Cold, In-Place Recycling on Indiana State Road 38

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A narrow, two-lane road in Indiana was widened in 1986 by cold recycling the existing bituminous pavement in place. Bituminous binder and surface were placed over this base. A five-year research project was planned to compare the cost, strength and performance of the pavement with recycled base to a control section with conventional widening and resurfacing. The continuing evaluation of this recycled pavement includes measuring roughness and deflections annually. Visual inspections monitor development of cracking and other distress. Cores are analyzed for density, voids, asphalt content, and Hveem stability. After one year in service, the recycled pavement is performing better than the conventional pavement. Transverse reflection and longitudinal widening cracks are beginning to develop on the resurfaced section. No cracks have appeared in the recycled section. There is no significant difference between deflections on the two types of pavement. The recycled section cost nearly twice as much as the conventional pavement, but initial costs are expected to drop somewhat as the technique becomes more common. Maintenance costs will likely be lower on the recycled pavement and may result in lower life-cycle costs. This technique will likely be used again in Indiana for roads with low to moderate traffic volumes (under 2,500 directional ADT). Evaluation will continue to assess the performance, service life, and life-cycle costs for this method. Cold, in-place recycling seems to be a viable way to rehabilitate old pavements and seems especially well suited to widening pavements on fairly low-volume roads.

A substantial portion of the Indiana state highway network still has inadequate lane widths, by present standards. During rehabilitation, these roads are frequently widened. The standard technique used in Indiana is to cut a trench along the edge of the pavement. Typically 6 to 10 inches of bituminous base are placed and compacted in the trench. The entire pavement is then resurfaced with 3 to 6 inches of bituminous surface or binder and surface.

This widening technique has been used for years with fairly good results. Problems often develop, however, that shorten the life of the pavement. The major problem is the development of a so-called widening crack running the length of the pavement where the new material separates slightly from the original pavement. The potential for this cracking can be lessened by cleaning and tacking the edge of the original pavement. All too often, however, the crack develops within two to three years of widening. Reflection cracking through the overlay is another common problem.

Last year a cold, in-place recycling process was used for the first time in Indiana. The technique had been used previously in Pennsylvania and a few other states. It allows widening the pavement without creating an interface between the old and new sections where cracks can occur. Recycling obliterates other longitudinal and transverse cracks, so reflection cracking does not occur. After one year in service, the recycled pavement is performing well. Indications are that the technique will completely obviate the widening crack and reflection cracks as well.

The pavement recycled here was built up of several layers of hot mix with both asphalt cements and emulsions.

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RESEARCH OBJECTIVES

A five-year research project was planned by the Indiana Department of Highways to study the cold, in-place recycling technique used on this project. Specifically, the research was designed to evaluate the efficiency of the recycling and the structural strength of the resulting pavement.

TECHNICAL APPROACH

This research compares the composite pavement with recycled base, binder and surface to the composite pavement with conventional widening and resurfacing. It was necessary to compare the composite pavements because different types and amounts of bituminous binder and surface were placed over the bases. The comparison focuses on cost and structural strength. Other factors are evaluated to ensure the quality of construction and to supplement the strength data. The tasks involved are as follows:

A. Before Construction
   1. Initial Dynaflect readings were recorded.
   2. The general condition of the existing pavement was documented.

B. During Construction
   1. In-place density was measured by nuclear gaüge. A test strip was rolled to establish the target density, according to Indiana Standard Specifications.
   2. Random samples of the recycled material were taken to assess the particle size, asphalt content, and moisture content.
   3. Observations were made of the recycling process to assist in evaluating the efficiency of the operation.

C. After Construction
   1. Dynaflect testing was conducted shortly after construction and will continue periodically for five years.

2. Roughness is evaluated annually in conjunction with the state roughness inventory.
3. Visual inspections are conducted at least annually, and focus on rutting, cracking, and other distresses.
4. Cores of the recycled pavement are taken and analyzed for density, voids, asphalt content, and Hveem stabilities.

SITE OF TESTING

State Road 38 is a rural, two-lane highway in west central Indiana. The site is shown in figure 1. This area of Indiana, like most of the state, is subject to wet, freezing conditions in the winter, with lows around −10°F. Several cycles of freezing and thawing occur during a typical Indiana winter. Hot, humid conditions prevail in the summer, with highs in the upper 90s. The roadway has already weathered one mild winter and one very hot summer.

The original roadway was composed of 7 inches of bituminous hot mix over a gravel base. The road had received surface seals, crack seals and patching, leading to some concern that the material could be quite variable. The existing pavement had an asphalt content of about 5.6 percent. Other asphalt and mix properties are shown in table 1.

The two-lane pavement was 20-ft wide. The earthen shoulders were, and still are, very narrow. The total project length was 9.76 miles. Of this length, the western half (4.88 miles) received the standard widening treatment. The eastern half was cold recycled in-place. The cross sections of the resurfaced and recycled pavements are shown in figure 2.

Traffic volumes varied slightly over the length of the contract. The western end, which was resurfaced, had a directional average daily traffic (ADT) count of 1,150 vehicles per day (vpd) over most of its length, when last counted in 1981. In the small town of Mulberry, the traffic volume increased to about 1,600 vehicles per day. The eastern, or recycled, portion had an ADT of 1,430 vpd. The traffic on the entire road is expected to increase significantly in the next few years due to construction of a large automobile manufacturing plant near Lafayette, 4 miles west of the project.

RECYCLING PROCESS

The eastern half of the project was cold recycled in-place, by a company from Philadelphia, Pennsylvania. This company has used cold, in-place recycling on about 4 million square yards of pavement in Pennsylvania, New York, and West Virginia. A Lafayette-based asphalt paving contractor was the

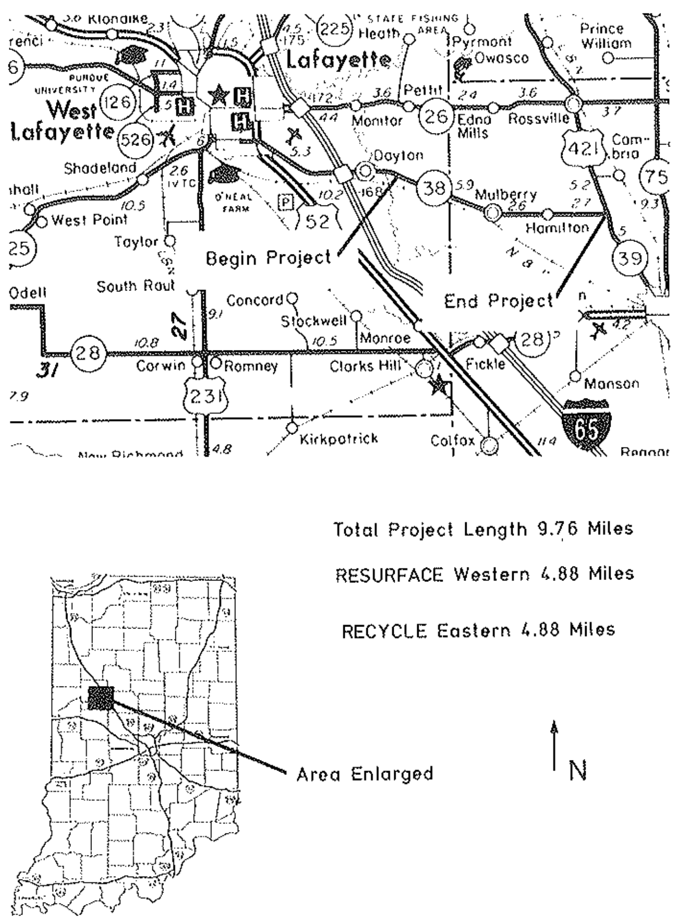

FIGURE 1 Location of test site.

TABLE 1 PROPERTIES OF RECOVERED ASPHALT

Asphalt Content	5.6%
Absolute Viscosity, 140°, 300mm Hg	11,670 poise
Asphalt Penetration, 77°, 5 sec.	36

RECOVERED AGGREGATE GRADATION

Sieve Size	Percent Passing
1"	100.0
3/4"	98.2
1/2"	85.4
3/8"	71.7
No. 4	39.1
No. 8	24.9
No. 16	18.1
No. 30	12.5
No. 50	7.8
No. 100	5.6
No. 200	4.3

prime contractor. The two companies worked together on the recycling, with the Pennsylvania company running the recycling machine and the Indiana contractor operating the grader, paver, rollers, and supply trucks.

The technique used required a minimum of equipment and material handling. The recycling train included the recycling machine, a water supply truck, an asphalt truck, and a conventional asphalt paver. Two rollers, one rubber tired and one vibratory, were used. A motor grader cut the widening trench ahead of the recycling and closed the shoulders after recycling. Two water trucks and two asphalt trucks were used to supply the recycling machine.

The primary piece of equipment was a downcutting recycling machine. This type of machine allowed the size of the milled material to be controlled by the forward speed. The milled material was mixed with water and asphalt emulsion at the cutter head. The water is used to facilitate coating. It also helped to control dust and to cool the cutter head.

A conveyor belt, attached to the recycling machine, discharged the recycled material into the hopper of a conventional paver. No windrowing was necessary. The paver was connected to the milling machine by a stiff leg to keep the two machines moving together.

The original 10-ft wide lanes were milled to a depth of 6 inches. A 1-in "cushion" was left to avoid milling into the subbase and to allow for some variation in the depth of material. The recycled material was relaid at a depth of about 5 inches to allow a finished lane width of 12 feet.

The rubber tired roller achieved most of the compaction. The vibratory roller followed to iron out the surface.

CONSTRUCTION OBSERVATIONS

This construction technique was totally new to the local paving crew, but they were able to adjust to it quickly. By the second day of recycling, they had learned to work with the recycling machine and the material it produced. The processed material was very sticky and hard to work by hand. There were no problems with rolling the recycled mix.

Recycling progressed at about 17 or 18 feet per minute after the start-up problems were solved. This is equivalent to placing about 375 to 400 tons per hour. Most downtime experienced during recycling was due to paver malfunctions. Efficiency varied from 68 to 93 percent.

The technique proved to be simple and efficient. The few problems experienced during this first attempt could be easily corrected. Better planning and more local experience should result in higher efficiency and production.

The recycled pavement was left exposed for seven weeks after recycling was completed, due to a series of delays. It is generally recommended to let this cold-recycled material cure for about two weeks before surfacing. A few soft spots showed up on this project before the binder was placed. The weak areas were believed to be caused by traffic action over localized areas of poor subgrade. All the soft spots were in the outer wheelpath near the shoulder, in the widened portion. This area had never been under traffic, and the trench had not been rolled when it was cut. The subgrade material, then, had never received much compaction. Traffic action plus heavy rains had brought the poor subgrade conditions to light.

The soft areas were cut out and patched with hot mix.

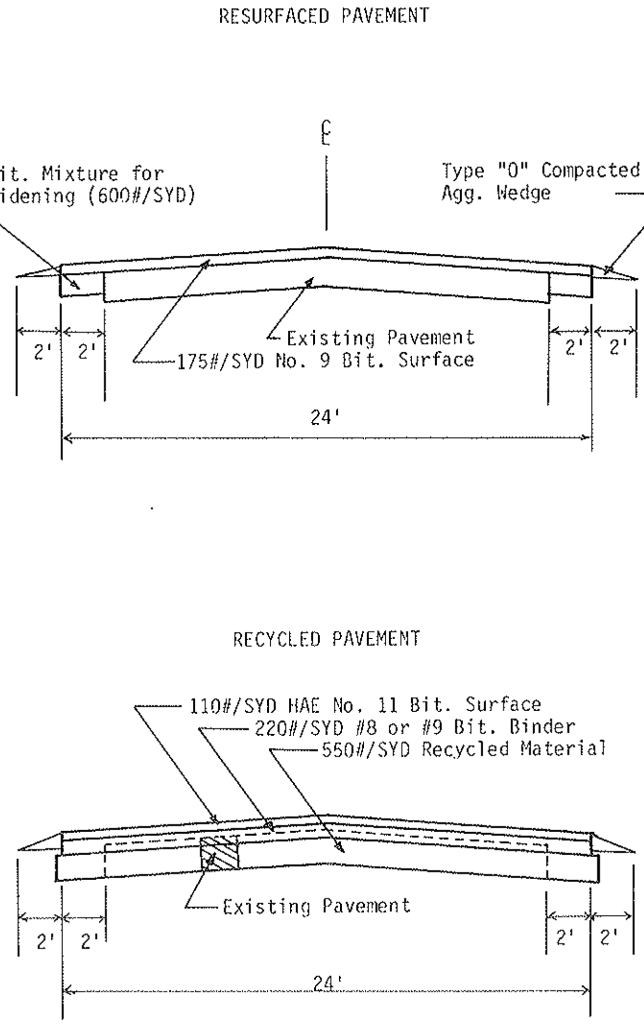

FIGURE 2 Typical cross sections.

Altogether, less than 1 ton of patching material was used. The patching evidently served its purpose; no further problems have developed to date.

RESULTS OF MATERIALS AND PERFORMANCE TESTING

Routine Construction Tests

Samples of the recycled material were taken randomly during construction and analyzed for asphalt content, moisture content, and aggregate gradation. Results of these tests are summarized in table 2. The gradation of the recycled material was finer than Indiana's dense-graded No. 5D Base. Specification limits for No. 5D Base are shown in table 2 for comparison. The recycled material was less variable than expected.

Approximately 2.5 percent asphalt emulsion was added during recycling. The emulsion used was AE-150, a medium-setting emulsion with about 69 percent residual asphalt and 4 to 4.5 percent kerosene. The specifications used in Indiana for AE-150 are listed in table 3. The amount of emulsion added was essentially determined and adjusted based on field experience. Very limited laboratory work was done before construction. The final asphalt content averaged 7.4 percent.

Density was monitored during construction with a nuclear gauge. A control strip was run at the beginning of recycling to establish a target density. Indiana's test strip method involves monitoring the increase in density with successive passes of a standard roller train until the density peaks. The target density is then set at the mean density of the test strip. The density of the recycled material had not peaked after 24 passes during the test strip rolling. Tiny cracks began to develop, which indicated the material was being over-compacted so rolling was terminated. The ambient temperature increased by 20° during the test strip rolling, which may help explain why the density did not peak.

The densities achieved during construction averaged 124.4 pounds per cubic foot ($s = 3.71$). A total of 220 tests were taken on the recycled material. No rutting or other distress, with the exception of those areas with a soft subgrade, occurred before the binder was placed, indicating the compaction was adequate.

After one year in service the recycled base is performing well. The results of various evaluations are as follows.

TABLE 2 RESULTS OF ROUTINE CONSTRUCTION TESTING

	Average	Standard Deviation
Asphalt Content	7.4%	0.45
Moisture Content	4.4%	0.88

Sieve Size	Aggregate Gradation RAP	No. 5D Base
1 1/2"	100.0%	100%
1"	100.0%	80-99%
3/4"	98.3%	68-90%
1/2"	87.5%	54-76%
3/8"	75.8%	45-67%
No. 4	48.1%	35-45%
No. 8	32.0%	20-45%
No. 16	22.3%	12-36%
No. 30	15.0%	7-28%
No. 50	8.8%	3-18%
No. 100	5.7%	1-12%
No. 200	4.2%	0-6%

TABLE 3 SPECIFICATIONS FOR AE-150 ASPHALT EMULSION

Furol Viscosity, 77°F, Min.	50 seconds
Residue from Residue by Distillation	68%
Oil Portion, from Residue by Distillation, ml. oil per 100 g. emulsion, Max.	7.0 ml.
Sieve Test, Max.	0.10%
Tests on Residue from Residue by Distillation	
Float Test at 140°F, Min.	1,200 seconds
Penetration, 77°F, 50 g, 5 sec.	100-300
Solubility in Organic Solvents, %, Min.	97.5%

Visual Inspections

After one unusually mild winter, a visual inspection of the conventionally resurfaced section revealed a few transverse reflection cracks and some faint, hairline cracking along the widening. This cracking will undoubtedly increase after a more typical Indiana winter. Within two or three years, it is expected that the widening cracks will be significant.

The recycled section, however, is virtually crack-free. There is no reflection cracking because all the existing cracks were obliterated during the recycling process. There is no widening crack because there is no interface between old and new mate-

TABLE 4 ROUGHNESS SUMMARY

	1986	1987
Conventional Pavement		
Eastbound	940	836
Westbound	846	869
Average	893	852
Recycled Pavement		
Eastbound	777	751
Westbound	652	688
Average	714	720

rial. An extremely hot summer has passed and no rutting is apparent in the recycled section. In short, there are no problems to date.

Roughness Data

The initial roughness was evaluated with the Cox Roadmeter in December 1986. Roughness measurements were performed again in July 1987. These results are summarized in table 4. Roughness measurements are included in this study mainly to monitor deterioration of the two pavements over time. The smoothness cannot be directly compared because the pavements include different surface materials and numbers of courses.

The readings indicate that the pavement with recycled base was initially smoother than the resurfaced pavement. One layer of hot asphaltic mixture was placed over the resurfaced pavement and two were placed over the recycled pavement, which helped level out the recycled section.

The follow-up testing in 1987 again showed the recycled pavement to be somewhat smoother than the resurfaced pavement. Neither pavement showed an increase in roughness. The roughness numbers measured in 1987 are not significantly different from those measured in 1986.

Dynaflect Deflections

Results of Dynaflect testing are shown in figures 3 and 4 and are summarized in table 5. Deflections measured before construction were essentially the same on the two portions of the project. The amount of variation in deflections, as indicated by the standard deviations and coefficients of variation, is also essentially the same.

After construction, the deflections were reduced by approximately half. The deflections measured on the recycled pavement were slightly lower than on the conventional resurface. The coefficients of variation show that the amount of variability is roughly the same as before construction.

Dynaflect measurements were made again in June of 1987. These results are not directly comparable to the previous tests because of the seasonal variation in deflection measurements on bituminous pavements. Nevertheless, the readings indicate that, even in the heat of summer, the pavement is now stronger than before construction. Again, there is no significant difference between the two pavement types.

Analysis of Cores

Cores of the recycled pavement were taken in July 1987 after the pavement had been in place for about one year. These cores were analyzed for density, voids, and Hveem R and S values. Cores will be taken annually to evaluate any further densification under traffic. The results of the 1987 analysis of cores are shown in table 6.

Intact cores of the recycled material were very difficult to take. The cores obtained were fragmented. An unsuccessful attempt was made to core without water to allow determination of the in situ moisture content of the recycled base.

PROJECT COSTS

Past experience has shown that a new technique or material is usually more expensive the first few times it is used than when it is more widely used. This is due, in part, to contractors becoming accustomed to the process and the problems they may encounter. Also, competition increases as more contractors obtain the necessary equipment and develop the expertise.

In the case of this new recycling technique, the cost for the recycled pavement was almost double the cost of the conventional pavement. The cost breakdown was as shown in table 7. If this recycling method is used more often in Indiana, the costs are expected to drop somewhat.

Since indications are that the recycled pavement will have significantly less cracking than the conventional pavement, at least initially, the maintenance costs will be reduced. Life-cycle costs for the recycled pavement may then be lower than for the conventional pavement, depending on the relative service lives of the two pavements. The continued evaluation of this project should help estimate the service lives of the pavements.

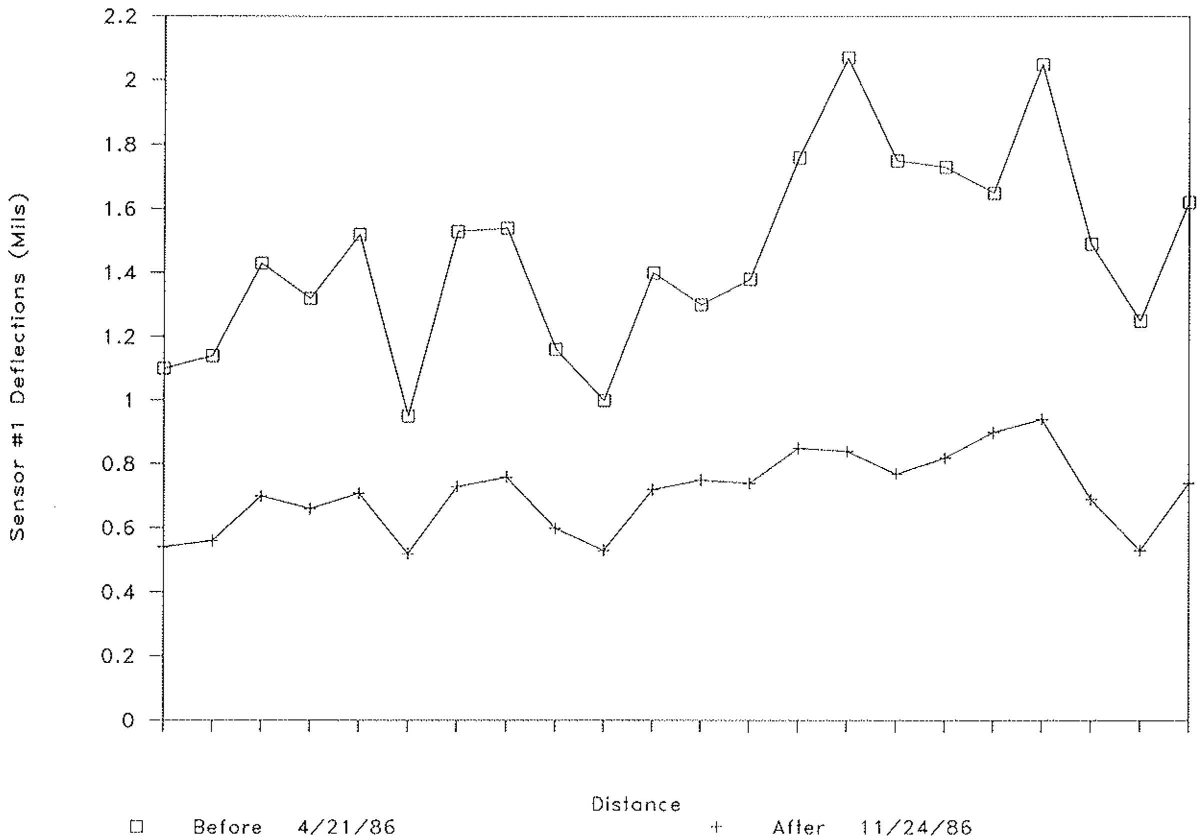

FIGURE 3 Dynaflect deflections, recycled section.

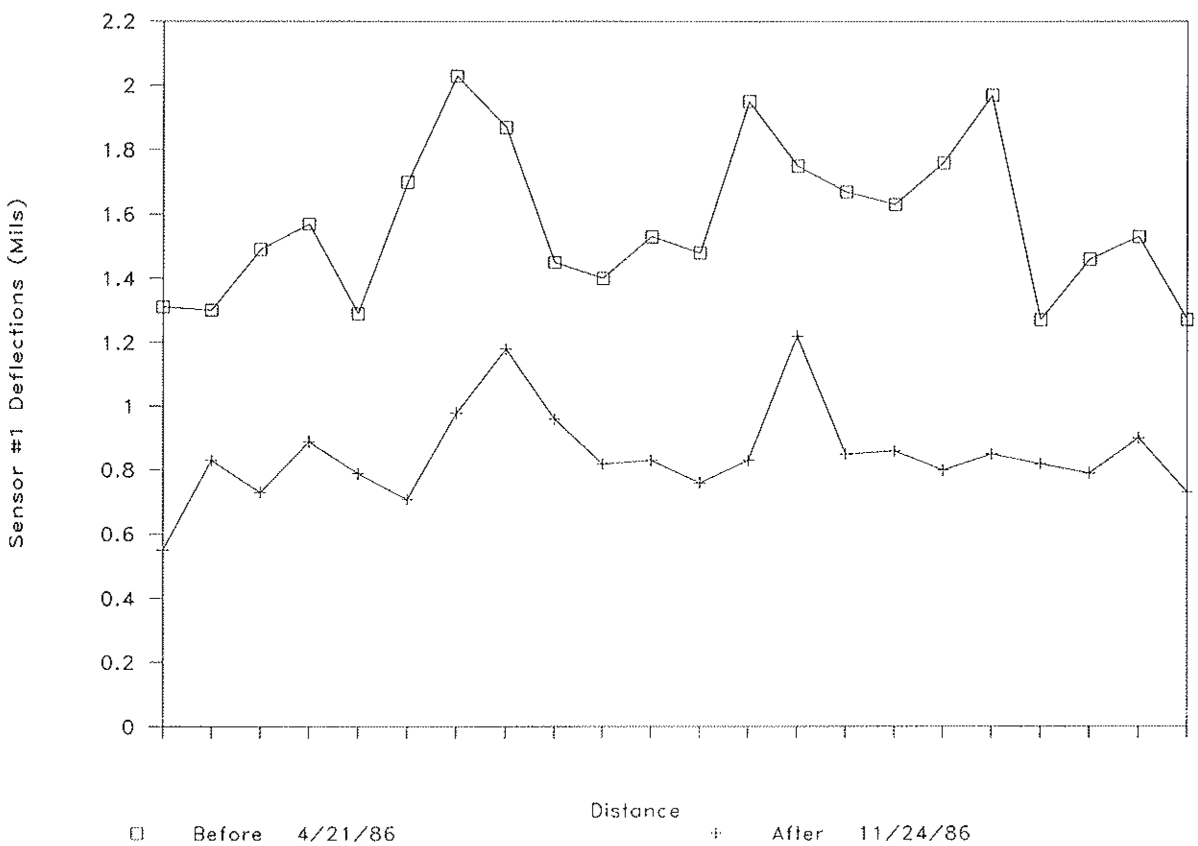

FIGURE 4 Dynaflect deflections, resurfaced section.

TABLE 5 DYNAFLECT DEFLECTIONS SUMMARY

	Before Construction	After Construction	
	4-86	11-86	6-87
Resurfaced Eastbound			
Average Sensor No. 1 (mils)	1.44	0.79	1.10
Standard Deviation (mils)	0.37	0.18	0.25
Coefficient of Variation (%)	25.7	22.8	22.7
Resurfaced Westbound			
Average Sensor No. 1 (mils)	1.52	0.84	1.24
Standard Deviation (mils)	0.42	0.20	0.34
Coefficient of Variation (%)	27.6	23.8	27.4
Recycled Eastbound			
Average Sensor No. 1 (mils)	1.50	0.73	1.24
Standard Deviation (mils)	0.38	0.18	0.36
Coefficient of Variation (%)	25.3	24.6	29.0
Recycled Westbound			
Average Sensor No. 1 (mils)	1.46	0.71	1.20
Standard Deviation (mils)	0.40	0.16	0.30
Coefficient of Variation (%)	27.4	22.5	25.0

TABLE 6 RESULTS OF ANALYSIS OF CORES

	Average	Standard Deviation
Density, pcf	141.5 pcf	3.1
Air Voids, %	5.0%	2.1
Hveem Stabilities		
S-value (140°)	25	--[1]
R-value (70°)	91[2]	--[1]

[1]Based on small sample size due to difficulties in getting samples of sufficient thickness for Hveem testing.

[2]Uncorrected for height of specimen.

CONCLUSIONS

After one year in service, the pavement with recycled base seems to be performing at least as well as the conventional pavement.

- The pavement with recycled base has less cracking than the conventional pavement. The deflections are essentially the same for the two types of pavements.
- Steps can be taken to improve the performance of the recycled pavement. When a widening trench is cut, as in this application, the trench should be rolled as specified for other widening. The length of time the recycled base is left without a surface should be limited to two weeks. This allows time for the base to cure, but limits the length of time the pavement is left open to traffic and weather.
- The efficiency of the recycling could be increased. The capacity of the water trucks should be similar to avoid delays.

TABLE 7 PROJECT COSTS

	Quantity	Unit Price	Total Cost
Resurfaced Section			
Widening(and Trenching)	3663 Tons	$23.00	$84,249.00
HAE No. 9 Surface	6118 Tons	$23.25	$142,243.50
Patching	52 Tons	$70.00	$3,640.00
Wedge and Level	796 Tons	$23.00	$18,308.00
Total			$248,440.50
	Cost per Lane Mile	$25,454.97	
Recycled Section			
Patching	1 Tons	$70.00	$70.00
Milling	57,300 SYD	$2.20	$126,060.00
Trenching	51,533 LFT	$0.20	$10,306.60
AE-150	460 Tons	$150.00	$69,000.00
Bit. Binder	7,560 Tons	$21.00	$158,760.00
HAE #11 Surface	3,780 Tons	$24.00	$90,720.00
Total			$454,916.60
	Cost per Lane Mile	$46,610.31	

Obviously, keeping the paver and other equipment in good repair would reduce down time.

- Further evaluation is necessary to determine the long-term performance and to estimate the service life of the recycled base, but at this point the recycled material is performing well.
- The recycled pavement cost nearly twice as much as the conventional pavement, but costs would likely drop if the process were used more. In this case, one more course of bituminous mix was placed over the recycled base, significantly increasing the cost over that of the resurfaced section. Life cycle costs for the recycled pavement may be lower than for the conventional pavement if the service life is comparable, due to reduced maintenance costs.

RECOMMENDATIONS

The experience with this recycling technique in Indiana has been very favorable so far. There is great interest in using the technique on more projects. Future uses may include the following:

- The use of more exotic binders, such as foamed asphalt, rejuvenators, polymer modifiers, etc.
- Improving granular bases or gravel roads; this may be especially attractive for county highway departments.
- Adding virgin aggregate, if needed, by spreading it on the roadway ahead of the recycling machine.
- Surfacing the recycled base with a double chip seal instead of a hot mix surface; again this may be especially useful on low-volume roads, such as county roads.

Further evaluation may show that this type of base can be used on roadways with higher traffic volumes. The increase in traffic volume due to the auto plant will be monitored on State Road 38. Until further evaluation shows that this type of base can withstand higher traffic volumes, it will only be used in low or moderate traffic volume situations in Indiana (under 2,500 directional ADT).

This cold, in-place recycling technique appears to be a viable way to rehabilitate old bituminous pavements and to prevent reflective cracking. Its use for widening bituminous pavements, as in this case, seems especially appropriate.

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