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Evaluation of the Performance of Cold-Mix Recycled Asphalt Concrete Pavement in Washington

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Recycling ACP-Cold Mix

EVALUATION OF THE PERFORMANCE OF COLD-MIX RECYCLED ASPHALT CONCRETE PAVEMENT IN WASHINGTON

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16. ABSTRACT

Often upgrading an aged asphalt concrete pavement involves overlaying a cracked pavement with new asphalt concrete. However, usually the substrate cracks reflect through the new overlay under repeated service loading. Full depth cold-mix recycled asphalt concrete is an alternative that eliminates the potential for reflective cracking.

Generally, the performance of cold-mix recycled asphalt concrete pavements in the United States supports its use as base course in flexible pavements. The conditions of three Washington experimental "cold-mix" pavements after about 6 years of service varied from fair to good, depending on the level of truck traffic. The wheeltrack rutting of those pavements was not significantly different from rutting that might be expected from conventional flexible pavements under the same conditions. Although the potential for fatigue cracking exists, as it does in conventional flexible pavements, full depth recycling of asphalt concrete eliminates the cause of reflective cracking.

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SUMMARY

The Washington State Department of Transportation (WSDOT) is investigating methods of upgrading aging pavements in the existing network of highways in the state. The majority of those highways were built with asphalt concrete pavement (ACP). Often upgrading an aged ACP involves overlaying a cracked pavement with a new ACP. However, the substrate cracks often reflect through the new overlay under repeated service loading, especially when the overlay is less than 1 inch thick. Full-depth cold-mix recycled asphalt concrete pavement (CMR-ACP) is one method to eliminate this reflective cracking. The operation is conducted at the construction site and involves milling and/or crushing the old ACP, mixing the material with an asphalt emulsion, and finally placing and compacting the cold mix. CMR-ACP is then overlaid with a new ACP. This process eliminates the existing crack pattern and the potential for reflective cracking. The process of recycling conserves natural resources and may reduce the construction cost.

Nevertheless, the cold-mix recycling of ACP has not yet proven to be totally reliable and durable, and its implementation is in its infancy. Since 1981, WSDOT has constructed three experimental cold-mix recycled projects. The further use of cold-mix recycling by WSDOT hinges on the success of those three experimental projects.

WSDOT initiated this research project with the objective of evaluating the general performance of CMR-ACP and the particular performance of the three WSDOT CMR-ACP test sections to make recommendations on the further use of CMR-ACP in Washington. The first task of the project involved reviewing the available literature and gathering information on the performance of CMR-ACP constructed by other U.S. highway agencies. After this task was completed the research team visited Washington's three CMR-ACP test sections, visually inspected

their conditions, and obtained field samples for laboratory tests. The laboratory test data and the data from the literature survey were analyzed for evidence that CMR-ACP may rut and crack under service loading or that it may deteriorate from water damage. Accordingly, recommendations are made regarding the design and construction of CMR-ACP to enhance the pavements' engineering properties and to prolong their service lives.

The performance of CMR-ACP in Washington and elsewhere in the United States supports the use of CMR-ACP as base course in flexible pavements. The conditions of three Washington CMR-ACP projects after about 6 years of service varied from fair to good, depending on the level of traffic. The wheeltrack rutting of the Washington CMR-ACP projects was not significantly different from rutting that might be expected from conventional flexible pavements under the same conditions. Although the potential for fatigue cracking still exists, as it does in conventional ACP, full depth recycling of ACP eliminates the cause of reflective cracking.

FINDINGS

This section summarizes the findings of this report on the performance of cold-mix recycled asphalt concrete pavement (CMR-ACP). The findings are based on tests conducted in this work as well as data obtained from other research.

PERFORMANCE

1. The performance of CMR-ACP in Washington and elsewhere in the United States supports the use of CMR-ACP as base course in flexible pavements. The overall conditions of the three Washington CMR-ACP projects after about 6 years of service varied from fair to good, depending on the level of traffic. The highest average daily traffic for those pavements was 4,750 units. The factors that determined the overall pavement condition in this evaluation were wheel-track rutting and cracking, determined during visual surveys.
2. The wheel-track rutting of the Washington CMR-ACP projects was not significantly different from rutting that might be expected from conventional flexible pavements performing under the same conditions. The average rut depth for the CMR-ACP project with the highest level of traffic and rutting was about 1/4 in.
3. Full depth recycling of ACP eliminates the cause of reflective cracking. The type of cracking noticed in the Washington CMR-ACP projects was not reflective cracking, rather it was isolated wheel-track cracking that usually initiates typical alligator (fatigue) cracking in flexible pavements.

MATERIAL CHARACTERISTICS

1. There are indications that a portion of the existing asphalt participates as part of the effective binder in the cold recycled mix. That participation occurs during the mixing and placing and/or during the service. The limited

data available from tests conducted in the current work indicate that the amount of existing asphalt that participates in the mix depends on the amount and viscosity of the emulsion residue and the viscosity of the aged asphalt. Larger amounts of emulsion residue, lower viscosities of the emulsion residue and lower viscosities of the existing (aged) asphalt all contribute to more participation of the existing asphalt in the recycled mix as an effective binder. In the three Washington CMR-ACP projects, the amount of existing asphalt that participates in the mix as an effective binder was roughly estimated to be from 1.5 percent to 2.0 percent of the weight of total mix, depending on the factors discussed.

2. The total effective binder content in CMR-ACP (i.e., the binder that actually fills the voids between particles) is the amount of emulsion residue plus the portion of the existing asphalt that participates in the mix as an effective binder. The aggregate and the remainder of the old asphalt act as "black aggregate" in the recycled mix. The viscosity of the effective binder, thus, depends on the viscosity of the emulsion residue and viscosity of the existing (aged) asphalt.

3. The stability of the three Washington CMR-ACP projects could not be measured directly from their core samples. The pavements' average void contents, from 9.5 percent to 12 percent indicated that the stability may be marginal for the highest void content; however, this does not pose a major problem, especially when CMR-ACP is used as base course. The low to moderate rutting of the three test pavements supported this opinion. Where some local severe rutting had occurred, test results showed the presence of extremely high asphalt content, which was due to an excessive amount of emulsified asphalt in the CMR-ACP. This is probably due to a non-uniform distribution of the emulsion in the recycled mix.

4. The flexibility of the Washington's CMR-ACP projects was slightly lower than the flexibility of Washington's overlaid hot-mix recycled asphalt concrete pavements (HMR-ACP), but it was more noticeably lower than the flexibility of Washington's non-overlaid conventional asphalt concrete pavements, in light of their age. This means that CMR-ACP may be more susceptible to fatigue cracking, given the same load conditions and structural design. The average resilient modulus of the three Washington CMR-ACP projects was 347,000 psi after 5 to 6 years of service. This compares less favorably to the average resilient modulus of 258,000 psi obtained for three Washington overlaid HMR-ACP projects after 6 years. Also, it compares less favorably to the average resilient modulus of 350,000 psi obtained for 16 Washington non-overlaid conventional asphalt concrete pavements after 12 years considering the age and exposure factors. Higher resilient modulus values can be expected of asphalt mixes as they age.
5. The durability of the three Washington's CMR-ACP projects was either marginal or not satisfactory. This was because of the relatively high void content of the CMR-ACP mixes after 5 to 6 years of service (i.e., from 9.5 percent to 12 percent). Depending on the amount of void content, a reduction of 18 percent to 34 percent in the resilient modulus values were obtained after the core samples of the CMR-ACP projects were water saturated. Note that CMR-ACP with void content as small as 5 percent (after one year of service) has been constructed in the United States. The average void content of the three Washington overlaid HMR-ACP projects was 6 percent after 6 years of service.

RECOMMENDATIONS

The results of the current investigation indicate that full depth cold-mix recycled asphalt concrete pavement (CMR-ACP) is an effective method of rehabilitating aged flexible pavements to eliminate the potential for reflective cracking. Continuation of the use of CMR-ACP as the base course in flexible pavements is recommended.

MIX DESIGN

1. The type and amount of the emulsion should be selected with the aim of incorporating the existing asphalt into the recycled mix as an effective binder to the extent that the field product of CMR-ACP will have a void content in the range of 6 percent to 8 percent after about 5 years of service. This will result in enhanced stability, flexibility, and durability of CMR-ACP.

   Based on the limited information available, as a guideline, for aged asphalts with viscosities above 20,000 poise, the addition of 2 percent (residue percent) of emulsified asphalt rejuvenators with a 300+ penetration is suggested. For extremely hard, aged asphalts with viscosities above 100,000 poise, the amount of the rejuvenator may be increased. For aged asphalts with viscosities below 20,000 poise, addition of 2 percent (residue percent) of emusified asphalts with a 100 to 250 penetration seems appropriate. The use of high viscosity emulsified asphalts with a penetration of below 100 seems to be effective with aged asphalts with viscosities below 1,000 poise. In this case, the addition of 3 percent (residue percent) of emulsified asphalt is suggested.

The use of high float emulsions may be considered if drainage of the emulsion from the aggregate is a problem. High float emulsions allow a thicker film on the aggregate. The addition of a polymer to the high float emulsion creates even a thicker film on the aggregate. The New Mexico Department of Transportation has used high float emulsions.

2. Water may be added during the recycling operation to control dust and facilitate uniform mixing. The total water content of the mix should be limited to 4 percent to satisfy compaction and void content requirements. That limit, however, may be increased, depending on the amount of raw aggregate added to the mix. Too much water in the mix can cause the CMR-ACP to rut before overlaying.
3. Presently, a maximum particle size of 1 to 1.5 inches is commonly used nationwide and seems to be satisfactory. A process involving screening of the pulverized ACP during construction is required to control particle size.

STRUCTURAL DESIGN

The thickness design of flexible pavements that use CMR-ACP as base course requires data on CMR-ACP's resilient modulus and fatigue tensile strength. Data on the fatigue tensile strength of CMR-ACP are presently lacking.

CONSTRUCTION

1. Although graders were used with satisfactory results in some projects, the preferred process for cold-recycling is a process that involves a train consisting of milling, mixing, and paving elements (Washington experience on Chewelah Project).
2. Compaction of CMR-ACP should be done at high ambient temperatures for maximum compactive effort and to allow the emulsion to break. Air temperatures below 60 to 70°F are not recommended (Kansas experience).

3. Compaction should be done with a heavy pneumatic roller. A steel roller should only be used as the finish roller to avoid sealing the surface in the initial breakdown, which can trap in moisture in the mix. The rollers should be held back 0.25 mile to allow moisture in the emulsion to break before compaction (New Mexico and Indiana experience).
4. Seven-day curing of CMR-ACP before overlaying seems sufficient. If during that period wheel rutting occurs, the asphalt concrete overlay can be applied in two lifts, with the first lift acting as a leveling course (Washington experience).

CHAPTER 1
INTRODUCTION

The Washington State Department of Transportation (WSDOT) is investigating methods of upgrading aging pavements in the existing network of highways in the state. The majority of those highways were built with asphalt concrete pavement (ACP). WSDOT is continually trying to find more effective and economical methods of reconstructing aging highways. Cold-mix recycled asphalt concrete pavement (CMR-ACP) promises to be an alternative to accomplish this task. The cold recycling operation is completed at the construction site. The operation includes milling the aged and deteriorated ACP, crushing the milled material to reduce its size, mixing the crushed material with an asphalt emulsion, and placing and compacting the cold mix. Because of its characteristics, CMR-ACP is best suited as base course. Thus, it should be covered with a conventional ACP to serve as the new wearing course.

The use of CMR-ACP is justified for the following reasons.

- Often reconstruction of an existing deteriorated ACP involves overlaying a cracked pavement with a new ACP. Examples of the cracking are alligator (fatigue) cracking and transverse thermal cracking. However, the substrate cracks act as stress risers and reflect through the new overlay under repeated service loading. Full depth cold-recycling of the aging pavement before the placement of the new overlay eliminates the existing crack pattern and the potential for reflection cracking.
- Upgrading of aging highways often requires their widening. General practice is to widen the existing pavement by paving its shoulder before placing the new ACP overlay on the entire pavement. The problem with this practice is that under repeated service loading a

longitudinal crack along the pavement reflects through the overlay where the underlying existing pavement separates from the paved shoulder. The cold-recycling operation allows milling and widening of the existing pavement without the creation of an interface, thus eliminating the potential for development of a "widening crack." This can be done by reducing the thickness of CMR-ACP to pave the shoulder with the recycled material.

- Natural resources (i.e., aggregate and asphalt) are dwindling, and their costs are rising. Recycling conserves natural resources and can reduce reconstruction costs.

Nevertheless, the cold-mix recycling of ACP has not yet proven to be totally reliable and durable, and its implementation is in its infancy. Since 1981, the WSDOT has constructed three experimental cold-mix recycling projects. No previous studies have evaluated the success of cold-mix recycling in the state of Washington. The further use of cold-mix recycling by the WSDOT hinges on the success of those three experimental projects.

OBJECTIVES

WSDOT initiated this research project with the objective of evaluating the general performance of CMR-ACP and the particular performance of the three WSDOT CMR-ACP test sections to make recommendations on the further use of CMR-ACP in Washington.

RESEARCH APPROACH

The first task of the project was to review the available literature and to gather information on the performance of CMR-ACP constructed by other U.S. highway agencies. After this task was completed, the research team visited Washington's three CMR-ACP sections to visually inspect their condition and to obtain field samples for laboratory tests. Subsequently, the WSDOT Materials

Laboratory tested the field samples and provided the researchers with laboratory test results. The testing of Washington's CMR-ACP experimental projects provided the research team with data on their various performance parameters. Those data were compared to similar data reported by other highway agencies regarding their CMR-ACP projects. Also, the data were compared to performance data obtained from conventional ACP and the performance data of the Washington's experimental hot-mix recycled asphalt concrete pavements (HMR-ACP). Data on the performance of Washington's HMR-ACP projects were provided by a recently concluded WSDOT research project. [1] After the data were analyzed and interpreted, recommendations were made on the further use of CMR-ACP in Washington, as well as on methods of its construction to achieve improved quality.

CHAPTER 2
REVIEW OF EXPERIMENTAL COLD-MIX RECYCLED ASPHALT CONCRETE PAVEMENTS IN THE U.S.

This chapter provides a digest of the results of previous experiments conducted by United States highway agencies to determine the performance of their experimental CMR-ACP projects.

KANSAS' EXPERIMENT [2]

A 0.5-mile CMR-ACP was constructed and overlaid with ACP. The original ACP had been surface treated a few times and had a total thickness of 8 in. It was 25 years old and had developed numerous cracks and had become rough. The main goal of the experiment was to eliminate the development of reflective cracking.

The 0.5-mile test section was divided into three subsections. The first subsection was milled 4 in. deep, and the milled material was relayed without the use of any added emulsion or rejuvenator. The second subsection was similar to the first one, but to it was added 2 percent ARA-1 asphalt rejuvenator and 1 percent water. In the third subsection, 2.25 in. of pavement were milled and removed, and then construction was the same as the second subsection. Those three subsections were designed to evaluate the effects of adding the rejuvenator and the effects of the thickness of the remaining cracked pavement under CMR-ACP.

Construction

While the old pavement was milled, the rejuvenator and water were pumped from a distributor into the miller. The miller mixed the millings with the rejuvenator and water. The windrow behind the miller was loaded into a paver by a windrow pickup attachment. The material without rejuvenator did not lay and compact well and developed many fine surface cracks. One day after constructing the CMR-ACP sub-sections, they were overlaid with 1.25 in. thick ACP. A second 1.25 in. new ACP was placed three weeks later.

Evaluation

The asphalt content of the old pavement was about 4 percent, and it had a viscosity of about 17,000 poise at 140°F at the time of construction. The asphalt rejuvenator residue had a viscosity of 140 poise at 140°F, and a penetration of 300+ at 77°F. The addition of 2 percent rejuvenator reduced the viscosity of the asphalt in the recycled pavement to 429 poise and increased its penetration to 250+. However, some hardening of the asphalt in the recycled mix was documented after construction. Seven months after construction the viscosity was measured at 2,020 poise, with a penetration of 130. The addition of 1 percent of water brought the total moisture content of the recycled mix to about 2.5 percent.

At the time of reconstruction, the air temperature varied from 60 to 70°F, and windrow temperatures of up to 100°F were recorded. Cores were obtained in the two CMR-ACP subsections with the rejuvenator immediately after the construction. Those cores had an average void content of 6.1 percent. Tests conducted on laboratory compacted samples indicated a reduction of about 75 percent in the void content when the cure and molding temperature increased from 80°F to 125°F.

All of the three subsections were visually inspected periodically. After 2.5 years of service, cracking and rutting were not problems.

PENNSYLVANIA'S EXPERIENCE [3]

By 1984 Pennsylvania had completed 15 cold mix recycling projects. Those projects were primarily used for the base course. However, on some very low volume roads, after the existing pavement had been recycled to a 3 to 4-inch depth, a single seal coat was applied as the wearing course.

Construction

In many projects, a reclaimer, with a cutting drum and a spray bar for emulsion, cut and milled the old pavement and mixed it with the emulsion at the same time. The requirement for the maximum size of the reclaimed material was that at least 95 percent pass through a 2-in. sieve. Since the recycling was using only a small amount of emulsion, it was difficult to disperse this small amount in the milled material because of the lack of sufficient moisture. Therefore, water had to be added to the milled material. To accomplish this, the reclaimer went over the road twice. The first pass was just to mill the old pavement (without adding the emulsion) and to add a sufficient amount of water to the loose material. The second pass of the reclaimer was necessary to add the emulsion and mix the loose material.

Evaluation

Generally, 2 to 3 percent of emulsion was used. The emulsion was CMS-2 emulsion with an asphalt residue penetration of 100 to 250. However, where the existing road contained relatively softer asphalt, CSS-1h emulsion with a residue penetration of 40 to 90 was used. The amount of added water was based on the dryness of the milled material. Water was added to obtain a moisture content in the loose material in the range of 3 to 5 percent.

A visual inspection of the projects about one year after their completion revealed that on the CMR-ACP projects covered with a single seal coat, potholes had developed where the seal coat was lost. Thus, application of at least two seal coats was considered advisable if a new overlay is not applied.

INDIANA'S EXPERIMENT [4]

In 1986 cold mix recycling was used in Indiana to widen and reconstruct 5 miles of a two lane rural highway (directional ADT under 2,500). The main objective of this project was to evaluate the effectiveness of cold recycled material as a base course to eliminate development of longitudinal "widening" cracking through the new ACP overlay. The original 10-ft. wide, 7-in. thick ACP lane was milled to a depth of 6 in. The recycled material was laid to a depth of 5 in. to allow a finish lane width of 12 ft. The entire pavement was then surfaced with a new ACP.

Construction

A motor grader cut the widening trench ahead of the recycling. The recycling train included a milling machine, water truck, asphalt truck, and paver. The milled material was mixed with water and asphalt emulsion in the miller head. Water was used to facilitate coating and to control dust. After the mixing, a conveyor belt discharged the material into a paver. After the paving, a pneumatic roller achieved most of the compaction. Subsequently, a vibratory roller ironed out the surface. The recycled pavement was left exposed to traffic for seven weeks before resurfacing because of delays. Generally, a two-week cure is recommended.

Evaluation

The existing ACP had an asphalt content of 5.6 percent with a viscosity of about 12,000 poise at 140°F and penetration of 36 at 77°F at the time of construction. The existing pavement was milled and crushed so that the maximum particle size was 1.5 in. Approximately 2 percent of asphalt emulsion was added during recycling. The emulsion was AE-150, a medium setting emulsion with a residue penetration of 100 to 300 at 77°F. The average moisture content of the recycled mix was 4.4 percent.

A visual inspection after one year of service showed no signs of reflective cracking, widening cracking, or rutting. Cores of the recycled pavement were taken for laboratory testing. The average percentage of air voids in the CMR-ACP was 5 percent. The average Hveem stability (uncorrected R-value at 77°F) was 91.

OHIO'S EXPERIMENT [5]

In 1985 approximately 2 miles of a low volume road in Ohio were experimentally reconstructed with the cold recycling technique. The road was built in 1968 as a 6-in., full depth ACP on subgrade. Before reconstruction, the pavement was cracked, rutted, and patched. The recycling produced a base course that was overlayed with ACP.

Construction

The recycling was done in a single pass. Four inches of the old pavement were milled, crushed, and passed through a 1-in. sieve. The millings were then mixed with Cyclogen ME rejuvenator (emulsified Cyclogen M) in the following trailer at a rate of 1.2 percent by total weight of mix. The mix was windrowed and aerated before it was spread by a grader. A vibratory roller then compacted the material. Traffic was allowed on the recycled pavement for at least 7 days, during which some soft areas failed and there were wheel track depressions. After necessary repairs were made, the surface was given a tack coat and 3 in. of ACP overlay were applied.

Evaluation

The average asphalt content of the old pavement was 5.3 percent, and its viscosity was 12,500 poise in 1985, the time of reconstruction. In 1986 and 1987 field cores were obtained from the CMR-ACP for laboratory tests to determine its characteristics. The average resilient modulus was 480,000 psi in 1986 and 270,000 psi in 1987, indicating about a 50 percent reduction in one year. (This is interesting, since the modulus is expected to increase in time as the asphalt ages.) The modulus of elasticity was reduced to almost zero after saturation and freeze-thaw cycling of the core samples. The 1986 cores showed an average void content of 14.3 percent. Fatigue tests on the 1986 core samples showed that the tensile strength of the CMR-ACP was about 10 psi for 10,000 load repetition, and about 3 psi for 100,000 load repetitions.

A visual inspection of the reconstructed pavement one month after the overlay revealed rutting and severe cracking in one location in a wheel track that had failed earlier before overlaying when traffic had been allowed on the pavement. The pavement showed no other problems 18 months after the reconstruction.

NEW MEXICO'S EXPERIMENTS [6]

In 1988 New Mexico reviewed the performance of 20 CMR-ACP projects that were in use in that state as early as 1984. Some of those projects were located in the interstate system and were subjected to high volume traffic. In general, the cold recycled material was considered an asphalt treated base overlaid with ACP. The main reason for cold recycling was to eliminate reflective cracking.

Construction

The cold recycling process consisted of milling the top 2- to 4-in. of the existing ACP. The milling machine towed two trailers. In the first trailer the milled material was crushed and screened so that 100 percent could pass a 11/4-in. sieve. In the second trailer the screened material was mixed with a high-float emulsion. High-float emulsions permit a thicker film on the aggregate, minimizing the possibility for drainage. They also make the viscosity less susceptible to temperature variation. The addition of a polymer to a high-float emulsion creates an even thicker film on the aggregate and makes the mix less susceptible to moisture and segregation. The high-float emulsion was normally added at rate of 0.8 percent to 3.5 percent by weight of aggregate. After the milled material was mixed, it was dropped into a windrow behind the train. The windrow was then picked up and fed into a conventional paver.

After the CMR-ACP was laid, rolling with a large pneumatic roller (35 to 45 tons) was followed by a steel wheel roller either in static or vibratory mode. Almost all of the compaction was achieved by the pneumatic roller. The steel roller was used as the finish roller. The rollers were held back about 1/4 mile to allow the emulsion to break and the water in the asphalt to separate before compaction. The use of a small pneumatic roller or a steel wheel roller for initial breakdown can seal the surface, trapping the moisture in the mix. Compaction was only a problem if there was too much moisture or too little emulsion in the mix. The maximum allowable moisture in the mix before compaction was 1 percent. The CMR-ACP was then overlaid with ACP. The thickness of the overlay varied from 1.5 in. to 4 in., depending on the project.

Evaluation

Cores taken from the projects after about four years of service revealed their engineering properties. The average compressive strength of the cores was about 250 psi, with 200 psi being the minimum acceptable for laboratory compacted cores. The average compressive strength for the laboratory made cores was about 450 psi. The average resilient modulus was about 700,000 psi, with a maximum of about 1,100,000 psi and a minimum of 300,000 psi. The average void content was about 9 percent, with a maximum of about 18 percent and a minimum of 4 percent. A field visual inspection was conducted in 1987. The 20 projects showed no sign of reflective cracking. Rutting was observed at isolated locations on one project. A coring operation revealed that the rutting was occurring in the new ACP overlay.

CHAPTER 3
BACKGROUND INFORMATION AND CONDITION OF WASHINGTON'S COLD-MIX RECYCLED ASPHALT CONCRETE TEST SECTIONS

WSDOT has constructed three experimental CMR-ACP projects. These are known as Valley to Chewelah (Contract 2294), County Well Road to Junction SR 22 (Contract 2340), and Brewster Airport to SR 17 (Contract 2421). The locations of the experimental projects within the state are shown in Figure 1. In all of the three projects, CMR-ACP was used as a treated base course, and it was overlaid with ACP wearing course. Table 1 presents tabulated background information on the three Washington CMR-ACP projects.

VALLEY TO CHEWELAH

This project was completed in 1982. Approximately 5 miles of the existing ACP were recycled. At the time of the reconstruction, the age of the existing AC was 20 years, its average thickness was 3.4 in., and its asphalt content was 5 percent. The existing pavement was severely cracked and spalled. After the top 4.2 in. of the roadway (3.4 in. ACP plus 0.8 in. of non-asphalt base course) were milled, the CMR-ACP was constructed and overlaid with 1.8 in. of class "F" ACP.

Construction

A milling machine milled the pavement while towing two trailers. In the first trailer the milled material was crushed and screened so that 100 percent could pass a 1.5-in. sieve. In the second trailer the screened material was mixed with ERA-75 emulsion (a recycling agent). Water was added to facilitate uniform mixing. After the milled material was mixed, it was dropped into a windrow behind the train. The windrow was then picked up and fed into a conventional paver. After paving and compacting and before overlaying, the CMR-ACP was opened to traffic for at least seven days to allow the emulsion to cure and water to evaporate. This project was rated the best in construction among the three projects.

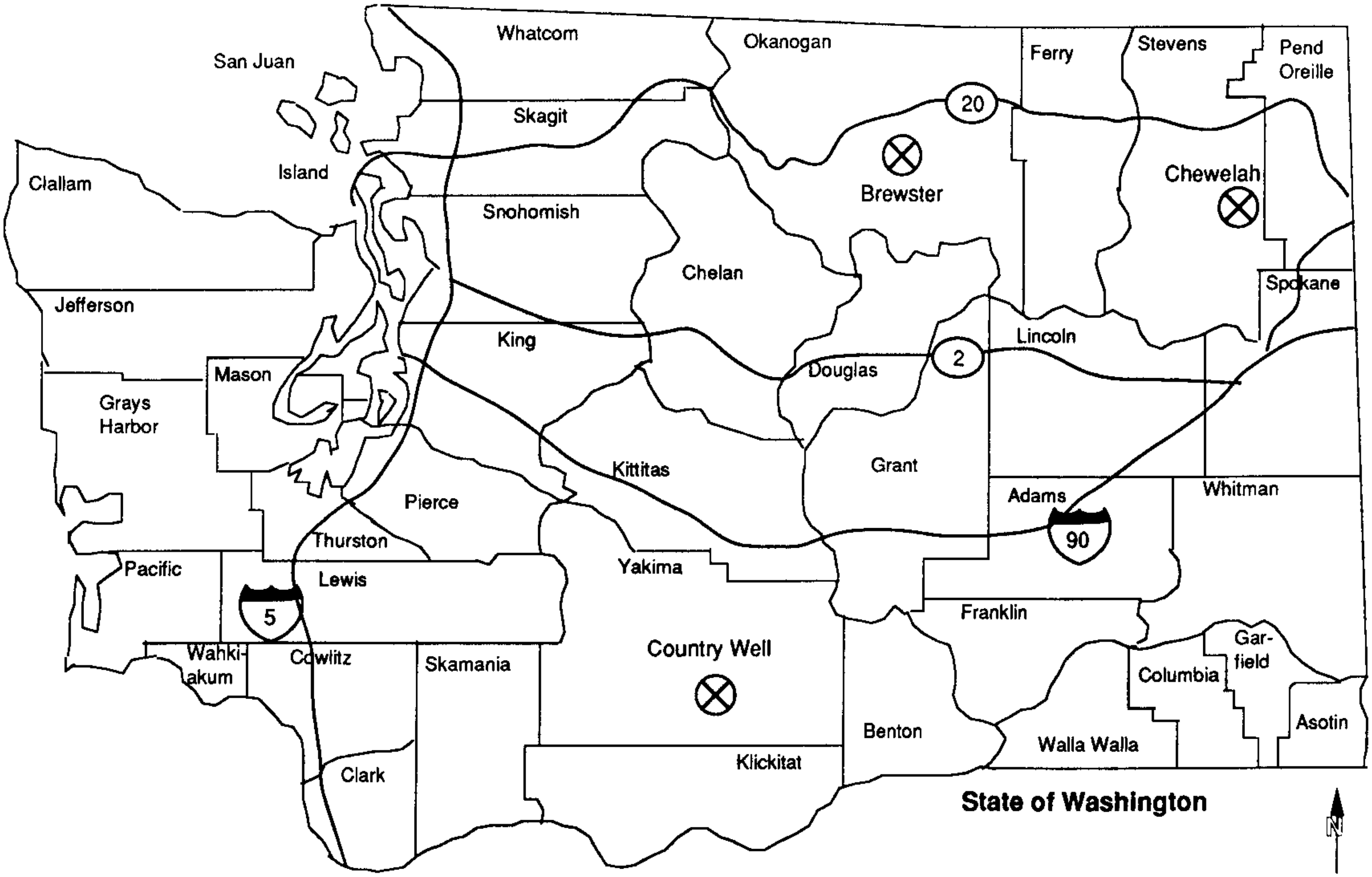

Figure 1. Location of WSDOT's Experimental Cold-mix Recycled Asphalt Concrete Pavements

Table 1. Summarized Background Information on Three Washington Cold-mix Recycled Asphalt Concrete Projects

		Project / Average Property	Chewelah	County Well	Brewster
Old Pavement		Year Built	1962	1979	1950
		Type	Class "B" ACP	BST	Army Corps ACP
		Thickness (in.)	3.4	1.2	3.2
		Binder content (%)	5.0	4.8	4.9
		Year recycled	1982	1982	1983
		Binder viscosity @ 140°F when recycled (poise)	154, 534	649	57,000
Recycled Pavement		Thickness (in.) [1]	4.2	2.5	4.4
		Binder content w/o emulsion [1]	4.1	2.6	3.8
	New Emulsion	Type	ERA - 75	CSS - 1h	CSS - 1
		Viscosity @ 140°F, residue (poise)	75	—	—
		Penetration @ 77°F, Residue	300+	40 - 90	100 - 250
		Content, target (%) [2]	3.2	5.5	3.25
		Residue content, target (%) [2]	1.9	3.3	2.0
		Water content	3% to 3.5% in RAP	6% limit	2% added, 6% limit

1. "Thickness" and "binder content" represent the old asphalt pavement plus the portion of non-asphalt granular top course included in the recycling.

2. Assuming the emulsion was distributed uniformly throughout the recycled mix.

Condition

The project was visually inspected in March of 1988. The road carries normal traffic, but with a high percentage of truck traffic (ADT of 4,750 and 17 percent trucks). Rutting was noticed in the wheel tracks. The average rut depth was roughly 1/4 in. However, severe local rutting had occurred in some locations, with a maximum rut depth of 1-3/8 in. Longitudinal cracking had occurred in many areas in the wheel tracks. This is an indication of the beginning of alligator fatigue cracking. Longitudinal cracking had also occurred in areas close to the paved shoulder. Note that WSDOT widened this roadway at the time of recycling by overlaying its existing BST shoulder. Under this condition, there is potential for a crack to develop and reflect through the overlay where the underlying CMR-ACP separates from the underlying BST shoulder. Some flushing was noticed in the Chewelah side. Generally, the condition of the pavement was fair six years after the recycling.

COUNTY WELL ROAD TO JUNCTION SR 22

This cold-recycling project was completed in 1982. Approximately 6 miles of the existing BST roadway were recycled. The existing BST was 3 years old at the time of reconstruction, and it had pot holes. The thickness of the BST was 1.2 in., and its asphalt content was 4.8 percent. After the top 2.5 in. of the roadway (1.2 in. of BST plus 1.3 in. of non-asphalt base course) was milled, the CMR-ACP was constructed and overlaid with 1.8 in. of class "B" ACP.

Construction

A miller pulverized the pavement in the first pass, and it mixed the millings with CSS-1h emulsion in the second pass. Water was added in the first pass for dust control. The maximum particle size was 1.5 in. Upon completion of the milling and mixing, the material was further mixed by windrowing with a grader. The grader then spread the recycled material to its proper shape. After the CMR-ACP was compacted, traffic was allowed for about eight days before overlaying. This time period was necessary to allow the emulsion to break and evaporation of the water. The final surface of CMR-ACP did not meet the specified 0.38-in. deviation in a 10-ft. straight edge. The irregularity was mainly due to wheel rutting. Therefore, the 1.8- in. overlay was applied in two lifts. The first lift was a 0.48-in. leveling course, followed by the remaining overlay. This project was considered the third best in construction among the three projects.

Condition

This project was visited and visually inspected in March of 1988. The road carries relatively light traffic, but the percentage of truck traffic is high (ADT of 3,050 and 30 percent trucks). Rutting was noticed in the wheel tracks, but it was insignificant. However, severe local rutting had occurred in some locations, with a maximum rut depth of 1-1/2 in. Some longitudinal cracking was observed in local areas in wheel tracks. This kind of cracking could initiate alligator (fatigue) cracking. However, the cracking was insignificant. Flushing was observed in the ACP overlay in many areas. In a few cases the flushing was accompanied with severe local rutting. Generally, the condition of the pavement was good after six years of service.

BREWSTER AIRPORT TO SR 17

The recycling project was approximately 2 miles long and was completed in 1983. The existing ACP was 33 years old at the time of the reconstruction, and it was severely cracked. The thickness of the ACP was 3.2 in., and its asphalt content was 4.9 percent. The recycling included milling the top 4.4 in. of the roadway (3.2 in. of ACP plus 1.2 in. of non-asphalt base course), constructing the CMR-ACP, and overlaying with 1.8 in. of class "B" ACP.

Construction

A milling machine pulverized the existing pavement in the first pass while adding water to the pulverized asphalt. The maximum particle size was 1.5 in. The moistened material was then windrowed with a grader, and CSS-1 emulsion was mixed in with the second pass of the miller. The addition of water was to facilitate uniform mixing. The pulverized material was loaded into trucks and transferred into a paver. After compaction, a poor ride resulted because of the uneven grade left in front of the paver by the loader. A grader was utilized to prepare a smooth track in front of the paver. The grader also followed the paver and bladed the surface in an attempt to eliminate some of the wrinkles. The CMR-ACP was opened to traffic for at least seven days to cure before overlaying. This resulted in raveling. To improve the quality of the remainder of the project, a few changes were made. The content of emulsifier was increased to reduce raveling, a new milling head was installed to produce a uniform gradation, and the pulverized ACP was spread to the proper grade by a grader instead of a paver. Those changes were effective and they resulted in improved ride. This project was rated the second best in construction among the three projects.

Condition

A visual inspection of this project in March of 1988 indicated that the pavement was in a very good condition after five years of service, with the exception of some local flushing in the overlay. This road carries relatively light traffic (ADT of 3,650 and 11 percent trucks).

CHAPTER 4
INTERPRETATION OF TEST DATA OF WASHINGTON'S COLD-MIX RECYCLED PAVEMENTS

In the summer of 1988 the WSDOT Materials laboratory obtained core samples from the three Washington cold-recycle projects for laboratory tests. A description of the core samples and the results of the laboratory tests that were conducted by the Materials Laboratory are provided in the appendix. The following is an analysis and interpretation of those results to determine the performance of Washington's cold-recycle projects and to suggest methods for improvement, if necessary.

VOIDS AND STABILITY

Asphalt concrete stability provides resistance against wheel rutting. The stability of an asphalt concrete that is saturated with a binder and has no voids in it is low. Thus, a certain void content is required to produce satisfactory stability. Generally in asphalt concrete, void contents in the range of 3 percent to 6 percent produce the maximum stability, depending on particle gradation. When the percentage of voids is increased above that range, the stability also decreases, but not as rapidly. Typically, field compacted conventional asphalt concrete has a void content in the range of 5 percent to 8 percent. The minimum required stability, based on Marshall and Hveem criteria (i.e., 750 lbs and a stabilometer value of 37, respectively), may be achieved at void contents as high as 10 percent at the expense of durability.

The stability values for the laboratory heated and compacted samples of the three CMR-ACP projects, prepared from their field samples, are given in Table 2. Those stability values are low, and, except in one case, they are less than the minimum required. However, the laboratory heated samples do not represent the field samples. A comparison of void content between the heated samples and the

Table 2. Average Void and Stability of Three Washington Cold-mix Recycled Asphalt Concrete Projects in 1988 (local severe rutting not included)

Average Property / Project		Chewelah	County Well	Brewster
Laboratory heated, compacted specimens	Hveem Stability	13	39	25
	Void Content (%)	0.2	5.8	1.6
	Total Binder Content [1]	6.0	3.5	5.4
Field specimens	Void Content (%)	9.8	12.0	9.7
	Estimate of total effective binder content (%) [2]	~3.5	~3.0	~3.5
	Existing emulsion residue (%) [3]	1.9	0.9	1.6
	Estimate of existing binder acting as an effective binder (%) [4]	~1.6	~2.1	~1.9

1. Original binder plus existing emulsion residue determined by extraction.
2. This is the amount of asphalt that actually participates as binder in the mix. It is determined by using void contents of field samples in Figure 2. This is done after subtracting 3% from field void contents to adjust for laboratory compaction.
3. Total binder content (see item 1 in Table 2) minus original binder content (see item 1 in Table 1).
4. Total effective binder content (see item 2 in Table 2) minus existing emulsion residue (see item 3 in Table 2).

field samples in Table 2 supports this opinion. The void contents of the field samples are significantly higher, even after considering that about 3 percent void content in the field samples are attributed to less aggressive compaction effort in the field. This is because in the heated samples all of the asphalts (i.e., the old asphalt and the added emulsion residue) participate in the mix as an effective binder; whereas, in the field samples the effective binder is the emulsion residue plus some of the old asphalt that might have participated in the recycled mix as an effective binder during the recycling process and/or service. This smaller amount of effective binder content, which produces higher void contents, can produce higher stabilities for the field samples than the laboratory heated samples.

As discussed previously, for the field samples of the Chewelah and Brewster projects, which had void contents in the range of 9.5 percent to 10 percent, as shown in Table 2, stability should not be a problem. For the field samples of the County Well project, the higher void content of 12 percent may produce marginal stability. However, this should not pose a major problem, since CMR-ACP is used as base course. The low to moderate rutting of the three test pavements supports this opinion.

Estimate of existing asphalt acting as an effective binder

In cold recycling the participation of existing asphalt in the mix as an effective binder is a complex process that depends on the properties of the emulsion and existing (aged) asphalt. Also, it is a function of the mechanical effects associated with mixing, compaction, traffic, and climate. [9]

A rough estimate may be made using the void contents of the field samples of the three projects to approximate the samples' corresponding effective binder contents. Such an approximation may be done by establishing a common relation between void content and effective binder content for those three mixes. This relation is possible because of the similarities in their aggregate gradations (see appendix). Figure 2 gives such relation, which was constructed with the three

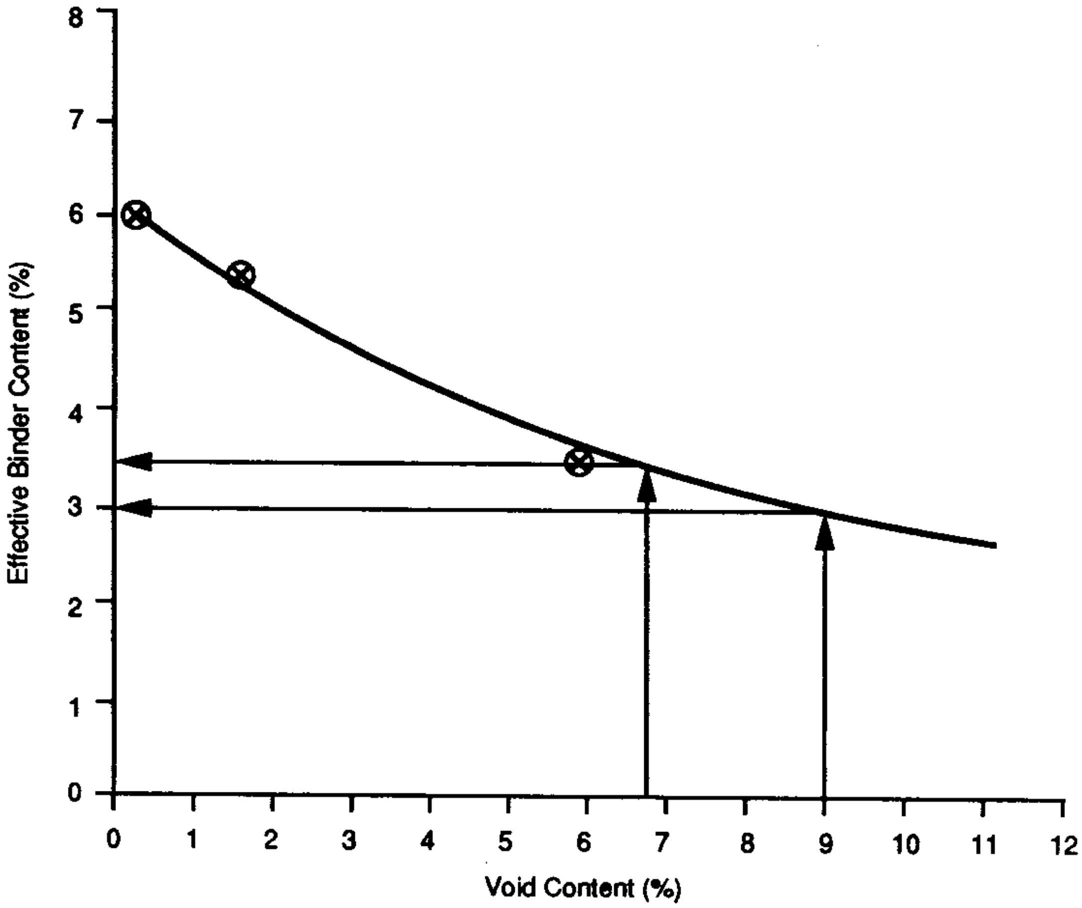

Figure 2. Relation between Void Content and Effective Binder Content of Three Washington Cold-mix Recycled Asphalt Concrete Projects

average data points available for the three mixes from their laboratory heated, compacted samples (Table 2). In Figure 2, the effective binder contents of the field samples of the three CMR-ACP projects are estimated from their void contents. However, before this was done, the void contents of the field samples (Table 2) were adjusted to represent laboratory compaction. This was done by assuming that laboratory compaction results in 3 percent less voids than field compaction for the same mix. The effective binder content, resulting from this procedure, as shown in Figure 2, is about 3.5 percent for the Chewelah and Brewster projects and about 3 percent for the County Well project.

On the other hand, the existing emulsion residue can be determined for those three projects as explained in Table 2. The difference between the estimated total effective binder content and the existing emulsion residue approximates the amount of the existing asphalt that has participated in the mix as an effective binder during the recycling process and/or service. As Table 2 indicates, the approximate amount of existing asphalt that acts as an effective binder is 1.6 percent and 1.9 percent for the Chewelah and Brewster projects, respectively, and approximately 2.1 percent for the County Well project. Both of the former projects used emulsions with lower viscosity residues in conjunction with hard, aged asphalts, as shown in Table 1. On the other hand, the latter project used an emulsion with higher viscosity residue in conjunction with a soft, aged asphalt (Table 1).

Severe local rutting

Severe local rutting had occurred in some locations in both the Chewelah and County Well projects. The maximum rut depth of those local areas was 1-3/8 in. for the Chewelah project and 1-1/2 in. for the County Well project. However, because of the repetition of traffic loads, the rutting of the County Well project should be considered more severe, regardless of its depth. Cores taken from the CMR-ACP in the rutted locations showed the presence of extremely high asphalt contents. The total asphalt content (i.e., the extracted asphalt, including the old asphalt and emulsion residue) in those locations was 7.2 percent for the Chewelah project and 9.5 percent for the County Well project. A comparison of those values of asphalt content with the average total asphalt contents for those two projects (Table 2) indicates that in the rutted locations the asphalt content was 1.2 percent more than the average for the Chewelah project and 6.0 percent more than the average for the County Well project. That increase in the asphalt content is due to excessive use of emulsion in those locations, which lowered the stability of the CMR-ACP and caused rutting. This opinion is further supported by the results on the viscosity of the extracted asphalt in the rutted locations, as discussed in the next section.

A final note: the extreme concentration of asphalt in the rutted areas of the County Well project is an indication of an extremely non-uniform distribution of the emulsion in its CMR-ACP mix. This can be a reason for the higher void content of CMR-ACP in the non-rutting areas of this project (i.e., 12 percent, Table 2). This also explains the difference between the target residue content of 3.3 percent (Table 1) and the average existing emulsion residue of 0.9 percent (Table 2) estimated for the non-rutting areas of the County Well project.

FLEXIBILITY

The flexibility of asphalt concrete contributes to its fatigue life. In time the binder in an aging asphalt concrete pavement becomes hard and impairs its flexibility. Recycling agents are used in hot-mix recycling to reduce the viscosity of the old asphalt and make it softer. In cold-mix recycling the reduction in viscosity must take place during the existing asphalt's participation in the mix as part of an effective binder. If that participation does not occur, then only the emulsion residue will function as an effective binder, and the old asphalt and aggregate will act as "black aggregate." In that case, the flexibility of the asphalt concrete will depend on the viscosity of the emulsion residue and its content. However, as Table 3 indicates,

Table 3. Average Binder Viscosity and Flexibility of Three Washington Cold-mix Recycled Asphalt Concrete Projects in 1988

Project Average Property		Chewelah	County Well	Brewster
New emulsion	Viscosity @ 140° F, residue (poise)	75	—	—
	Penetration @ 77° F, residue	300+	40-90	100-250
Extracted asphalt from field samples	Viscosity @ 140° F (poise)	21,200	23,500	48,700
	Penetration @ 77° F	25	22	15
Pavement	Resilient Modulus (psi)	212,000	306,000	524,000
	Resilient Modulus after saturation (psi)	161,000	202,000	429,000
	Ratio of saturated to dry Modulus of Resilience	0.76	0.66	0.82

there is no correlation between the viscosity of the emulsion residue and the resilient modulus values of the three CMR-ACP projects. For example, while the Brewster project had a higher penetration emulsion residue than the County Well project (Table 3), its modulus value is higher than that of the County Well project. The higher modulus value is not because of a low effective binder content, since the Brewster project had a lesser void content and consequently a higher effective binder content than the County Well Project (Table 2). On the other hand, as Table 3 shows, there is a correlation between the modulus values and the penetration of the extracted asphalt. Although the extracted asphalt does not completely represent the effective binder, it inherits the characteristics of the effective binder, since it comprises both the emulsion residue and aged old asphalt.

This analysis implies that the higher resilient modulus of the Brewster project is primarily caused by the higher viscosity of its old asphalt (Table 1) and supports the idea that some participation of the old asphalt in the mix occurs during the recycling process.

After 5 to 6 years of service, the resilient modulus of the three CMR-ACP projects varied from 212,000 psi to 524,000 psi, as shown in Table 3, and it averaged 347,000 psi. Mahoney et al. reported the resilient modulus for 16 non-overlaid ACP test sections in Washington. [6] This project analyzed their data and found that the average resilient modulus for those test sections was 350,000 psi for an average service period of 12 years. Peters et al. reported the resilient modulus of three Washington experimental overlaid HMR-ACP projects. [7] After six years of service the HMR-ACP projects had an average resilient modulus of 258,000 psi. This discussion shows that the flexibility of the CMR-ACP projects was slightly lower than that of the HMR-ACP projects. Also, the CMR-ACP projects were less flexible than the ACP test sections, in light of the age and exposure factor. Information obtained in the current work suggests that the flexibility of CMR-ACP can increase when the amount of emulsion residue increases and the residue's and old asphalt's viscosity decreases.

Severe local rutting

As discussed earlier, two of the CMR-ACP projects had some local severely rutted locations that had higher than average extracted asphalt contents. Table 4 presents the binder viscosity and flexibility of the CMR-ACP in the rutted locations. A comparison of Table 4 with Table 3 indicates that the modulus of elasticities of the rutted CMR-ACP were from 1/4th to 1/6th of the modulus of elasticities of the sound CMR-ACP. Also, that comparison indicates that the extracted asphalts from the rutted CMR-ACP had viscosities about 1/10th of the viscosity of asphalt extracted from the sound CMR-ACP. This discussion leads to the further point that

Table 4. Binder Viscosity and Flexibility of Severely Rutted Areas of Washington Cold-mix Recycled Asphalt Concrete Projects in 1988

Average Property \ Project		Chewelah	County Well
New emulsion	Viscosity @ 140° F, residue (poise)	75	—
	Penetration @ 77° F, residue	300+	40-90
Extracted asphalt from field samples	Viscosity @ 140° F, (poise)	1,675	2,486
	Penetration @ 77° F	70	61
Pavement	Modulus of Resilience (psi)	55,000	53,000

in the rutted areas, more than usual emulsion was added, and that the addition of the emulsion increased the flexibility.

DURABILITY

The durability of dense graded asphalt concrete is related to its void content. A requirement for void content, based on the Marshall design procedure, is that the void content in asphalt concrete used for a base course should be limited to 8 percent for satisfactory durability. That limitation is for laboratory compacted specimens. For field samples, the limitation on void content can be higher. Among the three Washington CMR-ACP projects, the Chewelah and Brewster had void contents between 9.5 percent and 10 percent after 5 to 6 years of service (Table 2). These contents may be considered the upper limit for field samples for satisfactory durability. The County Well project, on the other hand, had a 12 percent void content after 6 years of service, which should not be considered as satisfactory as the other two projects. Although County Well project has performed satisfactorily to date, the future performance is of concern with regard to water damage, due to its high void content and the results from the ratio of saturated to dry resilient modulus. The effects of void content on the durability of the CMR-ACP projects is evidenced by comparing their dry and saturated modulus of resilience, as shown in Table 3. While the decrease in modulus values after saturation was from 18 percent to 24 percent for the Chewelah and Brewster projects, (9.5 percent to 10 percent of voids), it was 34 percent for the County Well project (12 percent of voids).

Peters et al. reported the void contents of three Washington overlaid HMR-ACP projects after six years of service. [7] The average void content for the three projects was about 6 percent. That void content is lower than that obtained for Washington's CMR-ACP projects, and it is considered satisfactory as far as the durability of HMR-ACP is concerned. The lower void content of HMR-AC is a result of its higher effective binder content produced by heating of the old asphalt. If the production of a satisfactory void content in CMR-ACP is not feasible or desirable, then in consideration of durability, measures should be taken to minimize the intrusion of water into the base course, such as overlaying CMR-ACP with a dense asphalt concrete with a minimum void content.

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J.P. Walter, Bituminous Testing Engineer, WSDOT Materials Laboratory, developed the initial work plan, supervised the laboratory testing, and served as WSDOT technical monitor for the project. Ronald Schultz, Special Projects Engineer, WSDOT Materials Laboratory, conducted the field activities.

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APPENDIX

RESULTS OF LABORATORY TESTS ON CORE SAMPLES OF THREE WASHINGTON COLD-MIX RECYCLED ASPHALT CONCRETE PAVEMENTS

RECYCLING ACP - COLD MIX

Contracts	2294;	2340;	2421
SR numbers	395;	221;	97

* DESCRIPTION OF WORK TO BE DONE ON COLD RECYCLE CORES *

Note: Each contract has approximately 15 core sets. Each set has three cores - A, B and C.

The only labeling on the cores is on the bags.

1.) Designate each core in a set as A, B and C.

2.) Record any remarks about the core found on the bag.

3.) Label each core with
  a. contract number
  b. core number
  c. A, B or C letter designation.

4.) Carefully split off the top lift (s) and any lifts below the targeted recycle lift. Save any lifts above recycled lift discard any lifts found below.

5.) Core A: Do a 77 deg. Mr analysis and then saturate the core using the lottman desiccators and then do another 77 deg. Mr.

6.) Core B: Do bulk densities and rice densities on these cores. Save the core material.

7.) Heat and combine Cores A, B and C: Split out samples for...

  a. Compaction, bulk density and stability.

  b. Extraction (asphalt % and gradation)
  Abson (77 deg Pen and 140 deg Visc)

NOTE: **SAVE ALL CORE MATERIAL, ABSON MATERIAL AND AGG. FROM EXT.!**

Contract 2294 SR-395 Valley to Chewelah

Cold Recyle Completed 1982

CORE SET #	M.P.	LOCATION*	COMMENTS
1	203.41	4	Longitudinal crack left wheel path NB
2	203.65	3	Sound pavement - longitudianl crack right wheel path SB
3	203.94	2	Sound pavement A - 1/8" RUT
4	204.09	1	Flushed A - Flushed 5/16" RUT
5	204.32	4	Some longitudinal A - 1/4" RUT cracking - mottled surf
6	204.59	3	Sound pavement A - 3/8" RUT
7	204.79	2	Sound pavement A - 3/8" RUT
8	205.04	1	Sound pavement A - 5/16" RUT
9	205.28	4	Sound pavement A - 1/4" RUT
10	205.51	3	Sound pavement A - 1/4" RUT
11	205.83	2	Longitudinal cracking A - 7/16" RUT
12	205.96	1	Sound pavement A - 3/16" RUT
13	206.12	4	Sound pavement A - 5/16" RUT
14	206.23	3	Sound pavement 14 A - 3/16" RUT
15	206.35	2	Longitudinal cracking A - 3/8" RUT
SH SAG hump	207.32	1	One core each in sag and hump - 1 3/8" rut - SAG 1 5/8"
C1 crack 1	205.92	4	Core taken thru crack 1/4" WIDE 4" DE
C2 crack 2	206.34	1	Core taken thru crack 1/8" WIDE 4" DEEP

*LOCATION
1 = NB Outside wheel path
2 = NB Inside wheel path
3 = SB Inside wheel path
4 = SB Outside wheel path

Hump
Sag - 1 3/8"
Crack 2 - 1/8" wide 4" deep
Crack - 1/4" wide 4" deep

A's - all ME's
B's - Bulk Recs
C's - Hold (plastic box)

Stripping had
taken place

COLD RECYCLED ACP CORE DATA

CORE #	CONT #	MILE POST	LIFT HT	BULK LBS/CF	RICE LBS/CF	% RICE DENSITY	% AIR VOIDS
CH 1B	C 2294	203.41	0.29	135.1	148.6	90.9	9.1
CH 2B	C 2294	203.65	0.30	133.6	148.4	90.0	10.0
CH 3B	C 2294	203.94	0.32	133.1	149.6	89.0	11.0
CH 4B	C 2294	204.09	0.32	131.4	148.2	88.7	11.3
CH 5B	C 2294	204.32	0.31	137.0	148.3	92.4	7.6
CH 6B	C 2294	204.59	0.36	138.5	149.1	92.9	7.1
CH 7B	C 2294	204.79	0.33	133.3	148.0	90.1	9.9
CH 8B	C 2294	205.04	0.45	135.1	148.5	91.0	9.0
CH 9B	C 2294	205.28	0.34	135.6	149.9	90.5	9.5
CH 10B	C 2294	205.51	0.35	135.2	149.0	90.7	9.3
CH 11B	C 2294	205.83	0.39	136.3	149.0	91.5	8.5
CH 12B	C 2294	205.96	0.31	132.0	148.8	88.7	11.3
CH 13B	C 2294	206.12	0.29	133.8	148.4	90.2	9.8
CH 14B	C 2294	206.23	0.34	131.9	150.5	87.6	12.4
CH 15B	C 2294	206.35	0.29	132.1	148.9	88.7	11.3

Core densities not done on cores numbered CH SAG, CH HUMP, CH CRACK 1 and CH CRACK 2.

RECOMPACTED COLD RECYCLED CORES
* STABILITIES AND VOIDS *

August 8, 1988

CORE #	CONT #	MILE POST	#200	% ASPH	BULK LBS/CF	RICE LBS/CF	% AIR VOIDS	STAB.	VISUAL
CH 1	C 2294	203.41	8.9	6.5	147.8	148.6	0.5	4	N
CH 2	C 2294	203.65	7.5	5.9	149.2	148.4	-0.5	14	N
CH 3	C 2294	203.94	7.5	5.1	149.4	149.6	0.1	20	NR
CH 4	C 2294	204.09	7.2	6.2	148.8	148.2	-0.4	17	R
CH 5	C 2294	204.32	7.8	6.6	148.1	148.3	0.1	4	R
CH 6	C 2294	204.59	8.5	6.4	148.7	149.1	0.3	3	
CH 7	C 2294	204.79	7.6	6.2	148.0	148.0	0.0	12	NR
CH 8	C 2294	205.04	8.1	6.5	149.0	148.5	-0.3	4	NR
CH 9	C 2294	205.28	7.8	6.1	149.5	149.9	0.3	14	R
CH 10	C 2294	205.51	8.0	6.1	149.0	149.0	0.0	11	R
CH 11	C 2294	205.83	8.4	6.2	148.5	149.0	0.3	4	R
CH 12	C 2294	205.96	6.9	5.7	149.2	148.8	-0.3	14	R
CH 13	C 2294	206.12	7.7	6.7	148.2	148.4	0.1	13	R
CH 14	C 2294	206.23	7.1	4.8	147.8	150.5	1.8	48	DN
CH 15	C 2294	206.35	7.5	5.7	148.8	148.9	0.1	17	R
CH HUMP	C 2294	207.32	8.9	6.1	150.3	151.8	1.0	6	R

D=DRY N=NORMAL R=RICH

Insufficient material in cores numbered CH SAG, CH Crack 1 & CH Crack 2 to do compactions (bulk densities and stabilities).

COLD RECYCLED ACP CORE EXTRACTIONS

August 8, 1988

LAB #	5/8"	1/2"	3/8"	1/4"	#10	#40	#80	#200	ASPH %	S/S	77 F. PEN	140 F. VISC.
CH 1	100	100	95	80	47	27	17	8.9	6.5	5.3	30	7496
CH 2	100	99	90	73	42	23	14	7.5	5.9	5.6	21	15180
CH 3	100	99	88	70	42	23	14	7.5	5.1	5.6	14	28680
CH 4	99	98	89	69	39	22	13	7.2	6.2	5.4	21	16280
CH 5	100	100	91	75	44	24	15	7.8	6.6	5.6	29	8107
CH 6	100	100	90	74	44	25	15	8.5	6.4	5.2	49	3179
CH 7	100	100	90	74	45	24	14	7.6	6.2	5.9	36	6062
CH 8	100	100	92	76	45	25	15	8.1	6.5	5.6	29	6589
CH 9	100	99	92	78	47	25	15	7.8	6.1	6.0	17	23680
CH 10	100	100	92	78	46	25	15	8.0	6.1	5.8	30	7946
CH 11	100	100	94	78	48	27	16	8.4	6.2	5.7		
CH 12	100	99	88	70	40	22	13	6.9	5.7	5.8		19330
CH 13	100	99	91	78	46	25	15	7.7	6.7	6.0	18	20980
CH 14	100	100	91	74	44	23	14	7.1	4.8	6.2	9	64950
CH 15	100	99	92	76	43	24	14	7.5	5.7	5.7	18	65480
CH SAG	100	99	91	77	47	27	17	10.6	7.2	4.4	66	1857
CH HUMP	100	97	89	76	47	27	16	8.9	6.1	5.3	74	1492
CH CRACK 1	100	99	94	79	46	25	15	8.1	6.0	5.7		25151
CH CRACK 2	100	99	92	78	47	26	15	7.0	6.3	6.7		20211

Asphalt material from core number CH 10 was contaminated and was unable to be recovered for 77 F. Pen. or 140 F. Visc.

Insufficient material recovered from cores numbered CH 11, CH CRACK 1 and CH CRACK 2 in order to do 77 F. Pen. tests.

RESILIENT MODULUS RESULTS

August 8, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
CH 1A	C 2294	MP 208.41	1	77	170,549	120,066	145,308
CH 2A	C 2294	MP 203.65	2	77	312,282	343,125	327,704
CH 3A	C 2294	MP 203.94	3	77	447,516	516,365	481,941
CH 4A	C 2294	MP 204.09	4	77	227,616	235,465	231,541
CH 5A	C 2294	MP 204.32	5	77	159,297	147,176	153,237
CH 6A	C 2294	MP 204.59	6	77	71,895	56,078	63,987
CH 7A	C 2294	MP 204.79	7	77	213,793	185,287	199,540
CH 8A	C 2294	MP 205.04	8	77	128,059	128,059	128,059
CH 9A	C 2294	MP 205.28	9	77	195,726	182,849	189,288
CH 10A	C 2294	MP 205.51	10	77	139,721	146,686	143,204
CH 11A	C 2294	MP 205.83	11	77	141,833	126,232	134,033
CH 12A	C 2294	MP 205.96	12	77	219,138	224,806	221,972
CH 13A	C 2294	MP 206.12	13	77	187,814	138,389	163,102
CH 14A	C 2294	MP 206.23	14	77	370,575	402,338	386,457
CH 15A	C 2294	MP 206.35	15	77	237,690	196,491	217,091
CH SAG	C 2294	MP 207.32	SAG	77	61,971	55,586	58,779
CH HUMP	C 2294	MP 207.32	HUMP	77	54,475	49,936	52,206

All modulus values are in PSI.

Unable to do Resilient Modulus testing on CH CRACK 1 or CH CRACK 2 do to cracks in the cores.

RESILIENT MODULUS RESULTS

August 8, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
CH 1A	C 2294	203.41	SATURATED 1	77	111,172	119,665	115,419
CH 2A	C 2294	203.65	SATURATED 2	77	187,188	229,023	208,106
CH 3A	C 2294	203.94	SATURATED 3	77	138,638	116,515	127,577
CH 4A	C 2294	204.09	SATURATED 4	77	221,061	250,777	235,919
CH 5A	C 2294	204.32	SATURATED 5	77	142,529	130,928	136,729
CH 6A	C 2294	204.59	SATURATED 6	77	64,253	56,510	60,382
CH 7A	C 2294	204.79	SATURATED 7	77	218,013	222,287	220,150
CH 8A	C 2294	205.04	SATURATED 8	77	133,002	127,132	130,067
CH 9A	C 2294	205.28	SATURATED 9	77	164,042	155,297	159,670
CH 10A	C 2294	205.51	SATURATED 10	77	126,846	143,537	135,192
CH 11A	C 2294	205.83	SATURATED 11	77	149,244	152,133	150,689
CH 12A	C 2294	205.96	SATURATED 12	77	147,734	162,480	155,107
CH 13A	C 2294	206.12	SATURATED 13	77	235,404	210,297	222,851
CH 14A	C 2294	206.23	SATURATED 14	77	182,971	184,699	183,835
CH 15A	C 2294	206.35	SATURATED 15	77	200,369	184,956	192,663
CH SAG	C 2294	207.32	SATURATED SAG	77	52,112	53,849	52,981
CH HUMP	C 2294	207.32	SATURATED HUMP	77	49,215	41,485	45,350

All modulus values are in PSI.

Unable to do Resilient Modulus testing on CH CRACK 1 or CH CRACK 2 do to cracks in the cores.

~~[illegible]~~

Contract 2340 SR-221 County Well Road to Jct. SR-22

Cold Recyle Completed 1982

CORE SET #	M.P.	LOCATION*	COMMENTS
1	21.61	4	Sound pavement
2	21.45	3	Sound pavement ← C. sent movable to wet water drilling destroyed core
3	21.23	2	Sound pavement
4	21.03	1	Sound pavement
5	20.84	4	Flushed
6	20.64	3	Sound pavement
7	20.45	2	Sound pavement
8	20.16	1	Sound pavement
9	19.91	4	Flushed
10	19.67	3	Flushed
11	19.40	2	Sound pavement
12	19.17	1	Sound pavement
13	18.90	4	Sound pavement
14	18.49	3	Sound pavement
15	18.02	2	Sound pavement
SH	17.66	4	One core each in sag and hump - 1 1/2" rut

*LOCATION
1 = NB Outside wheel path
2 = NB Inside wheel path
3 = SB Inside wheel path
4 = SB Outside wheel path

ME's ARE MARKED (ME)
BUCKS & RICKS MARKED (B)
HOLDS ARE IN PLASTIC BAG

COLD RECYCLED ACP CORE DATA

CORE #	CONT #	MILE POST	LIFT HT	BULK LBS/CF	RICE LBS/CF	% RICE DENSITY	% AIR VOIDS
CW 1A	C 2340	21.61	0.16	145.4	166.9	87.1	12.9
CW 2A	C 2340	21.45	0.22	140.3	166.4	84.3	15.7
CW 3B	C 2340	21.23	0.29	138.4	153.6	90.1	9.9
CW 4B	C 2340	21.03	0.20	140.8	162.9	86.4	13.6
CW 5B	C 2340	20.84	0.16	139.4	160.1	87.1	12.9
CW 6A	C 2340	20.64	0.21	142.9	159.1	89.8	10.2
CW 7C	C 2340	20.45	0.20	137.0	164.9	83.1	16.9
CW 8B	C 2340	20.16	0.12	145.6	161.3	90.3	9.7
CW 9B	C 2340	19.81	0.21	147.7	161.1	91.7	8.3
CW 10B	C 2340	19.67	0.24	142.3	163.3	87.1	12.9
CW 11B	C 2340	19.40	0.12	149.8	160.8	93.2	6.8
CW 12C	C 2340	19.17	0.20	137.6	162.7	84.6	15.4
CW 13A	C 2340	18.90	0.16	144.1	159.9	90.1	9.9
CW 14B	C 2340	18.49	0.30	144.3	163.1	88.5	11.5
CW 15B	C 2340	18.02	0.21	140.5	161.6	86.9	13.1

Core densities not done on cores numbered CW SAG or CW HUMP.

RECOMPACTED COLD RECYCLED CORES
* STABILITIES AND VOIDS *

August 8, 1988

CORE #	CONT #	MILE POST	#200	% ASPH	BULK LBS/CF	RICE LBS/CF	% AIR VOIDS	STAB.	VISUAL
CW 1	C 2340	21.61	5.0	3.0	149.0	166.9	10.7	42	D
CW 2	C 2340	21.45	5.4	3.7	150.2	166.4	9.7	46	D
CW 3	C 2340	21.23	5.9	4.8	154.2	153.6	-0.4	27	D
CW 4	C 2340	21.03	6.7	4.1	152.3	162.8	6.5	41	DN
CW 5	C 2340	20.84	8.2	4.9	155.3	160.1	3.0	31	N
CW 6	C 2340	20.64	7.4	5.1	155.9	159.1	2.0	24	R
CW 7	C 2340	20.45	6.5	3.5	148.9	164.9	9.7	51	D
CW 9	C 2340	19.91	7.0	4.0	154.1	161.1	4.3	36	N
CW 10	C 2340	19.67	6.1	3.4	150.5	163.3	7.8	46	D
CW 12	C 2340	19.17	6.6	3.8	151.9	162.7	6.6	54	D
CW 13	C 2340	18.90	6.7	4.9	154.4	159.9	3.4	32	D
CW 14	C 2340	18.49	6.0	3.3	151.5	163.1	7.1	42	D
CW 15	C 2340	18.02	5.9	4.5	153.6	161.6	5.0	41	DN

D=DRY N=NORMAL R=RICH

Insufficient material in cores numbered CW SAG, CW HUMP, CW 8 and CW 11 to do compactions (bulk densities & stabilities).

COLD RECYCLED ACP CORE EXTRACTIONS

August 5, 1988

LAB #	5/8"	1/2"	3/8"	1/4"	#10	#40	#80	#200	ASPH %	S/S	77 F. PEN	140 F. VISC.
CW 1	100	97	88	67	32	14	8	5.0	3.0	6.4		23160
CW 2	100	99	86	69	37	16	9	5.4	3.7	6.9		23470
CW 3	97	91	84	69	38	19	11	5.9	4.9	6.4	15	31510
CW 4	100	99	93	76	39	17	11	6.7	4.1	5.8	23	13490
CW 5	100	100	95	83	45	20	13	8.2	4.9	5.5	18	22730
CW 6	99	98	91	73	38	18	12	7.4	5.1	5.1	19	20520
CW 7	97	94	90	77	40	17	11	6.5	3.5	6.2	8	83190
CW 8	100	99	91	77	41	18	11	6.9	5.1	5.9	23	13070
CW 9	100	97	91	74	37	17	11	7.0	4.0	5.3	24	11570
CW 10	100	98	92	76	37	17	10	6.1	3.4	6.1	31	7241
CW 11	100	100	93	75	40	17	12	7.7	3.1	5.2	39	5401
CW 12	100	99	92	75	37	17	11	6.6	3.8	5.6	9	61030
CW 13	100	98	93	72	40	19	11	6.7	4.9	6.0	19	17830
CW 14	100	97	89	71	34	16	10	6.0	3.3	5.7	33	7065
CW 15	99	97	87	70	36	16	10	5.9	4.5	6.1	24	11710
CW SAG	100	99	93	73	33	15	11	7.1	9.5	4.6	62	2500
CW HUMP	100	98	94	71	29	13	9	6.4	8.5	4.5	59	2471

RESILIENT MODULUS RESULTS

August 8, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
CW 8C	C 2340	20.16	8	77	443,203	478,659	460,931
CW 9C	C 2340	19.91	9	77	306,924	312,982	309,953
CW 10C	C 2340	19.67	10	77	306,560	285,546	296,053
CW 11A	C 2340	19.40	11	77	172,778	123,434	148,106
CW 12A	C 2340	19.17	12	77	458,291	464,204	461,248
CW 13B	C 2340	18.90	13	77	136,760	227,933	182,347
CW 14A	C 2340	18.49	14	77	299,119	270,226	284,673
CW SAG	C 2340	17.66	SAG	77	52,781	61,225	57,003
CW HUMP	C 2340	17.66	HUMP	77	56,078	43,042	49,560

All modulus values are in PSI.

Unable to resilient modulus testing on cores numbered CW 1, CW 2, CW 3, CW 4, CW 5, CW 6 or CW 7 because lift height measurements were not taken.

RESILIENT MODULUS RESULTS

August 5, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
CW 8C	C 2340	20.16	SATURATED 8	77	379,756	387,591	383,674
CW 9C	C 2340	19.91	SATURATED 9	77	203,050	215,481	209,266
CW 10C	C 2340	19.67	SATURATED 10	77	141,093	101,312	121,203
CW 11A	C 2340	19.40	SATURATED 11	77	101,363	108,993	105,178
CW 12A	C 2340	19.17	SATURATED 12	77	348,325	328,100	338,213
CW 13B	C 2340	18.90	SATURATED 13	77	126,046	151,255	138,651
CW 14A	C 2340	18.49	SATURATED 14	77	108,770	94,394	101,582
CW SAG	C 2340	17.66	SATURATED SAG	77	33,835	45,534	39,685
CW HUMP	C 2340	17.66	SATURATED HUMP	77	43,350	23,154	33,252

All modulus values are in PSI.

Unable to resilient modulus testing on cores numbered CW 1, CW 2, CW 3, CW 4, CW 5, CW 6 or CW 7 because lift height measurements were not taken.

Contract 2421 SR-97 Brewster Airport to SR-17

Cold Recyle Completed 1983

CORE SET #	M.P.	LOCATION*	COMMENTS
1	264.86	4	Sound pavement
2	264.71	3	Sound pavement
3	264.58	2	Flushed
4	264.45	1	Sound pavement
5	264.35	4	Sound pavement
6	264.20	3	Sound pavement
7	263.97	2	Sound pavement
8	263.84	1	Sound pavement
9	263.65	4	Sound pavement
10	263.52	3	Sound pavement → B - core cracked
11	263.35	2	Sound pavement
12	263.26	1	Flushed
13	263.16	4	Sound pavement
14	263.05	3	Sound pavement

*LOCATION
1 = NB Outside wheel path
2 = NB Inside wheel path
3 = SB Inside wheel path
4 = SB Outside wheel path

A's → me's

B's → Bulks & Ricers

C's → Hou's

COLD RECYCLED ACP CORE DATA

CORE #	CONT #	MILE POST	LIFT HT	BULK LBS/CF	RICE LBS/CF	% RICE DENSITY	% AIR VOIDS
BR 1B	C 2421	264.86	0.47	138.3	156.3	88.5	11.5
BR 2B	C 2421	264.71	0.48	139.1	156.0	89.2	10.8
BR 3B	C 2421	264.58	0.51	139.2	157.3	88.5	11.5
BR 4B	C 2421	264.45	0.45	138.9	156.9	88.5	11.5
BR 5B	C 2421	264.35	0.28	141.5	156.2	90.6	9.4
BR 6B	C 2421	264.20	0.43	144.0	153.2	94.0	6.0
BR 7B	C 2421	163.97	0.57	145.3	160.1	90.8	9.2
BR 8B	C 2421	263.84	0.41	142.3	155.2	91.7	8.3
BR 9B	C 2421	263.65	0.40	139.8	154.5	90.5	9.5
BR 10B	C 2421	163.52	0.44	144.9	153.7	94.3	5.7
BR 11B	C 2421	263.35	0.42	138.9	158.0	87.9	12.1
BR 12B	C 2421	263.26	0.39	143.9	154.8	93.0	7.0
BR 13B	C 2421	263.16	0.49	139.4	162.4	85.8	14.2
BR 14B	C 2421	263.05	0.40	142.1	156.5	90.8	9.2

RECOMPACTED COLD RECYCLED CORES
* STABILITIES AND VOIDS *

August 5, 1988

CORE #	CONT #	MILE POST	#200	% ASPH	BULK LBS/CF	RICE LBS/CF	% AIR VOIDS	STAB.	VISUAL
BR 1	C 2421	264.86	9.2	5.6	155.7	156.3	0.4	19	N
BR 2	C 2421	264.71	8.9	5.7	155.6	156.0	0.3	17	N
BR 3	C 2421	264.58	6.7	5.0	155.3	157.3	1.3	26	N
BR 4	C 2421	264.45	7.6	5.0	155.2	156.9	1.1	29	N
BR 5	C 2421	264.35	7.3	5.3	154.6	156.2	1.0	38	N
BR 6	C 2421	264.20	6.1	9.2	151.9	153.2	0.8	1	R
BR 7	C 2421	263.97	7.9	1.6	152.9	160.1	4.5	51	D
BR 8	C 2421	263.84	6.8	5.1	154.6	155.2	0.4	24	N
BR 9	C 2421	263.65	6.6	5.8	153.0	154.5	1.0	10	NR
BR 10	C 2421	263.52	7.3	6.0	155.0	153.7	-0.8	13	R
BR 11	C 2421	263.35	6.7	4.1	152.8	158.0	3.3	57	D
BR 12	C 2421	263.26	6.9	5.1	155.1	154.8	-0.2	21	N
BR 13	C 2421	263.16	6.9	5.8	153.4	162.4	5.5	32	N
BR 14	C 2421	263.05	6.5	6.5	153.3	156.5	2.0	10	R

D=DRY N=NORMAL R=RICH

COLD RECYCLED ACP CORE EXTRACTIONS

August 8, 1988

LAB #	5/8"	1/2"	3/8"	1/4"	#10	#40	#80	#200	ASPH %	S/S	77 F. PEN	140 F. VISC.
BR 1	98	97	86	70	43	24	16	9.2	5.6	4.7	16	41380
BR 2	99	96	88	70	43	23	15	8.9	5.7	4.8	13	53740
BR 3	97	94	80	61	36	18	11	6.7	5.0	5.4	18	27330
BR 4	98	94	85	69	40	20	12	7.6	5.0	5.3	12	58060
BR 5	98	94	83	65	39	19	12	7.3	5.3	5.3	17	24120
BR 6	100	95	85	68	41	21	13	7.6	6.9	5.4	22	17860
BR 7	97	90	76	59	38	22	14	7.9	3.8	4.8	11	82510
BR 8	95	94	78	62	38	20	12	6.8	5.1	5.6	13	56610
BR 9	93	89	78	62	39	20	12	6.6	5.8	5.9	9	66030
BR 10	97	95	84	69	43	22	12	7.3	6.0	5.9	34	7929
BR 11	100	97	86	66	39	20	12	6.7	4.1	5.8	7	139000
BR 12	98	94	80	65	38	19	12	6.9	5.1	5.5	14	37260
BR 13	99	96	88	74	44	21	13	6.9	5.8	6.4	13	37120
BR 14	97	94	80	63	37	19	11	6.5	6.5	5.7	16	33180

RESILIENT MODULUS RESULTS

August 4, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
BR 1A	C 2421	264.86	1	77.0	513,476	618,285	565,881
BR 2A	C 2421	246.71	2	77.0	385,303	277,277	331,290
BR 3A	C 2421	264.58	3	77.0	361,770	283,741	322,756
BR 4A	C 2421	264.45	4	77.0	390,582	365,544	378,063
BR 5A	C 2421	264.35	5	77.0	491,011	460,323	475,667
BR 6A	C 2421	264.20	6	77.0	392,978	236,357	314,668
BR 7A	C 2421	263.97	7	77.0	584,923	814,714	699,819
BR 8A	C 2421	263.84	8	77.0	284,777	234,393	259,585
BR 9A	C 2421	263.65	9	77.0	933,220	724,963	829,092
BR 10A	C 2421	263.52	10	77.0	174,885	127,328	151,107
BR 11A	C 2421	263.35	11	77.0	543,890	673,387	608,639
BR 12A	C 2421	263.26	12	77.0	708,559	684,847	696,703
BR 13A	C 2421	263.13	13	77.0	634,784	705,124	669,954
BR 14A	C 2421	263.05	14	77.0	491,011	701,291	596,151

All modulus values are in PSI.

RESILIENT MODULUS RESULTS

August 4, 1988

LAB #	CONT #	SITE #	SAMPLE #	TEMP	MR 0 DEG	MR 90 DEG	MR AVERAGE
BR 1A	C 2421	264.86	SATURATED 1	77	624,891	937,336	781,114
BR 2A	C 2421	264.71	SATURATED 2	77	468,668	611,306	539,987
BR 3A	C 2421	264.58	SATURATED 3	77	327,315	321,068	324,192
BR 4A	C 2421	264.45	SATURATED 4	77	264,073	357,160	310,617
BR 5A	C 2421	264.35	SATURATED 5	77	378,197	607,974	493,086
BR 6A	C 2421	264.20	SATURATED 6	77	243,418	260,105	251,762
BR 7A	C 2421	263.97	SATURATED 7	77	279,402	353,906	316,654
BR 8A	C 2421	263.84	SATURATED 8	77	183,318	176,030	179,674
BR 9A	C 2421	263.65	SATURATED 9	77	822,196	1,061,554	941,875
BR 10A	C 2421	263.52	SATURATED 10	77	122,699	121,411	122,055
BR 11A	C 2421	263.35	SATURATED 11	77	437,741	744,270	591,006
BR 12A	C 2421	263.26	SATURATED 12	77	1,102,057	772,118	937,088
BR 13A	C 2421	263.16	SATURATED 13	77	553,556	1,149,692	851,624
BR 14A	C 2421	263.05	SATURATED 14	77	547,845	861,586	704,716

All modulus values are in PSI.