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Interim Report

Evaluation of the Performance, Cost-Effectiveness, and Timing of Various Preventive Maintenances: Interim Report

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16. Abstract
This research is being conducted to evaluate the performance of various preventive maintenance treatments over time and under different environmental conditions to assess the economics of each treatment type. The first three tasks of this research are nearing completion. Task 1 is a review of the state of the practice for preventive maintenance. This review includes a conventional literature survey and interviews of maintenance and construction personnel throughout the state. Task 2 is a draft manual of best practices of pavement preventive maintenance and Task 3 includes selection and construction of full-scale test pavements for field evaluation of various preventive maintenance treatments. Results of Task 1 indicate there are three primary techniques utilized in Colorado for preventive maintenance of asphalt pavements and three for concrete pavements. These are for asphalt pavements: 1) crack sealing, 2) chip seals, and 3) thin hot mix asphalt overlays and for concrete pavements: 1) joint resealing, 2) cross-stitching, and 3) micro-grinding. Task 2 has resulted in a preliminary draft of what will become a best practices manual for the preventive maintenance techniques currently used in Colorado as well as additional methods used by other agencies. Full scale test sections were constructed as part of Task 3 in 2005 and some additional test sections previously constructed were also included for measurement of future performance. These test sections include crack sealing, chip seals, thin overlays, joint resealing, cross-stitching and micro-grinding.

Implementation: This in an interim report of research in progress. Implementation is not warranted at this time.

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by

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EXECUTIVE SUMMARY

This research is being conducted to evaluate the performance of various preventive maintenance treatments over time and under different environmental and construction conditions to assess the economics of each treatment type. The first three tasks of this research are nearing completion. Task 1 is a review of the state of the practice for preventive maintenance. This review includes a conventional literature survey and interviews of maintenance and construction personnel throughout the state. Task 2 is a draft manual of best practices of pavement preventive maintenance and Task 3 includes selection and construction of full-scale test pavements for field evaluation of various preventive maintenance treatments. Results of Task 1 indicate there are three primary techniques utilized in Colorado for preventive maintenance of asphalt pavements and three for concrete pavements. For asphalt pavements these are: 1) crack sealing, 2) chip seals, and 3) thin hot mix asphalt overlays. For concrete pavements treatments are: 1) joint resealing, 2) cross-stitching, and 3) micro-grinding. Task 2 has resulted in a preliminary draft of what will become a best practices manual for the preventive maintenance techniques currently used in Colorado as well as additional methods used by other agencies. Full scale test sections were constructed as part of Task 3 in 2005 and some additional test sections previously constructed were also included for measurement of future performance. These test sections include crack sealing, chip seals, thin overlays, joint resealing, cross-stitching and micro-grinding. Variables evaluated for crack sealing include two sealants, two climates, and presence or absence of a de-icing chemical prior to sealing operations. Chip seal variables include chip size and gradation and climate. Thin overlays include dense graded hot mix asphalt, ultra thin bonded wearing course, and stone matrix asphalt applied over both asphalt and concrete pavements. Cross-stitching of concrete was done using two methods including conventional deformed reinforcing steel and fiberglass panels.

IMPLEMENTATION STATEMENT

This is an interim report of research in progress. Implementation is not warranted at this time.

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1. INTRODUCTION

This research is intended to determine the most economical means of extending pavement life through preventive maintenance treatments in Colorado. The process proposed to accomplish this includes a survey of current published literature and interviews with individuals responsible for preventive maintenance, installation of experimental test pavements to measure performance under local conditions and recommendations based on the findings. This report documents the progress made for the first eighteen months of a five year study. This includes a survey of the literature, interviews with maintenance and construction personnel, the draft of a best practices manual, and the installation of most of the test pavements.

2. TASK 1 – Existing Preventive Maintenance Practices

Interviews were conducted with CDOT maintenance and construction personnel to determine the current methodology used for implementing pavement preventive maintenance. A summary of the current methods used, specific methodology for the methods and the decision process for implementing preventive maintenance is shown in Table 1.

Table 1. Interview Results: Preventive Maintenance Practices in Colorado in 2005

Current Methods Used	**Specific Methods**	**Decision Process**
1. Crack Seal (No Routing) 2. Chip Seal 3. Thin Overlay (<1.5in) includes any hot mix application 4. Slab Replacement 5. Joint Resealing 6. Microgrinding	Crack Seal 1. < ¼ inch wide cracks 2. Early winter/spring 3. Blow out cracks with compressed air 4. Heat lance used by some regions, however, one region indicated it was not effective if $MgCl_2$ was present. 5. CRS and blotter sand used by one region. 6. Hot pour sealants used by most regions a. Deery-D3405- will not stay in cracks if $MgCl_2$ has been used. However, one region indicated that if crack pouring is done in fall season before $MgCl_2$ use, the Deery product works acceptably. b. Asphalt rubber, (Meggison) – stays in cracks better if $MgCl_2$ has been used 7. Bump occurs in thin overlays if O/L placed before 1 year 8. Asphalt Rubber causes hump in crack as pavement temperature rises 9. Start on Nov 15, on or between snow storms Chip Seal 1. 3/8 in; HFMS-2P 2. Asphalt vendor takes chips and determines 'compatibility' with chips and supplies spread rate. 3. MS used because of increased time allowed before set 4. < 3000 ADT because of windshield damage 5. Estimated life is approx 5 yrs 6. 1/year for 'worse first' 7. HFMS-more forgiving than RS 8. $1/sy (DOT); $1.60 (Contract) 9. Double chip seals in one region Fog Seals 1. Use varies with Region Thin O/L 1. 1 in or less because of cost 2. Improve rideability/rut filling 3. Use whatever plant can supply that meets specs. SX with AC5 or AC10. No PG grades, yet. 4. One roller-10-15 ton vibratory/non-vibratory 5. Novachip - Best, but cannot afford if project is too small PCC 1. R&R backer rod and reseal joints	1. Road inventory randomly selected in one-mile increments. Budget identified based on issues in these segments. 2. TM2[1] identifies distress and reports to TM3 or LTC. LTC decides what to repair and how in early spring and fall seasons. 3. Preventive Maintenance-Do Something before 3 years old. 'Something' is usually: crack seal as cracks appear then chip seal if traffic is appropriate $150k spending limit if maintenance doing work. Coordinate with Engineering so Maintenance treatments do not get overlaid. 4. Six triggers from pavement management program: Age Rutting Cracking ADT 5. Crack seal when cracks get to about ¼ in - 9 to 12 mos before overlay to prevent bleed-through 6. Chip seal with DOT traveling crew 1 or 2 summers after crack sealing 7. Apply chip seals from 2.5-3 yrs after overlay applied 8. Expect 5 yrs service from chip seals 9. $150k limit is difficult to do enough work in some areas 10. With 5 yr window, this keeps them from sealing everything that is needy 11. Use pavement management program with judgement 12. Some believe PM program has flaws in triggers used to identify repairs 13. Better coordination needed with engineering to keep maint projects from getting O/L next year. 14. Fix worse first (about 50-75% of budget) 15. Preventive Maintenance (25-50% of budget)
Methods Eliminated		
1. Reclamite 2. Sand Seal – Believe contributes to rutting 3. Cold Patching 4. Fog Seals – Use varies		

* Note: Columns in Table 1 are independent of each other and do not necessarily relate directly.

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[1] See Figure 1 for organizational chart.

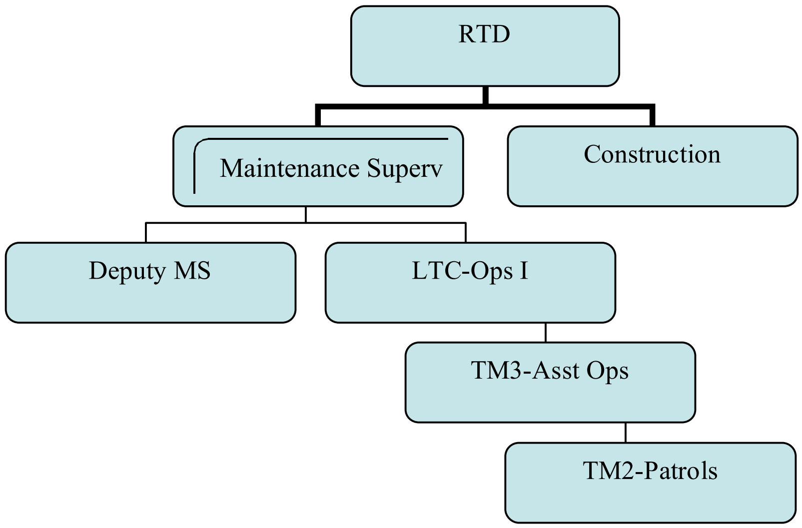


Figure 1. Organizational Structure for CDOT Region Maintenance

2.1 Task 1 – Literature Review

There is a significant volume of information available regarding preventive maintenance of pavements. The notion of applying incremental treatments to a pavement to extend serviceability is key to the concept of preventive maintenance. These incremental treatments are optimized when applied at the correct time. The correct time varies with traffic loading, pavement age, weather, materials, design, and construction quality (Peterson, 1981). However, most agree that preventive maintenance should be applied during the period when the pavement remains in good condition as shown in Figure 2 (Peterson, 1981) estimating that funds spent early in the life of the pavement will return significant cost savings (Johnson, 1983) as shown in Figure 3.

Routine maintenance and preventive maintenance are often confused and several definitions can be found in the literature. For example, routine maintenance is often synonymous with 'reactive' maintenance. 'Reactive' maintenance activities for pavements include pothole

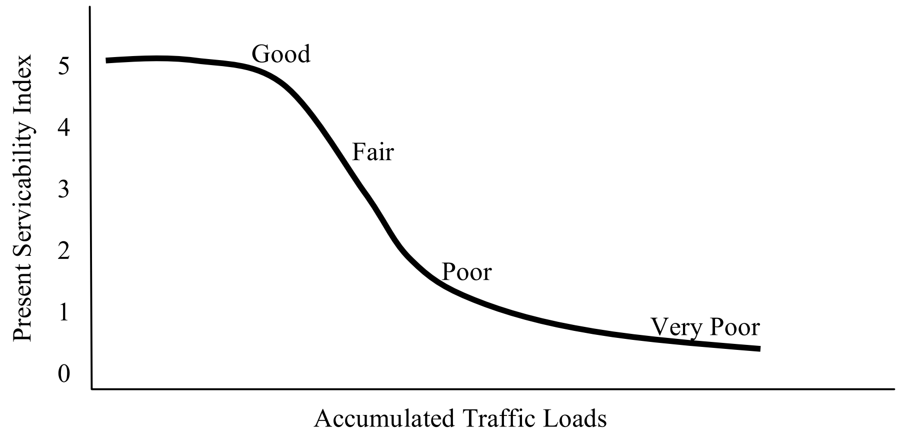


Figure 2. Typical Pavement Performance Curve, after Carey (1960)

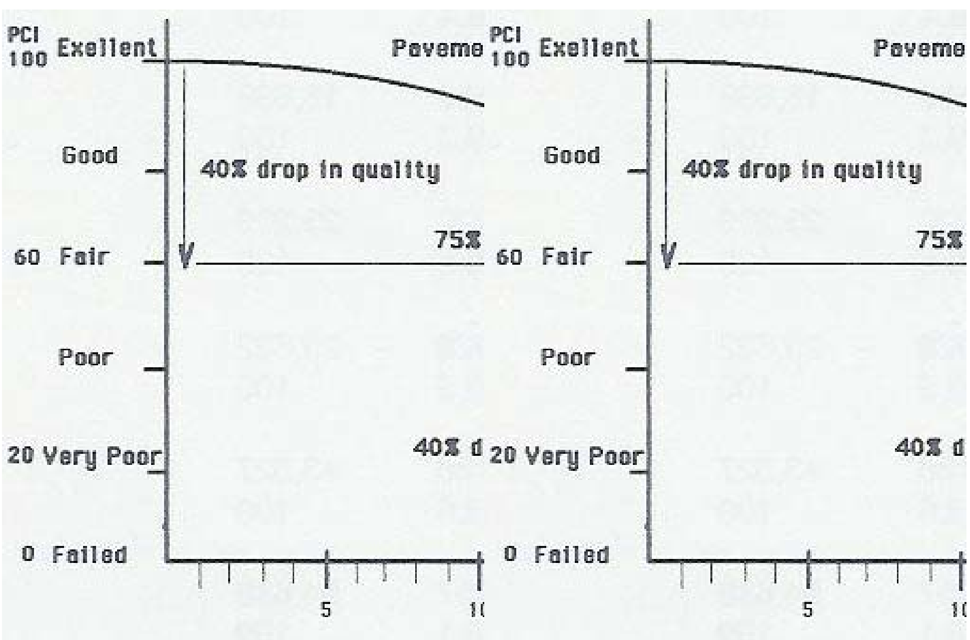


Figure 3. Typical Pavement Life Cycle (from O' Brien, L. G., 1989)

repair, blowup repair, and spall repair. Preventive maintenance is a programmed strategy intended to arrest light deterioration, retard progressive failures and reduce the need for 'reactive' maintenance. Preventive maintenance is usually a cyclic, planned event. Preventive maintenance is generally considered to not significantly improve load-carrying capacity but instead to extend the useful life of the pavement. Typical activities include crack and joint sealing, joint repair, limitied slab replacement, undersealing or mudjacking, surface treatments, grinding, machine-laid patching (O' Brien, L. G., 1989).

A survey of preventive maintenance practices (Zimmerman, 1995) indicated that strategies differ depending on the needs and objectives of each agency and that not one method is best suited to all agencies, as might be expected. This study found that the simplest methods of pavement management were practiced by most highway agencies surveyed. The study found that pavement condition surveys rather than more complex priority assessment models or network optimization models were being used.

The Strategic Highway Resarach Program SPS-3 and SPS-4 research studies included both asphalt and concrete pavement preventive maintenance treatments including slurry seal, chip seal, thin overlays, crack sealing and joint resealing. Expert Task Groups evaluated the performance of the test sections and a report (Morian, 1997) summarizing the ETG findings concluded that:

- Preventive maintenance treatments generally outperformed control sections
- Treatments applied to pavements in good condition have shown good results
- Traffic level and pavement structural adequacy did not appear to affect performance

A detailed analysis of the Long Term Pavement Performance (LTPP) data from the SPS sites through 2001 was accomplished by NCHRP Project 20-50(03/04) and reported by Hall, et al (2004). This report indicates that with respect to roughness, rutting and fatigue cracking, thin overlays were most effective followed by chip seals then slurry seals. As pavement roughness increased there was some evidence that chip seals had an effect on long term roughness. Slurry seals showed no effect on long term roughness. The thin overlays, as expected, were the only treatment to affect long term rutting. Fatigue cracking is significantly less in the thin overlay sections than corresponding control sections. The chip seal and slurry seal sections have less cracking than the control sections, as well. However, long term cracking has accelerated for both chip seal and slurry seal sections. Crack sealing did not reduce long term cracking and show more cracking than control sections. However, the report indicates that this may not be due to adverse effects of crack sealing, but rather to 1) sealing of new cracks (cracks that appeared after the initial treatment date), and/or 2) the greater visibility of sealed cracks. The study concluded that with respect to IRI reading, rutting and cracking on concrete pavements in the SPS-6 study that except for an 8 inch and 4 inch asphalt overlay on a cracked and seated concrete pavement that diamond grinding, full-depth repair and joint and crack sealing had the next best effect. It is interesting that no added benefit was associated with subdrainage improvement, load transfer restoration or undersealing.

Recent research (Peshkin, et al, 2004) indicates there is little or no guidance available for determining the optimal procedure and timing for preventive maintenance treatments. They found that timing of treatments was based on: 1) predetermined schedules, 2) time since a previous maintenance and rehabilitation event, 3) maintenance surveys, and 4) pavement management systems. One result of this research is analytical software called OPTime based on Microsoft® Excel which provides a means for identifying the optimal time to apply various preventive maintenance treatments.

There are many guidelines available for applying preventive maintenance treatments. Colorado maintenance personnel often refer to the 'Shaffer Memo' (Shaffer, 1991) developed by Doug Shaffer of CDOT to provide guidance to maintenance forces regarding crack filling and joint resealing operations. A more recent publication developed for CDOT (CDOT, 2004) provides guidelines for crack sealing, crack filling, sand seals, chip seals, micro-surfacing, thin bonded wearing courses, thin overlays (less than 1-1/2"), surface milling with non-structural HMA overlay (less than 1-1/2"), diamond grinding, concrete crack sealing, concrete joint resealing, partial depth concrete pavement repair, dowel bar retrofit, and full depth concrete pavement repair. This document also provides guidance regarding the expected life extension provided by each treatment when applied under appropriate conditions.

3.0 TASK 2 – Best Practices Manual

The first draft of the Best Practices Manual was submitted to the research panel for review and comment. This version of the manual is contained in Appendix A. A revised Best Practices manual is being prepared based on comments received from the panel and will be submitted upon completion.

4.0 TASK 3 – Field Tests

Test sections will be monitored during this research so quantitative measures can be developed to determine the effectiveness of various preventive maintenance treatments. Some of these test sections were constructed before research on this project began, but most have been, or will be constructed during the course of this research. Treatments placed during the course of this research include crack filling, chip seals and thin hot mix asphalt overlays on asphalt pavements and joint resealing, cross-stitching and diamond grinding on concrete pavements. Treatments placed prior to this research include thin stone matrix asphalt (SMA) and ultra-thin bonded wearing courses placed as a preventive maintenance treatment.

4.1 Crack Filling

Two sites were established in 2005 to evaluate crack filling performance. These sites are located on SH7 south of Estes Park and SH66 east of Lyons.

4.1.1 SH7, Estes Park: Crack Fill

These test sections were placed by CDOT maintenance personnel on May 5, 2005. They are located on SH7 in the southbound lane beginning at Milepost 3 (Station 0+00). Two types of crack filler were applied. These are from Deery and Meggison. The pavement was sprayed with magnesium chloride de-icing solution prior to crack filling for half of the sections and no magnesium chloride was applied in the other sections. The resulting test pavement factorial experiment has 2 crack fillers x 2 de-icing applications x 2 replicates = 8 test sections as shown in Table 2. There are six cracks treated

Table 2. Crack Fill Test Sections on SH7

Section No.	Crack No.	Dist (Ft)	Crack Fill Type	$MgCl_2$ Applied?
8	-	0.00		No
	1	15.25	Deery	
	2	28.25	None	
	3	37.25	Deery	
	4	52.67	None	
	5	64.17	Deery	
	6	80.08	None	
	7	90.33	Deery	
	8	106.67	None	
	9	121.83	Deery	
	10	135.08	None	
	11	153.67	Deery	
	12	182.08	None	
7	13	197.25	Megg	
	14	205.75	None	
	15	230.92	Megg	
	16	261.00	None	
	17	290.00	Megg	
	18	318.58	None	
	19	368.42	Megg	
	20	391.58	None	
	21	412.67	Megg	
	22	426.92	None	
	23	441.67	Megg	
	24	451.00	None	
6	25	468.33	Deery	
	26	496.58	None	
	27	514.00	Deery	
	28	540.75	None	
	29	553.92	Deery	
	30	584.42	None	
	31	610.92	Deery	
	32	631.33	None	
	33	651.42	Deery	
	34	672.08	None	
	35	683.33	Deery	
	36	708.50	None	
5	37	724.33	Megg	
	38	740.00	None	
	39	749.92	Megg	
	40	772.17	None	
	41	796.75	Megg	
	42	830.75	None	
	43	860.00	Megg	
	44	872.17	None	
	45	884.50	Megg	
	46	891.25	None	
	47	917.42	Megg	
	48	939.00	None	
4	49	946.83	Deery	Yes
	50	1002.08	None	
	51	1015.00	Deery	
	52	1033.50	None	
	53	1048.42	Deery	
	54	1078.00	None	
	55	1177.33	Deery	
	56	1244.58	None	
	57	1265.33	Deery	
	58	1285.08	None	
	59	1297.83	Deery	
	60	1309.25	None	
3	61	1318.08	Megg	
	62	1326.50	None	
	63	1337.42	Megg	
	64	1343.17	None	
	65	1348.50	Megg	
	66	1364.00	None	
	67	1371.08	Megg	
	68	1419.00	None	
	69	1429.00	Megg	
	70	1451.67	None	
	71	1460.75	Megg	
	72	1476.75	None	
2	73	1491.25	Deery	
	74	1506.83	None	
	75	1515.92	Deery	
	76	1547.00	None	
	77	1574.58	Deery	
	78	1581.67	None	
	79	1593.33	Deery	
	80	1609.00	None	
	81	1627.67	Deery	
	82	1653.92	None	
	83	1677.33	Deery	
	84	1685.00	None	
1	85	1703.00	Megg	
	86	1718.83	None	
	87	1729.08	Megg	
	88	1738.58	None	
	89	1753.17	Megg	
	90	1760.58	None	
	91	1776.00	Megg	
	92	1792.00	None	
	93	1802.00	Megg	
	94	1817.75	None	
	95	1835.67	Megg	
	96	1858.75	None	

in each section with six adjacent control cracks where no crack filler was applied. This results in twelve cracks per section or 96 cracks for performance evaluation over a distance of 1858.75 feet from milepost 3.

4.1.2 SH66, Lyons: Crack Fill

These test sections were placed by CDOT maintenance personnel on May 4, 2005. They are located on SH66 in the westbound lane beginning 14 feet west of Milepost 31 (Station 0+00). Two types of crack filler were applied. These are from Deery, Inc. and Meggison Enterprises, Inc. The pavement was sprayed with magnesium chloride de-icing solution prior to crack filling for half of the sections and no magnesium chloride was applied in the other sections. The resulting test pavement contains 2 crack fillers x 2 de-icing applications plus 2 controls x 2 replicates = 10 test sections as shown in Table 3. There are six cracks treated in each section. This results in 60 cracks for performance evaluation over a distance of 891 feet from milepost 31.

Table 3. Crack Fill Test Sections on SH66

Section No.	Crack No.	Dist (Ft)	Crack Fill Type	$MgCl_2$ Applied?
10	-	0.00		None
	1	13.42	Deery	
	2	43.42		
	3	63.83		
	4	85.50		
	5	127.33		
	6	137.50		
9	7	154.00	Megg	
	8	161.33		
	9	171.50		
	10	181.25		
	11	195.17		
	12	207.00		
8	13	225.92	Deery	
	14	234.83		
	15	247.00		
	16	253.25		
	17	262.67		
	18	277.25		
7	19	290.25	Megg	
	20	297.33		
	21	308.58		
	22	320.58		
	23	340.50		
	24	349.67		
6	25	365.50	None	
	26	370.25		
	27	379.83		
	28	396.42		
	29	404.58		
	30	455.50		

Section No.	Crack No.	Dist (Ft)	Crack Fill Type	$MgCl_2$ Applied?
5	31	467.43	Deery	Yes
	32	478.92		
	33	491.08		
	34	500.58		
	35	514.92		
	36	541.00		
4	37	561.00	Megg	
	38	574.67		
	39	587.08		
	40	602.00		
	41	613.83		
	42	623.17		
3	43	633.50	Deery	
	44	653.17		
	45	616.83		
	46	689.75		
	47	701.75		
	48	716.00		
2	49	730.92	Megg	
	50	745.43		
	51	758.00		
	52	771.33		
	53	784.92		
	54	825.08		
1	55	831.58	None	
	56	839.50		
	57	858.08		
	58	871.17		
	59	882.75		
	60	891.00		

4.2 Chip Seals

Two sites were established in 2005 to evaluate chip seal performance. These sites are located on US34 east of Drake and SH14 west of Briggsdale.

4.2.1 US34, Drake: Chip Seal

A contract chip seal by A-1 Chip Seal was placed on US34 east of Drake on July 18, 2005. Four 500 foot test sections were included as part of this research. The test sections are located in the eastbound and westbound lanes as shown in Figure 4. Chips used conform to the average gradation shown in Table 4 based on quality control tests shown in Appendix B. The results of the condition survey of the pavement conducted on June 20, 2005 are presented in Table 5.

Table 4. Material Properties of Aggregate Chips on US34, Drake

Sieve	Passing, %
3/8"	100
No. 4	5
No. 200	0.9

Table 5. Condition Survey of US34 Prior to Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	12	5	0
1+00 to 2+00	36	42	10
2+00 to 3+00	41	0	0
3+00 to 4+00	52	30	0
4+00 to 5+00	46	0	0
Section 2			
0+00 to 1+00	33	0	0
1+00 to 2+00	59	0	0
2+00 to 3+00	26	0	0
3+00 to 4+00	26	2	0
4+00 to 5+00	33	15	0
Section 3			
0+00 to 1+00	41	76	0
1+00 to 2+00	10	119	0
2+00 to 3+00	5	128	0
3+00 to 4+00	13	110	0
4+00 to 5+00	18	76	0
Section 4			
0+00 to 1+00	4	102	0
1+00 to 2+00	45	94	0
2+00 to 3+00	39	76	0
3+00 to 4+00	10	68	0
4+00 to 5+00	0	0	0

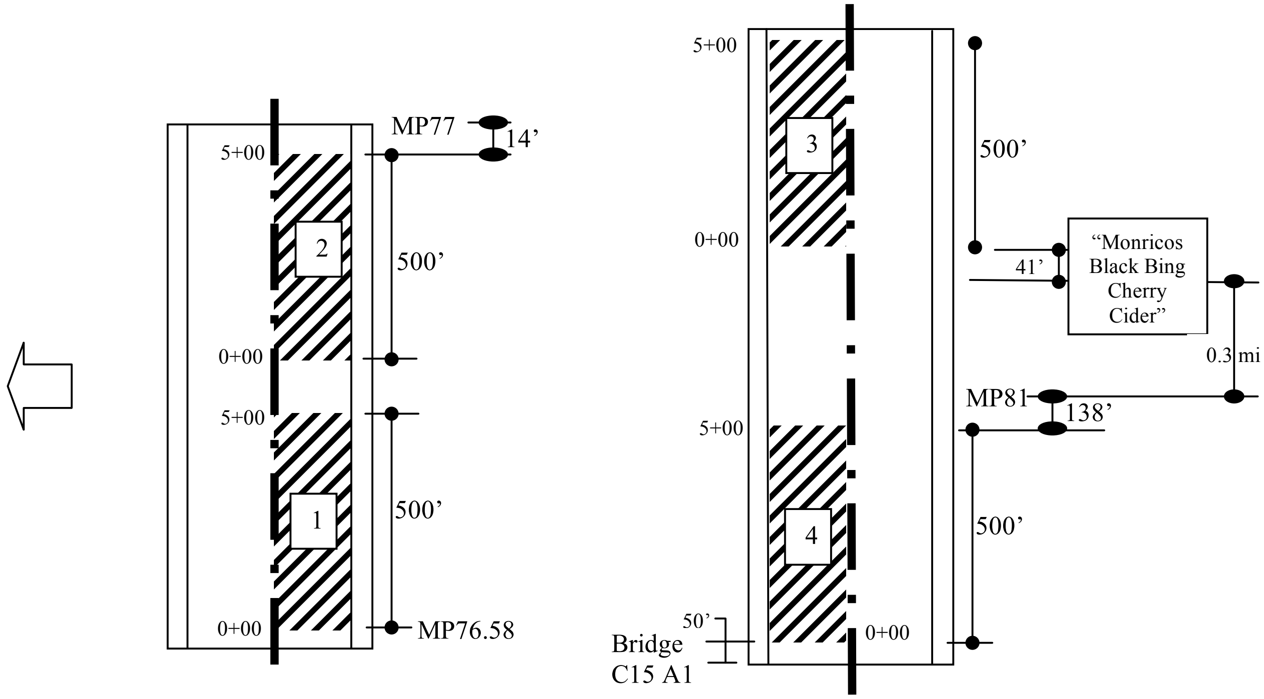


Figure 4. Chip Seal Test Sections US34 Drake

4.2.2 SH14, Briggsdale: Chip Seal

A contract chip seal by A-1 Chip Seal was placed on SH14 east of Briggsdale on August 22, 2005. Four 500 foot test sections were included as part of this research. The test sections are located in the eastbound and westbound lanes as shown in Figure 5. Test sections 1 and 2 were constructed using ½ inch one-sized chips based on average quality assurance tests as shown in Table 6 and reported in Appendix B. Emulsion properties are shown in Appendix B. Test sections 3 and 4 were constructed with the same 3/8 inch chips used for the US34 Drake test sections reported in Table 4. Asphalt and aggregate application rates are shown in Table 7. The results of the condition survey of the pavement conducted on July 14, 2005 are presented in Table 8.

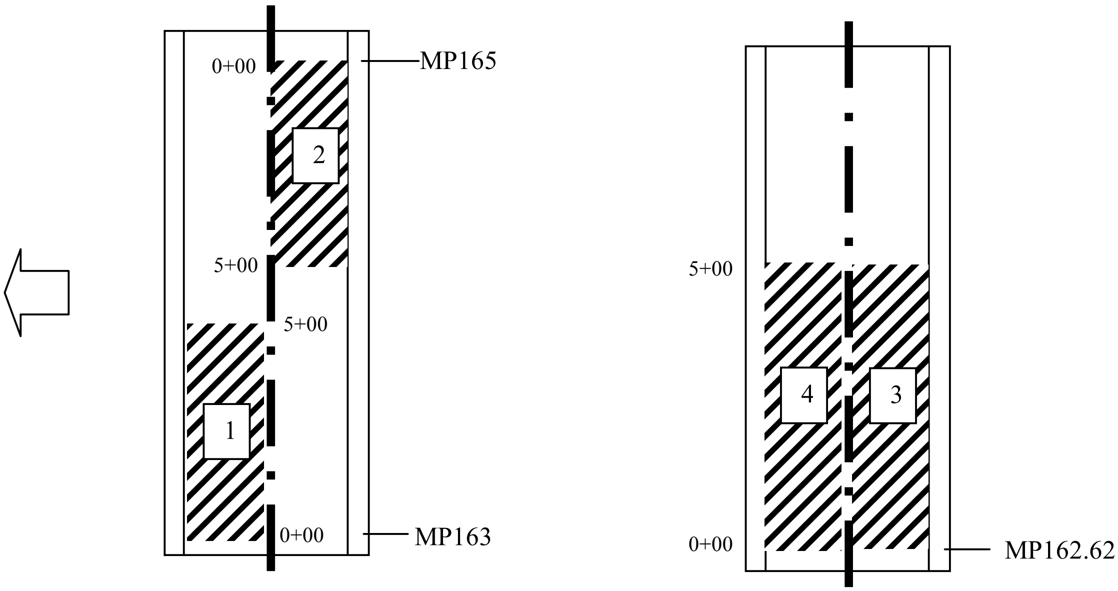


Figure 5. Chip Seal Test Sections SH14 West of Briggsdale

Table 6. Material Properties of Aggregate Chips on SH14, Briggsdale

Sieve	Passing, %
½”	100
5/16”	14
No. 4	2
No. 8	1
No. 30	1
No. 50	1
No. 100	1
No. 200	0.9

Table 7. Materials Application Rates for SH14 Chip Seal

Test Section	Chip	Chip Rate, psy	CRS-2P, gsy
1	½”	35	0.48
2	½”	35	0.48
3	3/8” ‘Drake’	28	0.42
4	3/8” ‘Drake’	28	0.42

Table 8. Condition Survey of SH14 Prior to Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	0	8	0
1+00 to 2+00	0	5	0
2+00 to 3+00	0	12	0
3+00 to 4+00	0	5	0
4+00 to 5+00	0	24	0
Section 2			
0+00 to 1+00	0	24	0
1+00 to 2+00	0	11	0
2+00 to 3+00	0	26	0
3+00 to 4+00	0	16	0
4+00 to 5+00	0	22	0
Section 3			
0+00 to 1+00	0	0	0
1+00 to 2+00	0	0	0
2+00 to 3+00	0	0	0
3+00 to 4+00	0	2	0
4+00 to 5+00	0	0	0
Section 4			
0+00 to 1+00	0	0	0
1+00 to 2+00	0	0	0
2+00 to 3+00	0	0	0
3+00 to 4+00	0	13	0
4+00 to 5+00	0	0	0

4.3 Thin Overlays

4.3.1 US6, Golden: Thin HMA

A thin hot mix asphalt overlay was placed by CDOT forces on June 23, 2005 on US6 in the southbound lanes at approximately 0.3 miles south of milepost 273. Two 500 foot test sections were identified as shown in Figure 6 and a condition survey conducted of the pavement prior to construction on June 23, 2005 is shown in Table 9.

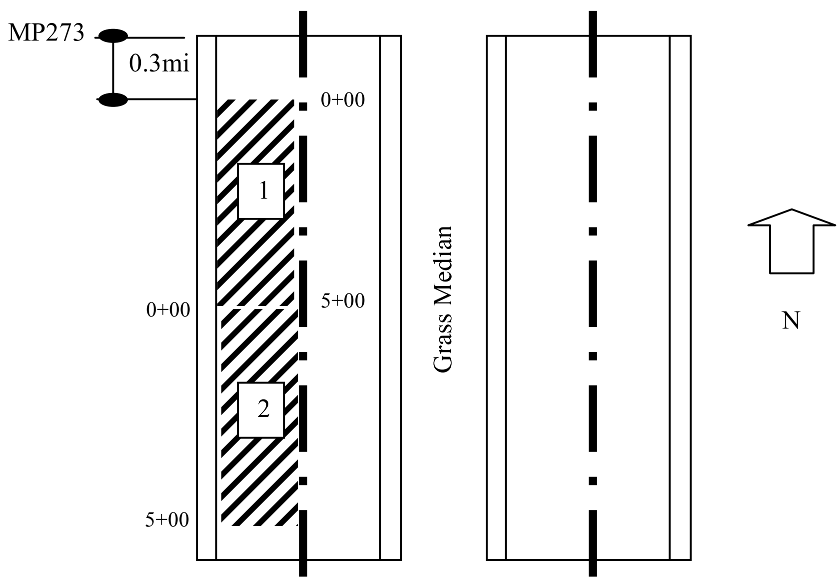


Figure 6. Thin Overlay Test Sections on US6, Golden

Table 9. Condition Survey of US6, Golden Prior to Construction

Section 1	Longitudinal, ft	Transverse, ft*	Alligator, sf**
0+00 to 1+00	0	34	100
1+00 to 2+00	0	12	100
2+00 to 3+00	0	48	100
3+00 to 4+00	0	12	100
4+00 to 5+00	0	54	100
Section 2			
0+00 to 1+00	3	45	100
1+00 to 2+00	0	25	100
2+00 to 3+00	0	37	100
3+00 to 4+00	0	42	100
4+00 to 5+00	0	30	100

* All transverse cracking was severe, ie, greater than 3/8 inch width

** Alligator cracking was severe and was located on the centerline joint

4.3.2 SH13, Rifle: Thin SMA

A stone matrix asphalt treatment was placed by United Companies on June 14, 2005 on the SH13-Truck Route west of Rifle. Four test sections were established in the northbound lanes as shown in Figure 7 on June 7, 2005 by measuring the cracking in the existing pavement. Results of this crack survey are shown in Table 10.

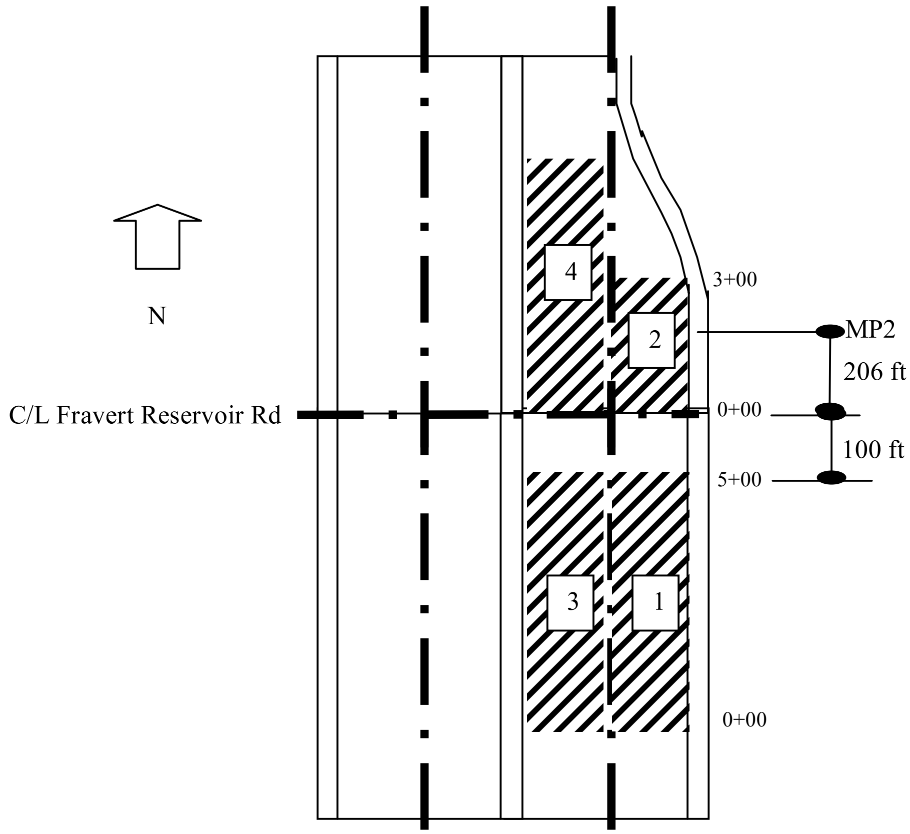


Figure 7. SMA Test Sections on SH13-Truck Route, Rifle

Table 10. Condition Survey of SH13-Truck Route, Rifle Prior to Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	4	23	0
1+00 to 2+00	0	55	0
2+00 to 3+00	0	42	0
3+00 to 4+00	0	36	0
4+00 to 5+00	0	43	0
Section 2			
0+00 to 1+00	21	60	0
1+00 to 2+00	0	53	0
2+00 to 3+00	0	37	0
Section 3			
0+00 to 1+00	0	24	
1+00 to 2+00	2	12	
2+00 to 3+00	0	27	
3+00 to 4+00	0	48	
4+00 to 5+00	0	37	
Section 4			
0+00 to 1+00	18	32	
1+00 to 2+00	0	29	
2+00 to 3+00	32	41	
3+00 to 4+00	22	50	
4+00 to 5+00	63	32	

4.3.3 I70, Glenwood Canyon: Thin SMA

A stone matrix asphalt surface was placed by United Companies on July 6, 2005 on the east and westbound lanes of I70 at approximately milepost 125. Two test sections were established in the eastbound lanes and two sections were established in westbound lanes as shown in Figure 8 prior to construction by measuring the cracking in the existing pavement. Results of this crack survey are shown in Table 11.

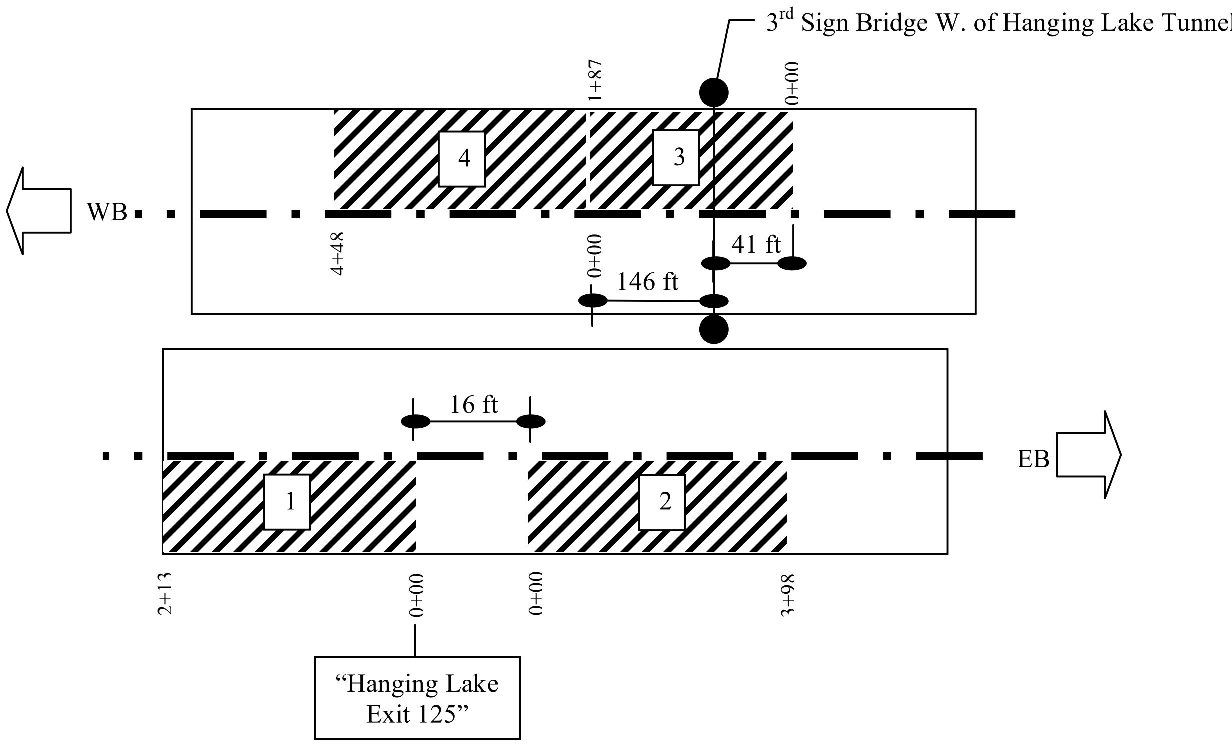


Figure 8. SMA Test Sections on I70, Glenwood Canyon

Table 11. Condition Survey of I70, Glenwood Canyon Prior to Construction

Section 1	Longitudinal, ft	Transverse, ft	Centerline Joint Sep
0+00 to 1+00	0	0	100
1+00 to 2+00	0	0	100
2+00 to 2+13	0	0	100
Section 2			
0+00 to 1+00	0	0	100
1+00 to 2+00	30	12	100
2+00 to 3+00	10	65	100
3+00 to 4+00	3	5	100
4+00 to 4+09	0	0	100
Section 3			
0+00 to 1+00	40	30	100
1+00 to 1+87	0	8	100
Section 4			
0+00 to 1+00	0	0	60
1+00 to 2+00	0	0	0
2+00 to 3+00	0	0	0
3+00 to 4+00	0	0	40
4+00 to 4+45	0	0	45

4.3.4 SH74, Evergreen: Thin SMA

A stone matrix asphalt surface was placed by Asphalt Paving Company in June, 2004 on SH74 north of Evergreen. Two test sections were established in the southbound driving lanes as shown in Figure 9 after construction on July 7, 2005 by measuring the cracking in the existing pavement. Results of this crack survey are shown in Table 12.

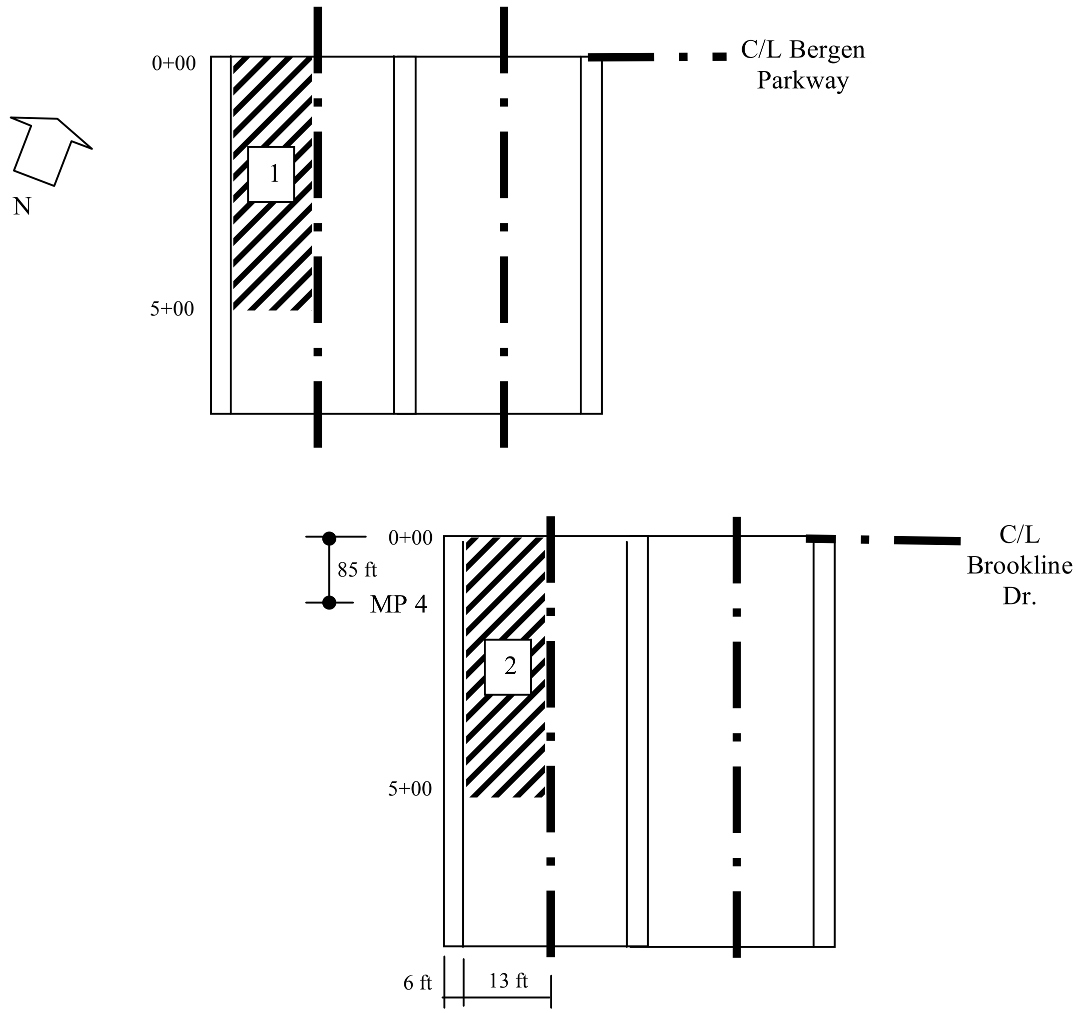


Figure 9. SMA Test Sections on SH74, Evergreen

Table 12. Condition Survey of SH74, Evergreen After Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	0	0	0
1+00 to 2+00	0	0	0
2+00 to 3+00	0	0	0
3+00 to 4+00	0	0	0
4+00 to 5+00	0	2	0
Section 2			
0+00 to 1+00	0	0	0
1+00 to 2+00	0	0	0
2+00 to 3+00	0	0	0
3+00 to 4+00	0	0	0
4+00 to 5+00	0	0	0

4.3.5 SH58, Golden: Ultrathin Bonded Wearing Course

An ultrathin bonded wearing course (UBWC) was placed by Lafarge on ??, 2004 on SH58 in Golden. Two test sections were established in the southbound driving lanes as shown in Figure 10 after construction on July 7, 2005 by measuring the cracking in the existing pavement. Results of this crack survey are shown in Table 13.

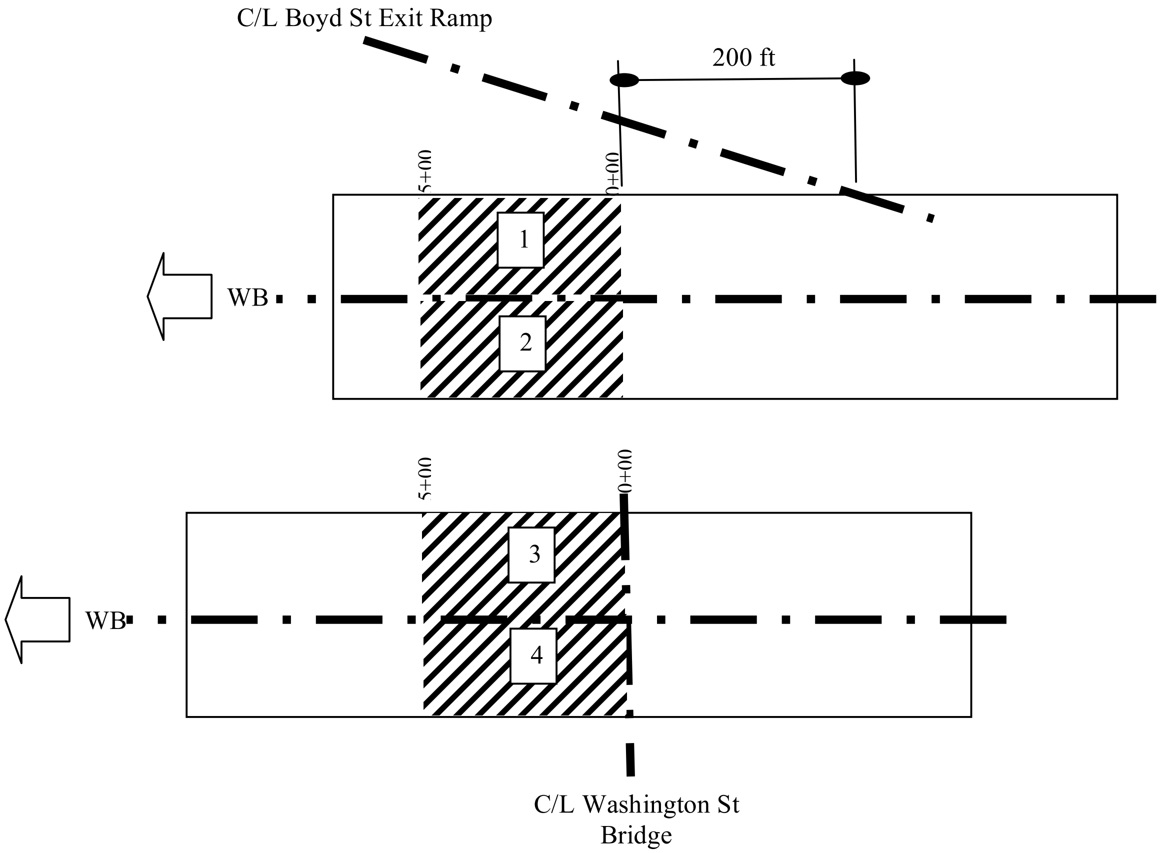


Figure 10. UBWC Test Sections on SH58, Golden

Table 13. Condition Survey of SH58, Golden After Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	0	48	0
1+00 to 2+00	0	36	0
2+00 to 3+00	0	36	0
3+00 to 4+00	0	12	0
4+00 to 5+00	0	39	0
Section 2			
0+00 to 1+00	2	14	0
1+00 to 2+00	18	28	0
2+00 to 3+00	12	40	0
3+00 to 4+00	30	2	0
4+00 to 5+00	90	50	0
Section 3			
0+00 to 1+00	0	12	0
1+00 to 2+00	0	36	0
2+00 to 3+00	0	43	0
3+00 to 4+00	0	36	0
4+00 to 5+00	0	36	0
Section 4			
0+00 to 1+00	22	26	0
1+00 to 2+00	108	38	0
2+00 to 3+00	60	60	0
3+00 to 4+00	104	77	0
4+00 to 5+00	61	52	0

4.3.6 Table Mesa Drive, Boulder: Ultrathin Bonded Wearing Course

An ultrathin bonded wearing course (UBWC) was placed by Lafarge on ??, 2004 on Table Mesa Drive in Boulder. Two test sections were established in the eastbound driving lanes as shown in Figure 11 after construction on June 8, 2005 by measuring the concrete joint reflection cracking in the pavement surface. Results of this crack survey are shown in Table 14.

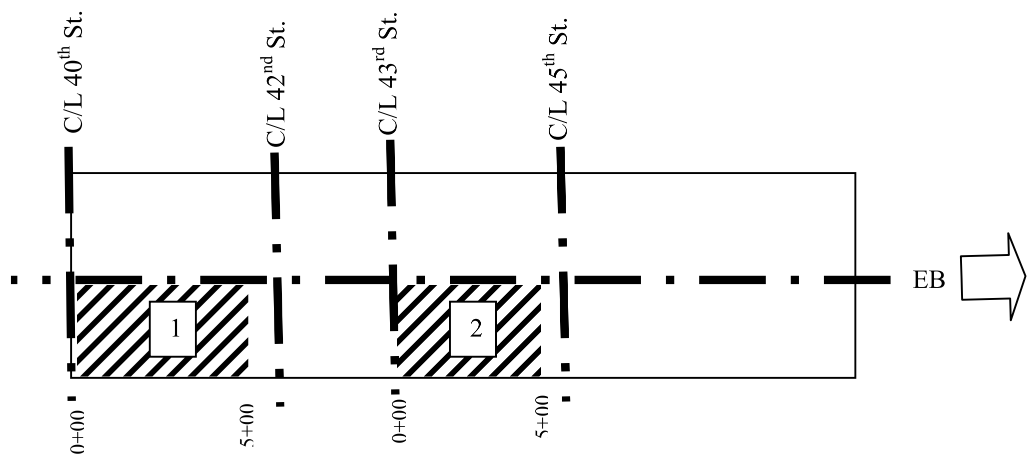


Figure 11. UBWC Test Sections on Table Mesa Dr., Boulder

Table 14. Condition Survey of Table Mesa, Boulder After Construction

Section 1	Longitudinal, ft	Transverse, ft	Alligator, sf
0+00 to 1+00	0	108	0
1+00 to 2+00	0	50	0
2+00 to 3+00	0	60	0
3+00 to 4+00	0	24	0
4+00 to 5+00	0	84	0
Section 2			
0+00 to 1+00	0	108	0
1+00 to 2+00	0	72	0
2+00 to 3+00	0	111	0
3+00 to 4+00	0	60	0
4+00 to 5+00	0	84	0

4.4 Concrete Joint Resealing and Crosss-stitching

4.4.1 US287, Campo: Joint Resealing

Joint resealing test sections were placed on the concrete pavement on US287 approximately 2.6 miles south of Campo at Milepost 3 in September, 2005. Test sections consisted of removing existing sealant by sawcutting and replacing with new sealant. Control sections consisted of leaving the existing sealant in place and not resealing. The locations of these test sections are shown on Figure 12. The original plan was to place test and control sections in the southbound lane. However, the contractor mistakenly removed and replaced all the sealant in the southbound lane. Therefore, the two sections shown in Figure 12 in the northbound lane will be used as control sections where sealant was not removed and replaced.

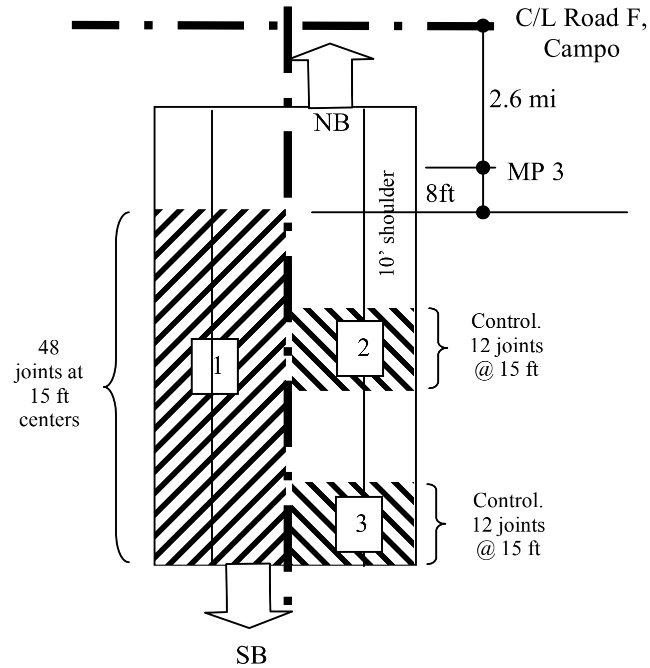


Figure 12. Joint Reseal Test Section Location on US287, Campo

4.4.1 US287, Campo: Cross-stitching

Cross-stitching test sections were placed on the concrete pavement on US287 approximately 1.0 miles south of Campo at milepost 8 in September, 2005. Test sections consisted of repair of a longitudinal crack in the concrete pavement using both conventional deformed reinforcement cross-stitches and fibreglass panels manufactured by Uretek, Inc. as shown in Figure 13. Control sections consisted of no repair to the concrete.

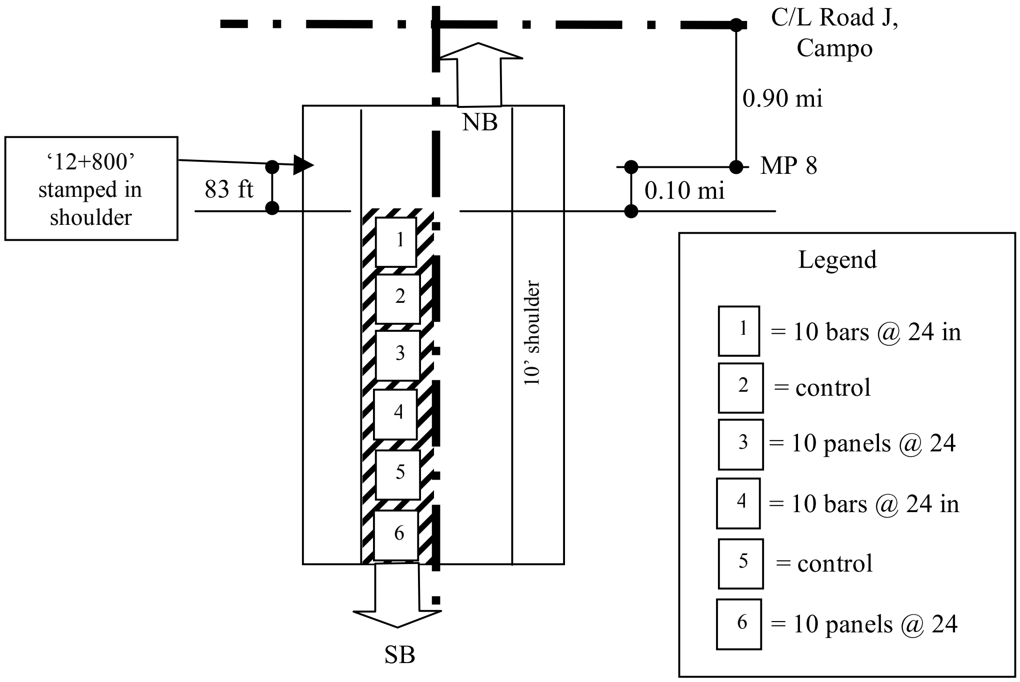


Figure 13. Cross-stitch Test Section Location on US287, Campo

4.5 Concrete Pavement Diamond Grinding

4.5.1 I-70, Rifle

Diamond grinding of the concrete pavement on I-70 near Rifle was done by American Civil Constructors, Inc. in September, 2005. Test and control sections to evaluate the effectiveness of this technique at approximately milepost 96 in the eastbound driving lane were installed September 13, 2005. No grinding of the pavement surface occurred in the control sections. Locations of the test and control sections are shown in Figure 14 and the condition survey results of the pavement are contained in Table 15.

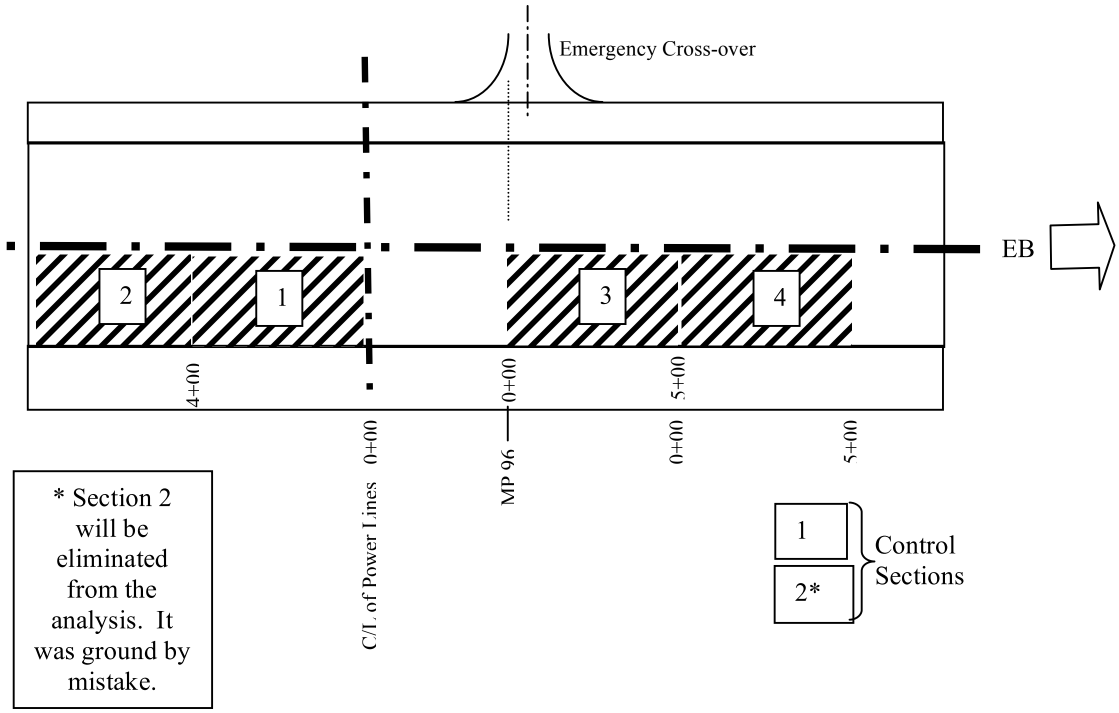


Figure 14. Diamond Grinding Test Section Location on I-70, Rifle

Table 15. Condition Survey of I-70, Rifle Before Construction

Section 1	Longitudinal, ft	Joints, #	Transverse, ft
0+00 to 1+00	0	6	0
1+00 to 2+00	0	6	0
2+00 to 3+00	0	6	0
3+00 to 4+00	0	7	12
4+00 to 5+00	0	7	24
Section 2			
0+00 to 1+00	0	6	0
1+00 to 2+00	0	6	12
2+00 to 3+00	0	7	0
3+00 to 4+00	0	6	0
4+00 to 5+00	0	6	0
Section 3			
0+00 to 1+00	0	6	36
1+00 to 2+00	0	6	24
2+00 to 3+00	0	7	36
3+00 to 4+00	0	6	36
4+00 to 5+00	35	6	24
Section 4			
0+00 to 1+00	30	6	24
1+00 to 2+00	35	7	12
2+00 to 3+00	20	6	30
3+00 to 4+00	12	6	24
4+00 to 5+00	0	7	36

5. FUTURE STUDY

Further test sections are planned for the 2006 construction season. These test sections have not been established at this writing but will include additional thin hot mix overlays at high elevation and low elevation and chip seals at both high and low elevation. The condition of the pavement test sections reported herein and those to be established in 2006 will be re-evaluated annually so the rate of distress can be documented and the effectiveness of the preventive maintenance treatments can be estimated.

REFERENCES

Carey, W. N., (1960). "The Pavement Serviceability-Performance Concept," *Highway Research Bulletin No. 250,* Highway Research Board, National Research Council.

Hall, K. T., Correa, C. E., and Simpson, A. L., (2002). "LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options", *National Cooperative Highway Research Program,* National Resarch Council.

Johnson, C., (1983). "Pavement (Maintnenace) Management Systems," *APWA Reporter*.

O' Brien, L. G., (1989). "Evolution and Benefits of Preventive Maintenance Strategies," *NCHRP Synthesis of Highway Practice 153,* Transportation Research Board, National Research Council, Washington, D. C.

Morian, D. A., Gibson, S. D., and Epps, J. A., (1997). "Pavement Treatment Effectiveness, 1995 SPS-3 and SPS-4 Site Evaluations, National Report," Report No. FHWA-RD-96-208.

Peshkin, D. G., Hoerner, T. E., and Zimmerman, K. A., (2004). "Optimal Timing of Pavement Maintenance Applications", *National Cooperative Highway Research Program Report 523,* Transportation Research Board.

Peterson, D. E., (1981). "Evaluation of Pavement Mainenance Strategies" *NCHRP Synthesis of Highway Practice 77,* Transportation Research Board, National Research Council, Washington, D. C.

Preventive Maintenance Program Guidelines, Colorado DOT, October 2004.

Shaffer, Doug, (1991). "Policy for Crack Filling and Joint Resealing in Colorado," Internal Memorandum, Colorado Department of Highways, January 24, 1991.

Zimmerman, K. A., and ERES Consultants, Inc. (1995). "Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments," *NCHRP Synthesis of Highway Practice 222,* Transportation Research Board, National Research Council, Washington, D. C.

APPENDIX A – Preventive Maintenance Best Practices Manual

Introduction

The purpose of this manual is to provide a reference describing the best methods to use when conducting certain preventive maintenance procedures on asphalt and concrete pavements in Colorado. The methods described in this manual are based on a review of the literature, a series of interviews conducted in each Colorado DOT region, full-scale field test sections and experience of the researchers.

For clarification, definitions have been offered (7) describing various types of pavement maintenance activities. These are:

- Preventive Maintenance
- Corrective Maintenance
- Emergency Maintenance

Preventive Maintenance: Activities intended to retard progressive pavement failures and reduce the need for corrective or emergency maintenance. Or, according to AASHTO: *"Preventive maintenance is the planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity)".*

Corrective Maintenance: Performed after a deficiency occurs in the pavement, such as loss of friction, moderate to severe rutting, or extensive cracking. Sometimes referred to as "reactive" maintenance.

Emergency Maintenance: Performed during an emergency situation, such as a popout in concrete pavement or severe pothole that needs repair immediately. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be performed.

Preventive maintenance is intended to prolong the interval before corrective and emergency maintenance are needed. And though all three types of maintenance are important, preventive maintenance activities should be the most cost-effective by prolonging pavement life.

Based on the interviews conducted in early 2005 three preventive maintenance processes are primarily used for asphalt pavements and three processes are primarily used for concrete pavements in Colorado. These processes are shown in Table 1.

Table 1 – Preventive Maintenance Processes Utilized in Colorado

Asphalt	Concrete
• Crack Filling (Sealing)	• Crack/Joint Sealing
• Chip Seals	• Cross-stitching
• Thin Overlays	• Diamond Grinding

These processes are the focus of this Best Practices Manual.

Crack Filling (Sealing)

There is a distinction made between crack filling and crack sealing in the literature (8) and also in the current Colorado DOT guidelines (23). Crack filling involves blowing a crack out with compressed air to remove debris and sealing the crack with an asphalt sealer. The cracks appropriate for crack filling are considered ‘non-working’ cracks, or cracks that do not move appreciably due to expansion and contraction or loading. Crack sealing is an operation that is applied to ‘working’ cracks defined by Galehouse (23) as "… *A crack in a pavement that undergoes significant deflection and thermal opening and closing movements greater than 2 mm (1/16 inch), typically oriented transversely to the pavement centerline*." Crack sealing consists of opening the crack by random crack saw or router to provide a definitive geometric cavity for the asphalt crack sealer to penetrate. Routing the crack prior to crack sealing is recommended by some agencies (6, 8) and considered cost effective. Canadian studies (13) describe what the geometry of the routed crack should be and the mechanism of the adhesion of the sealant to the routed crack face.

Routing cracks prior to filling with crack sealer is currently not practiced in Colorado. In fact, it has been advised against because of potential damage that could result (2) and the belief that it is uneconomical. However, recent observations in a neighboring state (6) shown in Figure 1 indicates that routing is being practiced prior to crack filling and may be economical when done under specific circumstances.

Figure 1 – Routing Cracks Prior to Crack Sealer Installation on I-25, NM

This manual will focus on crack filling as a preventive maintenance tool, since crack sealing is currently not practiced by CDOT.

The purpose of crack filling of asphalt pavements is to reduce the infiltration of water, anti-icing chemicals, and incompressibles into the pavement sub-structure. This reduces pavement degradation and helps extend service life (13). Crack sealing is most effective when applied to pavements in good condition (14), with low-to-moderate crack density, and where cracks show little or no branching as illustrated in Figure 2. Low to moderate density cracks are suitable for sealing, but high density crack patterns with excessive branching should be treated by other techniques.

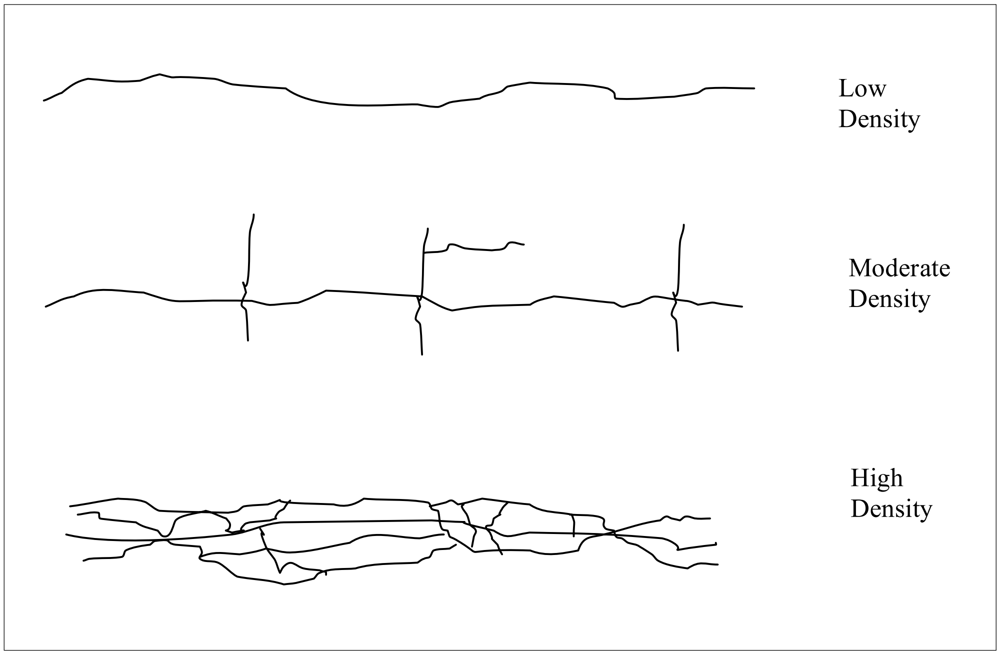


Figure 2- Example of Crack Density Levels

such as patching or resurfacing. Cracks with severe vertical distress such as cupping, faulting or show significant displacement when loaded are also unsuitable for crack sealing or filling and must be treated by patching or resurfacing after surface milling.

Pavement Selection

The condition of the pavement to be sealed has an effect on the performance of the crack filler. Only pavements that are structurally sound and show low levels of distress are candidates for crack filling. Table 2 has been adapted from the literature (8, 23) to give some guidance regarding the type of pavement that is a candidate for crack filling.

Table 2 - Pavement Candidates for Crack Filling

		Density		
		Low, Transverse @ 75-100 ft (23 – 30 m) Longitudinal @ CL	Mod, Transverse @ 50 – 75 ft (15 – 23 m) Longitudinal @ Lane CLs	High, Transverse @ 25 – 50 ft (8 – 15 m) Longitudinal @ Lane CLs+
Description/ Width, inch	Slight, <1/4	1	2	3
	Intermediate, ¼ - ½	4	5	6
	Severe, > 1/2	7	8	9

1, 2, 3, 4, 5	Crack filling is appropriate
7 ,8	Crack filling is appropriate or Crack filling after routing
6,9	Crack filling is not recommended

Timing

Crack filling should be accomplished as soon after cracks appear in the pavement as possible. In fact, the longer the cracks are left unsealed, the wider they become, and a less effective seal results. Therefore, on older pavements with wider and more numerous cracks, the process of crack filling becomes more of a corrective procedure and less of a preventive process. However, the methods used for narrow cracks is essentially the same as for wider cracks, although the interval of time between applications will probably be different. When cracks less than 1/8 inch were filled by approved methods in Vancouver, Canada, the effectiveness reported was between 7 to 9 years (15). Galehouse (23) indicates that cracks should be sealed at two to four years if the base is granular and from one to two years if the underlying pavement is concrete.

Hot poured polymer modified crack sealers do not penetrate very narrow cracks well. Therefore, the literature (8) indicates that cracks should be greater than 1/8 inch wide before hot poured asphalt sealers are used. However, when cracks first appear in asphalt pavements they tend to be very narrow, often less than 1/8 inch. So, how can cracks be filled when they first appear if the cracks are too narrow for hot poured sealants? One answer might be to use asphalt emulsions. However, emulsions have been reported to typically fail after one or two winters (16). Perhaps one reason they are not used by CDOT. Another may be to use hot poured sealants that are not polymer modified but meet the ASTM D1190 (5) standard for conventional asphalt cements. These sealants tend to be less viscous than polymer modified asphalts and should be capable of filling relatively narrow cracks if a small 1/8 inch nozzle is used. Another option is to used a combination of materials. Asphalt emulsion could be used to fill the crack, then an 'overband' of polymer modified asphalt on the pavement surface to 'seal' the emulsion and improve treatment life. This practice has been reported as very successful on low traffic pavements in milder Canadian provinces (17) with sealant durability of 7 to 9 years (18).

Hot poured sealants work best if the surfaces of the pavement within the crack are dry and free of magnesium chloride residue. Also, crack sealants should be placed six to twelve months or longer in advance of overlay construction. This means crack sealing should occur in the fall season. The fall is best because temperatures are cool, but not cold, making crack widths approximately average for the year; that is, wider than summer, but narrower than winter. This means the material is easier to get into the crack than it would be in the summer when the crack is narrowest, and an excess of sealer is not put in the crack as would happen in the winter months. Also, the pavement has a better chance of not having been sprayed with anti-icing chemical, yet, as it would in the spring.

Therefore, spring is the second best time to crack seal although some literature suggests spring the best time when emulsions are used (8). If moisture is suspected in the crack the moisture should be removed prior to sealing. This is best accomplished with a heat lance. The lance should be capable of 3000F with 3000 feet per second air velocity at the nozzle (2).

Cracks should be filled in advance of overlay construction. Hot mix asphalt causes crack sealer to liquify. If the overlay thickness is two inches or less, the crack sealer can permeate through the overlay and cause a localized weakness in the pavement surface, slip plane, or bump. Therefore, crack sealer should be applied ahead of overlay operations as shown in Table 2.

Table 2 – Timing of Crack Fill Operations Prior to Overlays

Crack Width, in (mm)	Time Before Overlay, months
< 1/8 (3)	3
1/8 – ¼ (3-6)	6
¼ - ½ (6-12)	9
½-3/4 (12-19)	12

If conducted at the proper time, some report a life extension to the pavement of two to five years (8). Proper timing is considered to be a program where crack treatments are repeated more than once over the life of the pavement. This schedule is recommended after initial construction at an age of three to five years for the first application, then at an age of eight to ten years for the second application (8). The timing is dependent on the effectiveness of the sealant. Therefore, if the sealant opens up after five years, the next treatment must be applied to retain effective sealing of the pavement at that time. If the sealant separates in less than five years, the intervals between treatments will be shorter.

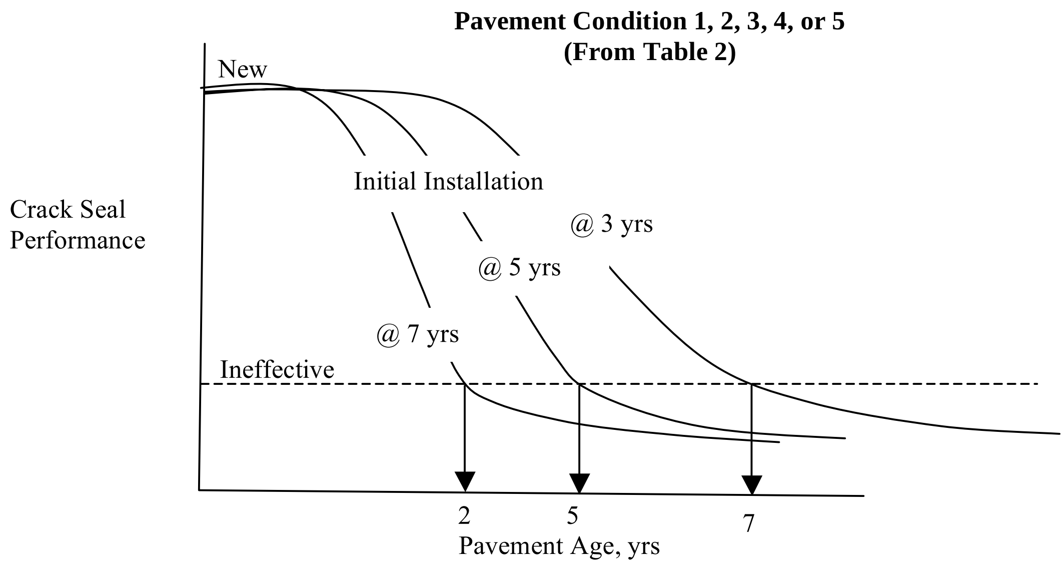


Figure 3 – Conceptual Relationship Between Initial Crack Fill Application and Performance

Conditions

The pavement should be as dry as possible before crack sealer is applied. As stated above, cool, but not cold ambient conditions should prevail. This means an air temperature of no less than 35F (8, 23) when sealing operations begin and an ambient temperature no greater than approximately 55F (8) during the sealing process. These conditions assure that the crack sealer will adhere to the pavement within the crack and that the crack will not be too wide, nor to narrow to accept the sealer.

If the crack contains moisture it must be dried using a heat lance to assure the best performance of the crack sealer. This process accomplishes two things: first, it dries the crack surfaces, and second, it softens the asphalt which provides improved adhesion. Reports in the literature indicate this process is essential if a minimum anticipated sealant life of five years is expected (11).

Some manufacturers claim their products will adhere as well in the presence of moisture as dry. However, unless these claims can be substantiated with quantitative evidence, it is best to avoid sealing operations under wet conditions.

Materials Selection

Crack filling with hot poured polymer modified asphalt cement is practiced in every region in Colorado as both a preventive and corrective maintenance procedure. Some regions have also used asphalt cement modified with ground tire rubber. Crack filling is usually conducted with CDOT maintenance personnel and is considered a routine practice.

The specification describing the material properties of polymer modified asphalt cement is ASTM D6690 (4). Currently, there is no ASTM or AASHTO standard describing ground tire rubber modified crack sealer.

Table 3 provides a summary of sealant performance in three Canadian provinces for products that met the appropriate ASTM specification at the time of the studies from 1995 to 2000. For comparison, the Denver metro area temperature range according to SHRP is 64C-22C at the 95% confidence level. Colorado currently uses the equivalent of an ASTM D3405 Type II.

Table 3 - Performance of Hot-Pour Sealants

	Vancouver	**Montréal**	**Ottawa**
Temp. range °C[a] (F)	–22 to 52 (-8 to 126)	–28 to 58 (-18 to 136)	–34 to 58 (-29 to 136)
Original sealant type	I	II	IV
1-year failure[b] level	0% to 5%	6% to 11%	7% to 55%
4-year failure level	20% to 23%	16% to 28%	not determined

[a] Pavement surface temperatures according to Superpave.
[b] Sum of debonding, splitting, and pull-out lengths.
From: Vancouver (17); Montréal (12); Ottawa (20)

An excerpt of ASTM D6690 is shown in Table 3 showing the properties for the three types of sealants above. ASTM D6690 classifies sealants as Type I to Type IV, and replaces ASTM D1190 (Type I) and ASTM D3405 (Type II).

Table 3 – Excerpt from ASTM D6690 (4)

	Type I	**Type II**	**Type IV**
Cone Penetration at 77F (25C), dmm	<90[a]	<90	90 to 150
Flow at 140F (60C)	≤5	≤3	≤3
Resilience, %	--	>60	> 60
Cyclic extension, %	50 at –18°C (5 cycles)	50 at –29°C (3 cycles)	200 at –29°C (3 cycles)

[a] 1dmm = 0.1 mm

Determination of which hot-poured sealants should be used under specific circumstances in Colorado should be evaluated over a 3 to 5 year period to evaluate performance of the sealants. Performance is reported to not be a linear relationship (12) and is represented as such conceptually in Figure 3.

Installation

Hot Pour Sealants

Crack treatment performance depends on three factors: 1) pavement condition, 2) product utilized, and 3) installation. Installation is affected by air temperature, pavement temperature and moisture. Installation includes crack cleaning, heating of the sealant, pouring, finishing with a squeegee, and protection with blotter materials, if necessary. Maximum crack opening occurs during the coldest months of the winter, as would be expected. Therefore, the most strain occurs to the sealant during this period when temperatures are low and extension is high, with movements of ¼ to 1 inch possible. This is the reason crack filling should be performed in the spring or fall. During these seasons temperatures are moderate and cracks are open to about average the annual cycle. However, the best conditions with respect to sealant adhesion to the crack face is in the summer when moisture is lowest and temperatures are highest. Unfortunately, if the sealant is applied in the summer, it will experience significantly higher strain in the winter and may fail due to excessive extension. Therefore, timing of the installation is a compromise placing the sealant at a time best suited to sealant adhesion (summer) when extension of the sealant could cause failure, and a time when moisture could cause poor sealant adhesion (spring or fall) but extension will be reduced.

The first step in crack filling is cleaning any debris from inside the crack. This is done using compressed air. Air pressure should not exceed 100 psi to assure damage does not result to crack faces. Figure 4 shows an operator cleaning a crack with compressed air.

Figure 4 – Cleaning Crack with Compressed Air

Moisture causes a lack of bonding of the crack filler to the crack faces. Therefore moisture must be removed prior to filling the crack with sealant. The compressed air will remove some moisture, but not all. Therefore, a heat lance as shown in Figure 5 should be used if additional moisture is present in the crack after the compressed air operation. The heat lance warms the crack surface and evaporates some of the moisture (21). The heat lance is not a cleaning tool and should only be used at temperatures below 950F and when the tip is 2 to 4 inches from the crack. The color of the hot end of the heat lance is a good indication of its temperature. If it is bright orange to bright red, the temperature is 1100F to 1900F; if it is dark red, 950F to 1100F; if it is black, 750F to 950F. Overheating of the crack leads to lower sealant adhesion (22). The heat lance is often most beneficial when crack sealing operations are done at air temperatures between 40 to 50F. However, at these temperatures in the morning, dew is often present, so more care must be applied in removing this moisture.

Once the crack is warmed using the heat lance it is ready to be filled with sealant.
A pressure distributor as shown in Figure 6 is the recommended equipment for all crack sealing operations. A gravity feed pour pot is not recommended because of the difficulty associated with applying a uniform quantity of material.

After the crack is filled, all excess material must be scraped form the pavement surface using a squeegee as shown in Figure 7. Occasionally, traffic may pick up fresh crack

Figure 5 – Heat Lance

sealer. If this occurs two solutions should be explored. One, evaluate the quantity of crack sealer being applied and make sure it is not excessive. The squeegee process should leave very little crack sealer remaining on the horizontal pavement surface. If the quantity is excessive, evaluate the squeegee operation, and make changes to reduce the quantity of crack sealer on the surface. If the quantity is not excessive, and traffic still picks up the crack sealer, apply sand as a blotter to the area on the horizontal pavement surface containing the crack sealer to reduce the adhesivity of the crack sealer. If this does not solve the issue, keep traffic off of the pavement until the crack sealer has cooled and does not stick to the tires.

Figure 6 – Pressure Distributor for Crack Sealing

Figure 7 – Squeegee Application After Crack Pouring

Preparing of Hot-Applied Sealants

Before being poured, crack sealant should be melted in a double-jacketed reservoir. Hot oil circulates in the jacket, preventing the direct heating of the sealant. This reduces sealant degradation. The melter is also equipped with a central agitator that must allow for efficient heat transfer throughout the sealant and for preventing hot spots. Gauges measure oil and sealant temperatures. The gauges must be calibrated every spring. It is highly recommended that supervisors and inspectors carry a hand-held thermometer to verify that the sealant gauge is indeed calibrated. An infrared thermometer can also be used to monitor temperature, but it becomes unreliable when the sealant emits fumes. Figure 8 shows one sealant melter that conforms to these requirements.

Figure 8 – Crack Seal Melter

Crack sealant degrades every time it is heated. Degradation is kept to a minimum by short heating times at temperatures below 350F. Reheating sealant must be avoided; a workday should begin with an empty crack seal melter. The overnight heating of sealant even at low temperatures, such as 175F, so the crew can begin work faster in the morning, must also be avoided.

Therefore, the basic steps involved in crack filling are described in the simplified diagram shown in Figure 9.

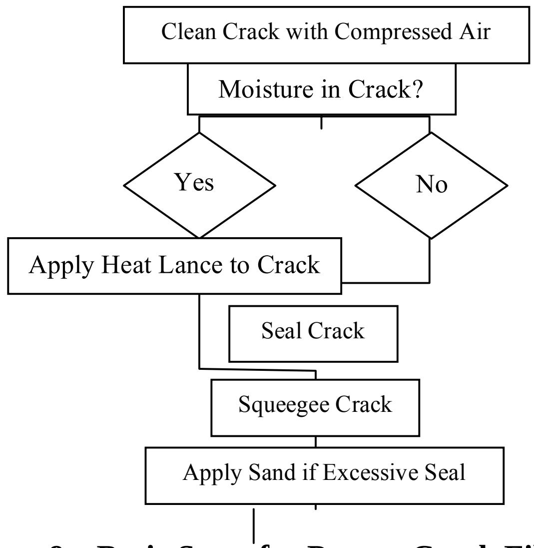


Figure 9 – Basic Steps for Proper Crack Filling

Cold Emulsion

Crack filling with asphalt emulsions should be done in late spring. Cracks that formed during winter are narrowest at this point and should not be moving. Since emulsion contains about 30 to 40% water, evaporation of this water can occur for the remainder of the spring and summer before winter exposure. Emulsions should be applied when air temperatures are above 65F, although they can be applied as cold as 50F. Complete curing takes eight to twelve hours. Low temperatures and a high relative humidity extend curing time. Freezing temperatures or rain will adversely affect emulsion performance and should not be expected within 24 hours of application. Therefore, conditions for emulsion application are best in late morning or afternoon. Very narrow cracks and cracks that are not moving can be treated in summer.

Cleaning Crack

Crack preparation is most important. A high percentage of material failure can be attributed to adhesion failure that results from dirty or moist cracks (11).

Dust and debris must be cleaned out of the crack or the crack sealer will adhere to the debris and not the crack face. As much debris as possible must be removed from the pavement surface so dust is not blown back into the crack just before it is sealed.

Debris and loose asphalt pavement fragments in and around the crack must be removed before sealing. This is best done with dry high-pressure air, free of oil. A compressor equipped with oil and moisture filters and providing at least 100 psi must be used. To check for oil or moisture, the compressor hose can be aimed at the side of a tire. Clean, dry air leaves no residue. Dry, high-pressure air removes some moisture from the crack.

Preparation and Application of Cold Emulsion

Asphalt emulsions used for crack filling are suspensions of asphalt, latex rubber, or other polymers in water. They are ready to use, but they can only be stored for a limited time. Emulsions where the water and asphalt have separated should not be used. Separation of the asphalt and water phases should only occur after the emulsions have been applied to the crack. The time required for this setting, or breaking, depends on temperature and humidity. Emulsions should become dry to the touch in 15 to 45 minutes. Complete hardening should take eight to twelve hours. Therefore, traffic should not be allowed on the sealed cracks until several hours after application of the sealer.

Cracks should be filled flush with the pavement surface with little or no excess.

Once the filler is poured, it should be left uncovered until fully cured.

Chip Seals

Chip seals in Colorado are primarily constructed using crushed natural mineral aggregates and either medium setting or rapid setting anionic or cationic emulsified asphalts. This type of chip seal is the basis for the following discussion.

Pavement Selection

Chip seals have two purposes: 1) they are intended to seal the surface of an asphalt pavement from moisture and air, and 2) they can improve the frictional characteristics of a pavement. Application of chip seals should be done when an asphalt pavement has just begun to oxidize and change color to a faded gray. Chip seals should not be applied to pavements with distress such as high severity cracking, raveling, or potholes (24) and application of a chip seal to rutted pavements should be evaluated in advance to determine if another preventive maintenance treatment would be more appropriate. The Long-Term Pavement Performance (LTPP) program of the Strategic Highway Research Program (SHRP) included a study focusing on the timing of pavement maintenance actions. It found that roads containing high levels of distress when chip seals were applied had a probability of failure that was two to four times greater than roads in good condition when the chip seals were applied. It also found that the chip seals tended to provide better economics with respect to preventing future distress better than the other treatments evaluated (25). Survey respondents in a recent NCHRP Synthesis (26) indicated that determining when to use a chip seal could result from a combination of factors, ranging from formula-driven algorithms to birthday sealing or visual evaluation of the pavement surface.

Timing

Personnel from nine states in the NCHRP Synthesis (26) indicated they got excellent service life from chip seals. These personnel included maintenance forces from Colorado DOT in Alamosa, Grand Junction, Montrose, Sterling, and Trinidad. These groups indicated they use chip seals as a preventive maintenance tool on a five year cycle. These agencies reported an expectation of six year service life from chip seals on this cycle. This is important because the construction cycle is shorter than the expected life cycle of the seal, which provides an extension to the service life of the pavement, in other words, preventive maintenance. However, interviews (27) with maintenance personnel in all of the maintenance sections in Colorado indicated that some chip seals are still applied to pavements in poor to very poor condition using a ‘worse first’ policy.

Conditions

Weather conditions are often responsible for premature failure of chip seals (28). Because the performance of anionic emulsions depends on evaporation for developing adhesive properties, ambient and pavement temperatures, relative humidity, wind velocity, and precipitation all affect early performance of chip seals constructed with this type of emulsion. In addition, cationic emulsions are also susceptible to early failure if moisture in the form of precipitation contacts the chip seal before breaking or setting of the emulsion occurs. Ideal chip seal weather conditions are those with low relative humidity, low wind velocity, and increasing temperatures during the day the chip seal is constructed (29).

Ambient Temperature

Ambient air temperature affects the performance of chip seals (28). Warm, but not hot, ambient air temperatures help reduce emulsion set time and promote adhesion between the emulsion residue and the aggregate chip and between the aggregate chip and the pavement surface. Specifications from several states (30, 31, 32, 33) require ambient air temperature to be a minimum of 50F (10C) when using emulsions for chip seals. However, according to a recent NCHRP Synthesis (26) the Indiana DOT allows placement in air temperatures below 50F if the aggregate has been heated to a temperature between 120F to 150F (34). High temperature can adversely affect emulsion set time, also. Consequently, California Department of Transportation specifies a maximum ambient air temperature of 110F (43C) for chip seal construction (35).

Pavement Temperature

The temperature of the pavement to be sealed affects binder adhesion to the aggregate chips and pavement surface. If the surface temperature is too low, poor adhesion can result because of slow setting of the emulsion so the Asphalt Institute recommends a surface temperature of 70F (21C) when constructing chip seals (36). However, experience by the author indicates that when air temperature is predicted to increase during the day chip seal construction can begin at pavement surface temperatures below 70F. However, high pavement temperatures can also be a problem. If the viscosity of the emulsion residue is too low, aggregate chips are not secured to the pavement surface with enough adhesion and can be picked up by traffic or pneumatic rollers jeopardizing the chip seal. Michigan DOT (37) limits chip seal construction to surface temperatures less than 130F (54C) and Ohio DOT (38) limits surface temperature to 140F (60C).

Precipitation

Chip seals should never be constructed if precipitation is expected before the emulsion has time to set. Emulsified asphalt is a mixture of asphalt and water and soluble in water. Therefore, if rain occurs before the emulsion sets, it is possible the rain will wash the emulsion off the pavement surface requiring the chip seal be reconstructed. However, in the event that rainfall occurs before the emulsion is set, it may be possible to save the chip seal using the following steps: 1) cover the emulsion as soon as possible with at least two times the design quantity of aggregate, 2) make one pass of the surface with pneumatic rollers to just set the chips in place, 3) do not allow traffic on the surface until the emulsion has set.

Wind

Wind decreases the set time for asphalt emulsions. Therefore, the wind speed has an effect on how close the rollers should be to the asphalt distributor during construction of the chip seal. The higher the wind speed, the faster the set, and the closer the rollers should be to the distributor. In addition, higher wind speed allows for earlier sweeping and removal of traffic control. However, if wind speed is too high, e.g. 25 mph or greater, the spray pattern of the asphalt distributor could be affected. In this case, either a shield should be installed to deflect the wind, or construction operations should cease until wind speed decreases. Also, wind can blow emulsion across to the adjacent traffic lane, creating potential claims from passing motorists.

Materials

Aggregate Chips

The aggregate used for chip seals defines how well the seal will perform. The best aggregates have high durability, abrasion resistance, contain little, if any dust, and are as nearly one-sized as possible. The surface texture should be rough and the aggregate should be resistant to polishing under traffic. Some believe aggregates carry an electrostatic charge. It seems reasonable that calcareous aggregates such as limestone or dolomite could be positively charged while silaceous aggregates like granite would have a negative charge. This would mean that anionic emulsions being negatively charged should adhere better to calcareous aggregates and cationic emulsions should adhere better to silaceous aggregates. The authors found little in the literature (46) that supports or contradicts this notion, although there is some evidence from interviews that does support this theory (27). More work should be done on this subject since many chip seals are constructed with aggregates produced from sand and gravel sources which often contain both silaceous and calcareous rocks.

Gradation

Aggregate gradation has much to do with how well a chip seal will perform. Although graded aggregate seals have been successfully constructed (43), most agree that the closer to one-sized a chip seal aggregate is, the higher the probability of success. The reason for this is that if the chip seal aggregate contains a wide range of aggregate sizes the smaller sizes are likely to become embedded in the emulsion before the large sizes. If this happens, the large sizes will not have adequate binder to hold them in place and may become dislodged and become potential projectiles. One-size aggregates produce a more uniform thickness and consequently a more consistent embedment in the asphalt binder. This contributes to improved aggregate retention, friction, and drainage characteristics (40).

Larger aggregates such as ½-inch, or even ¾-inch can be used in chip seals. The advantages are increased asphalt binder and therefore, more sealing potential. Also, since these aggregates are larger, they have a wider margin for error with respect to asphalt quantity. However, the disadvantages of large sized chip seal aggregates include increased tire noise, and increased cost due to higher binder volume. Increased risk of windshield damage has been offered as a disadvantage, as well. Although, this may be true, the adherence of large sized stones should be equal to smaller aggregates if the design binder quantity and design chip quantity are appropriate. Also, larger stones have more mass than smaller stones. Therefore, more energy would be required to dislodge them and make them projectiles.

The most important factor regarding gradation is the amount of material finer than the No. 200 screen. Colorado (30) limits this to 1%. Other states have similar requirements (30). Material passing the No. 200 screen can prevent asphalt binders from adhering to the surface of the aggregate resulting in retention problems (43).

Shape

Aggregate shape is important to the success of a chip seal. An angular, blocky shape is preferable to a flat and elongated shape. Flat and elongated shapes tend to become submerged in the asphalt binder resulting in a flushed surface. Cubical and angular shapes do not tend to become reoriented under traffic (39), so flushing is much less likely. Cubical and angular shapes also provide a more predictable shape for determining asphalt quantity during the design and construction phase of the project and cubical and angular shapes interlock better than flat and elongated shapes providing better long term particle retention and stability. Flat and elongated particles can be determined by laboratory testing using either the flat and elongated test methods for Superpave or the Flakiness Index (41, 42, 43).

Aggregate for chip seals should be fractured mechanically. Rounded aggregates displace easier and do not interlock well. Therefore, Colorado requires that 90 percent of the plus No. 4 sizes have at least two faces fractured by mechanical means when tested using Colorado Procedure 45 (30).

Moisture

A damp aggregate provides a better surface for asphalt emulsion to adhere to. Therefore, aggregate stockpiles should be sprayed with water one to two days before the start of the chip seal operations. This spraying accomplishes two things: 1) the moisture provides a mechanism for the emulsion to absorb into the voids of the aggregate by capillary action, and 2) the spraying may wash off some minus No. 200 particles, reducing the chance for this dust to interfere with the adhesion of the binder to the aggregate surface.

Toughness and Soundness

Chip seal aggregates must be very tough, sound particles. The Los Angeles Abrasion test (45) is specified by most agencies to qualify aggregates for use as chip seal aggregates. Colorado DOT specifies a maximum of 35 percent loss (30). However, some studies (47) have shown that for high traffic pavements in excess of 7500 vehicles per day per lane, 35 percent loss may be too high and should be reduced to no more than 25 percent loss.

Emulsified Asphalt

Emulsified asphalt for chip sealing should have a consistency that allows for uniformly covering the pavement surface while not so fluid that it forms puddles or flows across the pavement. The binder should develop adhesion quickly upon application of the cover aggregate chips.

Two types of emulsified asphalt are specified by Colorado DOT (30): 1) Cationic CRS-2P and 2) Anionic HFRS-2P. Please note that in Table 702-4, the 'max' and 'min' columns are reversed.

Construction

Five types of equipment are needed to construct a chip seal. These are:

1. Asphalt Distributor
2. Aggregate Chip Spreader
3. Rollers
4. Dump Trucks
5. Brooms

Asphalt Distributor

The asphalt distributor is a self-propelled vehicle with a tank for holding the asphalt emulsion and a spraybar for applying the emulsion to the roadway. Although it is not specifically required by CDOT in Section 409.05 (30), computerized distributors which control the application rate of the emulsion are highly desirable. However, even with computer control, it is recommended that each nozzle of the distributor be calibrated prior to use. Research has shown that even when new, nozzle output can be highly variable (47). Also, before spraying operations begin the angle of each nozzle in the spraybar should be checked. The angle of each nozzle must be the same and in accordance with the manufacturer's recommendation. Angles of from 15 to 30 degrees from horizontal are typical as shown in Figure 10.

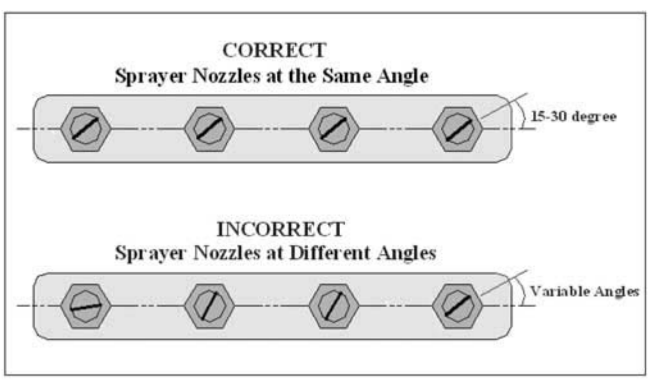


Figure 10 - Nozzle Alignment.

Aggregate Chip Spreader

The aggregate chip spreader must apply a uniform, even layer of aggregate across the full width of the binder. Figure 11 shows an example of a typical self-propelled aggregate spreader.

Figure 11 – Self-Propelled Aggregate Chip Spreader

A self-propelled spreader, equipped with a receiving hopper in the rear, belt conveyors to carry the aggregate to the spreading hopper, and a spreading hopper with adjustable discharge gates, is the preferred equipment for use. A discharge roller that assists in ensuring uniform transverse application rates is often located at the bottom of the discharge gate. Some equipment is available with variable-width spreading hoppers that hydraulically extend to adjust to changing spread widths. Many chip spreaders are equipped with computerized controls that allow the spread rate to remain constant as the speed of the spreader changes. This ensures a constant application rate, regardless of travel speed. Also, spreaders should be equipped so larger aggregates are forced to hit the emulsion before smaller aggregates. This is in accordance with CDOT specifications Section 409.05 (30).

The time required between emulsion application and chip application varies. If the chips are allowed onto the emulsion too soon, the chips may roll over because the emulsion has not had time to develop sufficient viscosity. And, if chips are kept off the surface too long, the emulsion may partially break, reducing adhesive ability. Therefore, the time allowed before chips are allowed onto the emulsion is critical to a successful chip seal.

One method the author recommends based on observations of experienced chip seal contractors consists of casting some chips onto the emulsion coating the pavement surface at varying time intervals after the emulsion has been sprayed. If the chips roll over in the emulsion, not enough time has elapsed. If the chips stick to the surface and do not roll over, it is time to apply the aggregate chips.

Rollers

Rollers follow the aggregate spreader to force the aggregate into the asphalt emulsion. This provides initial embedment of the aggregate into the emulsion and reduces the chance that aggregate will become dislodged after opening to traffic. This operation has been well documented and has changed little since early evaluations (46). The distance between the rollers and the chip spreader should be adjusted so the rollers do not pick up excess chips. This must be evaluated in the field on each project since the adhesion of the chips to the emulsion will vary with substrate temperature, wind speed, emulsion properties, moisture in the chips and roller speed, to name several. Two types of rollers are used for chip seals in North America, 1) rubber tire (pneumatic) and 2) steel-wheel. There is some controversy regarding use of steel-wheel rollers on chip seals.

<u>Rubber Tire Rollers</u>

Rubber tire, or pneumatic, rollers are used on virtually every chip seal project. The number of rollers may vary, but there should always be at least two of these rollers. Rubber tire rollers work well on chip seals because the contact pressure between the roll and the aggregate chip will not exceed the tire pressure of the roller. This pressure may vary but should be a maximum of approximately 80 to 90 psi.

Roller speed is important. If the rollers are moving too fast, chips may become dislodged during rolling, jeopardizing performance of the chip seal. Speed should be no faster than a fast walk, or about 3 miles per hour.

<u>Steel Wheel Rollers</u>

Use of steel-wheeled rollers is controversial. Some believe a steel-wheel roller provides a smoother surface than the rubber tire roller and should always be used following rubber tire rolling. Others believe use of the steel wheel roller is risky because of possible crushing that can occur to the aggregates under the very high stresses imposed by such rollers. In addition, unless aggregates are of very uniform size, the larger aggregates will support the load of the rigid steel drum, preventing any contact with smaller aggregates. And, steel wheel rollers may not contact aggregates in rutted areas of the pavement leaving these aggregates unseated.

Vacuums and Brooms

The surface of the pavement requires cleaning before the chip seal is applied and the chip seal requires cleaning of excess chips before traffic is allowed on the new surface. Two different types of equipment are used for these purposes: 1) vacuums, and 2) brooms.

Vacuums

Vacuums work by removing dust, debris, loose chips and moisture from the pavement surface through brooms and vacuum or just vacuum alone. A vacuum sweeper consists of brooms and a vacuum system. The brooms sweep debris or moisture to a centrally located vacuum system which lifts the materials and deposits them into a storage tank. A vacuum pickup removes dust, debris, loose chips and moisture by vacuum, only. The advantage of the vacuum pickup is that it does not contact the surface of the chip seal with brooms and therefore, causes less potential damage than brooms or sweepers.

Brooms

Rotary push brooms can be used to clean the pavement surface prior to construction and also remove excess chips from the pavement surface. When used to remove excess chips rotary brooms must be used with extreme caution because too much downward pressure on the broom can destroy the fresh chip seal. Therefore, the skill of the broom operator is important to the success of the chip seal and the amount of time that elapses between chip application and brooming is a function of operator skill.

Fog Seal

A fog seal may be applied to the chip seal surface following brooming and vacuum operations and before striping. This is an optional technique consisting of a light application (less than 0.10 gallons per square yard) of diluted asphalt emulsion (CSS-1h or SS-1h) sprayed on the chip seal surface prior to striping. The fog seal provides two potential benefits: 1) it makes the pavement surface dark, emphasizing the new striping, and providing improved visibility, and 2) it provides a small amount of extra binder to aid in chip retention. Other than these two potential benefits, no economic benefit has been reported.

Thin Overlays

Thin overlays for preventive maintenance are defined as hot mixed asphalt concrete pavement (HMA) overlays applied to existing pavements for the purpose of restoring surface texture or removing permanent deformation. Thin overlays are used for pavements where chip seals are considered inappropriate. Thin overlays are HMA of 1.5 inches compacted thickness or less. This includes, but is not limited to, dense graded HMA, stone mastic (matrix) asphalt (SMA), and ultrathin bonded wearing courses.

Pavement Selection

The asphalt pavement to be restored using thin overlays should be in good to fair condition. This means cracking should be of low to moderate severity and should have been crack sealed between 6 and 12 months of the thin overlay application. Raveling should be of low to moderate severity with depressions caused by stripping of the surface no greater than ¼-inch in depth. There should be no potholes. However, if potholes have been adequately repaired by cutting out the affected area and placing and compacting new HMA, thin overlays may still be effective.

Timing

Thin overlays must be constructed during the warmest part of the construction season. Temperatures of the surface and ambient air must be in accordance with Section 401 of the standard specifications (30) and not less than 60F. This is because compaction of overlays of less than 1.5 inches is very difficult under the best conditions since temperature loss of thin asphalt mixtures occurs very rapidly. In fact, the time required for a 1 inch lift to cool to a temperature (175F) where compaction is very difficult is 6 minutes if the air temperature is 60F and the mixture is delivered to the paver at 300F (49).

Conditions

Weather conditions are critical to the successful construction of thin overlays. Compaction is difficult under the best conditions for dense graded HBP when applied in thin lifts as described in the previous paragraph, so weather must be warm and dry before attempting this type of construction. Although SMA and thin-bonded overlays do not require the level of compaction as dense graded mixtures, they do require rolling to seat the aggregates in place and cool, or wet weather is detrimental to this objective.

Materials Selection

Hot Mixed Asphalt
Hot mixed asphalt (HMA) used for thin overlays must meet the requirements of Section 702.01 for asphalt cements and Section 703.04 for mineral aggregates.

SMA

SMA used as a preventive maintenance treatment must meet requirements specified in CDOT Special Provisions.

Ultrathin Bonded Wearing Course

Ultrathin Bonded Wearing Courses used as a preventive maintenance treatment must meet requirements specified in CDOT Special Provisions for these products.

Installation

Construction of thin HBP and SMA should follow procedures specified in Sections 401 for mixing, hauling, laydown and compaction (30).

Concrete Pavement Preventive Maintenance

Joint Resealing

Joint resealing consists of replacing the joint sealer in joints or cracks of Portland cement concrete (PCC) pavements. The objective of resealing joints in concrete pavements is to return sealant integrity to the joint to prevent further intrusion of moisture or incompressible solids into the joint. Reducing moisture infiltration into the joint reduces the potential for pumping and consequent loss of subgrade strength, and eliminating entry of incompressibles into the joint reduces the potential for joint damage caused by compressive forces.

Pavement Selection

When to reseal joints in concrete pavements is an important decision. If done too early in the life of the joint seal, funds may be wasted, and if done too late, deterioration may have begun reducing the effectiveness of the sealant. Some agencies replace joint and crack sealant when some percentage of the existing joint or crack sealant has failed. This varies between 25 and 50 percent according to Evans, et al (50). They go on to recommend a more analytical method for determining the best candidate pavements for resealing in their updated version of Strategic Highway Research Program (SHRP) report H-349 (50). The method they recommend uses a worksheet shown in Figure 11 to estimate 1) sealant condition, 2) pavement condition, 3) traffic, and 4) climate. The decision whether to reseal is then determined from Table 4. This system results in a seal condition number (SCN) which is a function of the number of low, medium and high-severity seal conditions which are a function of seal leakage and stone intrusion of the seal. Pavement condition is evaluated based on the presence of pumping, faulting, D-cracking, compression spalling at the joints, and blowups. Environment is evaluated based on the potential for moisture intrusion and freeze-thaw using the criteria shown in Table 5. Traffic is evaluated based on three levels of traffic volume as shown in Table 6.

Seal Condition			
	Low	Med	High
Water entering, % length	< 10	10-30	> 30
Stone intrusion	L	M	H
Seal Rating	**Good**	**Fair**	**Poor**

Environmental Conditions	
Avg annual precip., mm	
Days ≤ 0°C	
Avg low / high temp, °C	
Climatic Region [a]	**WF WNF DF DNF**

Traffic Conditions			
ADT (vpd); % Trucks			
Traffic Level [b]	**Low**	**Med**	**High**

Pavement Condition			
	Low	Med	High
Expected Pavement Life, yrs.	> 10	5-10	< 5
Average faulting, mm	<1.5	1.5-3.0	>3.0
Corner breaks, % slabs	< 1	1-5	> 5
Pumping, % joints	< 1	1-5	> 5
Spalls >25 mm, % slabs	< 5	5-10	>10
Pavement Rating	**Good**	**Fair**	**Poor**

Current Joint Design	
Sealant age, yrs	
Avg. sealant depth, mm	
Avg. joint width, mm	
Avg. joint depth, mm	
Max. joint spacing, m	

[a] See table 2.
[b] See table 3.

Figure 11 – Concrete Pavement Joint/Survey Form (50)

Table 4 – Decision Table for Resealing Concrete Joints

Sealant Rating[a]	Pvmt. Rating	Traffic Rating	Climatic Region			
			Freeze		Nonfreeze	
			Wet	Dry	Wet	Dry
Fair	Good	Low	Possibly	Possibly	Possibly	Possibly
Fair	Good	Med	**Yes**	Possibly	Possibly	Possibly
Fair	Good	High	**Yes**	**Yes**	**Yes**	Possibly
Fair	Fair	Low	**Yes**	Possibly	Possibly	Possibly
Fair	Fair	Med	**Yes**	**Yes**	**Yes**	Possibly
Fair	Fair	High	**Yes**	**Yes**	**Yes**	Possibly
Fair	Poor	Low	Possibly	Possibly	Possibly	Possibly
Fair	Poor	Med	**Yes**	**Yes**	**Yes**	Possibly
Fair	Poor	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Good	Low	**Yes**	Possibly	Possibly	Possibly
Poor	Good	Med	**Yes**	**Yes**	**Yes**	Possibly
Poor	Good	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Fair	Low	**Yes**	**Yes**	**Yes**	Possibly
Poor	Fair	Med	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Fair	High	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Poor	Low	**Yes**	**Yes**	**Yes**	Possibly
Poor	Poor	Med	**Yes**	**Yes**	**Yes**	**Yes**
Poor	Poor	High	**Yes**	**Yes**	**Yes**	**Yes**

Table 5 - Climatic Region Parameters (50)

Climatic Region	Mean annual days < =0°C	Average annual Precipitation, in (mm)
Wet-Freeze	> 100	>= 25 (635)
Wet-Nonfreeze	< 100	>= 25 (635)
Dry-Freeze	> 100	<= 25 (635)
Dry-Nonfreeze	< 100	<= 25 (635)

Table 6 - Traffic-Level Rating (50)

Traffic Level	ADT, vpd all lanes
Low	< 5,000
Medium	5,000 to 35,000
High	>35,000

Conditions

Joints and cracks should be sealed immediately following final cleaning and placing of bond breakers, if used. Sealing should only be done when the walls of the joint are dust free and dry, and when weather conditions meet the manufacturer's recommendations (51).

Materials Selection

Sealants

Many different types of sealants are available for resealing concrete pavements. The type to use depends on how much movement is expected in the pavement joints. Table 7 is reproduced from the literature (50) and includes most of the commonly used sealants, applicable specifications, the maximum extension allowed, and the approximate cost.

Table 7 - Summary of Sealant Materials (50)

Sealant Material	Applicable Specifications	Design Extension, % [a]	Cost Range, $/lb [b]
PVC Coal Tar	ASTM D 3406	10 to 20%	$1.75 to $2.75
Rubberized Asphalt	ASTMD 1190, AASHTO M 173, ASTM D 3405,	15 to 30%	$0.60 to $1.00

	AASHTO M 301		
Low Modulus Rubberized Asphalt	Modified ASTM D 3405	30 to 50%	$0.70 to $1.20
Polysulfide (1 & 2 Part)	Fed SS-S-200E	10 to 20%	Not Available
Polyurethane	Fed SS-S-200E	10 to 20%	$5.20 to $7.20
Silicone (non-sag)	ASTM D 5893	30 to 50%	$6.50 to $9.00
Silicone (self-leveling")	ASTM D 5893	30 to 50%	$6.50 to $9.50

[a] Consult manufacturers for specific design extensions.
[b] Based on 1998 estimated costs.

Backer Rod

Backer rod is placed in the joint prior to sealing for three reasons:
1) it keeps the sealant from filling up the joint reservoir and seeping into the contraction crack beneath, which reduces cost,
2) it prevents the sealant from bonding to the bottom of the reservoir, which keeps the sealant in tension rather than combined tension and shear, and
3) it maintains a consistent sealant thickness.

Backer rod should be flexible, compressible, not shrink, not absorptive, and not reactive with the sealant. A list of several types of common backer rod are shown in Table 8.

Table 8 - Backer Rod Materials (50)

Backer Material Type	Applicable Standard	Properties	Compatibility
Extruded closed-cell polyethylene	ASTM D 5249 Type 3	NMA, ECI, NS	Most cold-applied sealants
Cross-linked extruded closed-cell polyethylene	ASTM D 5249 Type I	HR, NMA, ECI, NS	Most hot- and cold-applied sealants
Extruded polyolefin	ASTM D 5249 Type 3	NMA, NS, NG, CI, IJ	Most cold-applied sealants

CI = Chemically inert
NG = Non-gassing
ECI = Essentially chemically inert
NMA = Non-moisture absorbing
HR = Heat resistant
NS = Non-staining
II = Fills irregular joints well

Joint Reservoir Dimensions

The width and the thickness of the sealant in the joint affects performance of the seal. Therefore, there are recommended ratios of width to thickness (W:T), called the shape factor, depending on what type of sealant is used. Figure 12 shows a typical joint cross-section with backer rod and sealant in the joint and dimensions W and T. Table 9 summarizes typical shape factors for different types of sealants.

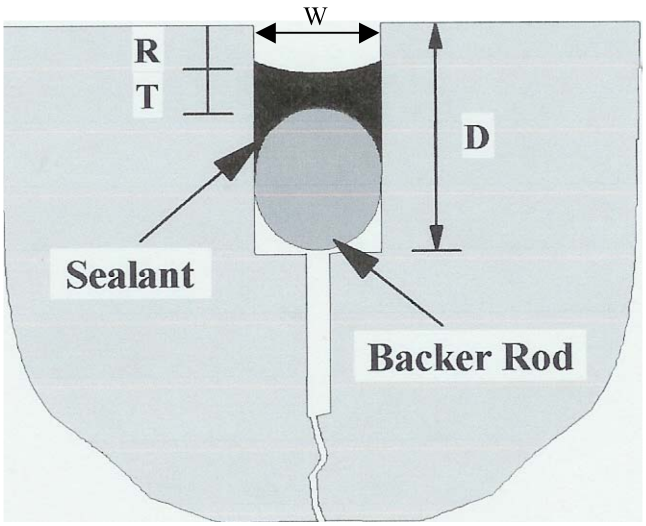


Figure 12 – Typical Joint Cross-section

Table 9 - Recommended Shape Factors.

Sealant Material Type	Typical Shape Factor (W:T)
Rubberized Asphalt	1:1
Silicone[a]	2:1
PVC Coal Tar	1:2
Polysulfide and Polyurethane	1:1

[a] minimum thickness = 6mm; maximum thickness = 13mm

In addition, the joint width should be wide enough so the sealant does not stretch more than 20 percent in winter. Therefore, the joint width is a function of joint spacing. Based on this criteria values for minimum joint width are shown in Table 10.

Table 10 - Typical joint design dimensions.

Maximum Joint Spacing, ft (m)	Minimum Joint Width, in (mm) [a]	
	Nonfteeze Region[b]	Freeze Region [c]
<=4.6	0.25 (6)	0.40 (10)
4.7 to 7.6	0.25- 0.40 (6 - 10)	0.40-0.50 (10 – 13)
7.7 to 12.2	0.40-0.50 (10 - 13)	0.50-0.75 (13 - 19)
12.3 to 18.3	0.50-0.75 (13 - 19)	0.75-1.1 (19 - 29)

[a] Installation temperature is 81F (27°C), base is stabilized, $\%E_{max}$ <=20%.
[b] Minimum nonfreeze region temperature is 19F (-7°C).
[C] Lowest freeze region mean monthly temperature is, -15F (-26°C).

Installation

Sealant removal and replacement methods depend on several factors including: joint dimensions, hardness of existing sealant, and cleanliness of the joint after sealant removal. A flow diagram based on the description of the joint preparation and installation process in the literature (50) is shown in Figure 13 and depicts the decision process.

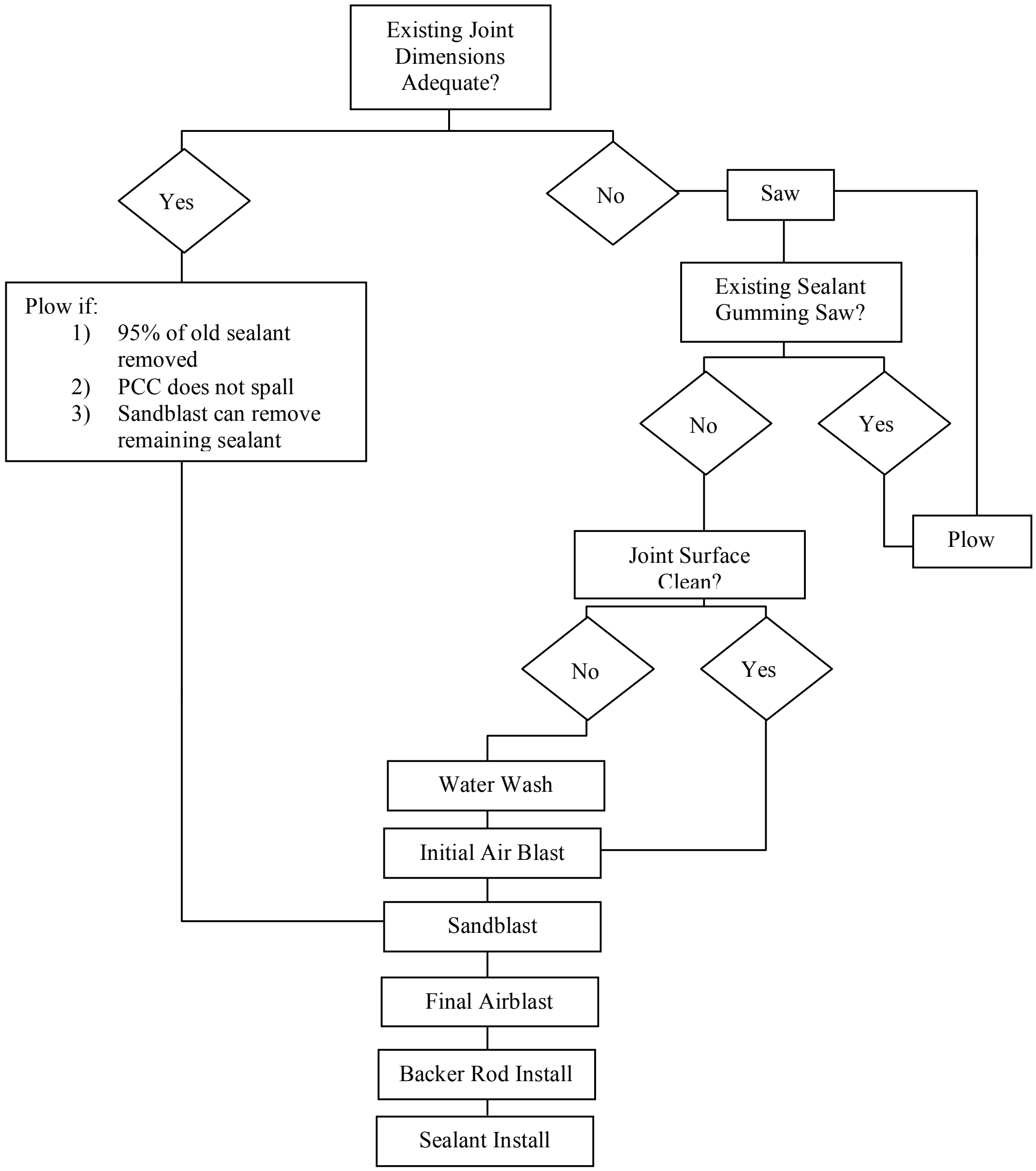


Figure 13 – Decision Process for Joint Resealing

Diamond Grinding

Diamond grinding is used to restore the surface longitudinal profile and improved ride quality of a concrete pavement. Benefits from diamond grinding include: the removal of joint crack faults and improvement of skid resistance.

Pavement Selection

The pavement should not have corner breaks, spalling or popouts. The visible surface distress may include low severity cracking, faults not exceeding 0.25 inch, and moderate to severe polishing.

Diamond grinding repairs functional deficiencies of the pavement. Structural deficiencies will require an overlay or reconstruction. Pavements with moderate to advanced material related distresses such as alkali-silica reaction or D-cracking are not good candidates for diamond grinding.

Tables 11 and 12 (52) provide a guide for determining when diamond grinding is appropriate as a function of pavement type and traffic level.

Table 11 - Trigger Values for Diamond Grinding (52)

	JPCP			JRCP			CRCP		
Traffic Volumes*	High	Med	Low	High	Med	Low	High	Med	Low
Faulting avg inches (mm)	0.08 (2)	0.08 (2)	0.08 (2)	0.16 (4)	0.16 (4)	0.16 (4)		N.A.	
IRI in/mi	63	76	90	63	76	90	63	76	90

*Volumes: High ADT>10,000; Med 3000<ADT<10,000; Low ADT <3,000

Table 12 - Limit Values for Diamond Grinding (52)

	JPCP			JRCP			CRCP		
Traffic Volumes*	High	Med	Low	High	Med	Low	High	Med	Low
Faulting avg, inches (mm)	0.35 (9)	0.5 (13)	0.6 (15)	0.35 (9)	0.5 (13)	0.6 (15)		N.A.	
IRI in/mi	160	190	222	160	190	222	160	190	222

*Volumes: High ADT>10,000; Med 3000<ADT<10,000; Low ADT <3,000

Factors which require other repairs to be made before diamond grinding include:

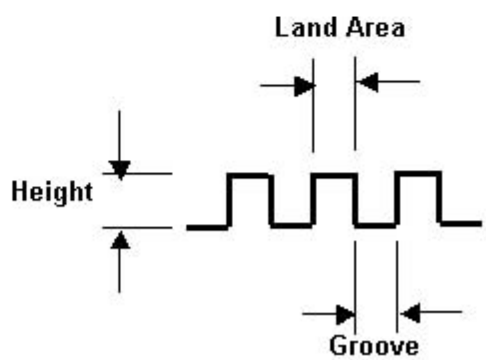
- Evidence of severe drainage or erosion indicated by severe faulting (> ¼ in) or pumping,
- The presence of progressive transverse slab cracking and corner breaks in jointed pavements.
- Joints and transverse cracks with a load transfer of less than 60 percent should be retrofitted with dowels prior to diamond grinding (see publication FHWA-SA-97-103 for more information on load transfer restoration). An effort should be made to restrict total deflection of slabs at the joints to less than 1/64-inch. Slab stabilization can be used to restrict the total deflection of slabs.
- Significant slab replacement and repair.

Conditions

Diamond grinding must not be done when the water used for lubricating the diamond grinding equipment could freeze (53).

Installation

Diamond grinding equipment should be purpose-built, self-propelled equipment for grinding concrete pavement in the longitudinal direction. The equipment should not cause undue strain or damage to the underlying surface of the pavement, cause ravels, aggregate fracture, spalls, or disturbance to the transverse or longitudinal joints. The cross-sectional pattern should conform to that shown in Figure 14.



	Range of Values mm (in)	Hard Aggregate mm (in)	Soft Aggregate mm (in)
Grooves	2.0 – 4.0 (0.08-0.16)	2.5 – 4.0 (0.1-0.16)	2.5 – 4.0 (0.1-0.16)
Land Area	1.5 – 3.5 (0.06-0.14)	2.0 (0.08)	2.5 (0.1)
Height	1.5 (0.06)	1.5 (0.06)	1.5 (0.06)
No. Grooves per meter	164 – 194 (50-60)	174 – 194 (53-60)	164 – 177 (50-54)

Figure 14 – Approximate Geometry of Diamond Grinding Cross-Section (52)

Equipment will be used to vacuum the surface of the pavement after grinding to remove excess slurry and for preventing dust from escaping into the air.

The transverse slope of the pavement shall be uniform so that no depressions or misalignment of the slope greater than 0.10 percent exists when tested with a 10 foot straightedge (53). This requirement does not apply across longitudinal joints. Adequate cross slope drainage must result after grinding so that ponding of water does not occur.

All joints shall be sealed after grinding is completed.

Cross-stitching

Pavement Selection

Cross-stitching is a preventive maintenance technique intended for concrete pavements in good condition except for the few longitudinal cracks needing repair. Cross-stitching maintains aggregate interlock at the crack or joint by providing reinforcement. Tie bars or fiberglass panels used for cross-stitching prevent the crack or joint from vertical or horizontal movement.

Installation

The cross-stitch process requires holes to be drilled in the pavement at an angle of 35 to 45 degrees from the horizontal perpendicular to the crack or joint. The holes should intersect the crack or joint at mid-slab depth. A ¾-inch deformed reinforcing bar is inserted into a 1-1/8 inch diameter hole. Holes should be drilled on 24 to 36 inch centers depending on traffic level. Heavy truck traffic requires 24 inch centers. Drills that minimize damage to the pavement should be used. Drilling debris should be removed by blowing compressed air into the hole. Epoxy resin should be injected into the holes prior to inserting the tie bars. The volume of epoxy resin injected should be the hole volume minus the bar volume. Tie bars should be inserted into the holes while the epoxy is still liquid with about 1 inch of the bar remaining above the pavement surface (54).

References

1. Crack width reference
2. Shafer, Douglas, "Policy for Crack Filling and Joint Resealing in Colorado", internal CDOT memo, January 24, 1991.
3. ASTM D3405
4. ASTM D6690-01, "Standard Specification for Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements", Volume 04.03, *Road and Paving Materials; Vehicle-Pavement Systems*, Section 4, Construction.
5. ASTM D1190
6. Principal Investigator witnessed routing of cracks on I-25 near Santa Fe, NM on August ??, 2005. Interview of state authorities scheduled to determine justification.
7. Johnson, Ann M., "Best Practices Handbook on Asphalt Pavement Maintenance", University of Minnesota Center for Transportation Studies, Report MN/RC 2000-04, February, 2000.
8. Masson, Jean-François Masson, Boudreau, Sylvain. and Girard, Claire. "Guidelines for Sealing and Filling Cracks in Asphalt Concrete*", National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices,* www.infraguide.gc.ca, March 2003.
9. Eaton, R.A. and J. Ashcraft, 1992. *State-of-the-art survey of flexible pavement crack sealing procedures in the United States*. Report 92-18, Cold Regions Research & Engineering Laboratory, U.S. Army Corps of Engineers, Hanover, N.H.
10. Smith, K.L. and A.R. Romine, 1993a. "Materials and Procedure for Sealing and Filling Cracks in Asphalt-Surfaced Pavements," Strategic Highway Research Program, National Research Council, Washington, D.C. Report SHRP-H-348.
11. Masson, J-F. and M.A. Lacasse, 1999. "Effect of Hot-Air Lance on Crack Sealant Adhesion," *Journal of Transportation Engineering,* 125(4), pp. 357-363.
12. Masson, J-F., P. Collins, and P-P. Légaré, 1999. "Performance of Pavement Crack Sealants in Cold Urban Conditions," *Canadian Journal of Civil Engineering*, Vol. 26, pp. 395-401.
13. Ponniah, J.E. and G.E. Kennepohl, 1996. "Crack Sealing in Flexible Pavements: A Life-Cycle Cost Analysis," *Transportation Research Record 1529*, Transportation Research Board, Washington, D.C., pp. 86-94.
14. FHWA (Federal Highway Administration), 1998. *Techniques for pavement rehabilitation—Reference manual*, 6th edition, FHWA/HI-98-033, Federal Highway Administration, Washington, D.C.
15. Marino, J., 1996. Hot-Pour Crack Sealing Application Procedures and Guidelines Current to September 1996, City of Vancouver Engineering Services, Streets Division, Materials Engineering Branch.
16. Evers, R.C., 1981. Evaluation of Crack-Sealing Compounds for Asphaltic Pavements, Ontario Ministry of Transportation and Communications. Project No. 33, Interim Report No. 1.
17. Marino, J., 1995. *Hot-Pour Crackseal Annual Report*, City of Vancouver Engineering Services, Streets Division, Materials Engineering Branch, June.
18. Marino, J., 1996. *Hot-Pour Crack Sealing Application Procedures and Guidelines Current to September 1996*, City of Vancouver Engineering Services, Streets Division, Materials Engineering Branch.
19. Masson, J-F., C. Lauzier, P.Collins, and M.A. Lacasse, 1998. "Sealant Degradation During Crack Sealing of Pavements," *Journal of Materials in Civil Engineering*, Vol 10, No. 4, pp. 250-255. MTO (Ministry of Transportation of Ontario) 1990. *Maintenance and Rehabilitation,* Chapter 4 in Pavement Design and Rehabilitation Manual, Ministry of Transportation of Ontario, Downsview, ON
20. Corbett, M.A. and K. Lauter, 2000. "Field Evaluation of Crack Sealing in Cold Climate," *Proceedings of the Canadian Technical Asphalt Association,* Vol. 45, pp. 192-202.
21. Smith, K.L. and A.R. Romine, 1993b. *Innovative Materials Development and Testing, Volume 3: Treatment of Cracks in Asphalt Concrete-Surfaced Pavements*, Strategic Highway Research Program, National Research Council, Washington, D.C. Report SHRP-H-354.

22. Masson, J-F. and M.A. Lacasse, 2000. "A Review of Adhesion Mechanisms at the Crack Sealant/Asphalt Concrete Interface," in *Durability of Building and Construction Sealants,* RILEM PRO 10, edited by A.T. Wolf. RILEM Publications S.A.R.L., Cachan, France, pp. 259-274.
23. Colorado DOT "Preventive Maintenance Program Guidelines", October 2004. Prepared by Larry Galehouse. .
24. Moulthrop, J., "Pavement Preservation: Protecting the Investment," Presented at the Northeast Asphalt User Producer Group (NEAUPG) Annual Meeting, Wilkes-Barre, Pa., Oct. 27, 2003.
25. Eltahan, A.A., J.F. Daleiden, and A.L. Simpson, "Effectiveness of Maintenance Treatments of Flexible Pavements," *Transportation Research Record 1680,* Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 18–25.
26. Gransberg, Douglas, and James, David M. B., "Chip Seal Best Practices: A Synthesis of Highway Practice, NCHRP Synthesis 342, Washington, D. C., 2005.
27. Interviews with Colorado DOT maintenance personnel in 2004-2005 as part of Task 1 of Study No.10.50, "Evaluation of the Performance, Cost-Effectiveness, and Timing of Various Preventive Maintenances".
28. *Asphalt Surface Treatments—Construction Techniques,* Educational Series No. 12 (ES-12), Asphalt Institute, Lexington, Ky., 1988.
29. *Maintenance Chip Seal Manual,* Montana Department of Transportation, Helena, 2000.
30. Colorado Department of Transportation, "Standard Specification for Road and Bridge Construction", 1999.
31. Texas Department of Transportation…
32. Missouri Department of Transportation…
33. New Mexico Department of Transportation…
34. *Seal Coat Placement,* Indiana Department of Transportation Training Manual, Indianapolis, http://www.in.gov/dot/div/training/manuals/hotmix/chap-ter_09.pdf April 2, 2004.
35. California Department of Transportation….
36. *Asphalt Surface Treatments—Specifications,* Educational Series No. 11 (ES-11), Asphalt Institute, Lexington, KY..
37. Michigan DOT…
38. Ohio DOT…
39. Janisch, D.W. and F.S. Gaillard, *Minnesota Seal Coat Handbook,* MN/RC-1999-07, Minnesota Department of Transportation, Office of Minnesota Road Research, Maplewood, 1998.
40. McHattie, R.L., *Asphalt Surface Treatment Guide,* Report FHWA-AK-RD-01-03, Alaska Department of Transportation and Public Facilities, Juneau, 2001.
41. Seal Coat and Surface Treatment Manual, Texas Department of Transportation, Austin, 2003.
42. McLeod, N.W., "Basic Principles for the Design and Construction of Seal Coats and Surface Treatments", *Proceedings of the Association of Asphalt Paving Technologists*, St. Paul, Minn., 1960.
43. McLeod, N.W., "A General Method of Design for Seal Coats and Surface Treatments," *Proceedings of the Association of Asphalt Paving Technologists,* Vol. 38, St. Paul, Minn., 1969.
44. Shuler, S., "High-Traffic Chip-Seal Construction: The Tulsa Test Road," *Transportation Research Record 1300,* Transportation Research Board, National Research Council, Washington, D.C., 1991.
45. AASHTO T96…
46. Yazgan, B. and S. Senadheera, *A New Testing Protocol for Seal Coat (Chip Seal) Material,* Texas Tech University, Lubbock, 2003.
47. Shuler, S., "Chip Seals for High Traffic Pavements," *Transportation Research Record 1259,* Transportation Research Board, National Research Council, Washington, D.C., 1990.
48. Benson, F.J. and B.M. Gallaway, "Retention of Cover Stone by Asphalt Surface Treatments," *Bulletin 133,* Texas Engineering Experiment Station, Texas A&M University System, College Station, 1953.
49. "Hot Mix Asphalt Paving Handbook 2000", US Army Corps of Engineers, AC 150/5370-14A, Appendix 1.
50. Evans, I. D., Smith, K. L., and Romine, A. R., "Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavements-Manual of Practice", FHWA-RD-99-146.

51. Unified Facilities Guide Specifications, U.S. Army Corps of Engineers, Division 02-Site Construction, Resealing Joints in Rigid Pavement, August 2004.
52. "Concrete Pavement Rehabilitation -Guide for Diamond Grinding", Correa, A. L, and Wong, B., FHWA Southern Resource Center, June 2001.
53. Michigan Department of Transportation, "Special Provision for Diamond Grinding Concrete Pavement, FUSP600(A), September, 1999.
54. "Stitching Concrete Pavement Cracks and Joints", Special Report Concrete Pavement Technology and Research, American Concrete Pavement Association and International Grooving and Grinding Association, SR903P, 2001.

APPENDIX B – Chip Test Results

COLORADO DEPARTMENT OF TRANSPORTATION
Region 4 Materials Lab
Evans, Colorado

Project:	STA 0142-045
Subacct:	15204
Location:	SH14 Chipseal
Supplier:	Asphalt Paving
Date:	08/24/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled: 08/23/05
Field Sheet Number: 152120
Other Info: Sample #15

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS	STATUS
1"			
3/4"			
1/2"	100	100	PASS
5/16"	14	0-15	PASS
#4	2	0-3	PASS
#8	1		
#16	1		
#30	1		
#50	1		
#100	1		
#200	0.9	0-1.2	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

Region lab results by B. Cloepfil

Gary L. DeWitt
Region 4 Materials Engineer

COLORADO DEPARTMENT OF TRANSPORTATION
Region 4 Materials Lab
Evans, Colorado

Project:	STA 0142-045
Subacct:	15204
Location:	SH14 Chipseal
Supplier:	Asphalt Paving
Date:	08/24/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled:	08/23/05
Field Sheet Number:	152121
Other Info:	Sample #16

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS	STATUS
1"			
3/4"			
1/2"	100	100	PASS
5/16"	15	0-15	PASS
#4	2	0-3	PASS
#8	2		
#16	1		
#30	1		
#50	1		
#100	1		
#200	0.8	0-1.2	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

Region lab results by B. Cloepfil

Gary L. DeWitt
Region 4 Materials Engineer

COLORADO DEPARTMENT OF TRANSPORTATION
Region 4 Materials Lab
Evans, Colorado

Project:	STA 0142-045
Subacct:	15204
Location:	SH14 Chipseal
Supplier:	Asphalt Paving
Date:	08/24/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled: 08/23/05
Field Sheet Number: 152122
Other Info: Sample #17

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS	STATUS
1"			
3/4"			
1/2"	100	100	PASS
5/16"	15	0-15	PASS
#4	2	0-3	PASS
#8	2		
#16	1		
#30	1		
#50	1		
#100	1		
#200	0.9	0-1.2	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

Region lab results by B. Cloepfil

Gary L. DeWitt
Region 4 Materials Engineer

COLORADO DEPARTMENT OF TRANSPORTATION
Region 4 Materials Lab
Evans, Colorado

Project:	STA 0142-045
Subacct:	15204
Location:	SH14 Chipseal
Supplier:	Asphalt Paving
Date:	08/24/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled: 08/23/05
Field Sheet Number: 152123
Other Info: Sample #18

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS	STATUS
1"			
3/4"			
1/2"	100	100	PASS
5/16"	13	0-15	PASS
#4	2	0-3	PASS
#8	1		
#16	1		
#30	1		
#50	1		
#100	1		
#200	1.0	0-1.2	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

Region lab results by B. Cloepfil

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Region 4 Materials Lab
Evans, Colorado

Project:	STA 0341-065
Subacct:	15225
Location:	SH34 Chipseal
Supplier:	Asphalt Paving
Date:	07/21/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled:	07/21/05
Field Sheet Number:	152143
Other Info:	Sample #21

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS (Type I Special)	STATUS
1"			
3/4"			
1/2"			
3/8"	100	100	PASS
#4	5	0 - 10	PASS
#8			
#16			
#30			
#50			
#100			
#200	0.8	0 - 1.7	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

Region lab results by B. Cloepfil

Gary L. DeWitt
Region 4 Materials Engineer

COLORADO DEPARTMENT OF TRANSPORTATION
Region 4 Materials Lab
Evans, Colorado

Project:	STA 0341-065
Subacct:	15225
Location:	SH34 Chipseal
Supplier:	Asphalt Paving
Date:	07/21/05

TEST REPORT

Shown below are the test results of one sample of Chips submitted to the Region Lab for Tests

Date Sampled:	07/21/05
Field Sheet Number:	152144
Other Info:	Sample #22

SIEVE SIZE	PERCENT PASSING	SPECIFICATIONS (Type I Special)	STATUS
1"			
3/4"			
1/2"			
3/8"	100	100	PASS
#4	5	0 - 10	PASS
#8			
#16			
#30			
#50			
#100			
#200	1.1	0 - 1.7	PASS
LA Abrasion	n/a	25 max.	n/a
Fractured Faces	n/a	100	n/a
Flat & Elongated	n/a	12 max	n/a

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