starting point in the field, subject to necessary adjustments by persons experienced in cold recycling.

First, the coating of the recycled mix is examined after the surface dries. If the coating is not satisfactory (less than 75 percent), the moisture content is adjusted before the emulsion content. If the mix lacks cohesion in spite of an adequate coating, the emulsion content is increased. A crude test for evaluating cohesion has been used. A ball of the recycled mix is made by squeezing it in the palm of one's hand. If the ball falls apart (friable) after the pressure is released, the mix lacks cohesion. The palm of one's hand should also be examined for stains. If specks of bitumen are present, the emulsion content is generally adequate. A palm that is almost completely stained by bitumen indicates an excessive emulsion content.

The Recycling of Cold-Mix, In-Place Asphalt for Low-Volume Roads in Ohio

S. W. DUDLEY, K. MAJIDZADEH, AND K. KALOUSH

A discussion is presented of a study that was initiated in 1984 to develop specification guidelines and mix design recommendations and to obtain long-term performance data on cold-mix recycling for low-volume roads in Ohio. Future investment planning motivated the Ohio Department of Transportation to consider cold-mix recycling of low-volume roads as a maintenance alternative. Two mainline low-volume roads were selected for this study. The documentation and evaluation of the project are discussed in two parts. The first part includes the site selection criteria, preconstruction evaluation, mix designs, construction specifications, and construction monitoring. The second part includes a discussion of the performance evaluation through field inspection, data collection, and laboratory evaluation of material properties.

Maintenance of low-volume roads usually consists of patching, application of seal coats, and, in some situations, thin asphalt overlays. In most cases these maintenance procedures are only temporary and offer no corrective solution to the structural adequacy of the pavement.

In recent years, pavement recycling technology has attracted significant national attention and has become an attractive rehabilitation alternative. Cold-mix recycling in particular is an attractive option to conserve materials and energy by salvaging old pavements as stabilized bases with improved drainage, alignment, and grade.

Cold recycling can be performed either in a central plant or on-site. High production rates can be obtained from central plant recycling; mixes that contain up to 100 percent reclaimed pavement material can be produced. In-place recycling, however, is more appropriate for low-volume roads because the recycling can be done on site.

Similar equipment is used for in-place recycling as for in-place stabilization operations. In fact, the cold-mix, in-place recycling of bituminous pavement layers can be combined with the stabilization of the underlying unbound layers. The equipment that is typically used for in-place, cold-mix recycling consists of rollers, bulldozers, scarifiers, planers, milling machines, rotary mixers, motor graders, windrow devices, power brooms, self-propelled vibratory or steel-tired tandem and pneumatic-tired rollers, water distributors, and other equipment.

The only additional requirement over soil stabilization equipment is the extra power or wear resistance needed to properly size the existing bituminous pavement layers. The recent development in pulverizers, traveling hammer mills, and cold milling machines has had a significant influence on existing construction techniques and the establishment of this process as a viable option.

BINDER REQUIREMENT

Asphalt cement and emulsions have been used in cold-mix recycling since the early 1940s. Conventional equipment was used to crush old bituminous surfacings and combine the pulverized material with part of the unstabilized base or new aggregate to form reconstituted pavements.

Several binders are currently used to upgrade or stabilize existing pavements. Bituminous binders are best suited to well-graded blends of material and offer considerable benefits because of their versatility, the achievable particle bond, the

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resulting flexible strength, and the reduction in permeability. Moreover, the existing hard and brittle binders can be modified by special bituminous additives and incorporated in the production of new mixtures that perform satisfactorily. Emulsions often are the best choice because of the inherent moisture content of the treated material. Both medium-setting and slow-setting emulsion types can be used.

One of the requirements to develop a well-designed, cold-mix material is to add binder to soften the mixture and add stability and strength. The most common binders for cold-mix recycling are generally medium-curing cutbacks of the grade MC800, cement, and water. Soft or high penetration asphalts that range between 200 to 300 penetration have also been used and, in many instances, slow- or medium-setting asphalt emulsions such as CMS have been used.

MIXTURE CHARACTERISTICS

It should be emphasized that one of the justifications for the use of cold-mix recycling is the savings in energy that results from the elimination of heat from the bituminous mixing process.

The major problem to be expected in the cold-mix recycling process is mixture compaction, which stems from the lack of application of heat to the mix. It is difficult to mix the crushed aggregate, crushed pavement, binder, softening agents, and old asphalt. In order to enhance the initial mixing process, it is customary to add more water to facilitate the coating of the aggregate and asphalt binder. The poor mixing characteristics of binder and aggregates could also result in asphalt bleeding to the surface of the pavement. Cold-mixed recycling mixtures are obviously susceptible to other distress modes such as rutting, raveling, fatigue, and other failures directly associated with the strength and environmental conditions of bituminous mixtures.

MIXTURE CHARACTERIZATION

Laboratory Procedures

Mixing and coating, which are affected by construction methods as well as the mixture design, greatly influence the performance of the recycled pavements. Therefore, laboratory analyses need to be correlated with field experience to be significant. The density of the compacted mix and the percentage of absorption and the resistance to water damage are important tests. The mixture variables in cold-mix recycling are binder content, moisture content, curing time, aggregate characteristics, compaction method, and binder consistency.

No universally accepted method currently exists for curing, mix design, and sample preparation for cold-mix recycling. Specimen preparation procedures in this study followed the Purdue University and the Asphalt Institute methods, with some modifications (*1*, *2*). The following is a summary of the sample preparation and testing methods that were used:

- The reclaimed material was divided into individual samples.
- The designated amount of water was added and the materials were mixed with a spoon by hand.
- The mix was left alone for 10 to 15 min.
- The required amount of rejuvenator was added and the material was mixed both mechanically and by hand. The total mixing time was 2 min, which included a 30-sec period of hand mixing in between periods of mechanical mixing.
- The mix was cured for 1 hr in a forced-draft oven at 140°F and was then remixed for 30 sec with a mechanical mixer before it was compacted.
- The mix was then compacted into Marshall specimens using 50 blows per face.
- The samples were extruded within a reasonable period of time (24 hrs).
- The specimens were left to cure for 48 hrs before they were tested.
- Marshall testing procedures for cold mixes, as specified in AASHTO T245, were adopted.

WITCO Mix Design Procedure

The WITCO mix design method was also used to determine the asphalt demand for the recycled mixture and the type of rejuvenator to be used. According to this method, the following are the four basic properties of the existing pavement to be recycled:

- Asphalt content,
- Asphalt penetration at 25°C or viscosity at 60°C,
- Aggregate gradation, and
- Asphalt demand as determined by the following formula.

$$P = (4R + 7S + 12F)/100 \times 1.1$$

where

P = weight percentage of asphalt in the mix,
R = weight percentage of rock in the aggregate (portion retained on No. 8 sieve),
S = weight percentage of sand in the aggregate (portion passing No. 8 and retained on No. 200 sieve), and
F = weight percentage of fines in the aggregate (portion passing No. 200 sieve).

A nomograph is then used to estimate the amount of recycling agent needed to modify the viscosity of the old asphalt. This is followed by a laboratory mix design using the Marshall method to ensure that minimum requirements are met.

SITE SELECTION AND PRECONSTRUCTION INVESTIGATION

Two low-volume roads were selected for this study. The two projects are State Routes (SRs) 761 and 564, which are located in Noble County, Ohio. State Route 761 was built in 1968 as a full-depth asphalt pavement on a soil subgrade. State Route 564 was a soil-aggregate road that was upgraded with chip-seal treatments. Maps of the projects' locations are shown in Figure 1. The beginning and ending log miles of each project are shown in the following table.

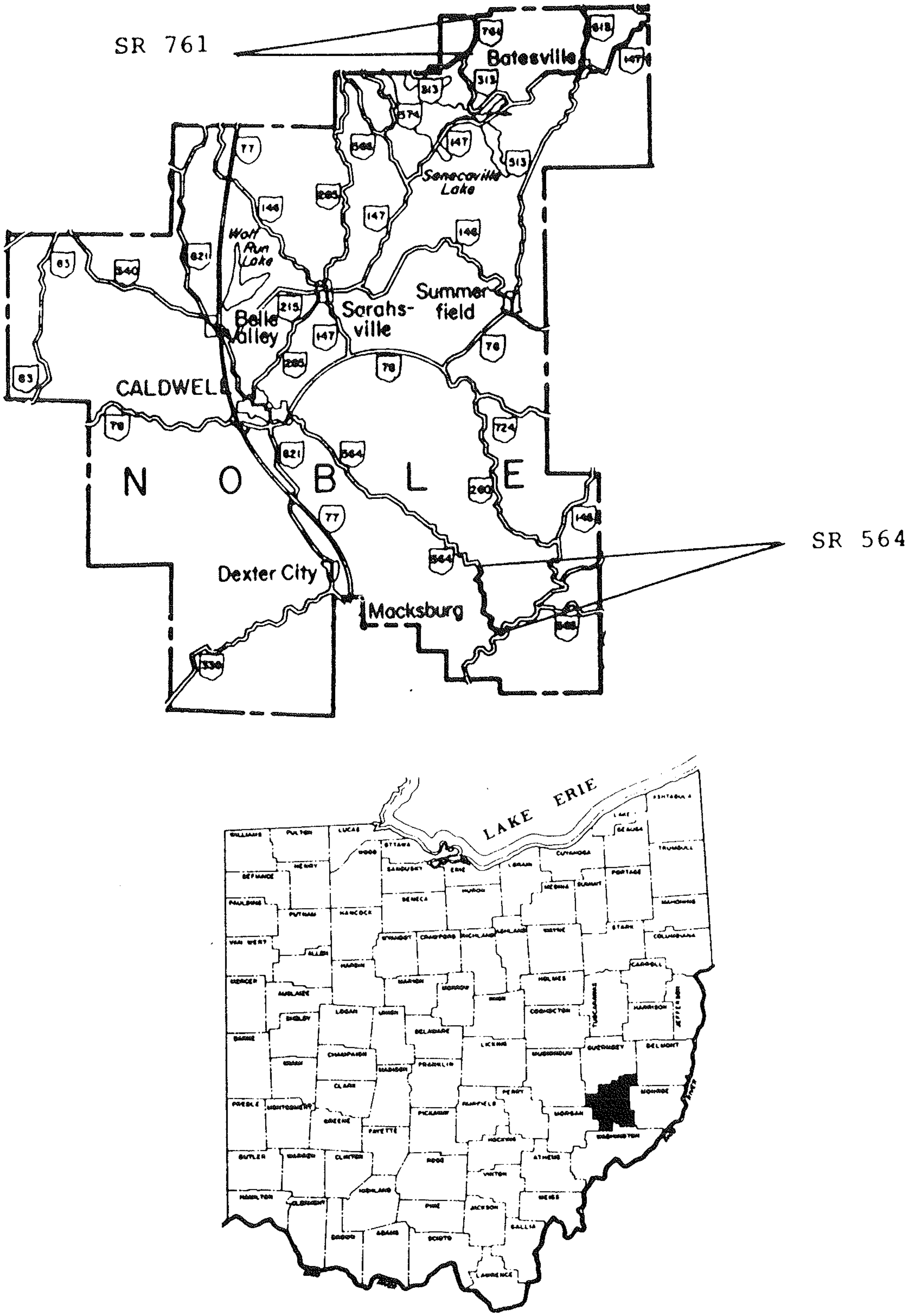

FIGURE 1 Project locations.

	Beginning and Ending Log Points	*Net Length (mi)*
SR 564	10.63-11.98	1.35
	13.05-13.70	0.65
SR 761	0.00-1.90	1.90

State Routes 564 and 761 were visited by Ohio Department of Transportation (ODOT) and Resource International, Inc. engineers on November 15, 1984. The purpose of this visit was to identify the problems in each project and verify that these projects were candidates for recycling. State Route 564 was in poor condition. Severe potholes and raveling were evident in many locations. The beginning and the ending sections of the 3-mi road were in better condition and suffered from moderate cracking and raveling. The middle 1-mi section of the road (excluded in the previous table) was reconstructed by the Department of Natural Resources in 1983. The reconstruction consisted of 6 in of aggregate base (ODOT Specification 304), 6 in of bituminous aggregate base (ODOT Specification 301), and 3 in of asphalt concrete leveling and surface courses (ODOT Specifications 403 and 404). The candidate section for recycling of SR 564 is in a high water region that had experienced occasional flooding during the last 2 years. Routine maintenance work included patching and application of tar.

State Route 761 was rated to be in poor condition. Debonding was identified in the pavement layer and severe transverse cracking was identified along the pavement length. In addition, moderate longitudinal cracks, rutting, and poor drainage were occasionally noted. It was concluded that both projects were in poor condition and were candidates for rehabilitation.

Laboratory Evaluation of Pavement Cores

Nine pavement cores with soil samples were extracted at random from SR 564 for further laboratory investigation. Three cores failed when they were removed from the core barrel. Three more fell apart when they were cut in preparation for testing. It was noted that mud layers formed between the asphalt in some cores. The thickness of the cores varied from 5 to 7 in. The asphalt content averaged 3.3 percent and the viscosity was 64 poises, according to AASHTO T202. Additional test results detected the presence of chemicals such as aliphatic oil. The Marshall stability was low and averaged 395 lbs at 77°F. These data are summarized in Table 1.

Five cores were also extracted from SR 761 for laboratory evaluation. These cores were smoothly divided into two parts that represented the debonded surface and the leveling courses. The total thickness of the pavement averaged 6 in. The asphalt content was 5.3 percent and the viscosity was 12,500 poises. These data are summarized in Table 1.

Soil classification data for both projects are presented in Table 2. The soil of SR 564 was classified as A-2-4 and the soil of SR 761 as A-6, according to AASHO classifications.

MIX DESIGN ANALYSIS AND DEVELOPMENT OF CONSTRUCTION SPECIFICATIONS

In accordance with the mix design procedures discussed previously, mix design analyses were performed on in situ materials. The aggregate gradation of SR 564 complied with specifications; therefore, no additional aggregates were necessary. Because of the low asphalt content and viscosity, it was decided to use a CSS-1H asphalt emulsion, and a cationic slow-setting emulsion with a harder base asphalt (ASTM D977-77 standard specification) as a recycling agent (*3*). Laboratory trial mixes were performed and included recompacted samples with water and mixes with the emulsified asphalt added at different percentages. Two criteria were used to optimize the mixture: Marshall stability and indirect tensile strength. The test results of these trial mixes are shown in Table 3.

Trial mixes with SS-1 emulsified asphalt, a softer asphalt base, and Cyclogen M were designed for SR 761. Analysis indicated that virgin aggregates were needed to control the total asphalt content in the recycled mix if SS-1 was to be used. The mix design analysis for Cyclogen M indicated a blending ratio of 24 percent of the rejuvenator with the aged asphalt (1.2 percent by total weight of mixture). These results are summarized in Table 4.

A thickness design analysis using the Asphalt Institute procedure for cold-mix recycling indicated that the minimum required thickness for SR 564 was 4 in with a 2-in, hot-mix surface course (*2*). This was based on a CBR value of 15 and two 18-kip equivalent axle loads per day. The minimum required thickness for SR 761 was 4.5 in with a 2-in, hot-mix surface course based on a CBR of 3 and one 18-kip equivalent axle load per day.

In summary, based on field and laboratory evaluation, it was decided to recycle the top 6 in of SR 564 with CSS-1H at 6.8 percent by total weight. The recycled base would be overlayed by a 3-in bituminous aggregate base and 1 in of an asphalt concrete surface course. It was believed that the emulsion would act as a binder and not as an agent to restore the existing asphalt properties.

It was also decided to recycle the top 4 in of SR 761 with Cyclogen M and overlay it with 1-1/2 in of an asphalt concrete leveling course, and 1-1/2 in of an asphalt concrete surface

TABLE 1 LABORATORY EVALUATION OF THE EXISTING PAVEMENT

	SR 564	SR 761	
Thickness, in	5-7	6	
AC content, percent	3.3	5.3	
Viscosity, poises	64	12,500	
Density, pcf	132	136-139	
Stability at 77°F	395	1,151-2,166	
Flow, 01 in	13	14-12	
Gradation % passing	SR 564	SR 761	Bituminous aggregate Base specification
1 in	97.4	100	75-100
3/8 in	68.3	66.2	-
No. 4	42.3	44.1	25-60
No. 8	26.0	36.3	15-45
No. 16	16.7	29.9	10-35
No. 30	10.7	20.6	
No. 50	6.4	8.1	3-18
No. 100	3.7	2.9	-
No. 200	1.9	1.7	1-7

TABLE 2 SOIL DATA

Test Results	SR 564	SR 761
Water content, percent	8.4	20.7
Unit wt., lb/ft	143.8	100.6
Percent fines, #200	3.4	67.3
Liquid limit	39	39
Plastic limit	20	27
Plasticity index	9	12
AASHO soil classification	A-2-4	A-6

course. The installation of shallow pipe underdrains was also recommended because of the poor existing drainage. Specifications and plans were developed and are available from the Ohio Department of Transportation or Resource International, Inc.

PERFORMANCE MONITORING

Construction Techniques

Construction started on September 9, 1985, and continued through that month. The existing pavement was milled and processed with a CMI Rotomill, which is a two-engine milling machine with a 12-ft-wide cutter head. The machine had the capability to mill the old surface at a variable depth up to 7 in. The material was crushed and screened through a 1-in sieve on the first trailer. Millings that did not pass the 1-in sieve were crushed again. The millings that passed the 1-in sieve were mixed with the emulsion at the second trailer. A tanker truck that preceded the CMI supplied the emulsion to a meter at which the number of gallons distributed were monitored. The mixture was then windrowed and aerated before it was spread and shaped by a grader. The material was then compacted with a vibratory roller.

The existing pavement on SR 564 was believed to be 6 in deep. During the milling process, the thickness of the pavement varied between 2 and 7 in. The depth control was easily adjusted, but in some sections the subgrade materials could not be avoided. Virgin aggregates were applied at those sections to increase the base thickness. The CSS-1H emulsion was applied at 5 gal/yd^2. In some instances, the distributor meter malfunctioned and the millings were saturated with the emulsion. This created soft sections in the road. The process was performed in two passes and because the pavement width was only 20 ft, a 2-ft section was overlapped in the second pass.

About ten 300-ft, full-depth patches were constructed with pipe underdrains on SR 761. The subgrade was so soft that the construction equipment could not proceed. Other sections in the road deteriorated badly. During the milling operations, the remaining 2 in of pavement did not support the CMI as well as expected. Cyclogen ME (emulsified Cyclogen M) was distributed and mixed with the pavement material at 1.5 gal/yd^2. In comparison with SR 564, the mixture was noticeably softer. The recycling agent was sprayed over the compacted pavement as an additional seal.

Traffic was allowed to return to the recycled pavement for at least 7 and up to 12 days, during which time some occasional rain was experienced. The surface was then swept and given a tack coat. It was noticed that some soft areas had failed and there were wheel track depressions in both pavements. Four inches of hot mix were applied on SR 564 and 3 in on SR 761.

Material Properties of SR 564

Fifty-two cores were extracted along the length of the project on November 11, 1985. All extracted cores were 4 in. in diameter and extended through both the overlay and the recycled layer. Some difficulty was encountered when drilling through the recycled layer at sections that were earlier identified as having soft pavement material. However, representative cores from those sections were extracted successfully. The cores were cut and measured for thickness and unit weight. Measurements indicated that the overlay thickness was an average of 4.2 in and the recycled layer thickness ranged from 1.7 to 6.0 in with an average value of 3.5 in. The asphalt content averaged 10.2

TABLE 3 TEST RESULTS OF MIX DESIGN TRIALS FOR SR 564

Percent CCS-1H	Unit, wt. pcf	Stability 140° F	Stability 77° F	Tensile Strength, PSI
0	142.9	-	-	13
4.3	137.3	-	-	74
5.2	134.0	528	3524	-
6.8	135.5	427	4841	61
8.3	134	454	3015	85

TABLE 4 TEST RESULTS OF MIX DESIGN TRIALS FOR SR 761

AC	Percent Virgin Aggregates	Unit Wt. pcf	Stability at 140/77° F	Tensile Strength
Percent SS-1				
5.8	40	123.4	50/2025	21
6.3	30	121.9	114/1995	25
7.8	0	125.6	108/2226	54
Percent Cyclogen M				
1.2	0	133.1	210/3444	32

percent with a standard deviation of 3.2 percent. The average gradation is shown in Figure 2. The CSS1-H emulsion samples that were collected during construction had a Saybol viscosity of 35 S (77° F) and met the specification requirements (20 to 100 S).

A laboratory testing program was undertaken to evaluate the recycled pavement cores. Tests were conducted and the results are shown in Table 5. In addition, 40 samples were fabricated using the same materials and proportions that were used in the field mix. The laboratory samples were subjected to the same testing program and the results are also shown in Table 5.

The coefficients of variation indicate that there is scattering in some of the test data for both field and laboratory samples. Variations in gradation and asphalt content from sample to sample is typical for cold mixes. In addition, exact weight by sample splitting is not feasible because milled materials are tested and aggregates are not. Therefore, differences in weight and height from sample to sample are inevitable.

The modulus of resilience and indirect tensile strength values for both laboratory and field samples of SR 564 were generally good. Lottman's accelerated moisture damage test was used to determine the durability of the recycled pavement to freezing and thawing. The resilient modulus and the tensile strength for field cores were reduced by 41 and 46 percent, respectively, when subjected to freeze and thaw cycles. These values can be compared to 59 and 42 percent, respectively, for specimens fabricated in the laboratory. Although no minimum value criteria were agreed on for fracture toughness and stability, the results of these tests are considered satisfactory for base courses.

An immersion-tension test was performed to simulate the effect of water (140° F) on the tensile strength of the compacted mixtures. Test results were satisfactory and showed a 24 and 35 percent reduction in strength for field and laboratory samples, respectively.

Material Properties of SR 761

Two attempts were made to extract cores from this project on November 14 and December 17, 1985. Neither attempt was successful in obtaining intact cores. The cores crumbled when they were removed from the core barrel. It was noted that only the top 0.5 to 1 in of the recycled layer was intact. The remaining 3 in failed. It was suspected that the excess moisture in the rejuvenator did not have enough time to escape and adequate stability values were not reached before the overlay was applied. Cyclogen ME samples that were collected during construction were tested for Saybol viscosity at 77° F. The average viscosity value was 11.7 S and did not meet the minimum requirement of 15S. This could have been another indication that excess moisture was mixed with the rejuvenator.

Forty laboratory samples were also fabricated with the same materials and proportions that were used in the field mix for SR

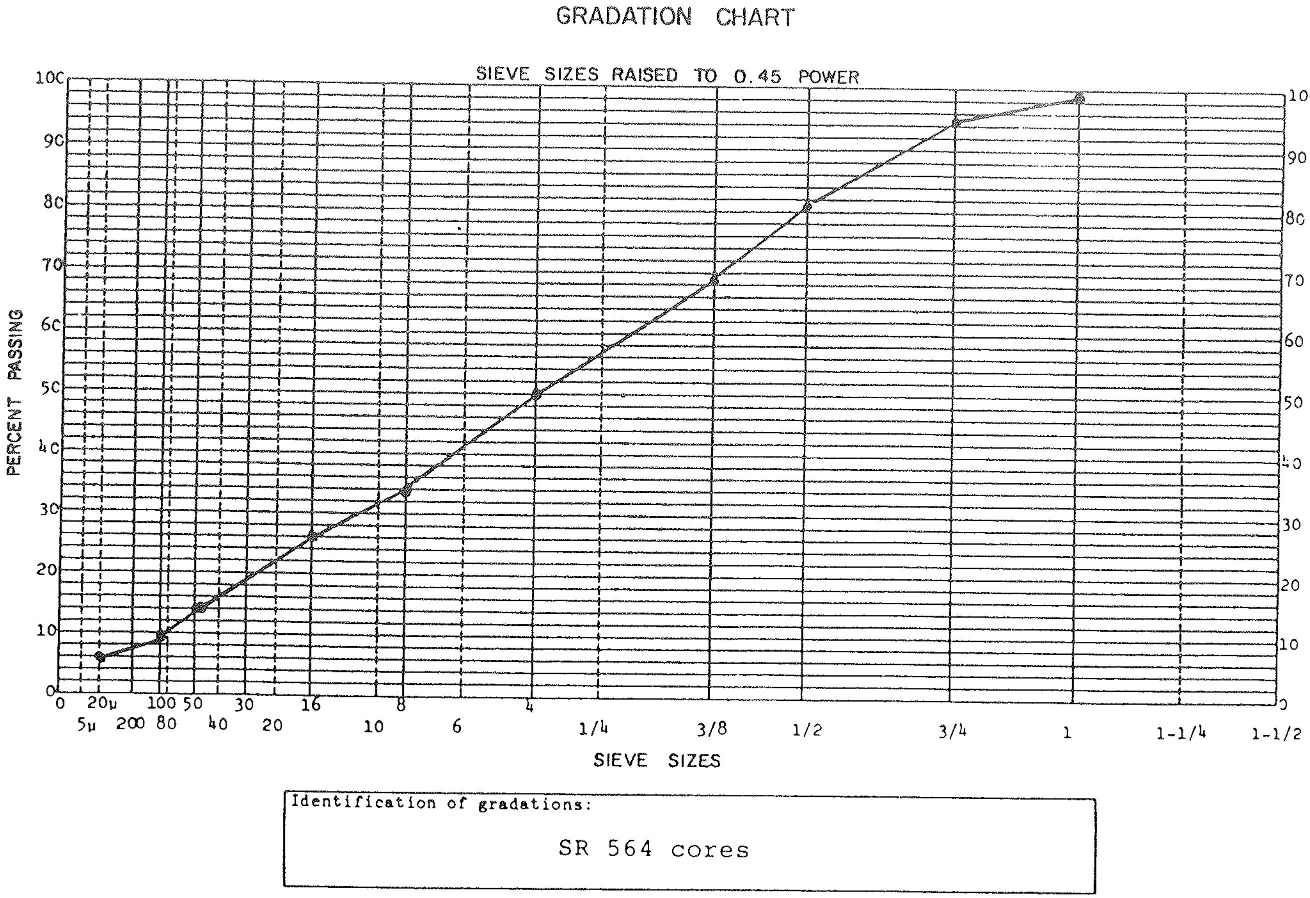

FIGURE 2 Percentage passing various sieve sizes for SR 564.

TABLE 5 PHYSICAL AND ENGINEERING PROPERTIES OF LABORATORY AND FIELD CORES

	LABORATORY SAMPLES SR 564				FIELD CORES SR 564				LABORATORY SAMPLES SR 761			
TEST	n	$\bar{x}$	σ	C.V%	n	$\bar{x}$	σ	C.V%	n	$\bar{x}$	σ	C.V%
Thickness, in	40	2.62	0.05	2	N26	2.49	0.07	3	40	2.51	0.04	2
					S26	2.28	0.34	15				
Unit weight, pcf	40	133.6	0.90	1	N26	134.4	3.9	3	40	132.9	1.15	1
					S26	130.8	3.8	3				
MR @ 70°F (x10^{6}psi)	11	0.66	0.18	27	28	0.88	0.48	55	18	0.29	0.15	52
Durability Tests**												
MR @ 70°F (x16^{6}psi)	6	0.44	0.18	28	6	1.02	0.3	29	6	0.38	0.21	55
MR @ 70°F (x16^{6}psi), (a)	3	0.50	0.17	34	3	0.67	0.08	11	3	0.25	0.11	44
MR @ 70°F (x16^{6}psi), (b)	1*	0.18	-	-	3	0.6	0.35	58	3	0.17	0.03	18
σ_y @ 70°F, psi	3	50.3	1.7	3	4	67.5	12.4	18	3	34.3	1.25	4
σ_y @ 70°F, psi (a)	3	47.7	3.2	7	3	57.9	6.9	12	3	17.4	5.1	29
σ_y @ 70°F, psi (b)	1*	29.1	-	-	3	36.6	13.7	37	3	11.1	2.1	19
KIC (psi in)	4	292	45.8	16	4	191	71.3	37	3	158.3	2.62	2
Immersion Tension												
σ_y before, psi	3	50.3	1.7	3	4	67.5	12.4	18	3	34.3	1.25	4
σ_y after, psi	3	32.6	8.6	26	3	51	1.5	3	1*	13.15	-	-
Stability, @140°F, lbs	3	408	36.8	9	4	493	94.3	19	3	227	22.4	10
Stability, @ 70°F, lbs									3	3360	540	16

* Two samples failed
** Lottman's procedure
(a) Vacuum saturation only
(b) Freeze and thaw

n = No. of samples
$\bar{x}$ = Average value
σ = Standard deviation
C = Coefficient of variation

761. Ten samples were prepared to study the effect of curing on the mixture. Samples were placed in an air draft oven at 140°F for 1, 2, and 3 weeks. Curing was an important factor to consider for SR 761 samples.

The test results for SR 761 laboratory samples showed a 55 percent reduction in modulus of resilience, a 68 percent reduction in tensile strength when subjected to a freeze and thaw cycle, and a 62 percent reduction in immersion-tensile strength test. Stability values at 77°F were acceptable, but values at 140°F were not. All test results were generally 50 percent lower than those of SR 564 samples. Specimens cured at 140°F showed a significant increase of 93 percent in modulus of resilience and an increase of 82 percent in tensile strength after 2 weeks. Those percentages increased to 138 and 124, respectively, after 3 weeks, as shown in Figures 3 and 4.

A second set of field cores from both projects will be collected 1 year after construction, and will be subjected to a similar testing program.

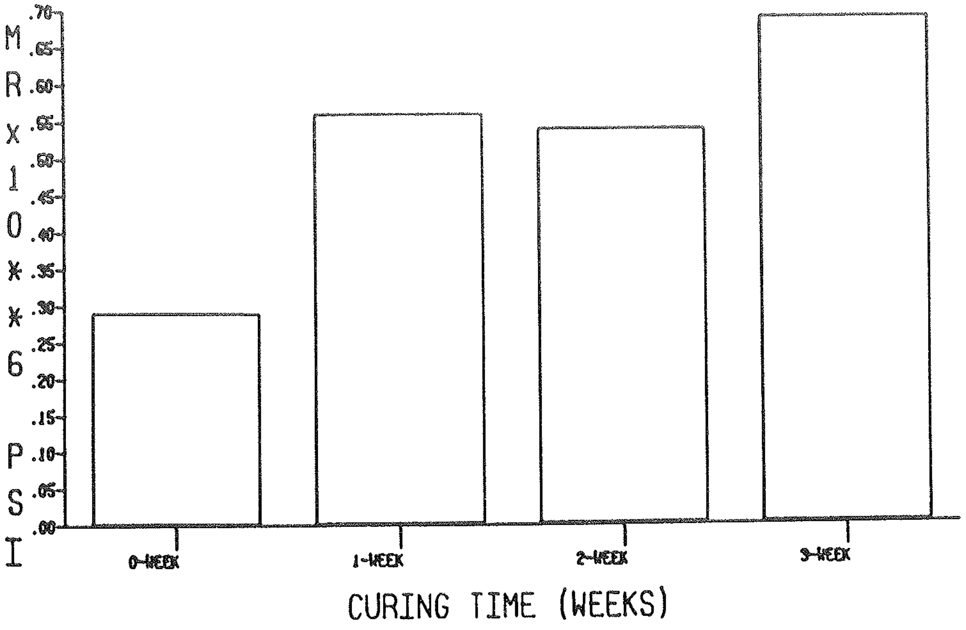

FIGURE 3 Modulus of resilience versus curing time for SR 761.

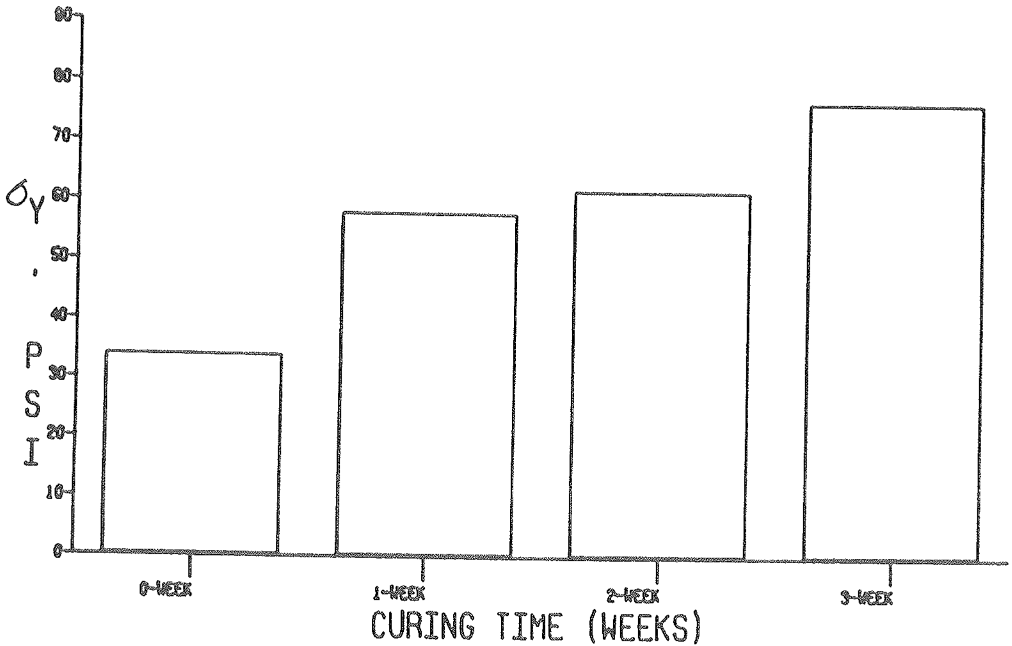

FIGURE 4 Indirect tensile strength versus curing time for SR 761.

Condition Survey

A surface condition survey of SR 564 before the overlay was applied revealed that the recycled layer had a tendency to ravel at the curves. Two soft sections were identified for wheel track densification. The emulsion saturated the mixture during construction on the first section; the subgrade material mixed with the emulsion because of a lack of pavement thickness on the second section. Other sections were in good condition. State Route 564 was visited 1 and 6 months after the overlay was applied. The pavement performed adequately and there was no indication of any failure in the recycled base underneath it. A visual inspection of SR 761, before the overlay was applied, revealed rutted sections under the wheel path and occasional raveling. Two severely damaged sections were compacted, broomed, and sealed before the overlay was applied.

State Route 761 was visited 1 month after the overlay was applied. Problems were noted in only one location. A 20-ft section that had failed earlier had rutted and was severely cracked in the wheel paths. The cracks had been sealed by district maintenance personnel. The project showed no other problems 6 months after construction.

Deflection Measurements

A Dynaflect deflectometer was used to measure deflections on the two pavements on December 5, 1985. The air temperature on that day was 40° F, and the pavement temperature was 52° F. These data are summarized in Table 6.

The maximum deflection (W1) is an indication of total pavement structure and its support conditions (*4*). Weak support conditions are generally associated with an increase in the maximum deflection. A range of 0.7 to 1.0 milli-inches is considered to represent the transition from satisfactory to unsatisfactory performance. The recycled section of SR 564 indicated an average maximum deflection value of 0.56 milli-inches, which is a comparable value for the adjacent newly constructed section. Both sections were considered satisfactory, as shown in Figure 5. State Route 761, however, had an average maximum deflection value of 1.09 milli-inches, which indicated an unsatisfactory performance. A plot for W1 versus stations is shown in Figure 6. It should be noted that the maximum deflection was reduced at locations at which full-depth asphalt patches were constructed for drainage.

The pavement's spreadability is a function of the pavement's

TABLE 6 DYNAFLECT DEFLECTION MEASUREMENTS

	SR 564				SR 761				Newly constructed** section SR 564			
	W1	S%	SCI	BCI	W1	S%	SCI	BCI	W1	S%	SCI	BCI
Average	0.56	62.7	0.14	0.04	1.09	58.2	0.28	0.13	0.56	67.1	0.12	0.06
Low	0.37	51.9	0.09	0.02	0.45	44.4	0.08	0.05	0.35	61.8	0.08	0.03
High	0.91	70.0	0.22	0.08	1.98	74.3	0.63	0.26	0.73	71.5	0.15	0.08
SD*	0.15	4.2	0.03	0.02	0.41	7.4	0.14	0.05	0.10	2.8	0.02	0.01

* SD Standard Deviations

** Section reconstructed in 1983 6" Aggregate base
6" Bituminous aggregate base
3" Asphalt concrete

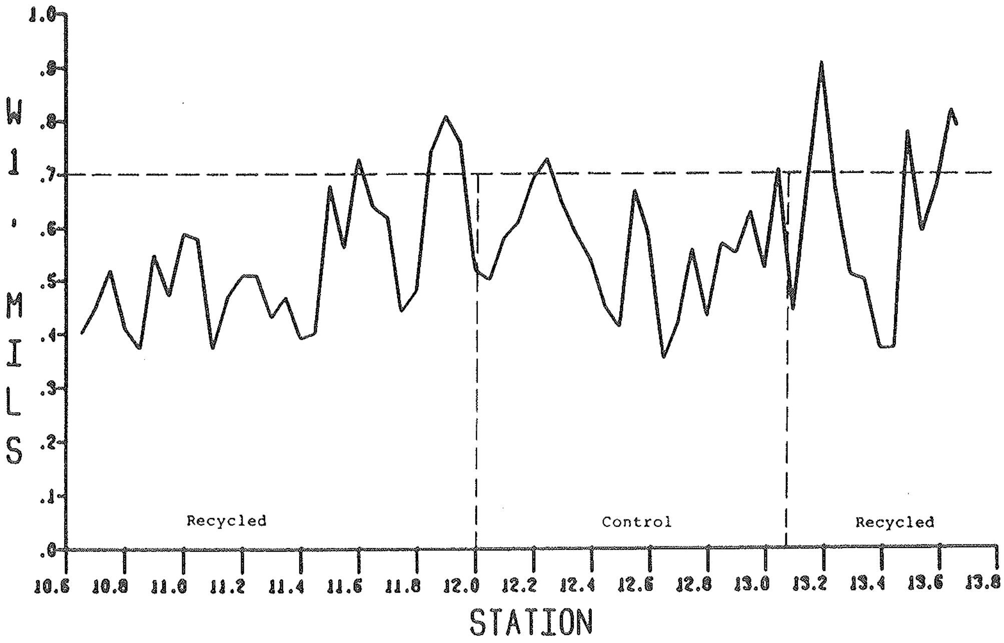

FIGURE 5 Maximum deflection versus station for SR 564.

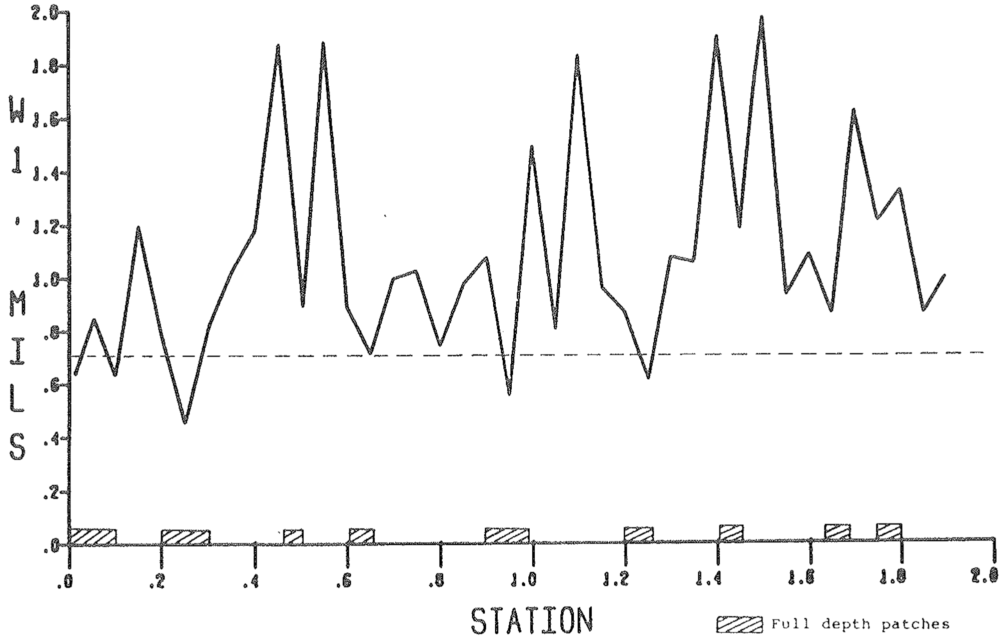

FIGURE 6 Maximum deflection versus station for SR 761.

stiffness and its ability to distribute loads. Typical values for spreadability usually range from 60 to 75 percent. The spreadability values for SR 564 and SR 761 are considered satisfactory and marginal, respectively.

The Surface Curvature Index (SCI) is inversely proportionate to the radius of curvature and directly proportionate to the tensile stresses and strains at the bottom of the asphalt layer. In flexible pavements, SCI values greater than 0.25 milli-inches are considered unsatisfactory and indicate poor pavement conditions. The SCI values of SR 564 were satisfactory, but the SCI values of SR 761 indicate poor performance.

The Base Curvature Index (BCI) is a parameter used in deflection of subgrade problems and base support conditions. Values greater than 0.15 correspond to poor subgrade and base conditions. The BCI values of SR 761 indicated poor conditions, but the BCI values of SR 564 indicate satisfactory conditions.

It can be concluded that the structural performance of SR 564 is considered satisfactory and better than that of SR 761. Deflection data will be collected periodically to detect any change in the performance of both routes.

INITIAL CONCLUSIONS

Based on the initial laboratory test results, field condition evaluation, and deflection measurements of both projects, the following initial conclusions can be made:

- The performance of SR 564 (recycled with CSS-1H) is satisfactory.
- The performance of SR 761 (recycled with Cyclogen ME) is unsatisfactory. However, this should not be taken as an indication that the concept of cold recycling or the use of chemical rejuvenators are responsible for the road's poor performance. The lack of an adequate soil structure and curing time proved to be major reasons for the unsatisfactory performance of this project.
- A second set of field cores and deflection measurements should be collected 1 year from the date of construction to detect any changes in the performance of the recycled layer.
- The general appraisal of everyone involved in these projects was favorable to the concept of recycling low-volume roads into stabilized bases. Construction problems and future pavement performance will enable the Ohio Department of Transportation to modify and improve construction specifications for future projects.

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Cold, In-Place Asphalt Pavement Recycling

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Many rural, low-volume asphalt roads constructed since 1955 have a rough riding surface, show signs of thermal cracking, and are in need of rehabilitation. Laboratory tests were initiated to discover which oil-based products, in addition to those currently marketed, would produce workability and Marshall test values in a recycled mix equivalent to those commonly used in conventional cold-mix construction. Three additives were selected for use in an experimental project. The additives varied from a marketed cold-mix rejuvenator to a gas/oil with a high paraffin content. A recycle train was used to gain precise control of additive content and the reclaimed asphalt pavement (RAP) gradation, and because a high production rate would lessen the inconvenience to the traveling public. Test data from the project, such as ambient and mix temperatures and the RAP gradation, were compared to laboratory test data. The pavement was tested to determine density and asphalt properties during and at the completion of the project. Testing is being repeated annually to document any changes in those values. The actual pavement condition is also being visually inspected to determine which additive is most effective in retarding thermal cracking in the recycled pavement.

The pavement to be recycled was a 24-yr-old, 4-in thick, cold, road-mixed, blade-laid bituminous base in which a sand-gravel aggregate and cutback asphalt were used as binders. Transverse thermal cracks allowed water to enter, which resulted in depressions adjacent to the cracks. Maintenance resealing had added about 1 in of thickness to the pavement. Severely depressed sections adjacent to the transverse cracks had also received a 3-in overlay of cold mix similar to that used in the original construction. The life of the thin overlays had been only 3 to 5 yrs, by which time the pavement surface again became rough.

Because of the limited amount of funds available for the maintenance and construction of low-volume paved county roads, a search began for a low-cost additive that could be mixed with the pulverized reclaimed asphalt pavement (RAP). This would enable the mixture to be relaid and form a stable, relatively waterproof pavement without the cracks that were allowing water to enter the subgrade.

The rip, crush, and relay method of recycling, in which 4 to 6 percent water is added to aid compaction, had been practiced for several years with pavements less than 3 in thick. The results were acceptable, except that the lack of waterproofing had caused some failures and random cracking was observed after 1 year.

The prices that were quoted for the milling, pulverizing, and mixing of an additive indicated that cold recycling with a

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