Washington State Chip Seal Study

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Approximately 50 percent of the Washington State highway system, 3,500 center line miles, has a bituminous surface treatment (BST) surface. The use of BST is coincident with that portion of the state system with traffic volumes of 2,000 ADT or less. Recent specification changes such as increasing emulsion yields, decreasing aggregate yields, reducing the allowable time between placement of emulsion and aggregate, and early brooming, along with central office involvement in the BST process have positively affected the quality of the Washington State Department of Transportation's chip seals. However, some of the chip seals constructed in western Washington in 1988 generated adverse publicity because of dust, traffic delays, and windshield damage. This study recaps the recent specification and construction procedure changes, looks into the details of nine recently completed chip seal projects in western Washington, and also supports the following recommendations, among others: use of polymerized emulsions in western Washington, strong central office support and review of the BST program, use of maintenance people with strong working BST experience as chip seal inspectors, use of finer chips in areas of heavy bicycle traffic to provide a smoother, more uniform surface, and early season completion of BST work.

Approximately 50 percent of the Washington State highway system has a bituminous surface treatment (BST) surface. The vast majority of this mileage is made up of the low volume-roads in eastern Washington. The use of BSTs is coincident with the 40 percent of the state system that has traffic volumes of 2,000 ADT or less. In this study, reference is made to both BSTs and chip seals. Both terms will be used interchangeably throughout the paper to reduce repetition, since they refer to the same process.

Although BSTs were widely used in both eastern and western Washington for many years, their use diminished markedly from the mid-1960s through the mid-1980s. During this period, BSTs were all but eliminated in western Washington and severely curtailed in some eastern districts. This was most likely due to improved funding for pavement rehabilitation and inherent problems with BSTs, such as chip loss and windshield damage. Figure 1 is a map of Washington State showing the six transportation districts.

In the early 1980s, the use of chip seals was reconsidered in light of their favorable cost and good performance on low-volume roads. A committee review of BST costs and performance resulted in the issuance of a policy letter that indicated that BST was to be considered the pavement surface of choice for all roads with ADTs less than 2,000 vehicles per day. Exceptions were allowed for economic or environmental risks. This use of chip seals was also encouraged in many cases where the ADTs exceeded 2,000 vehicles per day.

With the renewed use of chip seals, construction problems increased owing largely to the loss of experience and knowledge in the chip sealing process. In 1985, District 5 asked the Washington State Paving and Materials offices to review their 1984 seal coat program in light of the large number of problems encountered.

In response to this report, two of the authors reviewed at length the 1984 and 1985 districtwide chip seals placed in Districts 2, 5, and 6. It soon became apparent that BST construction techniques and procedures differed from district to district and even project engineer to project engineer. The result was a wide range in quality of BST construction throughout all the districts. Some of the most common problems were

- Flushing,
- Windshield damage,
- Aggregate loss, and
- Excessive aggregate use.

The field reviews were followed by a literature search (*1–5*) and extensive discussions with other western states regarding basic chip sealing procedures. This review indicated a clear need to overhaul the BST specifications, push for statewide uniformity of construction inspection procedures, and focus on the following basic guidelines of chip sealing:

1. Use of clean single-sized chips: the existing ½ to ¼ in. Washington State Department of Transportation (WSDOT) aggregate specification works well. (Grading requirements of the various chip sizes used by WSDOT.)
2. Chip yields should be tightly controlled to minimize waste and windshield damage: the field review indicated chip rates of 35 to 60 lb/yd^2 were used where 25 to 30 lb/yd^2 was more than adequate in all cases for ½ to ¼ in. chips.
3. Asphalt emulsion rates should be such that the chips embed about 50 to 70 percent into the asphalt film: for ½ to ¼ in. chips this rate is about 0.45 gal/yd^2 over normal pavement. The field review indicated rates of 0.25 to 0.45 gal/yd^2 were used, in the past, with almost all of the lower application rates losing chips.
4. A chokestone course of ¼ in.- 0 helps to complete the aggregate matrix and lock down single-sized chips when applied immediately after the initial rolling. The field review indicated that chokestone was used sporadically with mixed results, most likely caused by high-chip rates and inconsistent chokestone application procedures.
5. When emulsions are used, rolling that embeds chips or lays them on their flat side must occur immediately after chip placement: the field review indicated a broad range of times between chip placement and rolling, from immediately to in excess of one-half hour in some cases. The standard specifications in effect at that time provided no time limit.

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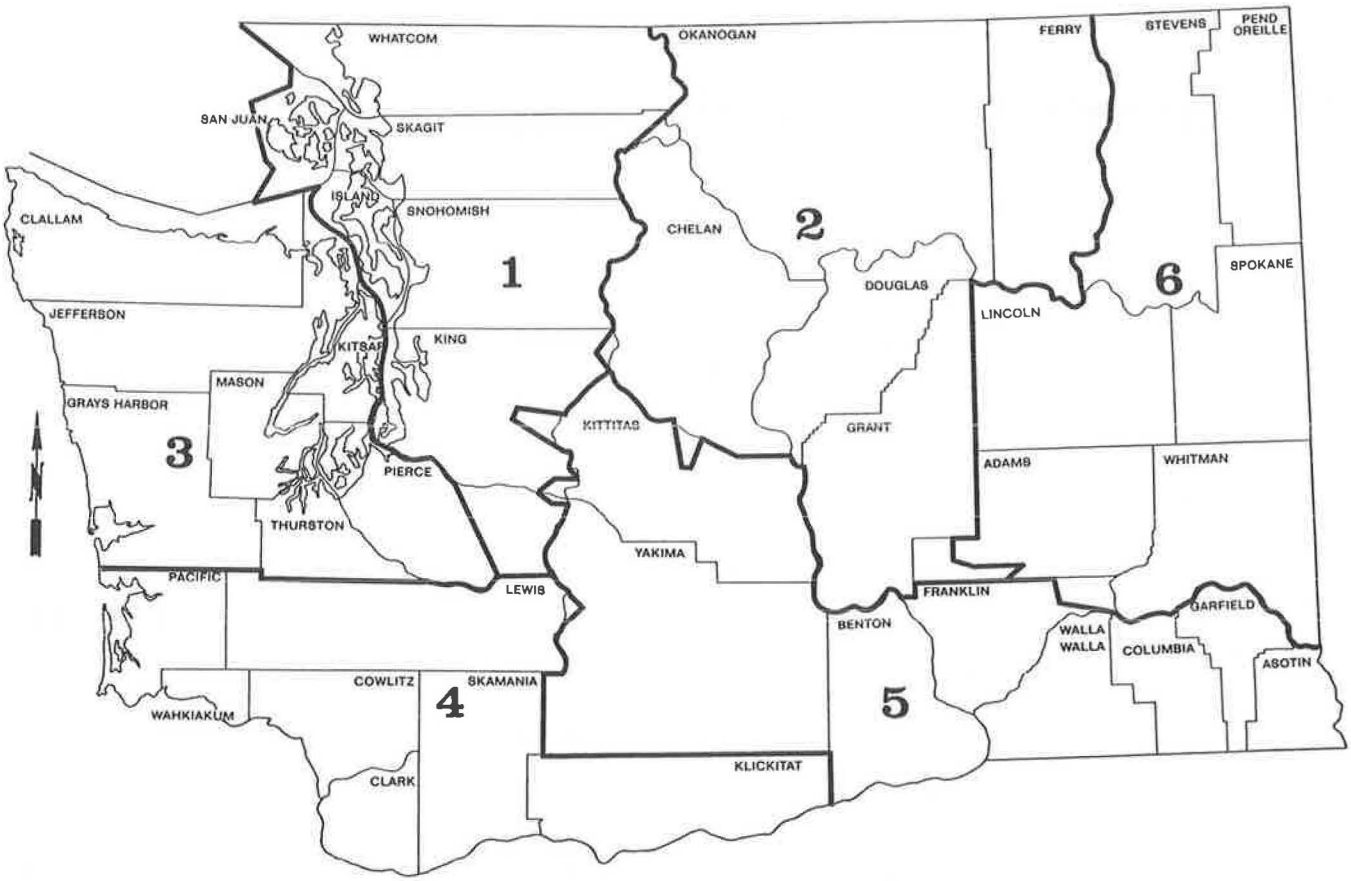


FIGURE 1 Map of Washington State showing the six transportation districts.

6. Brooming should be accomplished as soon as possible after the emulsion has set up: brooming can usually be accomplished the morning after the shot. The existing specification called for final brooming after 5 days.

7. Where embedment is low and there are signs of chip loss after brooming or exposure to traffic, a fog seal of CSS-one asphalt emulsion can be used to increase embedment and eliminate or reduce winter chip loss.

In spring 1986, these guidelines were reviewed with the project engineers and inspectors assigned to major chip seal projects that summer. The direction was to implement these guidelines as much as practical on the existing projects. Embedment guidelines for emulsion application rates and pan tests for chip rates were also initiated.

As a result of additional field reviews in 1986, discussions with either front-line inspectors or project engineers or both, and a BST wrap-up meeting held in fall 1986, the BST specifications were completely revised in early 1987. The specifications changes of major impact are outlined as follows:

1. Construction requirements.
   a. Application rates.
      (1) Emulsion yields were increased, by approximately 10 percent.
      (2) Chip yields were decreased, by approximately 25 percent.
      (3) A BST preseal was added.
   b. Longitudinal joints were limited to
      (1) Center line of the roadway.
      (2) Center of the driving lanes.
      (3) Edge of the driving lanes.
   c. In lieu of repairing joint defects, the engineer, at his or her option, could deduct $200 for each defective joint.
   d. To mitigate emulsion undersprays and gaps, a minimum of 100 gal of material was required to remain in the distributor at the end of each application.
   e. The maximum allowable time between the placement of emulsion and chips was limited to 3 min.
   f. All chip stockpiles must be watered down to provide uniformly damp material at the time of placement. It is preferable that the stockpiles be watered down the night before placement to ensure a surface damp, not wet, aggregate during placement.
   g. Rollers.
      (1) A minimum of 3 rollers were required.
      (2) Two pneumatic-tired rollers were required for the coarse aggregate.
      (3) The third roller that provides the final rolling must be a smooth steel wheel for multiple application seals used for new construction and a pneumatic for single-application seals.

(4) Maximum roller speed was set at 5 mph.

h. The fine chips (chokestone) must be applied with spreading equipment immediately following the initial rolling of the coarse chips.
i. Brooming was required before 10 a.m. the following morning.
j. The existing 5-day brooming requirement was deleted.

2. Correction of defects: provided for a CSS-1 fog seal if necessary. The field personnel were instructed to check the chip embedment into the emulsion and, if the embedment were less than 50 percent or there were signs of chip loss, then the fog seal should be ordered.

The authors again spent time in summer 1987 visiting BST projects throughout the state. The revised specifications were explained to field personnel, both WSDOT and contractor, along with more emphasis on simple quality control checks like the "pan test" (*3*) for predicting chip yields and embedment checks for monitoring chip retention. Another BST wrap-up meeting was held in fall 1987. The specifications were fine tuned as outlined as follows:

1. Construction requirements.
   a. Brooms must be motorized with a positive means of controlling vertical pressure.
   b. On new construction, the need to loosen the upper half inch of material prior to prime coat application was limited to cutback asphalts only.
   c. Some of the emulsion and chip application rate bands were broadened to more accurately reflect actual practice.
   d. The maximum allowable time between the placement of emulsion and chips was reduced to 1 min; however, the engineer may increase this time if field conditions warrant.
   e. A second spreader box was required to place the choke.
   f. Provide for remobilization of equipment to rebroom areas designated by the engineer.
   g. Asphalt for fog seal.
      (1) The application rate was decreased.
      (2) Dilution with water is required at the rate of one part water to one part emulsified asphalt.
   h. An "additional brooming" item was added.

In 1988, communications between headquarters and the district continued. Also, a video on BST construction and inspection practices was produced and made a part of the construction inspection training program.

The recent specification changes and central office involvement in the BST process have positively affected the quality of our chip seals. These strategies have also markedly reduced the chip loss and windshield damage on each project. For example, WSDOT now documents somewhere between 2 and 10 windshield complaints per project. This is contrasted with earlier projects, where the number of broken windshields occasionally exceeded 200.

STUDY ELEMENTS AND PLAN OF ACTION

In light of adverse publicity generated by some western Washington chip seals constructed in 1988, there was a perception that chip seals might not be appropriate for that side of the state because of the cooler climate and greater traffic volumes. It was decided to look into the details of the most recent west side chip seal projects to determine if the chip seal program should continue in western Washington.

The authors formed the nucleus of a chip seal review team. Nine BST projects were targeted for review. These projects, two in District 1, two in District 3, and five in District 4, were constructed in 1987 and 1988. Figure 2 is a map of western Washington showing the study areas.

Information was collected three ways:

1. Meetings were held with each district staff to discuss their individual experiences with BST projects, both good and bad.
2. A questionnaire was sent to each project engineer involved with the work. The completed questionnaires provided information on application rates, chip yields, equipment used, construction procedures, and other important performance data. Figure 3 is a graph showing chip and emulsion yields. Table 1 lists project information. Table 2 recaps the questionnaire data.
3. In spring 1989, each project was field reviewed by at least one member of the study team. In most cases, either district construction or maintenance personnel or both often participated in the field reviews. A post-construction evaluation form was completed for each project. The field reviews gave the study team members an excellent opportunity to look at past work and think about the future direction of west side chip seals. Table 3 recaps information gathered during the post-construction evaluations.

FINDINGS AND CONCLUSIONS

On the basis of field reviews, discussions with the districts, and analyzing information received, the authors came to the following conclusions:

Flushing

Flushing or fat spots exist when either surplus emulsion migrates over the top of the seal coat chips or the chips are pushed into existing fatty pavements. In some cases, the seal coat chips ravel away from the emulsion, again leaving a flushed surface. Among the causes of flushing found are:

1. Bleed throughs: existing flushed pavements and cold mix patches have a strong tendency to migrate through chip seals, producing "reflective flushing."
2. Too much emulsion: if the emulsion application rates are too heavy or a fog seal is used when it is not needed, then the seal will flush.
3. Improper construction of transverse joints: if building paper is not used at transverse joints, the joints will often receive a double application of asphalt, causing almost immediate flushing, which may be tracked down the roadway.
4. Allowing emulsions to break before applying chips: once the emulsions break, chip retention is minimal, resulting in areas of uncovered emulsion and a flushed pavement.

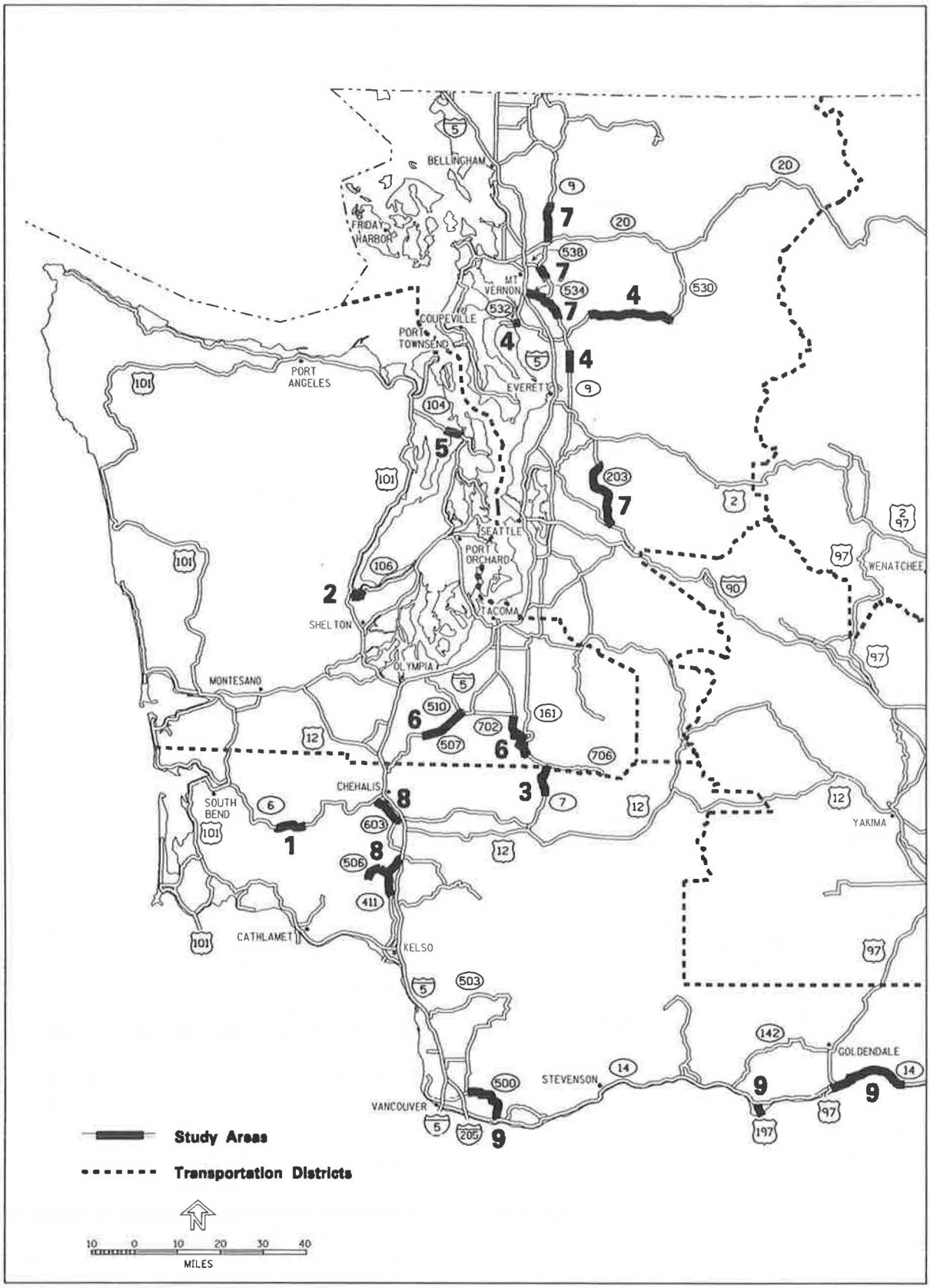
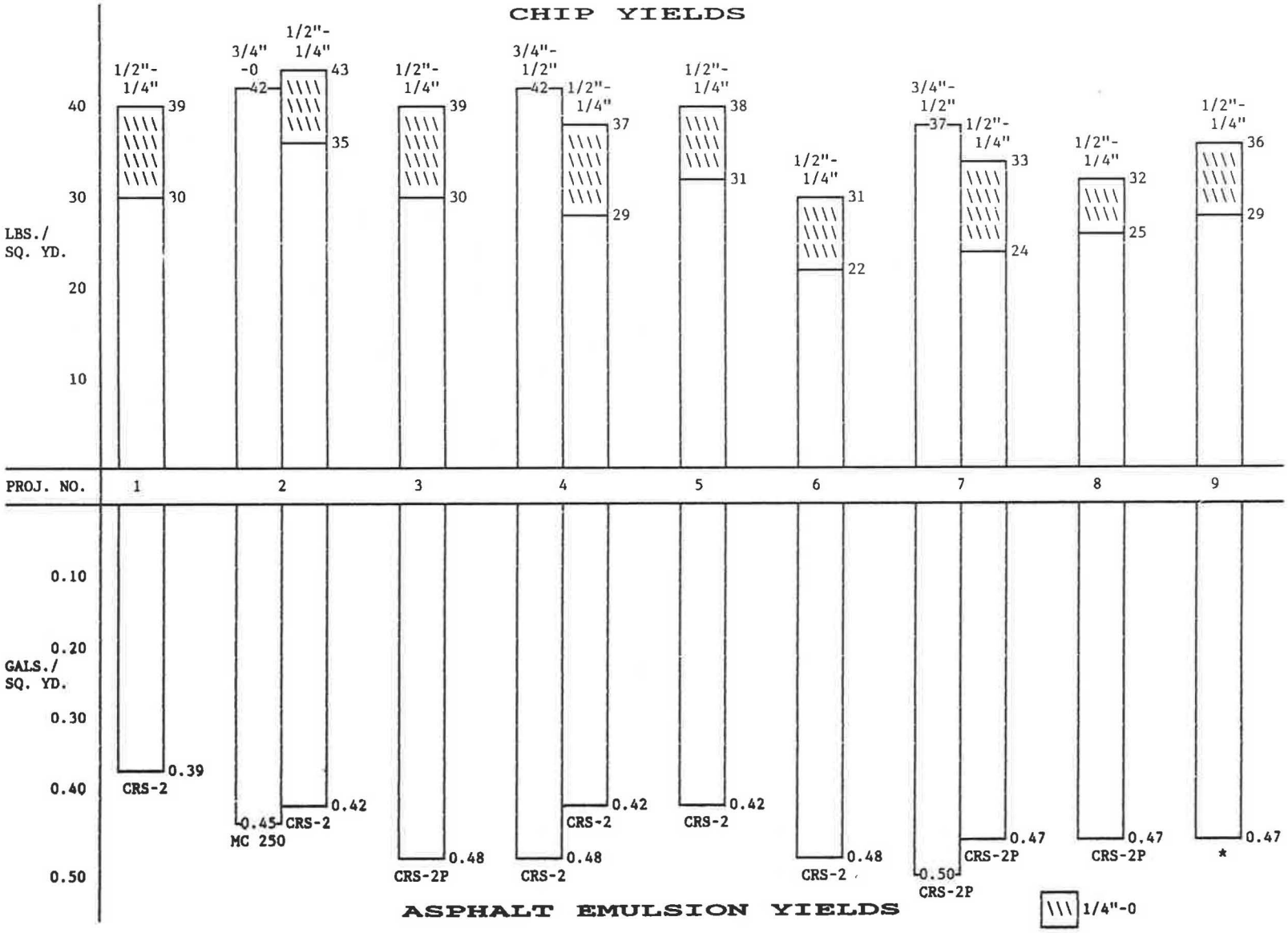


FIGURE 2 Map of western Washington showing study areas.



* CRS-2P USED ON SR 500 (WESTERN WASHINGTON)
CRS-2 USED ON SR 14 AND SR 197 (EASTERN WASHINGTON)

FIGURE 3 Graph of chip and emulsion yields.

TABLE 1 PROJECT INFORMATION

PROJECT NUMBER	PROJECT	DISTRICT	SR NO.	CONST. PERIOD
1	CONTRACT 3122 FRANCES TO ROCK CR.	4	6	JULY
2	CONTRACT 3205 SKOKOMISH RIVER BR. 106/2	3	CO.RD.	AUG.
3	CONTRACT 3235 MP 6.24 TO PLEASANT VALLEY RD.	4	7	JULY
4	CONTRACT 3249 DISTRICT WIDE SEAL - NORTH	1	9 530 532	JULY-AUG.
5	CONTRACT 3308 SR 101 TO HOOD CANAL BR.	3	104	JULY
6	CONTRACT 3318 RAINIER TO YELM ALDER TO SR 702	3	7 507	AUG.-SEPT.
7	CONTRACT 3415 DISTRICT 1 CHIP SEAL - 1988	1	9 203 528 534	JULY-AUG.
8	CONTRACT 3444 DISTRICT 4 CHIP SEAL NORTH - 1988	4	411 506 603	AUG.
9	CONTRACT 3459 DISTRICT 4 CHIP SEAL SOUTH - 1988	4	14 197 500	AUG.

5. Improper crack sealing techniques and/or materials: the study team saw evidence of previous crack sealed areas bleeding through the seal coats. "Band-aid"-type crack seals (those with an excess of material on the pavement) almost always bleed through. Also crack sealing materials that do not meet the Specifications for Concrete Joint Sealer, Hot Poured Elastic Type (ASTM D-1190), have a tendency to bleed.

Flushing is inherent in the BST process and will be difficult to completely eliminate. However, there are certain things that can be done to mitigate flushing:

1. Prepaving evaluations: by use of the video road logs or preferably field reviews, the existing roadway surface can be evaluated prior to constructing the seal coat. If areas of ¼ mi or longer are either too rich or too dry, the emulsion application rates should be adjusted to fit the field conditions. Smaller areas of dry pavement can be corrected by fog sealing prior to placing the normal chip seal.

2. Embedment checks: this simple process should be used several times a day to determine the depth of emulsion around the chip. One should typically look for about 50 percent embedment after initial rolling and about 70 percent after two or more weeks of traffic. The emulsion application rates should be adjusted to achieve proper embedment.

3. Judicious use of fog seals: the specifications provide for a fog seal if necessary to add additional emulsion to the system. If a fog seal is applied when not warranted, then flushing will follow. Embedment checks should be made to determine the need for a fog seal.

Raveling

Raveling is the loss of chips from the seal coat. Chip loss can occur immediately after chip placement or, in some cases, months later by snow plow blades. One of the most undesirable effects of raveling is continued windshield damage. Some of the causes of raveling are listed:

1. Dry or open pavements: these pavement absorb some of the emulsion intended for the new seal coat, leaving a shortage of emulsion on the surface to embed the new chips.
2. Hot mix patches: recently laid hot mix patches also readily absorb emulsion in much the same manner as dry or open pavements.
3. Shaded areas: chip loss appears to be greater in shaded areas, all other things being equal.
4. Too many chips: chips placed more than one rock deep are wasted. Worse yet, most of the excess chips will leave the roadway, taking some emulsion with them. Further, the excess chips break windshields.
5. Chips too wet or dirty: chips containing either more than 1 percent 200 material or too much moisture will not be properly bound by the emulsion.
6. Allowing emulsions to break before applying chips: once the emulsion breaks, chip retention is minimal, resulting in both excessive raveling and windshield damage.
7. Late season work: any BST work performed after August 15 in western Washington will have a strong potential for raveling and early failure. Late season work does not provide for adequate cure and increased embedment of chips under traffic. The field reviews substantiated this. The projects with the lowest ratings were constructed after August 15.

The following steps can be taken to mitigate ravelings:

1. Use of preseals: a preseal is a light application of emulsion (0.15 to 0.20 gal/yd^2) followed by a light application of ¼ in.- 0 chips (8 to 15 lb/yd^2). When constructed prior to placement of the seal coat over pavements that are dry, cracked, open, or have had recent hot mix patches, the preseal provides a more uniform and less porous surface. This also results in a more consistent final product. The preseal also provides a cost effective crack seal when the existing pavement has excessive alligator cracking.
2. Embedment checks: see discussion under "Flushing."
3. Prepaving evaluations: see discussion under "Flushing." Also, the application rates should be increased in heavily shaded areas.

TABLE 2 QUESTIONNAIRE RESULTS

PROJECT NO.	SR NO.	TRAFFIC ADT	TRAFFIC % TRUCKS	CONST. TEMP MAX	CONST. TEMP MIN	POLYMER USED	OIL TO ROCK TIME (1)	CHOKE-STONE USED	AGG. TO CHOKE TIME (2)	TRAFFIC PILOTED (HRS.)	ROADWAY SWEPT	ADJUST-MENTS MADE (3)	HOW (4)	PAN TEST	EMBED-MENT CHECK	HOW OFTEN	WINDSHIELD INFO COM-PLAINTS (6)	WINDSHIELD INFO MORE OR LESS (7)	WINDSHIELD INFO HOW MANY (8)	FOG SEAL
1	6	1150	12	75	58	NO	3 MIN	YES	2 HRS	2	2 HRS	NO	---	YES	YES	4/DAY	30	---	---	YES
2	CO.RD.	---	---	70	60	NO	5 MIN	YES	4 HRS	10	24 HRS	YES	FIELD REVIEW	YES	YES	500 FT	---	---	---	NO
3	7	---	---	85	60	YES	1 MIN	YES	5 MIN	2	NEXT DAY	NO	---	YES	YES	CONSTANT	0	LESS	30	NO
4	9 530 532	6000 3700 9100	7 13.5 2	84	60	NO NO NO	2 MIN	YES	5 MIN	24	NEXT DAY	NO	---	NO	YES	4/DAY	200	MORE	100	YES
5	104	7600	12	80	60	NO	2 MIN	YES	1.5 HRS	6.5	NEXT DAY	NO	---	YES	NO	---	0	---	---	NO
6	7 507	2000 3200	--- ---	80	60	NO NO	1 MIN	YES	3 MIN	2	NEXT DAY	YES	FIELD REVIEW	YES	YES	CONSTANT	1	LESS	29	YES
7	9 203 528 534	6000 TO 1950 4000 TO 7200 --- 650	3.5 TO 15 10 TO 11 --- 1.5	94	60	YES YES YES YES	1 MIN	YES	20 MIN	24	NEXT DAY	NO	---	NO	YES	4/DAY	20	LESS	200	YES
8	411 506 603	1460 2050 570	9 --- ---	95	60	YES YES YES	1 MIN	YES	10 MIN	10	NEXT DAY	YES	FIELD REVIEW	NO	YES	CONSTANT (5)	3	LESS	---	YES
9	14 197 500	1200 2500 2500	14 11 5	85	60	YES NO NO	45 SEC	YES	15 MIN	10.5	NEXT DAY	YES	FIELD REVIEW	NO	YES	OFTEN	12	SAME	---	NO

(1) WHAT WAS THE MAXIMUM TIME LAPSE FROM PLACEMENT OF OIL TO PLACEMENT OF AGGREGATE?
(2) WHAT WAS THE MAXIMUM TIME LAPSE FROM PLACEMENT OF AGGREGATE TO PLACEMENT OF CHOKE?
(3) WERE OIL AND ROCK APPLICATION RATES ADJUSTED TO FIT FIELD CONDITIONS?
(4) IF (3) IS YES, HOW?
(5) ALSO, A HAND PUSH BROOM WAS USED TO DETERMINE QUANTITY OF EXCESS AGGREGATE.
(6) NUMBER OF COMPLAINTS PER PROJECT.
(7) WERE THE WINDSHIELD DAMAGE COMPLAINTS MORE OR LESS THAN IN RECENT YEARS?
(8) HOW MANY MORE OR LESS?

TABLE 3 POSTCONSTRUCTION EVALUATIONS

PROJECT NO.	SR NO.	POLYMER USED	POST SEAL CONDITION [0-10]	AGGREGATE LOSS (%)				BLEEDING (%)				AGGREGATE EMBEDMENT (%)				SEE COMMENT	COMMENTS
				OUTER WHEEL PATH	INNER WHEEL PATH	BETWEEN WHEEL PATHS	CENTER-LINE	OWP (1)	IWP (2)	BWP (3)	CTL (4)	OWP (1)	IWP (2)	BWP (3)	CTL (4)		
1	6	NO	FAIR [6]	<5	<5	<5	<5	5-25	<5	<5	<5	80	80	70	70	(5),(6)	(1) OUTER WHEEL PATH.
																	(2) INNER WHEEL PATH.
																	(3) BETWEEN WHEEL PATHS.
2	CO.RD.	NO	FAIR [4]	5-25	5-25	5-25	5-25	<5	<5	<5	<5	<50	<50	40	40	(7),(8) (9)	(4) CENTERLINE.
																	(5) POT HOLES AND POP OUTS FROM COLD PATCHES.
3	7	YES	GOOD [7]	<5	<5	<5	<5	<5	<5	<5	<5	85	85	75	75	(10)	(6) BLEEDING IN AREAS OF COLD PATCHES.
																	(7) VARIABLE ROCK LOSS.
																	(8) DEFINITE STREAKING OF EMULSION.
4	9	NO	GOOD [10]	<5	<5	<5	<5	<5	<5	<5	<5	70	70	65	65	(11)	(9) ROCK LOSS APPEARS DUE
	530	NO	FAIR [4]	<5	<5	<5	<5	5-25	5-25	<5	<5	90	90	75	75	(12)	TO LOW EMULSION RATES
	532	NO	GOOD [9]	<5	<5	<5	<5	<5	<5	<5	<5	75	75	65	65	(13)	AND LOTS OF SHADE.
																	(10) NO DIFFERENCE BETWEEN THE CRS-2P & THE CONTROL SECTIONS OF CRS-2.
5	104	NO	GOOD [8]	<5	<5	<5	<5	<5	<5	<5	<5	70	70	70	70	(14) (15)	(11) ALTERNATE ROUTES WERE AVAILABLE TO TRAFFIC.
																	(12) LOSS OF 3/4"-1/2" AGG. 200 WINDSHIELD
6	7	NO	FAIR [3]	<5	<5	<5	<5	>25	>25	<5	<5	95	95	85	85		COMPLAINTS.
	507	NO	FAIR [4]	<5	<5	<5	<5	5-25	5-25	<5	<5	90	90	75	75		(13) TRAFFIC DELAYS WITH NO BYPASS ROUTES CAUSED CONSIDERABLE PR PROBLEMS.
7	9	YES	GOOD [9]	<5	<5	5-25	5-25	<5	<5	<5	<5	60	60	50	50	(16)	(14) MAINTENANCE HAS PATCHED
	203	YES	GOOD [9]	<5	<5	<5	<5	<5	<5	<5	<5	75	75	60	60		SEVERAL FLUSHED AREAS.
	528	YES	GOOD [9]	<5	<5	<5	<5	<5	<5	<5	<5	65	65	55	55		(15) REPORTED DELAY BETWEEN
	534	YES	GOOD [9.5]	<5	<5	<5	<5	<5	<5	<5	<5	65	65	60	60	(17)	SPREADER AND DISTRIBUTOR ALLOWING OIL TO FLOW INTO RUTS-1000' OR MORE DELAY
																	(16) MINOR CHIP LOSS IN SHADY AREAS.
8	411	YES	GOOD [8]	<5	<5	<5	<5	<5	<5	<5	<5	75	75	65	65	(18)	(17) PAVEMENT WAS IN VERY GOOD
	506	YES	GOOD [8]	<5	<5	<5	<5	<5	<5	<5	<5	75	75	65	65	(18)	CONDITION PRIOR TO
	603	YES	GOOD [9]	<5	<5	<5	<5	<5	<5	<5	<5	75	75	65	65		CHIP SEAL.
																	(18) MOST JOINTS SHOW THE DOUBLE APPLICATION OF OIL
9	14	YES	GOOD [10]	<5	<5	<5	<5	<5	<5	<5	<5	65	65	60	60	(19)	THAT IS INHERENT WITH NOT
	197	NO	GOOD [7]	<5	<5	<5	<5	<5	<5	<5	<5	70	70	50	50		USING PAPER AT THE JOINTS
	500	NO	GOOD [8.5]	<5	<5	<5	<5	<5	<5	<5	<5	65	65	60	60	(19)	(19) VERY UNIFORM SEAL.

TABLE 4 GRADING REQUIREMENTS

PASSING SIEVE	Crushed Screening Percent Passing				
	3/4"-1/2"	1/2"-1/4"	3/8"-#10	1/4"-#10	1/4"-0"
1" square	100	---	---	---	---
3/4" square	95-100	---	---	---	---
5/8" square	---	100	---	---	---
1/2" square	0-20	95-100	100	---	---
3/8" square	0-5	---	90-100	100	100
1/4" square	---	0-15	50-75	70-100	90-100
U.S. No. 10	---	0-3	0-10	10-60	30-60
U.S. No. 40	---	---	---	0-2	---
U.S. No. 100	---	---	---	0-1	---
U.S. No. 200	0-1.0	0-1.0	0-1.0	---	0-10.0
% fracture, by weight, min.	75	75	75	75	75

All percentages are by weight.

The fracture requirement shall be at least one fractured face and will apply to material retained on each sieve size No. 10 and above if that sieve retains more than 5 percent of the total sample.

The finished product shall be clean, uniform in quality, and free from wood, bark, roots, and other deleterious materials.

Crushed screenings shall be substantially free from adherent coatings. The presence of a thin, firmly adhering film of weathered rock shall not be considered as coating unless it exists on more than 50 percent of the surface area of any size between successive laboratory sieves.

The portion of aggregate for bituminous surface treatment retained on a 1/4-inch sieve shall not contain more than 0.1 percent deleterious materials by weight.

4. Chip and emulsion rates: the initial chip yield can be determined by hand spreading the chips one stone deep in a flat pan to calculate a pound per square yard application rate. Field embedment checks should be used either to verify, adjust, or verify and adjust asphalt application rates.

5. Judicious use of fog seals: see discussion under "Flushing."

6. Timely application of chips: the area covered by a spread of emulsion must be covered with chips before the emulsion breaks. The standard specifications now state, "within 1 minute."

7. Timing of contracts: BST work should be performed between May 15 and August 15. There was a consistent pattern of poor success with late season work. Strong consideration should be given to establishing a cutoff date for advertising BST projects—such as "no later than March 1." This would accomplish the following: (a) Provide lead time for crushing to ensure that all BST work is completed on August 15, (b) allow successful bidders to schedule their state and county work in a rational manner, and (c) reduce the raveling and early failure problems often associated with late season work.

Political Pressure and Public Relations

The BST process, with its associated traffic delays, dust, flying chips, windshield damage, flushing, and raveling is an inconvenience to the traveling public that can become an administrative nightmare. Also, bicyclists have complained of the rough ride BST presents. It is interesting to note that of all the projects studied by the review team, the project that suffered the most negative public criticism was one of the better constructed. The public image of BST projects can be improved by

1. Cutting down on dust: a $\frac{1}{4}$ in. No. 10 material can be used for choke in lieu of the currently specified $\frac{1}{4}$ in- 0. This clean material will virtually eliminate the dust problem.

2. By using Class D ($\frac{3}{8}$ in.- No. 10 chips) seals on routes with heavy bicycle traffic: Class D seals provide a smoother, more uniform surface than the standard Class C ($\frac{1}{2}$ to $\frac{1}{4}$ in. chips) seal. The result is usually a more pleasant ride for bicyclists.

3. Use of polymer emulsions for better chip retention: polymer emulsions are now specified for all west side chip seal work. This practice should be continued. Experience to date shows polymers offer the following advantages over normal emulsions: less windshield damage, better chip adhesion, less chip loss due to brooming, open to traffic earlier, seals alligatored areas better, and helps to fill and bond thermal cracks.

4. Enhancing traffic control: it is important to keep traffic flowing and disruptions to a minimum. Better enforcement (possibly hiring off-duty law enforcement personnel) will keep motorists from running the flagging stops. Also, the hours and days of work in areas of high peak hour traffic or weekend recreational use should be restricted by special provision.

Impacts of Traffic and Trucks

Generally, more construction quality, windshield damage, and public regulation problems were evident on the routes with either high average daily traffic counts (ADTs) or truck percentages or both. To make BST programs more cost effective and palatable to the traveling public, other methods of system preservation should be considered when the ADT exceeds 5,000 and/or the truck percentage exceeds 15 without regard to ADT levels between 2,000 and 5,000 vehicles per day.

Inspection Procedures

Skilled and experienced inspectors are a key element in a quality BST program. Listed are some things that can be done to keep the quality of our BST inspection at a high level:

1. Consider using maintenance people who have extensive experience placing BST as inspectors on chip seal projects.
2. Provide inexperienced project people with preconstruction training.
3. Provide someone with extensive chip seal experience to work with the inexperienced crews the first day or two of chip seal construction.
4. Continue with central office support and review of the BST program.
5. Continue with the BST module in the construction inspection training program.
6. West side construction inspection trainers may need to gain more hands-on experience with chip seals.

RECOMMENDATIONS

The conclusion of the chip seal review team is that BST construction is a cost effective, viable method of system preservation. The chip seal program should continue in western Washington at about its current level. Improvements will be seen to both equipment and personnel training as the contractors gain more experience and the BST program continues on the west side. Also, WSDOT inspectors are becoming more proficient and are able to identify and correct substandard construction practices and equipment.

As part of the ongoing effort to improve the quality of the BST product, the following recommendations are presented:

1. Continue using polymerized emulsions for all west side seal coat work.
2. Continue strong central office support and review of the BST program.
3. Consider using maintenance people with strong BST experience as chip seal inspectors.
4. Consider establishing March 1 as cut-off date for advertising BST projects.
5. Consider using a clean $\frac{1}{4}$ in.-No. 10 chips for choke in areas where dust will be a problem.
6. Consider using Class D ($\frac{3}{8}$ in.-No. 10 chips) seals in areas of heavy bicycle traffic to provide a smoother, more uniform surface.
7. Consider using system preservation methods other than BST on sections that can be considered high risk from a traffic standpoint, particularly where there is no diversion route. High-risk level seems to be ADTs in excess of 5,000 and/or truck percentages greater then 15 percent within the 2,000 to 5,000 ADT range. WSDOT, in concert with the asphalt cement and asphalt paving industries, is working on an intermediate treatment (somewhere between ACP Class G and BST) that uses softer base asphalts with polymers and is placed with conventional paving equipment. This innovative thinking should be encouraged.

On the basis of the performance to date of the nine chip seal projects studied and the anticipated improvements to BST quality that will be brought about by implementation of these recommendations, it can be reasonably predicted that chip seals will provide a performance period of at least 5 years. The seals should therefore be eligible for federal aid financing in accordance with the current FHWA Pavement Management and Design Policy (FHPM 6-2-4-1).

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