Evaluation of Asphalt Additives: Lava Butte Road–Fremont Highway Junction

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In August 1985 an experimental road section that incorporated different asphalt additives was constructed near Bend, Oregon. Ten sections were constructed using mix designs furnished by the additive supplier or by the Oregon Department of Transportation (ODOT). In this paper are described the experimental study, including the mix design process, and the construction process, including quality control data and unit prices. Preliminary data on mix properties and field performance are also presented. Significant findings include (a) mix design techniques used by the additive suppliers are, in some cases, not well defined or documented; (b) mix design results obtained by ODOT after construction differ slightly from those recommended by the additive suppliers; (c) there were no major problems during construction of the different mixes; (d) there are significant differences in the preliminary mix properties of additive types; and (e) the performance of all of the test sections after 1 year is good.

A considerable number of Oregon highways are in need of a stable and durable overlay to regain an acceptable serviceability rating. Principal reasons for this include surfacing deficiencies such as fatigue cracking, raveling, deformation, and thermal distress. The primary overlay treatments to date have been thick (2- to 6-in.) dense-graded hot mixes on high-volume highways and open-graded cold mixes on lower volume highways. In recent years, thick hot asphalt concrete overlays have been effective in delaying reflective cracking but have experienced premature longitudinal cracking and stripping. Emulsion cold mixes, surface seals using cationic or high-float emulsions, and hot mixes with lime-treated aggregates have not appeared to exhibit these early performance problems *(1)*.

Today there are numerous additives being sold that are reported to improve the performance of asphalt concrete overlays by eliminating or reducing deformation, surface raveling (stripping is a major problem), and reflective or thermal cracking *(2)*. Because these additives usually add significantly to project costs, it is important to determine their effectiveness under field conditions and to evaluate the cost-effectiveness of their use.

In the summer of 1985, the Oregon Department of Transportation (ODOT) initiated a field study to investigate the use of various asphalt additives. The purpose of the study was twofold:

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1. To evaluate the effectiveness of 10 hot-mix overlay test sections, incorporating various additives to extend the life of asphalt concrete pavements, and
2. To determine the cost-effectiveness of each compared with a conventional asphalt concrete mix.

Products evaluated included

1. PlusRide® 12—coarse-ground rubber in a mix with modified aggregate gradation and asphalt containing Pave Bond (antistripping agent),
2. Arm-R-Shield—asphalt concrete containing fine-ground rubber in asphalt in a mix with conventional aggregate gradation,
3. Fiber Pave®—polypropylene fiber in a mix with asphalt containing Pave Bond and a conventional aggregate gradation,
4. BoniFibers®—polyester fiber in a mix with asphalt containing Pave Bond and a conventional aggregate gradation,
5. Pave Bond®—asphalt containing an antistripping agent in a mix with a conventional aggregate gradation,
6. Pave Bond® and lime—lime-treated aggregate and asphalt containing an antistripping agent in a mix with a conventional aggregate gradation,
7. Lime—lime-treated aggregate in a mix with a conventional aggregate gradation,
8. No additive—a conventional asphalt concrete mix,
9. CA(P)-1—polymer contained in asphalt in a mix with a conventional aggregate gradation, and
10. CA(P)-1 with lime—polymer contained in asphalt with lime-treated aggregate in a conventional mix.

In this paper are presented mix design, construction process, initial mix property, and performance data for the test sections. The project will continue to be monitored during the next 3 years to identify performance differences among the various materials.

DESCRIPTION OF PROJECT

The experimental project is located on US-97 (Oregon Highway 4) approximately 20 mi south of Bend (Figure 1). The weather in the area is considered very severe. Temperatures range from −10°F in the winter to 100°F in the summer, with daily temperature ranges of about 40°F. There are snow and ice from November through February *(3)*.

The test sections were part of an overlay project scheduled for a 20-mi section of roadway that was structurally inadequate and suffering considerable distress. An asphalt concrete overlay was selected to correct the deficiencies. Instead of using

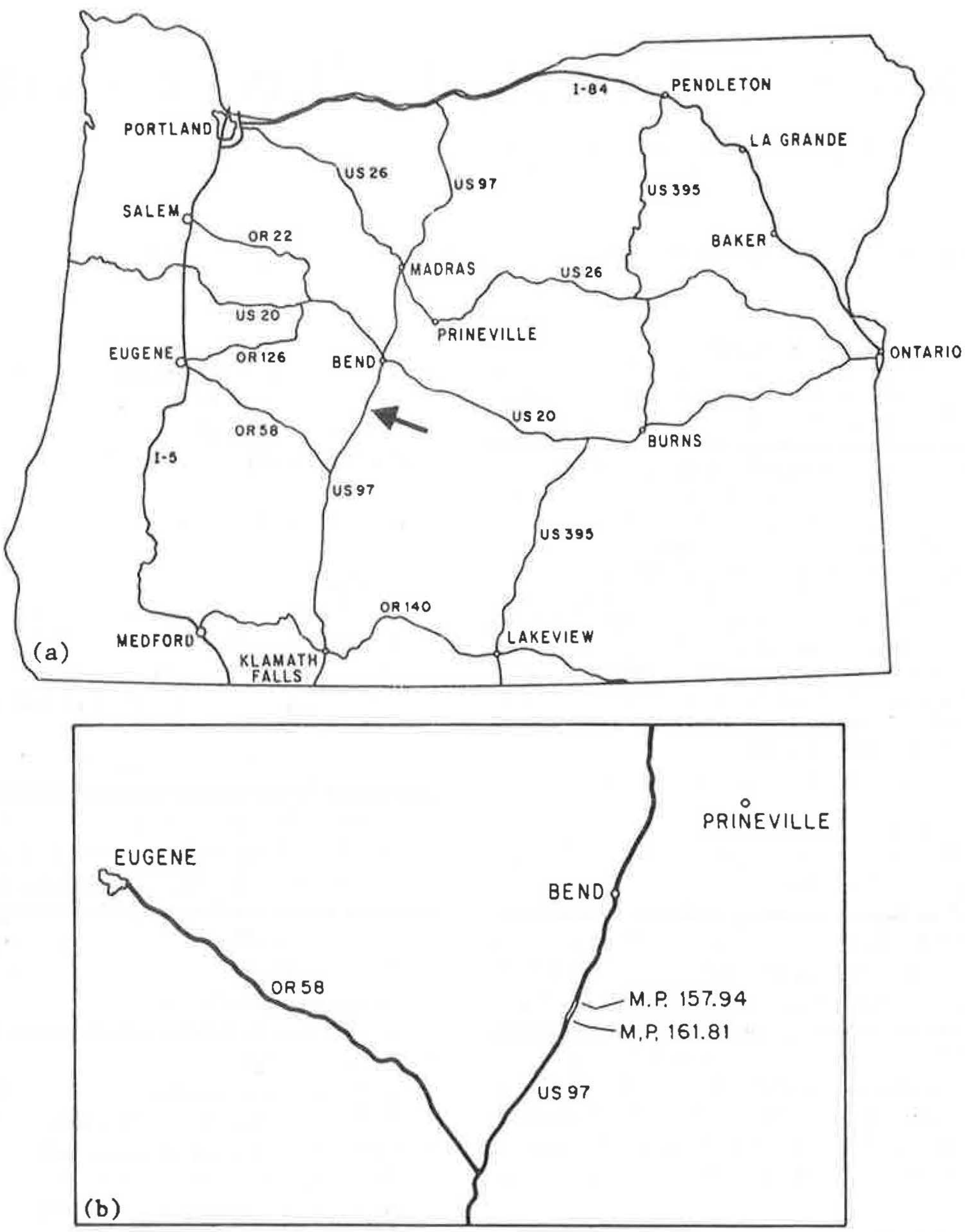

FIGURE 1 Location of asphalt additives test road: (a) general and (b) close up.

conventional asphalt concrete throughout the project, 10 sections with experimental features were placed for evaluation. Each test section was a minimum of 0.5 mi in length and included a 12-ft-wide travel lane. A 0.5-mi section of dense-graded hot mix with no additive served as the control. A layout of the test sites as they were actually constructed is shown in Figure 2. The 0.5-mi sections were selected for the following reasons:

1. The handling and placement characteristics of each material are different and adjustments would be necessary during construction and
2. It is advantageous to measure performance over long sections to minimize statistical errors.

Condition of Pavement

Before construction of the overlays, an extensive survey was made to evaluate the type and extent of distress along the existing pavement. Within each designated test section, a 250-ft site that represented conditions of the entire section was selected. For each 250-ft inspection site, a record of distress types, including a map of all cracks, was made *(4)*. Figure 2 also shows the general location of the inspection sites. In general, there was considerable alligator and thermal cracking as well as patching (Figure 3). The overall condition rating for the project was poor.

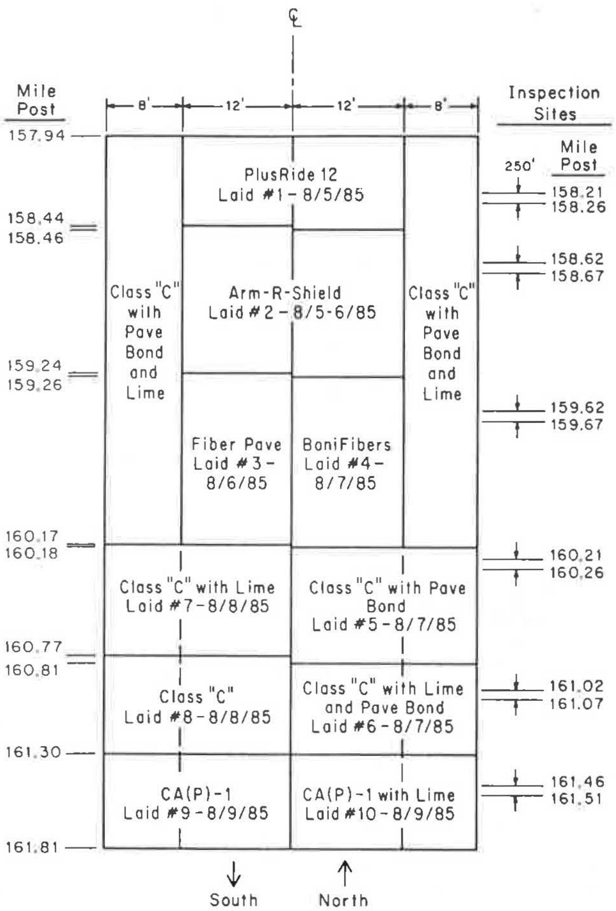

FIGURE 2 Layout of test sections.

Pavement Deflections

Pavement surface deflections to evaluate the structural adequacy of the existing roadway were taken before the overlay was placed. The ODOT Dynaflect was used to measure surface deflections. Deflection measurements were taken every 50 ft within each test section for a distance of about 500 ft. This 500-ft section was selected to overlap the 250-ft inspection site for evaluating pavement condition. In general, there was considerable variation among the sections in terms of structural adequacy. The deflection data were used to determine the overlay requirements, following a modification of the California overlay design procedure *(5–7)*. The recommended section is as folows:

1. Top lift (13/4 in.)—experimental feature,
2. Bottom lift (1½ in.)—Oregon Class-C mix, and
3. Leveling course (as needed)—Oregon Class-C mix.

MIX DESIGNS

Job Mix Designs

For each of the experimental sections, the additive supplier or the ODOT Materials Section recommended the job mix asphalt content and gradation. All mixes, except PlusRide, were designed using the C-mix aggregate gradation given in Tables 1 and 2. In some cases, both coarse and fine aggregate were treated by pug mill mixing dry lime and water. The 5-day minimum period for mellowing aggregates in a stockpile was extended to from 60 to 90 days to fit the contractor's operations.

TABLE 1 GRADATION OF MIX (% passing)

Gradation	C-Mix	PlusRide
3/4 in.	100	–
5/8 in.	–	100
1/2 in.	99	89
3/8 in.	89	76
1/4 in.	66	38
No. 10	32	31
No. 30	–	19
No. 40	14	17
No. 200	5.8	8.9

The asphalt cement used was an AC-20 from Chevron's Willbridge Refinery in Portland, Oregon. Properties of the AC-20 and its specification requirements are given in Table 3. This material was used in all experimental features except where the polymer-modified asphalt was used. Table 4 gives a summary of the properties of Chevron's CA(P)-1.

FIGURE 3 Typical pavement condition before overlay: (*top*) milepost 158.21 looking south and (*bottom*) milepost 158.26 looking north.

TABLE 2 AGGREGATE PROPERTIES AND SPECIFICATIONS

Property	Actual Coarse	Actual Fine	Specification Coarse	Specification Fine
Specific gravity (AASHTO T-85				
Bulk	2.57	2.63	–	–
Saturated surface dry	2.64	2.69	–	–
Los Angeles abrasion (AASHTO T-96) (%)	28.4	–	30 max	–
Sand equivalent (AASHTO T-176)	–	–	–	–
Percentage crushed faces (OSHD T-213)	90	–	60 min	60 min
Sulfate soundness (OSHD T-206) (%)	0.6	2.7	12 max	12 max
Degradation (OSHD T-208)				
Passing No. 20 sieve (%)	21.9	10.8	30 max	30 max
Sediment height (in.)	0.3	0.3	3.0 max	4.0 max
Friable particles (AASHTO T-112) (%)	0.2	0.4	1.0 max	1.5 max

NOTE: OSHD = Oregon State Highway Division.

TABLE 3 PROPERTIES OF AC-20 ASPHALT CEMENT

Property	Actual	Specification
Viscosity at 140°F (poise)	2040	2000 ± 400
Viscosity at 275°F (cSt)	352	230 min
Penetration at 77°F (dmm)	58	50 min
Flash point, COC[a] (°F) (AASHTO T-73)	600	450 min
Solubility in trichloroethylene (%)	99.86	99 min
Tests on residue		
Viscosity at 140°F (poise)	6122	8000 max
Ductility at 77°F (cm)	–	75 min

[a]COC = Cleveland open cup.

The mix procedures and criteria for each experimental feature are given in Table 5. As noted, for some of the additives the mix design procedures and criteria are not well defined. The resulting asphalt contents are given in Table 6.

ODOT Mix Designs

After the project was constructed, ODOT performed detailed mix designs using their current mix design procedures *(8)*. This was done to verify the potential use of the current ODOT design method with modified asphalts. Mix design criteria used to evaluate the various experimental features (except PlusRide) are summarized as follows:

TABLE 4 PRELIMINARY PRODUCT SPECIFICATION, CHEVRON POLYMER ASPHALT CA(P)-1

Property	ASTM Test Method	CA(P)-1 Specification	CA(P)-1 Properties
Original test Properties			
Penetration at 77°F (dmm)	D 5	85 min	113
Viscosity at 140°F (poise)	D 2171	1600–2400	2092
Viscosity at 275°F (cSt)	D 2170	325 min	676
Flash point, COC (°F)	D 92	450 min	500
Ductility at 77°F (cm)	D 113	100 min	150+
Ductility at 39.2°F (cm) (5 cm/min pull rate)	D 113	25 min	32
Toughness (in.-lb)	–[a]	75 min	124
Tenacity (in.-lb)	–[a]	50 min	101
Properties After Rolling Thin-Film Oven Test			
Viscosity at 140°F (poise)	D 2872	10 000 max	4980
Ductility at 77°F (cm)	D 113	100 min	150+
Ductility at 39.2°F (cm) (5 cm/min pull rate)	D 113	8 min	13
Toughness (in.-lb)	–[a]	100 min	325
Tenacity (in.-lb)	–[a]	75 min	346

[a]Benson method of toughness and tenacity: 20 in./min pull rate, 7/8-in.-diameter tension head.

TABLE 5 MIX DESIGN PROCEDURES AND CRITERIA USED, ADDITIVE SUPPLIERS AND ODOT

Feature	Method	Compactive Effort	Additive	Design Criteria	Comments
PlusRide	Marshall	50 blows/side	3% rubber granules by weight of total mix	3% air voids	Mix is rich in asphalt and filler, has high coarse aggregate content, and is gap graded
Arm-R-Shield	Marshall	75 blows/side	20% rubber by weight of asphalt binder	Stability (lb): 1,500 min Flow: 8–18 in. × 10^{-3} Voids: 3–5%	Asphalt-rubber is reacted at elevated temperature before use Mix is rich in asphalt
Fiber Pave (polypropylene)	None given	–	0.3% fiber by weight of total mix	Asphalt content increased 0.3% over the standard mix	
BoniFibers (polyester)	None given	–	0.25% fiber by weight of total mix	Asphalt content increased 0.3% over the standard mix	
Chevron CA(P)-1	Hveem	150 blows/500 psi	5.0% of asphalt binder	Stability: 30 min Appearance: shiny	Polymer with and without lime-treated aggregate
All other mixes	Hveem (ODOT)	150 blows/500 psi	0.5% Pave Bond by weight of asphalt binder or 1.0% lime slurry by weight of aggregate, or both	Stability: 30 min Voids: 4–5% IRS: 75% min Modulus ratio: 70% min	For details of mix design procedure see Sullivan et al. *(8)*

- Asphalt film thickness — Sufficient to thick
- Air voids (%) — 3.0 to 5.0
- Stability, first compaction — 30 min
- Stability, second compaction — 30 min
- Index of retained strength, IRS (%) — 75 min
- Modulus ratio (%) — 70 min

For PlusRide, the asphalt content was selected at a void content of 3 percent. A summary of these mix designs, with appropriate comments, is given in Table 7. As indicated, there are only

TABLE 6 MIX DESIGN RESULTS (from additive suppliers)

Additive	Recommended Asphalt Content (%) With Lime	Without Lime
PlusRide	–	8.0
Arm-R-Shield	–	8.0
Fiber Pave	–	6.7
BoniFibers	–	6.7
CA(P)-1	6.5	6.5

NOTE: Percentage by weight of total mix.

TABLE 7 SUMMARY OF MIX DESIGNS PERFORMED BY ODOT FOLLOWING CONSTRUCTION

			Properties of Mix at Design Asphalt Content					
Material	Additive (%)	Basis for A/C Recommendation	Recommended Asphalt Content (% of total mix)	Hveem Stability	IRS (%)	Voids (%)	Diametral Modulus (psi)	Modulus Ratio (freeze-thaw)
PlusRide	3.00	3% voids	7.5	4	53	2.9	183,900	0.65
Arm-R-Shield	20.00[a]	Std[b] ODOT criteria	8.2	31	47	4.8	86,500	0.53
Fiber Pave[c]	0.30	Std ODOT criteria	7.0	36	100+	5.9	182,600	0.58
BoniFibers[c]	0.25	Std ODOT criteria	7.0	38	90	5.7	273,000	0.74
Treated with Pave Bond[c]	0.50[a]	Std ODOT criteria	5.9	39	99+	4.9	327,000	0.75
Treated with Pave Bond	0.50[a]	Std ODOT criteria	6.5	32	100+	4.7	350,000	1.03
Control	–	Std ODOT criteria	6.5	37	79	5.0	280,000	0.44
Control[c]	–	Std ODOT criteria	6.0	39	93	4.9	337,000	0.92
Chevron CA(P)-1	5.00[a]	Std ODOT criteria	6.5	39	73	4.9	160,000	0.68
Chevron[c] CA(P)-1	5.00[a]	Std ODOT criteria	6.9	39	91	4.9	110,000	0.79

[a]Percentage liquid binder.
[b]Std = standard.
[c]Aggregate is precoated with 1% lime slurry.

slight differences in asphalt contents recommended by the additive supplier and ODOT.

CONSTRUCTION PROCESS

Construction Procedures

Standard construction equipment was used for all sections. A conventional batch plant (Cedar Rapids Model 6000) was used to prepare the mixtures. Bottom dump trucks were used to transport the material to the job site. The mix was laid with a Cedar Rapids paver (Model 520). Compaction was accomplished using a 10-ton vibratory roller for breakdown, a 5-ton pneumatic roller as intermediate, and a 10-ton steel roller for finish compaction. The target density was 92 percent of maximum gravity (AASHTO T-209) for all sections. For the PlusRide and fiber sections, the additive was added as a dry mix cycle before the mixing operation. For the Arm-R-Shield, Pave Bond, and Chevron polymer-modified mixes, the additive was added to the asphalt before mixing. The standard tack coat was 0.03 gal/yd^2 of Chevron CSS-1. Specific construction details for each product are summarized next.

PlusRide®

In this product, the granulated rubber produced from shredded tires replaces a portion of the 1/4-in. to No. 10–sized aggregate. The PlusRide material was added to the batch plant via the top hopper. One hundred eighty pounds of rubber were added to every 3-ton batch of mix produced (3.0 percent). Asphalt content was set at 8 percent of the total weight of mix. Mix temperature was 340°F to 355°F, and laydown temperature was approximately 320°F in the windrow ahead of the paver. Compaction temperature was about 270°F to 280°F.

Construction proceeded rapidly without any major problems. The supplier recommended that rubber-tired rollers not be used and that a soap solution be used with the other rollers to prevent "pickup." Three roller passes, one static (breakdown) followed by a vibration pass and a static finish pass at 140°F, achieved the desired percentage of compaction. No pneumatic rolling was allowed because of pickup. Two additional passes increased the density, but the next pass resulted in cracking and lowered the density. Traffic traveled over the mat after it had been finish-rolled and the temperature had dropped to approximately 140°F. Initially, the mixture appeared to flush under traffic, but by the next day evidence of flushing could not be found. The mixture also was quite sticky and tacky on the surface.

Arm-R-Shield

The second section constructed incorporated a rubber-modified asphalt from Arizona Refining Company. Recycled rubber was melted with the AC-20 asphalt at 400°F in a mobile mixing truck supplied by Arizona Refining. After the rubber and asphalt had been blended, the asphalt-rubber mixture was transferred to a distributor truck for storage. Introduction of this additive into the mix presented some unique problems. Because the plant storage tanks already contained unmodified liquid asphalt, the asphalt modified with Arm-R-Shield had to be pumped from the distributor truck into the pug mill. The asphalt content for mix containing modified asphalt was set at 8 percent by weight of total mix. Because the binder contains 20 percent rubber, the actual components were 6.4 percent liquid asphalt and 1.6 percent rubber additive. Each 3-ton batch was mixed for from 3 to 15 sec before the modified asphalt was added and for 35 additional seconds after it was added. The production of the mix was extremely slow: 3-ton batches took from 2 to 7 min to mix. The plant operator thought that the slow production resulted from the material being very viscous and extremely hard to pump. Under normal production, this problem probably would not have occurred because larger plant storage tanks and hoses would have been used.

Mix temperatures of from 340°F to 350°F at the plant discharge, laydown temperatures between 315°F and 350°F in the windrow ahead of the paver, and mat temperatures after laydown of from 285°F to 295°F were recorded during the 2 days of operation. Blue smoke and steam appeared during laydown.

The roller operator attempted to compact directly behind the paver; however, the mix lacked stability and started to be picked up by the roller wheels. Because of these problems and the hot laydown temperature, the breakdown compaction equipment started rolling 600 to 800 ft behind the paver. The normal rolling pattern both days was two vibratory passes and one static pass with another vibratory roller pass for finish. During the first day, the mix moved under the rollers and wrinkled badly even though it was laid down without excessive cracking under the finish roller. On the second day, mix placed did not exhibit the tendency to "crawl." Neither the factory representative nor others at the job site could determine a reason for the difference in mix behavior. The only significant change in conditions was a 40°F to 50°F reduction in the surface temperature. It was difficult to achieve the desired 92 percent compaction as measured by the nuclear gauge. Even after 11 passes with both static and vibratory rollers, the mixture never achieved the desired compaction of 92 percent. However, compaction of 93.1 percent was obtained for a core taken August 8. Readings with the nuclear density gauge taken August 8 at the same location indicated compaction of 91.9 percent.

The pavement material was much "stickier" than PlusRide and remained in this condition until traffic had been on it for some time. This presented no problem. Extraction of asphalt from the mix (using a vacuum extractor) was difficult; washing took approximately 2 hr.

Fiber Pave®

Polypropylene fiber was used in the next test section constructed. The manufacturer of the Fiber Pave 3010 is Hercules, Inc. The fiber material was added to the pug mill. A crane hoisted the crates of material to the top of the batch plant and two workers fed one 18-lb bag of material for each 3-ton batch (0.3 percent). Each batch took approximately 30 sec; the workers were signaled from the control shack when to add the fibers. There were some initial clogging problems, but these were resolved by dumping the material down another hopper chute.

The specification for use of the material stated that the mix temperature could not be above 290°F. The addition of fiber and a 0.3 percent increase in the liquid asphalt content were the only deviations from normal Class-C mix components. The technical representative from Hercules was on site to oversee production. He noted that the mixture should have a stringy texture. If the mix temperature is too hot, the fibers melt and do not produce the desired consistency. However, the stringy texture made the mix difficult to rake.

Mix temperatures recorded were 285°F at the plant discharge, 265°F to 280°F in the windrow ahead of the paver, and 239°F to 248°F behind the paver. The existing surface temperatures ahead of the paver were 120°F to 125°F. The original rolling pattern called for two vibratory rollers, but this pattern was later modified to include a pneumatic roller for breakdown. The pneumatic rollers were added because of difficulty in meeting compaction criteria (92 percent of maximum density).

BoniFibers®

BoniFibers is the trade name of the polyester fiber used on this section. The method used to add Fiber Pave to the mix was also used for BoniFibers: two workers fed 15 lb of material into each 3-ton batch (0.25 percent). Asphalt content was increased 0.3 percent from that of the standard mix to 6.7 percent in this mix. The rest of the material and plant settings were not changed from the standard Class-C requirements. Mix temperatures of 305°F to 310°F at the plant discharge, laydown temperatures of 275°F to 305°F in the windrow ahead of the paver, mat temperatures directly behind the paver of 256°F to 285°F, and surface temperatures ahead of the paver of 60°F to 70°F were recorded. After the first pass with the breakdown roller this material appeared very brown, similar to a conventional mix with insufficient binder content. After 2 days of traffic it turned black. It should be noted that the fibers were not dry mixed before addition of the asphalt. This resulted in poor fiber dispersion in the mix and formation of fiber balls throughout the section. It is uncertain what effect this will have on the performance of this section.

The desired 92 percent compaction was difficult to attain. This could have been the result of one roller having mechanical difficulty, which delayed the paving operation. To provide adequate equipment, one static steel roller and two pneumatic rollers were added. The use of additional rollers resulted in overcompaction and a subsequent reduction in the density values.

Pave Bond® (with and without lime)

Two sections were specifically constructed to evaluate asphalt treated with 0.5 percent Pave Bond: one with lime and one without. Mix temperature at the plant was recorded as 300°F ± 10°F. Laydown temperatures of 295°F to 305°F in the windrow ahead of the paver, mat temperatures of 280°F to 290°F, and a surface temperature of 80°F were recorded. Four rollers were used to obtain compaction: two passes of a three-wheeled roller for breakdown, three passes with a vibratory roller (one static and two vibratory), two to four passes with a rubber-tired roller for intermediate rolling, and one or two static passes with the vibratory roller for finish rolling. Densities were reasonably close to the desired 92 percent compaction. No problems were encountered during construction of either of the two mix sections. Both mixes laid the same as a standard Class-C asphalt concrete mix.

Control (with and without lime)

Control sections consisted of a standard Class-C asphalt concrete mix. Mixing and compaction techniques were similar to those used for sections containing Pave Bond. Two control sections were constructed: one with lime treatment and one without. No special problems were encountered during construction of either section.

Chevron Modified Asphalt [CA(P)-1]

Two sections were constructed using Chevron polymer-modified asphalt: one section with lime-treated aggregate and one without. Mix temperatures at the plant discharge were originally set at 340°F. Laydown temperatures were 315°F to 320°F in the windrow ahead of the paver, and a mat temperature behind the paver of 285°F and an air temperature of 66°F were recorded for the mixture without lime-treated aggregate. Mix temperatures of 340°F at the plant discharge, laydown temperatures of 315°F to 335°F in the windrow ahead of the paver, mat temperatures behind the paver of 290°F to 305°F, and surface temperatures ahead of the paver of 110°F were recorded for the mixture with lime-treated aggregates. The Chevron representative considered the elevated temperature essential to obtain good bond of binder to stone, so all trucks were covered with tarps. The increased temperature was the only deviation from normal Class-C mix settings and components.

Breakdown rolling was accomplished with two passes of a three-wheeled steel roller, intermediate rolling with two or three passes with the pneumatic roller and three passes with the vibratory roller (one static and two vibratory), and finish rolling with one static pass of the vibratory roller. The mix without lime was deformed under the rollers, but the mix with lime was quite stable. This may have been caused by the CSS-1 tack coat. The section without lime-treated aggregate received 0.05 gal/yd^2 whereas the section with lime-treated aggregate and all other test sections received 0.03 gal/yd^2. When construction was completed, both sections looked satisfactory and compaction exceeded the desired 92 percent.

Quality Control Data

Tables 8 and 9 give summaries of the construction test results from daily plant reports. These results indicate that

1. The asphalt content and mix gradation generally fell within the mix design tolerances for all mixes. The exception

TABLE 8 SUMMARY OF CONSTRUCTION TEST RESULTS FROM DAILY REPORTS—SPECIAL ADDITIVES

	PlusRide		Arm-R-Shield		Fiber Pave Polypropylene Fiber		BoniFibers Polyester Fiber		CA(P)-1 Without Lime		CA(P)-1 With Lime	
	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance
Gradation (% passing)												
3/4 in.	–	–	100	100	100	100	100	100	100	100	100	100
5/8 in.	100	94–100	–	–	–	–	–	–	–	–	–	–
1/2 in.	–	–	98	95–100	97	95–100	97	95–100	97	95–100	97	95–100
3/8 in.	78–79	70–82	–	–	–	–	–	–	–	–	–	–
1/4 in.	47–48	32–44	60	60–72	63	60–72	66	60–72	65	60–72	65	60–72
No. 10	36–37	27–35	31	28–36	31	28–36	32	28–36	30	28–36	32	28–36
No. 30	21	15–23	–	–	–	–	–	–	–	–	–	–
No. 40	–	–	12	8–26	14	8–26	14	8–26	14	8–26	14	8–26
No. 200	7.4–7.9	6.9–10.9	5.0	3.8–7.8	5.5	3.8–7.8	5.5	3.8–7.8	6.5	3.8–7.8	6.2	3.8–7.8
Asphalt content (%)	8.5–9.0	7.6–8.4	7.6^a	7.5–8.5^a	6.7	6.3–7.3	6.5	6.2–7.2	6.4^a	5.9–6.9^a	6.6^a	5.9–6.9^a
Additives (%)	3.0 rubber in mix 0.5 Pave Bond 0.0 lime	2.85–3.15	20 rubber in asphalt 0.0 Pave Bond 0.0 lime		0.3 fiber 0.5 Pave Bond 0.0 lime		0.25 fiber 0.50 Pave Bond 0.00 lime		5.0 polymer based on asphalt weight 0.0 Pave Bond 0.0 lime		5.0 polymer based on asphalt weight 0.0 Pave Bond 1.0 lime	
Mix temperature (°F)	325–355	325–360	340–350	340 min	285	290 max	305	325 max	325–340	340	340	340
Laydown temperature (°F)	317–321	300 min	317–350	285–325	265–280	245–290	275–305	280±	315–320	–	315–335	–
Density (%)	92.5–96.7	92 min	85.9–92.9	92 min	86.0–90.9	92 min	86.2–92.7	92 min	93.1–95.4	92 min	92.8–94.5	92 min

^{a}Includes asphalt additive.

TABLE 9 SUMMARY OF CONSTRUCTION TEST RESULTS FROM DAILY PLANT REPORTS—CONVENTIONAL ADDITIVES

	Control With Lime		Control Without Lime		Pave Bond Without Lime		Pave Bond With Lime	
	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance	Mix Test Value	Mix Design Tolerance
Gradation (% passing)								
3/4 in.	100	100	100	100	100	100	100	100
5/8 in.	–	–	–	–	–	–	–	–
1/2 in.	98	95–100	98	95–100	97	95–100	98	95–100
3/8 in.	–	–	–	–	–	–	–	–
1/4 in.	69	60–72	64	60–72	66	60–72	64	60–72
No. 10	32	28–36	32	28–36	33	28–36	31	28–36
No. 30	–	–	–	–	–	–	–	–
No. 40	14	8–26	13	8–26	14	8–26	14	8–26
No. 200	5.8	3.8–7.8	5.5	3.8–7.8	5.9	3.8–7.8	5.4	3.8–7.8
Asphalt content (%)	6.4	5.9–6.9	6.3	5.9–6.9	6.2[a]	5.9–6.9[a]	6.2[a]	5.9–6.9[a]
Additives (%)	0.0 Pave Bond 1.0 lime based on aggregate weight		0.0 Pave Bond 0.0 lime		0.5 Pave Bond 0.0 lime		0.5 Pave Bond 1.0 lime	
Mix temperature (°F)	305	325 max	305	325 max	305	325 max	305	325 max
Laydown temperature (°F)	290	280±	290	280±	285	280±	285	280±
Density (%)	93.1–94.7	92 min	89.4–94.0	92 min	89.1–91.7	92 min	91.4–92.4	92 min

[a]Includes asphalt additive.

TABLE 10 UNIT PRICES

Material	Asphalt Concrete Mixture[a] ($/ton)	Liquid Asphalt[b] (% binder/ton and $/ton mix)	Lime Credit ($/ton mix)	Total Cost ($/ton)
PlusRide	30.00	8.0 15.72		45.72
Arm-R-Shield	20.00	8.0 60.00		80.00
Fiber Pave	30.00	6.8 13.36	−1.45	41.91
BoniFibers	30.00	6.7 13.17	−1.45	41.72
C-mix with Pave Bond without lime	11.00	6.4 12.58	−1.45	22.13
C-mix with Pave Bond with lime	11.00	6.4 12.58		23.58
Control without Pave Bond with lime	11.00	6.4 12.10		23.10
Control without Pave Bond without lime	11.00	6.4 12.10	−1.45	21.65
C-mix with CA(P)-1	11.00	6.4 17.86	−1.45	27.41
C-mix with CA(P)-1 with lime	11.00	6.4 17.86		28.86

[a]Excludes liquid asphalt and additives in liquid asphalt.
[b]AC-20 = $189.00/ton, AC-20 with 0.5% Pave Bond = $196.50/ton, AC-20 with CA(P)-1 = $279.00/ton, and Arm-R-Shield = $750.00/ton.

was the asphalt content for PlusRide. All tests for the PlusRide mix showed an asphalt content higher than the design tolerance.

2. The mix and laydown temperatures generally conformed to specifications.
3. Many of the results of nuclear density tests failed to meet the specified 92 percent minimum value based on AASHTO T-209.

In general, the quality control tests indicated no major problems in the mix with the exception of low densities (high voids).

Unit Cost Evaluation

Unit costs given in Table 10 are predominantly contractor bid prices with a few negotiated costs included. Even though small quantities are involved and the contractor had no experience with most of the materials, these bid prices are considered a reasonable approximation of actual installation costs.

A separate bid item was included for each class of asphaltic concrete mix to cover the contractor's cost of aggregate, mixing, handling, and placing. The cost of fibers and crumb rubber added directly to the mixture was also included in the mixture bid item. Liquid asphalt, including additives added to the liquid asphalt before mixing, was bid separately. Total cost of the mix in place was dependent on the quantity of liquid asphalt incorporated in the mix. The designed percentage of asphalt for each type of mix is also included in Table 10 and used to calculate the cost per ton of mix.

Lime treatment of aggregate was specified for all mixtures except PlusRide and Arm-R-Shield. Therefore, when lime treatment was not used in a mixture, a $1.45/ton credit was subtracted from the mix unit price.

CA(P)-1 polymer-modified asphalt was furnished by Chevron USA at the price of AC-20 liquid asphalt. Chevron reported that the polymer-modified asphalt is being sold at from $80 to $100 per ton premium. For the sake of a fair evaluation, an average of $90 was assumed for this evaluation.

MIX PROPERTIES

Mix Properties—September 1985

Two 4-in. and three 6-in. cores were taken from each experimental section shortly after construction. The 4-in. cores were tested for density, voids, modulus, and stability. The 6-in. cores were tested for gradation, asphalt content, and asphalt properties. In addition, mix sampled during construction (box samples) was compacted and tested for Hveem stability, modulus fatigue, and index of retained strength.

The results of the tests on the 4-in. cores are given in Table 11. The following significant items are noted:

1. Modulus values (at 77°F) range from 93,000 psi for Arm-R-Shield to 590,000 psi for the C-mix with Pave Bond and lime-treated aggregate;
2. In-place voids range from 3.7 percent for PlusRide to 8.1 percent for BoniFibers; this is in conflict with the results of the construction quality control tests reported in Tables 8 and 9; and
3. Hveem stability values (in place) are in the normal range, except for PlusRide.

Table 12 gives a summary of the results of gradation and asphalt property tests on box samples of mix (obtained during construction) and on 6-in. cores obtained shortly after construction. The results presented in this table indicate that

TABLE 11 SUMMARY OF TEST RESULTS, 4-IN. CORES (September 1985)

Property	PlusRide	Arm-R-Shield	Fiber Pave	BoniFibers	Pave Bond Without Lime	Pave Bond With Lime	Control With Lime	Control Without Lime	CA(P)-1 Without Lime	CA(P)-1 With Lime
Unconditioned modulus at 77°F (1,000 psi)	264	93	111	137	275	590	209	256	352	366
Gravity										
In place (voids)	2.21	2.27	2.28	2.26	2.34	2.31	2.31	2.30	2.36	2.31
	(3.7)	(6.9)	(6.5)	(8.1)	(5.3)	(6.6)	(6.9)	(7.1)	(4.9)	(6.9)
Recompacted (voids)	2.23	2.38	2.42	2.41	2.44	2.45	2.43	2.41	2.46	2.45
	(2.8)	(2.4)	(0.8)	(2.0)	(1.2)	(0.9)	(2.1)	(2.6)	(0.9)	(1.2)
Relative compaction (%)	96.3	93.1	93.5	91.9	94.7	93.4	93.1	92.9	95.1	93.2
Maximum theoretical gravity	2.295	2.438	2.439	2.458	2.470	2.473	2.481	2.475	2.481	2.480
Hveem stability at 140°F										
In place	2	29	12	14	29	16	24	18	25	22
Recompacted	1	18	21	29	19	32	3	34	22	24

TABLE 12 SUMMARY OF MIX AND ASPHALT PROPERTY TEST RESULTS, 6-IN. CORES AND BOX SAMPLES (September 1985)

	PlusRide		Arm-R-Shield	Fiber Pave	BoniFibers	Pave Bond Without Lime	Pave Bond With Lime	Control With Lime	Control Without Lime	CA(P)-1 Without Lime	CA(P)-1 With Lime
	1	2									
Gradation[a]											
(% passing)											
3/4 in.	100	100	100	100	100	100	100	100	100	100	100
1/2 in.	97	95	98	97	98	97	99	98	98	100	99
3/8 in.	77	72	86	84	85	88	88	83	84	88	85
1/4 in.	47	43	62	64	66	68	67	66	66	66	63
No. 4	42	38	51	54	54	56	56	55	54	54	52
No. 10	35	33	30	32	31	32	32	32	32	32	32
No. 40	18	16	13	14	14	14	14	14	13	14	14
No. 20	7.0	6.2	5.8	6.1	5.8	6.2	6.4	6.7	6.0	5.9	5.5
Asphalt content (%)	8.5	7.8	6.8	7.0	6.9	6.2	6.3	6.3	6.3	7.2	6.4
Asphalt properties[a]											
Viscosity at 140°F (poises)	3319	4479	3302	8064	9130	8120	7637	5650	6560	8013	10 100
Kinematic viscosity at 275°F (cSt)	445	514	849	597	591	624	572	534	568	1040	1137
Penetration (dmm)	40	42	75	27	22	23	22	25	21	40	36
Asphalt properties[b]											
Viscosity at 140°F (poises)	2070	–	2733	5739	7231	7669	2574	6542	8435	9962	12 478
Kinematic viscosity at 275°F (cSt)	374	–	929	539	599	599	635	560	609	1093	1369
Penetration (dmm)	55	–	78	32	29	28	25	26	28	37	34
Mix properties											
Stability	8	5	37	44	39	44	40	39	41	41	37
IRS (%)	64	82	93	94	92	95	100	94	97	84	91
Modulus ratio (freeze-thaw)	0.73	0.63	0.70	0.76	0.84	0.92	0.85	0.90	0.78	0.73	1.00

[a]Box samples.
[b]6-in. cores.

1. The asphalt content and mix gradation were more or less in compliance with the job mix formula.
2. The viscosities of the recovered asphalt from the box samples generally were higher than those measured on the core samples. This is because these loose materials were tested up to 1 or 2 months after sampling. The highest viscosity at 140°F was measured on the polymer-modified asphalt in both cases.
3. The viscosities at 140°F of the rubber-modified asphalts were lower than those of the other mixes.
4. The penetration values at 77°F for the rubber- and polymer-modified asphalts were higher than for the other materials.
5. The Hveem stability values of laboratory-compacted box samples were all greater than 30 except for the PlusRide mix.
6. The index of retained strength (IRS) of all mixes was greater than 75 percent minimum except for PlusRide.
7. The modulus ratios (after freeze-thaw conditioning) were all greater than the 0.70 minimum except for PlusRide.

Mix Properties—March and June 1986

Diametral modulus and fatigue tests were performed on cores taken from all sections in March 1986 *(9)*. The tests were run in accordance with ASTM D 4123. In March both modulus and fatigue tests were run at 200 microstrain and 73°F. In June modulus and fatigue tests were conducted at both 200 and 100 microstrain and at 73°F. Table 13 gives a summary of the results of the tests on field cores.

Discussion of Test Results

The results of the testing are discussed in the following subsections.

Hveem Stability

All materials except PlusRide have in-place stability values within the expected range for cores. PlusRide has a stability value of 2. This is also true for laboratory-compacted samples. Despite the low value for PlusRide, there is no evidence of rutting. This would indicate that the use of stability criteria for evaluating the PlusRide mix may be inappropriate.

Modulus Values

At present, modulus values are not considered directly in the mix design or selection of additives. The tests on cores taken in 1985 and 1986 indicate that most of the materials are increasing in stiffness (Figure 4). The exceptions are the polymer-modified asphalt mixes and one of the conventional mixes.

Modulus Ratio

A minimum modulus ratio of 0.7 is required in mix designs to provide adequate resistance to pavement damage from freeze-thaw effects. The mix design modulus ratios (Table 7) indicate satisfactory freeze-thaw resistance for all mixes with lime-treated aggregate, Pave Bond, and BoniFibers.

Fatigue Results

The fatigue results on the cores clearly indicate that the polymer-modified mixes and the PlusRide mix are more resistant to cracking. The significance of the testing is that all of the other mixes have fatigue properties comparable to those of conventional mixtures. The design of a durable flexible pavement

TABLE 13 SUMMARY OF MODULUS AND FATIGUE TEST DATA (field cores)

Mix Type	Avg Density (pcf)	Avg Modulus[a] (1,000 psi)	Load Applications to Failure
March 1986			
PlusRide	137.6	272	15,942
Arm-R-Shield	141.7	194	4,171
Fiber Pave	144.2	400	6,708
BoniFibers	142.2	387	4,487
Pave Bond without lime	144.0	475	5,347
Pave Bond with lime	145.0	506	6,052
Control	144.9	457	7,094
Control with lime	147.4	511	4,986
CA(P)-1 without lime	148.4	284	21,187
CA(P)-1 with lime	144.4	298	37,375
June 1986			
PlusRide	136.2	341	88,500[b]
Arm-R-Shield	139.4	196	19,876[b]
CA(P)-1 without lime	147.7	304	19,208 122,043[b]
CA(P)-1 with lime	143.8	287	200,598[b] 31,432

[a]Tests run at 73°F and 200 microstrain, except as noted.
[b]Tests run at 73°F and 100 microstrain.

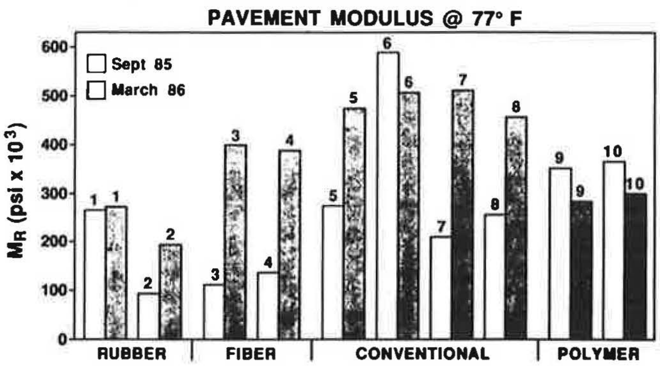

FIGURE 4 Variation in asphalt concrete stiffness with time.

FIGURE 5 Typical pavement condition of PlusRide after overlay (milepost 158.21 looking south).

FIGURE 6 Typical pavement condition of Arm-R-Shield after overlay (milepost 158.62 looking south).

FIGURE 7 Typical pavement condition of Class-C mix with polymer-modified asphalt and lime-treated aggregate (milepost 161.46 looking south).

requires high-level fatigue properties along with adequate resistance to freeze-thaw effects.

Future Test Schedule

Additional cores are scheduled to be taken in September 1986, 1987, and 1988. These results are expected to provide a better indication of changes in mix properties and features over time.

PERFORMANCE EVALUATION

During September and October 1985 the test road was evaluated for

- Pavement condition,
- Surface deflection,
- Skid resistance, and
- Ride.

The pavement surface within the limits of the project and within the limits of the test site is in good condition. Within the limits of the test sites, only one small crack and no significant rutting were observed. Figures 5–7 show the typical condition of the pavement.

Tables 14 and 15 give summaries of the results of deflection measurements and skid and ride tests. The results generally indicate that

1. The average deflection of the before condition (May 1985) varied considerably among sections;
2. The average deflections of the after condition (September 1985) are fairly uniform with most values ranging between 0.015 and 0.021 in.;
3. The reduction in deflection generally ranged between 50 and 70 percent;
4. The skid numbers for all sections are considered good and were about the same; the exception was the PlusRide section that exhibited the lowest value; and
5. The ride numbers for all sections were about the same and generally on the same order as those for conventional state projects.

In general, the results would indicate little variation in structural adequacy, skid, or ride among the various sections.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

On the basis of the results of this design and construction project, the following conclusions appear to be warranted:

1. The test site appears to be an excellent choice for evaluating the effects of asphalt additives on resistance to cracking and stripping because of previous performance problems in the vicinity.
2. Mix design techniques used by some additive suppliers are not well defined or documented.
3. Mix design results generated by the ODOT agree reasonably well with those recommended by the additive suppliers.
4. There were no major problems with the construction of the different mixes.

5. There are significant differences in the mix properties of the different materials.

6. The performance of all of the test sections after 1 year of service is good. There is no cracking, rutting, or extensive raveling of the pavement sections. However, failures have been experienced in this general area within 2 to 4 years after construction.

TABLE 14 SUMMARY OF EQUIVALENT BENKLEMAN BEAM DEFLECTIONS (10^{-3}) BEFORE AND AFTER OVERLAY

Material	Lane	Before 5/85	After 9/85	Percentage Reduction
PlusRide	SB	36.6	16.2	56
	NB	52.4	18.2	65
Arm-R-Shield	SB	59.3	17.2	71
	NB	53.9	15.7	71
Fiber Pave	SB	39.2	15.9	59
BoniFiber	NB	56.1	15.7	72
Class C (with Pave Bond)	NB	71.2	20.6	71
Class C (with lime and Pave Bond)	NB	48.9	20.6	58
Control (with lime)	SB	75.8	31.1	59
Control (without lime)	SB	48.0	18.1	62
CA(P)-1 (without lime)	SB	49.8	25.4	49
CA(P)-1 (with lime)	NB	32.3	23.1	28

NOTE: Equivalent Benkleman beam corrected to 70°F. SB = southbound and NB = northbound.

TABLE 15 SUMMARY OF SKID TESTS AND RIDE TESTS (October 1985)

Direction	Product	Avg Skid No.	Avg Mays Meter Ride Tests (in./0.1 mi/mi)
SB	PlusRide	44.3	34.3
NB	PlusRide	46.9	34.8
SB	Arm-R-Shield	48.4	33.7
NB	Arm-R-Shield	51.1	39.1
SB	Fiber Pave	52.1	34.9
NB	BoniFibers	52.9	26.4
NB	Class C (with Pave Bond)	55.6	35.0
NB	Class C (with lime and Pave Bond)	57.3	23.6
SB	Control (with lime)	53.3	32.4
SB	Control (without lime)	56.7	30.0
SB	CA(P)-1 (without lime)	52.9	28.4
NB	CA(P)-1 (with lime)	56.9	35.5

NOTE: SB = southbound; NB = northbound.

Recommendations

The following recommendations are warranted as a result of the findings:

1. Continue to monitor each of the sections for changes in performance. This should be done twice a year (fall and spring).

2. Continue to core the project to detect changes in mix properties. This should be done at least once a year, beginning fall 1986.

This monitoring program is expected to identify clearly how the mixes perform under severe traffic and environmental conditions.

ACKNOWLEDGMENT

This paper is the first of several reports on the evaluation of asphalt and mix additives in asphalt concrete paving on the Lava Butte Road–Fremont Highway Junction project on US-97 near Bend, Oregon. The study was funded jointly by FHWA and the Oregon Department of Transportation. The authors are particularly indebted to Jerry Thackery, Project Manager, Region 4, ODOT; Scott Nodes and Steve Walker, Research Specialists, ODOT; Glenn Boyle, Bituminous Mix Design Group Leader, ODOT; and Mark Hanson, Research Assistant, Oregon State University. This paper was typed by Gail Mathieson Barnes and graphics were prepared by Linda Haygarth.

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Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures To Meet Structural Requirements.