Cold Recycling of Asphalt Pavements on Low-Volume Roads

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Cold recycling can play a major role in the upgrade of secondary low-volume roads. Many farm-to-market roads exist in Pennsylvania that are good candidates for cold recycling with emulsified asphalt. Many roads have been built up over the years with open-graded cold mixtures (travel plant mix) or layer after layer of seal coats and surface treatments. These roads are also heavily patched. It is necessary to obtain a uniform, strengthened base course if these so-called "pancake" roads are to be upgraded and widened at the same time. Cold recycling is a good upgrading strategy to accomplish this. The Pennsylvania Department of Transportation had completed about 90 cold-mix recycling projects by the end of 1985. All three modes of cold-mix recycling have been attempted: central plant mixing, mobile plant mixing, and in-place mixing. The Pennsylvania Department of Transportation's guidelines for selecting suitable candidate projects and standard specifications for a cold recycled base course are provided. The current mix design procedures, which are at a developmental stage, are also provided. The optimum emulsion content is selected by considering (a) bulk specific gravity of the compacted specimen, (b) initial resilient modulus, and (c) resilient modulus after vacuum saturation with water. Case histories are included of some projects that were completed by use of mobile mixing plant and in-place mixing in which different equipment was used. Experience in cold recycling indicates a need for obtaining optimum moisture content in the reclaimed asphalt pavement material so that the emulsified asphalt can be dispersed effectively in the mix. The recycled mixtures are usually susceptible to damage from moisture intrusion and abrasion by traffic. It is therefore necessary to cover these mixtures with at least two applications of a surface treatment to avoid ravelling and potholing.

Pennsylvania, like many other states, is not currently building many new highways. The existing highways are being maintained and upgraded as part of the so-called 3R Program: Restoration, Resurfacing, and Rehabilitation. Cold-mix recycling can play a major role in upgrading the secondary low-volume roads. An attempt is being made to use cold-mix recycling on roads that are far from the central mix plants. No standard design procedure exists for designing these recycled mixtures, and much work needs to be done. In fact, no generally accepted, standard design procedure exists for the cold mixtures that contain 100 percent virgin aggregate. Therefore, an attempt is being made to work on the design and construction of cold recycling projects at the same time, because cold recycling appears to be an economical upgrading strategy. So far, about 90 cold-mix recycling projects have been completed.

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Cold-mix recycling is primarily being used for the base course. However, on some very low-volume roads, a 3- to 4-in depth of the existing roadway was recycled and a single seal coat was applied as the wearing course. Based on experience, at least a double seal coat must be used.

SELECTION OF PROJECTS

Many roads, like the one shown in Figure 1, are very good candidates for recycling. This road has many transverse, longitudinal, and reflected widening cracks. Many of these roads were widened in the past, and each time an overlay was applied, widening reflection cracks developed. Cold-mix recycling eliminates these cracks and provides a base with a uniform support across the entire width of the pavement. Roads have also been built up over the years with open-graded cold mixtures or layer after layer of surface treatments. These roads are also heavily patched. The base is of a very nonuniform type, and if a hot-mix overlay is simply applied on these surfaces, extensive cracking will develop. These roads are also good candidates for simultaneous recycling and widening.

Guidelines have been provided to the engineering districts that include information on the characteristics of cold recycled mixtures, the selection of projects, the estimation of quantities of materials, and construction. These guidelines aid the pavement management engineer in the development of cold recycling projects.

Standard specifications have been developed for cold recycled, bituminous base courses. These specifications are versatile and permit the use of available or innovative recycling equipment and procedures. Information on these guidelines and specifications is available from the Materials Testing Division of the Pennsylvania Department of Transportation.

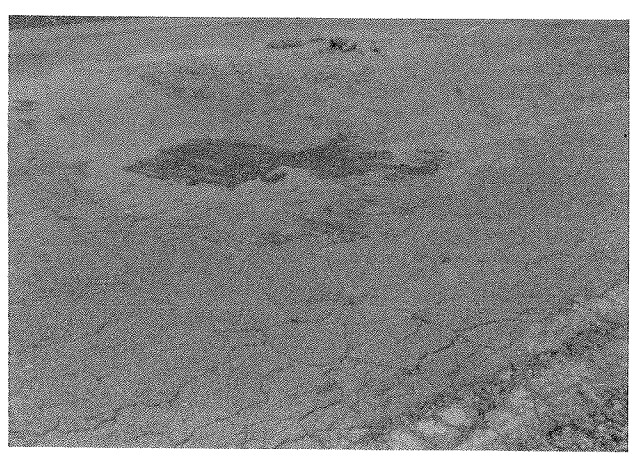

FIGURE 1 Existing road surface on the Chester County project.

MIX DESIGN

As was mentioned earlier, the mix design procedures are still at the development stage. Although it is desirable, it is not always possible to obtain a sample of the reclaimed asphalt pavement (RAP) material to design the recycled mixture in the laboratory. A RAP is defined as a removed or processed pavement that contains bitumen and aggregate. Fifteen 6-in-diameter pavement cores are usually obtained from representative sections of the project. These cores are crushed in a laboratory jaw-crusher to generate RAP for mix design purposes. Evidently, the RAP obtained during the actual recycling operation is most likely to vary in gradation and particle shape from the laboratory-made RAP depending on such factors as the equipment type and rate of milling. This requires that field adjustments be made to the design moisture content and emulsion content during construction.

The following tests are run on the RAP:

- Gradation of the RAP,
- Abson recovery of aged asphalt in the RAP to determine viscosity at 140° F and penetration at 77° F, and
- An extraction analysis to determine the percentage of asphalt content and the gradation of the aggregate in the RAP.

Based on the results of these tests, the emulsion type (CMS-2 or CSS-1h) is selected, and the need for blending a virgin aggregate is also established. If the RAP consists of a hot mix, the penetration of the recovered asphalt is usually low, such as 15 to 20. In these cases, the use of a CMS-2 emulsion that has an asphalt residue of 100 to 250 penetration is preferred. However, there are many cases in which the RAP comes from a road that was built over the years with seal coats, surface treatments, or cold mixes and that contains a relatively softer asphalt. In this case, the use of a CSS-1h emulsion that has an asphalt residue of 40 to 90 penetration is preferred. The addition of virgin aggregate to the RAP is considered if the RAP (a) consists of a sand mix, (b) contains excessive binder, or (c) does not have an acceptable gradation.

Optimum Moisture Content

Several 500-gram batches of the RAP (100 percent passing 1-in sieve) are made. The emulsion content is kept constant at 2.5 percent by weight of RAP, if 100 percent RAP is used. The initial moisture content is varied in increments of 1 percent. After the emulsion is mixed by hand for 2 min, the mix should have a ≥90 percent coating. Mixes are unacceptable if (a) they strip or stiffen excessively on mixing, (b) break prematurely, and (c) become excessively soupy and segregate on standing. A working range of optimum moisture content was established for use in the field. The RAP is maintained at ambient temperature and emulsion is used at 140° ± 10° F to prepare the mixes.

Optimum Emulsion Content

Three mixtures are each made with at least four emulsion contents using the established optimum moisture content. If 100 percent RAP is used, 2.0, 2.5, 3 0, and 3.5 percent emulsion contents are normally used. If a RAP and virgin aggregate blend is used, higher emulsion contents are attempted. The following procedures are used to prepare and test the specimens:

- The loose mixture is cured in an oven at 105° F for 45 min. It is then remixed for 30 sec and allowed to cool to room temperature.
- The specimen is compacted in a Marshall mold with 75 blows on each side. Prior to 1985, 50 blows were used. The practice was changed to 75 blows because there were some indications from the field projects that the in-place density was higher.
- The specimens are extruded from the molds on the following day, and cured in a forced-draft oven at 104° F for 3 days.
- The bulk specific gravity and the resilient modulus (M_R) of all specimens are determined at 77° F.
- The specimens are vacuum-saturated by immersing them under 1 in of water and applying a vacuum of 26-in H_g for 30 min. The vacuum is gradually released and the specimens are left submerged in water for at least 30 min.
- The specimens are removed from the water and the percentage of water absorbed during vacuum saturation is determined.
- The resilient modulus (M_R) of the specimens after this moisture conditioning is determined and the percent retained M_R is calculated.
- The Marshall stability and flow at 77° F of the moisture-conditioned specimens are determined. If the stability-flow curves do not peak, all stability values that correspond to a flow of 10 units are reported.

The optimum emulsion content is selected by considering the following test parameters:

- Bulk specific gravity of the compacted specimen,
- Initial resilient modulus (M_R),
- Resilient modulus (M_R) after vacuum saturation, and
- Percent retained M_R.

The initial resilient modulus (M_R) usually decreases as the emulsion content is increased. However, the rate of decrease of the M_R value and the M_R values after vacuum saturation are considered to establish the optimum emulsion content. No limiting values or acceptance criteria have been established for these test parameters. The optimum moisture and emulsion contents are recommended as a starting point in the field, and are subject to adjustment as needed.

CASE HISTORIES

Three modes of cold-mix recycling have been tried: central plant mixing, mobile plant mixing, and in-place mixing.

In central plant mixing, the RAP material is hauled to a central mixing plant, mixed with emulsion, and returned to the site and laid through a paver. This is usually not the most economical recycling method. A stabilization plant (Figure 2) is typically used. Segregation problems have been reported as a result of handling and transporting the RAP and recycled mix.

In mobile plant mixing, the pavement is milled and the RAP is loaded on a truck that feeds a mobile mixing plant, such as a

Midland Motopaver, where the emulsion is added and the mixture is laid.

In in-place mixing, the recycling is performed in-place by a train of equipment that mills, adds emulsion, mixes, and lays. Most cold recycling projects were performed in this manner using a wide range of equipment.

Some of the projects that were completed by means of the mobile mixing plant and in-place mixing are discussed in the following sections.

Chester County Project

The first cold recycling project was located on Gum Tree Road in Chester County near Philadelphia and a Midland Motopaver was used. This road (Figure 1) had a lot of patches and alligator cracking, which indicated a poor base. A Roto Mill was used to mill 3 in of the existing road. The RAP from the windrow was picked up to be loaded on the truck (Figure 3). The truck discharged the RAP into the Midland Motopaver where it was mixed with 2 percent CMS-2 emulsion (approximately 5 gal/ton of the RAP by weight) in the pugmill and laid through a screed (Figure 4). The recycled mix was laid to give a compacted base course of 5 in thickness (Figure 5). This compacted recycled base course was opened to traffic for a couple of weeks (Figure 6) before it was overlaid with 1-1/2 in of hot mix. This road was completed in 1980 and it carries a lot of truck traffic. So far, it is performing very well. It should be mentioned that the road was also widened during the recycling process.

Susquehanna County Projects

We completed five in-place recycling projects that totaled 16.6 mi in 1983 in Susquehanna County, which is in northeastern Pennsylvania. Most of the low-volume roads have been built up over the years with macadams, seal coats, and surface treatments and are heavily patched, as shown in Figure 7.

A Bros reclaimer, which pushes the emulsion tanker, as shown in Figure 8, was used on these five projects. The Bros reclaimer has a cutting drum and a spray bar for emulsion. It

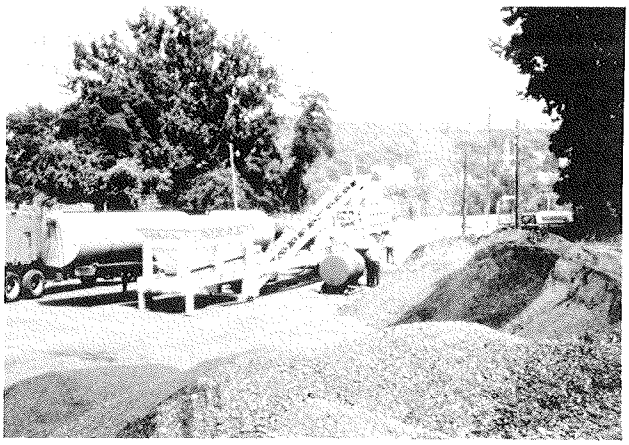

FIGURE 2 Typical stabilization plant for cold recycling.

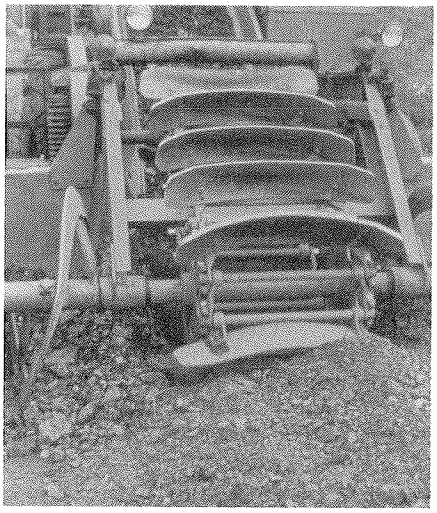

FIGURE 3 Recycled asphalt pavement being picked up from the windrow on the Chester County project.

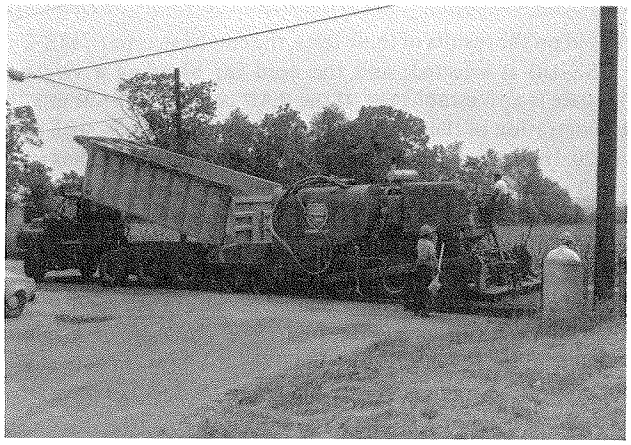

FIGURE 4 Recycled asphalt pavement being discharged into the Midland Motopaver on the Chester County project.

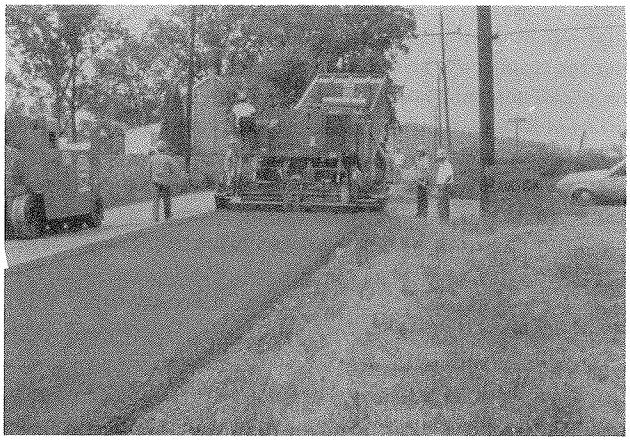

FIGURE 5 Laydown behind the Motopaver on the Chester County project.

FIGURE 6 Completed roadway on the Chester County project.

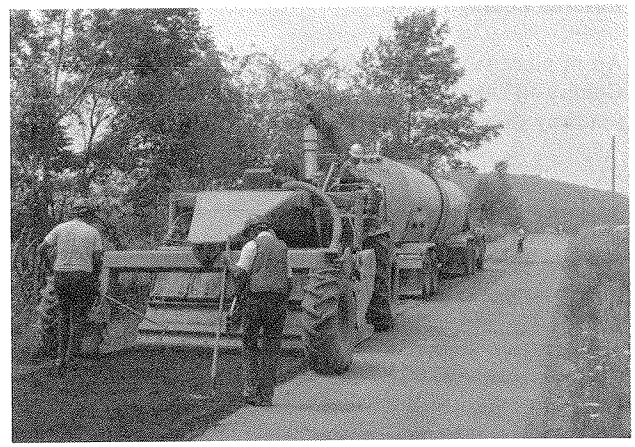

FIGURE 8 Equipment train in which Bros reclaimer is shown on the Susquehanna County project.

FIGURE 7 Existing road surface on the Susquehanna County project.

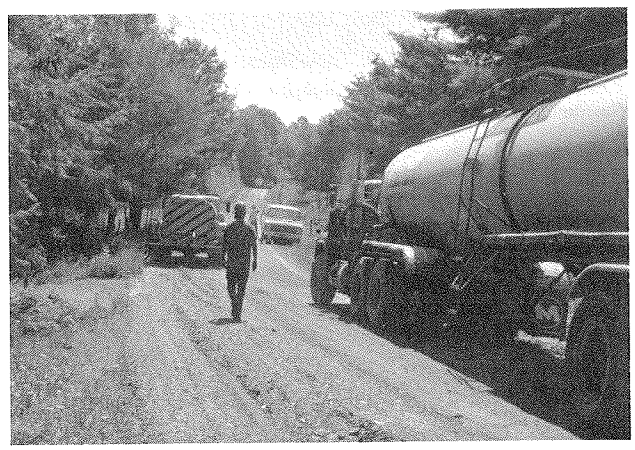

FIGURE 9 Application of water after the first pass of the reclaimer on the Susquehanna County project.

cuts and mixes the emulsion at the same time. Because about 2 to 3 percent CMS-2 emulsion was being used, it was difficult to disperse this small amount in the RAP because of the lack of sufficient moisture content that was determined in the laboratory. The water tanker shown in Figure 9 was brought in to raise the moisture content in the RAP to a range of 3 to 5 percent. The reclaimer therefore had to go over the road twice. The first pass was performed to reclaim (without adding emulsion) so that the water could be added to the loose RAP; the second pass was necessary to add and mix the emulsion.

The compacted, recycled base course appeared to be very dense. It was covered with a single application of seal coat. As was mentioned earlier, at least a double application is recommended because the cold recycled mix is generally not adequately water- and abrasion-resistant. These projects were completed in August and September of 1983. The pictures shown in Figures 10 and 11 were taken in March 1984 after a snowfall and the road surface is partially wet. The surface was good in some sections (Figure 10). However, when the single seal coat was lost, potholes like those shown in Figure 11 developed.

The inadequacy of a single seal coat is shown in Figure 12, in which the large stones of recycled base course can be seen through the seal coat. After 2 years of service, three projects were patched and a double surface treatment was applied. The condition of the road in July 1986, after this treatment was applied, is shown in Figure 13.

FIGURE 10 Roadway after the first winter on the Susquehanna County project (good section).

Luzerne County Project

An in-place recycling project was also completed in Luzerne County on Legislative Route 40060 in 1983. The existing 4.5-mi roadway shown in Figure 14 was narrow, badly cracked, and heavily patched, and had an unsatisfactory cross-section. A Raygo Barco Mill (Figure 15) was used for recycling. This machine has a cutting drum and two spray bars for water and emulsion. Two small water tanks with a capacity of 250 gallons each are mounted on the machine. It pushes the emulsion

FIGURE 11 Roadway with potholes after the first winter on the Susquehanna County project.

FIGURE 12 Large stones of recycled base showing through a single seal coat.

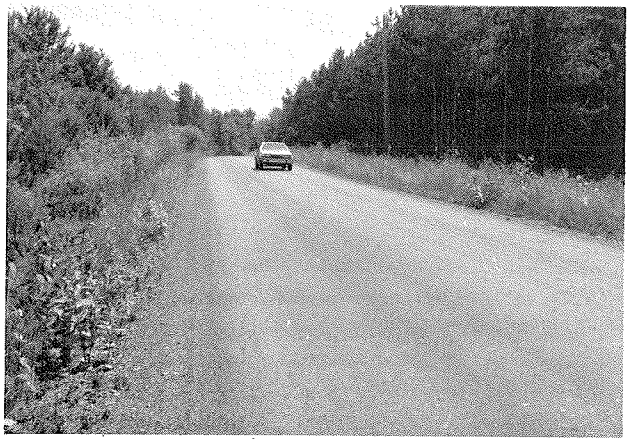

FIGURE 13 Roadway after double surface treatment on the Susquehanna County project.

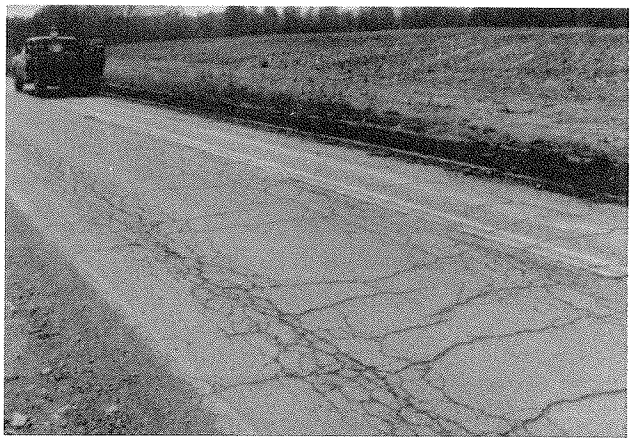

FIGURE 14 Existing road surface on the Luzerne County project.

FIGURE 15 RayGo BarcoMill equipment on the Luzerne County project.

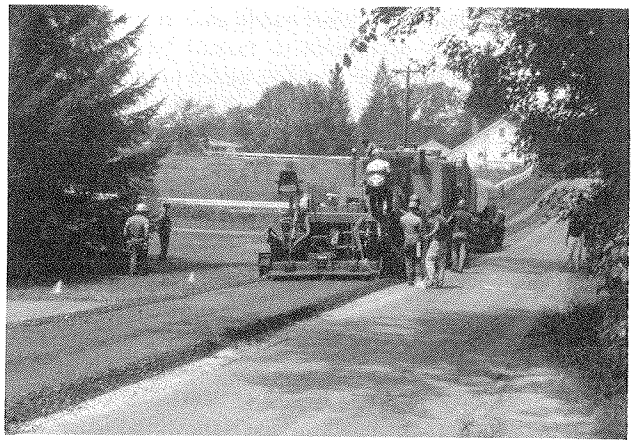

FIGURE 16 Equipment train on the Luzerne County project.

tanker in front and pulls a paver behind. The existing roadway was milled and recycled to a depth of 3 in by the equipment train shown in Figure 16. A section of the existing roadway had only a 1-1/2-in bituminous overlay. This required the addition of 1-1/2-in virgin aggregate to make up the total 3-in recycled depth. The virgin aggregate was spread ahead of the recycling train.

A CSS-1h emulsion was used on this project. Fortunately, the RAP had a substantial amount of initial moisture, because it rained before the job was started. Therefore, not much water

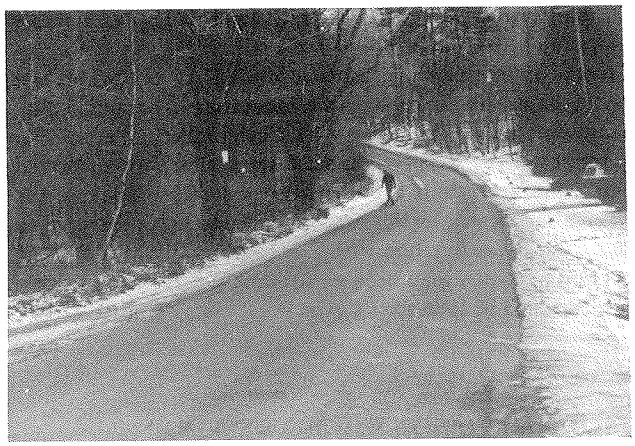

FIGURE 17 Roadway after the first winter on the Luzerne County project.

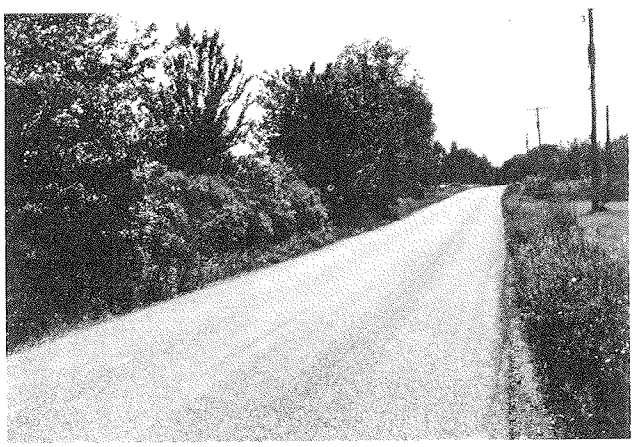

FIGURE 18 Roadway after 2 years on the Luzerne County project.

FIGURE 19 Roadway on the Luzerne County project; (l) without seal coat, (r) with seal coat.

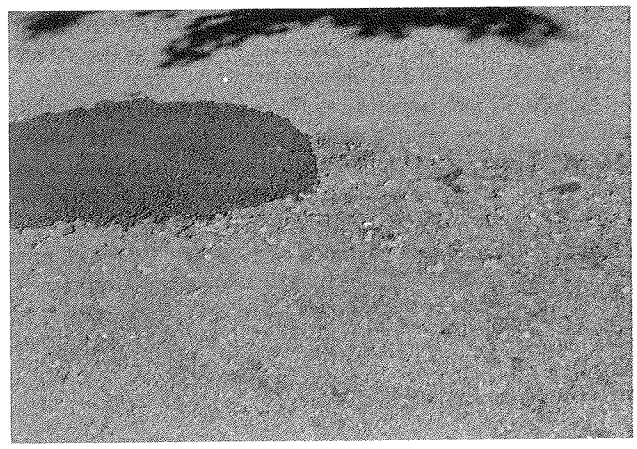

FIGURE 20 Patched pothole and adjacent section with lost seal coat on the Luzerne County project.

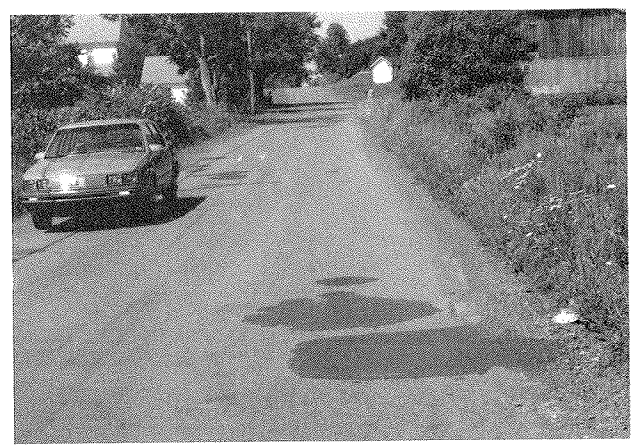

FIGURE 21 Potholed section of roadway on the Luzerne County project in which 100% recycled asphalt pavement was used.

FIGURE 22 Good section of the Luzerne County project in which a 50/50 blend of recycled asphalt pavement and virgin aggregate was used.

had to be drawn from the two small tanks, and the recycled mix was satisfactory. However, if the RAP was relatively dry, these tanks would have had to have been replenished with water very frequently, which can pose problems on these narrow hilly roads. Although this recycled project also had a single seal coat, it was performing very well after the winter of 1983 to 1984, as can be seen in Figure 17, which was taken in March 1984. The condition of the roadway in June 1985, after 2 yrs, can be seen in Figure 18. A few (5 to 6) potholes had appeared, which indicated the need for another application of a seal coat.

This project was inspected again in July 1986. A section in which the seal coat was lost can be seen in Figure 19 (left side of picture); the section is on the verge of developing a pothole. A pothole patch that was placed in such a section is shown in Figure 20.

After 3 years, the section in which 100 percent RAP was used has more potholes (Figure 21) than the section in which a 50/50 blend of RAP and virgin aggregate was used (Figure 22).

Mercer County Project

Another in-place recycling project was completed in Mercer County on Traffic Route 208 (west of I-79 London interchange) in May 1985. The recycling train consisted of an emulsion tanker, a CMI milling machine, a CMI crusher, and a Barber-Greene paver, as shown in Figures 23 through 26. The milled material passed over a 1-1/2-in scalping screen. The oversized material was fed into the crusher by a conveyor (Figure 23) to reduce its size. The material was milled and recycled to a 3-in depth. Because no provision was made for adding water before the material was mixed with the CSS-1h emulsion, the latter was diluted with water in a 50:50 ratio to provide an acceptable dispersion of the binder.

It was noted that the gradation of the RAP on this project was significantly finer than the laboratory-generated RAP. About 3 percent (approximately 7-1/2 gal/ton) CSS-1h emulsion by weight of the RAP was used. Compaction was performed with a vibratory and a pneumatic-tired roller. Because the average daily traffic on this road was 2,000 to 3,000, the recycled base course was overlaid with 3-1/2-in hot-mix overlay. The recycled pavement had been performing satisfactorily when it was inspected in 1986 after 1 year.

FIELD ADJUSTMENTS TO MIX DESIGN

As was mentioned earlier, the optimum moisture and emulsion contents from the laboratory-mix design are recommended as a

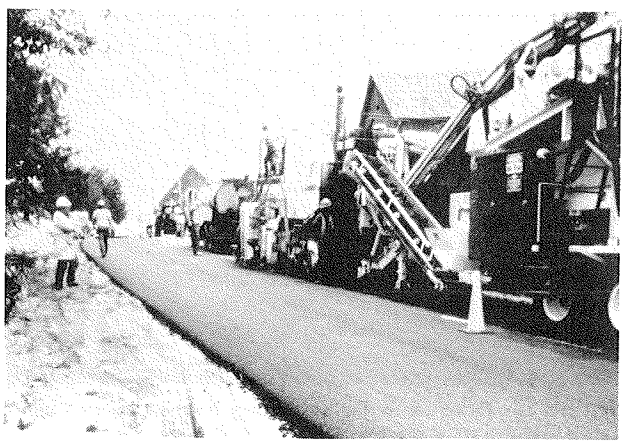

FIGURE 23 Recycling train on the Mercer County project.

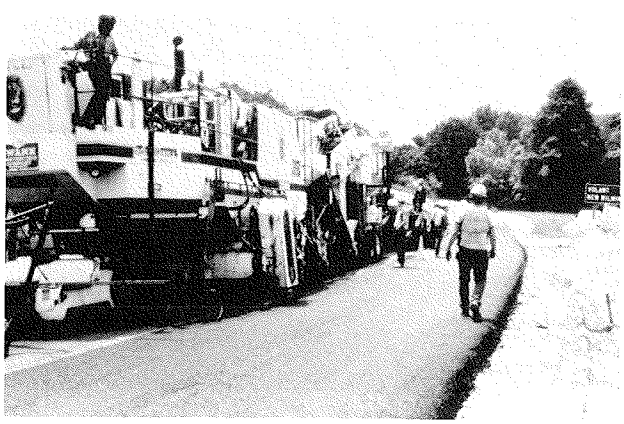

FIGURE 24 Miller and crusher on the Mercer County project.

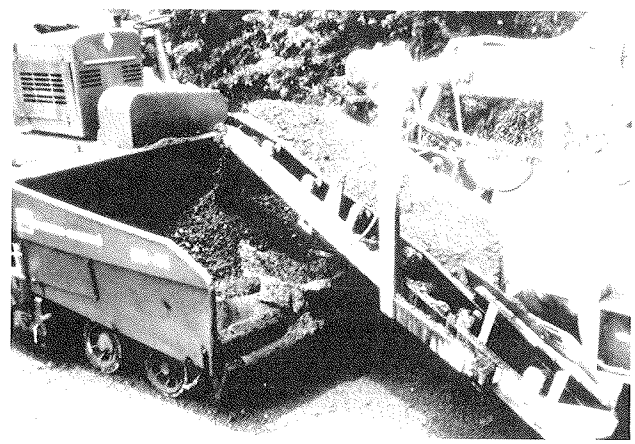

FIGURE 25 Recycled mix being discharged into the paver on the Mercer County project.

FIGURE 26 Mix laydown on the Mercer County project.

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

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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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