Performance of Recycled Asphalt Concrete Overlays in Southwestern Arizona

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Recycled asphalt concrete overlay is a routine rehabilitation strategy for most highway agencies. In 1981 the Arizona Department of Transportation constructed an experimental asphalt concrete overlay project on Interstate 8 in southwestern Arizona. The project consisted of eight test sections comparing long-term performance of recycled and virgin asphalt concrete overlays in an arid climate. Mays meter roughness, Mu meter skid number, and percentage cracked data were collected on different test sections over the service life of the project. A visual distress survey was conducted on each section at the end of service life. Rut depth and falling weight deflectometer measurements were also taken before rehabilitation of the 1981 project. Analysis of roughness, skid, and cracking data indicates that the recycled and virgin asphalt concrete overlays have performed similarly. The poor condition of one virgin overlay section at the end of the service life appeared to be caused by weaker subgrade support. The thicker overlays performed better than did the thinner overlays. Considerable rutting was observed on the thicker overlay sections partly because of densification of asphalt concrete mixes under traffic load. The average annual maintenance costs for different test sections were similar.

Asphalt concrete overlays are the most widely used method for rehabilitation of asphalt concrete pavements in the United States. Pavement surface preparation and type and thickness of overlay are the most important details of such rehabilitation methods (*1*). The Arizona Department of Transportation (ADOT) has been active in recycling asphalt concrete pavements since the late 1970s. Although experience with recycled pavement was mixed, the practice was continued because the process was economical. In 1981 ADOT constructed an experimental overlay project incorporating both virgin and recycled asphalt concrete mixes and different overlay thicknesses with and without surface preparation by milling.

The project is in southwestern Arizona approximately 64 km (40 mi) west of Casa Grande extending from milepost 134.56 to milepost 145.0 on both directions of Interstate-8. Interstate-8 is one of the major east-west trucking routes in Arizona. It is a divided highway, 11.8 m (38 ft) wide with 1.2-m (4-ft) inner and 3.1-m (10-ft) outer asphalt concrete shoulder, with two lanes in each direction.

During a distress survey of this project in summer 1990, all sections exhibited varying degrees of structural distresses. The project was rehabilitated in fall 1991. This paper describes and compares the performance of recycled asphalt concrete overlays with virgin asphalt concrete overlays after 9 years in service.

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LAYOUT AND DESCRIPTION OF TEST SECTIONS

Layout and Pavement Sections

Eight test sections incorporating virgin and recycled asphalt concrete were constructed on the project. Table 1 presents the physical description of the test sections, and Figure 1 shows the pavement cross sections. Each type of mix was represented by four sections. Preoverlay surface preparation was represented by "milling" and "no milling." Four sections are "mill and replace," and the rest are overlays over existing pavements. The overlay thickness on two sections is 102 mm (4 in.), and the other six have 51-mm (2-in.) overlays. Test Sections 1, 2, 5, and 6 have granular aggregate bases. Sections 3, 4, 7, and 8 have cement-treated bases. The overlays were designed for a 10-year life.

As-Built Asphaltic Mix Design Information

Selected information from the as-built mix designs for both recycled and virgin mixes are shown in Table 2. The binder content of the recycled mix was approximately 0.5 percent higher than the content of the virgin mix, but the design virgin bitumen content for this mix was 3.0 percent. The binders used on this project were AR-4000 and AR-8000 for the recycled and virgin mix, respectively. The recycled mix had 50 percent recycled asphalt pavement materials in the mix. The bulk and maximum densities of both mixes were comparable. Both mixes had 1 percent liquid antistripping agent.

Soils and Geology

The geological formation of the area is weakly to moderately consolidated alluvium of late Tertiary and early Quaternary ages. The vegetation is Sonoran desert scrub in lower Colorado subdivision. The soils in this area are mostly arid soils with pedogenic horizons and low organic matter. These soils are mostly fine silts to poorly graded sand with some gravels.

Climate

The climate in the vicinity of the project is arid. The Strategic Highway Research Program has designated this region as "dry no-freeze" (*1*). The 30-year average annual maximum temperature is 32°C (89°F), and the minimum is 13°C (56°F) (*2*). The 30-year annual rainfall is 148 mm (5.8 in.). The referenced meteorological data were recorded at the National Weather Services station at Gila Bend, Arizona.

TABLE 1 Test Section Locations and Features

OVERLAY THICK. (mm)	RECYCLED AC		VIRGIN AC	
	MILL and REPLACE	NO MILLING	MILL and REPLACE	NO MILLING
51	Section: 3 Direction: EB M.P.: 141.0 - 142.0 Length: 1.61 km Section (mm): 152 SB 152 CTB 76 AC Section: 7 Direction: WB M.P.: 138-137 Length: 1.61 km Section (mm): 152 SB 152 CTB 76 AC	Section: 5 Direction: WB M.P.:135.60 - 134.56 Length:1.67 km Section (mm): 203 SB 102 AB 76 AC	Section: 4 Direction: EB M.P.: 144.0 - 145.0 Length: 1.61 km Section (mm): 152 SB 152 CTB 76 AC Section: 8 Direction: WB M.P.: 145-144 Length: 1.61 km Section (mm): 152 SB 152 CTB 76 AC	Section : 6 Direction: WB M.P.: 136.63-135.60 Length:1.66 km Section (mm): 203 SB 102 AB 76 AC
102		Section: 1 Direction: EB M.P.: 134.56-135.60 Length: 1.67 km Section (mm): 203 SB 102 AB 76 AC		Section: 2 Direction: EB M.P.: 135.60-136.63 Length: 1.66 km Section (mm): 203 SB 102 AB 76 AC

Notes:
1. AB = Aggregate Base
2. AC = Asphalt Concrete
3. CTB = Cement Treated Base
4. SB = Subbase (Select Material)
5. 1 mm = 0.04 in, 1 km = 0.63 miles

Traffic History

The average annual daily traffic on this project was approximately 7,900 in 1990. Figure 2 shows the cumulative 18-kip equivalent single-axle loads (ESALs) on this project since construction. The cumulative traffic carried by this project was approximately 7 million ESALs.

FUNCTIONAL PAVEMENT PERFORMANCE

The functional performance of the roadway can best be described by its serviceability. In this paper, the present serviceability is described in terms of roughness, measured by the Mays ride meter, and frictional characteristics, assessed using the Mu meter.

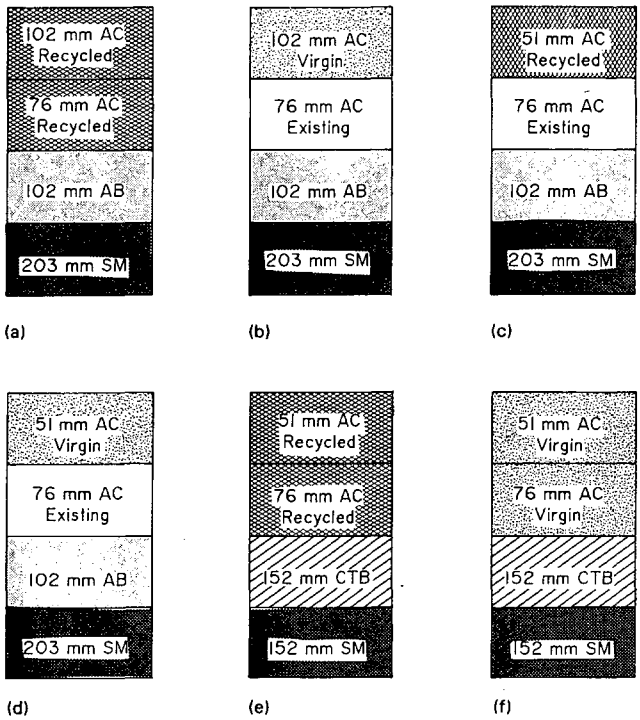
ADOT performs an annual inventory of its highway network and records this information on a route-milepost basis for the pavement management system (PMS). Roughness, skid, cracking, patching, rutting (for flexible pavements), and faulting (for portland cement concrete pavements) are measured in the travel lane and entered into the PMS data base. Roughness is determined by a Mays ride meter (car) traveling at 50 mph, which obtains continuous readings between mileposts. The readings are summarized in in./mi and the results assigned to the milepost location at which the readings begin. When the field data is obtained it is normalized to 1972 calibration values to provide consistency with time. Skid (friction) is determined by a Mu meter, which is a continuous, recording, friction-measuring trailer. Continuous readings are obtained for a 153-m (500-ft) section of wet pavement starting at a milepost location. The readings are averaged and assigned to the milepost. The percent cracking data are collected at every milepost location by comparing the pavement condition of a 93-m^2 (1000-ft^2) pavement section with a standard set of photographs showing different percentages of cracking.

To use these data, the following table shows milepost locations chosen to be representative of the test sections (where EB is eastbound and WB is westbound).

Test Section (Number and Direction)	*Milepost*
1, EB	135.0
2, EB	136.0
3, EB	141.0
4, EB	144.0
5, WB	135.0
6, WB	136.0
7, WB	138.0
8, WB	145.0

Test Sections 1, 2, 5, and 6 are situated within a milepost. The Mays roughness data for these sections are tainted because of the data collection process.

The years for which the performance data are available in the PMS data base for different attributes are shown in the following table.



Note: AC = Asphalt Concrete, AB = Aggregate Base, SM = Select Material/Subbase
CTB = Cement Treated Base

FIGURE 1 Pavement cross sections: (*a*) Section E, (*b*) Section 2, (*c*) Section 5, (*d*) Section 6, (*e*) Sections 3 and 7, (*f*) Sections 4 and 8.

Attribute	*Period of Data*
Mays roughness	1972–1990
Mu meter skid	1980–1985, 1987, 1989, 1990
Percent cracking	1978–1990

To find the rate of change of the attributes over the service lives of the test sections, linear regression models were developed for each attribute (except rut depth) taking the corresponding attribute as the dependent variable and age since construction (in 1982) as the independent variable. The linear model was chosen on the basis of the value of F-ratio in the analysis of variance for significance of regression. These models were subsequently used for analysis of roughness, skid resistance, and cracking history of different sections.

Roughness

Table 3 gives the roughness history of the test sections. The average Mays meter roughness before rehabilitation (in 1990) for sections with recycled overlay is 139 cm/km (88 in./mi) compared with 151 cm/km (96 in./mi) for sections with virgin overlay. However, before construction of experimental test sections, average roughness of virgin sections (336 cm/km) was much higher than that for recycled sections (267 cm/km). The average as-built Mays roughness for the recycled sections was between 65 cm/km (41 in./mi) and 90 cm/km (57 in./mi) with an average of 79 cm/km (50 in./mi). The corresponding values for virgin overlay sections are 52 cm/km (33 in./mi), 77 cm/km (49 in./mi), and 66 cm/km (42 in./mi). The rate of increase of roughness for all sections was between 9 and 17 cm/km/year (6 and 11 in./mi/year) with the virgin sections showing slightly higher rate of increase. The 102-mm (4-in.) overlay sections were built to be considerably smoother than 51-mm (2-in.) overlays and remained so at the end of the service lives. The mill and replace sections had average roughness comparable to simple overlay sections before rehabilitation in 1991. Average preoverlay roughness of mill and replace sections was considerably higher: 357 cm/km (226 in./mi) compared with 226 cm/km (143 in./mi) for nonmilled sections.

TABLE 2 As-Built Mix Design Information

Aggregate				Density (kN/m³)		Marshall Stability (N)	Flow (%)	Immersion - Compression Retention (%)	Asphalt Cement		
Coarse (%)	Intermediate (%)	Fine (%)	Passed #200 (%)	Bulk	Maximum				Content (%)	Type	Viscosity Range (Pa.s)
(a) Virgin Mix											
25	15	51	9	22.6	23.83	-	-	70	5.2	AR-8000	600-1,000
(b) Recycled Mix											
12.5	7.5	25.5	4.5	22.4	23.80	607	11	58	5.6	AR-4000	300-500

Notes: i) Both mix used 1% liquid anti-stripping agent (pave bond special)
ii) Aggregate for recycle mix used 50% recycled aggregate.
iii) Design bitumen content in recycled mix is 3.0%
iv) 1 kN/m³ = 6.361 lb/ft³, 1 N = 4.445 lbs, 1 poise = 0.10 Pa.s

Skid Resistance

There is no apparent difference between 1990 Mu meter values of sections with virgin and recycled overlays (Table 4). The Mu meter values for sections with virgin and recycled overlays at the end of service lives are 66 and 65, respectively.

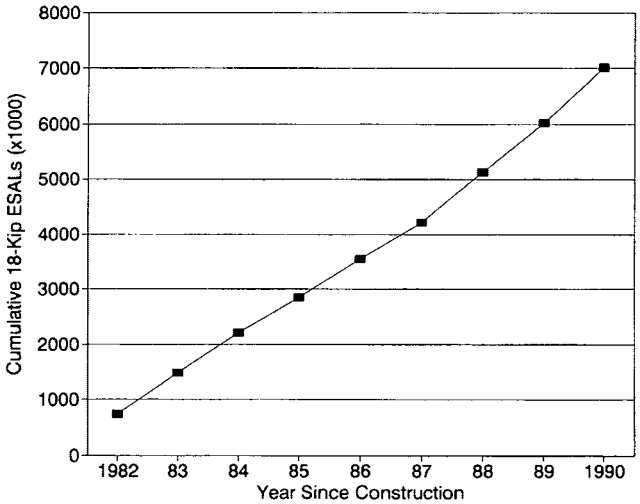


FIGURE 2 Traffic history of project.

The rate of decrease of skid resistance, as indicated by the rate of decrease of the Mu meter value, is similar for both types of overlay. As can be expected, the skid resistance of 102-mm (4-in.) and 51-mm (2-in.) overlays as well as sections with mill and replace and no-milling were similar at the end of service lives.

STRUCTURAL PAVEMENT PERFORMANCE

The structural condition of the pavement was evaluated by pavement distress surveys and falling weight deflectometer testings. In addition to the historical crack data available in ADOT's PMS data base, pavement distress surveys were conducted using the PAVER (*3*) in 1990. Rut depth measurements were also taken on each section with a 3-m (10-ft) straight edge.

Cracking

Table 5 shows the cracking history of all sections. The two recycled sections in the eastbound direction had more cracking in 1990 than did the virgin sections of identical structure. However, in the westbound direction, the recycled and virgin overlays with identical structural sections had similar percentages of cracking. The average cracking for 102-mm (4-in.)

TABLE 3 Test Section Roughness History

Test Section	Pre-expt. Overlay Roughness (cm/km) (1981)	As-built Roughness (1982) (cm/km)	Rate of Roughness Increase (cm/km)	Current Roughness (1990) (cm/km)
1, EB (recycled)	175	65	11	118
2, EB (virgin)	233	58	9	104
3, EB (recycled)	437	90	9	189
4, EB (virgin)	607	121	19	197
5, WB (recycled)	246	80	10	140
6, WB (virgin)	248	74	18	155
7, WB (recycled)	208	77	10	125
8, WB (virgin)	396	52	17	148
Average: recycled virgin	267 336	79 66	10 14	139 151
Average: 102-mm 51-mm	205 320	62 76	10 12	112 147
Average: No-milling Mill & Pave	226 357	69 74	12 12	129 147

TABLE 4 Test Section Skid Resistance History

Test Section	Pre-expt. Overlay Mu-meter Value (1981)	As-built Mu-meter Value (1982)	Rate of Mu-meter Value Decrease (units/year)	Current Mu-meter Value (1990)
1, EB (recycled)	72	77	2.3	63
2, EB (virgin)	75	77	2.5	65
3, EB (recycled)	69	79	2.2	65
4, EB (virgin)	67	79	1.7	67
5, WB (recycled)	73	77	1.7	65
6, WB (virgin)	79	79	1.5	67
7, WB (recycled)	79	79	1.2	67
8, WB (virgin)	77	77	1.6	66
Average:				
recycled	73	79	1.85	65
virgin	75	78	1.83	66
Average:				
102-mm	74	77	2.4	62
51-mm	74	78	1.65	66
Average:				
No-milling	73	78	2.0	65
Mill & Pave	73	79	1.7	66

overlays was much less than for 51-mm (2-in.) overlays. On the average, the rate of increase of cracking was slightly higher for sections with virgin overlays than for sections with recycled overlays. Although the sections with mill and replace strategy had higher preoverlay cracking, they showed less cracking in 1990 compared with sections with no milling.

Visual Distress Survey

A PAVER condition survey was conducted on each test section in May 1990. Approximately 30 percent of the area in each test section was surveyed. The survey consisted of observing 19 distress types on asphalt concrete pavements on 61-m (200-ft) sample units The sample units were chosen systematically on each section; the first sample unit was chosen at random. Five rut depth measurements were taken on each sample unit at 15-m (50-ft) intervals using a 3-m (10-ft) straight edge and a ruler. On average, 43 readings were taken on each section. The predominant distresses were found to be alligator cracking, longitudinal and transverse cracking, block cracking, and weathering. Pavement condition index (PCI) was calculated for each sample unit using the Micro-PAVER program (*3*). Rut depths were omitted from the calculation of PCI because of the difficulty associated with defining the actual rutted area.

Paver Survey Results

Table 6 shows the results of the PAVER survey for each test section. From the results it is evident that, once rutting is ignored, the load-associated distresses fairly dominated the PCI values for most of the test sections. The climate-associated deduct values (for block cracking and weathering) also contributed considerably to the lower PCI values of all sections. The average PCI value for Section 1 [recycled 102-mm (4-in.) overlay] is 71, slightly higher than for Section 2 [virgin 102-mm (4-in.) overlay]. For 51-mm (2-in.) overlays, the mean PCI value for recycled sections is 42 compared with 29 for virgin overlays. Students' *t*-tests conducted between the means of PCI values for virgin and recycled overlays showed no significant difference at 5 percent level of significance. The 102-mm (4-in.) overlays have performed better than 51-mm (2-in.) overlays. A significant difference was found between the means of PCI values for 51-mm (2-in.) and 102-mm (4-in.) overlays at a 5 percent level of significance. The mean PCI value for the mill and replace sections with 51-mm (2-in.) overlays 3 and 4 is 41, which is almost equal to the mean value, 39, for the existing Sections 5 and 6 with 51-mm (2-in.) overlays. Again, the mean PCI value for sections with recycled mix with mill and replace strategy was 44 compared with 24 for overlay sections with virgin mix on the existing pavement.

TABLE 5 Test Section Cracking History

Test Section	Pre-expt. Overlay Cracking (1981) (%)	Rate of Cracking Progression (%/ year)	Current Cracking (1990) (%)
1, EB (recycled)	6	0.3	2
2, EB (virgin)	15	0.0	0
3, EB (recycled)	50	1.3	10
4, EB (virgin)	15	0.8	6
5, WB (recycled)	15	3.1	20
6, WB (virgin)	25	3.2	20
7, WB (recycled)	30	1.9	12
8, WB (virgin)	12	1.8	12
Average: recycled virgin	25 17	1.6 1.9	11 10
Average: 102-mm 51-mm	11 25	0.2 2.0	1 13
Average: No-milling Mill & Pave	15 27	1.7 1.4	11 8

Rut Depth Measurements

The mean rut depth values for different sections are also shown in Table 6. The average values vary from 4 mm (0.15 in.) to 13 mm (0.50 in.). The 102-mm (4-in.) overlay sections have higher rut depths than do 51-mm (2-in.) overlays. Densification of asphalt concrete in the wheelpaths of the 102-mm (4-in.) overlays was suspected to be responsible for excessive rutting on these sections. Test sections with 102-mm (4-in.) overlays exhibited higher rut depths than did sections with 51-mm (2-in.) overlays. The mean rut depths recorded on Sections 1 (recycled) and 2 (virgin) were 13 mm (0.50 in.) and 12 mm (0.48 in.), respectively. The corresponding values for 51-mm (2-in.) recycled and virgin overlay sections were 6 mm (0.22 in.) and 5 mm (0.20 in.), respectively.

Bulk Density and Air Voids

As mentioned earlier, the 102-mm (4-in.) overlay sections had higher rut depths than did 51-mm (2-in.) overlay sections. Densification of asphalt concrete mix in the wheelpaths on the 102-mm (4-in.) overlays was suspected to be responsible for this excessive rutting. To verify this, bulk density test results from five cores obtained from the between wheelpath locations were compared with the test results from five cores retrieved from the outer wheelpath locations for Sections 1, 2, 5, and 6. The summary statistics for bulk density of the recycled mix for Sections 1 and 5 for both locations are shown in Table 7. Table 7 also presents the summary statistics of percent air voids of the virgin mix in Sections 2 and 6 for both locations. Students' *t*-tests between the means of these pa-

TABLE 6 PAVER and Rut Depth Survey Results

Section Number	PCI[1]			Load Assoc. Deduct Values (%)	Climate Assoc. Deduct Values (%)	Other Deduct Values (%)	Average Rut Depth (mm)
	Mean	S.D.	C.V. (%)				
1, EB	71	12	17	44	41	15	13
2, EB	69	13	19	50	45	5	10
3, EB	50	12	24	58	42	0	5
4, EB	32	18	56	68	31	1	5
5, WB	37	12	32	66	34	0	5
6, WB	41	17	42	62	38	0	4
7, WB	38	16	43	46	54	0	6
8, WB	15	13	84	56	43	1	6

Notes:
1. Excludes rutting
2. 1 mm = 0.04 in
3. Average: Recycle PCI = 49
   Virgin PCI = 39

   102-mm overlay PCI = 70
   51-mm overlay PCI = 36

   No-milling PCI = 55
   Mill & Pave PCI = 34

TABLE 7 Percent Air Voids and Bulk Density for Sections with Aggregate Base

Section No.	Air Voids (%)						Bulk Density (kN/m³)					
	Outer Wheel Path			Between Wheel Path			Outer Wheel Path			Between Wheel Path		
	$\bar{x}$	σ	n	$\bar{x}$	σ	n	$\bar{x}$	σ	n	$\bar{x}$	σ	n
1, EB (Recycle)	-	-	-	-	-	-	23.3	0.19	5	22.7	0.35	5
2, EB (Virgin)	1.99	0.57	5	4.66	1.13	5	-	-	-	-	-	-
5, WB (Recycle)	-	-	-	-	-	-	23.3	0.23	5	22.9	0.19	5
6, WB (Virgin)	1.52	1.04	5	2.82	0.58	3	-	-	-	-	-	-

Note: 1 kN/m³ = 6.361 lb/ft³

rameters for the two locations show significant difference at 10 percent level of significance. The *t*-test results indicate the densification in the outer wheelpath locations for all sections. Densification of asphalt concrete mixes on these sections might have contributed to the observed higher rut depths. Again, Table 7 indicates that lower amount of densification had occurred on Section 6, which had also the lowest mean rut depth value (4 mm, or 0.15 in.).

Deflection Testing

Deflection data were collected at five random locations on each of the eight test sections with a Dynatest 8000 falling weight deflectometer in May 1990. Seven sensors were used, with the first sensor at the center of the loading plate and six others at a uniform radial distance 305 mm (12 in.) apart. Three drops of falling weight deflectometer load were used for target loadings of 27 kN (6,000 lb), 40 kN (9,000 lb), and 67 kN (15,000 lb).

Backcalculation Results

The subgrade moduli were backcalculated from falling weight deflectometer data using an elastic layer analysis backcalculation scheme, BKCHEVM (*4*). Table 8 gives the average and range of subgrade moduli for each test section. The estimated subgrade moduli were unusually high. The effect of rigid bottom was not fully taken into account in the backcalculation process. This may have had an effect on the backcalculated subgrade moduli. The table indicates that test Section 8 has the lowest average subgrade modulus among all test sections. The lower range of subgrade moduli on this test section might be responsible for the extensive alligator cracking observed on this section during the PAVER survey.

TABLE 8 Test Section Subgrade Moduli

Test Section No. and Direction	Subgrade Modulus (MPa)	
	Mean	Range
1, EB	5.5	4.2 - 9.9
2, EB	4.6	5.5 - 4.2
3, EB	4.5	3.5 - 5.7
4, EB	4.1	3.2 - 4.4
5, WB	4.5	4.2 - 4.9
6, WB	5.8	4.2 - 9.9
7, WB	4.1	3.8 - 4.2
8, WB	3.8	2.9 - 4.2

Note: 1 MPa = 0.145 ksi

Material Related Problems

Because ADOT's PMS does not report any material related distress such as stripping, no records are available on the development of this distress. However, prerehabilitation inspection of this project did not reveal any stripping problem.

MAINTENANCE COSTS

Significant maintenance activities were performed on this project just before the rehabilitation project. A fog seal coat was applied to the project in 1988. Figures 3 and 4 show the reported annual average maintenance cost per mile from the PMS data base for different strategies from 1981 through 1990. As noted, very high maintenance costs are evident during 1990 just before the rehabilitation. The average annual maintenance costs for all strategies were similar.

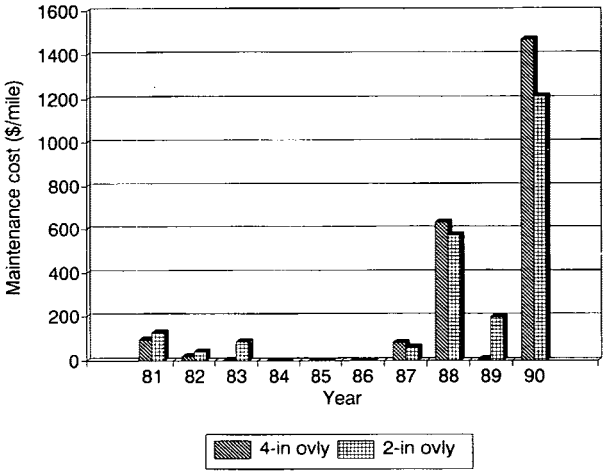


FIGURE 3 Average annual maintenance costs for overlays with different thicknesses.

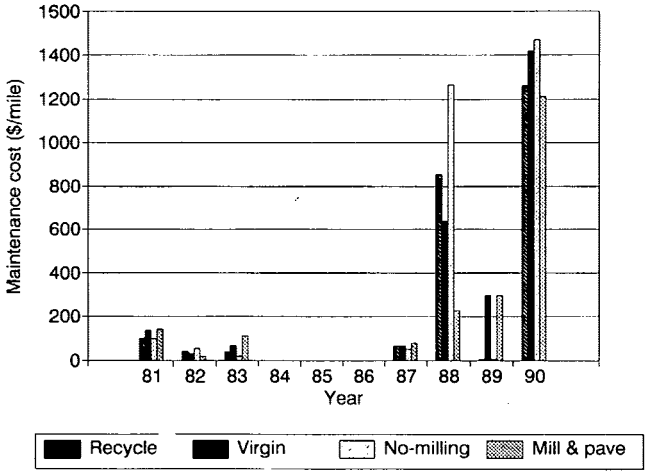


FIGURE 4 Average annual maintenance costs for overlays with different mixes.

CONCLUSIONS

- The test sections for the experimental overlay project, designed for a 10-year life, have performed satisfactorily throughout the service period. The functional performances of recycled and virgin mix overlays were similar. The 102-mm (4-in.) overlays were built to be smoother than 51-mm (2-in.) overlays and remained so at the end of their service lives.
- The 102-mm (4-in.) overlays performed slightly better than did the 51-mm (2-in.) overlays when evaluated by the load-associated distresses (except rutting). However, the amount of cracking on the thicker overlays was considerably less than on the thinner overlays.
- The average rut depth on the 102-mm (4-in.) overlays was about twice that on the 51-mm (2-in.) overlays. Densification of both types of mixes under traffic wheel load was mostly responsible for rutting on the thicker overlays. The virgin mix had slightly less rutting than the recycled mix.
- The mill and replace strategy before overlay placement did not appear to provide more added life than did the simple overlay strategy. Although the sections using mill and replace strategy were originally in worse condition, these sections performed better than did the simple overlay sections.
- For the design using the mill and replace strategy before overlay, the recycled mix outperformed the virgin mix.
- After 10 years, both the 102-mm (4-in.) and 51-mm (2-in.) overlays required rehabilitation, which suggests that the 51-mm (2-in.) overlay design strategy was the most cost effective. The average annual maintenance costs for different strategies were similar.

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