	---	---	---	---	60-100	83.5
#16	0-8	1.9	0-8	4.8	35-65	58.8
#50	---	---	---	---	10-30	19.3
#100	---	---	---	---	5-15	11.2
#200	---	---	---	---	0-8	6.5
Sodium Sulfate Soundness, % Loss	20 Max.	33.0	20 Max.	30.7	15 Max.	15.2
Los Angeles Abrasion, % Loss	45 Max.	33.0	45 Max.	30.0	---	---
Deleterious Material, %	10 Max.	0.0	10 Max.	0.1	5 Max.	0.0
Absorption, %	---	4.1	---	5.0	---	7.25
Specific Gravity, Saturated Surface Dry	---	2.45	---	2.42	---	2.37

[a] --- Denotes No Specification

TABLE 6: ASPHALT CONCRETE BINDER MIXTURE DESIGN DATA FOR FULL-DEPTH AC INLAY

TEST	SPECIFICATION	RECYCLED ASPHALT CONCRETE	RECYCLED/VIRGIN BLEND ASPHALT CONCRETE MIX 1[b]	RECYCLED/VIRGIN BLEND ASPHALT CONCRETE MIX 2[c]	VIRGIN ASPHALT CONCRETE
Gradation, % Passing					
1"	100	100	100	100	100
3/4"	82-100	92	92	95	93
1/2"	50-82	69	65	72	71
3/8"	---[a]	58	53	60	56
#4	24-50	39	39	40	41
#8	16-36	30	30	28	28
#16	10-25	23	24	20	20
#30	---	16	17	14	13
#50	4-12	7	7	8	6
#100	3-9	5	5	5	5
#200	2-6	4.0	4.2	4.1	4.0
Asphalt, % Total Mix	3-9	5.2	5.0	5.1	5.0
Air Voids, %	3-5	4.0	4.0	4.0	4.0
Voids in the Mineral Aggregate, %	14 Min.	12.0	12.5	11.9	14.0
Marshall Stability, lbs.	2,000 Min.	2,850	2,240	3,224	2,185
Marshall Flow, 1/100 In.	8-16	10.0	8.0	12.8	8.0
Tensile Strength Ratio	---	0.82	Not Run	0.84	0.60

[a] --- Denotes No Specification

[b] Mix 1 Contained CA-11 Virgin Aggregate and CA-16 and FA-20 Recycled Concrete Aggregate

[c] Mix 2 Contained CA-11 and CA-16 Virgin Aggregate and FA-20 Recycled Concrete Aggregate

TABLE 7: ASPHALT CONCRETE SURFACE MIXTURE DESIGN DATA FOR FULL-DEPTH AC INLAY

TEST	SPECIFICATION	VIRGIN ASPHALT CONCRETE
Gradation, % Passing		
3/4"	100	100
1/2"	90-100	100
3/8"	66-100	93
#4	24-65	59
#8	16-48	35
#16	10-32	25
#30	---[a]	17
#50	4-15	8
#100	3-10	6
#200	3-9	4.9
Asphalt, % of Total Mix	3-9	6.0
Air Voids, %	3-5	4.1
Voids in the Mineral Aggregate, %	15 Minimum	15.9
Marshall Stability, lbs.	2,000 Minimum	2,000
Marshall Flow, 1/100 in.	8-16	8.0
Tensile Strength Ratio	---	0.77

[a] --- Denotes No Specification

	FIELD TESTS		STRENGTHS, PSI (DATE CAST)			
			COMPRESSIVE		FLEXURAL	
DATE	SLUMP, IN.	AIR, %	7-DAY	14-DAY	7-DAY	14-DAY
9/22/86	3.0,3.0	6.7,7.4	N/A	N/A	719	918
9/23/86	2.75,2.75,2.5	5.1,7.2,8.0,8.1	N/A	N/A	737	830
9/25/86	2.5,2.5,2.5,2.5	7.8,6.0,6.3,7.5,6.7, 6.2,5.8,5.5	N/A	N/A	798	877
9/26/86	3.0,2.75	5.5,5.8,6.4,6.0	N/A	N/A	782	853
9/29/86	2.0,2.0,2.5,2.25	5.6,6.0,5.0,5.9,5.1, 5.2,6.6,5.5	N/A	N/A	798	890
10/6/86	0.75,2.0,3.0,2.5	5.1,6.1,7.8,5.6,5.1,6.0	N/A	N/A	790	840
10/7/86	3.25,1.5,2.0,1.75,1.75	6.3,5.0,5.1,5.5,5.8, 5.8,5.4,4.8	2,534*	2,949*	863	887
10/8/86	2.0,1.5	5.4,5.1,6.4,6.8,6.3, 6.0,5.8,7.0,5.8	N/A	N/A	801	855
10/9/86	1.5	5.3,5.0,5.2,5.8,7.2,5.8	N/A	N/A	777	868
10/11/86	1.5,2.0,2.0	5.2,7.4,6.3,6.0,6.7, 6.3,5.5,5.6,5.6	N/A	N/A	709	785
10/15/86	2.0,1.75,2.25	5.9,5.6,5.2,5.8,5.4, 6.4,6.4,6.3,6.1,7.0,7.2	N/A	N/A	735	796
10/16/86	2.5,2.0	6.8,6.3,6.3,6.5,6.8	N/A	N/A	760	837

TABLE 8: 1986 DAILY MATERIAL PROPERTY TESTS FOR CRC INLAY

	FIELD TESTS		STRENGTHS, PSI (DATE CAST)			
			COMPRESSIVE		FLEXURAL	
DATE	SLUMP, IN.	AIR, %	7-DAY	14-DAY	7-DAY	14-DAY
10/17/86	1.5,2.0,1.25,1.25	6.1,6.8,6.3,5.6,6.8 7.2,7.2,7.5,6.4,6.2,5.6	3,512	4,197	796	865
10/18/86	2.25,1.75,2.0	6.0,6.8,5.6,6.9,7.1,6.9	N/A	N/A	764	814
10/20/86	2.75	7.6,7.8,7.5	N/A	N/A	700	814
10/21/86	3.25,3.0	8.2,7.0,8.0,7.4	N/A	N/A	676	839
	AVG. = 2:20 IN. STD. DEV. = 0.58 IN. n = 45	AVG. = 6.25% STD. DEV. = 0.84% n = 104	AVG. = 3,023 PSI STD. DEV. = --- n = 2	AVG.= 3,573 PSI STD. DEV. = --- n = 2	AVG. = 762.8 PSI STD. DEV. = 47.7 PSI n = 16	AVG. = 848.0 PSI STD. DEV. = 35.9 PSI n = 16
	SPECIFICATION: 3 IN.MAX.	SPECIFICATION: 5-8%	SPECIFICATION: 3,500 PSI MIN. @ 14-DAY; 3,325 MIN. WITH FLYASH		SPECIFICATION: 650 PSI MIN. @ 14-DAY; 620 PSI WITH FLY ASH	
			*10/7/86 CYLINDERS ARE LOW - WERE LEFT IN SUN			

N/A denotes test not taken.

TABLE 8: 1986 DAILY MATERIAL PROPERTY TESTS FOR CRC INLAY (CONTINUED)

	FIELD TESTS		STRENGTHS, PSI (DATE CAST)			
			COMPRESSIVE		FLEXURAL	
DATE	SLUMP, IN.	AIR, %	7-DAY	14-DAY	7-DAY	14-DAY
6/9/87	1.5,1.75	6.4,6.1	N/A	N/A	859	941
6/15/87	1.25,2.25	5.2,5.4,5.7,6.2,6.4	N/A	N/A	825	925
6/16/87	2.5,2.5,2.0	6.4,5.8,6.1,6.1,6.2,6.4	N/A	N/A	805	838
6/17/87	2.25,3.0,2.0,2.0	5.5,5.8,7.6,6.1,6.4,5.8, 5.3,5.5,6.0	N/A	N/A	862	912
6/18/87	2.0,2.75,2.0,2.25,2.0	7.1,6.6,7.1,7.8,7.4,7.0, 6.7,8.1,8.1	N/A	N/A	806	914
6/19/87	3.0,2.0	6.6,7.8,6.8,6.1,6.8,7.0	N/A	N/A	809	818
6/22/87	1.75	8.0,6.5,8.1	N/A	N/A	868	974
6/25/87	2.25,2.25	7.9,6.5,7.0,7.0,6.1,6.5, 6.5	N/A	N/A	799	856
6/26/87	1.75,2.25	6.7,5.7,6.1,7.6,5.7	N/A	N/A	N/A	N/A
6/27/87	2.5,1.75,2.0	6.4,6.3,5.9,6.6,5.9,6.6, 7.7	N/A	N/A	839	
6/29/87	1.75,1.5	6.5,7.1,6.7	N/A	N/A	774	863

TABLE 9: 1987 DAILY MATERIAL PROPERTY TESTS FOR CRC INLAY

	FIELD TESTS		STRENGTHS, PSI (DATE CAST) COMPRESSIVE		FLEXURAL	
DATE	SLUMP, IN.	AIR, %	7-DAY	14-DAY	7-DAY	14-DAY
6/30/87	2.5,1.5,2.25,2.5	7.5,6.3,7.8,6.0,7.5,6.7, 6.8,6.5,7.1	N/A	N/A	805	939
7/2/87	1.75,3.25,2.5	6.1,7.3,8.4,5.9,6.8,8.0, 6.5,6.3,6.2,6.5	N/A	N/A	694	762
7/3/87	2.0,2.25,2.0	7.1,8.0,8.4,7.5,7.5, 6.7,8.0	N/A	N/A	910	901
	AVG. = 2.14 IN. STD. DEV. = 0.44 IN. n = 38	AVG. = 6.71% STD. DEV. = 0.78% n = 88			AVG. = 819.6 PSI STD. DEV. = 52.6 PSI n = 13	AVG. = 886.9 PSI STD. DEV. = 60.7 PSI n = 12
	SPECIFICATION: 3 IN.MAX.	SPECIFICATION: 5-8%	SPECIFICATION: 3,500 PSI MIN. @ 14-DAY; 3,325 PSI. WITH FLYASH		SPECIFICATION: 650 PSI MIN. @ 14-DAY; 620 PSI WITH FLY ASH	

N/A denotes not test taken.

TABLE 9: 1987 DAILY MATERIAL PROPERTY TESTS FOR CRC INLAY (CONTINUED)

TABLE 10: FRICTION TEST RESULTS FOR RECYCLED INLAY PROJECTS

AVERAGE FRICTION NUMBER, TRAFFIC LANE

PAVEMENT AGE, YEARS	TREADED TIRE	SMOOTH TIRE
CRC INLAY		
5.40	57	45
4.68	53	46
4.51	55	50
3.64	57	51
2.71	53	48
2.47	56	52
1.97	53	48
1.72	53	46
1.49	57	51
0.99	57	58
0.78	56	49
0.45	51	52
	AVG. = 54.8	AVG. = 49.7
FULL-DEPTH AC-INLAY		
4.32	60	42
3.44	62	40
2.89	63	38
1.91	58	42
0.81	57	40
	AVG. = 60.0	AVG. = 40.4

TABLE 11: RIDE QUALITY TEST RESULTS FOR RECYCLED INLAY PROJECTS

ROUGHNESS INDEX, IN./MILE/ADJECTIVE RATING - TRAFFIC LANE

TEST DATE	NORTHBOUND	SOUTHBOUND
CRC INLAY		
3/23/92[a]	105/SMOOTH	115/SMOOTH
4/25/91[a]	101/SMOOTH	106/SMOOTH
6/21/90[a]	100/SMOOTH	105/SMOOTH
3/12/90[b]	87/SMOOTH	95/SLIGHTLY ROUGH
4/10/89[b]	88/SMOOTH	98/SLIGHTLY ROUGH
8/31/88[b]	80/SMOOTH	92/SLIGHTLY ROUGH
2/23/87[b]	72/VERY SMOOTH	NOT YET CONSTRUCTED
FULL-DEPTH AC INLAY		
3/24/92[a]	52/SMOOTH	64/SMOOTH
4/25/91[a]	60/SMOOTH	57/SMOOTH
5/31/90[a]	52/SMOOTH	59/SMOOTH
3/15/88[b]	46/VERY SMOOTH	51/VERY SMOOTH

[a] Test taken with Illinois' road profiler and measured using the International Rougness Index

IN./MILE	ADJECTIVE RATING
0-190	SMOOTH
191-320	MEDIUM
321 or GREATER	ROUGH

[b] Test taken with Illinois' roadometer and measured using the Illinois Roadometer Roughness Index for PCC and bituminous pavement

PCC, IN./MILE	BITUMINOUS, IN./MILE	ADJECTIVE RATING
75 OR LESS	60 or less	VERY SMOOTH
76-90	61-75	SMOOTH
91-125	76-105	SLIGHTLY ROUGH
126-170	106-145	ROUGH
171-220	146-190	VERY ROUGH
221-375	191-330	UNSATISFACTORY

TABLE 12: TABULATION OF DISTRESS FOR MARCH 1990 SURVEY OF CRC INLAY

SECTION	LENGTH, FEET	DISTRESS	SEVERITY	AMOUNT (NORTHBOUND) PL[a]	DL[b]	(SOUTHBOUND) PL[c]	DL[d]	UNITS
ALL NORTHBOUND AND SOUTHBOUND	21,739 (whole section not surveyed)	Construction joint deterioration	LOW	2	1	–	–	number
		Potholes and localized distress	LOW	–	2	–	1	number
		Potholes and localized distress	MED.	–	1	–	1	number
		Longitudinal cracking	LOW	–	–	–	15	lineal feet
		Random longitudinal cracking (CL)[e]	LOW	–	–	119	427	lineal feet
		Random longitudinal cracking (CL)[e]	MED.	–	–	–	25	lineal feet
		Random longitudinal cracking (CL)[e]	HIGH	–	–	–	20	lineal feet
		Permanent patch deterioration	LOW	–	13	–	–	square feet

[a] Approximately 500,000 ESAL's at time of survey
[b] Approximately 2,200,000 ESAL's at time of survey
[c] Approximately 180,000 ESAL's at time of survey
[d] Approximately 1,650,000 ESAL's at time of survey
[e] CL = Centerline

TABLE 13: TABULATION OF DISTRESS FOR APRIL 1992 SURVEY OF CRC INLAY

SECTION	LENGTH, FEET	DISTRESS	SEVERITY	AMOUNT (NORTHBOUND) PL[a]	AMOUNT (NORTHBOUND) DL[b]	AMOUNT (SOUTHBOUND) PL[c]	AMOUNT (SOUTHBOUND) DL[d]	UNITS
ALL NORTHBOUND AND SOUTHBOUND	21,739 (whole section not surveyed)	Potholes and localized distress	LOW	–	7	1	3	number
		Potholes and localized distress	MED.	–	1	–	2	number
		Permanent patch deterioration	LOW	–	20	–	–	square feet
		Longitudinal cracking	LOW	–	–	–	21	lineal feet
		Punchouts	HIGH	–	–	–	1	number
		Random longitudinal cracking (CL)[e]	LOW	–	–	189	604	lineal feet
		Random longitudinal cracking (CL)[e]	MED.	–	–	–	25	lineal feet
		Random longitudinal cracking (CL)[e]	HIGH	–	–	–	7	lineal feet

[a] Approximately 650,000 ESAL's at time of survey
[b] Approximately 3,570,000 ESAL's at time of survey
[c] Approximately 340,000 ESAL's at time of survey
[d] Approximately 3,030,000 ESAL's at time of survey
[e] CL = Centerline

TABLE 14: TABULATION OF DISTRESS FOR MARCH 1990 SURVEY OF FULL-DEPTH AC INLAY

SECTION	LENGTH, FEET	DISTRESS	SEVERITY	AMOUNT (NORTHBOUND) PL[a]	AMOUNT (NORTHBOUND) DL[b]	AMOUNT (SOUTHBOUND) PL[c]	AMOUNT (SOUTHBOUND) DL[d]	UNITS
B (NORTHBOUND)	19,050	Transverse cracking	LOW	2	1	–	–	number
		Asphalt bleeding	–	–	62	–	–	lane-feet
C (NORTHBOUND)	2,809	None	–	–	–	–	–	
A (SOUTHBOUND)	21,859	Asphalt bleeding	–	–	–	–	35	lane-feet

[a] Approximately 100,000 ESAL's at time of survey
[b] Approximately 900,000 ESAL's at time of survey
[c] Approximately 290,000 ESAL's at time of survey
[d] Approximately 1,280,000 ESAL's at time of survey

TABLE 15: TABULATION OF DISTRESS FOR MARCH 1992 SURVEY OF FULL-DEPTH AC INLAY

SECTION	LENGTH, FEET	DISTRESS	SEVERITY	AMOUNT (NORTHBOUND) PL[a]	AMOUNT (NORTHBOUND) DL[b]	AMOUNT (SOUTHBOUND) PL[c]	AMOUNT (SOUTHBOUND) DL[d]	UNITS
B (NORTHBOUND)	19,050	Asphalt bleeding	–	36	182	–	–	lane-feet
		Transverse cracking	LOW	1	1	–	–	number
C (NORTHBOUND)	2,809	Asphalt bleeding	–	–	28	–	–	lane-feet
		Longitudinal cracking	LOW	–	100	–	–	lineal feet
A (SOUTHBOUND)	21,859	Asphalt bleeding	–	–	–	30	147	lane-feet

[a] Approximately 180,000 ESAL's at time of survey
[b] Approximately 1,640,000 ESAL's at time of survey
[c] Approximately 370,000 ESAL's at time of survey
[d] Approximately 2,020,000 ESAL's at time of survey

TABLE 16: FULL-DEPTH AC INLAY RUT DEPTH DATA

DATE	AVERAGE RUT GAUGE RUT DEPTH, INCHES		AVERAGE ROAD PROFILER RUT DEPTH, INCHES	
	NORTHBOUND DRIVING LANE	SOUTHBOUND DRIVING LANE	NORTHBOUND DRIVING LANE	SOUTHBOUND DRIVING LANE
7/88	0.12 (0.31×10^6)[a]	0.04 (0.69×10^6)		
8/89	0.09 (0.68×10^6)	0.10 (1.06×10^6)		
3/90	0.11 (0.90×10^6)	0.11 (1.28×10^6)		
5/90			0.08 (0.97×10^6)	0.12 (1.35×10^6)
4/91			0.19 (1.30×10^6)	0.26 (1.68×10^6)
3/92			0.26 (1.64×10^6)	0.33 (2.02×10^6)

[a]Numbers in Parentheses Indicate Approximate Number of 18-kip Equivalent Single Axle Loads to Date.

STATISTICS FOR DEFLECTIONS, AREAS, AND ERI

			CENTER PANEL (AVG.)							TRUE EDGES (AVG) (AWAY FROM CRACKS)					
DATE	DIR	TEMP	# OF TESTS (a)	D0 (MILS)	D1 (MILS)	D2 (MILS)	D3 (MILS)	AREA (INCH) (b)	ERI (PSI) (c)	# OF TESTS (a)	D0 (MILS)	D1 (MILS)	D2 (MILS)	D3 (MILS)	AREA (INCH) (b)
07/06/88	S	85	144	3.7	3.4	3.0	2.7	31.6	10186	72	7.9	7.4	6.5	5.5	31.1
09/06/88	N	79	39	3.9	3.6	3.2	2.7	31.0	9812	57	5.0	4.6	4.1	3.4	31.1
03/29/89	N	48	96	3.1	2.8	2.5	2.1	30.8	12708	54	6.7	6.1	5.3	4.5	30.5
03/30/89	S	40	78	4.0	3.7	3.2	2.7	30.7	9917	42	10.3	9.5	8.2	6.8	30.7
08/29/89	N	90	51	4.6	4.2	3.8	3.2	31.1	7970	26	5.3	4.9	4.3	3.6	30.7
08/31/89	S	76	75	3.0	2.8	2.5	2.2	30.8	12549	39	9.2	8.6	7.7	6.6	31.4
04/17/90	N	36	105	3.6	3.3	2.9	2.4	30.4	11332	54	6.4	5.9	5.2	4.3	30.8
04/16/90	S	44	108	4.0	3.6	3.2	2.6	30.7	10301	54	6.2	5.6	4.8	3.9	30.3
04/24/91	N	49	105	3.4	3.1	2.7	2.3	31.0	11929	57	6.0	5.7	5.0	4.3	31.5
04/24/91	S	57	96	3.8	3.6	3.1	2.6	31.5	10358	54	6.0	5.6	4.9	4.0	31.0

STATISTICS FOR CRACK LOAD TRANSFER EFFICIENCY (LTE)

			EDGE OF PAVEMENT		OUTER WHEEL PATH	
DATE	DIR	TEMP	# OF TESTS (a)	LTE (%) (d)	# OF TESTS (a)	LTE (%) (d)
07/06/88	S	85	72	92.7	72	92.6
09/06/88	N	79	3	91.4	111	91.9
03/29/89	N	48	96	92.9	102	92.6
03/30/89	S	40	72	93.3	72	92.9
08/29/89	N	90	51	93.8	51	92.2
08/31/89	S	76	72	93.5	72	91.0
04/17/90	N	36	99	93.8	102	92.4
04/16/90	S	44	105	92.3	105	92.2
04/24/91	N	49	99	94.2	99	93.4
04/24/91	S	57	99	94.4	99	93.3

(a) Data represents average of 4,000, 8,000, and 12,000-lb. drops per location, each normalized to a 9,000 lb. load

(b) Area (inch) = $6\left(1 + 2\frac{D1}{D0} + 2\frac{D2}{D0} + \frac{D3}{D0}\right)$ (REF. 15)

(c) ERi (psi) = $25{,}700 - 7{,}280 \cdot D3 + 530 \cdot (D3)^2$
$R^2 = 0.962$ SEE = 0.94 (REF. 15)

(d) Load transfer efficiency calculated by dividing the deflection 12 inches from the load, on the unloaded side of the crack, by the deflection beneath the loaded plate.

TABLE 18A: FULL-DEPTH AC INLAY FWD DATA SUMMARY--SECTION A

DATE	PAVT. TEMP., °F (a)	# OF TESTS	D0 (MILS) (b) AVG.	D0 S.D.	D0 CV(%)	D1 (MILS) (b) AVG.	D1 S.D.	D1 CV(%)	D2 (MILS) (b) AVG.	D2 S.D.	D2 CV(%)	D3 (MILS) (b) AVG.	D3 S.D.	D3 CV(%)
12/08/87	46	94	3.30	0.43	13.00	2.58	0.38	14.61	2.25	0.33	14.81	1.90	0.28	14.85
06/07/88	90	14	6.96	1.26	18.04	4.33	0.97	22.54	3.36	0.73	21.71	2.57	0.53	20.74
	97	34	7.10	1.12	15.78	4.49	0.82	18.30	3.52	0.59	16.76	2.71	0.41	15.30
	106	63	6.84	1.37	20.05	4.14	1.08	4.14	3.24	0.82	25.33	2.48	0.60	24.01
10/18/88	51	34	3.52	0.66	18.71	2.64	0.56	21.26	2.22	0.49	21.86	1.84	0.40	21.95
	62	72	4.37	0.75	17.09	3.23	0.53	16.52	2.67	0.42	15.62	2.19	0.33	14.87
03/14/89	63	80	3.97	0.63	15.81	2.92	0.44	15.08	2.49	0.36	14.52	2.09	0.29	14.02
	68	26	4.07	0.78	19.17	2.92	0.55	18.92	2.48	0.44	17.91	2.05	0.34	16.58
08/16/89	87	26	7.20	1.61	22.32	4.62	1.34	28.97	3.57	1.03	28.82	2.75	0.76	27.73
	90	26	7.05	0.80	11.36	4.23	0.68	16.14	3.37	0.52	15.43	2.64	0.37	14.12
	93	25	6.54	1.54	23.54	3.90	1.27	32.72	3.05	0.95	31.14	2.37	0.66	27.98
	95	27	7.02	1.89	26.92	4.26	1.45	34.08	3.27	1.04	31.79	2.51	0.71	28.30
10/4/89	71.5	57	4.59	0.64	13.99	3.32	0.49	14.75	2.77	0.40	14.53	2.24	0.32	14.24
	75.5	52	4.85	1.15	23.74	3.30	0.88	26.84	2.70	0.70	25.84	2.16	0.52	24.14

DATE	PAVT. TEMP., °F (a)	#OF TESTS	EAC (KSI) (c) AVG.	EAC S.D.	EAC CV(%)	ERI (KSI) (d) AVG.	ERI S.D.	ERI CV(%)	AREA (INCHES) (e) AVG.	AREA S.D.	AREA CV(%)
12/08/87	46	94	801.09	256.48	32.02	15.58	1.21	7.76	27.00	1.14	4.23
06/07/88	90	14	241.59	44.52	18.39	12.93	1.91	14.76	21.43	1.41	6.58
	97	34	239.36	41.51	17.34	12.37	1.50	12.15	21.83	1.14	5.23
	106	63	232.18	46.45	20.01	13.30	2.26	16.98	21.03	1.51	7.19
10/18/88	51	34	735.29	226.65	30.83	15.86	1.66	10.47	25.66	1.68	6.55
	62	72	646.24	311.80	48.25	14.38	1.28	8.92	25.31	1.41	5.57
03/14/89	63	80	643.23	281.19	43.72	14.77	1.23	8.32	25.62	1.72	6.72
	68	26	522.76	181.71	34.76	14.93	1.37	9.18	25.04	1.37	5.46
08/16/89	87	26	257.25	42.06	16.35	12.34	2.59	21.00	21.79	1.16	5.33
	90	26	215.48	24.55	11.39	12.61	1.39	11.00	21.15	1.08	5.10
	93	25	247.12	40.58	16.42	13.75	2.52	18.33	20.74	1.75	8.45
	95	27	246.35	63.10	25.62	13.24	2.57	19.42	20.88	1.46	7.00
10/4/89	71.5	57	493.89	161.32	32.66	14.15	1.25	8.87	24.91	1.39	5.58
	75.5	52	386.62	93.33	24.14	14.56	2.09	14.37	23.44	1.35	5.76

TABLE 18A: FULL-DEPTH AC INLAY FWD DATA SUMMARY--SECTION A (CONT'D)

DATE	PAVT. TEMP., °F (a)	# OF TESTS	D0 (MILS) (b) AVG.	D0 S.D.	D0 CV(%)	D1 (MILS) (b) AVG.	D1 S.D.	D1 CV(%)	D2 (MILS) (b) AVG.	D2 S.D.	D2 CV(%)	D3 (MILS) (b) AVG.	D3 S.D.	D3 CV(%)
12/08/87	46	94	3.30	0.43	13.00	2.58	0.38	14.61	2.25	0.33	14.81	1.90	0.28	14.85
07/18/90	97.4	40	8.30	1.60	19.10	5.40	1.30	24.00	4.00	1.00	23.90	3.00	0.07	23.40
	99.8	67	8.20	1.90	23.50	5.10	1.50	28.90	3.80	1.00	27.80	2.80	0.07	25.60
06/25/91	91	62	7.80	1.30	16.80	5.00	1.00	20.70	3.70	0.80	20.30	2.80	0.50	19.00
	93	28	6.50	1.70	26.20	4.20	1.40	32.50	3.10	1.00	32.40	2.40	0.70	30.70
	96	17	7.00	2.20	31.80	4.80	1.60	33.60	3.50	1.10	30.20	2.60	0.60	25.20

DATE	PAVT. TEMP., °F (a)	# OF TESTS	E_{AC} (KSI) (c) AVG.	E_{AC} S.D.	E_{AC} CV(%)	E_{Ri} (KSI) (d) AVG.	E_{Ri} S.D.	E_{Ri} CV(%)	AREA (INCHES) (e) AVG.	AREA S.D.	AREA CV(%)
07/18/90	97.4	40	243.40	52.30	21.50	11.50	2.30	20.20	21.60	1.20	5.80
	99.8	67	224.30	51.10	22.80	12.10	2.60	21.20	20.90	1.30	6.10
06/25/91	91	62	244.70	49.30	20.20	12.10	1.90	15.60	21.50	1.10	5.10
	93	28	317.20	69.60	21.90	13.80	2.70	19.90	21.50	1.40	6.40
	96	17	362.80	153.70	42.40	13.30	3.00	22.70	22.30	1.20	5.20

(a) Pavement Temperatures at Nominal 6-in. Depth Before April 1990; Nominal 9-in. Depth After

(b) D0, D1, D2, and D3 are Surface Deflections at 0, 12, 24, and 36-Inch Offsets (Respectively) From the Center of the Loading Plate

(c) $\log E_{AC}$ (KSI) = 1.846-[4.902xLOG (D0-D1)]+[5.189xLOG (D0-D2)]-[1.282xLOG (D1-D3)]
$R^2 = 0.998$ SEE= 0.018 (M. R. Thompson, unpublished data)

(d) E_{Ri} (KSI) = $24.7-(5.41 \times D3)+(0.31 \times D3^2)$ (Ref. 15)
$R^2 = 0.98$ SEE = 0.64

(e) Area (inch) = $6\left(1 + 2\frac{D1}{D0} + 2\frac{D2}{D0} + \frac{D3}{D0}\right)$ (Ref. 15)

TABLE 18B: FULL-DEPTH AC INLAY FWD DATA SUMMARY - SECTIONS B AND C

DATE	PAVT. TEMP., °F (a)	# OF TESTS	D0 (MILS) (b) AVG.	D0 S.D.	D0 CV(%)	D1 (MILS) (b) AVG.	D1 S.D.	D1 CV(%)	D2 (MILS) (b) AVG.	D2 S.D.	D2 CV(%)	D3 (MILS) (b) AVG.	D3 S.D.	D3 CV(%)
12/08/87	46	109	3.02	0.44	14.68	2.47	0.41	16.72	2.16	0.38	17.63	1.83	0.32	17.60
06/07/88	118	68	5.94	1.10	18.47	3.78	0.91	4.14	3.05	0.70	23.03	2.36	0.51	21.47
	127	39	6.39	1.34	21.03	4.18	1.04	24.96	3.35	0.83	24.74	2.56	0.61	23.94
10/19/88	73	27	3.08	0.35	11.42	2.53	0.33	12.98	2.17	0.28	12.99	1.82	0.24	13.19
	79	26	3.17	0.51	16.06	2.54	0.48	19.04	2.14	0.42	19.68	1.82	0.35	19.42
	82	28	3.69	0.58	15.80	2.95	0.56	18.85	2.51	0.47	18.81	2.07	0.37	17.99
	86	27	3.78	0.38	9.92	3.09	0.36	11.74	2.61	0.31	11.82	2.16	0.27	12.64
03/14/89	68	108	3.09	0.41	13.41	2.52	0.39	15.52	2.18	0.34	15.70	1.87	0.29	15.31
08/16/89	101	102	5.45	1.03	18.97	3.57	0.88	24.75	2.90	0.70	24.02	2.30	0.53	22.84
10/04/89	83	26	3.87	0.74	19.08	2.79	0.69	24.79	2.31	0.59	25.50	1.87	0.46	24.56
	79	28	3.61	0.69	19.01	2.72	0.61	22.55	2.31	0.52	22.43	1.91	0.41	21.70
10/05/89	66	27	3.45	0.47	13.57	2.71	0.40	14.83	2.31	0.35	14.98	1.95	0.27	13.62
	60	28	3.45	0.32	9.21	2.85	0.32	11.05	2.44	0.26	10.49	2.05	0.22	10.66

DATE	PAVT. TEMP., °F (a)	#OF TESTS	E_{AC} (KSI) (c) AVG.	E_{AC} S.D.	E_{AC} CV(%)	E_{Ri} (KSI) (d) AVG.	E_{Ri} S.D.	E_{Ri} CV(%)	AREA (INCHES) (e) AVG.	AREA S.D.	AREA CV(%)
12/08/87	46	109	1167.14	309.43	26.51	15.89	1.40	8.78	27.92	0.89	3.18
06/07/88	118	68	269.98	48.89	18.11	13.75	1.99	14.48	22.04	1.27	5.78
	127	39	271.69	62.63	23.05	12.98	2.19	16.83	22.50	1.49	6.63
10/19/88	73	27	1349.01	756.24	56.06	15.91	1.03	6.46	27.78	0.92	3.30
	79	26	1234.00	322.80	26.20	15.92	1.52	9.56	27.10	1.07	3.95
	82	28	953.07	340.83	35.76	14.88	1.54	10.38	27.01	1.11	4.10
	86	27	1137.95	360.67	31.69	14.47	1.10	7.63	27.47	0.75	2.74
03/14/89	68	108	1326.26	459.18	34.62	15.71	1.23	7.81	27.82	0.79	2.84
08/16/89	101	102	326.76	84.36	25.82	13.98	2.06	14.71	22.64	1.51	6.69
10/04/89	83	26	573.60	84.50	14.73	15.72	1.96	12.50	24.52	1.45	5.90
	79	28	672.00	164.77	24.52	15.55	1.75	11.23	25.77	1.24	4.81
10/05/89	66	27	912.21	212.52	23.30	15.37	1.15	7.46	26.82	0.95	3.54
	60	28	1282.89	397.07	30.95	14.91	0.91	6.07	27.95	0.70	2.51

TABLE 18B: FULL-DEPTH AC INLAY FWD DATA SUMMARY - SECTIONS B AND C (CONT'D)

DATE	PAVT. TEMP., °F (a)	# OF TESTS	D0 (MILS) (b) AVG.	D0 (MILS) (b) S.D.	D0 (MILS) (b) CV(%)	D1 (MILS) (b) AVG.	D1 (MILS) (b) S.D.	D1 (MILS) (b) CV(%)	D2 (MILS) (b) AVG.	D2 (MILS) (b) S.D.	D2 (MILS) (b) CV(%)	D3 (MILS) (b) AVG.	D3 (MILS) (b) S.D.	D3 (MILS) (b) CV(%)
07/18/90	103	26	5.30	0.70	14.00	3.70	0.60	15.50	3.00	0.50	15.10	2.30	0.30	14.50
	105	27	5.70	1.00	17.70	3.80	0.90	23.90	3.00	0.70	23.60	2.30	0.50	23.00
	107	53	6.30	1.10	18.00	4.40	1.00	21.60	3.50	0.80	21.70	2.70	0.60	21.00
06/25/91	99	32	4.30	0.60	13.70	3.20	0.60	17.70	2.60	0.40	17.30	2.00	0.30	16.40
	100	34	5.20	0.80	15.00	3.80	0.70	19.20	3.00	0.60	19.70	2.30	0.50	19.70
	101	41	5.20	0.80	15.10	3.80	0.70	18.00	3.10	0.60	18.60	2.40	0.40	18.00

DATE	PAVT. TEMP., °F (a)	# OF TESTS	E_{AC} (KSI) (c) AVG.	E_{AC} (KSI) (c) S.D.	E_{AC} (KSI) (c) CV(%)	E_{Ri} (KSI) (d) AVG.	E_{Ri} (KSI) (d) S.D.	E_{Ri} (KSI) (d) CV(%)	AREA (INCHES) (e) AVG.	AREA (INCHES) (e) S.D.	AREA (INCHES) (e) CV(%)
07/18/90	103	26	383.30	69.70	18.20	13.80	1.30	9.80	23.90	0.90	3.80
	105	27	332.30	60.20	18.10	14.10	2.10	15.00	22.60	1.30	5.90
	107	53	350.20	90.60	25.90	12.50	2.10	16.50	23.50	1.20	5.10
06/25/91	99	32	577.50	153.30	26.50	15.10	1.40	9.30	24.50	1.10	4.60
	100	34	527.20	108.40	20.60	13.80	1.90	13.40	24.50	1.20	5.00
	101	41	528.30	125.50	23.70	13.50	1.70	12.60	24.80	1.10	4.30

(a) Pavement Temperatures at Nominal 6-in. Depth Before April 1990; Nominal 9-in. Depth After

(b) DO, D1, D2, and D3 are Surface Deflections at 0, 12, 24, and 36-Inch Offsets (Respectively) From the Center of the Loading Plate

(c) $\log E_{AC}$ (KSI) $= 1.846-[4.902 \times \log(D0-D1)]+[5.189 \times \log(D0-D2)]-[1.282 \times \log(D1-D3)]$
$R^2 = 0.998$ SEE= 0.018 (M. R. Thompson, unpublished data)

(d) E_{Ri} (KSI) $= 24.7-(5.41 \times D3)+(0.31 \times D3^2)$ (Ref. 15)
$R^2 = 0.98$ SEE = 0.64

(e) Area (inch)$=6\left(1 + 2\frac{D1}{D0} + 2\frac{D2}{D0} + \frac{D3}{D0}\right)$ (Ref. 15)

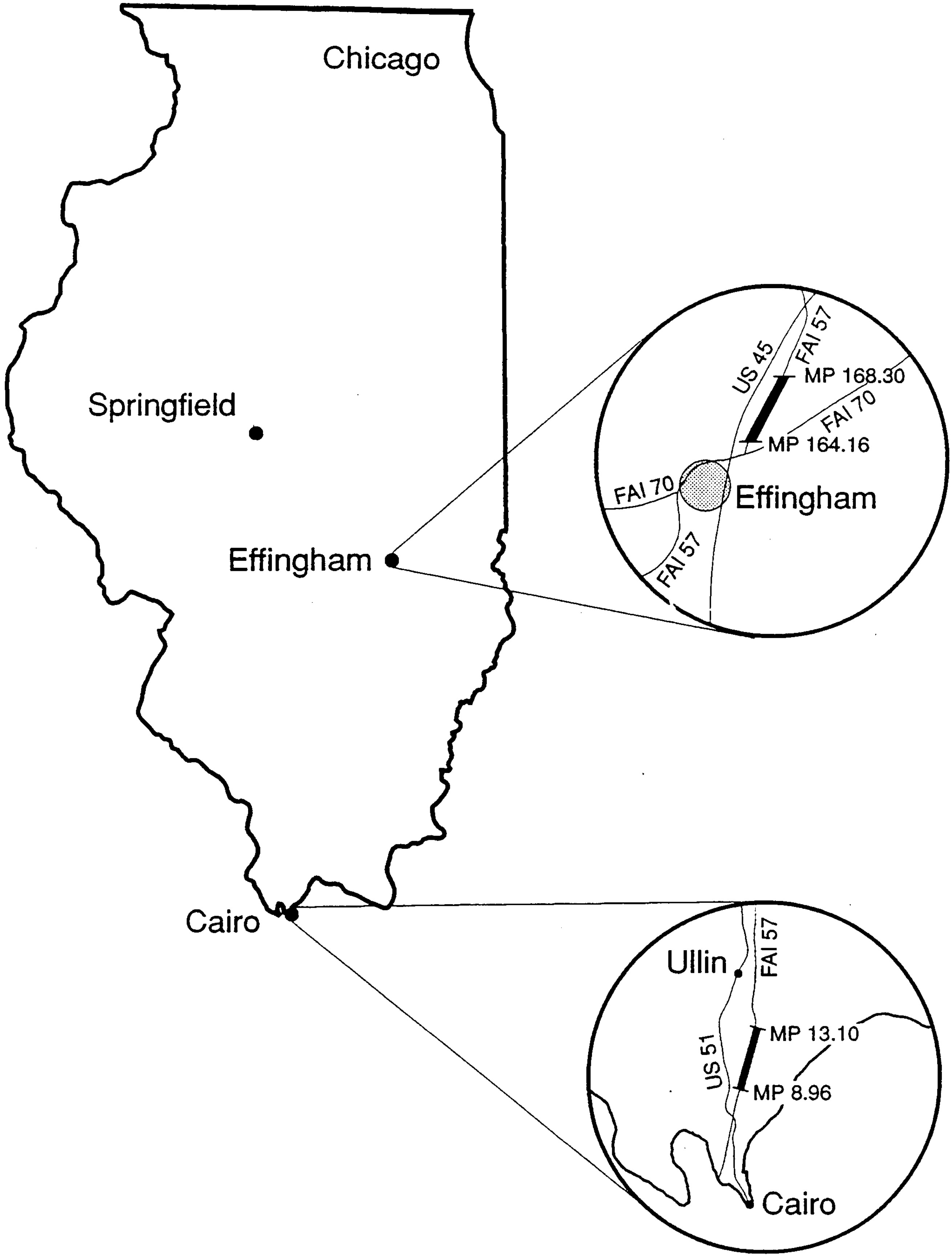


Figure 1. Location Map of Recycled Inlay Projects.

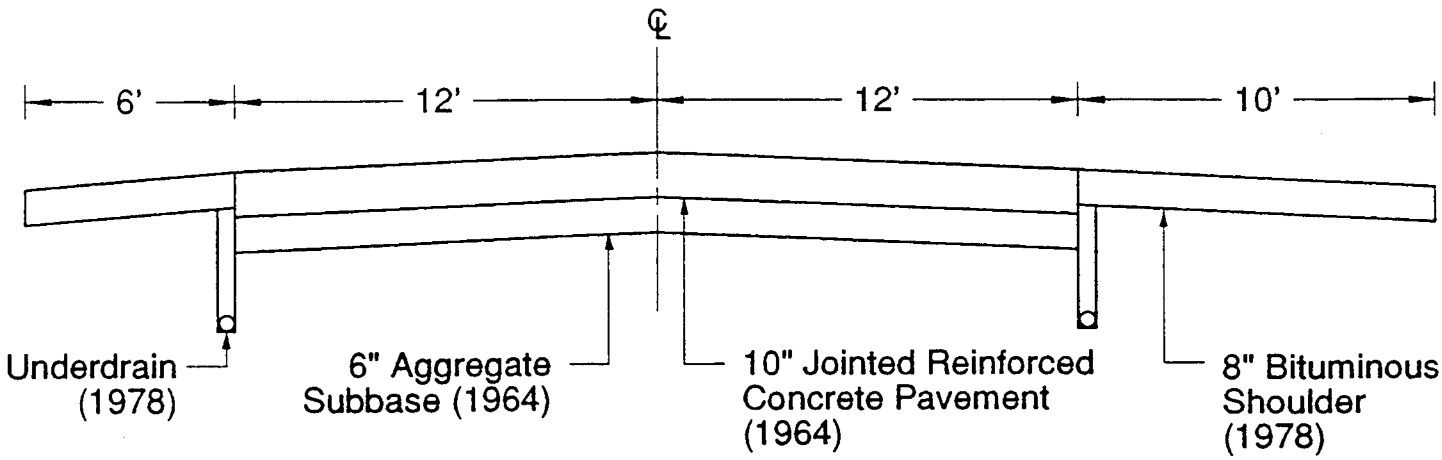


Figure 2. Original Pavement Cross Section - CRC Inlay.

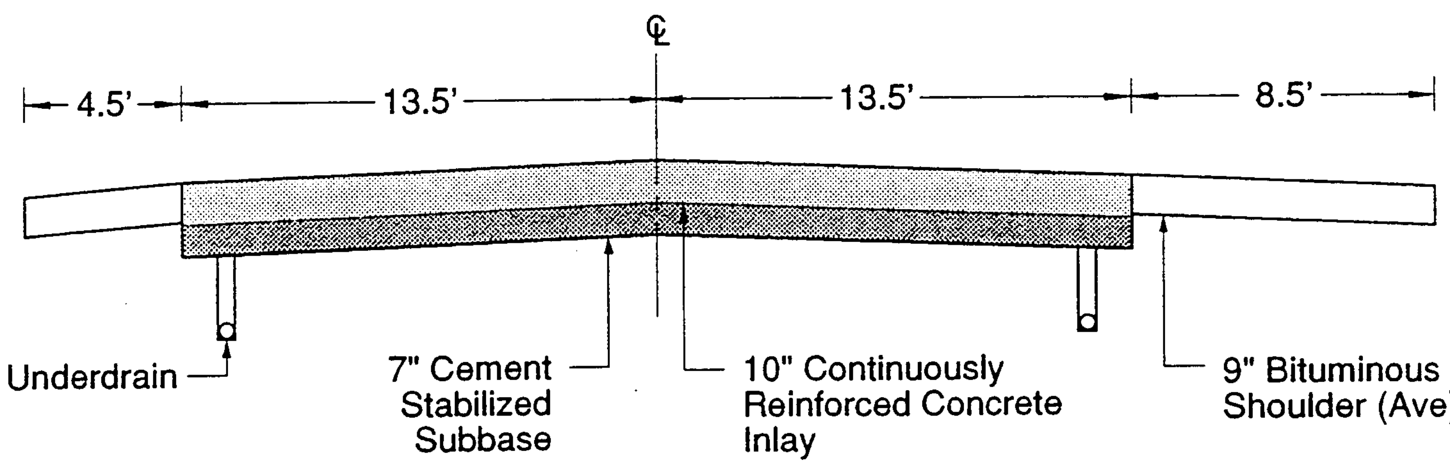


Figure 3. Cross Section of CRC Inlay.

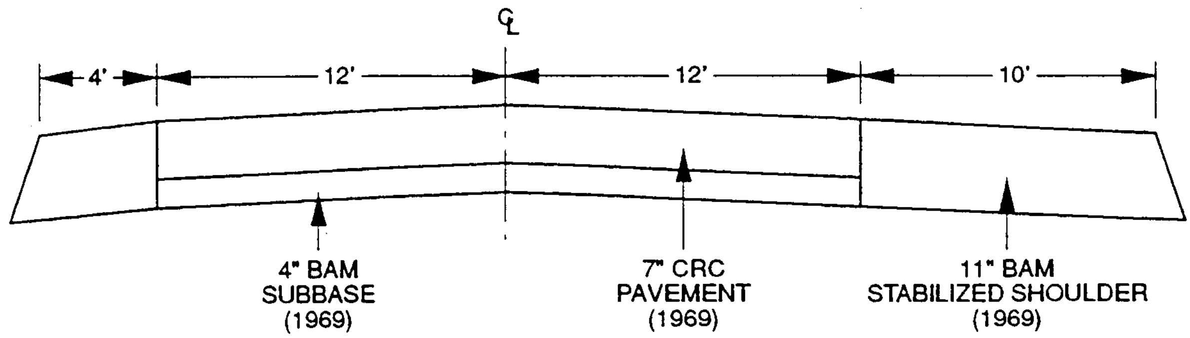


Figure 4: Original Pavement Cross Section - Full-Depth AC Inlay.

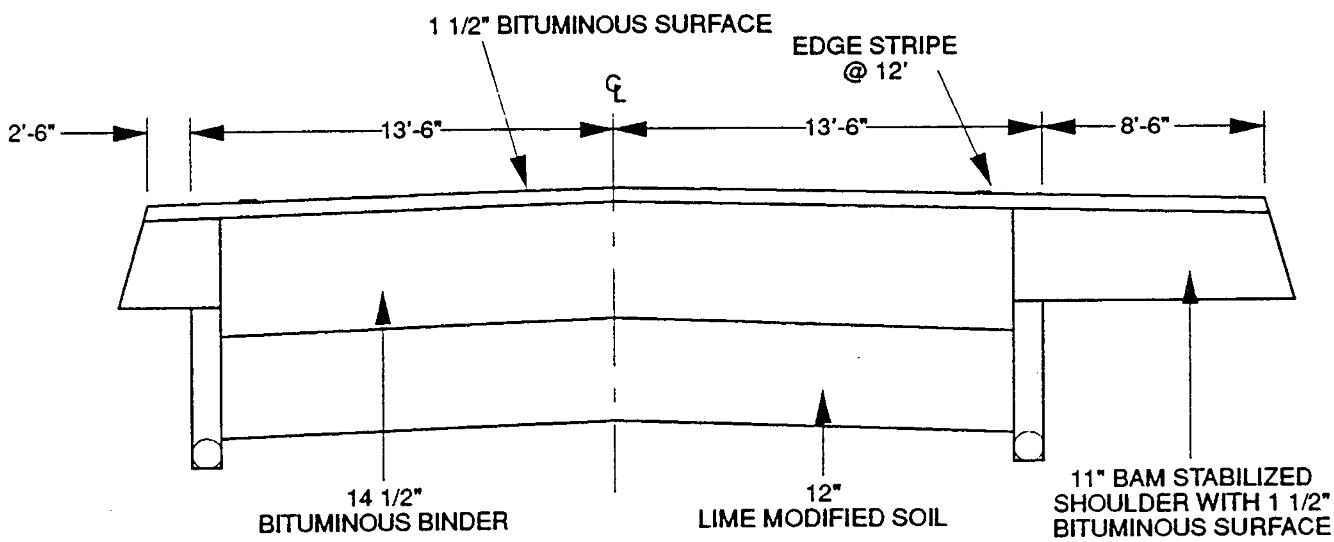


Figure 5: Cross Section of Full-Depth AC Inlay.

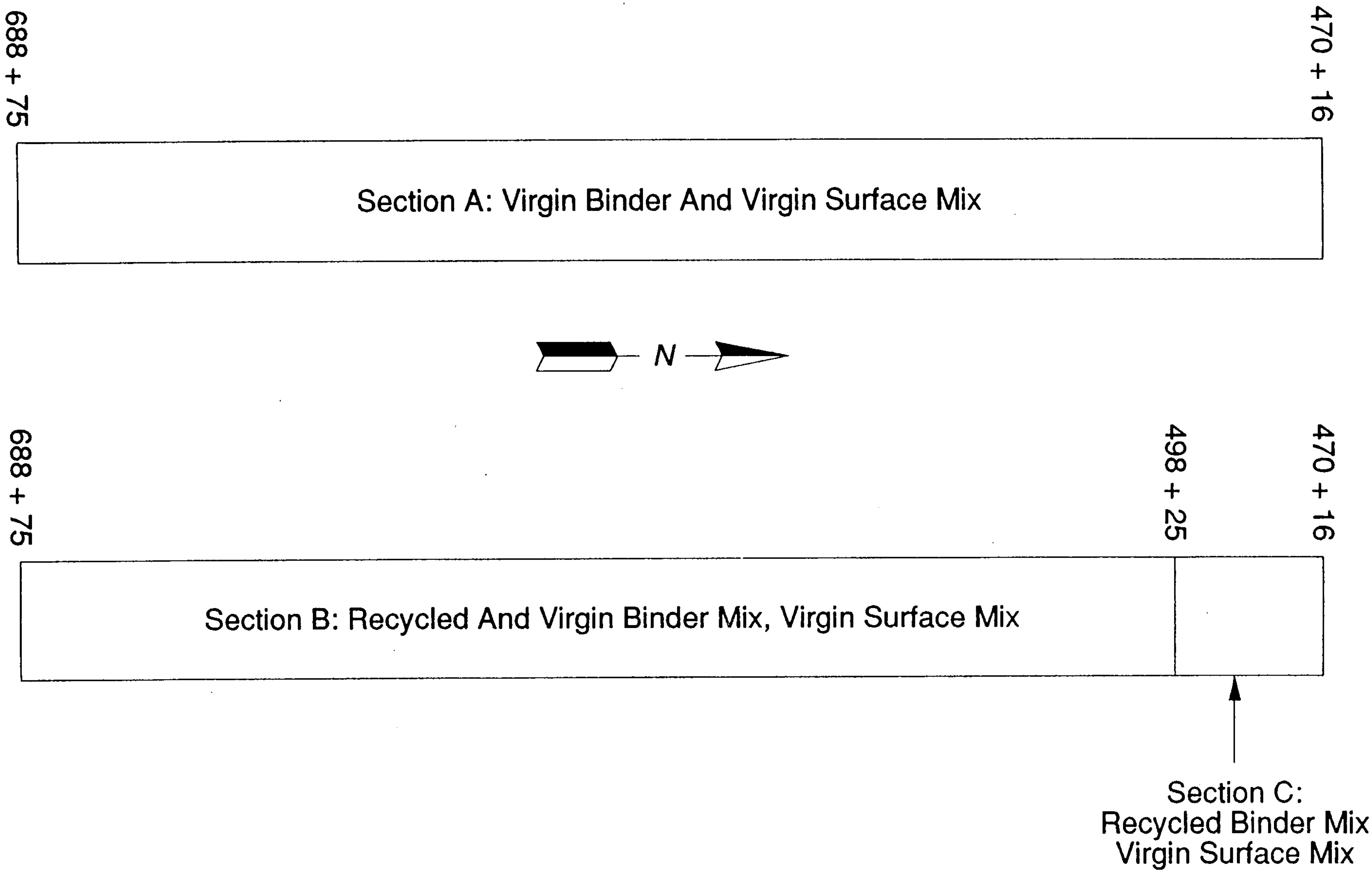


Figure 6: Limits and Layout of the Full-Depth AC Inlay.

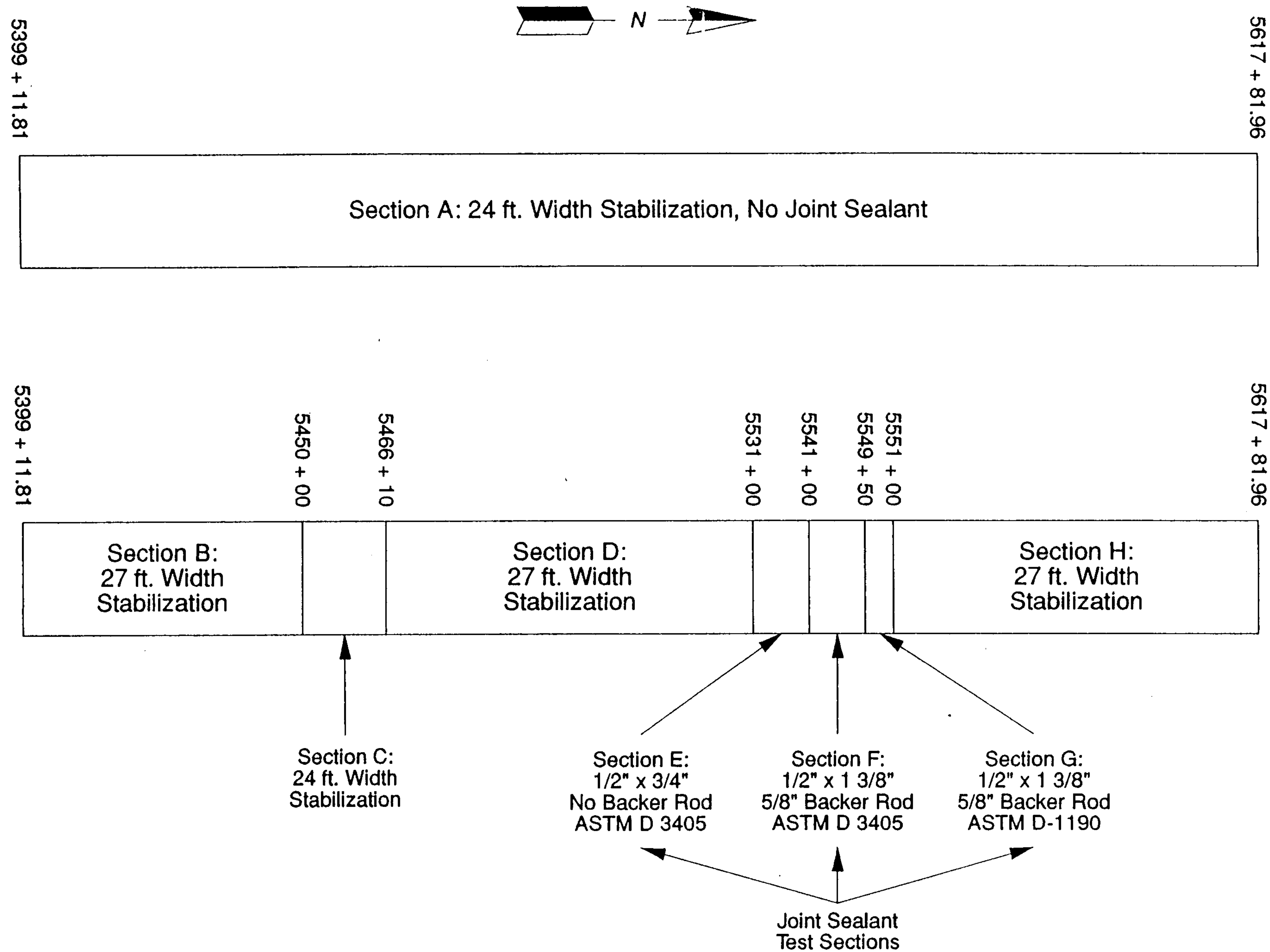
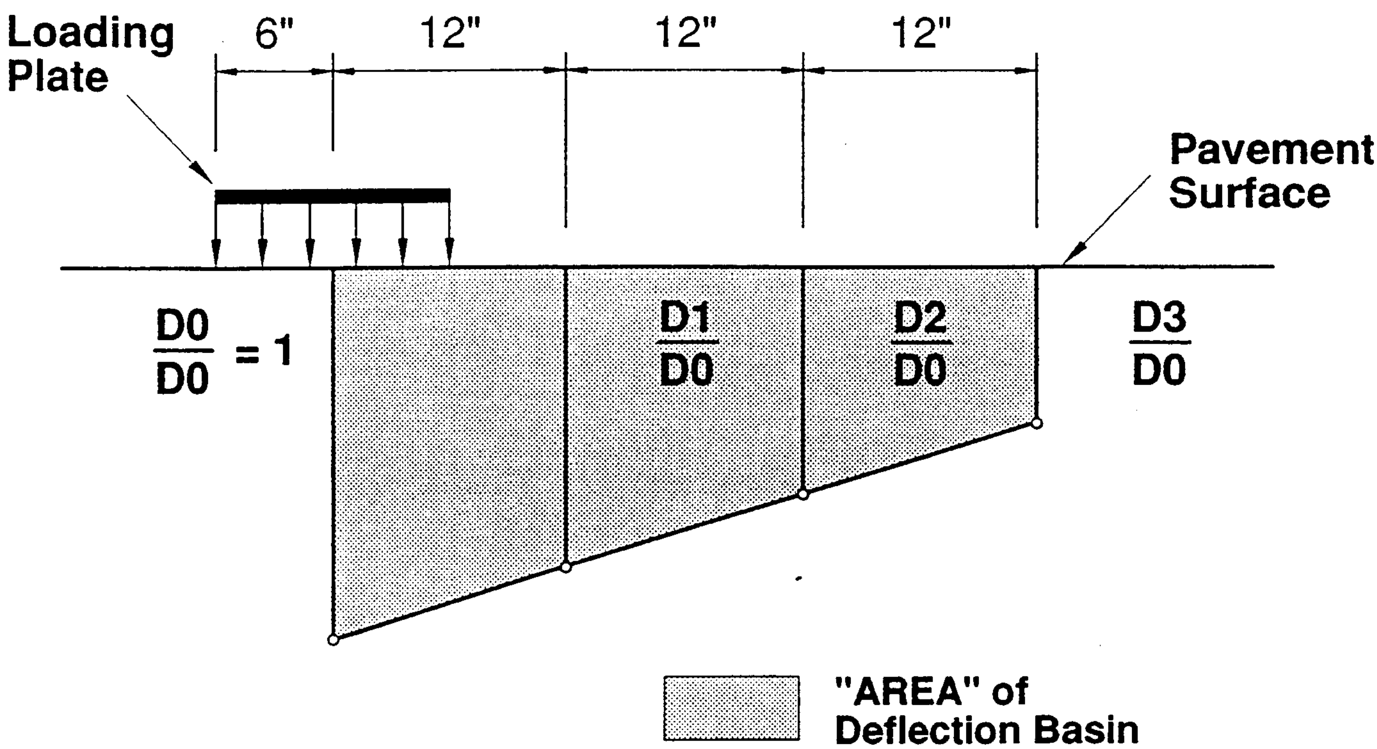


Figure 7: Limits and Layout of the CRC Inlay.



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

Figure 8: Deflection Area Basin.

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Backcalculated E_{ac} Versus Temperature

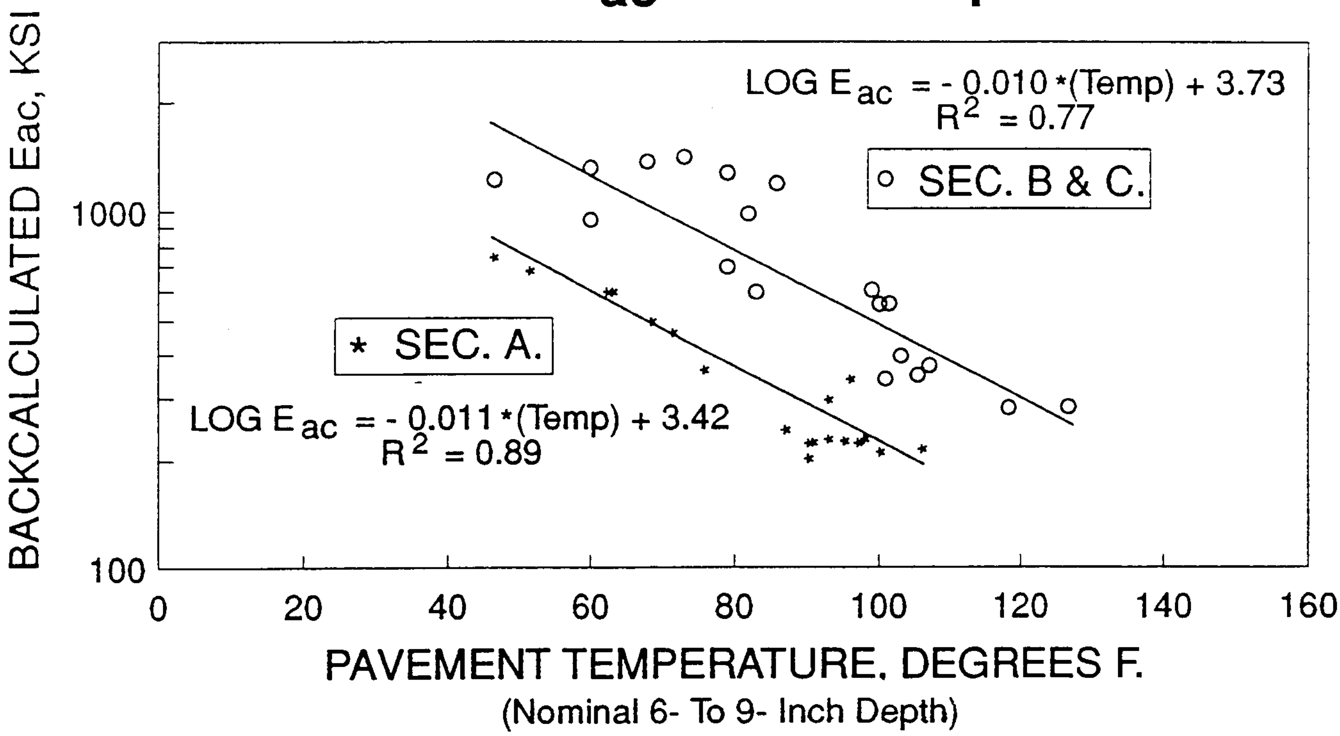

Figure 9: Backcalculated E_{AC} vs. Pavement Temperature Relationship Full-Depth AC Inlay