MICROSILICA MODIFIED CONCRETE FOR BRIDGE DECK OVERLAYS

Second-Year Interim Report

FHWA Experimental Features
OR 89-03A, OR 89-03B, and 89-03C

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16. Abstract

This report summarizes the performance of microsilica concrete (MC) overlays on seven distressed Portland cement concrete bridge decks at three sites in Oregon. This report emphasizes the overlays' condition after two, or in some cases, three years of use.

After two or three years, there was cracking on all seven overlays and delamination on five overlays. On the two overlays without delaminations, the cracking had not increased during the second year of use. On the five overlays with delaminations, the number and length of the cracks and the number and size of the delaminations increased during the second and/or third year of use.

Despite the cracking, all of the overlays had no excessive surface wear or rutting, spalling around the crack edges, potholes, or popouts. No maintenance was required during the second, and in some cases the third year of overlay life except on one overlay where methacrylate and sand were used at a cost of $4,000. All of the overlays had adequate tire-to-pavement friction numbers.

The overlays met two of their three design objectives after two or three years of use. They were still adding strength to the deck and providing a smooth and durable wearing surface. However, as they were cracked, it is surmised that they were no longer sealing the underlying deck from the intrusion of chlorides.

The Oregon Department of Transportation (ODOT) is continuing to specify MC as an overlay material. Experience with the material and revision of the MC specifications has reduced construction problems, and consequently, improved the quality of the overlays.

It is recommended that the causes of the cracking on these overlays be investigated.

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DISCLAIMER

Microsilica Modified Concrete for Bridge Deck Overlays

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

Prior to 1989, latex modified concrete (LMC) was almost always used in bridge deck overlays by the Oregon Department of Transportation (ODOT) to add structural strength, to provide a smooth and durable wearing surface, and to seal the deck from the intrusion of chlorides from deicing agents or other sources.

Manufacturers of microsilica admixtures claimed microsilica modified concrete (MC) could be used as a cost-effective alternative to LMC in bridge deck overlays. The manufacturers said MC had the structural strength, resistance to wear, and impermeability to chloride intrusion needed for a concrete overlay. In addition, they claimed the material would be less costly to produce than LMC, as it could be mixed in a conventional concrete batch plant like portland cement concrete (PCC). LMC, in contrast, usually requires the added expense of mobile mixing plants at the jobsite.

In order to gain experience with this material, the ODOT used MC to overlay seven bridge decks in 1989. The specifications for all projects were written to allow the use of MC containing "Force 10,000" microsilica slurry made by W.R. Grace, Inc.

1.2 OBJECTIVES AND SCOPE

The objective of this study is to see if MC can be a suitable alternative to LMC for structural deck overlays. A construction report for these overlays, covering the pouring, finishing, curing, construction costs, and post-construction inspection results was published in October 1990 (*1*). A first year interim report was published in November 1991 (*2*). A final report will be published after the fourth year's inspections.

This interim report covers the first two to three years of performance of the overlays, with emphasis on cracking, delamination, and tire-to-pavement friction. A summary of the surface inspection results and maintenance activities since construction is included in the Appendix.

2.0 SITE DESCRIPTION AND MATERIALS

2.1 LOCATION AND LAYOUT

The overlays are listed in Table 2.1. Their locations are shown in Figure 2.1. The location of the pours on the bridge decks are shown in Figure 2.2.

Table 2.1: Overlay Listing

ODOT Bridge No.	Bridge Name	Dates of Pouring	Highway	Milepoint	No. of Pours
9260B	Northbound Colestin Road Overcrossing Bridge	4/27/89	Pacific (OR #1 or US #I-5)	4.61	1
9260B	Southbound Colestin Road Overcrossing Bridge	8/31/89 9/6/89	Pacific (OR #1 or US #I-5)	4.61	2
9184A	Northbound Neil Creek Road Overcrossing Bridge	5/11/89	Pacific (OR #1 or US #I-5)	10.34	1
9184A	Southbound Neil Creek Road Overcrossing Bridge	9/14/89	Pacific (OR #1 or US #I-5)	10.34	1
7036	Holladay Street Ramp Bridge	4/29/89 5/6/89	Columbia River (OR #2 or US #I-84)	1.32	2
7040AA	Grand Avenue Ramp Bridge	9/9/89	Columbia River (OR #2 or US #I-84)	.52	1
8498W	Westbound Meacham Overcrossing Bridge	8/3/89 8/9/89 8/10/89	Old Oregon Trail (OR #6 or US #I-84)	237.95	3

2.2 ENVIRONMENT AND TRAFFIC

Climate and traffic data are summarized in Table 2.2 (*3,4*).

Table 2.2: Environment and Traffic

	Colestin Road Bridge	Neil Creek Bridge	Holladay Street Ramp Bridge	Grand Avenue Ramp Bridge	Westbound Meacham Over-crossing Bridge
Elevation, Feet (m)	4,275 (1,303)	2,565 (782)	125 (38)	65 (20)	3,740 (1,140)
Avg. Daily Temp. of Coldest Month, °F (°C) (January)	30 (-1)	32 (0)	41 (5)	41 (5)	28 (-2)
Mean Daily Temp. Swing in January, °F (°C)	14 (8)	14 (8)	11 (6)	11 (6)	14 (8)
Avg. Daily Temp. of Hottest Month, °F (°C) (July)	63 (17)	64 (18)	66 (19)	66 (19)	63 (17)
Mean Daily Temp. Swing in July, °F (°C)	31 (17)	32 (18)	23 (13)	23 (13)	32 (18)
Average Annual Precipitation, Inches (cm)	39 (99)	39 (99)	39 (99)	39 (99)	30 (76)
1991 Avg. Daily Two-Way Traffic (Vehicles/Day)[a]	13,025	13,150	-	-	6,450
Heavy Trucks (% of ADT)[b]	30	30	-	-	43

[a]These bridge decks carry one-way traffic. Consequently, they carry about ½ of the two-way traffic loading.

[b]Single unit, 2 axle, 6 tire or larger vehicles are classified as "heavy trucks".

2.3 MATERIALS

The MC for the Colestin Road Overcrossing Bridge and Neil Creek Road Overcrossing Bridge overlays contained:

Cement - Calaveras Type II.
Aggregates - ¾ - #4 inch (19 - 4.75 mm) crushed river gravel and natural sand from Kendall Bar on the Rogue River.
Additives - "Force 10,000" microsilica, "WRDA 19" high range water reducer (superplasticizer), "Daratard 17" set retarder, and "Daravair" air entrainment agent.

The MC for the Holladay Street Ramp Bridge and Grand Avenue Ramp Bridge contained:

Cement - Ashgrove Type I.
Aggregates - ¾ - #4 (19 - 4.75 mm) inch crushed river gravel and natural sand dredged from the Willamette River near Ross Island.
Additives - "Force 10,000" microsilica, "WRDA 19" high range water reducer (superplasticizer), "WRDA 79" Type A water reducer, and "Darex" air entrainment agent.

The MC for the Westbound Meacham Overcrossing Bridge contained:

Cement - Ashgrove Type I.
Aggregates - ¾ - #4 inch (19 - 4.75 mm) crushed river gravel and natural sand from the R.D. Mac pit on the Grande Ronde River near Island City.
Additives - "Force 10,000" microsilica, "WRDA 19" high range water reducer (superplasticizer), "WRDA 79" Type A water reducer, and "Daravair" air entrainment agent.

The microsilica and all other additives were made by:

W.R. Grace & Co.
Construction Products Division
62 Whittemore Avenue
Cambridge, Massachusetts 02140
(617) 876-1400

The "Force 10,000" microsilica was supplied in a water based slurry. The primary ingredient was finely powdered microsilica produced as a by-product from the manufacture of metallic silicon. For all project's mix designs, the cement content was identical to the typical ODOT conventional concrete. The microsilica was in addition to this cement content and was 7.9 percent of the weight of the cement.

3.0 OVERLAY PERFORMANCE

This chapter describes the condition of the overlays at the time of the latest inspections and deck repair since construction. Summaries of the individual overlays' condition since construction are in the Appendix.

3.1 PERFORMANCE OF COLESTIN ROAD OVERCROSSING BRIDGE AND NEIL CREEK ROAD OVERCROSSING BRIDGE OVERLAYS

The latest inspection was performed in June 1992, and the inspection for the first year interim report was done in September 1990. During the 21-month period between these inspections, all of these overlays had:

1) No excessive rutting or surface wear.

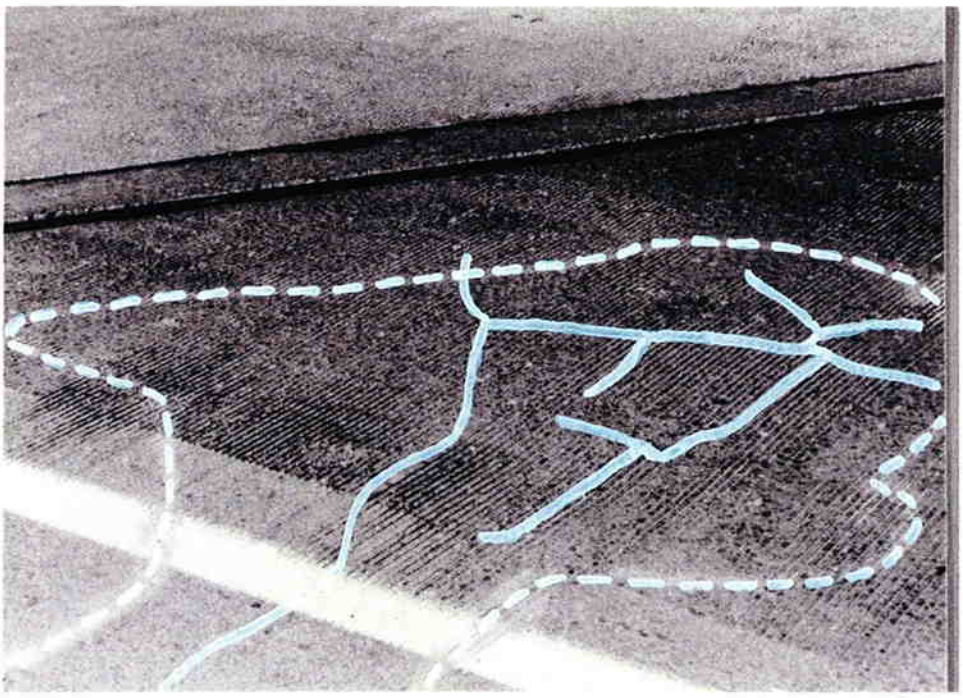
2) No potholes, spalling, or popouts.

3) A slight increase in surface crack length, width, and frequency.

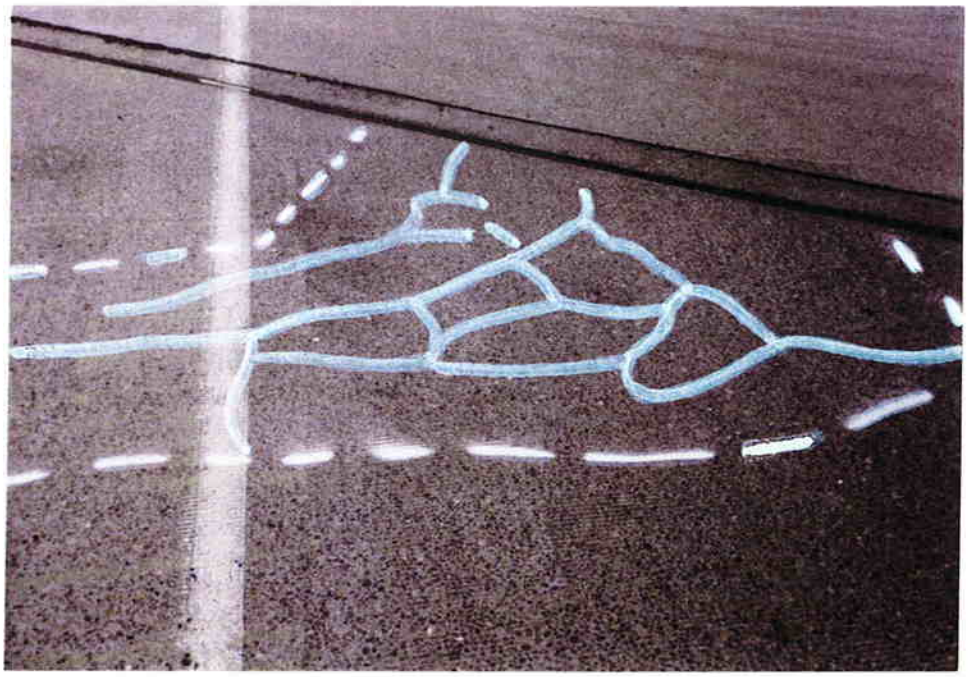
In 1992, all four of the overlays had areas of highly visible surface cracking. Most of these cracks were in a map or alligator pattern, they were 1/16 inches or less in width, and their edges were not spalled. The deck around the edges of many of these cracks was stained with a fine white powder. Typically, these stains indicate water is pumping in and out of the cracks when traffic moves across the span. Many of the cracks in the alligator patterns were over delaminated areas. Outside of the areas with more visible cracking, all of the decks had fine cracking over their entire surface. This cracking was not easily visible, and the crack edges were not spalled.

Many of the areas which were cracked in 1992 were also cracked in 1990. However, in 1990, there were not as many cracks. Figure 3.1a shows a typical crack pattern. This photo was taken in 1990 on the Colestin Road Overcrossing Bridge. Cracks were present, but they had not interconnected into an alligator pattern. Figure 3.1b shows the same cracked area in 1992. The cracks had interconnected to form an alligator pattern. This was typical of many cracked areas on these overlays.

4) An increase in the number and size of delaminations. In 1992, all four of these overlays had delaminated areas. Betwen 1990 and 1992, the percentage of the deck area which was delaminated increased from an average of



a) Cracking and Delamination on the South End of the Overlay in September 1990. In These Enhanced Photographs, Cracks are Marked by Solid White Lines, and the Edges of Delamination are Marked by Dashed White Lines.



b) The Delaminated Area Shown in Figure 3.1a During June 1992. The Cracking and Delamination had Increased.

Figure 3.1: Cracking and Delamination on the Northbound Colestin Road Overcrossing Bridge Overlay

1.25 percent to an average of 3.75 percent. Figure 3.1 shows a typical large delamination in 1990, and again in 1992. As shown in the photographs, delamination increased in size during the two-year period.

3.2 PERFORMANCE OF HOLLADAY STREET RAMP BRIDGE AND GRAND AVENUE RAMP BRIDGE OVERLAYS

The latest inspection was done in October 1991, and the previous inspection, summarized in the first-year interim report, was done in October 1990. During the 12 months between the inspections, the overlays had:

1) No excessive rutting or surface wear.

2) No potholes, spalling, or popouts.

3) No increase in cracking on either overlay since the 1990 inspection.

In 1990, the Holladay overlay had cracking on 50 percent of the right lane and 30 percent of the left lane. The cracks were deeper and connected into an alligator pattern near the ends of the bridge. The Grand Avenue overlay had short hairline alligator cracking on 34 percent of its deck area. None of these cracks had spalled edges.

4) No delaminations.

3.3 PERFORMANCE OF THE WESTBOUND MEACHAM OVERCROSSING BRIDGE OVERLAY

The inspection for the first-year interim report was done in November 1990, and the last inspection was done in July 1991. During the eight month period between the inspections, the overlays had:

1) No excessive rutting or surface wear.

2) No potholes, popouts, or spalling.

3) A slight increase in cracking.

Between 1990 and 1991, the amount of cracking increased from approximately 3.4 to 3.9 lineal feet per square yard of deck surface. These cracks were very fine and their edges were not spalled. A typical square yard of the overlay in 1991 is shown in Figure 3.2.

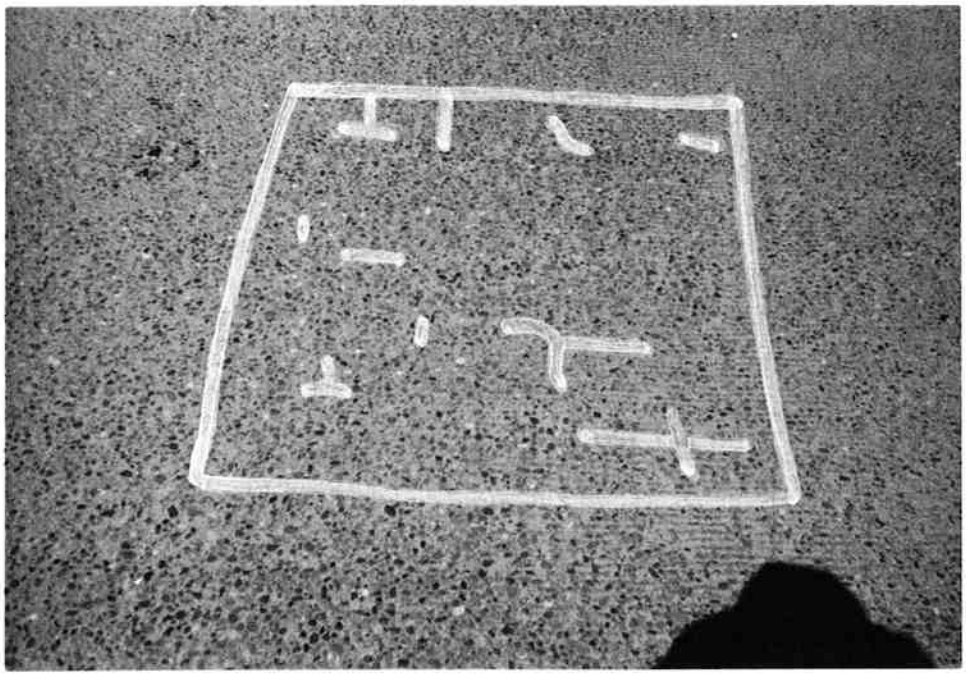


Figure 3.2: A Typical Square Yard of the Meacham Overcrossing Bridge Overlay. In This Enhanced Photograph the Square Denotes the Boundaries of the Square Yard, and the Lines Within the Square Denote Cracks.

3.4 PAVEMENT FRICTION

In 1991, wheel-to-wheel pavement friction testing was done at speeds near 40 mph on the two year old overlays using a K.J. Law trailer. The test methods, calibration techniques, and equipment conformed to AASHTO standards.

All MC overlays had adequate friction numbers. Also, the average friction numbers for the MC overlays were higher than typical values for PCC pavements. In addition, the MC overlay's average friction number was substantially higher than the average friction number from 34 tests on two-year-old LMC overlays on two typical Oregon bridges.

3.5 MAINTENANCE

Some delamination repair and crack sealing were done after the curing blankets were removed and before the decks were opened to traffic. The contractor paid for these repairs. The only other repair or maintenance was the sealing of the Northbound Colestin Road Overcrossing Bridge deck with methacrylate seal and sand in November 1989 (*1*). This repair cost the ODOT about $4,000. Details on maintenance are in the Appendix.

4.0 ADDITIONAL ODOT EXPERIENCE WITH MICROSILICA

Although there were problems with the MC overlays in this study, the ODOT continues to specify MC as an overlay material. The agency feels the newer MC overlays may be more successful than the overlays in this study because:

1) Contractors and ODOT field personnel are gaining experience with the material.

2) MC is specified as an alternative to LMC on projects where the agency anticipates that MC can be placed within 90 minutes of initial mixing. On remote projects or other jobs where placement within 90 minutes may not be possible, LMC is specified. On the overlays in this study, the duration between batching and placing some loads often exceeded 90 minutes. Usually these loads were hard to place and finish, and often they would crack shortly after placement.

3) The MC specifications (*5*) were revised to allow the use of densified microsilica as well as slurried microsilica. Contractors in Oregon have found this form of microsilica easier to handle than the slurry, and it is used most often. The specifications for the MC in this study allowed slurry only.

4) Changes in the specifications for air content, slump, deck preparation, finishing, grooving, and environmental conditions during placement provide higher quality MC bridge deck overlays (*1*).

These changes have improved the short-term performance of MC overlays. For example, adherence to the batch-to-placement time limits and the environment during placement appears to be lowering the instances when the overlays have plastic or drying shrinkage cracks. The effect of these changes on long-term performance remains to be seen, as overlays constructed with the various versions of revised specifications are only one, two, or three years old.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

After two or, in some cases, three years, the overlays were still meeting their design goal of adding structural strength. None of the cracks and delaminations were severe enough to weaken the overlays. In addition, the overlays were satisfying their design goal of giving a smooth and durable surface. The cracked and delaminated areas were still intact. However, the overlays were not meeting their design objective of sealing the underlying deck from chlorides. Water can contact the underlying deck through cracks in the overlays, delaminations under cracked sections of the overlay, and delaminations adjacent to construction and/or expansion joints.

Aside from cracking and delamination, MC appears to be a hard and durable overlay material. The Colestin Road Overcrossing Bridge and the Neil Creek Road Overcrossing Bridge are good examples: these decks are on a heavily travelled freeway in a snow zone where vehicles often use tire studs, cables, or chains. Under these conditions, MC has been excellent at resisting abrasion damage.

The MC overlays appear to have better surface friction properties than PCC and LMC. This is a tentative conclusion, however, as it is based on limited data. More data on the surface friction of these concretes is needed to make a firm conclusion.

Preliminary findings suggest that the rate of deterioration may be a function of both construction quality control and the environment. Bridges in an environment with more freeze-thaw cycles may fail more rapidly. The causes of premature MC overlay failures need further investigation.

5.2 RECOMMENDATIONS

The causes of the cracking in these overlays should be investigated. Much of the cracking may be due to plastic and drying shrinkage. This type of cracking may be prevented by improved construction practices. Also, some cracking may be caused by other sources, such as cracks in the underlying deck reflecting through the overlay, or excessive structural deflections. If the MC overlays are either prone, resistant to reflective cracking, or cracking due to excess deflections, these properties may need to be considered during the overlay's structural design.

6.0 REFERENCES

1. Bo Miller, Microsilica Modified Concrete for Bridge Deck Overlays, Construction Report (Salem, Oregon: Oregon Department of Transportation, October 1990).

2. Bo Miller, Microsilica Modified Concrete for Bridge Deck Overlays, First Year Interim Report (Salem, Oregon: Oregon Department of Transportation, November 1991).

3. William Loy and others, Atlas of Oregon (Eugene, Oregon: University of Oregon Books, 1976), pp. 130-32, 135.

4. Oregon Department of Transportation, 1991 Traffic Volume Tables, (Salem, Oregon: Oregon Department of Transportation, June 1992).

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Appendix

SURFACE CONDITION AND MAINTENANCE

Table A-1a: Surface Condition and Maintenance

Northbound Colestin Road Overcrossing Bridge Overlay

Date of Inspection or Repair	Comments
April, '89	Poured.
May, '89	Isolated cracks were found when the deck was uncovered after the cure. The cracks were sealed with methacrylate sealer. Isolated delaminations were chipped out and repaired with MC.
November, '89	Extensive map cracking was found. The deck was flooded with Concresive 2075 methacrylate sealer and covered with #30 grit sand. 1.9 percent of the surface was delaminated. The delaminations were scattered throughout the deck, and most were one to three square feet in area.
September, '90	Severe alligator cracks were found on 2 percent of the surface. Alligator cracking was starting on 1 percent of the surface. Severe cracking was found between the inside fog line and face of the inside bridge rail. Random transverse and longitudinal cracks up to six feet long were found on the right lane. Cracking was found on the strip of MC between the expansion joint and the poured filler on the ends of the bridge. Little cracking was seen on the left lane.
August, '91	New cracks were seen throughout deck. Many of these cracks were perpendicular to the bridge centerline. The old cracks which were sealed with the methacrylate sealer were still sealed.
April, '92	Open map and alligator cracking was seen throughout the deck surface. The methacrylate sealer was no longer visible in many of the previously sealed cracks.
June, '92	Highly visible cracks were found on 60 percent of the right lane's surface. Fine cracks were seen on the remainder of the deck. 2.6 percent of the deck surface area was delaminated. Surface wear was minimal and no rutting was found.

Table A-1b: Surface Condition and Maintenance

Southbound Colestin Road Overcrossing Bridge Overlay

Date of Inspection or Repair	Comments
August and September, '89	Poured.
September, '89	No cracking or delaminations were found when deck was uncovered after the cure.
September, 90	0.7 percent of the surface was delaminated. Most delaminations were on the right edge of Pour 2 where it abutted Pour 1. Several cracks 20 to 30 feet long were found in Pour 1, the climbing lane, near the leading edge of the bridge. Scattered cracks up to 12 feet long were found throughout the rest of Pour 1 and Pour 2. Cracking was found on the strip of MC between the expansion joints and the poured filler on both ends of bridge.
June, '92	Highly visible cracks were seen on 30 percent of the climbing lane's area, and 50 percent of the center lane's area. Fine cracks were found on the remainder of the deck. 5.1 percent of the deck area was delaminated. Surface wear was minimal, and no rutting was found.

Table A-1c: Surface Condition and Maintenance

Northbound Neil Creek Road Overcrossing Bridge Overlay

Date of Inspection or Repair	Comments
May, '89	Poured.
May, '89	No cracks were found when the deck was uncovered after the cure. A few delaminations were found. They were chipped out and repaired with MC.
November, '89	No cracks were found. 1.4 percent of the surface was delaminated. 0.3 to 1.0 feet of the leading edge of the deck was delaminated. There were scattered small delaminations throughout the rest of the deck.
September, '90	Random cracks up to nine feet long were found on both travel lanes. One foot long cracks extended from the outside bridge rail into the deck at one to one and a half-foot intervals. 2.2 percent of the surface was delaminated. These delaminations were scattered, as noted in the November '89 inspection.
June, '92	Highly visible cracks were seen on 30 percent of the deck area. Fine cracks were found on the remainder of the deck. 6.8 percent of the surface was delaminated. Surface wear was minimal, and no rutting was found.

Table A-1d: Surface Condition and Maintenance

Southbound Neil Creek Road Overcrossing Bridge Overlay

Date of Inspection or Repair	Comments
September, '89	Poured.
September, '89	No cracks or delaminations were found when the deck was uncovered after the cure.
September, '90	Alligator pattern cracking was found on 22 percent of the deck, and scattered cracks up to 36 inches long were seen on the rest of the span. 0.2 percent of the deck was delaminated. There were two delaminations, and both were under sections of the deck that were alligator cracked.
June, '92	Highly visible cracks were found on 30 percent of the deck area. Fine cracks were found on the remainder of the deck. Less than 1 percent of the deck was delaminated. Surface wear was minimal and no rutting was found.

Table A-1e: Surface Condition and Maintenance

Holladay Street Ramp Bridge Overlay

Date of Inspection or Repair	Comments
April-May, '89	Poured.
May, '89	On Pour 1, the right lane, four one-inch long shrinkage cracks were found immediately after the curing blankets were removed. Three short longitudinal cracks appeared in the deep (five to seven inches) section of the overlay at the west end of the bridge after the cure blankets were off for 24 hours. The cracks were sealed. Diamond grinding was used to smooth the rough surface of Pour 1. No cracks were seen on Pour 2, the left lane, and no grinding was needed. No delaminations were found.
October, '90	Cracking was found on 50 percent of the right lane and 30 percent of the left lane. Near both ends of the bridge, the cracks appeared to be deeper and were alligatored. The cracking was most severe on the deep section of the overlay at the west end of the right lane. Alligator cracking was also noted on a short section of standard PCC mix located at the east end of the right lane. This PCC was used in the last truckload of mix for the right lane, as the concrete supplier ran out of MC mix. No delaminations were found.
October, '91	No delaminations were found. No changes were reported since the last inspection. Overall condition appeared to be stable and no maintenance has been required. There was no excessive surface wear or rutting.

Table A-1f: Surface Condition and Maintenance

Grand Avenue Ramp Bridge Overlay

Date of Inspection or Repair	Comments
September, '89	Poured.
September, '89	No cracks were seen when the curing blankets were removed.
	Grinding was done on a small section of the overlay to correct the deck profile. No delaminations were found.
October, '90	Short hairline alligator cracking was noted on 34 percent of the MC overlay. Short transverse cracks were noted on 24 percent of the widened PCC deck near the right bridge rail. No delaminations were detected.
October, '91	No delaminations were found. No changes since the last inspection. Overall condition appeared to be stable and no maintenance has been required. There was no excessive surface wear or rutting.

Table A-1g: Surface Condition and Maintenance

Westbound Meacham Overcrossing Bridge Overlay

Date of Inspection or Repair	Comments
August, '89	Poured.
September, '89	Three cracks one to one and a half feet long were found and sealed on Pour 1. Construction personnel feel that these cracks may be tears from tinning. No cracks were found on any other spans. 0.3 percent of Pour 1 and 0.1 percent of Pours 2 and 3 were delaminated. Almost all delaminations were on the west edges of the pours adjacent to the expansion joints. All delaminations were chipped out and repaired with MC.
November, '90	Isolated scattered cracks were found on Pours 1 and 3, with the heaviest cracking on Pour 1. Little or no cracking was found on Pour 2. The crack intensity was estimated to be 3.4 lineal feet per square yard of deck area. 0.1 percent of Pour 1, .01 percent of Pour 2, and .04 percent of Pour 3 were delaminated. Almost all delaminations were under or next to patches made on delaminations found in September, 1990.
July, '91	Isolated scattered cracks were found on all pours. There was less cracking on Pour 2 than on Pours 1 and 3. The cracks were fine, randomly oriented, and they did not connect into a map or alligator pattern. The crack intensity was estimated to be 3.9 lineal feet of cracks per square yard of deck area. 0.4 percent of Pour 1, .06 percent of Pour 2. and 0.2 percent of Pour 3 were delaminated. There was no excessive surface wear or rutting.