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State-of-the-Practice in Chip Seal, Slurry Seal, Micro Surfacing, and Thin Lift Asphalt Overlay Construction Quality Assurance

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Nevada Department of Transportation

1263 South Stewart Street

Carson City, NV 89712

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16. Abstract
This project summarizes current quality assurance "best" practices used by selected public agencies for constructing successful Chip Seal, Slurry Seal, Micro Surfacing and Thin Lift Asphalt Overlay pavement preventive maintenance treatments. These practices are considered "best" practices, as such practices, when adhered to, lead to long-lasting and high-quality preventive maintenance treatments. A key finding from this study was the appreciable difference in practices with changes in climate zones, particularly for Chip Seals. The main difference was observed in the type of asphalt binder to be used. There were also several similarities between the treatments, particularly between the micro surfacing and slurry seal treatments. Another key area of importance was the apparent inconsistency in specifying calendar date limits for construction for some agencies, even ones that would encounter undesirable weather conditions. This finding indicates that either dates need to be specified for increased treatment performance, or that there are some practices that are in place that may not be in the specifications—or noted during interviews—but can still lead to quality preventive maintenance treatments. Differences in the equipment specification details existed between agencies. Some agencies indicated extensive method specification details, whereas others indicated more broad specification details. Further, while the construction process itself was similar among the agencies for each treatment, the inspection processes followed by each of the agencies for all four treatments showed remarkable diversity in the actual process followed and the general requirements for inspection, including test strip requirements. Some agencies did not require test strips at any time before, during, or after construction. Some agencies determine opening to traffic times based upon the type of roadway that was treated, which seems to take the effect of traffic into consideration.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ACRONYMS

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACBFS	Air-Cooled Blast Furnace Slag
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
APA	Asphalt Pavement Analyzer
AR	Asphalt Rubber
ASTM	American Society for Testing and Materials
BOL	Bills of Lading
Caltrans	California Department of Transportation
CCS	Crushed Carbonate Stone
cm	Centimeter(s)
CRM	Crumb Rubber-Modified
CSSA	California Chip Seal Association
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FWD	Falling Weight Deflectometer
gal	Gallon(s)
G_{mm}	Theoretical Maximum Specific Gravity
G_{mb}	Bulk Specific Gravity of the Mix
HMA	Hot Mix Asphalt
IA	Independent Assurance
IS	Information Series
ISSA	International Slurry Surfacing Association
JMF	Job-Mix Formula
kg	Kilogram(s)
lb	Pound(s)

MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
mph	Miles per Hour
N	Newton
MTV	Material Transfer Vehicle
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technologies
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal Maximum Aggregate Size
oz	Ounce
ODOT	Ohio Department of Transportation
psi	Pounds per square inch
ppm	Parts-Per-Million
PWL	Percent Within Limits
QA	Quality Assurance
QC	Quality Control
QCP	Quality Control Plan
RAP	Recycled Asphalt Pavement
SBR	Styrene-Butadiene-Rubber
SBS	Styrene-Butadiene-Styrene
SHA(s)	State Highway Agency(ies)
SMC	Schedule for Materials Control
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
UNR	University of Nevada, Reno
US	United States
VDOT	Virginia Department of Transportation
VMA	Voids in Mineral Aggregates

WMA	Warm Mix Asphalt
yd	Yard

CHAPTER 1 INTRODUCTION

The investment in public roads in the United States (US) is estimated to be $100 billion with an additional $7 billion spent annually on road maintenance activities.[1,2] This investment has been made because the roadway network is critical to the national economy and quality of life for the estimated 323 million people living in the US.[3] One of the most effective methods to extend pavement life is utilizing proper preventive maintenance and rehabilitation strategies. Routine preventive maintenance work is performed on roadways that are ideally still in relatively good condition. Pavement preventive maintenance strategies include surface treatments which improve or maintain the roadway's functional performance. These treatments include Chip Seal, Slurry Seal, Micro Surfacing, and Thin Lift Asphalt Overlay. For these preventive maintenance treatments to positively impact pavement performance, certain practices must be followed. Key items that must be considered for successful preventive maintenance treatment experiences include proper:

- Project selection—applying the right treatment to the right project at the right time;
- Materials selection and design—higher quality materials lead to longer treatment life; and
- Construction procedures—properly-constructed treatments last longer than poorly-constructed treatments.

While the procedure for accomplishing project selection is not often listed in agency specifications, most do include materials selection, design, and construction requirements. During the literature review phase of this project, it was observed that many agencies have extensive materials and construction specifications, but several do not have robust quality assurance (QA) practices in the agency specifications. Pavement preventive maintenance treatment performance is highly dependent on proper QA practices.

The objective of this project is to identify, and document QA pavement preventive maintenance treatment state-of-the-practice items that are successfully used by leading state highway agencies (SHAs) throughout the US. Leading agencies are those with extensive history in the successful use of specific pavement preventive maintenance treatments. Initially, the project scope was limited to chip seal, slurry seal, and micro surfacing pavement preventive maintenance treatments only. However, the thin lift asphalt overlay treatment was added, as this treatment has similar functional performance goals as the other three treatments. It is important to note that although proper project selection is critical to successful preventive maintenance treatments—as will be highlighted in Section 1.3—*Summary of Literature Review*, the state-of-the-practice for proper project selection processes is beyond the scope of this project.

1.1 Project Scope

A primary objective of this project is to determine how the lead SHAs design, construct and perform QA on successful (well-performing) pavement preventive maintenance treatments. With that "state-of-the-practice" information captured, it can then be disseminated to other agencies for use in improving individual specifications, with particular interest in enhancing construction QA specification practices.

In order to meet the overall objective of this project the following steps were utilized:

- Step 1) form a national panel by selecting a variety of experts in the field,
- Step 2) host a face-to-face panel meeting,
- Step 3) create and conduct a survey of the SHAs,
- Step 4) summarize the survey findings,
- Step 5) select lead agencies for each treatment,
- Step 6) develop a summary of practices and specifications for lead agencies,
- Step 7) obtain case study documentation, and
- Step 8) develop the technical briefs and final report documents.

A panel of national experts was formed from members of transportation agencies and the asphalt industry to provide insight and guidance into how to select key construction and QA factors, to assist in creating and conducting the surveys, and for reviewing the technical brief documents and final report. The panel members included one individual from the Federal Highway Administration (FHWA), four individuals from various SHAs, one individual from a local transportation agency, two individuals from the industry, and one individual from academia.

A face-to-face panel meeting was then organized at the University of Nevada, Reno (UNR). During this meeting, the key factors affecting preventive maintenance treatment performance were identified and discussed and the format for surveying the SHAs was determined. Initially, only SHAs were to be considered in the survey. However, during the meeting, it was agreed that in order to obtain a clearer picture of all of the current preventive maintenance treatment practices, local agencies and major contractors should also be surveyed.

Due to the broad scope of agencies and contractors to be surveyed, as well as potential access to certain amounts of information, a two tiers survey was developed:

- A Tier 1 Survey that was more brief and concise which allowed to eliminate some agencies as potential lead agencies;
- A Tier 2 Survey that was more detailed and allowed for the selection of the final lead agencies.

Both surveys were sent to agencies and contractors. The Tier 1 survey was the same format for agencies and contractors. The Tier 2 survey had different formats for the agencies and the contractors. First the Tier 1 survey was sent to all of the 50 SHAs and several local agencies. Upon receiving all of the responses, the Tier 2 survey was drafted, reviewed, finalized, and sent to those entities selected from the Tier 1 survey. These surveys are discussed in more detail in Chapter 2.

Upon receiving the survey responses, and based on the analyzed data, three to four SHAs for each treatment were identified and selected. Phone interviews were then conducted with members of each agency. These interviews collected in-depth information regarding each agency's use of the pavement preventive maintenance treatments. The information that was collected included documentation from well-constructed projects that can be used in the case studies, as well as any identified state-of-the-practice or opportunities for improvement. In parallel to these interviews, the specifications for each agency were reviewed and summarized in detail in Chapter 3. Chapter 4 presents a summary of documentation that was submitted by the

agencies for use in case studies. These documents included specifications, mix design and inspection records, pavement performance records, and construction records. The overall objective of Chapter 4 is to discuss the project practices that led to quality projects for each case study, as well as to compare the project's practices to those listed in the specifications and determined from the interviews. The final task of this project involved drafting the report and the technical briefs. Each treatment will have a separate technical brief document.

1.2 Pavement Preventive Maintenance Treatment Definitions

For the purposes of this project, the following definitions were used for each preventive maintenance treatment.

- Chip Seal: "consists of a uniform spray application of an asphalt binder followed by a uniform application of a graded cover coat aggregate which is then rolled with pneumatic tire rollers over a properly prepared surface."[(4)]
- Slurry Seal: "consists of a mixture of emulsified asphalt, well-graded crushed aggregate, mineral fillers, additives and water that is properly proportioned, mixed, and uniformly spread on a properly prepared surface." [(5)] It is important to note that some slurry seal treatments may use polymer-modified emulsion.
- Micro Surfacing: "consists of a mixture of polymer-modified emulsified asphalt, mineral aggregate, water, and additives, proportioned, mixed and uniformly spread over a properly prepared surface."[(6)]
- Thin Lift Asphalt Overlay: "consists of a fine-graded asphalt surface mix 1.5 inch or less in thickness that is mixed and placed on a prepared surface."[(7)] It is important to note that while some of the literature specifies thin lift asphalt overlays as layers with a thickness of 1.5 inches or less, only agencies with a maximum thin lift asphalt overlay thickness of 1 inch or less were considered in this study.

1.3 Summary of Literature Review

A literature review was performed to determine which factors have been commonly found to contribute to pavement preventive maintenance treatment quality. Therefore, it focused on industry association guidelines and recent national-level syntheses, rather than on the literature published by individual SHAs. The literature review is structured by pavement preventive maintenance treatment type and a brief summary of common items among the treatment types is provided.

1.3.1. Chip Seal

The International Slurry Surfacing Association (ISSA) publication A165—*Recommended Performance Guidelines for Chip Seal* document discusses the recommended design guidelines for chip seal preventive maintenance treatments.[(4)] It outlines aggregate sizing, asphalt binder emulsion quality and spray application, equipment calibration, and construction practices. As will be shown later, agencies used two main categories of chip seals that were considered for this project—cold-applied and hot-applied chip seals. Cold-applied chip seals are those that use asphalt emulsion or cutbacks (the latter is less common and may be phased out entirely). Hot-applied chip seals use PG binders or other hot asphalt cements. The A165 publication only mentions cold-applied chip seals, but it is important to remind the reader that asphalt emulsion is

not the only binder type being used by SHAs. The National Cooperative Highway Research Program's (NCHRP's) Synthesis 342—*Chip Seal Best Practices* surveyed SHAs, as well as select agencies in Canada regarding the current practices followed when placing a chip seal preventive maintenance treatment.[8] It defines the diverse types of recognized chip seals (single, double, triple, etc.) and places a heavy emphasis on contracting practices, materials, construction equipment and practices, and quality control (QC) during the treatment's placement.

The California Chip Seal Association (CCSA)'s *Six Steps to a Better Chip Seal* document summarizes six identified best practices for quality chip seal construction.[9] As with the ISSA document, the primary chip seal category that was discussed was cold-applied chip seals. The six steps outlined include climate, surface preparation, traffic control, spread rates, construction techniques, and materials. Hot, dry weather is best for proper emulsion setting and curing. The road surface must be cleaned and repaired prior to application. Repairs may include filling potholes, leveling ruts, sealing large cracks, repairing broken edges, and scarifying and re-compacting and/or stabilizing an aggregate base, if necessary. The document states that if a chip seal is placed over any of these types of pavement distresses, these distresses can be expected to reappear in a brief time. Traffic should be kept under 25 mph until after the emulsion sets, and the rolling and first sweeping are completed. Spread rates must be tailored to each project. Properly adjusted and maintained equipment, proper timing, and good teamwork are all practices that ensure quality chip seals. Finally, the aggregate should be clean and dry, otherwise the emulsion won't adhere to the aggregates' surface.

1.3.2. Slurry Seal

The ISSA A105—*Recommended Performance Guideline for Emulsified Asphalt Slurry Seal* publication discusses the recommended guidelines for the design and construction of successful slurry seal treatments.[5] It discusses aggregate requirements, including size and gradation, asphalt emulsion binder grades, mineral fillers, material quality testing, construction practices, equipment calibration and project payment.

The South African Bitumen Association's Manual 28—*Best Practices for the Design and Construction of Slurry Seals* also discusses best practices for constructing quality slurry seals.[10] This document is specific to the placement of slurry seal treatments in South Africa, but there are many practices that can be applied to the various conditions that are encountered throughout the US. It outlines recommendations for slurry seal application, as well as defining slurry seal types. There is a strong emphasis on laboratory testing for material and mix design, QA and construction practices, environmental considerations—such as climate, and surface preparation.

1.3.3. Micro Surfacing

The micro surfacing literature review included a review of the ISSA A143—*Recommended Performance Guidelines for Polymer-Modified Micro Surfacing* publication.[6] This document discusses the recommended design and construction guidelines for micro surfacing treatments and outlines aggregate types and sizes, materials quality, construction practices, equipment, and climate conditions at the time of placement. The NCHRP Synthesis 411—*Micro Surfacing, A Synthesis of Highway Practice* describes surveyed SHAs practices regarding micro surfacing construction.[11] A heavy emphasis is placed on construction equipment and contracting

practices, materials, quality assurance, and project selection. The last point is summarized within the document as selecting the "right application for the right project at the right time."[11]

1.3.4. Thin Lift Asphalt Overlay

The NCHRP Synthesis 464—*Thin Asphalt Overlays* discusses a survey sent to all SHAs, a select number of industry representatives, and Canadian Provinces and Puerto Rico regarding the criteria used for selecting, constructing, and maintaining a thin lift asphalt overlay treatment for pavement preventive maintenance.[12] There is a heavy emphasis on the basic mix designs, distresses addressed using this treatment, service life, and other factors as related to the surveyed SHAs responses regarding construction practices.

The National Asphalt Pavement Association (NAPA) Information Series (IS) 135—*Thin Asphalt Overlays for Pavement Preventive Maintenance* publication defines the process of selecting and placing a thin lift asphalt overlay—which was defined as an overlay with a thickness of 1.5 inches or less.[7] It outlines points regarding project evaluation, materials selection and mix design, construction and quality control practices, and performance. Thin lift asphalt overlays can remedy bleeding, raveling, non-wheel-path longitudinal cracking, and transverse cracking distresses.[7] It is important to note that any type cracking will eventually reflect in the thin lift asphalt overlay. Thus, projects that exhibit any of these distresses may be good candidates for thin lift asphalt overlay treatments. Other distresses can be addressed if cores reveal that structural distresses are not present. For example, if rutting is a primary mode of distress, cores must show that the rutting is present only in the surface layer, as opposed to full-depth rutting. Good mix designs for thin lift asphalt overlays will specify smaller maximum aggregate sizes and higher asphalt content than thicker-lift mixes, particularly with mix designs that follow the Superpave methodology.[7] Construction and quality control practices, stockpile maintenance, volumetric properties verification, and continuous-run placement all contribute to successful thin lift asphalt overlay treatments. Finally, thin lift asphalt overlays were reported to result in extended pavement service lives, which is a key benefit to using overlays as preventive maintenance and/or rehabilitation strategies.

The National Center for Asphalt Technologies (NCAT) publication *Thin Hot Mix Asphalt (HMA) Overlays for Pavement Preventive Maintenance and Low Volume Asphalt Roads* discusses a study that details the usage, design, and performance of thin lift asphalt overlays on low-traffic-volume roads.[13] The study analyzed cost reductions using various treatments. Some details include various types of pavement preventive maintenance treatments. The study discusses both chip seals and thin lift asphalt overlays but focuses primarily on the design and application of thin lift asphalt overlays. The cost reduction analysis of thin lift asphalt overlays was examined by determining the effects of the use of warm mix asphalt (WMA) additives, recycled materials, and layer thickness reduction. The study's implications can apply to both low- and high-traffic-volume roads.

1.3.5. Common Practices

All of the treatments that were identified from the literature review included testing and using quality materials, proper mix design development, proper application and spread rates, construction equipment calibration and construction practices, and proper QA practices. Further,

all of the treatments include climate considerations, project selection, and surface preparation practices.

CHAPTER 2 SUMMARY OF SURVEYS

The first survey (Tier 1 Survey) was a nationwide brief and concise survey to help identify state and local agencies and contractors who have the most experience in utilizing and constructing each of the subject preventive maintenance treatments. The survey was designed to determine each respondent's level of experience in using/constructing Chip Seal, Slurry Seal, Micro Surfacing and Thin Lift Asphalt Overlays. SHAs, local agencies and ISSA contractor members were invited to reply. For consistency in the responses, the survey provided general definitions for each of the four preventive maintenance treatments (see Section 1.2). The following list of questions were given to agencies.

- How many years has your agency been using the following pavement treatments?
- Approximately how many lane miles of each treatment do you construct a year?
- What are your top reasons for using each pavement treatment?
- Please list 2 or 3 contractors that have worked with your agency on constructing these types of treatments?

The following list of questions were given to contractors.

- How many years has your company been constructing the following pavement treatments?
- Approximately how many lane miles of treatment do you construct a year?
- Please list the agencies for which you have constructed most projects for.

The second survey (Tier 2 Survey) was prepared for a select group of SHAs, local agencies, and contractors based on the responses from the Tier 1 Survey. A standard set of questions were prepared, and each selected agency/contractor was contacted for a one-on-one verbal survey. The first part of the survey was a review of the agency/contractor response to the Tier 1 Survey to confirm or correct those responses. The second half of the survey were a series of questions specifically directed to agencies or contractors. The agency/contractor was only asked to respond in the survey for preventive maintenance surfaces they noted in the Tier 1 Survey. The following list of questions were given to agencies.

- What are your primary selection criteria for using a Chip Seal, a Slurry Seal, Micro Surfacing or a Thin Overlay treatment?
- Do you currently have a mix design process that you refer to when designing the treatment?
- Do you currently have standard construction specifications?
- Is the treatment application/construction being done by agency or qualified contractor crew?
- If a combination of both agency and contractor crews is used, approximately how many projects/or lane-miles (%) are done by agency versus contractor crew?
- Have you noticed a difference in the early performance (e.g., early failures) between those that are done by an agency crew or a contractor crew?
- Have you noticed a difference in the overall long-term performance between those that are done by an agency crew or a contractor crew?
- What percent of your projects have problems with early failure (within 1-2 years) vs. late-stage performance loss regardless whether the work has been done with the agency crew or the contractor crew?

- What do you think might have caused the early distresses and do you have supporting information that you can share?
- Do you think early failures are related to different climatic conditions in your state?
- What key aspects of proper construction do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?
- What types of asphalt binders/emulsions do you specify?

In addition to the question above, each agency was asked about a QA program for each treatment using the following questions.

- Do you have an established Quality Assurance program?
- Who performs Quality Control for materials?
- Who performs Quality Control for Inspection including equipment?
- Who performs the Acceptance for materials?
- Who performs the Acceptance for Inspection including equipment?
- Does your Quality Assurance program include an independent assurance (IA)?
- Does your independent assurance (IA) require lab accreditation, personnel certification, and proficiency samples?
- What is the reason for not having a Quality Assurance program for your treatment?
- What areas of your Quality Assurance program do you see need improvement?

The following list of questions were given to contractors.

- Does your company conduct or contract with a consulting firm for QC testing or inspection, including equipment?
- How many early failures (within 1-2 years) have you experienced over the last five years?
- What are the primary distresses that your preventive maintenance treatments have experienced in the past?
- What you think caused the early distresses that you've identified, and do you have supporting information that you can share?
- Do you think early failures are related to different climatic conditions across the state?
- What key aspects of proper construction do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?
- What areas of the specifications do you see need improvement?

2.1 General Findings from Each Survey

2.1.1. Tier 1 Survey Results

The results of the Tier 1 Survey are discussed below. More detailed information from the first survey is summarized in Appendix A. Table 2.1 divides the responses received into state agency, local agency, and contractor for each climate zone. The table shows a lower number of responses than the bar graphs under Question 2 in Appendix A because incomplete surveys were removed as part of evaluating the responses before preparing this table. Overall, responses were submitted from 34 States. Representatives from 31 SHAs, an impressive 78 local agencies, and 35

contractors submitted responses. Agencies and contractors in wet-freeze climate had the highest participation.

Table 2.1. Responses by Climatic Zone, State, and Organization.

Climate Zone	State	State Highway Agency	Local Agency	Contractor
All				1
Dry, Freeze	ID UT WY OR WA	5	25	4
Dry, No Freeze	CA NV OK TX	2	19	5
Wet, Freeze	CT DE IL IN IA KS ME MD MA MI MN NE OH PA VT VA WV WI	19	29	17
Wet, No Freeze	FL GA HI LA MS NC SC	5	5	9
Total	34	31	78	35

Table 2.2 shows the treatment types that are most and least used by agencies in each climate zone based on the Tier 1 Survey responses. This demographic only reflects the pool of agency survey responses which is not an objective random sample. The lower portion of the table expresses the number of responses as a percentage of the total agency responses for each climate zone. For example, in the upper half of the table, 24 of 30 agency respondents in the dry-freeze climate indicated the use of chips seals which represents 80% of the respondents as listed in the lower half of the table. Chip seals dominate the dry-freeze zone with 80% of the 30 respondents indicating the use of chip seals. The use of the other three treatments by the respondents in the dry-freeze zone ranged from 43% to 57%. In the dry-no freeze zone, slurry seals were most dominant with 90% of the 21 respondents, and thin lift asphalt overlays were least dominant at only 38% of respondents using asphalt thin lifts. Two thirds of the dry-no freeze respondents were using micro surfacing and chip seals.

In the wet-freeze zone, chip seals were most dominant (83%) and slurry seals were least dominant (33%). Half of the agencies in the wet-freeze zone were using micro surfacing and two-thirds were using thin lift asphalt overlays. In the wet-no freeze zone, thin lift asphalt overlays were most dominant (90%) and slurry seals were the least dominant (30%). The use of micro surfacing and chips seals was generally strong at 80% and 70%, respectively. The highlighted values in certain cells (bolded and underlined) indicate the percent of agency responses for a treatment type that were the most and least dominate for each climate zone. The green highlighted cell, 79%, in the “Total (yes)” row indicate the largest percentage of responses from all agencies in all zones—in this case, chip seals had the largest percentage of responses.

Observations from this table can also be viewed by the use of a specific treatment across all climate zones. Based on the agency responses, slurry seals are very dominant (90%) in the dry-no freeze climate zone. Less than half the agencies in the other climate zones use slurry seal treatments. Micro surfacing is mostly used (80%) in the wet-no freeze climate and used by half of the agencies in other zones. Chip seals are used by 70% or more of the agencies in all climate

zones. Finally, thin lift asphalt overlay surfaces are very dominant (90%) by agencies in the wet-no freeze climate and least used (38%) by agencies in the dry-no freeze climate.

Table 2.2. Treatment Types Most and Least Used by Agencies in Each Climatic Zone.

Climatic Zone	Chip Seal	Slurry Seal	Micro Surfacing	Thin Lift Asphalt Overlay	Total
Total Count					
Total (yes)	86	52	59	66	109
Dry, freeze	24	14	13	17	30
Dry, no freeze	15	19	14	8	21
Wet, freeze	40	16	24	32	48
Wet, no freeze	7	3	8	9	10
Percentage of total					
Total (yes)	79%	48%	54%	61%	
Dry, freeze	**80%**	47%	**43%**	57%	
Dry, no freeze	71%	**90%**	67%	**38%**	
Wet, freeze	**83%**	**33%**	50%	67%	
Wet, no freeze	70%	**30%**	80%	**90%**	

Table 2.3 further divides the agency responses by state DOT and local agencies. There are differences in the most and least dominant surface treatments used between state DOT and local agencies. For example, the use of thin lift asphalt overlay is higher for DOTs than for local agencies. These results must be kept in perspective. Four of the eight categories (agency type and climate) have five or less total respondents such that small differences between treatment use are expressed as large differences in percentage of use. As with Table 2.2, the highlighted values in certain cells indicate the largest and smallest percentages of agency total responses for each climate zone for the four treatments. The highlighted cell in the "Total (yes)" row indicates the treatment with the highest percentage of responses from all agencies in all climate zones—in this case, the chip seal (90%) and thin lift asphalt overlay (94%) treatments are both dominant for state DOT respondents and chip seal treatment (74%) for local agency respondents.

In some cases both state DOT and local agency responses in Table 2.3 correlate well with the combined agency response in Table 2.2, such as high use of thin lift asphalt overlays in wet-no freeze climate and high use of slurry seals in dry-no freeze climate. State DOT responses alone did not correlate well in some cases due to the limited number of responses. The state DOT responses do show that micro surfacing, chip seals and thin lift asphalt overlays are all used by most State DOTs. This reflects the larger, more diverse pavement preventive maintenance programs. On the other hand, local agencies have a preferred treatment type that varies by climate. Local agencies in the dry-freeze and wet-freeze climates tend to favor chip seals, local agencies in the dry-no freeze favor slurry seals, and local agencies in the wet-no freeze climate use thin lift asphalt overlays.

Table 2.3. Treatment Types Most and Least Used by State and Local Agencies.

Agency	Climatic Zone	Chip Seal	Slurry Seal	Micro Surfacing	Thin Lift Asphalt Overlay	Total
Total Count						
State DOT	Total (yes)	28	14	24	29	31
	Dry, freeze	5	2	3	4	5
	Dry, no freeze	2	2	2	1	2
	Wet, freeze	16	9	14	19	19
	Wet, no freeze	5	1	5	5	5
Local	Total (yes)	58	38	35	37	78
	Dry, freeze	19	12	10	13	25
	Dry, no freeze	13	17	12	7	19
	Wet, freeze	24	7	10	13	29
	Wet, no freeze	2	2	3	4	5
Percentage of total						
State DOT	Total (yes)	90%	45%	77%	94%	
	Dry, freeze	**100%**	**40%**	60%	80%	
	Dry, no freeze	100%	100%	100%	**50%**	
	Wet, freeze	84%	**47%**	74%	**100%**	
	Wet, no freeze	100%	**20%**	100%	100%	
Local	Total (yes)	74%	49%	45%	47%	
	Dry, freeze	**76%**	48%	**40%**	52%	
	Dry, no freeze	68%	**89%**	63%	**37%**	
	Wet, freeze	**83%**	**24%**	34%	45%	
	Wet, no freeze	**40%**	**40%**	60%	**80%**	

The attempt was to identify at least one SHA, one local agency, and one contractor for each of the four climatic zones to cover the four preventive maintenance treatments. This was accomplished by analyzing the Tier 1 Survey responses to select agencies and contractors for the Tier 2 Surveys based on each respondent's level of experience (number of years) and amount of work (lane miles per year) for each preventive maintenance treatment type and the climate zone associated with that location. Each treatment/climate subgroup was evaluated to identify the respondent that expressed the most experience (level 3) and the highest amount of work (level 3). In many cases the respondent was selected based on the combined activity with multiple preventive maintenance treatments. The extent of coverage for each treatment was dependent on the depth of responses to the survey. Table 2.4 shows the selected agencies and contractors for the Tier 2 Survey. The legend below the table indicates the numbering convention used in the table. The response to each treatment is composed of a value for number of years used and the number of miles constructed each year. The numbers 1, 2 and 3 represent increasing use, respectively. For example, for Washington DOT, the agency indicated that it has constructed slurry seals for 20+ years and constructs 0-50 lane-miles of slurry seal treatments per year. The shading in the table is used to delineate the values from each other.

Table 2.4. Selected Agencies and Contractors for Tier 2 Survey.

Climatic Zone	State	Agency	Contractor	Chip Seal		Slurry Seal		Micro Surfacing		Thin Lift Asphalt Overlay	
				Years	Miles	Years	Miles	Years	Miles	Years	Miles
Dry, freeze	Washington	DOT	N/A	3	3	3	1			3	3
	Washington	Spokane County	N/A	3	3					1	1
	Oregon	Deschutes County	N/A	3	3						
	Oregon	City of Eugene	N/A	3	1	3	1			3	1
	Utah	N/A	Geneva Rock Products	3	2	1	1	1	3	3	2
Dry, no freeze	California	DOT	N/A	3	3	3	3	2	2	3	3
	Texas	N/A	Ramming Paving Company, Ltd	3	3	2		2	2	2	3
	California	N/A	Mission Paving and Sealing, Inc.			3	3			3	3
	California	N/A	VSS International, Inc.	3	3	3	3	3	3		
Wet, freeze	Ohio	DOT	N/A	3	2			3	2	3	3
	Virginia	DOT	N/A	3	3	3	3	3	3	2	1
	Minnesota	DOT	N/A	3	3			2	2	1	1
	Ohio	City of Columbus	N/A	3	1	3	1	3	1		
	Indiana	N/A	Pavement Solutions, Inc.			2	2	2	2		
	Iowa	N/A	LL Pelling Co.	3	3					1	1
	Maine	N/A	Lane Construction	2	1					1	2
Wet, no freeze	North Carolina	DOT	N/A	3	3	3	1	3	1	3	2
	Florida	N/A	Ranger Construction Industries, Inc.							3	3
All	All	N/A	Vance Brothers, Inc	3	3	3	3	3	3		

Legend

Years of Experience:
1 0-10 Years
2 11-20 Years
3 20+ Years

Annual Lane Miles Constructed:
1 0-50 Lane Miles
2 51-100 Lane Miles
3 100+ Lane Miles

2.1.2. Tier 2 Survey Results

The results of the Tier 2 Survey are discussed below. All six SHAs, four local agencies, and eight contractors listed in Table 2.4 responded. More detailed information from the Tier 2 Survey results is summarized in Appendix A. The agency responses to the general questions are summarized in Table 2.5. The agency QA questions and responses are summarized in Table 2.6. The contractor questions and responses are summarized in Table 2.7.

Table 2.5. Summary of Agency Responses to the General Questions of Tier 2 Survey.

Tier 2 Questions	Agency Responses
What are your primary selection criteria for using a Chip Seal, a Slurry Seal, a Micro Surfacing or a Thin Overlay treatment?	There was not a predominant criterion noted in the responses. All four criteria listed in the question were used by one or more agency for each preventive maintenance treatment.
Do you currently have a mix design process that you refer to when designing the treatment?	There was a reasonably equal split between the agency having a mix design procedure and the agency using the contractor's mix design process.
Do you currently have standard construction specifications?	A clear majority of the agencies are using a special provision as a construction specification.
Is the treatment application/construction being done by agency or qualified contractor crew?	For chip seals there was a split between agencies that had agency crews to do a nominal 50% of the construction and agencies who used contractors for all projects. For slurry seals, micro surfacing, and thin lift asphalt overlays the agencies predominantly use contractors for the projects.
If a combination of both agency and contractor crews is used, approximately how many projects/or lane-miles (%) are done by agency versus contractor crew?	This question was dropped from further consideration because the use of agency crews was very small.
Have you noticed a difference in the early performance (e.g., early failures) between those that are done by an agency crew or a contractor crew?	This question was dropped from further consideration because the use of agency crews was very small.
Have you noticed a difference in the overall long-term performance between those that are done by an agency crew or a contractor crew?	This question was dropped from further consideration because the use of agency crews was very small.
What percent of your projects have problems with early failure (within 1-2 years) vs. late-stage performance loss regardless whether the work has been done with the agency crew or the contractor crew?	The responses were mixed. There were similar number of responses to early-stage failure as there were late-stage failures.
What do you think might have caused the early distresses and do you have supporting information that you can share?	The responses were mixed. Materials and temperature were slightly more prevalent.
Do you think early failures are related to different climatic conditions in your state?	The responses were mixed. More agencies indicated that climate was a factor for chip seals and micro surfacing.
What key aspects of proper construction do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?	Verification of materials and application rates was important for all four preventive maintenance surfaces. Equipment calibration was noted for chip seals and micro surfacing. Personnel certification and surface preparation were important for thin lift asphalt overlays.
What types of asphalt binders/emulsions do you specify?	As expected, all slurry seals and micro surfacing use an emulsion and all thin lift asphalt overlays use hot asphalt binder. There was an even split between agencies using emulsion or hot asphalt binder for chip seals.

Table 2.6. Summary of Agency Responses to Quality Assurance Questions of Tier 2 Survey.

Tier 2 Questions	Agency Responses
Do you have an established Quality Assurance program?	The agencies have a QA program for each of the preventive maintenance treatments they use. Only one local agency indicated they did not have a formal chip seal QA program because the agency used its own forces.
Who performs Quality Control for materials?	Most agencies make the contractor responsible for QC of the materials.
Who performs Quality Control for Inspection including equipment?	Most agencies make the contractor responsible for the QC for inspection.
Who performs the Acceptance for materials?	As expected, the agencies perform testing for acceptance of materials.
Who performs the Acceptance for Inspection including equipment?	Most agencies perform acceptance inspection, but some will use a consultant.
Does your Quality Assurance program include an independent assurance (IA)?	Approximately two-thirds of agencies have IA for chip seals, slurry seals and micro surfacing. Over eighty percent have IA for thin lift asphalt overlays.
Does your independent assurance (IA) require lab accreditation, personnel certification, and proficiency samples?	The agencies do use laboratory accreditation, personnel certification, and proficiency samples for all four pavement preventive maintenance treatments.
What is the reason for not having a Quality Assurance program for your treatment?	As stated earlier, one local agency has its own chip seal crew and does not have a formal QA program.
What areas of your Quality Assurance program do you see need improvement?	The predominant response was a need for training the agency inspectors on the pavement preventive maintenance treatment equipment and processes.

Table 2.7. Summary of Contractor Responses to Tier 2 Survey.

Tier 2 Questions	Contractor Responses
Does your company conduct or contract with a consulting firm for QC testing or inspection, including equipment?	Most of the contractors conduct materials QC or rely on an aggregate supplier for aggregate testing and emulsion supplier for mix design. All of the contractors perform field and equipment inspection.
How many early failures (within 1-2 years) have you experienced over the last five years?	The contractors consistently responded that no or very few early (less than one percent) failures occurred. Some contractors noted the early failures were due to surface preparation, aggregate-emulsion compatibility, and emulsion quality.
What are the primary distresses that your preventive maintenance treatments have experienced in the past?	Chip loss and bleeding were the most common distress for chip seals. Raveling was the most common distress for slurry seals and micro surfacing. Reflective cracking was the most common distress for thin lift asphalt overlays.
What you think caused the early distresses that you've identified, and do you have supporting information that you can share?	The most prominent responses were the project was not suitable for pavement preventive maintenance, time of placement was too early or too late, and material quality/incompatibility.
Do you think early failures are related to different climatic conditions across the state?	Yes, a number of contractors noted that the SHA has different climate related restrictions for the north and south locations.
What key aspects of proper construction do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?	The four key aspects noted by the contractors were verification of the materials and application rates, surface preparation, equipment calibration, and certified personnel.
What areas of the specifications do you see need improvement?	Each contractor's response reflected the problems encountered in each contractor's area. The more common issues were to improve the mix design process, training for agency and contractor personnel, more agency oversight, and enforce placement temperature restrictions.

2.2 Case Studies

Based on the Tier 2 Survey responses, three agencies in each of the four climate zones were selected for an in-depth interview and consideration for case studies. The criteria used to select the agencies included the level of experience and volume of projects with a specific treatment and geographic/climate location. The initial list of selected agencies is given in Table 2.8.

Table 2.8. Initial Agency Selection for the Case Studies.

Treatment	Agencies
Chip Seal	California (Caltrans), Minnesota (MnDOT), Texas (TxDOT)
Slurry Seal	California (Caltrans), City of Columbus (Ohio), Virginia (VDOT)
Micro Surfacing	California (Caltrans), Minnesota (MnDOT), Virginia (VDOT)
Thin Lift Asphalt Overlay	California (Caltrans), Florida (FDOT), Washington (WashDOT)

After the initial selection of the agencies (Table 2.8), a further interview was conducted to obtain more detailed information regarding specific projects that could be used for drafting the case studies for each treatment. Upon contacting the agencies, Washington DOT indicated that the thin lift asphalt overlays used are at a thickness of 1.5 inches or less. For the purposes of this project, that thickness is outside the definition of the thin lift asphalt overlay adopted in this study (refer to Section 1.2). Thus, Washington DOT was excluded, and a new lead agency was needed for the thin lift asphalt overlay treatment.

After re-reviewing the results from the Tier 1 Survey, two agencies were contacted regarding thin lift asphalt overlay treatments—Michigan DOT and Ohio DOT. Both were able to provide information and project documentation to be used, so both were included for the thin lift asphalt overlay treatment. Further, an independent interview was conducted with Spokane County Public Works in Washington State regarding the county's use of chip seals. This local agency was also able to provide information, so the agency was included for the chip seal treatment. Figure 2.1 and Table 2.9 display the final agency selection for the case studies.

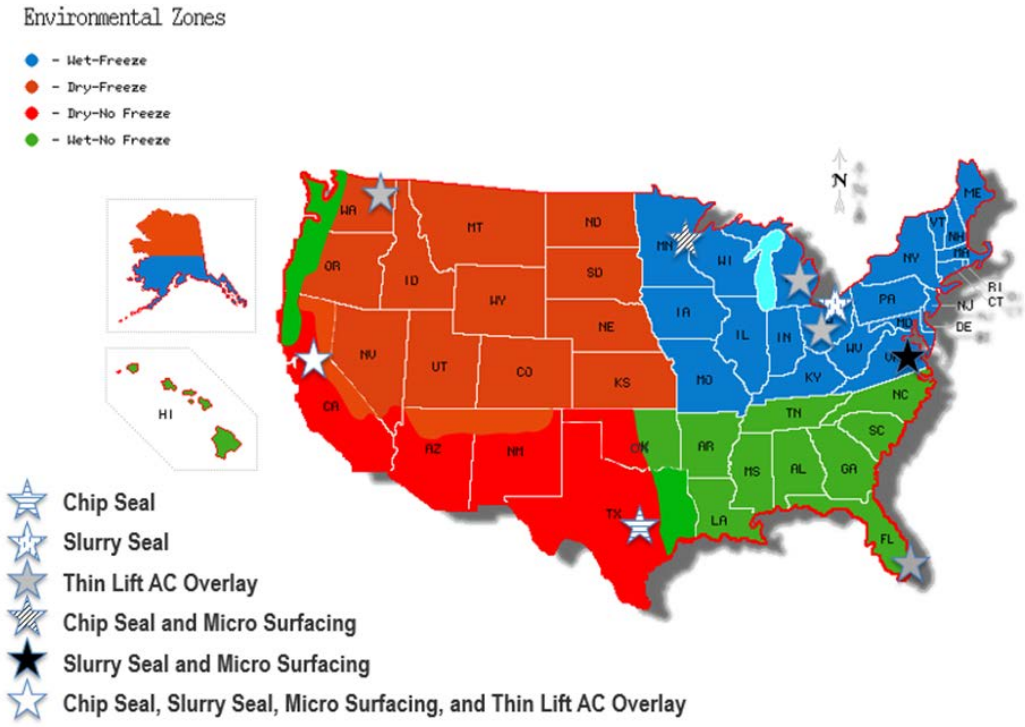

Figure 2.1. Photo. US map showing final agency selection for the Case Studies.

Table 2.9. Final Agency Selection for the Case Studies.

Treatment	Agencies
Chip Seal	California, Minnesota, Spokane County (Washington), Texas
Slurry Seal	California, City of Columbus (Ohio), Virginia
Micro Surfacing	California, Minnesota, Virginia
Thin Lift Asphalt Overlay	California, Florida, Michigan, Ohio

2.3 Additional Observations from Tier 2 Interviews

This section takes a closer look at Tier 2 responses for two key agency questions and similar contractor questions:

(1) What key aspects of proper construction do you, as an agency, notice tend to result in a successful performance with a given pavement preventive maintenance treatment?
(2) What key aspects of proper construction do you, as a contractor, notice tend to result in a successful performance with a given pavement preventive maintenance treatment?
(3) What areas of your agency Quality Assurance program do you see need improvement?
(4) What areas of the specifications do you, as a contractor, see need improvement?

The common responses are merged for each preventive maintenance treatment. Construction practices that were reported as key aspects to successful performance of chip seal, slurry seal, micro surfacing, and thin lift asphalt overlay are summarized in Table 2.10 through Table 2.13.

Table 2.10. Identified Key Chip Seal Construction Practices.

Chip Seal Construction Practice	Number of Responding Agencies
Material application rates verified by test strip	8 of 9 agencies and 4 of 4 contractors
Equipment calibration	8 of 9 agencies and 2 of 4 contractors
Surface preparation	4 of 9 agencies and 3 of 4 contractors
Specifications and QA program improvements needed	7 of 8 agencies

Table 2.11. Identified Key Slurry Seal Construction Practices.

Slurry Seal Construction Practice	Number of Responding Agencies
Material verification	5 of 5 agencies and 3 of 4 contractors
Application rates verified by test strip	2 of 5 agencies and 3 of 4 contractors
Specifications and QA program improvements needed	2 of 5 agencies and 2 of 4 contractors

Table 2.12. Identified Key Micro Surfacing Construction Practices.

Micro Surfacing Construction Practice	Number of Responding Agencies
Equipment preparation	4 of 5 agencies and 1 of 3 contractors
Materials verification	4 of 5 agencies and 2 of 3 contractors
Application rates verified by test strip	3 of 5 agencies and 3 of 3 contractors
Specifications and QA program improvements needed	4 of 5 agencies and 1 of 3 contractors

Table 2.13. Identified Key Thin Lift Asphalt Overlay Construction Practices.

Thin Lift Asphalt Overlay Construction Practice	Number of Responding Agencies
Surface preparation, including tack coat	5 of 6 agencies and 3 of 5 contractors
Qualified personnel	4 of 6 agencies and 3 of 5 contractors
Quality materials and mix design	3 of 6 agencies and 5 of 5 contractors
Specifications and QA program improvements needed	3 of 6 agencies and 1 of 5 contractors

CHAPTER 3 SUMMARY OF QA SPECIFICATIONS AND PRACTICES

3.1 Introduction

This chapter details the identified lead agencies' current standard specifications and special provisions for the construction and QA practices of all four pavement preventive maintenance treatments. The chapter begins with chip seal, continues to slurry seal, micro surfacing, and thin lift asphalt overlay treatments. It will conclude with a summary of those practices currently conducted by the agencies that were identified as being representative of the state-of-the-practice for the construction of quality pavement preventive maintenance treatments. These practices were determined from the Tier 2 agency interviews and confirmed from the specifications. It is important to note that these practices are identified from the perspective of the selected agencies.

For consistency, the following definitions are used for Quality Assurance, Quality Control, Acceptance, Inspection and Independent Assurance throughout the report *(Transportation Research Board (TRB)'s Circular E-C173).*[14]

- ***Quality Assurance (QA).*** *Involves all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service or meets specification criteria. QA includes the elements of QC, IA, acceptance, dispute resolution, laboratory accreditation, and personnel certification.*
- ***Quality Control (QC).*** *The system used by a contractor to monitor, assess and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. QC includes sampling, testing, inspection, and corrective action (where required) to maintain continuous control of a production or placement process and it may or may not be specified by the governing agency (DOT, etc.).*
- ***Acceptance.*** *The process whereby all factors used by the agency (i.e., sampling, testing, and inspection) are evaluated to determine the degree of compliance with contract requirements and to determine the corresponding value for a given product. Where contractor test results are used in the agency's acceptance decision, the acceptance process includes contractor testing, agency verification and validation, and possibly dispute resolution.*
- ***Inspection.*** *The act of examining, measuring, or testing to determine the degree of compliance with requirements.*
- ***Independent Assurance (IA).*** *IA provides an unbiased, independent verification of the reliability of the acceptance (or verification) data obtained by the agency and the data obtained by the contractor. The results of IA testing or inspection are not to be used as a basis of acceptance.*

3.2 Chip Seal Preservation Treatment

The chip seal specifications for the California Department of Transportation (Caltrans), Minnesota Department of Transportation (MnDOT), Spokane County in Washington, and Texas Department of Transportation (TxDOT) are outlined in this section. The information obtained from each agency's specifications come from the standard specifications as well as a few supplementary documents. For Caltrans, the reference material is the *2015 Standard Specifications and 2015 Revised Standard Specifications.*[15] For MnDOT, the reference

materials are the *Standard Specifications for Construction*, *Schedule of Materials Control for 2016 Standard Specifications*, and the *Seal Coat Handbook*.[16,17,18] Spokane County uses the Washington Department of Transportation's *Standard Specifications for Road, Bridge, and Municipal Construction* (2016).[19] The reference materials for TxDOT are the *Standard Specifications for Construction and Maintenance for Highways, Streets and Bridges* and the *Seal Coat and Surface Treatment Manual*.[20,21]

Some of the agencies use different names in lieu of the standard "chip seal." MnDOT and TxDOT refer to chip seals as "seal coats." To aid in clarity and consistency, all such treatments that have the definition of a chip seal will be referred to as chip seals. A chip seal, as defined in Section 1.2, "consists of a uniform spray application of an asphalt binder followed by a uniform application of a graded cover coat aggregate which is then rolled with pneumatic tire rollers over a properly prepared surface."[4] Chip seal definitions indicated in each agency's specifications are listed below:

- *Caltrans.* Defined based on type of bituminous material: "…includes applying an asphaltic emulsion—polymer-modified or not—followed by aggregate and then a flush coat." For asphalt rubber binder chip seals, defined as "applying asphalt rubber binder followed by heated aggregate pre-coated with asphalt binder followed by flush coat."
- *MnDOT.* "An application of applying bituminous material, a single layer of aggregate and a fog seal on a prepared surface."
- *Spokane County.* "This method requires the placing of one application of emulsified asphalt and one or more sizes of aggregate as specified to an existing pavement to seal and rejuvenate the surface and to produce a uniform Roadway surface with acceptable non-skid characteristics."
- *TxDOT.* "A surface treatment consisting of one or more applications of asphalt material covered with a single layer of aggregate."

3.2.1. Materials and Testing Specifications

3.2.1.a. Asphalt Binders

The Caltrans chip seal binder specification indicates the potential use of a variety of binders to accommodate the varying climates found across the state of California. Specified grades are only explicit for polymer-modified emulsion chip seals. Elastomeric polymer modified emulsion grades PMRS-2, PMRS-2h, PMCRS-2, and PMCRS-2h are indicated. Other acceptable binders are PG binders, which may be either unmodified or modified with a resinous aromatic hydrocarbon or crumb rubber. It is important to note that the only asphalt binder chip seals indicated in the Caltrans specifications are those that use crumb rubber-modified (CRM) binder.

The Caltrans specification for bituminous material quality tests indicates that the tests used depend on type of binder being used. For CRM binder, the following specification requirements apply: the blend must be 79% asphalt binder by weight, 21% CRM by weight, plus 2.5 to 6% resinous aromatic hydrocarbon by total weight of binder and rubber. The CRM must be processed according to the requirements detailed in the specifications. Table 3.1 shows the asphalt binder quality tests used by all four agencies.

Table 3.1. Chip Seal Asphalt Binder Quality Tests.

Asphalt Binder	Agencies			
	Caltrans	**MnDOT**	**Spokane County**	**TxDOT**
Unmodified Asphalt Emulsion	Saybolt-Furol Viscosity, Sieve Test, 24-hour Storage Stability, Residue by Distillation, Particle Charge, Penetration, Ductility, and Solubility.	Not specified.	Not specified.	Viscosity, the Sieve Test, Demulsibility, Distillation, Penetration, Ductility and the Float Test.
Modified Asphalt Emulsion	Unmodified emulsion tests, plus Penetration at 25°C and at 4°C, Torsional Recovery, and Ring and Ball Softening Point	Amended AASHTO M316—*Standard Specification for Polymer-Modified Emulsified Asphalt* to include Distillation and Penetration tests.[22]	Saybolt-Furol Viscosity, Storage Stability, Demulsibility, Particle Charge, Sieve Test, Cement Mixing, Oil Distillate, Penetration, Ductility and Solubility.	Viscosity, the Sieve Test, Demulsibility, Distillation, Penetration, Ductility and the Float Test.
Unmodified Binder	Not specified.	Not specified.	Not specified.	Aged Viscosity, Penetration and Virgin Viscosity.
Modified Binder	Descending Viscosity, Viscosity at 375°F, Cone Penetration and Resilience at 25°C, and Softening Point.	Not specified.	Not specified.	Aged Viscosity, Penetration and Virgin Viscosity.
Cutback	Not specified.	Not specified.	Not specified.	Viscosity, Flash Point, Distillation, Specific Gravity (for in-field temperature-volume corrections) and Penetration/Ductility.

The MnDOT chip seal specification indicates using only CRS-2P emulsion and requires that the polymer modification be done prior to emulsification—that is, the base binder is polymer-modified, rather than the final emulsion. MnDOT's specifications indicate that MnDOT recommends a fog seal be applied after a chip seal. CSS-1h or CFS-1h emulsions may be used. CSS-1h is to be diluted in a 1:1 ratio and be at least 29% residue. The CFS-1h emulsion must meet the requirements of AASHTO M208—*Standard Specification for Cationic Emulsified Asphalt*, be 29% residue or higher.[23] The standard includes requirements for the Penetration and Sieve Test. The target fog seal application rate must be between 0.05-0.10 gal/yd^2. All emulsion sampling and testing is done per the requirements of a multi-DOT collaborative known as the "Combined State Binder Group." The emulsion supplier is in charge of performing QC tests on the emulsion. Random sampling is conducted and arranged by the MnDOT Chemical Laboratory for Acceptance testing. The Spokane County chip seal specification indicates only CRS-2P emulsion for chip seals.

The TxDOT chip seal specification indicates that both paving grade asphalts and emulsions may be used for chip seals. The TxDOT Manual identifies AC-5, AC-10, AC-5 with 2% polymer, AC-15P, AC-15-5TR and Asphalt Rubber (AR) types AR-II and AR-III. It also identifies HFRS-2, MS-2, CRS-2, CRS-2h, HFRS-2P and CRS-2P emulsions. For cool weather conditions the emulsion and cutback grades RS-1P, CRS-1P, RC-250, RC-800, RC-3000, MC-250, MC-800, MC-3000 and MC-2400L may be used. When AR binder is used, the Contractor must have a design that describes the raw materials sources and properties, binder formulation, and field rubber mixing procedure. The Contractor must produce the AR binder per the approved design and, at the end of every work shift, provide the Engineer with QC production documentation that includes batch quantities, temperatures, times and viscosity measures. The TxDOT chip seal specification indicate that tests on the binders depend on the binder type.

3.2.1.b. Aggregates

The Caltrans chip seal specifications indicate chip seal aggregate types to be used are broken stone, crushed gravel or a blend of the two. The gradation to be used varies based on the type of chip seal. For both non-polymer and polymer-modified asphalt emulsion chip seals, the aggregate is *graded* only, with coarse, medium, medium-fine and fine gradations. The Maximum Aggregate Sizes (MAS) are ¾ inch, ½ inch, 3/8 inch and 3/8-inch sieves, respectively. The percentage of aggregate passing the No. 200 sieve must be between 0-2% for all four gradations and both types of emulsion chip seals. For asphalt binder chip seals, the aggregate is *graded* only, with either a coarse, medium or fine gradation. All gradations have a ¾ inch MAS. The percentage of aggregate passing the No. 200 sieve must be between 0-1% for both gradations. Table 3.2 shows the aggregate quality tests used by each agency.

Table 3.2. Chip Seal Aggregate Quality Tests.

Aggregate Test	Agencies			
	Caltrans	MnDOT	Spokane County	TxDOT
L.A. Abrasion	X	X	X	X
Percent Crushed Particles	X			
Flat and Elongated Particles	X	X		
Film Stripping	X			
Aggregate Angularity	X			X
Durability	X	X	X	
Gradation	X	X	X	X
Cleanness Value	X			
Shale Content		X		
Flakiness Index		X		X
Deleterious Material				X
Decantation				X
Dry Loose Unit Weight				X
Pressure Slaking				X
Micro-Deval Abrasion				X
Freeze-Thaw Loss				X
Water Absorption				X
Soundness				X
Bulk Specific Gravity				X
Board Test				X

The Caltrans chip seal specifications indicate that pre-coated aggregate must be used for asphalt rubber binder chip seals. The Caltrans specification for pre-coated aggregate indicates that the pre-coating operation must be done at a *Material Plant Quality Plan*-authorized central mixing plant, without re-combining collected fine materials with the pre-coated aggregate.[(24)] The aggregate must be pre-heated to 260-325°F. It is mixed with any acceptable PG-grade binder, added at 0.5 to 1% by dry weight of aggregate. The material must be used immediately, as this type of aggregate is not allowed to be stockpiled.

The MnDOT chip seal aggregate specification indicates that Class-A—crushed quarry source, Class-B—Other or Class-C—Crushed Gravel aggregates may be used. These aggregates are

graded and *fine*. Per MnDOT, for chip seals, fine aggregate is defined as that amount that passes the ½ inch sieve. The five gradations to be used are FA-1, 2, 2½, 3 and 3½. All aggregate must pass the ¼ inch sieve for FA-1 and FA-2, must pass the 3/8 inch sieve for FA-2½ and FA-3, and must pass the ½ inch sieve for FA-3½. The percent passing the No. 200 sieve must be between 0-1% for all gradations.

The Spokane County chip seal specification indicates that the aggregate type is basalt only, with sizes of 5/8 inch by No. 4, 1/2 inch by No. 4, and 3/8 inch by No. 4. If using choke stone, the size is No. 4. Per an interview, it was indicated that typically 3/8 inch *single-size* chips are used on arterials and 1/4 inch by No. 10 aggregates are used on lower volume roads.[25] Also, there have been some projects that used 3/8 inch aggregate in the actual lanes and 1/4 inch by No. 10 on shoulders when high bicycle traffic is expected. These gradation bands are narrow. Spokane County does not allow pre-coated aggregate. Per an interview, Spokane County owns the basalt quarries used for chip seal aggregate sources.[25] The aggregate Gradation is checked prior to production.

The TxDOT chip seal specification indicates that a Type B Surface Aggregate Classification is to be used. This classification includes crushed gravel, slag or stone, or a pre-coated limestone aggregate ("Limestone Rock Asphalt", per TxDOT specifications). Type A may also be used, depending on the traffic levels of the project. The aggregate types included in this classification are gravel, crushed slag or stone, or limestone rock asphalt. The aggregate may be graded, or single-size and the gradations are 1, 2, 3S, 3, 4S, 4, 5S and 5, where the S denotes a single-size gradation. The MAS is 7/8 inch for Grade 1 and Grade 2, ¾ inch for Grades 3 and 3S, 5/8 inch for Grade 4 and 4S, and ½ inch for Grade 5 and 5S, respectively. The percentage of materials passing the No. 8 sieve must be between 0-1% for Grades 1, 2, 3S and 3 (non-lightweight), and between 0-2% for Grades 3 (lightweight), 4S, 4 and 5. In practice, Grade 4 is the most commonly used, with some use of Grades 3 and 5.

The TxDOT chip seal specification indicates that pre-coated aggregate may be used. If used, the virgin aggregate is to be uniformly coated with an asphalt material to the Engineer's satisfaction and the aggregate must meet certain quality requirements. Some aggregates are not permitted for use in pre-coating—e.g., lightweight aggregates. The final product must be able to be uniformly spread using mechanical spreading equipment. The Engineer may select a target percentage of asphalt content, which is to be maintained to within ±0.3%. The Engineer may require trial batches from the Contractor to estimate target value. The pre-coating material may be removed from the aggregate samples to test for quality compliance. If checking Gradation, the pre-coating material will remain intact.

3.2.1.c. Other Materials

The Caltrans chip seal specifications indicate that the only additives used are those that are added to the emulsion or asphalt binder being used for the particular project (polymer or CRM). No other additives are indicated as being permitted in chip seal treatments. The MnDOT chip seal specification indicates water as an additive, which must be potable, clean, un-salty, free of deleterious or detrimental substances and must be compatible with the emulsion used in the chip seal. No other additives are indicated in the specifications. The Spokane County chip seal specification does not indicate additive use. The TxDOT chip seal specification does not indicate

the use of additives in chip seals. However, the use of an asphalt anti-strip additive with pre-coated aggregate may be required and must meet the requirements of Item 301—*Asphalt Antistripping Agents* on the use of anti-strip additives with asphalt material.[26]

3.2.1.d. Mix Design

The Caltrans chip seal specification does not indicate a chip seal mix design method. It is implied that the Contractor is the designer of record.

The MnDOT chip seal specification indicates that all MnDOT chip seals are designed using a modified version of the McLeod Method, which was detailed in the MnDOT *Handbook*. The modification allows for more asphalt emulsion to be used in the non-wheel path areas to prevent snowplow damage. The mix design method considers the traffic volume and surface conditions of the project. The traffic volume controls the amount of residue needed to achieve a chip embedment of 70%. If there is a higher traffic volume, then less residue is needed, as traffic will ensure that the 70% embedment criteria is met. This lower residue amount may also prevent flushing or bleeding in the finished product. The surface conditions of the existing pavement also control the amount of emulsion. A flushed, bleeding surface requires much less emulsion than one which is dry, oxidized and pocked. The application rate of the emulsion also depends on the consensus properties of the aggregate, i.e., gradation, shape and absorption.

The MnDOT chip seal specification further indicates that the Contractor is the designer of record for a chip seal project and must submit, within 2 weeks of the project's start, the aggregate gradation and quality tests, such as durability, design application rates for emulsion and aggregate and 150 lb of aggregate from each source. If these materials are not received, MnDOT may postpone work until all components are received and meet the Engineer's approval.

The Spokane County chip seal specification does not indicate a mix design method. However, the specifications do indicate that the Project Engineer will determine the final material application rates. During an interview, Spokane County indicated the use of the McLeod mix design method as a basis for determining the application rates.[25] As Spokane County performs all of the construction work, Spokane County's Engineer is the designer of record.

The TxDOT chip seal specification does not indicate a mix design method. The TxDOT *Seal Coat and Surface Treatment Manual* indicates that TxDOT's primary mix design method is the Modified Kearby Design Method.[21] It is further indicated that TxDOT also uses the Modified McLeod Method, although its use is less common in Texas chip seals. In contrast to the Modified McLeod, the Modified Kearby Method relies more heavily on the volumetric properties of the aggregate—Specific Gravity, Unit Weight, and Board Test results (amount of aggregate needed to cover a one-square-yard area, as measured on a board)—to determine the application rate for the binder. The Modified Kearby mix design method also relies on the conditions of the existing pavement. The aggregate spread rate is based solely on the Board Test results. It is implied that the Contractor is the designer of record.

3.2.1.e. Mix Verification

The Caltrans chip seal specifications indicate that mix verification includes the results of the Vialit test. The Vialit test is a measure of the chip retention percentage at the determined asphalt

content. Per Caltrans, the binder must heated to the field temperatures and sprayed at the target application rate during the test's preparation. This test is to be conducted by an authorized laboratory.

The MnDOT chip seal specification indicates using the *Schedule of Materials Control for 2016 Standard Specifications* to determine the testing needed to check for the material quality in MnDOT chip seal mix designs.[17] For the complete mix design, one design must have been completed and submitted to the Engineer two weeks prior to the start of work for testing. In addition to the Job-Mix Formula (JMF), the Contractor must submit 150 lb of aggregate to the Department for the testing of the aggregate gradation and quality tests, as well as to verify the test results from the Contractor. The Spokane County and TxDOT chip seal specificatiosn do not indicate mix verification practices.

3.2.2. Construction Inspection Practices

3.2.2.a. Equipment

The chip seal equipment specifications and requirements for all four lead agencies are summarized in Table 3.3. The Caltrans chip seal specifications indicate equipment requirements for binder distributor, haul trucks, aggregate spreader, rollers, and brooms. The Caltrans specifications do not indicate calibration procedures but may instead require the Contractors to follow the equipment manufacturers' recommended calibration procedures.

The MnDOT chip seal specification indicates equipment requirements for binder distributors, aggregate spreaders, rollers, and brooms. However, no specific equipment calibration practices are indicated. In MnDOT's *Seal Coat Handbook*, equipment calibration was mentioned and is recommended to be done on both the aggregate spreader and the distributor prior to every project's start.[18] The application rates should be checked and adjusted 'frequently' during the first day of construction. Thereafter, MnDOT checks the application rates once per day. The *Handbook* recommends that the spreader be calibrated *before* the distributor and conducted per American Society for Testing and Materials (ASTM) D5624—*Standard Practice for Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications* in the presence of the Engineer.[28] This calibration should be done early in the project, well before construction. However, if circumstances require, the calibration can be done as late as one day prior to the start of work.

The Spokane County chip seal specification (from the Washington DOT specification) indicates equipment requirements for binder distributors, spreaders, rollers, and brooms. The calibration procedures are not indicated in the specifications, although the agency owns the construction equipment used on chip seal projects and thus self-calibrates the machines.

The TxDOT chip seal specification indicates equipment requirements for binder distributors, haul trucks, aggregate spreaders, rollers, and brooms. Equipment calibration is required prior to construction. The actual calibration procedures are not indicated in the specifications, although the TxDOT *Manual* contains a recommended calibration procedure.[21]

3.2.2.b. Climate Limits

The Caltrans chip seal specifications do not indicate calendar date limits. The allowable temperatures are based upon the type of binder used. For unmodified emulsions, the ambient temperature must be 65-110°F and surface temperature must be at least 80°F. The emulsion is not to be applied if the air temperature is forecasted to drop below 39°F within the next 24 hours. For modified emulsions, the ambient air temperature must be 60-105°F and surface temperature must be a minimum of 80°F. The emulsion is also not to be applied if the air temperature is forecasted to drop below 39°F within the next 24 hours. For asphalt rubber binders, the ambient temperature must be 60-105°F and the surface temperature must be a minimum of 55°F. The binder is not to be applied in damp areas or in high-wind conditions.

The MnDOT chip seal specification indicates calendar date limits for chip seal construction. The date limits depend upon where the project is located within the state of Minnesota. If the project is located in the North or North Central Zone (also known as the Spring Restriction Zones), the construction season is from May 15 to August 10. If it is located south of these zones, the construction season is from May 15 to August 31. It is indicated that work is to be done only during daylight hours, and only if the air and surface temperatures are 60°F and rising. The surface must be free of standing water. Placement is not allowed in foggy weather or if the forecast indicates impending precipitation will inhibit proper curing and opening to traffic.

The Spokane County chip seal specification indicates calendar date limits from May 1 to August 31. The surface temperature must be at least 55ºF and the air temperature 60ºF and rising. The air temperature must not be less than 70ºF when falling and the wind must be less than 10 mph, as estimated by the Engineer. The surface temperature must not exceed 130ºF or as otherwise determined by the Engineer, and the emulsion must not be applied if it cannot be fully covered within one hour of darkness. The road must be free of standing water.

The TxDOT chip seal specification does not indicate specific calendar date limits for construction. The *Seal Coat Manual* mentions that the best season is one with “low wind and higher temperatures,” which usually occurs from June to September.[21] The TxDOT specification indicates that night-time paving operations are permitted. The allowable temperature ranges for application vary by the type of binder. For all chip seals, air temperature must be at least 50°F and rising. The chip seal treatment is not to be placed if the air temperature is 60°F and falling or if the surface temperature is below 60°F. For polymer-modified asphalt cements, air temperature must be at least 70°F and rising. Placing polymer-modified asphalt cement chip seals is restricted if air temperature is 80°F and falling or if the surface temperature is below 70°F. For asphalt-rubber binders, the air temperature must be at least 70°F and rising or above 80°F and stable. Placing asphalt rubber binder chip seals is restricted if the surface temperature is below 70°F.

Table 3.3. Summary of Chip Seal Equipment Specifications.

Equipment Type	Specification			
	Caltrans	**MnDOT**	**Spokane County**	**TxDOT**
Binder Distributor	• Pressure distributor with circulating, insulated tanks and 9-foot spray bar. • Distribution system capable of maintaining target rate to within ±0.02 gal/yd2 • Include monitoring units to monitor binder quantities and control distribution. • Includes mixing and heating unit for CRM binder chip seals.	• Equipped with accurate metering and other devices. • Power-operated pump delivering emulsion to full-circulation, laterally- and vertically-adjustable spray bar. • Spray bar capable of uniform application across widths up to 15 ft.	• Pressure distributor capable of spraying emulsion at target rate and temperature. • Adjustable spray bar with pressure pump and gauge.	• Capable of applying asphalt binder at specified rate. • If using transverse variable rate, nozzles outside wheel paths must have higher volumetric output than nozzles inside wheel path. • If asphalt rubber binder, must have tank agitator. • Calibration conducted per Tex-922-K—Test Procedure for Calibrating Asphalt Distribution Equipment.[27]
Haul Trucks	• Have tailgate for discharging aggregate, and a device for attaching truck to spreader. • Must have tarp if using pre-coated aggregate for haul times longer than 30 minutes.	Not specified.	Not specified.	• Uniform capacity. • Each with calibration records and bed dimensions.
Aggregate Spreader	• Self-propelled with rear hopper, belt conveyor and front spreading hopper. • Capable of uniform spreading over set width.	• Self-propelled mechanical-type on pneumatic tires. • Capable of uniform aggregate spreading over set width.	• Self-propelled, supported on four or more pneumatic tires. • Metering devices to accurately spread aggregate over road width. • Has positive control operation.	• Continuous-feed self-propelled capable of applying aggregate uniformly at specified rate. • Use second spreader for raked-in aggregate.
Rollers	• Pneumatic or foam-filled tire oscillating rollers. • Self-propelled, reversible. • Tires of equal size and can carry 3,000 lb load with tire pressures of 100±5 psi or foam-filled.	• Three rollers needed. • Pneumatic-tire self-propelled rollers with effective compaction width of 5 ft. • Gross weight of 3,000-5,000 lb, depending on traffic.	• Self-propelled pneumatic-tire rollers. • Each must weigh 12 tons. • Provide constant contact pressure. • Steel drum roller may be used.	• Light pneumatic-tire rollers with loads of 4.5-9 tons. • Contact pressure 45 psi and speed of 2-6 mph. • At least nine tires.
Brooms	• Self-propelled and able to remove aggregate from barriers	• Motorized, able to control vertical pressure. • Able to clean surface of loose material before and after treatment.	• Motorized and capable of vertical pressure control.	• Motorized, used for final sweeping.

3.2.2.c. Surface Preparation

The Caltrans chip seal specifications indicate that the surface preparation practices include covering manholes, valves and monument covers, grates or other exposed facilities using plastic or construction paper secured by tape or another adhesive. The surface is to be cleaned immediately before applying binder by removing any deleterious substances and drying the surface if necessary using the self-propelled rotary brooms.

The MnDOT chip seal specification indicates that surface preparation practices include cleaning the pavement and any surface depressions. Iron fixtures must be covered to prevent the emulsion from adhering to its surface and used covers must be removed before the road opening to traffic. A tack coat is recommended and would be applied during other surface preparation activities. MnDOT's tack coat consists of a 1:1 diluted CSS-1h emulsion applied at a rate of 0.05-0.10 gal/yd^2.

The Spokane County chip seal specification indicates that surface preparation practices include sweeping the surface with a power broom until it is free from dirt or other foreign matter. Hand push brooms are used to clean materials left by the power broom. The use of other equipment may be necessary to thoroughly clean the Roadway prior to the application of emulsion. Repairs on the existing pavement may be necessary and must be done according to the applicable section of the Washington DOT specifications. If any reparations are made, these areas must be fog sealed. HMA-repaired areas may require a second fog seal depending on the surface texture as required by the Project Engineer. The pavement surface must be dry prior to fog sealing. Per an interview, Spokane County indicated that the road surface is to be crack-sealed with rubberized crack sealer one year before the anticipated chip seal activities.[(25)]

The TxDOT chip seal specification indicates that surface preparation practices include removing all existing pavement markers—repairing any damage incurred during this operation as directed, removing all dust, dirt, vegetation and other deleterious substances, blading the pavement edges, and applying a tack coat, if directed, and before applying any hot rubberized asphalt crack sealing to the existing surface. Though not commonly used, TxDOT's tack coat consists of a SS-1h or CSS-1h emulsion or a PG of 58 or higher. Application rates are not indicated.

3.2.2.d. Inspection

The Caltrans chip seal specifications indicate inspection requirements for application rates, among others. Binder application temperatures vary by type of binder. For unmodified and modified emulsions, the application temperature range is not indicated. For asphalt rubber binders, the application temperature range is 375-415°F. For asphalt rubber binder, the crew must cover binder with aggregate within 2 minutes of the binder's application.

The aggregate must be spread within 10% of the target application rate and uniformly across the full width of one lane in one operation. Any excess aggregate must be swept from joints before applying the chip seal to the adjacent lane. The roller speeds must be slow enough to prevent roll-over of the aggregate during construction. It is also imperative to not allow aggregate to drop from the spreader if the spreader is not moving; any aggregate that drops in this case must be removed prior to continuing. If the Contractor is using pre-coated aggregates, the aggregates

must be heated to a temperature of 225-325°F, then covered with tarps for haul times exceeding 30 minutes or in ambient air temperatures of less than 65°F. Longitudinal joint overlap must not exceed four inches, unless such overlap is authorized.

The Contractor performs initial rolling with one coverage of a pneumatic-tire roller and final rolling with two coverages. For asphalt rubber binder chip seals, initial rolling is performed with pneumatic-tire rollers, within 90 seconds of spreading aggregate. An 8- to 10-ton steel-wheel roller for final rolling may be used, if authorized. Once rolling is completed, sweeping must commence. Excess aggregates from roadway and adjacent areas must be swept. After sweeping, the Contractor may apply a flush coat (also referred to as a sand seal) if it is specified. Sweeping takes place as early as after two to four hours of having controlled traffic routed over new treatment for two-lane, two-way roads, or two to four hours after aggregates have been placed for multi-lane roads. Final sweeping is to be done immediately before opening lane to un-controlled traffic.

The MnDOT chip seal specification indicates that inspection includes requiring the Contractor to first verify the target application rates. MnDOT's specification indicates that the initial target application rates are those that are stated in the mix design and must be checked using a 200-foot test strip to ensure that the materials' application rates are adequate, given the current pavement conditions. The target materials application rates may be influenced by the characteristics of the pavement surface. The asphalt emulsion must be applied uniformly and at a constant temperature—140°F for CRS-2P. Within one minute of the emulsion application, the aggregate is to be spread. The aggregate's application rate must be maintained within ±1 lb/yd^2 of the target rate. The aggregate must also be uniformly damp prior to placement. While not stated in the specifications, the *Seal Coat Handbook* recommends that a Field Inspector inspect the wheel path areas for proper aggregate embedment during the test strip placement.(18) If the embedment is not adequate, adjustments can be made to the application rates of the aggregates and emulsion if conditions require it, but in order to do so, the Contractor must construct another 200-foot test strip, to verify the revised rates.

After the aggregate embedment from the test strip is checked and the application rates are deemed adequate, the construction process continues. Initial rolling must be done within two minutes of spreading the aggregate. The operating speed must be five mph or less and there must be at least three complete passes made, covering the full roadway width with each pass. After rolling is complete, the entire surface must be hard-swept using the motorized brooms, and surplus aggregate must be removed and disposed of as the Engineer deems appropriate. One day after construction, a fog seal treatment is applied with a CSS-1h emulsion heated to a temperature of 100°F. Per an interview, 100% on-site inspection does not occur to verify application rates.(29) Rather, the yield is checked once per day by the Contractor, and verified once per day by a MnDOT representative.

The Spokane County chip seal specification for the construction inspection indicates the process outlined below. As it was indicated that the county performs its own work, any instances of the word "Contractor" have been replaced with the term "agency crew." To ensure uniform distribution of emulsified asphalt and that the distributor is correctly calibrated, the agency crew must construct a minimum 1,000-foot test strip when beginning a section, per the Washington

DOT specifications. Before application to the roadway, the binder must be heated to 125-195°F. All aggregate stockpiles shall be watered down to provide aggregates that are uniformly damp at the time of placement.

After the binder has been spread evenly over the roadway surface, aggregates of the type specified is evenly applied to the surface by spreader equipment. The aggregate must be spread in one operation in such a manner that an eight-inch strip of emulsified asphalt is left exposed along the longitudinal joint to form a lap for the succeeding applications of emulsified asphalt. If necessary, thin or bare spots in the spread of aggregate shall be corrected immediately by re-spreading with the chip spreader or by hand-spreading the aggregate.

A minimum of three pneumatic tired rollers providing at least two complete coverages to the roadway immediately behind the spreading equipment for the coarse aggregates shall be required. The maximum rate of roller travel is limited to eight miles per hour. If using choke stone, the agency crew must apply the aggregates to the roadway with additional spreading equipment immediately following the initial rolling of the coarse aggregates, unless otherwise specified. Excess aggregates must be removed. At least one pass with a pneumatic roller shall be made across the entire width of the applied choke stone. The operation of trucks hauling aggregate from the stockpile shall be so regulated that no damage, as determined by the Project Engineer, will result to the highway or the freshly applied chip seal treatment.

The completed surface must be allowed to cure and then swept as soon as practical. If the sweeping causes the aggregate to be turned or if the Engineer determines that additional curing time is needed, the agency crew shall broom the roadway when directed by the Engineer. If, after completion of the initial sweeping, the Engineer determines the need to remobilize for additional sweeping, the agency crew shall re-sweep the areas designated by the Engineer. The agency crew can apply water for dust control during sweeping operations when safety or environmental concerns arise, or as otherwise determined by the Engineer.

The TxDOT chip seal specification indicates that the inspection process begins with calculations of material quantities. The “rock land” (area of roadway that is covered by one truckload of aggregate) and “shot” (area of roadway covered by one distributor load of binder) lengths must be calculated. The shot length must be an even multiple of rock land. Immediately before placement, the distributor must have enough material to cover the entire shot length. The maximum shot width is that of the current transverse distribution of the emulsion distributor, if using transverse distribution, or the aggregate spreader box, whichever is less. Adjust shot width as needed, so as not to encroach on traffic or interfere with the traffic control plan. The binder application temperature is selected, depending on type of binder and maintain that temperature to within ±15°F and not above the maximum allowable temperature, according to Table 3.4.

Table 3.4. Recommended Binder Application Temperatures by TxDOT.

Bitumen	Application Range	Maximum Temperature
AC-5, AC-10	275-350°F	350°F
AC-5 with 2% polymer, AC-15P, AC-15-5TR	300-375°F	375°F
HFRS-2, MS-2, CRS-2, CRS-2h, HFRS-2P, CRS-2P	120-160°F	180°F
AR Type II and III	325-425°F	425°F
RS-1P, CRS-1P	50-130°F	140°F
RC-250	125-180°F	200°F
RC-800	170-230°F	260°F
RC-3000	215-275°F	285°F
MC-250	125-210°F	240°F
MC-800	175-260°F	275°F
MC-3000, MC-2400L	225-275°F	290°F

Once application begins, the binder application rate must be monitored for non-uniformity. There must be sufficient pressure in the distributor to fully flair nozzles during application. If non-uniform binder application due to streaking, ridging, puddling or flowing off the road surface occurs, the application must stop and equipment condition, operating procedures, temperature and material properties all must be verified and changed as necessary. If the non-uniformity is due to the emulsion's viscosity, it is to be replaced with a correct binder material. The Engineer may require test strips at any time at the Contractor's expense if non-uniformity continues after corrective action has been taken and if the binder application rate varies by more than 0.03 gal/yd^2 from the target on three or more consecutive shot lengths or if the application rate on any one shot differs by more than 0.05 gal/yd^2. The Engineer will approve the test strip location and may require further strips until the treatment meets the specification requirement. If the aggregate application becomes non-uniform, production is stopped, and equipment condition, operating procedures and transverse application rate are verified. The non-uniformity cause must be determined and corrected.

Immediately after the asphalt shot, apply aggregates uniformly at the directed rate without causing aggregate roll-over. The aggregate and binder application rates should be monitored closely. Stop application if application rates not uniform in both the longitudinal and transverse direction. The aggregate rate should be within ±1 lb/yd^2 of the target rate in the transverse direction. Once the cover aggregates have been applied, the area is inspected for any uncovered areas. Areas of incomplete coverage are to be patched prior to rolling using hand-spotting or other approved method. Begin rolling as soon as aggregates are applied, using enough rollers in staggered pattern to cover entire mat width in one pass. Complete at least five passes—or three if using emulsion as the binder material. Stop the treatment application if the rollers are unable to keep up with the aggregate spreader; allow rollers to catch up and resume application. Keep roller tires binder-free. If racked-in aggregates are to be used, apply after patching, uniformly at the directed rate and before opening to traffic.

3.2.2.e. Mix Adjustments

The Caltrans chip seal specifications indicate mix adjustments for asphalt rubber binder chip seals. These include the allowance for a decrease in binder application rate in the wheel path by 0.050 gal/yd^2. No other adjustments are indicated.

The MnDOT chip seal specification indicates application rate adjustments, both before and during construction. The first adjustments are made before construction with the test strip, allowing the Contractor and the Engineer to determine the appropriate rates based upon current roadway conditions. If any additional adjustments need to be made to the application rates during construction, the Contractor must construct another test strip. Another mix adjustment may occur during construction. The equipment application rates should be checked and adjusted "frequently" during the first day of construction.

The Spokane County chip seal specification indicates that the only mix adjustments that occur are those conducted prior to the construction of a new section. The exact adjustments to be made are not indicated.

The TxDOT chip seal specification indicates that mix adjustments are required in order to correct non-uniform application or if current conditions necessitate adjusting the application rates. Any adjustments require a test strip to be constructed to verify that the adjustments achieve an adequate treatment application.

3.2.2.f. Opening to Traffic

The Caltrans chip seal specification indicates that the opening to traffic varies depending on the type of roadway being treated. On two-lane two-way roads, traffic must be controlled with a pilot car for two to four hours prior to opening to un-controlled traffic. For multi-lane highways, while traffic is controlled with pilot cars, no more than one lane can be open in the direction of travel and must be controlled for two hours post-sweeping before opening to un-controlled traffic.

The MnDOT chip seal specification indicates that one day of curing after hard sweeping is required and then a CSS-1h emulsion fog seal is to be applied. Once the fog seal emulsion has set, a final sweep is conducted and then the roadway is opened to traffic.

The Spokane County chip seal specification indicates that the only requirement is that traffic will not be allowed on the prepared surface until the first application of emulsified asphalt and aggregate has been completed, which includes sweeping.

The TxDOT chip seal specification does not indicate curing practices. TxDOT's *Seal Coat Manual* states that opening to traffic depends on the traffic volume and roadway speed and binder types.[21] Asphalt cements harden earlier, thus allowing for quicker traffic opening, as do emulsions when placed in the summer. However, when emulsions are placed in cool areas or in areas with 50% relative humidity or higher, there is a longer curing time. Lower-volume, low-speed roads can be opened sooner than high-volume, high-speed roads. Allowing piloted slow-moving traffic atop the new treatment can give the aggregate an orientation that is beneficial and not easily obtained by pneumatic-tire rollers. Curing must also take into account the possibility

of rain. If there is precipitation, traffic is not to be permitted atop the new treatment until the rain ceases and the treatment cures fully.

3.2.2.g. Post-Construction Monitoring

The Caltrans specifications for monitoring practices indicate that the treatment is to be maintained by the Contractor until final acceptance. The Contractor must perform a final sweep the morning after application on lanes opened to un-controlled traffic before starting other activities. The Contractor must maintain the treatment for four consecutive days after the day of aggregate application. Maintenance includes sweeping and keeping surface free of loose aggregate, preventing corrugations and taking care not to dislodge aggregate during sweeping.

The MnDOT chip seal specification indicates that the Contractor is responsible for any damages done to vehicles post-construction until the roadways and shoulders are completely swept, all loose aggregates are removed, and permanent markings are placed, *unless* MnDOT is going to place the permanent markings. In the latter case, the Contractor is relieved of responsibility after fog sealing is complete.

The Spokane County chip seal specification does not indicate post-construction monitoring practices, other than monitoring and repairing any damages incurred until final acceptance.

The TxDOT chip seal specification indicates that post-construction monitoring practices include a requirement that the Contractor is to maintain the treatment until the Engineer accepts the work, repairing any damages incurred until final acceptance.

3.2.3. Quality Assurance Specifications

3.2.3.a. Quality Control and Acceptance

The Caltrans chip seal specification indicates Quality Assurance criteria for all of the chip seal types. The specifications include both Quality Control and Department Acceptance. They have submittal requirements that include submitting material samples and QC test results prior to starting the project. The Caltrans Submittal requirements include submitting the following prior to construction:

- For all chip seals, 15 days prior to start of work, Contractor must submit the samples for asphalt emulsion, samples for polymer-modified asphalt emulsion, or samples for asphalt rubber binder.
    - All samples must have the supplier and type/grade of bitumen, type of modifier used, percent crumb rubber if used, and copy of test results on the binder.
    - Further requirements include the source and type of asphalt modifier, percent asphalt modifier added by weight of asphalt, combined percent of asphalt modifier and binder by total weight of blended CRM binder, the test results for the quality characteristics, each source and type of both scrap tire rubber and high natural scrap tire rubber, percentage of each by total weight asphalt rubber binder and the test results for the quality characteristics, including minimum reaction time and temperature.
- The Contractor must also submit a 50-lb sample of uncoated aggregate and the test results for the following (within the time limit indicated in parentheses)

    - Gradation (within 24 hours of test prior to construction), L.A. Abrasion (within 48 hours of test prior to construction), Percent crushed particles (within 48 hours of test prior to construction), Flat and elongated particles (within 48 hours of test prior to construction), Film-stripping (within 48 hours of test prior to construction), Cleanness Value (within 24 hours of test prior to construction) and Durability (within 48 hours of test prior to construction)
- Finally, the Contractor must submit Vialit test results (tested per Caltrans' *Method of Test for Vialit Test for Aggregate Retention in Chip Seals "French Chip"*), which shows the percent of chip retention in the asphalt binder.[30]

The QC requirements for aggregate include the following tests to be performed on uncoated aggregate, except film-stripping. For all chip seals, tests include L.A. Abrasion Loss, Percent Crushed Particles for coarse and fine aggregate, Flat and Elongated Particles, Durability, Gradation and Cleanness Value. The Quality Control requirements for the binder depends on the binder type being used. The Contractor must complete a test for the asphalt emulsion spread rate (if using emulsion) once per day per distributor from the surface of the pavement.

Further tests for emulsions include Saybolt-Furol Viscosity, Sieve Test, 24-hour Storage Stability, Residue by Distillation, Particle Charge, Penetration at 25°C and at 4°C, Ductility, Solubility, Torsional Recovery and Ring and Ball Softening Point (last two are for polymer-modified emulsion). These tests are conducted on samples taken from the distributor at mid-load or from a sampling "tap" or "thief." Any test conducted on polymer-modified asphalt emulsion represents 55 tons or 1 day's production, whichever is less.

If asphalt rubber binder is used, the QC tests include Descending Viscosity (readings taken starting 45 minutes after rubber addition, taken every 30 minutes until 2 consecutive readings are the same; tested once per lot from the reaction vessel), Viscosity at 375°F (readings taken 15 minutes before use per lot from the distribution truck), Cone Penetration and Resilience at 25°C and Softening Point (all taken once per lot from the distribution truck and tested in the laboratory). A 6-qt sample is taken once per five lots or once per day, whichever is greater, and submitted to Caltrans for Acceptance testing.

The Contractor must submit, in writing to the Engineer, a detailed list of existing defective areas in the pavement, identifying lane direction and number, mile post locations and type of defect at least seven days before starting application. Recognized defects include rutting in excess of 3/8 inch and flushing. Caltrans' final acceptance does not apply to areas of the existing surface identified by the Contractor as being defective prior to construction. The Caltrans Acceptance for the final chip seal is based on visual inspection of the finished surface, looking for:
1) the chip seal has a uniform surface texture;
2) No raveling is present. It is considered defective if affected area is greater than 0.5 ft^2;
3) No flushing or bleeding is present. It is considered defective if affected area is greater than 0.5ft^2; and
4) No streaking is present. It is considered defective if affected area is greater than 0.5ft^2

Acceptance includes asphalt binder acceptance, which is based upon the sampling and testing performed by Caltrans for compliance to the specification quality characteristic as described in

the Quality Control section. Aggregate Acceptance is based upon the sampling and testing performed by Caltrans for specification compliance of the aggregate to the tests previously outlined in the Aggregates sub-section of the Materials section.

The MnDOT chip seal specification indicates requirements for both Acceptance and QC testing, although limited. The QC specifications indicate that the Contractor must conduct sampling and testing per the MnDOT *Schedule for Materials Control* (SMC) and the test results obtained must be submitted within 24 hours of the test's completion. The Contractor is responsible for QC testing on all materials except for the emulsion, which is the responsibility of the emulsion supplier. The first load of emulsion that is produced is to be sampled and tested. Thereafter, the emulsion sampling and testing frequency is reduced to once per 50,000 gallons. The primary quality tests used by MnDOT are not indicated in either the SMC or the standard specifications. The Contractor conducts gradation on samples taken from the aggregate stockpiles once per day or once per 1,500 tons of aggregate during production and once per day from the chip spreader hopper during chip seal placement. MnDOT samples aggregate from the aggregate stockpile prior to the project's start and conducts testing on a 30 lb sample taken from the spreader hopper by the Contractor during construction.

Aggregates are evaluated by MnDOT for specification compliance during the aggregate producer's production testing. MnDOT also samples and performs agency tests according to the SMC. Once the project is complete, MnDOT pays for emulsion by the gallon and aggregate by the square yard. MnDOT does not allow for materials or workmanship warranties because the materials are already accepted by certification prior to the chip seal's construction.

The Spokane County chip seal specification does not indicate QC or Acceptance criteria. Spokane County has indicated that informal QC criteria are used for chip seals, per an interview.[25] It was indicated that the foreman is responsible for production quality. The equipment calibrations and chip seal workmanship are also inspected by the foreman. The emulsions are accepted on Certificates of Compliance and are typically not sampled and/or tested during production. Finally, aggregates are accepted based on gradation, which is tested during annual crushing operations or from a sample from material supplier.

The TxDOT chip seal specification indicates QC and Acceptance. The QA specification is primarily focused on Contractor QC testing. This includes the Contractor's testing of materials to be used in the project, the equipment calibration records, temporary storage placement and removal, blend designs for asphalt rubber binder, if using, adjustments to the application rates using test strips if the application becomes non-uniform and maintaining the new treatment until the Engineer accepts it. Acceptance includes Engineer review of the Contractor's calibration data to ensure that proper application rates will be achieved prior to construction, verifying application rates during construction and final acceptance.

3.2.3.b. State-of-the-practice

The identified state-of-the-practice included 1) proper project selection, and pre-sealing and paver patching preparation, 2) annual training of chip seal crews, 3) performing equipment maintenance and calibration activities, and 4) mandating low-abrasion aggregates. The enforcement of wintertime construction shut-down is also a state-of-the-practice, especially in

wet-freeze climates. Further, the use of certified products by the Contractor is a factor that MnDOT relies heavily upon to increase chip seal performance. Some agencies' entire specifications were key to successful experiences with chip seals.

Other recommended state-of-the-practice items for chip seal preservation treatments includes:

- Selecting quality asphalt binder and aggregate materials.
  - Emulsion or paving grade based on climate conditions.
  - Tough and abrasion resistant aggregates.
- Performing a mix design as a basis for determining application rates.
  - The McLeod method is a common mix design method that allows for modifications.
- Calibrating equipment with the materials to be used during construction.
  - Recommended to be done prior to every project.
- Proper surface preparation to achieve a clean surface to obtain bond between the pavement surface and the chip seal.
  - Pre-sealing the roadway ahead of chip seal construction.
  - Prevent the crack sealing material from swelling under the new treatment.
  - Paver patching as a part of surface preparation.
    - Mitigate the effects of surface depressions (rutting, potholes, etc.) on the newly constructed treatment.
- Constructing a test strip.
  - Recommended to be done on every project, under conditions similar to those that are anticipated during construction.
- Training of chip seal crews and inspectors.
  - Ensure that all members of the crew possess the knowledge required to construct a quality treatment.
  - Inspectors can perform duties necessary to achieve quality product.
- Enforcing appropriate climatic conditions during construction.
  - The enforcement of wintertime construction shut-down, especially in wet-freeze climates.
  - No impending precipitation within, typically, the next 24 hours to 72 hours.
  - Specifying maximum surface temperature.
- Inspection of binder application rate and temperature.
  - Chip retention can be achieved.
- Requirements for contractor QC testing during construction.
  - Aggregate Gradation, L.A. Abrasion, Flakiness Index, asphalt binder quality testing.
- Requirements for agency Acceptance sampling and testing during construction.
  - Accepting binder based on Certificate of Compliance.
  - Requires binder supplier to produce a quality product.
  - Aggregate gradation most common.
  - Verifying Contractor QC data and mix design.

3.2.3.c. Opportunities for Improvements

There were a few components indicated by the agencies in the follow-up interviews that were identified as opportunities for improvements to the specifications and construction practices.

Among these is the need for experience and training of inspection personnel. This gap is due to the significant turn-over of inspection personnel and lower management emphasis on implementing actual on-site inspection practices. There is also an identified need for more robust QC and Acceptance specifications. Another area for improvement is in the equipment calibration.

During the follow-up interviews, it was indicated that some agencies conduct equipment inspections only once per year. Equipment calibration may need to be checked prior to the construction phase of every project. If the agency specifications do not indicate calibration requirements, the equipment manufacturers' calibration procedures shall be followed. Another area that may benefit from improvement is in the operation of haul trucks. It may be beneficial to stagger the haul trucks across the newly-constructed chip seal treatment when loading the chip spreader, if such an operation pattern is possible. A final issue arises in project selection. Many chip seal preventive maintenance treatments have been placed on top of poor, severely-distressed pavements, as a corrective technique, instead of the as-intended preventive maintenance strategy.

3.3 Slurry Seal Preservation Treatment

The slurry seal specifications for the California Department of Transportation (Caltrans), City of Columbus-Ohio, and Virginia Department of Transportation (VDOT) are outlined in this section. The information obtained for each of the agencies was found in Caltrans' *2015 Standard Specifications and 2015 Revised Standard Specifications*, City of Columbus' *2012 Construction and Materials Specifications*, and VDOT's *Special Provisions for 2016 Road and Bridge Specifications*.[15,31,32]

Slurry Seal, as defined in Section 1.2, "consists of a mixture of emulsified asphalt, well-graded crushed aggregate, mineral fillers, additives and water that is properly proportioned, mixed, and uniformly spread on a properly prepared surface."[5] Slurry seal definitions indicated in each agency's specifications are listed below.

- Caltrans: "consists of spreading a mixture of asphaltic emulsion or polymer-modified asphaltic emulsion, aggregate, set-control additives, and water on a surface or pavement."
- City of Columbus: "consists of a mixture of emulsified asphalt, mineral aggregate, and water; properly proportioned, mixed, and spread evenly on the surface."
- VDOT: Definition not indicated in specifications or special provisions.

3.3.1. Materials and Testing Specifications

3.3.1.a. Asphalt Binders

The Caltrans slurry seal specification indicates that the emulsion to be used in slurry seals is PMCQS-1h. Either neoprene polymer or butadiene and styrene copolymer can be used for modification. The polymer must be homogeneous and milled into the asphaltic emulsion in a colloid mill. The emulsion must meet Caltrans' requirements for quality. If a tack coat is used, an SS or CSS grade asphalt emulsion mixed with additional water at a 3:1 ratio is used. The selected target tack coat application rate should be between 0.08-0.15 gal/yd^2. The City of Columbus slurry seal specification indicates that the primary emulsions are QS or CQS. The VDOT special provision indicates that the slurry seal emulsion type is CQS-1h. Table 3.5 shows the asphalt emulsion quality tests used by each agency.

Table 3.5. Slurry Seal Asphalt Binder Quality Tests.

Asphalt Binder	Agencies		
	Caltrans	**City of Columbus**	**VDOT**
Unmodified Asphalt Emulsion	Not specified.	Viscosity at 77°F, Residue from Distillation, Sieve Test and Particle Charge. The quality tests on Residue are Penetration at 77°F, Solubility, and Ductility at 77°F.	Saybolt-Furol Viscosity, Sieve Test, Demulsibility, Particle Charge, Residue by Distillation, Penetration on the residue, and Emulsion Setting Time.
Modified Asphalt Emulsion	Saybolt-Furol viscosity, the Sieve test, Storage stability after 1 day, Residue by Evaporation, and Particle Charge. The tests on Residue are Penetration, Ductility, and Torsional Recovery or Polymer Content.	Not specified.	Not specified.

3.3.1.b. *Aggregates*

The Caltrans slurry seal specification indicates that the aggregate types to be used are rock dust or sand. The gradation types are Type I, II and III, which reflect each slurry seal type. The Type I gradation has a MAS of No. 4. The Type II and III gradations have a MAS of 3/8 inch. Particles larger than No. 50 must be 100% crushed, and the aggregate must be free of vegetation and deleterious substances, clay and caked or oversized particles.

The City of Columbus slurry seal specification indicates that the aggregate types are 100% crushed gravel, slag or approved limestone. The aggregates must have a sand equivalent greater than 45. The aggregate gradations are for Type I, II and III, all with a MAS of 3/8 inch. Aggregates are to be pre-wetted before mixing. Engineer approves aggregates source prior to work, and aggregates must have a proven durability record for the anticipated traffic levels. The VDOT slurry seal special provision indicates that the aggregates type is non-polished crushed stone only. Gradations are Type A, B and C with MAS of 3/8 inch for all three types. Table 3.6 shows the aggregate quality tests used by all of the agencies.

Table 3.6. Slurry Seal Aggregate Quality Tests.

Aggregate Test	Agencies		
	Caltrans	**City of Columbus**	**VDOT**
Sand Equivalent	X	X	X
Durability	X		
L.A. Abrasion		X	
Gradation			X
Soundness			X
Organic Impurities			X
Void Content			X
Deleterious Material			X

3.3.1.c. Other Materials

The Caltrans slurry seal specification indicates that set-control additives may be used. However, the specifications do not indicate requirements for the types of additives allowed.

The City of Columbus slurry seal specification indicates that mineral fillers—primarily Portland cement and limestone dust—may be used and added to the aggregate blend. The filler must meet the gradation's requirements of ASTM D242—*Standard Specification for Mineral Filler for Bituminous Paving Mixtures* and are only to be used to provide sufficient mixture workability.(33)

The VDOT slurry seal special provision indicates that non-air-entrained Type I Portland cement or hydrated lime may be used as a mineral filler. The use of water is also indicated. The Portland cement must conform to AASHTO M85—*Standard Specification for Portland Cement*.(34) The hydrated lime must conform to ASTM C207—*Standard Specification for Hydrated Lime for Masonry Purposes*.(35) The water must be clean, clear, and free from any deleterious materials and must have a pH of 4.5-8.5.

3.3.1.d. Mix Design

The Caltrans slurry seal specification indicates the use of the ISSA mix design methods and tests. It is implied that the Contractor is the designer of record. The mix design must state the percentage of emulsion by dry weight of aggregate, which must also fall within specified ranges. The percentage ranges vary between slurry seal types. For Type I, the emulsion range is 15-20%. For Type II, the range is 12-18% and for Type III the range is 10-15%. Once the mix design is complete, the Contractor must submit a report and mix design to the agency. The report and mix design must include the specific materials to be used. The laboratory report must include the test results used in the mix design and proportions dry weight for aggregate of: filler determined from tests, minimum and maximum; water, minimum and maximum; asphalt solids content; and set control agent. The laboratory report must also include the comparison of slurry seal test results to the values indicated in the specification. If the materials change in the mix design, a new mix design and laboratory report must be submitted at least 10 days before starting work.

The final mix design must be able to allow traffic on the treatment within one hour post-construction with minimal damage inflicted.

The City of Columbus slurry seal specification indicates the use of the ISSA mix design, particularly using ISSA TB 111—*Outline Guide Design Procedure for Slurry Seal*.[36] The Contractor is the designer of record and prior to contract award, the Contractor must submit a trial mix design to the agency Engineer for approval. In addition to the mix design, the Contractor must also submit 11 lb of the selected aggregates, 1 gallon of selected emulsion, 0.5 kg of selected mineral filler, three Consistency test results, two Wet-Track Abrasion test results, and two Loaded-wheel tester test results—the last three items are those conducted on the complete mix design. Columbus is not capable of performing the other mix design tests. The Engineer reviews the prospective Contractor's mix design prior to awarding the project. The design asphalt content rates must be within the following ranges: 10-16% for Type I mix, 7.5-13.5% for Type II mix, and 6.5-12% for Type III mix. These ranges conform to the ISSA guidelines.

The VDOT slurry seal special provision indicates that VDOT uses department-created test methods for slurry seal mix designs. VDOT requires that the Contractor—also the designer of record—submit a trial mix design for each slurry type for Engineer approval, results of the VTM-60—*Compatibility Test of Slurry Seal Mixtures–(Asphalt Lab)*, and Wet-Track Abrasion test results—conducted once per mix type per aggregate type.[44] The Wet-Track Abrasion wear loss is not to exceed 75 grams/ft^2. The loss is used to determine the optimum asphalt content and to limit the acceptable asphalt content ranges. These ranges are 8.0–10.5% for Type A mix, 8.0–10.5% for Type B mix, and 7.0–9.5% for Type C.

3.3.1.e. *Mix Verification*

The Caltrans specification indicates that slurry seal mix verification tests include Consistency, Wet-Stripping, Compatibility, Cohesion and Wet-Track Abrasion.

City of Columbus indicates that only the aggregates gradation is checked to verify the mix design, per an interview.[38] The slurry seal specification states that tests for Mixing Time, Set Time, Water Resistance, Coating and Wet Track Abrasion are used to verify the slurry seal mix design.

The VDOT slurry seal special provision indicates that VDOT reviews the Contractor-submitted mix design test results for verification, particularly the Wet-Track Abrasion test results. The aggregates gradation is tested based on the approved aggregates producer's modified acceptance production control plan. The Contractor must submit 6 quarts of emulsion and 50,000 grams of aggregates to the agency for asphalt content testing done by VDOT via the Ignition Method or the Nuclear Gauge Method. Both tests are conducted per VDOT's own test methods—VTM-102—*Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method – (Asphalt Lab)* and VTM-93—*Nuclear Asphalt Content Gauge Determination For H.M.A. and Slurry Seal Mixtures – (Asphalt Lab)*, respectively.[39,40] Samples of the completed mix are taken and also tested by VDOT for asphalt content. At the start of production, each of these samples are to represent no more than 25,000 yd^2 of slurry seal mix, taken from each mixing unit. Once

the production becomes consistent and asphalt content conforms to specification requirements, the sampling and testing frequency is reduced to once per 50,000 yd^2.

3.3.2. Construction Inspection Practices

3.3.2.a. Equipment

The slurry seal equipment specification details for all three lead agencies are summarized in Table 3.7. The Caltrans slurry seal specification indicates equipment requirements for mixing equipment (truck-mounted or continuous) and a spreader box. If using truck-mounted spreaders, at least two must be present on every jobsite. In the presence of the Engineer, each mixer-spreader used is calibrated at least five business days before slurry placement is to occur. The calibration is conducted per Caltrans' *Material Plant Quality Program.*[24] If Caltrans authorizes a mixer-spreader truck to be used, its calibration is valid for six months provided that the Contractor:

- Uses the same truck verified with a unique identifying number,
- Uses the same materials in compliance with the authorized mix design, and
- Does not perform any repair or alteration to the proportioning systems.

The adjustable cut-off gate settings of each mixer-spreader truck on the project must be calibrated to achieve the correct delivery rate of aggregates and emulsion per revolution of the aggregates feeder.

The City of Columbus slurry seal specification indicates equipment requirements for continuous-flow mixing machines, spreading equipment, cleaning equipment, and auxiliary equipment such as hand squeegees. The Contractor must have a certificate from a professional Engineer or accredited testing facility that verifies that all equipment has been calibrated within the previous two months. The Contractor must provide two 10-ton mixing machines to each jobsite for continuous operation.

The VDOT slurry seal special provision indicates equipment requirements for a mobile mixing unit and spreader. The Contractor must have calibration data for the current calendar year for each mixing unit. The calibration is to be done using the same materials as those used in the project. The equipment must be designed or suitable to perform slurry application and be in good working condition.

Table 3.7. Summary of Slurry Seal Equipment Specifications.

Equipment Type	Specification		
	Caltrans	**City of Columbus (Ohio)**	**VDOT**
Mixing Equipment	• Must be able to proportion emulsion, water, aggregate and additives, and mix in continuous pug mill. • If truck-mounted mixer, must have: • Aggregate belt feeder with adjustable cut-off gate. • If continuous mixer, must have: • Material delivery systems to double-bladed shaft mixer. • Discharge of slurry seal mix on continuous basis. • Enough material to maintain continuous operation.	• Must be capable of accurately delivering and mixing materials and discharging slurry mix on continuous basis. • Must have fines feeder for mineral filler and water pressure system and fog spray bar for dampening surface ahead of spreading equipment.	• Mobile mixing unit equipped with accurate fines feeder for mineral filler and fog spray bar for fogging surface ahead of spreader. • Operates at 60 ft/minute and hold 5 tons of slurry mix or more. • Must be able to deliver continuous, homogeneous uniform slurry mix.
Spreading Equipment	• Spreader box capable of spreading an entire lane width. • Must be equipped with flexible rubber belting. • Must be equipped with flexible strike-off blades.	• Must be adjustable-width squeegee spreader box with flexible strike-offs and a steering mechanism.	• Must have flexible strike-off and squeegee to maintain constant surface contact. • Must have 16-inch burlap drag at rear to smooth surface.
Cleaning Equipment	Not specified.	• Includes power brooms, air compressors, water flushing systems and hand brooms. • Use a water flushing system with pressures greater than 1,000 psi and spray rate of 10 gal/minute for removing clay and mud.	Not specified.
Auxiliary Equipment	Not specified.	• Includes hand squeegees, shovels and other equipment for handwork.	Not specified.

3.3.2.b. Climate Limits

The Caltrans slurry seal specification indicates that the slurry seal should not be placed unless both the air and surface temperatures are above 50°F and rising. Neither temperature is allowed to be below 50°F and falling. The forecasted ambient air temperature must reach a high of at least 65°F within 24 hours of placement. Slurry seals are not to be placed if rain or temperatures below 36°F are expected within 24 hours of the treatment being placed. No calendar dates to begin or end construction are indicated in the Caltrans specifications.

The City of Columbus slurry seal specification indicates that the placement of slurry seal may begin when either the pavement or air temperatures are 45°F and rising. However, neither temperature can be 50°F and falling. If high humidity precludes or excessively prolongs adequate curing, the slurry seal treatment is not to be applied. No calendar dates to begin or end construction are indicated in the Columbus specifications.

The VDOT slurry seal special provision indicates that the surface temperature should be above 50°F and rising. The treatment can be placed if the surface temperature is 40°F and rising during the morning hours and provided that the anticipated high air temperature will be at least 60°F. The air temperature must not be expected to drop below 32°F in the next 24 hours post-construction. The specification also indicates that if the pavement temperature is above 90°F, the surface must be fogged with water at a rate of 0.05 gal/yd^2 immediately ahead of the spreader. The VDOT special provision does not indicate calendar dates that begin or end construction.

3.3.2.c. Surface Preparation

The Caltrans slurry seal specification indicates that the surface preparation practices include covering manholes, valve and monument covers, grates, or other exposed facilities located within the area of application. Next the pavement surface must be cleaned by removing loose particles of extraneous materials, including paving and dirt using any non-destructive method, such as flushing or sweeping prior to placing the slurry seal. A 3:1 diluted emulsion tack coat is to be applied, if required, at a selected target rate of 0.08-0.15 gal/yd^2.

The City of Columbus slurry seal specification indicates that surface preparation practices include sweeping, removing weeds, and executing a final cleaning ahead of the mixer. Any standard cleaning method can be used, except water flushing, which is not permitted where there is considerable cracking present in the surface. The Engineer gives final approval. A tack coat (0.05-0.10 gal/yd^2 of diluted emulsion) may be required if the surface is concrete or brick, absorptive asphalt or if the surface is polished and slick.

The VDOT slurry seal special provision indicates that the surface preparation practices include cleaning the surface of all loose material, vegetation, silt spots, or other materials using a broom method or compressed air.

3.3.2.d. Inspection

The Caltrans slurry seal specification indicates that the construction inspection process involves the following steps. First, the mix components must be proportioned in compliance with the authorized mix design. The different aggregate types must be proportioned and blended before adding other ingredients. After proportioning and mixing is complete, the slurry seal mixture

must be workable. After spreading, the mixture must be uniform and homogeneous, and there must not be separation of the emulsion and aggregate after setting.

The Engineer determines the exact spread rate for slurry seal. The completed rate must be within 10% of the Engineer's determined spread rate. The optimum target slurry seal spread rates must be within the ranges specified: 8-12 lb/yd^2 for Type I slurry; 10-15 lb./yd^2 for Type II slurry; and, 20-25 lb/yd^2 for Type III slurry. The slurry seal must be spread uniformly within the specified spread rate range. Spotting, re-handling, or shifting the slurry mixture is not allowed. In areas inaccessible to spreading equipment, hand tools or other authorized methods are used. If placing with hand tools, the area should be first lightly dampened, again while taking care not to handle or shift the material. The exact rate must be authorized by the Engineer. The finished surface must be smooth. The slurry seal must be protected from damage until it has cured so it will not adhere to or be picked up by vehicle tires.

The City of Columbus slurry seal specification indicates that the construction inspection process includes the following steps. First, the optimum JMF established from the mix design must first be translated to job control quantities by the Contractor per ISSA TB 107—*A Method for Unit Field Control of Slurry Seal Quantities.*(41) Spread rates are determined by the Contractor per ISSA TB 112—*Method to Estimate Slurry Seal Spread Rates and to Measure Pavement Macrotexture*, which bases application rates on the dry aggregate's unit weight.(42) The spread rates determined using ISSA TB 112 must also be within the allowable ranges stated in the specifications for each type of slurry seal (8-12 lb/yd^2 for Type I, 15-17 lb/yd^2 for Type II, and 15-22 lb/yd^2 for Type III). The slurry seal mixture must be of proper consistency at all times.

The VDOT slurry seal special provision indicates that the inspection process involves first ensuring that the slurry mixture be of a consistency such that it "rolls" in the spreader box in a continuous mass. Slurry seal mixture that segregates in the spreader box, so that flowing of liquid is evident, is not acceptable and is not to be applied. The liquid portion of a slurry mixture must not flow from either the spreader box or the applied slurry. Evidence of such flow is sufficient cause for rejection of the applied material. A mixing aid additive may be used when necessary to accommodate slow placements or high temperatures. Should oversize aggregates be encountered in the mix, the Contractor must immediately cease operation until approved corrective measures have been taken.

3.3.2.e. Mix Adjustments

The Caltrans slurry seal specification does not indicate any mix adjustments to be used for slurry seals. The test strip requirement does not apply when constructing slurry seals.

The City of Columbus slurry seal specification does not indicate mix adjustments. Per an interview, Columbus indicated that the agency allows for the Contractor to make mix adjustments, although the actual limits and the agency approval process are not available.(38)

The VDOT slurry seal special provision indicates that the Contractor should place a test strip prior to beginning the work, so as to allow the Engineer to verify the target application rate. The VDOT special provision also indicates that a mixing aid additive may be added if slow placement rates or elevated temperatures warrant its use.

3.3.2.f. Opening to Traffic

The Caltrans slurry seal specification indicates that the slurry seal surface must allow traffic within one hour after placement. The one-hour requirement is based upon the Contractor's approved mix design.

The City of Columbus slurry seal specification indicates that the treated areas will be allowed to cure until such time as the Engineer permits opening to traffic. Per an interview, it was indicated that the City of Columbus inspector is responsible for determining when the pavement is to be opened to traffic.[38] The practice may be conducted to remove the risk to the Contractor in the event that the pavement is opened too soon and is damaged by traffic.

The VDOT slurry seal special provision indicates that the slurry seal treatment must be cured until the treatment cannot be damaged by traffic. If and where earlier opening to traffic is necessary, such as at parking lot entrances and exits, the Contractor may lightly sand the surface using the same aggregates used in the treatment. The Contractor will then be required to remove excess aggregates from the roadway in curb and gutter sections.

3.3.2.g. Post-Construction Monitoring

The Caltrans slurry seal specification indicates that once the treatment is opened to traffic, the treatment must not show bleeding, raveling, separation, or other distresses for 15 days after construction.

The City of Columbus slurry seal specification indicates delayed-acceptance practices. A minimum of 30 days after the completion of the slurry seal project, the Engineer will inspect the project with the Contractor for surface flushing and loss of material. If either deficiency is found, corrective work is required. All corrective work must be completed within seven working days of the review, or by an agreed date. All costs associated with the completion of this corrective work, to the satisfaction of the Engineer, will be paid for by the Contractor. Per an interview, it was indicated that the 30-day requirement may be removed from current specifications and be replaced by a one-year material and workmanship warranty.[38]

The VDOT slurry seal special provision indicates that the Contractor must maintain the treatment until final acceptance. Per an interview, VDOT also monitors the treatment performance via network-level pavement condition surveys.[43]

3.3.3. Quality Assurance Specifications

3.3.3.a. Quality Control and Acceptance

The Caltrans slurry seal specification indicates both Quality Control and Department Acceptance requirements. QC includes requiring that the Contractor's testing laboratory sign the original laboratory report and mix design for the slurry seal. If the mix design consists of the same materials covered by a previous laboratory report, the previous laboratory report may be submitted and must include the material testing data performed within the previous 12 months. Each day, moisture data for the aggregate, collected every two hours, must be submitted if the Contractor is unable to maintain the moisture content to within a maximum daily variation of ±0.5%. The moisture content checks must be performed for each aggregate source using an

approved vehicle scale. Individual checks of the aggregates' belt feeder's delivery rate to the pugmill mixer must not vary more than two percent from the average of three runs of at least three tons each. Individual checks of the emulsion pump's delivery rate to the pugmill mixer must not vary more than 2% from the average of 3 runs of at least 500 gallons each.

Acceptance includes accepting aggregates based on compliance with the aggregate Gradation and Sand Equivalent requirements. An aggregate Gradation and Sand Equivalent test represents 300 tons or 1 day's production, whichever is less. If the test results for Gradation or Sand Equivalent do not comply with the specified requirements, the Contractor may remove the installed treatment represented by the test results or request it remains in place with a payment deduction. If the deduction request is authorized, Caltrans deducts $1.75 per ton of slurry seal for each noncompliant Gradation or Sand Equivalent test.

The City of Columbus slurry seal specification indicates both Quality Control and Acceptance. Quality Control includes verifying the mix consistency. The mixture's Cone Consistency test result must be controlled to 2.5-3.5 cm and the Contractor must keep a complete load-by-load record of the quantities used. Each morning, the Contractor must also give the agency a cone consistency test result obtained from each machine. The test is conducted per ISSA TB 106—*Slurry Seal Consistency Template.*(44) Acceptance includes surface preparation approval and material quality verification.

The VDOT slurry seal special provision indicates both Quality Control and Acceptance. QC includes continuously checking the mixture's consistency and aggregate abrasion loss. This testing is to be conducted by a VDOT-certified Slurry Surfacing Technician. This certification is given via VDOTs Materials Certification Schools for Surface Treatment and Slurry Surfacing. Acceptance includes taking slurry seal mixture samples from the mixing units—each representing a maximum of 25,000 yd^2 at start-up, then reduced to one sample every 50,000 yd^2—to check for asphalt content. The content must be within ±1.5% of JMF and if two successive tests from a mixing unit fail or if the failure is by more than 2%, that mixing unit is to be removed from service until approved by the Engineer. The mixture consistency is checked at least twice per day and if failure occurs, the mix must be immediately adjusted and re-tested. If two or more consecutive tests fail, then work must stop.

The Wet-Track Abrasion Test is the last test used for Acceptance. If Wet-Track Abrasion failure occurs, the Contractor may be required to adjust the mix or construction process. If either is conducted, the test must be rechecked before work can resume. If two or more consecutive tests fail, work must cease until the cause can be determined, remedied, and approved by Engineer. If, during the life of a project, excessive loss of cover aggregate occurs, the Engineer may suspend the work according to Section 108.05—*Suspension of Work Ordered by the Engineer* of the VDOT specifications until the cause of the loss of cover material is corrected.(45) The applied slurry mixture must be uniform in texture and must not flush under traffic. In the event a failure occurs prior to acceptance, the Contractor must repair or replace the failed treatment as directed by the Engineer.

3.3.3.b. State-of-the-practice

Identified state-of-the-practice includes using only Type II mixes and awarding projects to competent Contractors. These two practices have led to some agencies having successful experiences with slurry seals. Another practice involved the agency use of a separate document for sampling and controlling slurry seals.

Other recommended state-of-the-practice items for slurry seal preservation treatments include:

- Selecting quality asphalt binder and aggregate materials.
  - Quick-set asphalt emulsion.
  - Durable aggregates.
  - ISSA aggregate property tests are specified along with agency-specific tests.
- Performing a slurry seal mix design for the materials to be used during construction.
  - The ISSA method is a common slurry seal mix design standard.
- Calibrating equipment with the materials to be used during construction.
  - Recommended prior to every project.
- Proper surface preparation, including using a tack coat.
  - Achieve a clean surface to obtain bond between pavement surface and slurry seal.
- Constructing a test strip.
  - Recommended to be done on every project, under conditions similar to those that are anticipated during construction.
- Enforcing appropriate climatic conditions during construction.
  - Minimum surface and air temperatures.
  - No impending precipitation within, typically, the next 24 hours to 72 hours.
- Continuously monitoring the asphalt content and application rate of slurry seal mix during construction.
  - Ensuring proper curing prior to opening the treatment to traffic.
- Requiring Contractor's QC testing during construction.
  - Aggregate moisture content, asphalt binder property, residual asphalt binder content, and mix consistency.
- Requiring agency Acceptance sampling and testing during construction.
  - Emulsion and residual asphalt binder properties, residual asphalt binder content, mix consistency, and mix proportions.
  - Testing of mix proportions requires measuring the actual quantities of emulsion and aggregates used. If measured, they could be direct pay items. This can be challenging because of the need for weigh scales at the project. Thus, emphasizing the need for proper and frequent calibration if scales are not practically available.

An additional consideration that can support quality slurry seal construction is the use of qualified personnel for:

- Conducting slurry seal mix designs.
- Constructing slurry seal treatments.
- Inspecting slurry seal during construction.
- Field testing the slurry seal mix and materials.

3.3.3.c. Opportunities for Improvements

Some improvements could be made by including specific equipment calibration practices and updating specification details and requirements to reflect continuous changes in proper slurry seal construction practices. Other opportunities for improvement include requiring that the equipment calibration is checked, in the presence of the agency Engineer, at each project to ensure proper treatment application rates. If the agency specifications do not indicate calibration requirements, the equipment manufacturers' calibration procedures shall be followed. Finally, test strips could be mandatory, and each test strip should check the materials proportion optimization and that the proportions are kept within JMF tolerances, verify the application rate, check for uniformity of surface texture, ensure that the equipment is in good condition (no oil leaks, etc.), ensure that the workforce is well trained, check the cure time, evaluate workmanship and ensure proper alignment of the equipment.

3.4 Micro Surfacing Preservation Treatment

The micro surfacing specifications for the California Department of Transportation (Caltrans), the Minnesota Department of Transportation (MnDOT), and the Virginia Department of Transportation (VDOT) are outlined in this section. The information obtained from each agency originated from the following sources: for Caltrans, the reference document is the *2015 Standard Specifications and 2015 Revised Standard Specifications*; for MnDOT, the reference document is the *Standard Specifications for Construction, 2016 Edition* and the *Schedule for Materials Control for 2016 Standard Specifications*; and for VDOT, the reference document is the *Special Provisions for 2016 Road and Bridge Specifications*.[15,16,17,32]

Micro surfacing, as defined in Section 1.2, "consists of a mixture of polymer-modified emulsified asphalt, mineral aggregate, water, and additives, proportioned, mixed and uniformly spread over a properly prepared surface."[6] VDOT also uses term "latex-modified emulsion treatment" in reference to micro surfacing. Each agency's definition is listed below.

- Caltrans: "consists of spreading a mixture of micro surfacing emulsion, water, additives, mineral filler, and aggregate on the pavement."
- MnDOT: "a mixture of polymer modified asphalt emulsion, well-graded crushed mineral aggregate, mineral filler, water and other additives applied to a prepared surface."
- VDOT: No specification or special provision definition.

3.4.1. Materials and Testing Specifications

3.4.1.a. Asphalt Binders

The Caltrans micro surfacing specification indicates the use of an emulsion consisting of a homogeneous mixture of asphalt, polymer, and emulsifier solution. No specific grades are indicated. The emulsion must contain 3% polymer solids by weight of residual asphalt. The base asphalt binder must be modified with polymer prior to being emulsified.
The MnDOT micro surfacing specification indicates using CQS-1P or CQS-1hP emulsions. The emulsion must be polymer-modified with at least 3% natural latex polymers or a MnDOT-approved manmade latex, or styrene-butadiene-styrene (SBS) polymer. The emulsion must have at least 62% asphalt residue after distillation.

The VDOT micro surfacing special provision indicates using a quick-set CSS-1h latex-modified cationic emulsion conforming to the requirements of Section 210—*Asphalt Materials* of the VDOT specifications.(46) The residue by evaporation must be at least 62%. Latex modifier and emulsifiers must be milled into the asphalt emulsion by an approved manufacturer. Table 3.8 shows the asphalt emulsion quality tests for all three agencies.

Table 3.8. Micro Surfacing Asphalt Binder Quality Tests.

Asphalt Binder	Agencies		
	Caltrans	**MnDOT**	**VDOT**
Modified Asphalt Emulsion	Saybolt-Furol viscosity at 25°C, Sieve test, Settlement after 5 days, stability after 1 day, and Residue by evaporation. Tests on Residue are Complex Shear Modulus (G*) at 20ºC, Penetration at 25ºC, Phase angle at 50°C, Softening point, and Stiffness at -12°C.	Softening Point, Penetration at 77°F, and Solubility. Tests on residue are the same, with different value requirements.	Ring and Ball Softening Point, the "Towel Test" (VTM-89—*Quick-Set Emulsified Asphalt Setting Time*), and VTM-78—*Residue by Evaporation of Latex Modified Asphalt Emulsion.*(47,48) Sampled via VDOT Materials Division Manual of Instructions, Chapter V—*Sampling and Control of Asphalt Concrete*.(49)

3.4.1.b. Aggregates

The Caltrans micro surfacing specification indicates that the aggregate types are either rock dust or sand. Particles larger than No. 50 must be 100% crushed. The gradations are Type I, Type II and Type III. The gradation types are the same as those stated in the ISSA standard with the exception that Caltrans does not specify a gradation range for the No. 50 and No. 100 sieves. Additionally, Caltrans indicates a Type I micro surfacing, which is not a recognized type in the ISSA document. Type I has a MAS of No. 4 and Types II and III have a MAS of 3/8 inch. The aggregates must be free of vegetation and deleterious substances, clay and caked, or oversized particles. If blending aggregates from various sources, the aggregates from each source must comply with the aggregate specifications except gradation.

The MnDOT micro surfacing specification indicates that the aggregate types are Class A—crushed igneous bedrock or Taconite Tailings. The specifications allow the Contractor to blend Class B—carbonite and metamorphic rock aggregate with Class A or Taconite Tailings if the blended aggregates passing the 3/8 inch sieve and retained on the No. 16 sieve is at least 90% Class A—or Taconite or both—aggregates by weight. The gradation types are the same as those stated in the ISSA standard. As with Caltrans, however, MnDOT indicates a Type I micro surfacing, which is not an ISSA-recognized type. The gradations are Types I, II or III, to reflect the micro surfacing types. The Type I gradation has a MAS of No. 4. The Types II and III gradations have a MAS of 3/8 inch.

The VDOT micro surfacing special provision indicates that the aggregate type is a non-polishing crushed stone. The gradations are Types A, B, C and Rut-Filling. All gradations have a MAS of 3/8 inch, except Type A, which has a MAS of No. 4. Table 3.9 shows the aggregate quality tests used by the three agencies.

Table 3.9. Micro Surfacing Aggregate Quality Tests.

Aggregate Test	Agencies		
	Caltrans	**MnDOT**	**VDOT**
Sand Equivalent	X	X	
Percent Crushed Particles	X		
Durability	X		
L.A. Abrasion	X	X	
Solubility		X	
Soundness			X
Void Content			X
Organic Impurities			X
Deleterious Material			X

3.4.1.c. Other Materials

The Caltrans micro surfacing specification indicates the use of Portland cement in any combination of Types I, II and III. The specifications also indicate that an additive may be used, provided it does not adversely affect the treatment. The exact type of additive is not indicated. Any mineral filler that was used in the development of the mix design must be used in production of the final slurry seal.

The MnDOT micro surfacing specification indicates the use of Portland cement or hydrated lime as a mineral filler based on the mix design results' indication of the need for mineral filler. Portland cement must be Type I, obtained from a source on the Approved/Qualified Products List, tested according to the *Schedule of Materials Control* and tested for fineness and air permeability.[17] Hydrated lime must be Type S and meet ASTM C207—*Standard Specification for Hydrated Lime for Masonry Purposes*.[35] Water is also used and must be clean, not salty or brackish and free of injurious materials. Mix-set additives may be used although none are specified.

The VDOT micro surfacing special provision indicates that non-air-entrained Type I Portland cement conforming to Section 214—*Hydraulic Cement* or hydrated lime conforming to Section 240.02(a)—*Lime* of the VDOT standard specifications may be used.[50,51] Water must meet Section 216—*Water for Use with Cement or Lime* of the VDOT standard specifications.[52]

Additives may be used to control break/set time and must be specified in mix design although none are stated in the specifications.

3.4.1.d. Mix Design

The Caltrans micro surfacing specification indicates the use of the ISSA mix design method. It is implied that the Contractor is the designer of record. The percentages of each material must be stated by dry weight of aggregate and must be within the following ranges: 5.5-9.5% residual asphalt, 0-3% mineral filler, and water and additives as needed. The Contract Submittals include Contractor testing of the materials to be used in the mix design. At least 15 days before starting placement of a micro surfacing, the Contractor must submit two 1-quart wide-mouth plastic containers with screw top lid samples of micro surfacing emulsion, micro surfacing emulsion data that includes the supplier and type/grade of asphaltic emulsion, type of modifier polymer for micro surfacing emulsion, a copy of the specified test results for micro surfacing emulsion, and 50 lb of aggregates. Further, the Contractor must submit aggregate test results for Gradation, L.A. Abrasion, Percent of Crushed Particles, Sand Equivalent, and Durability.

At least 10 days before starting placement of a micro surfacing, the Contractor is to submit a laboratory report of test results and the proposed mix design from an authorized laboratory. The authorized laboratory must sign the laboratory report and mix design. The report must include test results used in the mix design compared with specification requirements, proportions based on the dry weight of aggregate, including ranges, for aggregate, water, additives, mineral filler and micro surfacing emulsion residual asphalt content. Recommended changes to the proportions based on heating the mixture to 100°F and mixing for 60 seconds, if atmospheric temperatures during application will be 90°F or above must also be included. These recommended changes should be considered for water, additives, and mineral filler. Quantitative moisture effects on the aggregate's unit weight determined under ASTM C29M—*Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate* must also be included.[53]

The MnDOT micro surfacing specification indicates the use of the ISSA mix design method. During an interview, the emulsion supplier was identified as the designer of record.[29] The complete mix design must be submitted within 10 business days before date of construction to MnDOT for review. The sources and materials used must be included. The JMF must contain 5.5-10.5% residual asphalt and 0.25-3.0% mineral filler, both by dry weight of aggregate. The mix design format is as follows: material sources—including the aggregate's gradation, sand equivalent, abrasion resistance, and soundness; field simulation tests—which include Wet-Stripping test, Wet-Track Abrasion Loss, Saturated Abrasion Compatibility, and trial Mix Times at 77°F and 100°F; JMF—which includes minimum and maximum percentages of filler and water, including aggregate moisture, percentage of mix-set additive, if using, residual asphalt content of the emulsion, percentage of residual asphalt, and signature and date. The target residual asphalt content must be between 5.5-10.5% dwa, and the mineral filler proportion must be 0.25-3% dwa.

The VDOT micro surfacing special provision indicates that VDOT has its own mix design method that uses some components of the Marshall Mix Design Method to test the micro surfacing mixtures. The mix design must be designed in a VDOT-approved laboratory by the Contractor for Engineer's approval and a JMF must have latex, aggregates, and emulsion

compatibility according to the Schulze-Breuer test or other Engineer-approved method, minimum Marshall Stability of 1,800 lb when tested in accordance with VTM-95—*Design of Latex Modified Emulsion Treatment (Micro surfacing)*, a flow of 6-16 units according to VTM-95, and asphalt content that gives 4.7% air voids in the mix for surface mixes and 6.5% air voids for rut-filling mixes.(54) The Contractor must also perform ignition oven calibrations and submit that with the JMF two weeks before work is to begin. The mix design proportioning is based on micro surfacing type. For Type A micro surfacing, the residual asphalt content must be between 5.5-6.5% and mineral filler must be from 0.26-3%. For Type B micro surfacing, the residual asphalt content must be between 6.5-8.5% and mineral filler must be from 0.26-3%. For Type C micro surfacing, the residual asphalt content must be between 5.0-7.5% and mineral filler must be from 0.25-3%. For Rut-filling micro surfacing, the residual asphalt content must be between 4.5-6.5% and mineral filler must be from 0.25-3%.

3.4.1.e. Mix Verification

The Caltrans micro surfacing specification indicates that the tests for mix verification on the micro surfacing mix design include Wet Cohesion at 30 minutes and at 60 minutes, Excess Asphalt, Wet Stripping, Wet-Track Abrasion Loss, Lateral Displacement, Specific Gravity after 1000 cycles of 57 kg, Classification Compatibility, and Mix Time at 25°C.

The MnDOT micro surfacing specification indicates that mix verification includes verifying that the individual proportions of materials must be shown to meet the mix design requirements. These requirements include developing a mix design that has a 90% or greater resistance to Wet-Stripping, less than 1.8 oz/ft^2 Wet-Track Abrasion Loss from 1-hour soak, less than 2.6 oz/ft^2 Wet-Track Abrasion Loss from 6-hour soak, less than 3-gram loss from Saturated Abrasion Compatibility test, mix time controllable to at least 120 seconds at 77°F, and mix time controllable to at least 35 seconds at 100°F. MnDOT is to review the Contractor's submitted mix design and perform the gradation and sand equivalence tests on the submitted aggregate samples. Per an interview, MnDOT indicated that the actual verification includes only checking the aggregate gradation.(29) MnDOT also indicated that a paper review of the submitted mix design results is conducted prior to construction.(29) If any of the Contractor's material sources—or the aggregate blend—changes, a new mix design must be submitted.

The VDOT micro surfacing special provision indicates that the mix verification includes Compatibility, Marshall stability and Flow, and Asphalt Content. The Contractor may be required to submit 50,000 grams of aggregate and 6 quarts of emulsion to VDOT for determining the asphalt content.

3.4.2. Construction Inspection Practices

3.4.2.a. Equipment

The micro surfacing equipment specification details for all three lead agencies are summarized in Table 3.10. The Caltrans micro surfacing equipment specification indicates requirements for mixing and spreading equipment (truck-mounted and continuous self-loading), standard spreader boxes, special spreader boxes (for edges or wheel depressions) and hand tools. If using truck-mounted mixers, two machines must be present on the jobsite. The calibration requirements include calibrating each mixer-spreader used in the presence of the Engineer. The Engineer must be notified at least five business days before calibrating.

Table 3.10. Summary of Micro Surfacing Equipment Specifications.

Equipment Type	Specification		
	Caltrans	**MnDOT**	**VDOT**
Mixing Equipment	• Must be able to proportion all materials and mix in continuous pug mill. • If truck-mounted mixer, must have: • Aggregate belt feeder with depth-monitoring device with automatic shut-down control. • Connections from belt feeder to emulsion pump with automatic shut-down control. • Emulsion storage located ahead of pump. • No-flow and belt feeder revolution warning systems. • If continuous mixer, must have: • Material delivery systems to double-bladed shaft mixer. • Discharge micro surfacing mix on continuous basis. • Sufficient storage capacity to maintain continuous operation.	• Must be continuous machine with aggregate belt feeder, positive displacement, and water-jacked pump for materials proportioning. • Must have mineral filler feed that can deliver accurate filler proportion to pug mill.	• Self-propelled, front-feed and continuously-loading. • Must proportion materials, mix and discharge uniform micro surfacing mixture on a continuous basis. • On treatment areas of less than 15,000 yd2, a portable mixing unit may be used, provided that a sufficient number of such units are present to ensure near-continuous operation. • Must have double-shaft mixer and operate at speeds of 60 ft/minute and able to produce 5 tons or more of mixture. • Must have individual volume and weight controls for each material. • Must provide water pressure system to fog surface ahead of spreader box.
Spreading Equipment	• Standard Spreader Box • Capable of spreading across 12-ft lane widths. • If larger than eight feet wide, must have baffles or motor augers to ensure uniform application on super-elevated sections and shoulders. • Must have series of strike-off devices at rear—leading strike-off and final strike-off. • Flexible drags not permitted. • Special Spreader Box • For shoulders, use edge box that ensures uniform and straight joints. • For scratch course, use standard spreader with adjustable steel strike-off in lieu of final. • For wheel path depressions, use adjustable strike-off of five to six feet wide to control depth. • Must have hydraulic augers or other device designed for rut-filling applications	• Spreader Box • Use mechanical-type box. • Must provide continuous material agitation. • Must have front and rear flexible seals and secondary strike-off to ensure smooth finished surface. • Burlap drags not permitted. • Rut-Filling Box • Use steel V-configuration screed box designed to fill ruts. • Capable of filling ruts across five-to-six-foot widths. • Must have strike-offs to control crowns.	• Spreader Box • Capable of spreading mixture at a uniform rate using mechanical equipment. • Must be operated to maintain homogeneous mixture and to ensure that premature breaking does not occur. • Must have front and rear flexible seals. • Must be maintained to prevent material loss on super-elevated curves. • Rut-Filling Box • Must be designed specifically for rut filling. • Must be one-half lane-width wide and equipped with V-auger configuration and dual strike-offs.
Hand Tools	• Only used in areas inaccessible to spreading equipment. • Dampen area with water prior to using hand tools.	Not specified.	Not specified.
Weighing Equipment	Not specified.	• Portable scales to accurately weigh material.	Not specified.

The calibration is conducted per Caltrans' *Material Plant Quality Program* document.[24] Before using a variable-rate emulsion pump, the pump must be calibrated and locked at the calibrated setting. For the aggregate belt feeder, the delivery rate for any individual check run must not deviate more than two percent from the average of the rates of three runs of at least three tons each. For the emulsion pump, the delivery rate for any individual check run must not deviate more than 2% from the average of the rates of 3 runs of at least 300 gal each. If Caltrans authorizes a mixer-spreader machine, its calibration is valid for six months provided the Contractor:

- Uses the same truck verified with a unique identifying number,
- Uses the same materials in compliance with the authorized mix design,
- Does not perform any repair or alteration to the proportioning systems.

The MnDOT equipment specifications indicate requirements for a mixing machine, a spreader box, a rut-filling box, and weighing equipment. The equipment calibrations must be conducted once per year and after equipment repairs have been completed. The mixing machine is to be calibrated prior to each use. Recalibration must be conducted for any changes that are made. Per the interview with the agency, the mixing machine is calibrated at three aggregate flow rates and for each emulsion and cement. The machines on the job are to be re-calibrated after a change in aggregate, asphalt emulsion source, or repairs are made to the aggregate feeding belt, gate, or emulsion pump.

The VDOT micro surfacing special provision indicates requirements for mixing equipment, a spreader box and if required, a pneumatic-tire roller. All equipment must be specifically designed for micro surfacing construction. Further, all equipment must be calibrated, and the data submitted by the Contractor must be of the current calendar year for each mixing unit using the same materials as those materials that are to be used on the project. Data must be presented on a graphic scale showing the proportioning control settings needed to obtain the optimum residual asphalt content needed based on the mix design and must be maintained with each unit.

3.4.2.b. Climate Limits

The Caltrans micro surfacing specification indicates that the treatment is to be placed only if both the air and surface temperatures are 50°F and rising. The micro surfacing treatment must not be placed if either temperature is below 50°F and falling. The expected high air temperature must be at least 65°F within the next 24 hours post-construction and must not be expected to drop below 36°F within the same time frame. The Caltrans micro surfacing specification does not indicate calendar dates to begin or end construction.

The MnDOT micro surfacing specification indicates that air and surface temperatures must be at least 50°F and rising. Micro surfacing is not to be placed during rainfall, or if the forecast indicates a temperature below 32°F within 48 hours post-construction. The MnDOT micro surfacing specification indicates that work is not to start after September 15.

The VDOT micro surfacing special provision indicates that the micro surfacing treatment is not to be applied on surfaces with puddled water or when the surface temperature is less than 50°F, except in the morning hours when the anticipated high air temperature is at least 60°F or higher and the surface temperature is to be 40°F and rising. The treatment can be placed if the air

temperature is not expected to drop below 32°F within the next 24 hours post-construction. Night paving is allowed, provided sufficient lighting is provided by the Contractor for proper construction. VDOT does not have any specified calendar dates to begin or end construction.

3.4.2.c. Surface Preparation

The Caltrans micro surfacing specification indicates that the surface preparation practices include covering manholes, valve and monument covers, grates, or other exposed features located within the area of application. The Contractor must also clean the pavement surface by removing loose particles of extraneous materials using any non-destructive method, such as flushing or sweeping, prior to construction. The Contractor may fog the roadway surface with water ahead of the spreader box. The fog spray must be adjusted for pavement temperature, surface texture and dryness

If work is required in the Contract for repairing wheel path depressions, the depressions and irregularities must be filled with micro surfacing material before spreading the actual micro surfacing treatment in full lane-widths. If the depressions are less than 0.5 inches deep, a scratch course can be used. If the depressions are 0.5 inches deep or more, the depressions must be filled using a wheel path depression—also known as rut-filling—box. If using a scratch course, it must be spread by adjusting the rigid strike-off in a scratch course box until it is directly in contact with the pavement surface. If using a rut-filling course, the micro surfacing material shall be applied with a wheel path depression rut box leaving a slight crown at the surface. Multiple applications are used to fill depressions more than 1.5 inch deep. No more than 1.5 inch of material is applied in a single application. Each filled wheel path depression is allowed to be compacted by traffic for at least 12 hours before placing additional micro surfacing mixture.

The MnDOT micro surfacing specification indicates that the surface preparation practices include cleaning the surface immediately before placing the micro surfacing. If a fog seal is required, the Contractor must apply the fog seal to surfaces before the first course of micro surfacing using CSS-1 or CSS-1h emulsion in accordance with the MnDOT specification 2355—*Bituminous Fog Seal*.[55] The diluted emulsion is applied at a rate of 0.05 to 0.10 gal/yd^2. The Contractor must limit the daily application of fog seal to that pavement area which is receiving micro surfacing on that same day. Fog sealed areas are not opened to traffic. The fog seal must be allowed to cure before applying the micro surfacing treatment. The Contractor must protect drainage structures, monument boxes, and water shut-offs during the application of the fog seal and during micro surfacing.

The VDOT micro surfacing special provision indicates that the surface preparation practices include cleaning the surface of all loose materials, vegetation, soils, and other materials. A 3:1 water-diluted CSS-1h emulsion tack coat must be applied at a rate of 0.05 gal/yd^2 prior to applying the micro surfacing treatment. Field conditions may necessitate uniform pre-wetting of the cured tack coat prior to applying the micro surfacing.

3.4.2.d. Inspection

The Caltrans micro surfacing specification indicates that the inspection process includes first proportioning the micro surfacing materials using the proportions outlined in the authorized mix design. The Engineer determines the exact spread rate for micro surfacing and the completed

spread rate must be within ten percent of that which was given by the Engineer. The micro surfacing can be placed either in the direction of traffic or in the opposite direction. The finished micro surfacing must be free of irregularities such as scratches or tear marks.

The MnDOT micro surfacing specification indicates that the inspection process includes first holding a pre-paving meeting with the Engineer on-site before beginning work. It is held to discuss the JMF, equipment condition and calibration, test strips, a detailed work schedule, and a traffic control plan. The application rate is checked by MnDOT once per day. Prior to treatment construction, a test strip is to be placed in a location approved by the Engineer. For each machine used, a one-lane-width-wide test strip at least 1,000 feet in length is constructed. The treatment application is to begin after dark, at least one hour after sunset and/or at least one hour before sunrise. The finished surfaces that were obtained from each of the machines are compared for variances in surface texture and appearance. The test strip is not to be constructed until the emulsion temperature in the mixture falls below 122°F. If the type of emulsion, type and size of aggregate, type of mineral or the lay down machine are changed, or field evidence shows that the system is out of control, a new test strip is constructed. Traffic is allowed on the test strip within one hour after application. The Engineer will evaluate whether any damage occurs and will inspect the completed test strip again after 12 hours of traffic to determine if the micro surfacing is acceptable. The Contractor may begin full production after the Engineer accepts a test strip.

The Engineer may waive the test strip requirement, if the Contractor submits evidence of the successful construction of a test strip on another project constructed during the same construction season, using the same mix design. Micro surfacing work is stopped if the system is out of control and cannot meet the requirements of the specification. If the system does not construct the micro surfacing treatment to meet the specification requirements, the Contractor must correct the system, to the approval of the Engineer, before re-starting the work.

The VDOT micro surfacing special provision indicates that the inspection process includes first determining the appropriate application rates. Application rates depend on type of micro surfacing treatment. The minimum rates are 16 lb/yd^2 for Type B mix and 20 lb/yd^2 for Type C mix. Surface course microsurfacing must be the final application and must be placed at a minimum rate of 16-20 lb/yd^2 for Type B mix and 18-22 lb/yd^2 for Type C mix. If neither rut-filling nor levelling is used, the application rates can be 18-22 lb/yd^2 for Type B and 20-24 lb/yd^2 for Type C. Application rates are verified by the Engineer, via Contractor-submitted weight tickets, daily delivery summaries and estimated aggregate loss or unused aggregate for each stockpile. The Engineer has final say in the event of a disagreement. Oversized aggregates and foreign materials should be screened from the stockpiles before the aggregates are delivered to the machine. All unused materials must be removed immediately from the end of each run. Loose aggregates must be immediately removed without damaging the surface at the Engineer's direction. The Engineer may reject any work because of poor workmanship, loss of texture, raveling, or apparent instability. The entire contracted area must be treated, and the mixture quantity stated in the contract must not be exceeded.

3.4.2.e. Mix Adjustments

The Caltrans micro surfacing specification indicates that mix adjustments occur if field conditions require adjustments to the proportions during construction. The Contractor must

obtain authorization before adjusting proportions. It is implied that the authorization comes from either the Engineer or Caltrans.

The MnDOT micro surfacing specification indicates that if adjustments are to be made, then a new test strip is to be constructed, to ensure that the adjustments do not affect the system. If the type of emulsion, aggregate type and size, mineral filler, lay down machine, or field evidence shows that the system is out of control, a new test strip is constructed. During an interview, MnDOT indicated that the Contractor controls the use of an emulsion break additive, but the Contractor cannot change the emulsion application rate.[29] Any mix adjustments require approval from the MnDOT inspector.

The VDOT micro surfacing special provision does not indicate mix adjustments. However, a mixing aid additive can be used to accommodate spreading due to slow placing or high temperatures. Water—in very limited quantities—may be sprayed into the spreader box to prevent build-up on the blades.

3.4.2.f. Opening to Traffic

The Caltrans micro surfacing specification indicates that the treatment must be protected from damage until it has set to the extent that it will not adhere to, or be picked up by, vehicle tires. The micro surfacing treatment must not exhibit distress from traffic such as bleeding, raveling, separation, or other distresses.

The MnDOT micro surfacing specification indicates that the micro surfacing is not to be opened to traffic until the treatment has cured sufficiently to prevent pickup by vehicle tires. A properly constructed micro surfacing treatment to be capable of carrying normal (i.e., no “stop-and-go”) traffic within one hour of application without damage. The treatment is to be protected from potential damage at intersections and driveways. Any damage to the surface caused by traffic is to be repaired at no additional cost to MnDOT. The inspector will confirm that the micro surfacing has cured within one hour on the first day of production, after the construction of the test strip. The Engineer will conduct three one-hour spot checks. If a spot check fails, stop work and construct a new test strip. MnDOT will consider any spot check or test strip failure as unacceptable work in accordance with 1512—*Unacceptable and Unauthorized Work*.[56] After the successful completion of three, one-hour spot checks on the first day of production, the Engineer will perform spot checks once a day.

The VDOT micro surfacing special provision indicates that curing practices include not allowing treated areas to be opened to traffic until the treatment has cured to the extent that it will not be damaged by traffic. If an earlier opening is necessary—such as at road entrances—the Contractor may sand the new surface with an aggregate cover that uses the same aggregate used in the mix. The Contractor may be required to remove the excess from the roadway and in curb and gutter areas.

3.4.2.g. Post-Construction Monitoring

The Caltrans micro surfacing specification indicates that post-construction monitoring practices include requiring the Contractor to sweep the fresh treatment daily for five days post-construction. The MnDOT micro surfacing specification indicates that the Contractor repair any

damages to the treatment immediately post-construction. The VDOT micro surfacing special provision does not indicate post-construction monitoring practices. During an interview, it was indicated that VDOT monitors projects—including preventive maintenance treatment projects—at the network level.(57)

3.4.3. Quality Assurance Specifications

3.4.3.a. Quality Control and Acceptance

The Caltrans micro surfacing specification indicates requirements for Quality Control and Department Acceptance. Also included in this section of the Caltrans specifications is the requirements for Submittals. The Acceptance aspect includes Caltrans' material testing and inspection of the final surface. Caltrans accepts aggregate based on compliance with the aggregate Gradation and Sand Equivalent requirements. An aggregate gradation or cleanness value test represents 300 tons or 1 day production, whichever is less. If the test results for aggregate gradation or Sand Equivalent do not comply with the specified requirements, the Contractor may remove the installed treatment represented by the test results or request it remain in place with a payment deduction. If the request is authorized, Caltrans deducts $2.00 per ton of micro surfacing for each noncompliant aggregate gradation and Sand Equivalent test.

The finished surface is accepted based on visual inspection for uniform surface texture throughout the work limits and acceptable marks in the surface—up to 4 marks in the completed surface that are up to 1 inch wide and up to 6-inch-long per 1,000 ft^2 of microsurfacing placed. The finished surface is rejected if marks in the completed micro surfacing surface are over 1 inch wide or 6-inch-long, or if there is: excessive raveling—consisting of the separation of the aggregate from the micro surfacing emulsion; bleeding—consisting of the occurrence of a film of asphaltic material on the surface of the micro surfacing; delaminating of micro surfacing from the existing pavement; rutting; or wash-boarding.

The QC aspect includes Contractor mix design testing. The testing laboratory must sign the original laboratory report and mix design. If the mix design consists of the same materials covered by a previous laboratory report, the Contractor may submit the previous laboratory report that must include material testing data performed within the previous 12 months for authorization. If materials change in the mix design, a new mix design and laboratory report must be submitted.

A laboratory report of test results and proposed mix design must be submitted 10 days before starting placement of micro surfacing. The report and mix design must include the specific materials to be used and show a comparison of test results and specifications. The report must also include test results used in the mix design, proportions of the following materials based on the aggregate's dry weight—Aggregate, water (minimum and maximum), additives, mineral filler (minimum and maximum), and micro surfacing emulsion residual asphalt content (minimum and maximum). It also needs to include recommended changes to the following proportions based on heating the mixture to 100°F and mixing for 60 seconds—Water, additives, mineral filler, comparison of each individual material's test results to the specified values, and the quantitative moisture effects on the aggregate's unit weight, as determined in accordance with ASTM C29M—*Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate.*(53) The recommended changes listed above do not apply to night-time applications or

if ambient temperatures below 90°F are forecast for daytime applications. Submit a certificate of compliance with each shipment of micro surfacing emulsion.

The MnDOT micro surfacing specification and the *Schedule of Materials Control* both indicate Quality Control and MnDOT Acceptance practices. The QC aspect includes sampling and testing materials. In the MnDOT specifications, the QC subsection of the micro surfacing specification includes details on sampling and testing emulsion and aggregates. Application rate verification is also discussed.

For the emulsion, the Contractor must provide a material Bills of Lading (BOL) for each batch of emulsion used which must include the supplier's name, plant location, emulsion grade, residual asphalt content, volume (gross and net, gallons), and batch number. The QC testing is to be conducted by the emulsion supplier, per MnDOT's SMC.

For the aggregate, the Contractor must sample and test according to the SMC. The frequency of aggregate testing, the timing (pre- vs. during production) and the sampling location depends upon the type of aggregate test being conducted. QC test results must be provided daily to the Engineer and a summary upon completion of the work must also be given. According to the SMC, for production gradation testing, the aggregate is to be sampled from the machine hopper and tested either once per day or once per 500 tons, whichever is less. The Contractor must also submit a 30-lb aggregate sample to MnDOT. For aggregate Moisture Content, the aggregate is to be sampled from the machine hopper and tested once per day or once per 500 tons, whichever is less. The Contractor must submit a 2-lb sample to MnDOT. For Sand Equivalence, the aggregate is to be sampled once per day. The sampling location is not specified. Micro surfacing application rates are to be verified by the Contractor at least three times per day.

Per MnDOT's specifications, the Acceptance aspect includes agency sampling and testing according to the MnDOT SMC.[16] These tests are to be conducted on the asphalt emulsion and the aggregate gradation and moisture content. In the SMC, MnDOT is responsible for verification testing of the production gradation, aggregate moisture, sand equivalence, asphalt binder tests and micro surfacing application rate. For production gradation, the agency is to sample and test once at the time of production. The aggregate moisture content is to be tested once per day during production. Sand Equivalence is tested once per project during the agency's review of the mix design prior to production. MnDOT samples and tests the micro surfacing emulsion on the first load of emulsion, and then once every 50,000 gallons. The application rate is to be verified by MnDOT once per day.

The VDOT micro surfacing special provision indicates requirements for Quality Control and Acceptance. Mixture samples that represent no more than 500 tons of mixture are to be taken during construction from each mixing unit for determining asphalt content. The determined asphalt content must be found to be within ±1.5% of the JMF target. If two successive tests from one mixing unit fail or if one test fails by more than two percent, that unit must be removed from the jobsite until the Engineer approves its resumption of work. Aggregate tests include gradation on samples from stockpiles designated by Contractor located in producer's quarry and acceptance will be based on approved aggregate producer's acceptance production control plan.

Samples for Marshall tests and asphalt content shall be taken from the completed mix for testing by the Department.

The frequency of sampling and testing will be established by the Engineer based upon the Department's acceptance program. The asphalt content will be determined by the Ignition Method (VTM-102—*Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method – (Asphalt Lab)*) or nuclear gauge (VTM-93—*Nuclear Asphalt Content Gauge Determination for H.M.A. and Slurry Seal Mixtures – (Asphalt Lab)*), as determined by the Engineer.[39,58] Based upon a visual examination or test results the Engineer may reject any work due to poor workmanship, loss of texture, raveling or apparent instability.

3.4.3.b. *State-of-the-practice*

The identified state-of-the-practice includes the entirety of some agencies' specification details, which are critical to performance, and enforcement of mandatory winter shutdowns in wet-freeze climate zones. Constructing a one-hour nighttime test strip that verifies the "true chemical break" of the emulsion is considered state-of-the-practice. Other practices include monitoring asphalt content during placement via sampling and testing and ensuring that the Contractor always has a certified technician on site. Screening oversized particles during the proportioning phase might also be considered state-of-the-practice, although in some areas where dust control is important, following such a practice may not be feasible. In those scenarios, the Contractor should work closely with aggregate producers to ensure that oversized particles are screened out prior to the aggregate's delivery to the job site.

Other recommended state-of-the-practice items for micro surfacing preservation treatments includes:

- Selecting quality asphalt binder and aggregate materials.
    - Latex-modified emulsion.
    - ISSA aggregate property tests are specified along with agency-specific tests.
- Performing a micro surfacing mix design for the materials to be used during construction.
    - The ISSA mix design method is a common micro surfacing mix design standard.
- Calibrating equipment with the materials to be used during construction.
    - Recommended to be done prior to every project.
- Proper surface preparation to achieve a clean surface to obtain bond between the pavement surface and the micro surfacing.
- Constructing a test strip.
    - Recommended to be done on every project, under conditions similar to those that are anticipated during construction.
- Requirements for contractor's QC testing during construction.
    - Aggregate production gradation and moisture content, asphalt binder property, residual asphalt binder content, and mix application rate.
- Requirements for agency Acceptance sampling and testing during construction.
    - Aggregate production gradation, moisture content, sand equivalent, and cleanness.
    - Emulsion and residual asphalt binder properties, residual asphalt binder content, and mix proportions.
    - Testing of mix proportions requires measuring the actual quantities of emulsion and aggregates used. If measured, they could be direct pay items. This can be

challenging because of the need for weigh scales at the project. Thus, emphasizing the need for proper and frequent calibration if scales are not practically available.

- Enforcing appropriate climatic conditions during construction.
  - Minimum surface and air temperatures of 50°F and rising.
  - Wintertime construction shutdowns.
  - No impending precipitation within, typically, the next 24 hours to 72 hours.
- Ensuring proper curing prior to opening the treatment to traffic.

An additional consideration that can support quality micro surfacing construction includes the use of qualified and/or certified personnel for:

- Conducting micro surfacing mix designs.
- Constructing micro surfacing treatments.
- Inspecting micro surfacing during construction.
- Field testing the micro surfacing mix and materials.

3.4.3.c. Opportunities for Improvements

Improvements can be made by incorporating more personnel training and improving and implementing QA programs. Another improvement can be to check for daily yield or treatment thickness. There is a general need for personnel training and more experience. Some agencies identified two problems that are common for inspection: (1) there is significant turn-over in inspection staff and (2) there is a "lack of emphasis" placed on the importance of effective treatment inspection. Some agencies' QA programs also need to improve the process used to review and approve mix design changes. Some QA programs do not address the control of moisture added to the mix. Some current emulsion specifications allow for a stiff base asphalt to be used, a practice that is currently being altered to allow a softer base asphalt requirement.

Some agencies could further improve practices by reviewing and revising the current specifications, allowing for general improvements to the overall quality of micro surfacing treatments, especially for inspection requirements. Further, some agencies indicate using a mix design method that does not use current accepted methods. Finally, annual equipment calibration is only sufficient if the project's test strips are required to verify that the calibration is correct, as some agencies do not monitor the completed surfaces for short periods in order to watch for material failure.

A final improvement can be made in terms of equipment calibration. Equipment calibration may need to be checked prior to the construction phase of every project. If the agency specifications do not indicate calibration requirements, the equipment manufacturers' calibration procedures shall be followed.

3.5 Thin Lift Asphalt Overlay Preservation Treatment

The thin lift asphalt overlay specifications for the California Department of Transportation (Caltrans), Florida Department of Transportation (FDOT), Michigan Department of Transportation (MDOT), and Ohio Department of Transportation (ODOT) are outlined in this section. The information obtained from each agency originated from the following sources: for Caltrans, the reference document is the *2015 Standard Specifications and 2015 Revised Standard*

Specifications; for FDOT, the reference document is the *Standard Specifications for Road and Bridge Construction*; for MDOT, the reference documents are the *2012 Standard Specifications for Construction* and the *Special Provision for Warranty Work Requirements for Hot Mix Asphalt Ultra-Thin Overlay*; and for ODOT, the reference document is the *Construction and Materials Specifications.*[15,59-62]

A Thin Lift Asphalt Overlay, as defined in Section 1.2, "consists of a fine-graded surface asphalt mix 1 inch or less in thickness that is mixed and placed on a prepared surface."[7] Each agency's definition is listed below. It is important to note that while these agencies have similar definitions for the treatment, the actual naming conventions vary slightly. For example, ODOT indicates that the name for such mixes is Fine-Graded Polymer Asphalt Concrete. MDOT refers to treatments of this type as Ultra-Thin Overlays. Both Caltrans and FDOT do not have stand-alone thin lift asphalt overlay specifications but instead, use small-NMAS mixes that adhere to each agency's hot-mix asphalt specifications. The agencies' specification definitions are listed below:

- Caltrans: No definition in standard specifications.
- FDOT: "A small nominal maximum aggregate size surface asphalt mix, 1-inch or less in thickness that is mixed, placed, and compacted atop a prepared surface."
- MDOT: No definition in warranty provision or standard specification.
- ODOT: "Consists of constructing a surface course of aggregate and polymer modified asphalt binder mixed in a central plant and spread and compacted on a prepared surface." A thickness is not indicated.

3.5.1. Materials and Testing Specifications

3.5.1.a. Asphalt Binders

The Caltrans thin lift asphalt overlay do not indicate asphalt binders to be used for thin lift asphalt overlays. The binder grade to be used is found in the special provisions for each individual project and is based on the climate zones of California. Caltrans uses PG asphalt binder grades PG58-22, PG64-16, PG64-10 and PG70-10. Caltrans also uses asphalt rubber binder for thin lift asphalt overlays. The binder must meet the specifications for quality. The FDOT hot-mix asphalt specification indicates using a polymer- or rubber-modified PG76-22 binder. The binder must meet the specification requirements for quality.

The MDOT thin lift asphalt overlay warranty provision indicates using a PG binder grade that is based upon the treatment's current two-way traffic volume. For a two-way average daily traffic (ADT) of less than 380, the required binder grade is PG58-28. For an ADT of 380-3,400, the required grade is PG64-28P and for an ADT of more than 3,400, the grade is PG70-28P. The asphalt binder must meet the requirements of Section 904—*Asphaltic Materials* in MDOT's specifications.[63] If recycled asphalt pavement (RAP) will be used, up to 27% replacement is allowed without a change in binder grade. If the RAP percentage is greater than 27%, a new binder grade is selected using a blending chart. The blending chart must be supplied with the RAP test data.

The ODOT thin lift asphalt overlay specification indicates the use of a PG76-22M binder. Another binder grade that is allowed is a PG64-22 binder that is modified by 5.0±0.3% by binder weight of styrene-butadiene-rubber (SBR) solids, such that the resulting blend will meet the

specification requirements for a PG76-22 binder post-modification, as outlined in Section 702.01—*Asphalt Binders* in the ODOT specifications. The SBR must conform to Section 702.14—*SBR Emulsion*.[64,65]

3.5.1.b. Aggregates

The Caltrans specification does not indicate aggregate types. The gradation must comply with the Caltrans Rubberized Hot-Mix Asphalt Gap-Graded specification, which for a thickness of 0.1 feet (1.2 inch) is a ½ inch MAS gradation.

The FDOT hot-mix asphalt specification indicates that the aggregate types are dependent upon the project's location in the state. If the project is located in the northern part of the state, the aggregate is granite. If the project is in the southern part, the aggregate is limestone. The gradations have NMAS values of 3/8 inch and No. 4, respectively. Table 3.11 shows the aggregate quality tests used by the four agencies.

Table 3.11. Thin Lift Asphalt Overlay Aggregate Quality Tests.

Aggregate Test	Agencies			
	Caltrans	FDOT	MDOT	ODOT
L.A. Abrasion	X	X	X	X
Percent Crushed Particles	X		X	X
Flat and Elongated Particles	X	X		
Aggregate Angularity	X		X	
Sand Equivalent	X			
Schist Content		X		
Aggregate Wear Index			X	
Unit Weight				X
Micro-Deval Abrasion				X
Soundness		X		X
Bulk Specific Gravity				

The MDOT thin lift asphalt overlay warranty provision does not indicate aggregate types. However, for fine aggregate to be used in MDOT's HMA mixtures, the aggregate types are natural aggregate, iron blast furnace slag, reverberatory furnace slag (produced during the refinement process of copper ore), steel furnace slag, manufactured fine aggregate, or a uniformly graded blend as fine aggregate. The required values are dependent upon the project's current two-way ADT. The aggregate gradation must have a MAS of ½ inch.

The ODOT thin lift asphalt overlay specification indicates that the aggregate types are natural sand or sand manufactured from stone, gravel, or Air-Cooled Blast Furnace Slag (ACBFS) for fine aggregate, and Crushed Carbonate Stone (CCS) or ACBFS for coarse aggregate. The gradations have MAS values of 3/8 inch for Type A mixes and ½ inch for Type B mixes.

3.5.1.c. Other Materials

The Caltrans rubberized hot-mix asphalt specification indicates the use of lime—applied either dry or using the slurry method—or liquid anti-strip. Warm-mix asphalt technologies may be used for rubberized hot-mix asphalt.

The FDOT hot-mix asphalt specification indicates that either a hydrated lime or liquid anti-strip treatment may be used in thin lift asphalt overlay mixes. Per an interview, FDOT indicated that lime is not always used in dense-graded mixtures.(66) Rather, the liquid anti-strip treatment is a more common method for reducing moisture susceptibility in dense-graded mixtures.

The MDOT thin lift asphalt overlay warranty provision indicates that mineral filler, anti-foaming agents, and RAP may be used in thin lift asphalt overlays. The mineral filler must be dry 3MF made of limestone dust, dolomite dust, fly ash collected by an electrostatic precipitation method, slag, or hydrated lime. The gradation must be 100% passing the No. 30 sieve and 75-100% passing the No. 200 sieve. The anti-foaming agent must be silicone material added in an amount not greater than five ppm. The RAP must be produced to the size required by the mix design.

The ODOT thin lift asphalt overlay specification indicates that up to 10% RAP in Type B mixes is allowed, but does not allow for RAP to be used in Type A mixes. Further, mineral filler is also allowed to be used. It must be made of limestone dust, Portland cement or other inert material. It must be dry and free of lumps and comply with specification gradation requirements. If an anti-strip additive is required, then liquid anti-strip or hydrated lime may be used.

3.5.1.d. Mix Design

The Caltrans specification indicates that the mix design method is the Superpave mix design. It is implied that the Contractor is the designer of record.

The FDOT hot-mix asphalt specification indicates the use of the Superpave mix design. The Contractor is the designer of record. The contractor's mix design is verified by FDOT.

The MDOT thin lift asphalt overlay warranty provision indicates the use of both the Marshall and Superpave mix design methods. The Contractor is the designer of record and must produce a mix design that meets the requirements of the MDOT *HMA Production Manual*.(67)

The ODOT thin lift asphalt overlay specification indicates that any mix design method that is outlined in the Asphalt Institute's *MS-2: Asphalt Mix Design Methods* may be used, with no particular method being explicitly required over another. It is implied that the Contractor is the designer of record.

3.5.1.e. Mix Verification

The Caltrans specification indicates that Caltrans performs tests for Gradation, Percent of Crushed Particles for Coarse and Fine Aggregate, L.A. Abrasion, and Sand Equivalent on the aggregates for mix verification. The completed mix is tested to determine Air Voids, Number of Gyrations, Voids in the Mineral Aggregate, Dust Proportion, Hamburg Wheel-Track Rutting Resistance and Moisture Susceptibility. Moisture Susceptibility is tested on the plant-produced mix.

The FDOT hot-mix asphalt specification indicates that the actual thin lift overlay mix verification includes testing for moisture susceptibility per FDOT's version of AASHTO T283. The resultant mixture must have a minimum tensile strength ratio of 0.8 and a minimum unconditioned tensile strength of 100 psi. Per an interview, it is indicated that one of FDOT's districts also uses the Asphalt Pavement Analyzer (APA) rutting test for mix verification.(66)

The MDOT thin lift asphalt overlay warranty specification indicates that mix verification is conducted per the MDOT *HMA Production Manual* for verification.(67) For all mix designs, the MDOT Bituminous Mix Design Unit will first conduct a paper review of the Contractor's submitted mix design documentation for specification compliance and will evaluate the mix design by entering the data into MDOT's Mix Design software. Next, the Contractor must submit the aggregates and mixture samples and test results for mix verification testing.

The ODOT thin lift asphalt overlay specification indicates that the requirements for Type B mixes include requiring the Contractor to submit a preliminary JMF to the ODOT Office of Materials Management (OMM) at least two weeks before starting work for preliminary approval. Once it has been approved, the Contractor is to perform a mix design and supply the data to ODOT. The Contractor must also submit a 5-lb uncompacted sample that represents the JMF. Final JMF approval is done by field verification. This is conducted by obtaining split samples from the Contractor QC or from independent sampling taken from the plant or the roadway. For Type B mixes, if the JMF contains gravel coarse aggregate or 25% or more of natural sand, tests for Moisture Susceptibility, Washed Gradation, and Adherent Fines for Each Component are to be conducted to determine the need for an anti-strip additive. If the OMM requires further testing, Gradation and Methylene Blue Absorption of Fine Aggregate (ODOT Supplement 1052—*Determination of Methylene Blue Adsorption Value of Mineral Aggregate Fillers and Fines)* may also be conducted.(68)

3.5.2. Construction Inspection Practices

3.5.2.a. Equipment

The thin lift asphalt overlay equipment specifications and requirements for all four lead agencies are summarized in Table 3.12. The Caltrans thin lift asphalt overlay equipment specification indicates equipment requirements for pavers, rollers, and material transfer vehicles (MTVs). There is also a provision for using method compaction. Calibration procedures are not indicated.

The FDOT hot-mix asphalt specification indicates equipment requirements for the paver and rollers. Equipment calibration requirements are not indicated.

Table 3.12. Summary of Thin Lift Asphalt Overlay Equipment Specifications.

Equipment Type	Specification			
	Caltrans	**FDOT**	**MDOT**	**ODOT**
Hauling	Not specified.	Not specified.	• Must be equipped to protect mixture from environment and heat loss.	• Must have light, clean, smooth beds for allowing entire mix quantity to be transferred. • Thin coat of release agent applied to bed before material is transferred into bed.
Paver	• Must be self-propelled, mechanical, with a heated screed or strike-off assembly capable of distributing mix across full lane width. • Must have a full-width compacting device. • Must have automatic screed controls to control thickness, grade, and slope.	• Must be self-propelled, steerable and equipped with a hopper and mechanical screed. • Screed must have grade and cross-slope controls, and extensions to provide preliminary compaction.	• Must have full-width vibratory or tamper-bar screed for spreading and finishing to required cross-slope and grade. • Must provide uniform surface. • Must have automatic grade and cross-slope controls.	• Must be self-contained and of sufficient design to receive, distribute, and strike-off mix onto roadway surface at rates and widths specified. • Must have automatic screed control systems. • Must be equipped to prevent segregation of material.
Roller	• Must have system that prevents mix from adhering to wheels. • If using method compaction, must have three rollers, each self-propelled and reversible. • One vibratory roller designed to compact HMA able to produce 2,500 vibrations per minute and weighing at least 7.5 tons. • One oscillating pneumatic-tire roller at least four ft wide with tires of equal size, inflated to 60 psi. • One steel-wheel two-axle roller with static weight of 7.5 tons.	• Must be able to meet density. • Must have system to prevent material from adhering to wheels. • If using standard rolling, must have self-propelled pneumatic-tire roller with 7 smooth-tread tires inflated to 50-55 psi, and a minimum weight of 6 tons.	• For steel-wheel rollers, must be self-propelled vibratory or static, tandem or three-wheel rollers. • Must have steering control and equipped with a system to prevent material adherence. • If vibratory roller, must have automatic vibration shut-off if speed drops below 0.5 mph. • For pneumatic-tire, must be self-propelled with seven wheels spaced on two axles with the front axle spacing overlapping rear axle spacing by 0.5 inch. • Must have smooth tires inflated to recommended pressure, be reversible, and equipped with system to prevent material adherence.	• Steel-wheel only. • If tandem, must have maximum capacity of 700 yd2/hour total weight of 8-12 tons and compression rolls of 200 lb/inch width. • If three-wheel, must have maximum capacity of 700 yd2/hour, total weight of 10 tons and compression rolls of 200 lb/inch width. • If trench, must have maximum capacity of 15 yd^2/hour and compression rolls of 300 lb/inch width. • Must have system to prevent material adherence.
Material Transfer Vehicle	• Must have sufficient storage capacity to prevent paver from stopping. • Must be able to either directly receive mixture or have a windrow pick-up device. • Must re-mix material using augers before transferring to paver. • Must be able to transfer mix directly to paver's hopper.	Not specified.	• Must be capable of delivering mix from haul truck to paver hopper in such a way as to maintain a constant paver speed. • Must have 10-ton hopper insert that is kept one-third full of mix.	• Must have a 10-ton paver hopper insert. • Must re-mix inside hopper insert or inside the vehicle. • Use on intermediate and surface course paving.

The MDOT thin lift asphalt warranty provision does not indicate equipment requirements. The MDOT standard specifications indicate equipment requirements for cold-milling equipment, hauling equipment, pressure distributor (for tack coat application), pavers, rollers, spreaders, material transfer devices, and light equipment. Calibration procedures are not indicated in the specifications.

The ODOT thin lift asphalt overlay specification indicates equipment requirements for the mixing plant, the hauling equipment, paver, MTV, and rollers. The plant is to be calibrated per Supplement 1101—*Asphalt Concrete Mixing Plants.*[69] The aggregate weighbridge and asphalt binder metering system are both to be calibrated. The calibration must be accurate within ±1.0%.

3.5.2.b. Climate Limits

The Caltrans thin lift asphalt overlay specification indicates that for unmodified asphalt binder, the minimum air temperature is 55°F and surface temperature is 60°F. The start and end dates for construction are not indicated in the specifications. Tarps are required on all haul trucks if the ambient air temperature is below 70°F or the haul time to the jobsite exceeds 30 minutes.

The FDOT hot-mix asphalt specification indicates that the asphalt mixture is not to be transported from the plant to the roadway unless all weather conditions are suitable for the paving operations. Place the mixture only when the air temperature in the shade is 50°F.

The MDOT thin lift asphalt warranty provision indicates that the mix is not to be placed if there is excessive moisture on the existing surface. The surface temperature for thin overlay placement must be at least 50°F, and frost is not to be present on the surface, particularly in shaded areas. Depending upon the location within Michigan, the start and end dates for construction vary. For the Upper Peninsula, the construction dates are from June 1 to October 15. For the Lower Peninsula, north of M-46, the construction dates are from May 15 to November 1. For the Lower Peninsula, south of M-46, the construction dates are from May 5 to November 15.

The ODOT thin lift asphalt overlay specification indicates that surface courses of less than 1 inch in thickness are not to be placed unless the surface temperature is at least 60°F. The air temperature must not be below 60°F. Polymer-modified asphalt courses are not to be placed after November 1. Insulated haul truck beds are required if transporting the material in ambient temperatures of 50°F or less or if the haul time is to exceed 20 minutes.

3.5.2.c. Surface Preparation

The Caltrans thin lift asphalt overlay specification indicates that the surface preparation practices include removing loose paving particles, dirt, and other extraneous material by any means including flushing and sweeping before paving.

The FDOT hot-mix asphalt specification indicates that the surface preparation practices include placing the mixture only when the surface upon which it is to be placed has been previously prepared, is intact, firm, dry, clean, and the tack or prime coat, with acceptable spread rate, is properly broken or cured. Before placing the mixture, the surface of the base or underlying pavement should be cleaned of all loose and deleterious material using power brooms or blowers, supplemented by hand sweeping where necessary. Next, a tack coat is applied on all

existing pavement surfaces that are to be overlaid with an asphalt mix as specified in Section 300—*Prime and Tack Coats* and between successive layers of all asphalt mixes.[70] Use a tack coat application rate defined in Table 300-1—*Tack Coat Application Rates* in the FDOT specifications.[70]

The MDOT thin lift asphalt overlay warranty provision indicates that the surface preparation practices include adjusting drainage structures, monument boxes and water shutoffs, cleaning the surface of dirt and debris using any method deemed adequate by the Engineer. This includes using the compressed-air system to remove loose material from joints and cracks and removing the existing pavement for butt joints, if required. The HMA shoulders must be removed from the roadway prior to construction. The shoulders must be cut to full depth to prevent the adjacent surface from being broken or torn. The HMA surface is to be cold-milled after MDOT approves the mix design and only once it is determined that there is enough mixture available to cover the milled surface. Once cold milling is complete, the surface is to be cleaned using the process described previously. Any patches that will inhibit the overlay's performance must be removed. Prior to construction, an SS-1h emulsion tack coat is to be applied at a rate of 0.11-0.15 gal/yd^2. Once all surface preparation activities are completed, the surface is to be sprayed uniformly with the tack coat with a pressure distributor that is positioned ahead of the paving operation. For thin lift asphalt overlays, the application rate is 0.11-0.15 gal/yd^2.

The ODOT thin lift asphalt overlay specification indicates that the surface preparation practices include cleaning the surface upon which the mixture is to be placed and keeping it free of materials that would contaminate the mixture, prevent mixture bonding or would otherwise interfere with spreading operations. Defective areas of pavement are to be corrected according to the Contract item or items indicated prior to spreading the course. The surfaces of gutters, manholes, curbs vertical pavement faces, or other structures need to be cleaned of foreign material and sprayed by a thick uniform covering of a PG grade binder, hot-applied asphaltic joint adhesive, or SBR emulsion.

3.5.2.d. Inspection

The Caltrans thin lift asphalt overlay specification indicates that the construction inspectors inspect the longitudinal joints, method compaction, and mat temperatures during construction. For longitudinal joints, joints in the top layer must match lane lines. The longitudinal joint offsets are alternated in the lower layers at least 6 inches from each side of the lane line. Other longitudinal joint placement patterns are allowed if authorized. If placing HMA against the edge of existing pavement, there is a need to saw cut or grind the pavement straight and vertical along the joint and remove extraneous material.

Method compaction is used for HMA pavement thicknesses of less than 1.8 inches. Method compaction must consist of performing breakdown compaction with 3 coverages using a vibratory roller. The speed of the vibratory roller in miles per hour must not exceed the vibrations per minute divided by 1,000. If the HMA layer thickness is less than 0.96 inch, turn the vibrator off, intermediate compaction of each layer of HMA with three coverages using a steel-wheel roller at a speed not to exceed 5 mph, and finish compaction of HMA is also completed with one coverage using a steel-wheel roller.

Start rolling at the lower edge and progress toward the highest part. The Engineer may order fewer coverages if the layer thickness of HMA is less than 1.8 inches. If the asphalt binder is modified, the first coverage of breakdown compaction must be completed before the mat temperature drops below 285°F. The breakdown and intermediate compaction must be completed before the mat temperature drops below 250°F. Final compaction must be completed before the mat temperature drops below 200°F. Once rolling is complete, sand is to be spread atop the new surface at a rate of 1-2 lb/yd^2.

The FDOT hot-mix asphalt specification indicates that the contractor quality control personnel (inspectors) monitor the mix temperature, spread rate, and the cross-slope. These requirements are verified by the construction inspectors. The mix temperature at the time of paving must be maintained within the master range as defined in the FDOT specifications. The temperatures are to be taken at the plant and the roadway and must be within the temperature tolerances stated in the contract and per the mix design. Mix temperatures on the roadway are taken for each mix design at least on the first five loads each day and once per five loads thereafter.

The spread rate must be within plus or minus 5% of the target spread rate. When determining the spread rate, at a minimum, an average of five truckloads of mix and at a maximum, an average of ten truckloads of mix are used. No vibratory compaction in the vertical direction will be allowed for layers one inch or less in thickness. FDOT does verify spread rate at a one check per lane, per lift, per day frequency, using truck ticket quantity and target lane area. Where density testing for acceptance is not required, the thin lift asphalt overlay (except for an open-graded friction course) is compacted following Section 330-7.2—*Standard Rolling Procedure* as indicated in the FDOT specifications or in accordance with the contractor proposed rolling procedure (equipment and pattern) as approved by the Engineer.[71] Produce a finished surface of uniform texture and compaction that is free of pulled, torn, raveled, crushed or loosened portions and free of segregation, bleeding, flushing, sand streaks, sand spots, or ripples.

Measure the cross-slope at a minimum frequency of one measurement every 100 ft per lane. When the average absolute deviation is consistently within the acceptance tolerance in Table 330-4—*Cross-Slope Acceptance Tolerance*, upon the approval of the Engineer, the cross-slope measurements may be reduced to one measurement every 200 ft.[72] The Engineer will verify the Contractor's cross slope measurements by randomly taking a minimum of ten cross slope measurements per lane per mile in tangent sections, at control points in transition sections, and a minimum of three cross slope measurements in fully super-elevated sections. The Contractor is responsible for having full-time quality control personnel for plant production and paving QC. FDOT has a full-time inspector for the project on paving days.

The MDOT thin lift asphalt overlay warranty provision and standard specification indicate that the construction inspectors are to monitor the mixture application rate and mat temperature. The mixture application rate is 83 lb/yd^2. The mix is to be placed to the slope and width shown on the plans. If delays cause paving to slow down and the temperature of the mat immediately behind the screed falls below 200°F, paving must stop and a transverse joint must be placed. If the temperature falls below 190°F before initial compaction, the mat is to be removed and replaced. The longitudinal joints are to conform to planned lane lines. If the first mat temperature falls

below 170°F before placing the adjacent mat, a tack coat is to be applied to the vertical edge of that mat. Each layer is to be rolled to the density required by the plans.

The ODOT thin lift asphalt overlay specification indicates that the construction inspectors monitor the spread rate, surface defects, mat temperature, and rolling. The mixture must be spread at the rate calculated using the required thickness and compacted width of the course being placed and weight-to-volume conversion factors established by the Engineer from the load tickets for each material. The rate must be maintained to within a tolerance limit of ±5% of the calculated weight per unit area.

On the first day or night of paving, the ODOT specifications indicate that the Contractor is to construct a test strip at least 1,000 ft long. The Contractor must demonstrate to the Engineer that the equipment is not segregating the mix and that the temperature differential of the mat surface is 35°F or less, when measured transversely. Any equipment or JMF that displays physical segregation, does not meet the temperature differential requirement, or both, must be removed, and a new test strip is to be constructed.

The mixture has to be spread and finished using the approved methods and equipment that will allow compaction to immediately follow paving. The screed and extensions must be pre-heated before placing mixture. A build-up of excess material in front of the screed is not permitted. If this occurs, the Engineer will require changes to the paver to correct it. Engineer will verify mix temperature upon arrival to the jobsite. The paver operation, screed and extension, and/or the mix design have to provide a mat that is free of inconsistencies, shadowing, streaking, tearing, pulling, or other deficiencies prior to compaction. If any of these occur, immediate action to correct the error must be taken. The use of strike-off plates or extensions only on irregular areas or on variable shoulders is allowed at the Engineer's direction.

Corrective action is to be taken if any defects are present in the mat surface that are within the Contractor's control, such as flushing. The defect must be removed and replaced or otherwise corrected to the Engineer's satisfaction. The spreading operation is to be correlated to the production rate and delivery of the mixture to maintain uniform, continuous progress. Erratic spreader operations due to irregular hauling vehicle contact, surging in the feed and distribution of the mix, or other causes, should be avoided. Sufficient spreader control must be maintained with regard to line and grade references. If excessive sticking occurs, it is an indicator of excessive cooling. If it is not resolved, the Engineer may require that the haul trucks have insulated beds.

The rolling operation is to begin immediately after spreading. The calculated spread rate is not to exceed twice the combined total roller capacities. The roller coverage required should to be completed during the time period in which the temperature of the mixture is sufficient for the roller coverage to be effective in compaction. A three-wheel roller for breakdown compaction should be used. For polymer-modified asphalt mixtures, a JMF approval letter must be submitted to the Engineer that specifies the design compaction temperature prior to placement. The temperature immediately prior to rolling must not be less than 290°F for hot mix asphalt and 250°F for warm mix asphalt. Rolling should begin at the sides longitudinally, parallel to the centerline, and at a slow uniform speed. After each coverage, the roller should be moved towards

the crown of the road, overlapping the previous lap by one half of the width of the previous pass. Rolling should continue until full coverage is complete and all roller marks are covered.

3.5.2.e. Mix Adjustments

The Caltrans specification indicates that mix adjustments are only allowed during the JMF verification phase of the project.

The FDOT hot-mix asphalt specification indicates that, during production, the Contractor may request a target value revision to a mix design, provided that the Contractor submits all requests for revisions to mix designs, along with supporting documentation, to the Engineer. To expedite the revision process, the request for revision or discussions on the possibility of a revision may be made verbally, but must be followed up by a written request. A follow-up sample must be obtained immediately after corrective actions are taken to assess the adequacy of the corrections. In the event the follow-up Process Control sample also fails to meet Specification requirements, the production of the asphalt mixture must stop until the problem is adequately resolved to the satisfaction of the QC Manager. The specification outlines the allowable ranges of adjustments that the Contractor can make for binder content and stockpile proportions. The Contractor must notify FDOT and get approval to make mix design target revisions. First approval is verbal (to keep operation moving) and is followed up with written request.

The MDOT thin lift asphalt overlay warranty provision does not indicate procedures for mix adjustments.

The ODOT thin lift asphalt overlay specification indicates that the Contractor may adjust the JMF's gradation within the first three days and within the specification limits without re-designing the mixture. If a re-design is needed, a new JMF is to be submitted according to the requirements of the initial JMF. Both the adjusted JMF and the original JMF are to be recorded during production of an acceptance lot on the Quality Control Report for that lot.

3.5.2.f. Opening to Traffic

The Caltrans thin lift asphalt overlay specification does not indicate criteria for opening the finished roadway to traffic. The FDOT hot-mix asphalt specification indicates that the overlay can be opened to traffic when the mat cools to 160°F. If traffic creates visible marks on the roadway surface, then the lane is closed until the mix cools further. The MDOT thin lift asphalt overlay warranty provision does not indicate criteria for opening to traffic. The ODOT thin lift asphalt overlay specification indicates that traffic is not to be allowed on the mix until it has cooled sufficiently such that bleeding will not occur.

3.5.2.g. Post-Construction Monitoring

The Caltrans and FDOT hot-mix asphalt specifications do not indicate post-construction monitoring practices. Per an interview, FDOT indicated that all projects are subjected to an annual warranty inspection and they have a three year materials and workmanship warranty.(66) The interviewee indicated that less than two percent of projects required warranty repair action. The MDOT thin lift asphalt overlay warranty provision indicates that a two-year warranty is issued for all work dated from the acceptance date. The ODOT thin lift asphalt overlay specification does not indicate requirements for post-construction monitoring.

3.5.3. Quality Assurance Specifications

3.5.3.a. Quality Control and Acceptance

The Caltrans thin lift asphalt overlay specification indicates requirements for Quality Control and Department Acceptance. QC includes testing the asphalt rubber binder (modifier, crumb-rubber modifier, and final blend), the aggregate and the completed mix. Testing on the asphalt rubber binder includes testing the asphalt modifier for Viscosity, Flash Point and Molecular Analysis for Asphaltenes and Aromatics (all tested once per shipment). The CRM is tested for Gradation (once per 10,000 lb for scrape tire rubber and once per 3,400 lb for high natural crumb rubber), Wire and Fabric Content, Specific Gravity (all three tested once per 10,000 lb) and Natural Rubber Content (once per 3,400 lb). Testing on the blended binder includes testing for Cone Penetration, Resilience, Softening Point (all tested once per lot) and Viscosity (tested 15 minutes before being used in a lot).

Testing of the aggregate includes tests for Gradation, Sand Equivalent, and Moisture Content (tested only at continuous mixing plants). All of these tests are conducted once per 750 tons of aggregates and on any remaining portion of aggregate at the end of production. Crushed Particles, L.A. Abrasion, Flat and Elongated Particles and Fine Aggregate Angularity are all tested once per 10,000 tons of aggregates or twice per project, whichever is greater.

HMA production sampling and testing on the completed mix includes testing for Asphalt Content (once per 750 tons), HMA Moisture Content (tested once per 2,500 tons but not less than once per paving day), Air Void Content (once per 4,000 tons or twice per 5 paving days, whichever is greater), Voids in Mineral Aggregates (VMA), Dust Proportion (both taken once per 10,000 tons or twice per project, whichever is greater), Hamburg Wheel Track and Moisture Susceptibility (both tested once per 10,000 tons or once per project, whichever is greater).

Acceptance includes aggregate testing for Gradation, Percent Crushed Particles, L.A. Abrasion, Sand Equivalent Flat and Elongated Particles and Fine Aggregate Angularity. In-place acceptance tests include Asphalt Content, HMA Moisture Content, Air Voids at N_{des}, VMA on both laboratory- and plant-produced HMA, Dust Proportion, Hamburg Wheel Track and Moisture Susceptibility. Acceptance sampling and testing frequencies are indicated in the Caltrans *Construction Manual*.[73]

The FDOT hot-mix asphalt specification indicates both Quality Control and Acceptance. The following attributes are to be monitored by both the Contractor and FDOT: pavement density, mix temperature, pavement smoothness, pavement cross-slope, mix spread rate, and pavement texture (for segregation). The Contractor must monitor the mat temperature, measure density every 1,500 ft, monitor the mix temperature every 5 trucks, and monitor the spread rate every 200 tons (average 5 trucks). The texture measurement is very general and must only be reported on the FDOT form for texture.

QC includes obtaining all samples randomly as directed by the Engineer. Should the Engineer determine that the QC requirements are not being met or that unsatisfactory results are being obtained, or should any instances of falsification of test data occur, acceptance of the Producer's QC Plan will be suspended, and production will be stopped. All QC testing should be completed within one working day from the time the samples were obtained.

A lot is terminated if: (1) An individual test result of a sublot for air voids does not meet the requirements of Table 334-5—*Master Production Range* of the FDOT specifications; (2) The average sublot density does not meet the requirements of Table 334-5; or (3) Two consecutive test results within the same LOT for gradation or asphalt binder content do not meet the requirements of Table 334-5.[74] When a Lot is terminated due to a QC failure, production of the mixture must stop until the problem is resolved.

For tack coats, the Contractor must provide the necessary QC of the prime and tack coats and application. All necessary corrections must be made immediately if the application rate varies by more than 0.01 gal/yd^2 or varies beyond the range established in 300-7—*Application of Prime Coat* or 300-8—*Application of Tack Coat*. The Engineer may take additional measurements at any time.[75,76] The Engineer will randomly check the Contractor's measurement to verify the spread rate. The target application rate may be adjusted by the Engineer to meet specific field conditions. The application rate must be determined and recorded at a minimum twice per day.

Acceptance includes mixture accepted at the plant with respect to Gradation, Asphalt Content, and Air Voids. The mixture will be accepted on the roadway with respect to density of roadway cores. To determine the validity of the Contractor's QC test results prior to use in the Acceptance decision, the Engineer will run verification tests. For plant testing, at the completion of each Lot, the Engineer will test a minimum of one verification split sample randomly selected from the Lot.

For pavement smoothness measurement, all straightedge testing must be performed in accordance with FM 5-509—*Florida Method of Test for Measurement of Pavement Smoothness With the 15-Foot Rolling and Manual Straight-Edge* in the outside wheel path of each lane. The Engineer may require additional testing at other locations within the lane.[77] For Process Control Testing, the Contractor is to assume full responsibility for controlling all paving operations and processes such that the requirements of these Specifications are continuously met. The final structural layer is straight edged in accordance with 330-9.4.2—*Test Method for Pavement Smoothness*, either behind the final roller of the paving train or as a separate operation.[78] The Engineer of the location and time of straightedge testing must be notified at a minimum of 48 hours before beginning testing. The Engineer will verify the straightedge testing by observing the QC straight edging operations.

Tests necessary for process control purposes must be performed at the plant and roadway. All process control test data are entered into the Department's database. The Engineer will not use these test results in the acceptance payment decision.

Acceptance will be on a Lot-by-Lot basis (for each mix design) based on tests of random samples obtained within each sublot taken at a frequency of one set of samples per sublot. A roadway Lot and a plant production Lot shall be the same. Acceptance of the mixture will be based on Contractor QC test results that have been verified by FDOT. Samples are obtained in accordance with FM 1-T 168—*Florida Method of Test for Sampling Bituminous Paving Mixtures.*[79] Samples are obtained at the plant of a sufficient quantity to be split into three smaller samples; one for QC, one for verification testing and one for resolution testing. Density

testing for acceptance will not be performed on open-graded friction courses or any course with a specified thickness less than 1 inch.

Each Lot will be defined (as selected by the Contractor prior to the start of the Lot) as either: (1) 2,000 tons, with each Lot subdivided into four equal sublots of 500 tons each; or (2) 4,000 tons, with each Lot subdivided into four equal sublots of 1,000 tons each. Before the beginning of a Lot, the Engineer will develop a random sampling plan for each sublot and direct the Contractor on sample points, based on tonnage, for each sublot during construction.

The MDOT warranty provision and standard specifications indicate requirements for thin lift asphalt overlay Quality Control and Acceptance. QC includes requiring the Contractor to devise and implement a Quality Control Plan (QCP) that conforms to the requirements of the *Production Manual*. It must include details for the project, personnel and responsibilities, documentation and the actual Quality Control process. QC tests include Asphalt Content. Both core and mixture samples are to be tested.

Acceptance includes Engineer inspection of field-placed material, QA sampling and testing and monitoring of the Contractor's adherence to the QCP. Field-placed material is to be inspected within 36 hours of placement. Acceptance is also based upon visual inspection, small tonnage testing, or QA sampling and testing. Visual inspection involves the Engineer accepting mix quantities of less than 500 tons according to the MDOT *Materials Quality Assurance Procedures Manual*.[80] Small tonnage involves Engineer testing of a mix according to the contract if the total mix tonnage for that mix does not exceed 5,000 tons. QA sampling and testing is to be conducted if the total tonnage is greater than 5,000 tons. The actual tests are not indicated. The asphalt binder will be accepted per MDOT's procedures. These procedures are also not indicated.

The ODOT specification indicates requirements for Quality Control and Acceptance. QC includes requiring the Contractor to create a QCP for each paving season. It must include the assignment of QC responsibilities (including responsibilities for a Quality Control Manager, a Level 2 Technician, Level 2 consultant technicians, if required, and a Field Quality Control Supervisor), a means of annual training for company and consultant technicians in ethical conduct, provisions to meet ODOT mix specifications, procedures for extra testing, warning band specifications to be used by technicians for all testing and how they will be used, and a method to maintain all worksheets and test and sample records for the plant or project for the duration of the contract or 5 years, whichever is longer. It must also include procedures for equipment calibration and documentation for all Level 2 laboratory equipment, method of Quick Calibration for each plant type, procedure for random sampling at the plant, procedures for processing, testing and documentation for RAP and RAS, procedure for ensuring that every Contractor employee has read the QCP and has access to the ODOT specifications, a procedure for ensuring asphalt binder BOL have the appropriate load number, binder source and grade and are reviewed against running JMFs and a record of review listing the information is kept throughout the project duration, a means to deliver mixture that meets uniformity/coating and hauling requirements, the defined roles of Field Quality Control Supervisors, and the signature of the QA Manager or other person of authority.

Other QC requirements include testing on the asphalt mix. The testing varies by mix type. For Type A mixtures, the Contractor is to perform tests for Gradation and Asphalt Content. If a single asphalt content varies by more than ±0.5% of the JMF's asphalt content, another sample must be taken and tested. If two consecutive asphalt content tests vary by more than ±0.5%, the ODOT Monitoring Team is to be notified and production is to cease immediately. the Monitoring Team is to be notified if the range difference of any three consecutive asphalt content tests is greater than 0.6, or if the range difference of any three gradation tests for the No. 4 sieve is greater than 10.0%. If these problems persist, production must cease. For Type B mixes, the Contractor is to perform tests for Asphalt Content, Gradation, Air Voids and Maximum Specific Gravity (MSG, in ODOT's specifications). Each test is to be performed at least once per half day of production or once per 1,400 tons, whichever is less. More testing is required at the start of production. Alternatively, Contractor may test a Sublot sample in lieu of the aforementioned tests, provided the Sublot sample was tested within one half-day of the production of that Sublot for all of the quality control properties.

Acceptance includes random testing. If the random testing conducted by ODOT verifies the Contractor's QC test results, the average of the Contractor's daily QC testing (for Type A mixes) or the average of the daily Sublot testing (for Type B mixes) will be used for Acceptance. Testing will be conducted upon independent samples. For plant sampling for Type A mixes, the Contractor's technician will select the truck from which the sample will be taken using the random procedure outlined in the QCP. The first three trucks are to be excluded, except when circumstances warrant inclusion. Samples are to be split by quartering on a hard surface. Each sample should be 22-27 lb. Sample mishandling will result in a change to Unconditional Acceptance.

For Type B mixes, samples are to be taken from the trucks at the plant. If workmanship problems persist, ODOT may require sampling in Lots of 3,000 tons and Sublots in 750 tons. If production is limited to less than 3,000 tons, the quantity produced is a partial Lot. For partial Lots of 1,500 tons or less, at least 2 Sublot samples are tested. Samples are collected by the Contractor from locations selected by ODOT's Monitoring Team or the Engineer and split between the two entities. For both mix types, the tests include Asphalt Content and the Percent of Material Passing the No. 4 Sieve.

Production may continue if Acceptance the Monitoring Team verifies that the QCP is being followed, the Acceptance tests are within specification limits and, for Type A mixes, the remaining sieves (excluding No. 4 sieve) do not exceed the specification limits. If the Contractor's test results are not verified, the Monitoring Team will investigate the cause. If the deviation between ODOT's and the Contractor's asphalt content results for both mixes exceeds the ±0.5% range or if the No. 4 sieve test exceeds the ±7.0% range, production must cease until the cause is corrected. Unconditional Acceptance occurs when the Contractor is removed from ODOT's Verification Acceptance. This will lead to requiring the Contractor to raise the QCP to an acceptable level as determined by ODOT before production can continue. ODOT will ensure that the project's Contractor's Prequalification Rating (C-95) will reflect the change to Unconditional Acceptance. Under this level of Acceptance, all of the Contractor's materials will be accepted for ODOT projects.

Acceptance for Type B mixes is based upon deviation from the JMF and range tolerance criteria for Asphalt Content, Percent of Material Passing the 1/2 inch sieve, Percent of Material Passing the No. 4 Sieve and the Percent of Material Passing the No. 8 Sieve. Sampling and testing is to be done on 5,000-ton Lots and 1,250-ton Sublots. These may be taken from the roadway or the plant.

3.5.3.b. *State-of-the-practice*

The identified state-of-the-practice include requiring that thin lift asphalt overlays be warrantied. Per an interview, it was indicated that an agency's requirements for full-time inspection and agency verification testing are key. "Verify and Document" is considered state-of-the-practice. A paver segregation specification improves the Contractor's attention-to-detail. Another practice involves requiring the Contractor to operate an accredited laboratory for mix design development.

Other recommended state-of-the-practice items for thin lift asphalt overlay preservation treatments include:

- Selecting quality asphalt binder and aggregate materials.
  - Using modified PG binders.
  - Aggregate types based on project's location may ensure durable aggregates.
  - Superpave asphalt binder and aggregate consensus property tests.
- Performing a thin lift asphalt overlay mix design for the materials to be used during construction.
  - The Superpave and Marshall methods are common mix design standards.
  - Testing the mix for moisture susceptibility.
- Enforcing appropriate climatic conditions during construction.
  - Minimum surface and air temperatures.
- Applying tack coats as part of surface preparation.
- Calibrating equipment with materials to be used during construction.
  - Recommended to be done prior to every project.
  - Mixing plant calibration can be involved.
- Constructing a test strip.
  - Recommended to be done on every project, under conditions similar to those that are anticipated during construction.
- Using a paver segregation specification.
  - Improves the Contractor's attention-to-detail.
- Using an MTV/MTD.
  - Prevents segregation.
- Using method compaction.
- Requiring full-time inspection and agency verification testing.
  - Continuously monitoring spread rates and mix temperatures during construction.
- Documenting all aspects of a project.
  - Aids in disputes and allows for achieving adequate quality.
- Requiring Contractor's QC testing during construction.
  - Aggregate consensus property testing, mix design testing for moisture susceptibility and rutting.
  - Creating a QCP.

- Requiring agency Acceptance sampling and testing during construction.
    - Testing complete mix in-place for Asphalt Content, Field Density.
    - Testing for smoothness/ride quality.
    - Requiring that thin lift asphalt overlays be warrantied.

3.5.3.c. *Opportunities for Improvements*

Improvements can be made by implementing some minor changes. An example of these changes is to allow incentive/disincentive for smoothness, which are currently under development for one agency, per an interview. Minor revisions to slightly increase field density criteria are also needed.

A final improvement can be made in terms of equipment calibration. Equipment calibration may need to be checked prior to the construction phase of every project. If the agency specifications do not indicate calibration requirements, the equipment manufacturers' calibration procedures shall be followed.

3.6 Overall Comparison of QA Specifications and Practices

The key findings from each of the reviewed surface treatments are summarized based upon the collected and presented information in the previous sections. The summary aims at highlighting critical factors that could be contributing to the quality construction of chip seal, slurry seal, micro surfacing, and thin lift asphalt overlay treatments.

3.6.1. Summary of Chip Seal State-of-the-Practice

Table 3.13 summarizes the identified state-of-the-practice from the Chip Seal specifications for Caltrans, MnDOT, Spokane County, and TxDOT. The following provides further details for each element of the specifications.

Asphalt Binders

- Caltrans and TxDOT indicate that various types are allowed, whereas MnDOT and Spokane County both indicate only one specific emulsion grade—CRS-2P.
- TxDOT indicates that cutbacks are allowed for asphalt binders.
    - Used primarily for winter or emergency maintenance activities

Table 3.13. Summary of Chip Seal Specifications for Lead Agencies.

Elements of Specifications[a]	Agency			
	Caltrans	MnDOT	Spokane County	TxDOT
Asphalt Binders	PG Binder—Unmodified/Modified. Emulsions—Unmodified/Modified.	Emulsions—CRS-2P only.	Emulsions—CRS-2P only.	PG Binder—Unmodified/Modified. Emulsions—Unmodified/Modified. Cutbacks.
Aggregates	Crushed stone and/or gravel. Pre-coated aggregate.	Crushed stone and/or gravel.	Basalt.	Slag and/or limestone. Pre-coated aggregate.
Mix Design/ Verification	Verification tests included.	McLeod—including modifications. Verification tests included.	McLeod—including modifications. Verification tests included.	McLeod—including modifications. Kearby—including modifications. Verification tests included.
Equipment and Calibration	Either equipment or calibration details	Either equipment or calibration details.	Either equipment or calibration details.	Both equipment and calibration details.
Calendar Date/Climate Limits	Temperatures only—ambient and/or surface. Calendar dates and/or temperatures vary with binder type.	Calendar dates and temperature limits.	Calendar dates and temperature limits.	Calendar dates and temperature limits. Calendar dates and/or temperatures vary with binder type.
Inspection	Inspection of application rates. Monitor rolling pattern. Monitor binder temperatures.	Inspection of application rates. Monitor rolling pattern. Test strip constructed. Monitor binder temperatures.	Monitor rolling pattern. Test strip constructed. Monitor binder temperatures.	Inspection of application rates. Monitor rolling pattern. Test strip constructed. Monitor binder temperatures.
Opening to Traffic	Opening to traffic > 2 hrs.	Not specified.	Not specified.	Not specified.
Quality Control	QC includes materials testing.	QC includes materials testing.	Not specified.	QC includes materials testing.
Acceptance	Acceptance includes materials testing.	Acceptance includes materials testing.	Not specified.	Acceptance includes materials testing.

[a]Information obtained from standard specifications, published documents, and phone interviews.

Aggregates

- All four agencies indicate at least one 3/8 inch MAS gradation or aggregate size.
- Caltrans and TxDOT both indicate pre-coated aggregates, which may aid in chip retention when used.
    - Primarily used in conjunction with a paving-grade asphalt binder.
- Caltrans only one to specify aggregate Cleanness Value.

Mix Design

- MnDOT, Spokane, TxDOT all use Modified McLeod, but TxDOT uses Modified Kearby more often.

Mix Verification

- MnDOT indicates that Contractor must submit materials to MnDOT for verification testing.

Equipment and Calibration

- Caltrans indicated the most details for equipment and calibration.

Climate Limits

- All four agencies had similar air and surface temperature minimum limitations.
- MnDOT and Spokane County have calendar date limits.
- Caltrans and Spokane County both indicate maximum surface temperature limitation.

Surface preparation

- All four agencies' specifications recommend tack coat activities.
    - May not actually be used in practice.

Inspection

- MnDOT and Spokane both require test strip.
- All four agencies had temperatures to which the asphalt material was to be heated, but there was not a general consensus between agencies regarding appropriate temperatures.
- Spokane indicates that three pneumatic-tire rollers are to be used, making two complete coverages on the treatment, whereas MnDOT requires three coverages. TxDOT requires five coverages (except for emulsion chip seals).
- TxDOT calculates materials quantities prior to the start of each job.
- All four agencies continuously monitor for non-uniformity.

Mix Adjustments

- All four agencies indicated that non-uniformity must be corrected; Caltrans and TxDOT indicate that wheel path asphalt binder application rates may be reduced.
- TxDOT's inspectors regularly adjust asphalt binder application rates based on field conditions.[(21)]
- MnDOT requires new test strip after each adjustment.

Opening to Traffic

- Caltrans varies opening to traffic times based upon roadway type.

Post-Construction Monitoring

- Caltrans indicates requiring Contractor to sweep treatment and maintain treatment for four consecutive days until final acceptance.

Quality Assurance Specifications

- Caltrans indicates that Contractor must inform Engineer about defective areas in the existing pavement.
- Caltrans indicates that Contractor must submit binder samples 15 days prior to starting work.
- Caltrans indicates that 50 lb of aggregate and test results must be submitted by Contractor within time indicated below
    - Gradation—within 24 hours of test, prior to construction.
    - L.A. Abrasion—within 48 hours of test, prior to construction.

  - Percent Crushed Particles—within 48 hours of test, prior to construction.
  - Flat and Elongated Particles—within 48 hours of test, prior to construction.
  - Film-stripping, if coated aggregate—within 48 hours of test, prior to construction.
  - Cleanness Value—within 24 hours of test, prior to construction.
  - Durability—within 48 hours of test, prior to construction.
- Caltrans indicates that the Contractor must submit a test result for the asphalt emulsion application rate once per day per distributor.
- Caltrans indicates that asphalt binder Descending Viscosity is to be tested 45 minutes after adding rubber, and checked every 30 minutes thereafter, until 2 consecutive readings are the same.
- MnDOT indicates that test results must be submitted within 24 hours of completing the test. Contractor responsible for all testing, except tests on emulsion, which is emulsion supplier's responsibility.
  - Emulsion tested from sample of first load, then once per 50,000 gallons of emulsion.
  - Aggregate gradation tested on samples taken from aggregate stockpiles at start-up once per day or once per 1,500 tons of aggregates and once per day on samples taken from chip spreader hopper during construction.

3.6.2. Summary of Slurry Seal State-of-the-Practice

Table 3.14 summarizes the identified state-of-the-practice from the Slurry Seal specifications for Caltrans, City of Columbus, and VDOT. The following provides further details for each element of the specifications.

Table 3.14. Summary of Slurry Seal Specifications for Lead Agencies.

Elements of Specifications[a]	Agency		
	Caltrans	**City of Columbus**	**VDOT**
Asphalt Binders	Emulsions—QS/CQS-1hP (PMCQS-1h).	Emulsions—QS/CQS.	Emulsions—QS/CQS-1h.
Aggregates	Sand and/or crushed rock dust.	Crushed gravel and/or stone. Sand and/or crushed rock dust.	Crushed gravel and/or stone.
Mix Design/ Verification	ISSA Mix Design Method—includes tests.	ISSA Mix Design Method—includes tests.	Agency mix design method. Agency verification tests.
Equipment and Calibration	Both equipment and calibration details.	Both equipment and calibration details.	Both equipment and calibration details.
Calendar Date/ Climate Limits	Temperature limits only.	Temperature limits only.	Temperature limits only.
Inspection	Inspection of application rates. Monitor mixture consistency.	Inspection of application rates. Monitor mixture consistency.	Test strip performed. Monitor mixture consistency.
Opening to Traffic	Opening to traffic 1-2 hrs.	Not specified.	Not specified.
Quality Control	QC includes materials testing.	QC includes materials testing.	QC includes materials testing.
Acceptance	Acceptance includes materials testing.	Acceptance includes materials testing.	Acceptance includes materials testing.
[a]Information obtained from standard specifications, published documents, and phone interviews.			

Asphalt Binders

- All three agencies specify only CQS/QS emulsion.
- Caltrans only agency to indicate polymer modification.

Aggregates

- All three agencies indicate at least one 3/8 inch MAS.
- All three agencies indicate Sand Equivalent as a quality test.
- City of Columbus and VDOT specify Portland cement. VDOT also indicates hydrated lime while city of Columbus also indicates limestone dust.

Mix Design

- Caltrans and the City of Columbus use ISSA mix design method and VDOT also uses its own method.
- Caltrans materials proportions: Type I—15-20% emulsion; Type II—12-18% emulsion; Type III—10-15% emulsion.
- City of Columbus materials proportions: Type I—10-16% residual asphalt, 8±2 lb/yd^2 aggregate; Type II—7.5-13.5% residual asphalt, 15±2 lb/yd^2 aggregate; Type III—6.5-12% residual asphalt, 20±3lb /yd^2 aggregate.
- VDOT materials proportions: Type A—8-10.5% residual asphalt content; Type B—8-10.5% residual asphalt content; Type C—7-9.5% residual asphalt content.

Mix Verification

- VDOT uses its own test methods for some mix verification tests, as noted below.
  - For asphalt content, use either ignition method *VTM-102—Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method – (Asphalt Lab)*; or nuclear gauge *VTM-93—Nuclear Asphalt Content Gauge Determination for H.M.A. and Slurry Seal Mixtures – (Asphalt Lab).*
- Tests are conducted on Contractor-submitted samples of aggregate (50,000 grams) and emulsion (6 quarts).

Equipment and Calibration

- Caltrans indicates both truck-mounted and self-propelled mixing machines may be used.
- City of Columbus indicates that two 10-ton mixing machines must be present at all times.
- City of Columbus indicates that cleaning equipment must be used and specifically designed to remove mud, clay and other deleterious materials from a pavement's surface.
- VDOT indicates that the slurry machine must be able to hold 5 tons of mix and operate at speeds of 60 ft/minute.

Climate Limits

- VDOT indicates that fogging the surface with water is allowed for surface temperatures higher than 90°F.
- All three agencies indicate similar minimum air and surface temperatures.
- All three agencies indicate that the treatment is not to be placed if freezing temperatures are predicted in the next 24 hours.

Surface preparation

- Caltrans and City of Columbus recommend tack coats.
  - Caltrans indicates that a 3:1 diluted emulsion tack coat may be applied at a rate of 0.08-0.15 gal/yd^2, if the bid documents require it.

  - City of Columbus indicates that a diluted emulsion should be applied in areas of pavement that are absorptive, on concrete or brick surfaces or in areas where the aggregate is polished, and at a selected target application rate between 0.05-0.10 gal/yd^2.

Inspection

- Caltrans aggregate application rates: Type I—8-12 lb/yd^2; Type II—10-15 lb/yd^2; Type III—20-25 lb/yd^2.
- City of Columbus aggregate application rates: Type I—8-12 lb/yd^2; Type II—15-17 lb/yd^2; Type III—15-22 lb/yd^2.
- All three agencies indicate that the mixture consistency must be continuously monitored.
- VDOT only agency to indicate test strip requirement.

Mix Adjustments

- VDOT and City of Columbus indicate mix adjustments.

Opening to Traffic

- Caltrans indicates opening to traffic within one hour of placement.

Post-Construction Monitoring

- Caltrans indicates requiring Contractor to sweep treatment and maintain treatment for four consecutive days until final acceptance.

Quality Assurance Specifications

- Caltrans indicates that the moisture content of the aggregate is to be monitored as part of QC, taken every two hours.
- Caltrans indicates that the emulsion delivery feed to pugmill is checked once per three runs or 500 gallons of emulsion, whichever is less, to ensure less than 2% variation between the three runs.
- Caltrans indicates Acceptance sampling and testing frequencies on the Gradation and Cleanness Value once per 300 tons or once per day, whichever is less.
  - Caltrans indicates deduction values of $2.00/ton for each non-compliant test.
- VDOT indicates continuous QC testing for mix consistency and abrasion loss.
- VDOT indicates Acceptance slurry seal mixture sampling taken from each unit.
  - Each sample represents 25,000 yd^2 of slurry seal mixture at start-up, and then each sample represents 50,000 yd^2. The samples are used to check residual asphalt content.
- VDOT indicates that Acceptance testing for mix consistency is conducted twice per day.
- City of Columbus and VDOT indicate that the mix consistency is to be continuously checked.
- Caltrans and VDOT indicate that the equipment is checked as part of QC.

3.6.3. Summary of Micro Surfacing State-of-the-Practice

Table 3.15 summarizes the identified state-of-the-practice from the Micro Surfacing specifications for Caltrans, MnDOT, and VDOT. The following provides further details for each element of the specifications.

Table 3.15. Summary of Micro Surfacing Specifications for Lead Agencies.

Elements of Specifications[a]	Agency		
	Caltrans	MnDOT	VDOT
Asphalt Binders	Emulsions—polymer-modified, no specific grade.	Emulsions—CQS-1P, CQS-1hP.	Emulsions—Quick-set CSS-1h. Uses CQS-1h, conforming to CSS-1h requirements. Latex-modified.
Aggregates	Sand and/or crushed rock dust.	Volcanic rock.	Crushed gravel and/or stone.
Mix Design/ Verification	ISSA Mix Design Method—includes tests; Agency verification tests.	ISSA Mix Design Method—includes tests; Agency verification tests.	Agency Mix Design Method; Agency verification tests.
Equipment and Calibration	Both equipment and calibration details.	Either equipment or calibration details.	Either equipment or calibration details.
Calendar Date/Climate Limits	Temperature limits only.	Calendar dates and temperature limits.	Temperature limits only.
Inspection	Inspection of application rates.	Inspection of application rates; Test strip performed; Monitor mixture consistency.	Inspection of application rates; Monitor mixture consistency.
Opening to Traffic	Opening to traffic 1-2 hrs.	Opening to traffic 1-2 hrs.	Not specified.
Quality Control	QC includes materials testing.	QC includes materials testing.	QC includes materials testing.
Acceptance	Acceptance includes materials testing.	Acceptance includes materials testing.	Acceptance includes materials testing.
[a]Information obtained from standard specifications, published documents, and phone interviews.			

Asphalt Binders

- All three agencies indicate using an emulsion modified with latex.
- Caltrans indicates that other polymers may be used.
- Caltrans tests residual asphalts for Complex Shear Modulus, G*.

Aggregates

- All three agencies indicate same NMAS for three micro surfacing types—I, II, III or A, B, C.
- VDOT indicates a fourth micro surfacing type—Rut-Filling.
- All three agencies indicate that Portland cement may be used as a mineral filler.
- MnDOT and VDOT also indicate hydrated lime can be used.

Mix Design

- All agencies use ISSA mix design method, except VDOT, which uses its own method.
- Caltrans' JMF must have 5.5-10.5% residual asphalt and 0-3% mineral filler.
- MnDOT indicates that the emulsion supplier is the designer of record.
- MnDOT's JMF must have 5.5-10.5% residual asphalt and 0.25-3.0% mineral filler.

Mix Verification

- VDOT uses its own test methods for mix verification.

Equipment and Calibration

- Caltrans indicated the most details for equipment and calibration.
- VDOT indicates requirements for a pneumatic-tire roller to be used, if needed.

Climate Limits

- MnDOT indicates calendar date limits for construction seasons.
- All three agencies indicate similar minimum air and surface temperatures.
- All three agencies indicate that the treatment is not to be placed if freezing temperatures are predicted in the next 24 hours.

Surface preparation

- Caltrans indicates requirements for repairing wheel path depressions, if required, as part of the surface preparation.
- MnDOT and VDOT both indicate emulsion fog seal requirements as part of surface preparation.
- Caltrans indicates that the pavement surface may be fogged with water ahead of the spreader box.

Inspection

- Caltrans Engineer determines application rates for each project.
- MnDOT indicates test strip, which is to be constructed at night
- VDOT aggregate application rates:
  - Type B—16 lb/yd^2 minimum; for surface course, 16-20 lb/yd^2; for non-rut-filling or levelling, 18-22 lb/yd^2.
  - Type C—20 lb/yd^2 minimum; for surface courses, 18-22 lb/yd^2; for non-rut-filling or levelling, 20-24 lb/yd^2.

Mix Adjustments

- Caltrans indicates mix proportion adjustments to accommodate field conditions.
- MnDOT requires a new test strip to be constructed if an adjustment is made.
  - Emulsion application rate cannot change.
- VDOT indicates that very limited amounts of water may be added to the spreader box to ensure appropriate consistency.

Opening to Traffic

- Caltrans indicates opening to traffic within two hours of placement.
- MnDOT indicates that the opening to traffic must be within one hour of placement.

Post-Construction Monitoring

- MnDOT indicates that damages are to be repaired by Contractor until final acceptance.

Quality Assurance Specifications

- Caltrans' final acceptance based upon visual inspection of surface.
- Caltrans indicates QC testing on the mix design.
- Caltrans indicates Acceptance testing on aggregate Gradation and Cleanness Value.
  - Sampling and testing is conducted once per 300 tons or once per day, whichever is less.
  - Deduction values of $1.75/ton for each non-compliant test.
- MnDOT indicates sampling and testing per MnDOT's Schedule of Materials Control.

  - Emulsion sampling and testing to be conducted by emulsion supplier.
- MnDOT indicates that Contractor aggregate QC sampling and testing frequency depends upon aggregate quality test to be conducted.
  - For Gradation, samples are taken from mixing machine's aggregate hopper and are taken and tested once per 500 tons or once per day, whichever is less.
  - MnDOT tests Gradation on 30-lb sample submitted by the Contractor at the beginning of production.
- For Moisture Content, samples are taken from the mixing machine's aggregate hopper and are taken and tested once per day or once per 500 tons, whichever is less.
  - MnDOT tests Moisture Content on 2-lb sample submitted each day by the Contractor during production.
- For Sand Equivalent, samples are to be tested once per day, with sampling location unspecified.
  - MnDOT tests Sand Equivalence once during the mix design phase.
- MnDOT indicates that Contractor must verify spread rates at least three times per day.
  - MnDOT verifies spread rate once per day.
- MnDOT indicates that Acceptance sampling and testing for the emulsion is conducted once on the first emulsion load, then once per 50,000 gallons of emulsion.
- VDOT indicates that QC micro surfacing mix samples are to be taken from each unit and must represent 500 tons of mix.
  - Tests conducted to determine asphalt content.
- VDOT indicates that QC aggregate samples are to be taken from stockpiles and tested for Gradation.
- VDOT indicates Acceptance sampling and frequency based on the current Department Acceptance program.
- VDOT indicates Acceptance testing for asphalt content conducted using the ignition method (VTM-102) or nuclear gauge (VTM-93)

3.6.4. Summary of Thin Lift Asphalt Overlay State-of-the-Practice

Table 3.16 summarizes the identified state-of-the-practice from the Thin Lift Asphalt Overlay specifications for Caltrans, FDOT, MDOT, and ODOT. The following provides further details for each element of the specifications.

Asphalt Binders

- FDOT and ODOT indicate polymer-modified PG76-22 asphalt binder.
- MDOT bases binder grade on traffic volume.

Aggregates

- Three of the agencies indicate at least one No. 4 NMAS gradation.
- FDOT's aggregate types depend on project location in the state.
- MDOT indicates that aggregate quality tests dependent upon traffic.

Table 3.16. Summary of Thin Lift Asphalt Overlay Specifications for Lead Agencies.

Elements of Specifications[a]	Agency			
	Caltrans	FDOT	MDOT	ODOT
Asphalt Binders	PG Binders—Modified.	PG Binders—Modified.	PG Binders—Modified and Unmodified.	PG Binders—Modified.
Aggregates	Not specified.	Granite, Limestone. Type depends on location.	Slag—diverse types.	Natural or manufactured sand.
Mix Design/ Verification	Superpave—includes modifications; Verification tests included.	Superpave—includes modifications; Verification tests included.	Superpave—includes modifications, Marshall—includes modifications; Verification tests included.	Other method; Verification tests included.
Equipment and Calibration	Either equipment or calibration details.	Either equipment or calibration details.	Either equipment or calibration details.	Both equipment or calibration details.
Calendar Date/Climate Limits	Temperature limits only—vary with binder grade	Temperature limits only.	Calendar dates and temperature limits.	Calendar dates and temperature limits.
Inspection	Method Compaction; Monitor mat/mix temperatures; inspect surface for defects and/or grade deviations.	Inspection of spread rates; Monitor mat/mix temperatures; rolling pattern monitored; inspect surface for defects and/or grade deviations.	Monitor mat/mix temperatures; rolling pattern monitored.	Inspection of spread rates; Monitor mat/mix temperatures; rolling pattern monitored; inspect surface for defects and/or grade deviations.
Opening to Traffic	Not specified.	Opening to traffic depends on mat temperature.	Not specified.	Not specified.
Quality Control	QC includes materials testing.	QC includes materials testing.	QC includes materials testing.	QC includes materials testing.
Acceptance	Acceptance includes materials testing.	Acceptance includes materials testing.	Acceptance includes materials testing.	Acceptance includes materials testing.
[a]Information obtained from standard specifications, published documents, and phone interviews.				

Other Materials

- Caltrans and FDOT indicate the use of liquid anti-strip.
  - Caltrans indicates that Contractor can forgo anti-strip if stripping test results demonstrate that the mix does not require anti-strip.
- MDOT and ODOT indicates the use of RAP and mineral filler.
- MDOT indicates anti-foaming agents.

Mix Design

- All four agencies use the Superpave mix design method.

Mix Verification

- Caltrans indicates that liquid anti-strip treatment is required for all mixes unless the mix design passes Caltrans' requirements for AASHTO T283 and modified AASHTO M324 without the use of liquid anti-strip.
- Caltrans and FDOT both test for moisture susceptibility in accordance with AASHTO T283.
- MDOT and ODOT both indicate that the Contractor must submit aggregate and binder samples to the agencies for mix verification.

- ODOT indicates that Contractor must submit a preliminary JMF to ODOT two weeks prior to starting work.
- ODOT indicates 5-lb uncompacted HMA sample to be submitted two weeks before starting work, obtained from split sampling.
- ODOT indicates testing for moisture susceptibility, washed gradation and adherent fines to determine the need for an anti-strip additive for Type B mixes with crushed coarse gravel or more than 25% natural sand.
- ODOT indicates using an Ohio DOT Supplement (1052—Determination of Methylene Blue Adsorption Value of Mineral Aggregate Fillers and Fines) for use in mix verification testing for Type B mixes, if needed.

Equipment and Calibration

- Caltrans indicated the most details for equipment and calibration.
- Three of the agencies indicate using a Material Transfer Device or Vehicle.

Climate Limits

- All had similar air and surface temperature minimum requirements.
- MDOT and ODOT indicate calendar date limits for construction.

Surface preparation

- FDOT and MDOT indicates applying a tack coat as part of surface preparation.
- MDOT indicates joint and shoulder removal activities as part of surface preparation.
  - Also indicates cold milling as part of surface preparation.

Inspection

- Caltrans indicates method compaction.
- FDOT and ODOT indicate that the mixture spread rate is monitored to ensure that it remains within ±5% of target rate.
- FDOT indicates continuous monitoring of the finished cross-slope.
- MDOT indicates a set mixture spread rate of 83 lb/yd^2.
- MDOT indicates that the primary inspection concern is the mat temperature.
- ODOT indicates that the Contractor must place a test strip before beginning work.
- ODOT indicates that the surface must be monitored, with corrective action
- All four agencies indicate using mat temperatures to begin and end compaction activities.

Mix Adjustments

- FDOT indicates that the Contractor may request a target value revision.

Opening to Traffic

- FDOT indicates that the opening to traffic may occur once the mat temperature has cooled to 160°F.

Post-Construction Monitoring

- FDOT indicates that a three-year materials and workmanship warranty is required for thin lift asphalt overlays.

- MDOT indicates that a two-year warranty is required for all work dated from the acceptance date.

Quality Assurance Specifications

- Caltrans indicates blended aggregate QC testing for Gradation, Sand Equivalent and Moisture Content on samples taken once per 750 tons of aggregate.
  - Virgin aggregate QC testing for Crushed Particles and L.A. Abrasion on samples taken once per 1,000 tons of aggregate, or twice per project, whichever is greater.
  - RAP QC testing for Gradation and Moisture Content on samples taken once per 1,000 tons, with 6 samples per fractionated stockpile at start-up and twice per day during construction being taken.
- Caltrans indicates mixture QC testing for Asphalt Content, Moisture Content, Air Void Content, VMA, Dust Proportion, Core Density, and Nuclear Gauge Density.
- FDOT indicates extensive Quality Assurance specifications for thin lift asphalt overlays.
- FDOT indicates that the Contractor must monitor the mat temperature and check the density once per 1,500 feet, monitor the mix temperature every five trucks and monitor the spread rate every 200 tons.
- FDOT indicates that all QC testing must be conducted within one working day from the time that QC samples were taken.
- FDOT indicates that the tack coat application rate must be measured twice per day or more.
- FDOT indicates that Acceptance testing is to be done once per lot for Gradation, Asphalt Content and Air Voids.
- FDOT indicates that mixture Acceptance done on a per-lot basis, based on sampling and testing conducted randomly, but at least once per sample set per sublot.
- MDOT indicates that Acceptance based on inspection of materials in-place.
  - Engineer inspects material 36 hours after placement, based upon visual inspection conducted once per 500 tons of mix.
- MDOT indicates QA sampling to be conducted once per 5,000 tons.
- ODOT's QC requirements are different between the two types of mixes—Type A and Type B.
- ODOT indicates that a comprehensive Quality Control Plan must be created each paving season.
- ODOT indicates Type B mix sampling taken once per half-day or once per 1,400 tons, whichever is less, and tested for Asphalt Content, Gradation, Air Voids and Maximum Specific Gravity.
  - Contractor may conduct Sublot testing as an alternative.
- ODOT indicates Acceptance testing is conducted randomly.
  - Acceptance samples for Type A mixes are to be taken from randomly-selected trucks at the plant.
  - Acceptance samples for Type B mixes are taken from trucks at the plant.
  - Each sample must represent a lot of 3,000 tons of mix with 750-ton sublots if workmanship problems are persistent.
  - Acceptance tests for both mix types include Asphalt Content and Percent of Material Passing No. 4 Sieve.

- Acceptance tests for Type B mixes also include Percent of Materials Passing the 1/2 inch Sieve and Percent of Materials Passing the No. 8 Sieve.
- Samples to be taken from roadway or plant on 5,000-ton lots with 1,250-ton sublots, if workmanship problems not persistent.

CHAPTER 4 CASE STUDIES

This chapter discusses the case studies that were drafted for some of the lead agencies based upon collected information from projects that were properly constructed. Some of these projects won awards for the workmanship and quality. The project information that was collected included mix design records, performance records, inspector records, construction records and other information. The projects' construction practices were then compared to the agency specifications. Finally, the practices were analyzed to determine which practices lead to a quality project.

Case studies are presented for chip seals in California and Spokane County. For slurry seals, projects in the City of Columbus and Virginia are presented. For micro surfacing, a project in Virginia is presented. For thin lift asphalt overlays, projects in Florida and Michigan are presented. It is important to note that, due to the varying amounts of information that were provided by each agency, the formatting for the case studies may not be completely uniform.

4.1 Asphalt Rubber Binder Chip Seal Treatment Project in California

4.1.1. Overall Project Description

This project consisted of a hot-applied asphalt rubber chip seal constructed on July 8, 2017 under Caltrans Standard Specifications. A flush coat (referred to also as sand seal) treatment was also applied atop the asphalt rubber chip seal. The sand seal is a sprayed application of asphalt emulsion followed by a covering of clean sand or fine aggregate. The roadway is a two-lane highway with narrow shoulders (approximately 3 ft) on US 395 between Mile Post 119-128.7. The only special provision related to construction or materials was the aggregate source L.A. Abrasion maximum loss of 25%. This requirement is imposed as the location is subjected to winter conditions (tire chains/studded tires and snow plows) typically from late October through March.

Caltrans QA staff on-site included a senior field inspector and a field inspector/materials tester under contract with a local engineering firm; both with extensive experience with asphalt rubber chip seal construction. The aggregate, asphalt rubber binder, and hot mix plant used to produce the pre-coated chips were all located in Alturas, California, approximately 30 minutes north of the project.

Before observations were made on the project, for safety the senior field inspector described the planned operations for the day and how escorting and communications would take place. Upon arriving at the Eagle Peak Rock and Paving, Inc. plant production facility, the visiting researchers were required to conform to MSHA Part 46—*Training Assistance* requirements including documented site-specific training.

The existing pavement was surfaced with a chip seal that had been applied in 2009 (8 years prior). Surface preparation included some dig out repairs and very limited crack filling. The pavement appeared to be in relative good condition with any structural deficiencies repaired by dig outs (areas of pavement that have been removed and replaced, particularly in wheel paths).

4.1.2. Collected Records

4.1.2.a. Specifications

The project was constructed per the requirements of Caltrans' *2015 Revised Standard Specifications*. The primary section relevant to this project is *Division V Surfacing and Pavements Section 37-2.05 Asphalt Binder Seal Coats*.

4.1.2.b. Mix Design Records

A paper mix design was not readily available onsite. Therefore, it was not collected.

4.1.2.c. Construction Records

Figure 4.1 displays a photograph of the inspector's application rate calculations. Further information was collected from the Caltrans Senior Inspector and Contract Inspector/Materials Tester via an on-site interview. Information collected in this manner included the asphalt binder and emulsion grades used for the chip seal and sand seal, respectively, aggregate size and quality tests run, sampling of materials for Acceptance testing, mix adjustments, construction process and QC/Acceptance requirements

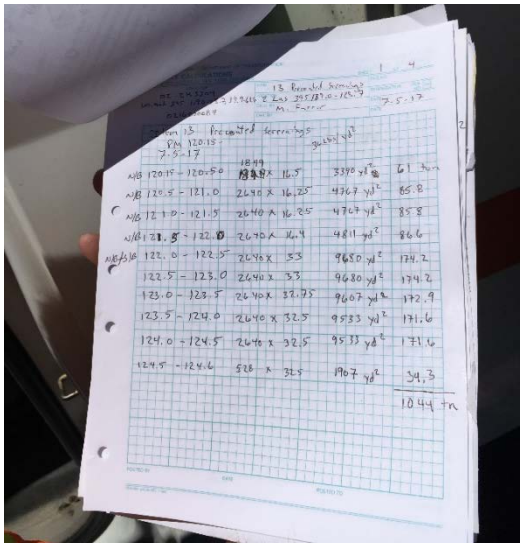

Figure 4.1. Photo. The senior field inspector's calculation for application rate verification.

4.1.2.d. Pavement Performance Records

Pavement performance records were not available for the project.

4.1.2.e. Inspection Records

Caltrans' on-site inspector allowed a photograph of the inspection records to be taken (Figure 4.1) for use in this case study. It includes the inspector's rough calculations of the application rates for the aggregate and binder for each section of the project.

4.1.3. Project Practices and Specifications

The Caltrans specification section regarding asphalt binder chip seals (Section 37-2.04 (B)) allows for a climate-zone-specific PG binder grade to be used—which is specified in the

project's special provisions, provided it is modified with at least 21% CRM by weight of virgin binder. The project visited in this case study used a PG64-16M binder that was modified with 21% CRM by weight. The blend formulation was conducted by the Contractor. The specifications regarding sand seals (or flush coats, Section 37-2.03) state that either a slow-setting or quick-setting emulsion is to be used. For this project, an SS-1 emulsion was used.

The specified aggregates to be used in the asphalt binder chip seals must be of broken stone, gravel or both, graded with either a NMAS of 1/2 inch or 3/8 inch. The exact gradation to be used is indicated in the project's special provisions. Either of these aggregates must be pre-coated with a small percentage of an approved asphalt binder in a plant authorized under Caltrans *Material Plant Quality Plan*.[24] The aggregate used on this project were of size 3/8 inch, single-sized and pre-coated with 0.5-1 percent of asphalt binder following Caltrans specifications. The sand seal specification required use of any type not containing organic matter or clay. It was not determined what type and gradation was used for the sand on the project.

The mix design method to be used for Caltrans chip seal projects is not expressly stated in the specifications. It was originally implied from the specifications that the Contractor is the designer of record. However, during a follow-up conversation with the Resident Engineer of District 2, it was determined that Caltrans is the designer of record for chip seal projects in that district. There is not a specific method used. Rather, only the binder grade and aggregate size were specified. The Senior Field Inspector indicated that application rate targets were provided by the Resident Engineer. The target asphalt binder application rate was 0.58 gal/yd^2 and the pre-coated chip spread rate target was 35±1 lb/yd^2. Application rates for the flush coat (referred to also as sand seal) were given for the emulsion, which was set at 0.12 gal/yd^2.

The verification tests used on the project included testing the aggregate for each of the aggregate tests at plant start-up. During production, the aggregate is sampled and tested for gradation and cleanness value. During start-up and throughout production, binder is sampled by a Contractor technician and sent by Caltrans to an independent laboratory for Acceptance testing (Softening Point and Viscosity at 375°F for CRM binder). On-site binder tests included viscosity, sieve analysis, and flash point. It was not determined whether the Vialit test—a test for determining the degree of aggregate retention in a given asphalt content percentage—was conducted.

The project's equipment included one on-sight asphalt storage container, two binder distributors equipped with an emission capture apparatus, one chip spreader—with a second one ready in case of break downs, thirteen haul trucks, two pneumatic-tire rollers, one front-steel-drum roller with two pneumatic rear tires, seven sweepers, an emulsion distributor and a blotter truck. Figure 4.2 shows a distributor truck with the emission apparatus. These are necessary when using asphalt binders modified with CRM at elevated temperatures. The project's binder temperature range was 385-415°F. Figure 4.3 shows the single-drum roller used on the project. While there is not a detail in the Caltrans specifications regarding equipment calibration, the Senior Field Inspector indicated that the equipment is expected to arrive on the jobsite calibrated. The calibration was indirectly verified daily with inspection of meters on the equipment and raw material plus total production quantity reconciliation. The Inspector further indicated that calibration is dependent upon existing conditions, the weather and material type. Other equipment employed requiring calibration were the asphalt rubber plant and hot mix plant

located at the hot plant site in Alturas. Both had to be calibrated per the Caltrans MPQP requirements (109) and verified by Caltrans Independent Assurance (IA) prior to use.

Figure 4.2. Photo. Asphalt binder distributor with emissions capture apparatus.

Figure 4.3. Photo. Single-drum steel roller.

The Caltrans specifications do not indicate calendar dates to begin and end the construction season. There are details that indicate the requisite ambient and/or surface temperatures needed to begin construction daily. For asphalt rubber binders, the ambient temperature must be 60-105°F and the surface temperature must be a minimum of 55°F. The binder is not to be applied in damp areas or in high-wind conditions. As the project was constructed in the summer, there was little concern of temperatures not reaching the minimum limits. The Senior Field Inspector indicated that the coolest temperatures observed during the project construction were an ambient temperature of 52°F and a corresponding pavement surface temperature of 56°F. The day of the site visit saw temperatures reach upwards of 90°F. Even with the elevated temperatures, embedded chips were found to be very stable upon the rapid opening to traffic due to the high stiffness of the asphalt rubber binder.

Surface preparation practices required by the Caltrans specifications include covering manholes, valves and monument covers, grates or other exposed facilities using plastic or construction paper secured by tape or another adhesive. The surface is to be cleaned immediately before applying binder by removing any deleterious substances and drying the surface if necessary using the self-propelled rotary brooms. The project's surface preparation included limited dig out repairs and very limited crack filling. The pavement appeared to be in relatively good condition, with any structural deficiencies repaired by the dig outs. No other surface preparation practices were determined.

Caltrans' specified construction inspection specifications include requirements for application rates, among others. For asphalt rubber binder, the crew must cover binder with aggregate within 2 minutes of the binder's application, and the application temperature must be maintained at a range of 375-415°F. The aggregate must be spread within 10% of target rate and uniformly across the full width of one lane in one operation. Any excess aggregate must be swept from joints before applying adjacent aggregate. The roller speeds must be slow enough to prevent roll-over of the aggregate during construction. It is also imperative to not allow aggregate to drop from the spreader if the spreader is not moving; any aggregate that drops in this case must be removed prior to continuing. Pre-coated aggregates must be heated to a temperature of 225-325°F, then covered with tarps for haul times exceeding 30 minutes or in ambient temperatures of less than 65°F.

Longitudinal joint overlap must not exceed 4 inch, unless such overlap is authorized. The Contractor can perform initial rolling with one coverage of a pneumatic-tire roller and final rolling with two coverages. The initial rolling is performed with pneumatic-tire rollers, within 90 seconds of spreading aggregate. An eight-to-ten-ton steel-wheel roller for final rolling may be used, if authorized. Once rolling is completed, sweeping must commence. Excess aggregates are swept from roadway and adjacent areas. After sweeping, the Contractor can apply the sand seal. The project's inspection process also included careful monitoring of application rates and temperature ranges. The driving lanes and shoulders were treated separately with the driving lane always treated first. The asphalt distributor began application on the lanes, covering the full 12-ft width in one pass. Construction joints always started and ended on builder paper. A second full distributor was ahead of the first, prepared to begin application once the first distributor was empty. The chip spreader followed immediately behind the distributor and spread the pre-coated chips at a uniform rate.

Application of both the asphalt binder and chips resulted in very uniform coverage. Figure 4.4 is a close-up of the chip seal mat surface after completion of the rolling operation. The workmanship associated with the application was continually monitored by both the Contractor's Project Manager and the Senior Inspector. The haul trucks were continuously rotating and unloading the chips into the spreader hopper. Haul times were less than 30 minutes, eliminating the need for tarping of the truck beds.

The rolling operation proceeded rather rapidly, using the two pneumatic rollers and the single-drum steel roller. The rollers engaged in an overlap pattern and performed two passes for one

complete coverage. The final rolling was conducted by the steel-drum roller and consisted of two coverages.

Figure 4.4. Photo. Chip seal surface upon completion of rolling operations.

At the longitudinal construction joints (centerline and shoulders) where overlaps of four to six inch occurred a slight streaking of what appeared to be lighter aggregate was visible after steel drum rolling as illustrated in Figure 4.5. However, it was not apparent when inspecting portions of the project that had been open to traffic for a couple of days. Interestingly, the senior inspector indicated that in his experience a project which incorporated a steel drum roller was quieter, in terms of noise pollution, than others that used different roller types.

Figure 4.5. Photo. Location of overlapped longitudinal joint after steel drum roller.

The sweeping operation included all seven sweepers continuously sweeping the treatment behind the rollers. This project had a flush coat (referred to also as sand seal) applied. The flush coat used the sand blotter finishing method. SS-1 emulsion was sprayed at a rate of 0.12 gal/yd^2,

followed by a coat of sand, spread as shown in Figure 4.6. The surface was then immediately and rigorously swept.

Figure 4.6. Photo. Sand distributor during flush coat surface treatment application.

The project inspector carefully monitored the application rates shown on the asphalt distributor and chip spreader comparing them with his own calculations to ensure that they matched each other and were within specification tolerances. His calculations for the application rates compared the amount spread onto the pavement to the amount of asphalt binder and aggregate indicated on haul tickets relative to the actual pavement surface area treated. This was conducted daily and verified accurate calibrations. Figure 4.1 illustrates a daily calculation example. Throughout the duration of the project asphalt binder application rates ranged from 0.58 gal/yd^2±0.05 and chip application rates varied from 34.6 to 37 lb/yd^2, both consistently in specification. The Caltrans' specified application rates are 28-40 lb/yd^2 for the aggregate and 0.55-0.65 gal/yd^2 for the binder.

Caltrans' allowable mix adjustments for asphalt binder chip seals include the allowance for a decrease in binder application rate in the wheel path by 0.050 gal/yd^2. No other adjustments are indicated. For this project, the only mix adjustment made was on the asphalt content used to coat the aggregate. The effectiveness of the pugmill at the hot plant was reduced prior due to a mechanical failure which ultimately required that the pugmill be replaced. During the period of reduced effectiveness, the asphalt content was increased from 0.5% to 1% by the resident engineer. Upon replacing the pugmill, the asphalt content was reduced back to 0.5%.

Caltrans' specifications require that the chip seal be opened to controlled traffic via a pilot car for two to four hours post-construction prior to opening the roadway to full traffic. This applies only to two-lane two-way roads, in which this project is included. For this project, the chip seal is to be continuously swept for four consecutive days and traffic is to be piloted during this time. After the four days, the treatment is open to full traffic. Chip loss appeared to be very minimal after sweeping on the day of construction.

Caltrans' specified post-construction monitoring practices indicate that the treatment is to be maintained by the Contractor until final acceptance. The Contractor must perform a final sweep the morning after application on lanes opened to un-controlled traffic before starting other activities. The Contractor must maintain the treatment for four consecutive days after the day of aggregate application. Maintenance includes sweeping and keeping surface free of loose aggregate, preventing corrugations and taking care not to dislodge aggregate during sweeping. For this project, the treatment was monitored for 15 consecutive days after final sweeping. Any failures must be repaired by the Contractor. No repairs had been required on the project as of the project visit.

The Caltrans chip seal Quality Control and Acceptance specifications for Caltrans' asphalt rubber chip seals were indicated discussed in detail in Chapter 3, Section 3.2.3. For this project, the Contractor Quality Control included only the testing on the asphalt rubber binder. The Caltrans Acceptance activities on-site included inspection, sampling, and testing of the aggregates.

The asphalt rubber binder was produced at the same location as the aggregates and hot plant used to produce the pre-coated chips. The plant was located approximately 30 minutes from the project. The Contract Inspector indicated that both the asphalt rubber and hot plant had been CT 109-certified per the Caltrans MPQP requirements prior to start of the project. The Quality Assurance Field Inspector on-site witnessed the Contractor's staff sample the virgin binder (one quart) and blended binder (five quarts) as shown in Figure 4.7. The inspector also monitored the temperatures of the virgin and asphalt rubber binders to ensure that they were within specification. At the time of sampling the inspector collected the certificate of compliance documents for the virgin binder and crumb rubber. A Caltrans TL0101 sample identification form is filled out and provided. The cans of binder were safely stored in the inspector's truck for delivery to the Caltrans laboratory. The Contract inspector ensured the documentation included certificates of compliance.

Figure 4.7. Photo. Sampling of asphalt binders.

The Contract Inspector indicated that on start-up evaluation aggregate samples were taken and source property requirements were verified. The Inspector also indicated that each day a hot bin

sample was taken by the hot plant operator while being witnessed by the inspector. Hot bin sampling is shown in Figure 4.8. The Contract Inspector tested the daily aggregate samples for compliance to gradation and cleanness value requirements.

Figure 4.8. Photo. Hot bin 3/8 inch chip sampling.

4.1.4. Inspection Practices Leading to Quality Project

Several inspection practices were observed on this project and they were clearly selected for the specific project traffic, climate, and construction conditions. The first practice was in project selection, as the relatively good pavement condition and dig-out repairs of structurally-deficient areas provide for high performance success. Examples include specifying: a very tough aggregate in an environment with tire chain/studded tires and snow plow exposure; asphalt rubber binder; and a steel drum finish roller. The use of a steel drum roller appeared to be beneficial and not destructive, likely because of the low L.A. Abrasion loss requirement for the specified aggregates. Plant and construction equipment calibration requirements were adhered to leading to positive construction. The distributors were properly calibrated, applied a uniform spread and did not leave streaks or puddles of binder on the surface. The chip spreading operation followed within seconds of applying the binder and provided complete and uniform coverage of the hot asphalt rubber binder.

Daily inspection, sampling and testing of the asphalt binder and aggregates at the hot plant assured quality materials on the grade. Continuous inspection during treatment application by both the Contractor and Caltrans inspector assured good workmanship and that any activities needing corrective action were identified very rapidly minimizing risk/repair work. The distributors stopped and started application atop builder paper leading to well-constructed transverse joints. Sweepers were able to keep loose chips down and there was proper signage. Pilot car operations ensured adequate flow and maintained traffic at a speed of 15 mph or less.

The Senior Inspector indicated that the Contractor had a strong desire to build a high-quality project.

Finally, there appeared to be very good communications and a positive spirit of partnering among the contractor and Caltrans staff. Collectively, use of the design, materials, construction, and quality control and acceptance practices identified have led to reliable performance of chip seals in a very challenging climate which exposes the pavements to chain/studded tire wear and snow plows. Typical asphalt rubber chip seal performance lives under these conditions on US and CA routes in District 2 are 8-10 years, which is very good for these specific conditions and traffic levels. Table 4.1 presents a summary of identified Caltrans inspection practices that led to quality chip seal projects.

Table 4.1. Summary of Caltrans Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
Low L.A. Abrasion Loss value for aggregates	No	Prevents excessive wear due to chain wear and studded tires used in area during winter
Proper inspection based upon site-specific conditions	No	Adjusts inspection tasks and goals to accommodate variations across projects.
Proper project selection	No	Prevents early distresses
Proper surface preparation	Yes	Although dig-outs not specified, were needed as part of surface preparation to repair structurally deficient areas to prevent early chip seal distresses
Use of asphalt rubber binder and pre-coated aggregates	Yes	Enhances aggregates retention
Proper equipment calibration	Yes	Ensures adequate spreading
Daily and continuous inspection	Yes	Maintains consistency and specification compliance
Effective communication	No	Allows both entities to create a good project.

4.2 Chip Seal Treatment Project in Spokane County, WA

4.2.2. Overall Project Description

Spokane County has had a long history of constructing chip seals. This case study is based around the site visit of several chip seal projects that Spokane County has constructed in the previous ten years. A total of 12 projects were inspected and one visit to a chip seal project that was under construction was conducted. The following information was obtained from an on-site interview.[25]

Spokane County maintains a total of 2,350 lane-miles of roadway, 1,150 of which are gravel. As was discussed in Chapter 3, Spokane County self-performs the construction of chip seals within the county, applying the preventive maintenance treatments on over 100 miles of roadways

annually. Spokane County owns 44 aggregate quarries, all chip seal equipment, and a falling weight deflectometer (FWD), the last of which is used for project selection.

One site that was visited was a project that was previously constructed on Hayford Road in Spokane County (9 miles northwest of Spokane city). The roadway is an asphalt concrete main arterial with an aggregate and hot-mix asphalt plant along the route. The ADT is approximately 16,000 vpd with 20% truck traffic. The project was constructed two years ago and shows minimal signs of distress.

4.2.3. Collected Records

4.2.3.a. Specifications

The project was constructed per the requirements of Washington Department of Transportation's *Standard Specifications for Road, Bridge, and Municipal Construction 2016*. The primary section relevant to this project is *Division V Surface Treatments and Pavements Section 5-02 Bituminous Surface Treatment*.

4.2.3.b. Mix Design Records

Spokane County indicates that the McCleod chip seal mix design method is used to develop baseline materials application rates.[25] The application rates may be adjusted later in the field, depending upon the conditions of the project. The mix design records were not collected. CRS-2P is used almost exclusively in Spokane County's chip seal treatment. Typically, 3/8 inch single-sized aggregates are used, a size that was adapted from MnDOT's specifications.[25]

For the Hayford Road project, a CRS-2P emulsion was used with 3/8 inch basalt aggregate. The final project was fogged with a CSS-1h emulsion. The application rates for the chip seal or fog seal emulsion, and aggregate are not indicated.

4.1.2.c. Construction Records

Spokane County's construction records were not collected. During the visit of the chip seal project that was under construction, it was observed that Spokane County performs crack sealing treatments atop the pavement to be treated with a chip seal one year prior to the chip seal application. Patches are also applied at this time, if needed. Patches consist of 3/8 inch HMA and are placed without the use of motor grading.

Another observation that was made is that Spokane County owns Bearcat pressure distributors, Etnyre aggregate spreaders, Dynapac CP232 pneumatic-tire rollers, a static Volvo DD140B steel drum roller, and end dump trucks. Spokane County calibrates and maintains the equipment. All equipment are between two and six years old.[25]

During placement, the emulsion is sprayed four inches past the pavement's edge and the joints are overlapped by four to six inch with emulsion.

4.1.2.d. Pavement Performance Records

Spokane County's inspection records were not collected.

4.2.4. Inspection Practices Leading to Quality Project

The primary observed practice that lead to a quality project was the application of the crack treatment one year prior to placing the chip seal treatment. Other practices included consistently calibrating and maintaining all equipment, overlapping joints with emulsion, and annual staff member training. Table 4.2 outlines the observed practices.

Table 4.2. Summary of Spokane County Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
Rubberized crack seal and patches one year before construction	No	Ensures adequate curing of crack seal treatment, which will prevent swelling in chip seal.
Proper equipment calibration and maintenance	No	Ensures that application rates will be uniform across all projects
Frequent personnel training	No	Ensures that, even if there is high turn-over, all chip seal crew members are competent and aware of the workflow and processes needed for quality.

4.3 Slurry Seal Treatment Project in City of Columbus, Ohio

4.3.1. Overall Project Description

This project is a city-wide, mostly residential, project with slurry seal treatment placed in 18 locations around the city (city-wide 2016 preventive surface treatment program). Slurry seal treatment was placed on 209 street segments for a total project quantity of 560,000 yd^2. Being residential streets, the traffic is low volume and the routes are two-lanes. The plans for the project were prepared by the City's Public Service Department, Division of Design and Construction. In addition to the slurry seal treatment, this project included a small number of street segments to receive micro surfacing or cape seal treatment. The project was constructed between August and November 2016 and was selected as a case study because the construction had few problems. Figure 4.9 below is one of the plan sheets for the project showing a group of street segments designated for slurry seal treatment. Note that the segments to be treated have a segment number for purposes of documenting progress and quantities. Also note that not all streets in this residential area received treatment.

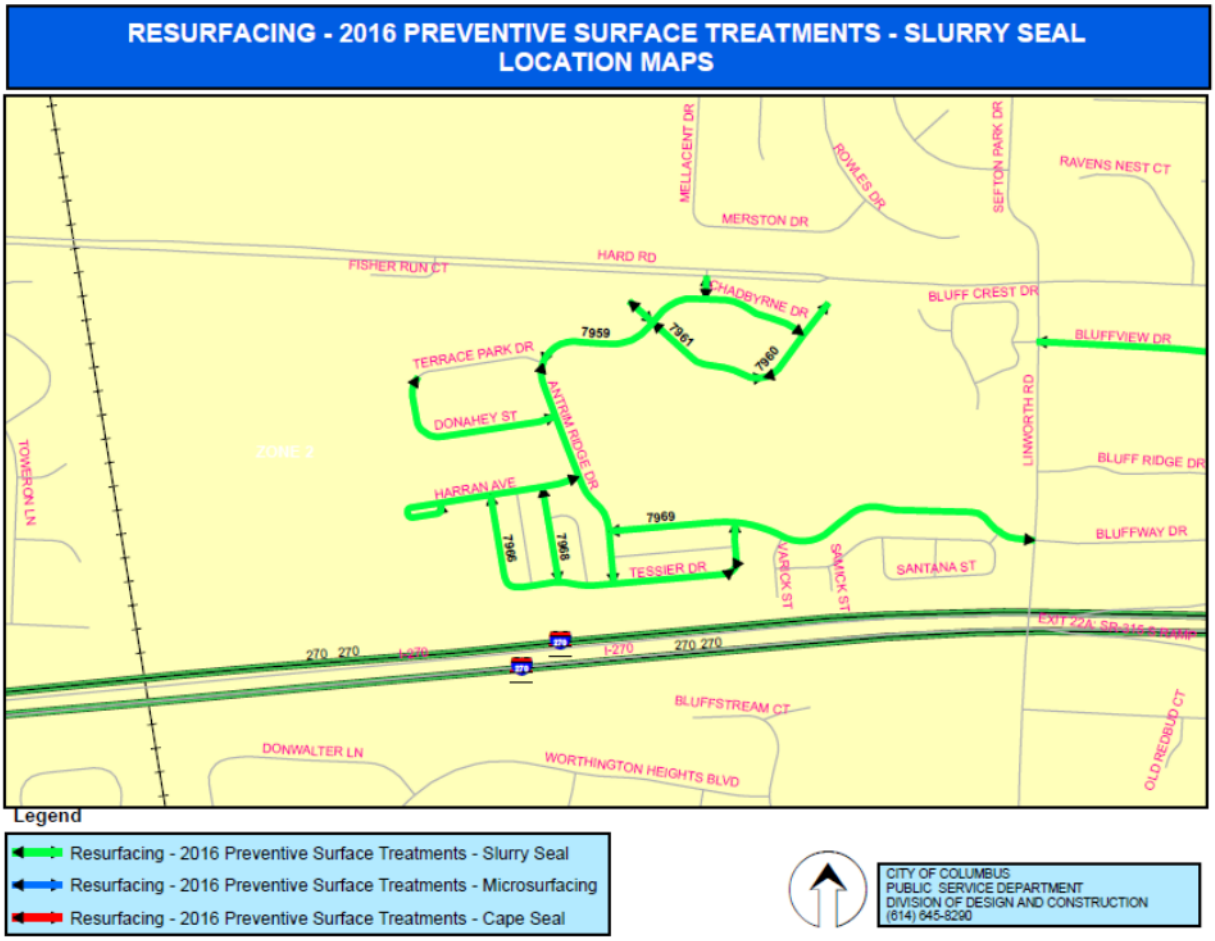

Figure 4.9. Photo. Map of street segments designated for slurry seal in City of Columbus.

4.3.2. Collected Records

4.3.2.a. Specifications

The construction specifications relevant to this project are: *400 Flexible Pavement, Item 417 – Asphalt Emulsion Slurry Seal*, and *Supplement 1032 – Asphalt Material Certification Requirements.*

4.3.2.b. Mix Design Records

The JMF used on the project was prepared by the contractor and emulsion supplier and is dated September 2, 2016. The report did not include the project number, mixture identification, name of the mix designer, nor any indication that the City reviewed and approved it. The specification does require the contractor to submit the JMF before the contract is awarded. Mix design sheet includes the material proportions, aggregate data, emulsion data, and slurry performance data. Results required by the specifications include aggregate sand equivalent, aggregate LA abrasion, emulsion residue, emulsion viscosity, asphalt residue penetration, asphalt residue ductility, slurry mix time, and slurry wet track loss, and others. All JMF values complied with the specification 417-02s, except the LA abrasion was slightly over the allowable limit.

The slurry mixture is No.4 NMAS limestone, 1.0% cement, 13.0% CSS-1h emulsion (8.8% asphalt residual), 11% water, and 0.02% unspecified additive. The aggregate came from an Ohio DOT pre-qualified supplier. The aggregate quality test results were reported on the JMF (Table 4.3).

Table 4.3. JMF for the Slurry Seal Project from City of Columbus.

Slurry Mix Properties	Results at 13% Emulsion	Specification, Type II
Mix time @ 77F (25C), TB113	250 seconds	120 seconds minimum
Mix time @ 100F (37.7C), TB113	44 seconds	Not specified.
Cohesion @ 30min, TB139	17 N kg-cm	12 N kg-cm minimum
Cohesion @ 60min, TB139	23 N kg-cm	20 N kg-cm minimum
Water Resistance Test, 30 min	Pass	Pass
WTAT 1 hour, TB100	3.3 grams/ft^2	75 grams/ft2 maximum
Cone Consistency Flow	3 cm	2.5-3.5 cm
Set Time Blotter Test	Pass	Pass
Coating Test	99%	90% minimum
Excess Asphalt/Sand Adhesion, TB109	24.7 grams/ft^2	60 grams/ft2 maximum
Gradation (Percent Passing)		
Passing 3/8 inch	100%	100%
Passing No. 4	99%	90-100%
Passing No. 8	79%	65-90%
Passing No. 16	54%	45-70%
Passing No. 30	36%	30-50%
Passing No. 50	25%	18-30%
Passing No. 100	20%	10-21%
Passing No. 200	14.7%	5-15%

4.3.3.c. Construction Records

The City of Columbus provided an example aggregate ticket for September 21, an example emulsion shipping ticket for September 21, one yield report, and the construction inspection daily record for the entire project from August 22 through December 20, 2016. The progression of work involved crack sealing, ADA curb repairs, pavement patching, slurry seal, and pavement markings. Placement of slurry seal treatment was performed between September 21 and October 17. The contractor placed 17,000 to 18,000 yd^2 of slurry seal per day operating multiple slurry trucks. The specification requires a minimum of two slurry trucks to provide a nearly continuous operation (*417.03 Equipment 1. Slurry Mixing Equipment*).

Six inspectors are listed as the inspector of slurry placement on different days. The primary documentation on the inspection reports were quantities placed on each roadway segment. Very few inspection reports note quantities of aggregates or emulsion delivered to the project. The contractor documented one yield report on September 21, the first day of slurry placement. The yield report covered 18,501 yd^2, with an emulsion content of 13.33%, residual asphalt content of 8.3%, and aggregate rate of 16.03 lb/yd^2. Other notes on the inspection reports generally

involved cleaning the street before placement (vegetation in the cracks), maintaining traffic control, and timely opening the street to traffic. Most reports list the morning low air temperature and afternoon high temperature, but there is no note stating if the slurry seal placement was delayed until the morning air and pavement temperature reached the specification minimum (45°F and rising) per specification *417.06—Weather Limitations*.[81] The specification calls for a thickness measurement every 1,000 yd^2 (*417.09—Method of Measurement)*, but the results (if measured) were not recorded on the inspection reports.[82]

4.3.3.d. Pavement Performance Records

The City of Columbus's pavement performance records were not collected. The project was just placed in 2016.

4.3.3.e. Inspection Records

The City of Columbus's inspection records were not collected with the submitted documentation.

4.3.3. Inspection Practices Leading to Quality Project

Table 4.4 presents a summary of identified City of Columbus inspection practices that lead to a quality slurry seal placement project.

Table 4.4. Summary of City of Columbus Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
Project size	No	The project was sufficient in size to achieve consistent placement for a large number of street segments.
On-site inspection	No	The city had an inspector on-site for every day of slurry seal treatment placement.
Provide a nearly continuous operation, minimum of two slurry trucks	Yes	The contractor placed 17,000 to 18,000 yd^2 of slurry per day operating multiple slurry trucks.

4.4 Slurry Seal Treatment Project in Virginia

4.4.1. Overall Project Description

This project placed slurry seal on ten routes; Type B slurry seal was placed on King George County routes 1108 and 1101, Richmond County route 1010, and Lancaster County route 354; Type C slurry seal was placed on Westmoreland County route 621, Lancaster County routes 637, 709 and 675, Northumberland route 621, and Spotsylvania County routes 656 and 1368. The routes are two-lane rural routes. Placement of the slurry seal began in March 2014 and ended in May 2014. Total quantity placed is unclear due insufficient information on individual inspection reports. The records provided for the case study do not include project plans so it is unknown if the project was designed by the DOT central office, DOT division, or a consultant.

4.4.2. Collected Records

4.4.2.a. Specifications

Construction specification relevant to this project is listed below. The special provision was issued in 2012 and reissued in 2016 (after the case study project). VDOT describes a slurry seal as an emulsified asphalt slurry seal.

SP312-000100-00 SPECIAL PROVISION FOR EMULSIFIED ASPHALT SLURRY SEAL

4.4.2.b. Mix Design Records

The job-mix formula (JMF) for the Type B slurry seal used on the project, designated lab mix 2, was prepared by Design Lab D913 and is dated February 26, 2014. It is unclear if the JMF was prepared by the emulsion supplier or the contractor. The JMF form includes the DOT approval signature. VDOT's JMF approval states that the mix is "approved for all projects of the Department for the type of mix and the calendar year shown." The approved JMF design summary includes the aggregate source and gradation, emulsion type, and design emulsion rate. Results required by the VDOT specification (SP312-100, Section II.E MIX DESIGN) include form TL-127, compatibility by Schulze-Breuer, and Wet Track Abrasion Test wear loss. The accepted residual asphalt rate is 7.0 to 10.0 percent which is an allowable tolerance of 1.5 percent above and below the target 8.5 percent.

The Type B slurry seal mixture consist of No. 4 NMAS granite aggregate, 1.0 percent hydrated lime, cement mineral filler as needed, and CQS-1H emulsion at 8.5 percent residual asphalt by aggregate weight. The report does not indicate the emulsion's residual asphalt rate. VDOT JMF also reports that the individual materials were tested and approved. A summary of the JMF gradation is shown in Table 4.5 below. VDOT did not provide the JMF for the Type C mix.

Table 4.5. Summary of Fredericksburg District, VA Slurry Seal Project JMF

Mix Gradation Percent Passing	Specification Type B	Sieve Size
100	100	3/8 inch
94	70-95	No. 4
65	45-70	No. 8
45	32-54	No. 16
34	23-38	No. 30
26	16-29	N0. 50
17	9-20	No. 100
9.1	5-12	No. 200

4.4.2.c. Construction Records

VDOT provided two types of construction records for the case study project, including asphalt mixture laboratory tests on Form TL-50 and application rate checks. No construction inspection reports were provided. VDOT provided 5 mixture test reports for the Type B mixture ranging from sample dates of March 21 to May 4. The reports identify the project, route, sample number, truck load number, and lab receiving date. The reports were too consistent on listing the quantity of mix the sample represents (all reports were 20,000 yd^2). SP312-100, Section II.G

MATERIALS, Mix Sampling and Testing, requires that samples represent a maximum 25,000 yd^2 at the start of production and can be increased to a sample every 50,000 yd^2 when the mix is consistent. The reports only list the aggregate gradation and residual asphalt content. The residual asphalt content ranged from 7.12 to 7.98 for the first three samples and jumped to 9.34 and 9.83 for the last two samples (the JMF range was 7.0 to 10.0). The P_{200} ranged from 13.0 to 14.6 which were on the high side of the target range of 5 to 15 percent.

VDOT only provided 1 aggregate application rate report on March 31 for the Type B slurry seal mixture. The report included the project identification, inspector's name, truck number, the spreader's aggregate calibration number (aggregate pounds per count), aggregate count for the period, area covered, and computed aggregate spread rate. The aggregate spread rate for the report was 15.37 lb/yd^2 and was significantly lower than the 16 lb/yd^2 target. The report includes a theoretical spread rate of 16 lb/yd^2, but there is no information about the source of that value.

VDOT provided 9 mixture test reports for the Type C mixture ranging from sample dates of April 8 to May 15. The reports identify the project, route, sample number, truck load number, and lab receiving date. The reports listed the quantity of mix the sample represents but there are questions about the quantities shown. SP312-100, Section II.G MATERIALS, Mix Sampling and Testing, requires that samples represent a maximum 25,000 yd^2 at the start of production and can be increased to a sample every 50,000 yd^2 when the mix is consistent. Six of the reports lists quantities from 70,000 to 170,000 yd^2. Most of the reports only list the residual asphalt content. The residual asphalt content ranged from 6.44 to 7.58 for the nine reports (the JMF range was 5.7 to 8.7). There are enough results to compute basic statistical parameters. The mean residual asphalt content was 6.8% and the standard deviation was 0.37. The range of measured tests suggest the deviation was skewed toward higher residual contents.

VDOT provided 10 aggregate application rate reports from April 8 to May 19 for the Type C slurry seal mixture. The reports included the project identification, inspector's name, truck number, the spreader's aggregate calibration number (aggregate pounds per count), aggregate count for the period, area covered, and computed aggregate spread rate. The aggregate spread rate for the reports ranged from 19.44 to 21.88 lb/yd^2 and the target was 20 lb/yd^2. There are enough results to compute basic statistical parameters. The mean aggregate spread rate was 20.6 lb/yd^2 and the standard deviation was 0.92. These values conclude that the placement rate was reasonably normally distributed when compared with the range and approximately 30% of the placement was below the target. The report includes a theoretical spread rate of 20 lb/yd^2, but there is no information about the source of that value. Projects records did not include data on placement temperature, equipment calibration, and time to open to traffic.

4.4.2.d. Pavement Performance Records

VDOT did not provide any post construction record of pavement performance. The project was placed in 2014.

4.4.3. Inspection Practices Leading to Quality Project

Table 4.6 presents a summary of identified VDOT inspection practices that lead to a quality slurry seal placement project.

Table 4.6. Summary of VDOT inspections practices for quality projects

Practice	In Specifications?	How Practice Affects Project Quality
Project size	No	The project combined multiple route segments to achieve a large project.
Certified Technician	SP312-100, Section II.H MATERIALS, Personnel	Knowledgeable staff on-site improves understanding for producing a consistent mixture.
Routine checks of residual asphalt content every 25,000 yd^2 of mixture placed, with reduced sampling to 50,000 yd^2 for consistent mixture.	SP312-100, Section II.G MATERIALS, Mix Sampling and Testing	Residual asphalt content is key to treatment consistency and performance. Routine measures of residual from slurry mix is important.
Routine checks of the treatment application rate	Field Office procedure	This QA practice monitors the consistency of the slurry equipment spread rate.

4.5 Micro Surfacing Treatment Project in Virginia

4.5.1. Overall Project Description

This project, LM6A-966-F14, P401, placed micro surfacing on three routes; Caroline County route VA-207, Richmond and Northumberland Counties route US-360, and Lancaster County route VA-200. The routes are two-lane rural minor arterials. Placement of the microsurfacing began in March 2014 and ended in May 2014. Total quantity placed was approximately 2,100 tons (200,000 yd^2).

4.5.2. Collected Records

4.3.2.a. Specifications

The construction specification relevant to this project is: *SP312-000110-00 Special Provision for Latex Modified Emulsion Treatment (Micro Surfacing)*. VDOT describes a micro surfacing as a latex-modified emulsion treatment.

4.3.2.b. Mix Design Records

The JMF for a latex modified type C microsurfacing used on the project, designated laboratory mix MD-313, was prepared by the emulsion supplier for the contractor and is dated March 10, 2013. A DOT approved JMF using the same MD-313 design was dated February 21, 2014. The VDOT JMF approval states that the mix is "approved for all projects of the Department for the type of mix and the calendar year shown." The emulsion supplier's mix design summary included the aggregate source and gradation, emulsion type, test results on the mixture at three emulsion rates, design emulsion rate, and mixture properties. Results required by the DOT specification (*SP312-110, Section III MIX DESIGN*) include compatibility by Schulze-Breuer,

Marshall Stability, flow, residual asphalt content at a target air voids, and proportion ranges for residual asphalt, mineral filler, and percent latex solids.

The VDOT mix design is unique in that it requires Marshall Mix Design procedures and mixture properties, such as stability, flow, and volumetric properties. The design emulsion rate is based on 4.7% air voids in the compacted mix and is reported as residual asphalt by weight of mix and residual asphalt by weight of aggregate. The report also includes Schulze-Breuer Compatibility for water absorption and abrasion loss. The DOT approved JMF reports the same materials and emulsion rate, but the listed ignition oven correction factor is different. The accepted residual asphalt rate is 5.4 to 8.4% which is an allowable tolerance of 1.5% above and below the target 6.9% (*SP312-110, Section V.E PROCEDURES, Test Requirements*).[83]

The micro surfacing mixture consisted of No. 4 NMAS granite aggregate, 1.0% type 1 cement mineral filler, CQS-1HLM emulsion at 6.9% residual asphalt by aggregate weight, and a field control additive. Neither report indicated the emulsion's residual asphalt rate. The DOT JMF also reported that the individual materials were tested and approved. A summary of the JMF is shown in Table 4.7.

Table 4.7. JMF for the Micro Surfacing Project from VDOT.

Micro Surfacing Mix Properties	Results at 6.5% Residual Asphalt	Specification Type C
Average Marshall Stability, VTM-95	3,163 lb	1,800 lb Minimum
Average Marshall Flow, VTM-95	0.14 inch	0.06-0.16 inch
Average Voids in Total Mix	5.3%	4.7%
Average VMA	18.3%	Not specified.
Asphalt Absorption	1.89%	Not specified.
Water Absorption, Schulze-Breuer	7.0%	Not specified.
Abrasion Loss, Schulze-Breuer	3.2%	Not specified.
Ignition Oven Correction Factor	0.042	Not specified.
Gradation (Percent Passing)		
Passing 3/8 inch	100%	100
Passing No. 4	85%	70-95
Passing No. 8	55%	45-70
Passing No. 16	39%	32-54
Passing No. 30	30%	23-38
Passing No. 50	24%	16-29
Passing No. 100	16%	9-20
Passing No. 200	8.9%	5-12

4.3.2.c. Construction Records

VDOT provided several types of construction records for the case study project, including emulsion tank reports, asphalt mixture laboratory tests, and application rate checks. No construction inspection reports were provided.

The emulsion supplier provided 29 certified asphalt emulsion test reports dating from March 14 to May 12. Each report includes the supplier's batch number, product name, quantity, and production date as well as the date sampled, name of the technician taking the sample, and the technician performing the tests. Test results are reported for sieve test, particle charge, residual asphalt percent, residual asphalt penetration, and residual asphalt softening point. All tests complied with *SP312-110, Section II.A MATERIALS, Emulsified Asphalt*. The residual asphalt ranged from 62 to 64.4% (minimum 62%), and ring & ball softening point ranged from 60.0°C to 71.0°C (minimum 60°C).

VDOT provided 6 mixture test reports ranging from sample dates of March 20 to May 2. The reports identify the project, route, sample number, truck load number, and lab receiving date. The report also listed the quantity of mix the sample represents, typically 500 ton lots. *SP312-110, Section V.E PROCEDURES, Test Requirements*, requires that samples represent a maximum 500 tons.(83) The reports only list the aggregate gradation and residual asphalt content. The residual asphalt content ranged from 5.84 to 7.22% (JMF range was 5.4 to 8.4%). The P-200 ranged from 11.6 to 14.1% which were at or above the target range of 5 to 12%. Three samples were delivered to the lab the day they were sampled, and three samples were delivered one to seven days after sampling.

VDOT provided 11 aggregate application rate reports beginning on March 20 and ending May 9. Each report included the project identification, inspector's name, truck number, the spreader's aggregate calibration number (aggregate pounds per count), aggregate count for the period, area covered, and computed aggregate spread rate. The spread rate over the 11 reports ranged from 19.77 lb/yd^2 to 27.08 lb/yd^2. Each report included a theoretical spread rate of 24 lb/yd^2, but there was no information about the source of that value. One report noted a minimum 20 lb/yd^2 for Type C micro surfacing. *SP312-110, Section V.C.3 PROCEDURES, Application Rates* requires 20 to 24 lb/yd^2 of mix for Type C micro surfacing.(84) Projects records did not include data on placement temperature, equipment calibration, and time to open to traffic.

4.3.2.d. Performance Records

VDOT did not provide post construction records of pavement performance. The project was placed in 2014.

4.5.3. Inspection Practices Leading to Quality Project

Table 4.5 presents a summary of identified VDOT inspection practices that lead to a quality micro surfacing placement project.

Table 4.5. Summary of VDOT Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
Project size	No	The project combined three route segments to achieve 200,000 yd^2 of placement.
Collection of emulsion tanker shipment tickets	Yes	The tickets provided a good record of emulsion quantity and quality.
Routine checks of residual asphalt content every 500 tons of mixture placed	Yes	Residual asphalt content is key to treatment consistency and performance. Routine measures of residual from micro surfacing is important.
Routine checks of the treatment application rate	Yes	This QA practice monitors the consistency of the micro surfacing equipment spread rate.

4.6 Thin Lift Asphalt Overlay Treatment Project in Florida

4.6.1. Overall Project Description

This project is a two-mile section of US-17, also Florida Route 5, near Georgia border. The traffic is 5,000 annual average daily traffic (AADT) which is classified as level B traffic. This is a two-lane roadway with a 12-ft lane and 4-ft paved shoulder in each direction. The plans for the project were prepared by a consultant. The project calls for milling and resurface 1-inch depth by 32 ft wide, placing 2,350 tons of FC-9.5 mix using asphalt-rubber binder. The project was constructed in July 2009 and was selected as a case study because the pavement is performing well.

4.6.2. Collected Records

4.5.2.a. *Specifications*

Construction specifications relevant to this project are listed below. Other related documents include Construction Training Qualification Program and Florida Test Methods.

- *105 QUALITY CONTROL PLAN*
- *300 PRIME AND TACK COATS*
- *320 HOT MIX ASPHALTS – PLANT METHODS AND EQUIPMENT*
- *327 MILLING OF EXISTING ASPHALT PAVEMENT*
- *330 HOT MIX ASPHALT–GENERAL CONSTRUCTION REQUIREMENTS*
- *334 SUPERPAVE ASPHALT CONCRETE*
- *337 ASPHALT CONCRETE FRICTION COURSES*

4.5.2.b. *Mix Design Records*

There were two JMFs approved for the project. SP 08-6327A was approved in July 2008 and SP 6327B was approved in July 2009. Both were prepared by an independent laboratory for the contractor. The surface thin lift asphalt mixture was a friction course (FC), 9.5 mm NMAS fine gradation, using four stockpiles from two aggregate sources. The JMF shows that the stockpiles

were sampled in March 2008. The asphalt binder contained 5% CRM by weight of binder. The PG grade of the base asphalt binder was not provided.

The mix followed Superpave mix design procedures with a 75-gyration design traffic level C. It is noted here that the plans called for a traffic level-B, but the mix was designed for a slightly higher traffic level C. The revised JMF, SP 08-6327B was simply a revision in the binder content from 5.5 to 5.8%. No additional mixture testing was performed as evident from the identical mixture properties listed on the two JMF forms. The JMF report shows 0.5% liquid anti-strip added to the mix, which satisfies the B traffic level mix criteria. However, the JMF classifies the mix as C traffic level, but does not include the retained strength and minimum unconditioned strength results required by the specifications. The JMF forms show DOT Office of Materials approval date and an expiration date. The form also includes a statement "The mix properties of the Job Mix Formula have been conditionally verified, pending final verification during production…." The mixture properties listed in the JMF are given below in Table 4.6.

Table 4.6. JMF for the Thin Lift Asphalt Overlay from FDOT.

Mix Properties	SP 08-6327A	SP 08-6327B
Asphalt Binder Content, P_b	5.5%	5.8%
Effective Asphalt Binder Content, P_{be}	4.7%	4.8%
Air Voids, V_a	4.0%	4.0%
VMA	15.2	15.5
Liquid Anti-Strip	0.5%	0.5%
Mixing Temperature	Target +/- 30°F	Target +/- 30°F
Compaction Temperature	Target +/- 30°F	Target +/- 30°F
Gradation (Percent Passing)		
Passing 1/2 inch	100%	100%
Passing 3/8 inch	99%	99%
Passing No. 4	74%	74%
Passing No. 8	49%	49%
Passing No. 16	38%	38%
Passing No. 30	30%	30%
Passing No. 50	25%	25%
Passing No. 100	12%	12%
Passing No. 200	5.6%	5.6%

Specification 334-3.2.7 lists twelve items that must be reported on the JMF. They include: (1) Traffic level and N-design gyrations; (2) Materials sources; (3) Aggregate source product code; (4) The gradation and proportions intended to be combined; (5) Combined aggregate gradation; (6) bulk specific gravity for each individual aggregate; (7) Percentage of asphalt binder by weight of total mix shown to the nearest 0.1%; (8) A target temperature for mixing and compaction; (9) Mixture properties at four different asphalt binder contents; (10) The name of Qualified Mix Designer; (11) Ignition oven calibration factor; and (12) The warm mix technology, if used. The two JMF reports for this case study project provide all the information, except the name of the mix designer. It is possible that information is provided on a JMF supporting document. Specification 334-3.2.6 outlines the moisture sensitivity criteria.

4.5.2.c. Construction Records

FDOT provided construction records for the three production lots defined for this project. The first lot, Lot-2, was a full 2,000-ton lot produced and placed over two consecutive days. Approximately half of Lot-2 failed to meet field density criteria and was removed. The second lot, Lot-3, was only 1,200 tons and placed over three non-consecutive days. At the end of Lot-3 the JMF was changed. The third lot and last, Lot-4, was only 94 tons. The lots were subdivided into 500-ton sublots for testing. The package of construction inspection documents for Lot-2 and Lot-3 were 145 pages each and included contractor truck tickets and DOT forms listed below. The project was constructed in July (in Florida) so air temperature is not an issue, but the review could not locate place in inspection forms to record air temperature, per Spec 330-3.2.2.—*Ambient Air Temperature*. The DOT generates a Percent Within Limits (PWL) pay factor based on P_8, P_{200}, P_b, V_a, and field core density. Pavement smoothness QC and verification is covered by a separate specification and was not provided as part for the case study. It is included in the discussion of the project's performance.

- Computer Invoices for Asphalt Concrete
- Asphalt Plant – Lot Information & Packet Cover Sheet
- Asphalt Plant – Lot Verification and Pay Factor Worksheet for Superpave Mixtures
- Asphalt Plant – Random Number Worksheet for Plant Samples
- Asphalt Plant – Random Numbers Worksheet for Roadway Density Cores
- Asphalt Plant – Verification Report
- Asphalt Roadway – Verification Report
- Cross- Slope Measurement Data Form
- Asphalt Plant – Daily Report of Quality Control
- Asphalt Plant Worksheet
- Gyratory Compactor Compaction Height Data Sheet
- Asphalt Plant Bulk Specific Gravity Worksheet

Production and paving for Lot-2 occurred on July 13-14. A QC report indicated the tack coat (trackless) was 160°F when placed and a yield check determined it was placed at 0.06 gal/yd^2, based on the entire day's placement length, meeting Spec 300-8.4. Mixture temperature when the truck left the plant was 300-315°F on 7/13 and 310-325°F on 7/14 based on hand written values on the truck tickets, meeting Spec 330-6.1.3. Lot-2 was a full lot comprised of four 500-ton sublots. Mixture test results indicated the P_8 gradation results (50.8 to 55.3%) failed to meet the P_8 target of 49.0% passing. The computed mixture spread rate was 111 lb/yd^2 on July 13 and 120 lb/yd^2 on July 14, which were above the target 110 lb/yd^2, meeting Spec 330-6.1.5.1. FDOT verification measurements of spread rate were 114.9 lb/yd^2 and 113.6 lb/yd^2 for the same days. Field density [90.5, 90.3, 88.3, 88.0], based on 5 cores per sublot, failed to meet the target 92%G_{mm} and minimum 89.5%G_{mm} in two sublots, per spec 330-7—*Compacting Mixture*.[(85)] It can be noted here that each sublot has an independent G_{mm} (theoretical maximum specific gravity) value. FDOT's verification process included testing split samples from sublot 2 and included mixture gradation, P_b, G_{mm}, G_{mb}; core density; mixture temperature; AR-binder viscosity; tack coat spread rate; tack temperature and rate, and pavement cross slope showed the contractor's QC and FDOT verification results were in tolerance.

Production and paving for Lot-3 occurred on July 14, 15 and 22. The lot was terminated at 1,260 tons so the JMF could be revised. Lot-3 was a partial lot comprised of two 500-ton sublots and

one small sublot. A QC report indicated the tack coat (trackless) was 150°F when placed on July 15 and a yield check determined it was placed at 0.07 gal/yd^2. Mix temperature when the truck left the plant was 300-305°F on 7/14-15 and 310-325°F on 7/22 based on hand written values on the truck tickets. The computed mixture spread rates on July 15 were 113 to 127 lb/yd^2, which was above the target 110 lb/yd^2. The FDOT measured verification spread rate was 112.5 lb/yd^2 in July 15. On July 22 the QC and verification spread rate was determined multiple times for small placements and most values were above 120 lb/yd^2. FDOT's verification reports tested split mixture samples from sublot 1 and field density cores from sublot 2. All verification tests showed that the contractor's QC and FDOT's verification results were within the specification tolerance.

Production and paving for Lot-4 occurred on July 23 using JMF SP 08-6327B. The lot ended at 94 tons, when the last of the FC-9.5 mixture was placed. Lot-4 was a partial lot comprised of one small sublot. A QC report indicated the tack coat (trackless) was 160°F when placed and a yield check determined it was placed at 0.04 gal/yd^2. Mixture temperature when the truck left the plant was 310-325°F based on hand written values on the truck tickets. The computed mixture spread rate was 142 lb/yd^2, which was well above the target 110 lb/yd^2. Some FDOT verification tests were performed on split mixture samples from sublot 1. All verification tests showed that the Contractor's QC and FDOT's verification results were within specification tolerance.

4.5.2.d. Pavement Performance Records

FDOT provided the pavement condition ratings for the roadway section from 1976 to 2017. The record included the pavement rating values cracking, ride, and rutting. Figure 4.10 displays the ratings for the roadway section for the last major rehabilitation and the thin lift asphalt overlay preventive maintenance. The data show the major rehabilitation was constructed in 1990 and performed very well through 1999. At that point in time the amount and severity of cracking increased and began influencing the ride. Just prior to the thin lift asphalt overlay, the pavement's cracking rating was only 4.5 and the ride rating dropped to 6.6. The rutting rating appeared to be very normal and only reflects common traffic consolidation early in the performance period. Conventional pavement preventive maintenance guidelines would recommend placing the preventive maintenance treatment when the level of pavement damage is minor to moderate. For this project the preventive maintenance may have performed even better if it was placed between year 9 and year 13 based on the data provided.

The performance of the thin lift asphalt overlay preventive maintenance reflects the condition of the underlying pavement. The degree of rutting distress was low in the pavement prior to the treatment and the rutting following the treatment is very limited. The rutting performance rating remains at 10 over the seven years of performance. The degree of cracking distress was high in the pavement prior to treatment and the rating increases to 10 immediately after the thin lift asphalt overlay is placed, then drops to 7 after 3 years. This is likely reflective cracking since the cracking rating before the treatment was 4.5. The cracking rating has not changed for the last two years. The ride value increased to 8.5 after the treatment. The ride did not recover to a rating of 10, which is common for a single thin lift asphalt overlay, and looking back at the rehabilitation project, the initial ride after rehabilitation also started at 8.5. The ride performance rating is slowly declining and may be influenced by the reflected cracking. Overall, the performance of

the thin lift asphalt overlay preventive maintenance treatment is good, when taking into account the condition of the pavement prior to the treatment.

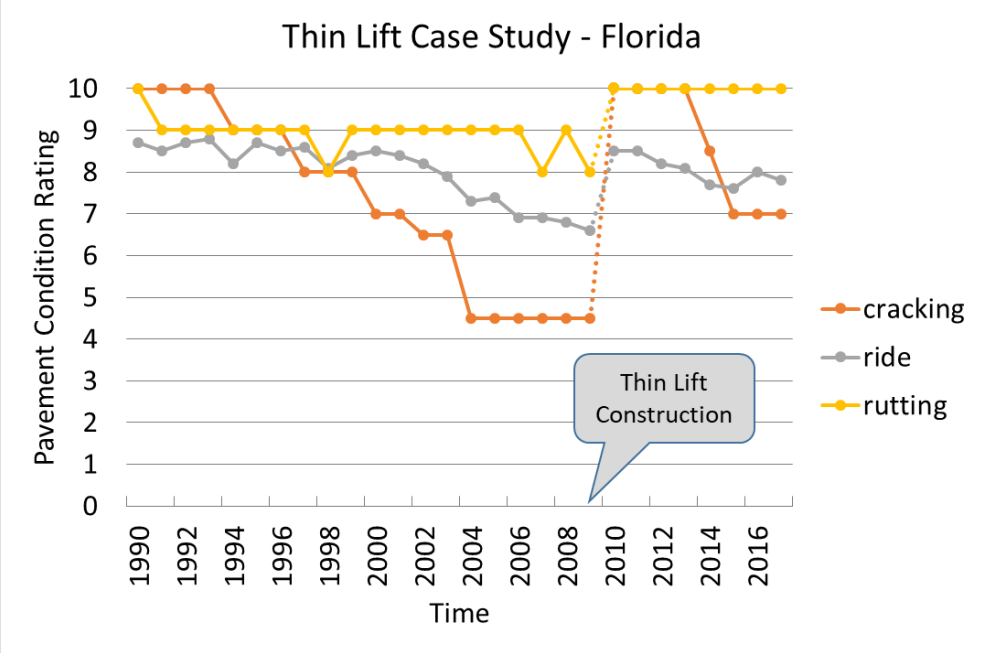

Figure 4.10. Graph. Pavement condition rating for various distress types as a function of time: shows how the rating changed from before the thin lift asphalt overlay construction and after.

4.5.2.e. *Inspection Records*

The FDOT documentation did not include inspection records.

4.6.3. Inspection Practices Leading to Quality Project

Table 4.7 presents a summary of identified FDOT inspection practices that lead to a quality thin lift asphalt overlay project.

Table 4.7. Summary of FDOT Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
"Verify and Document"	No	All materials are made to be within specification tolerance and documentation verifies.

4.7 Thin Lift Asphalt Overlay Treatment Project in Michigan

4.7.1. Overall Project Description

M-123, Superior Region. This project was a thin lift asphalt overlay section that was placed in Superior region of Michigan near the town of Trout Lake. It was placed in 2004 and involved placing 9,092 tons of Low-Volume Hot-Mix Asphalt on 12.028 miles of the M-123 road at 83

lb/yd^2 for a total square yardage of 206,538. It was a thin lift asphalt overlay placed atop another asphalt concrete roadway that had maintained traffic. This was a warranty project so there were not any incentives/penalties for Ride Quality or Quality Assurance Results.

M-48, Superior Region. This project was another thin lift asphalt overlay section that was placed in Superior region of Michigan near the towns of Raber, Pickford and Detour. It was placed in 2013 and involved placing 11,084 tons of Hot-Mix Asphalt on 16.075 miles of the M-48 road at 83 lb/yd^2. It was also a thin lift asphalt overlay placed atop another asphalt concrete roadway that had maintained traffic. This was also warranty project so again, there were not any incentives/penalties for Ride Quality or Quality Assurance Results.

4.7.2. Collected Records

4.6.2.a. Specifications

Construction specifications relevant to both project are listed below.

- *SECTION 501—PLANT-PRODUCED HOT-MIX ASPHALT.*
- *12SP504(C)—SPECIAL PROVISION FOR WARRANTY WORK REQUIREMENTS FOR HOT-MIX ASPHALT ULTRA-THIN OVERLAY.*
- *12SP500(B)—SPECIAL PROVISION FOR PAVEMENT PERFORMANCE WARRANTY.*

4.6.2.b. Mix Design Records

The JMF used on both projects was prepared by the Contractor. 12SP504(C) requires that the mix design meet the requirements laid out in **Error! Reference source not found.**. The asphalt binder grade information is not currently available for either project. Both projects used an application rate of 83 lb./yd.^{2}, per the 12SP504(C) provision.

Table 4.8. Mix Design Requirements for the Thin Lift Asphalt Overlay Mix 12SP504(C) from Michigan.

Mix Properties	Values
Percent Air Voids	4.5%
VMA	15.5%
Fines-to-Binder Ratio (Dust Proportion, %)	1.4% Max
Gradation (Percent Passing) Passing 1/2 inch Passing 3/8 inch Passing No. 4 Passing No. 8 Passing No. 30 Passing No. 200	 100% 99-100% 75-95% 55-75% 25-45% 3-8%

4.6.2.c. Construction Records

The first thin lift asphalt overlay was completed on July 29, 2004 and the second was completed on August 22, 2013. Both were well within the calendar date limits set forth in Section 501.03.I.1—*HMA Seasonal Limitations* of the MDOT standard specifications.[86]

4.6.2.d. Pavement Performance Records

MDOT did not include pavement performance records for either project in the submitted documentation.

4.6.2.e. Inspection Records

The documents submitted by MDOT did not include inspection records.

4.7.3. Inspection Practices Leading to Quality Project

Table 4.9 presents a summary of identified MDOT inspection practices that lead to quality thin lift asphalt overlay projects. Both projects were nominated for—and in the case of the M-123 project, won—an award for the practices that were undertaken throughout the project.

Table 4.9. Summary of FDOT Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Project Quality
Warranty Project	Yes	Guarantees good workmanship and adequate performance.
AADT-based binder grade requirements	Yes	Ensures adequate project-specific grade for both traffic and climate.

CHAPTER 5 CONCLUSIONS

This chapter gives an overall summary and conclusion to the findings from this study. It discusses the key identified best Quality Assurance practices for each treatment and looks for practices common to all treatments. It also discusses the primary practices that could be implemented in the future.

5.1 Common Identified State-of-the-practice and areas for improvement

One key area that all of the agencies can improve in is the requirement of a test strip. Test strips will ensure, among other things that the site was properly selected, the specifications are adequate and enforced, a proper roadway preparation process—both early and final preparation—was followed, the proper equipment was selected for the project, the mix design and equipment calibration were both accurate and the materials used have a consistent history of good performance. Further, the Contractor should have a history of constructing successful preventive maintenance treatments. Other key items that can be verified with a test strip include the application rates—that the selected rates are appropriate for the project, the inspection process—that the project is being properly inspected, the agency and the industry have a good working relationship—both entities must have shared goals. Finally, the project should be constructing using available resources, and test strips can ensure that the resources used are of appropriate quality.

A common state-of-the-practice task for ensuring high quality aggregate is to mandate a maximum L.A. Abrasion value. This will ensure that the aggregate will not be crushed under traffic.

5.1.1. Chip Seal Quality Assurance State-of-the-Practice

Identified practices that are common to all agencies for constructing chip seal treatments include climate-specific binder grade selection. Another chip seal practice is to provide pre-coated aggregates if using paving binder and using uncoated chips if using emulsion. Further, having robust materials quality testing procedures will help to increase the overall quality and performance of chip seals. Careful inspection of application rates will help mitigate the rise of early distresses. Further, requiring that the chip seal treatment be opened to traffic within one hour of its application, adequate and proper material quality and application rates can be achieved. For equipment, using pneumatic-tire rollers over steel-wheel rollers will help prevent aggregates degradation, as will requiring chip seal aggregate to have higher abrasion resistance values.

5.1.2. Slurry Seal Quality Assurance State-of-the-Practice

Identified practices that are common to all agencies for constructing slurry seal treatments include enforcing wintertime construction date limits, as with micro surfacing treatments. Crushed stone, gravel or sand are materials of high quality and the use of such aggregates should be considered state-of-the-practice. Calibrating the equipment and maintaining the equipment in the calibrated condition is a state-of-the-practice. Ensuring appropriate air and surface temperatures is critical to slurry seal treatment performance, as the temperature is directly linked

to adequate slurry seal curing. Monitoring the slurry seal's mixture consistency is deemed more critical than the application rates, as the consistency is a direct indicator of the adequacy of the materials proportions.

5.1.3. Micro Surfacing Quality Assurance State-of-the-Practice

Identified practices that are common to the three agencies for constructing micro surfacing treatments included enforcing wintertime construction date limits. This limit prevents the potential for improper emulsion curing, which thus prevents early distresses. Constructing test strips at night is also considered a state-of-the-practice. The practice allows for the determination of the true set-time of the emulsion, in the "worst-case scenario," ensuring that the application rates when placing the treatment during the optimal conditions are adequate. Other practices include carefully monitoring for the residual asphalt content of the micro surfacing for proper emulsion application rates. Mixture consistency should also be monitored to ensure adequate materials proportions. Further, by verifying that the emulsion is of adequate quality and the application rate is appropriate will ensure that the treatment will be opened to traffic within one to two hours. Finally, QC and Acceptance testing should include testing the individual materials and the completed mix design to ensure material quality and compatibility.

5.1.4. Thin Lift Asphalt Overlay Quality Assurance State-of-the-Practice

Identified practices that are common to all agencies for constructing thin lift asphalt overlays included ensuring full-time inspection staff is on-hand to maintain near-continuous overlay construction and to capture any defects early in the construction process. Some agencies specify using anti-segregation equipment during the thin lift asphalt overlay construction, which eliminates mix segregation and thus, ensures adequate quality and long-term treatment performance. Other state-of-the-practice include using an accepted mix design method for designing thin lift asphalt overlays.

5.2 Common Identified Areas for Improvement

Identified areas for improvement that are common to all agencies include the implementation of more personnel training and proper equipment calibration practices into the current standard specifications. Proper equipment calibration practices can help ensure that proper application rates are continuously maintained.

Chip seal construction specifications could be improved through implementation of an accepted chip seal mix design method for determining the target materials application rates. Slurry seal construction specifications can be improved through incorporating calendar date limits, in addition to temperature limits. Another improvement could be made in incorporating specific traffic opening times, either general or individually determined from a cohesion test. Micro surfacing construction specifications could be improved through more robust Quality Assurance specifications, particularly through updating the mix design approval process. Thin lift asphalt overlay construction specifications could be improved through the addition of a ride quality requirement for final acceptance. Also including opening to traffic criteria in the specifications could help to improve the overall construction process, as proper traffic control can be maintained, and a consistent workflow can be achieved. A final overall improvement could be

made by consistently updating preventive maintenance treatment specifications to reflect the improvements made to the preventive maintenance strategies over time. In an industry of continuous change, it is critical to stay up-to-date in order to ensure successful experiences with preventive maintenance treatments.

CHAPTER 6 ACKNOWLEDGMENT

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72. Florida Department of Transportation, "Standard Specifications for Road and Bridge Construction," Sect. 330, Table 330-4—*Cross-Slope Acceptance Tolerance*, January 2015, pp. 261.
73. California Department of Transportation, "Construction Manual", 2014, pp. 6-1.27-6-1.30.
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75. Florida Department of Transportation, "Standard Specifications for Road and Bridge Construction," Sect. 300-7—*Application of Prime Coat*, January 2015, pp. 238-239.
76. Florida Department of Transportation, "Standard Specifications for Road and Bridge Construction," Sect. 300-8—*Application of Tack Coat*, January 2015, pp. 239-240.
77. FM 5-509—*Florida Method of Test for Measurement of Pavement Smoothness With the 15-Foot Rolling and Manual Straight-Edge*, prepared for the Florida Department of Transportation, March 2008, 4 pp.
78. Florida Department of Transportation, "Standard Specifications for Road and Bridge Construction," Sect. 330-9.4.2—*Test Method for Pavement Smoothness*, January 2015, pp. 261.
79. FM 1-T 168—*Florida Method of Test for Sampling Bituminous Paving Mixtures*, prepared for the Florida Department of Transportation, December 2014, 4 pp.
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84. Virginia Department of Transportation, "Special Provisions for 2016 Road and Bridge Specifications," Sect. SP312-110—V.C.3 *PROCEDURES, Application Rates*, 2016, pp. 3-63.
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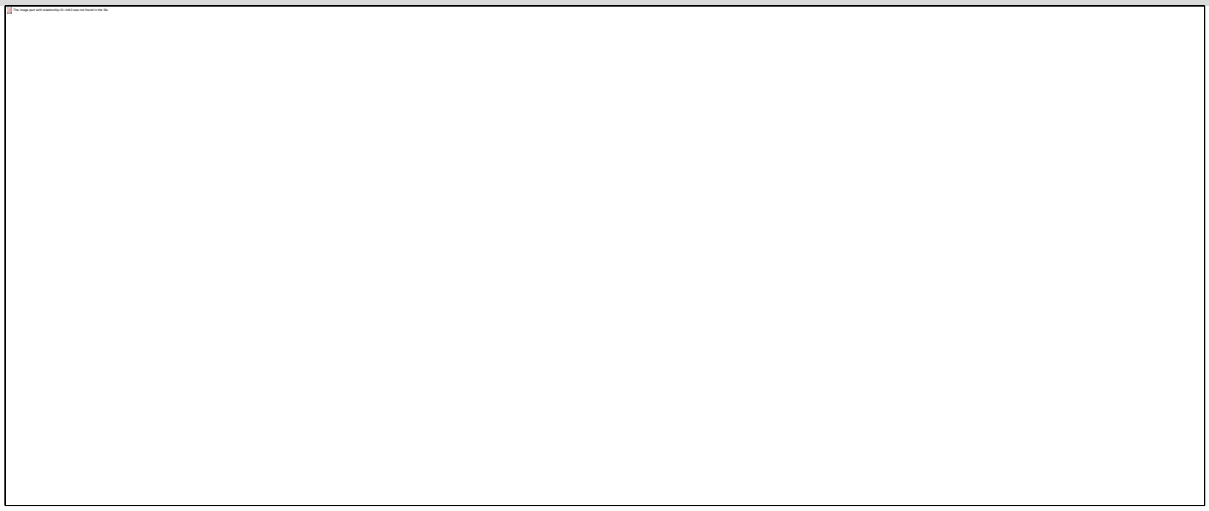
APPENDIX A SUMMARIZED RESULTS OF SURVEYS

A.1 TIER 1 SURVEY RESULTS

1. Do you represent an Owner Agency or Contractor?

#	Answer		Response	%
1	Owner Agency		124	68%
2	Contractor		58	32%
	Total		182	100%

2. Does your agency use any of the following pavement treatments?



#	Question	Yes	No	Total Responses
1	Slurry Seal	60	64	124
2	Micro Surfacing	67	57	124
3	Chip Seal	97	27	124
5	Thin Lift Asphalt Overlay	80	44	124

3. How many years has your agency/company been using [surface type]?

1 0-10 Years
2 11-20 Years
3 20+ Years

4. Approximately how many lane miles of [surface type] do you contract/construct a year?

1 0-50 Lane Miles
2 51-100 Lane Miles
3 100+ Lane Miles

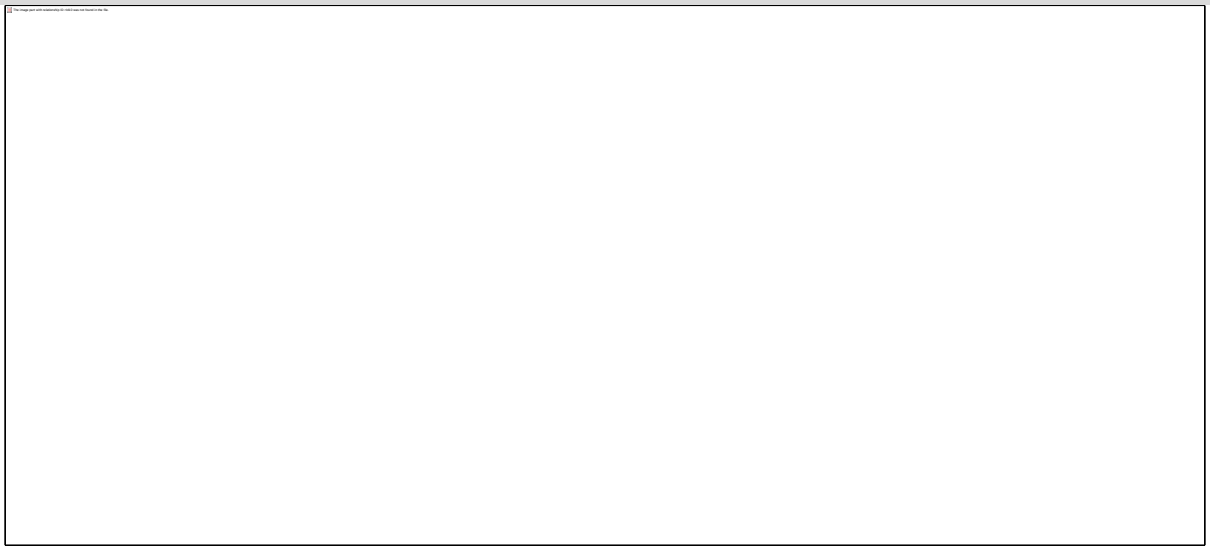
5. How many years has your agency been using Chip Seal treatments?

#	Answer		Response	%
1	0-10 Years		13	15%
2	11-20 Years		6	7%
3	20+ Years		70	79%
	Total		89	100%

6. Approximately how many lane miles of Chip Seal treatment do you contract/construct a year?

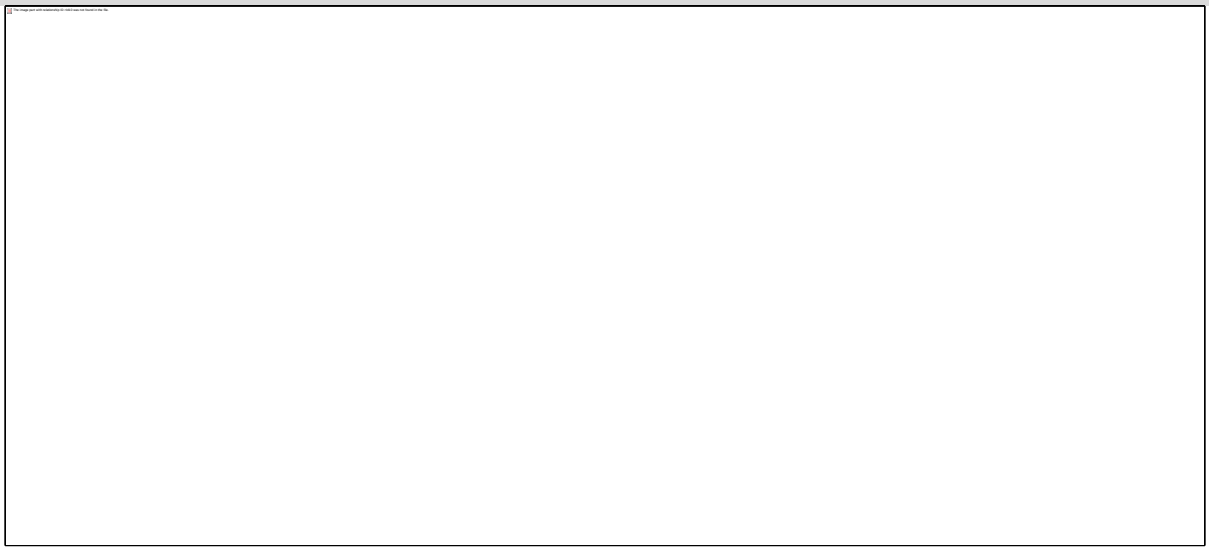
#	Answer		Response	%
1	0-50 Lane Miles		55	62%
2	51-100 Lane Miles		12	13%
3	100+ Lane Miles		22	25%
	Total		89	100%

7. Drag and drop each item to rank your top applications for Chip Seals from 1 (most common) to 4 (least common).



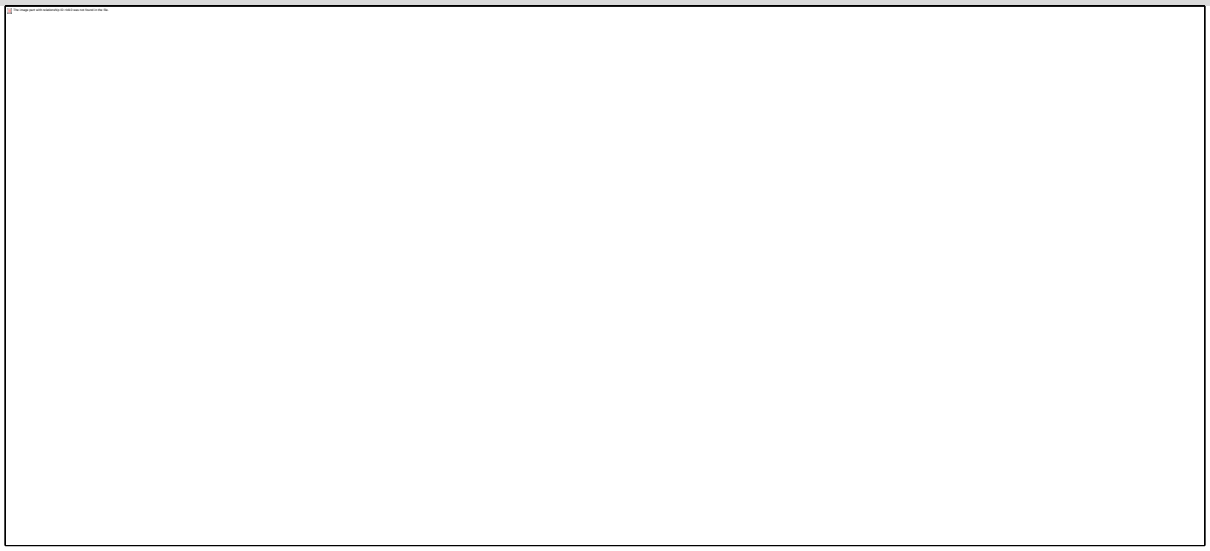
#	Answer	1	2	3	4	Total Responses
1	Preventive maintenance	30	25	9	3	67
2	Preventive maintenance	30	33	3	1	67
3	Final surface as part of minor rehabilitation	7	7	46	7	67
4	Final surface as part of major rehabilitation	0	2	9	56	67
	Total	67	67	67	67	-

8. How many years has your agency been using Micro Surfacing treatments?



#	Answer		Response	%
1	0-10 Years		32	58%
2	11-20 Years		18	33%
3	20+ Years		5	9%
	Total		55	100%

9. Approximately how many lane miles of Micro Surfacing treatment do you contract/construct a year?

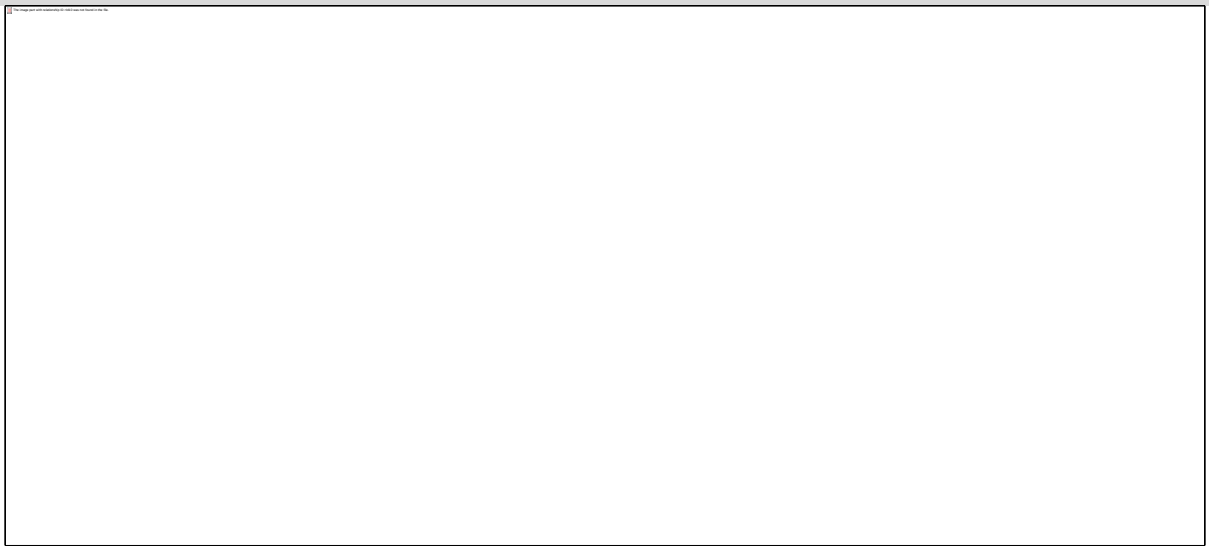


#	Answer		Response	%
1	0-50 Lane Miles		44	79%
2	51-100 Lane Miles		7	13%
3	100+ Lane Miles		5	9%
	Total		56	100%

10. Drag and drop each item to rank your top applications for Micro Surfacing from 1 (most common) to 4 (least common).

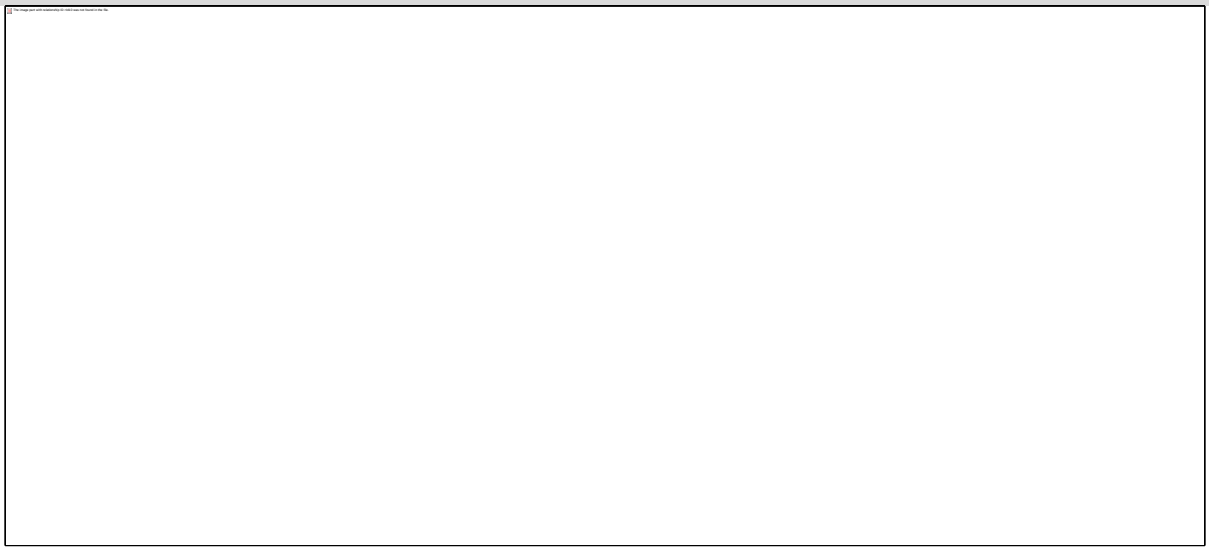
#	Answer	1	2	3	4	Total Responses
1	Preventive maintenance	11	19	5	2	37
2	Preventive maintenance	21	11	4	1	37
3	Final surface as part of minor rehabilitation	4	6	23	4	37
4	Final surface as part of major rehabilitation	1	1	5	30	37
	Total	37	37	37	37	-

11. How many years has your agency been using Slurry Seal treatments?



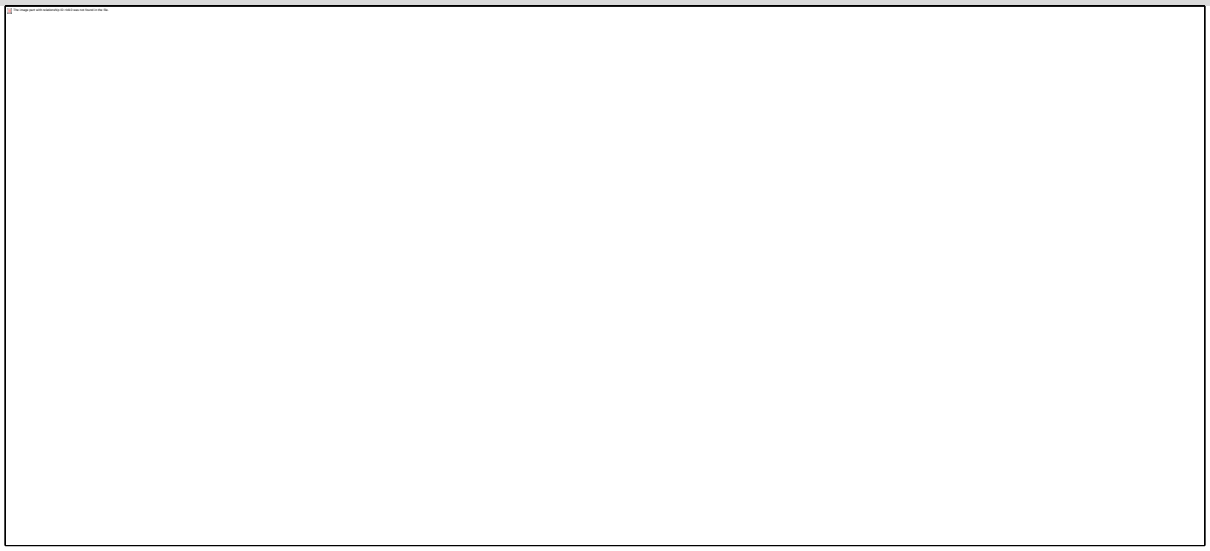
#	Answer		Response	%
1	0-10 Years		13	28%
2	11-20 Years		14	30%
3	20+ Years		19	41%
	Total		46	100%

12. Approximately how many lane miles of Slurry Seal treatment do you contract/construct a year?



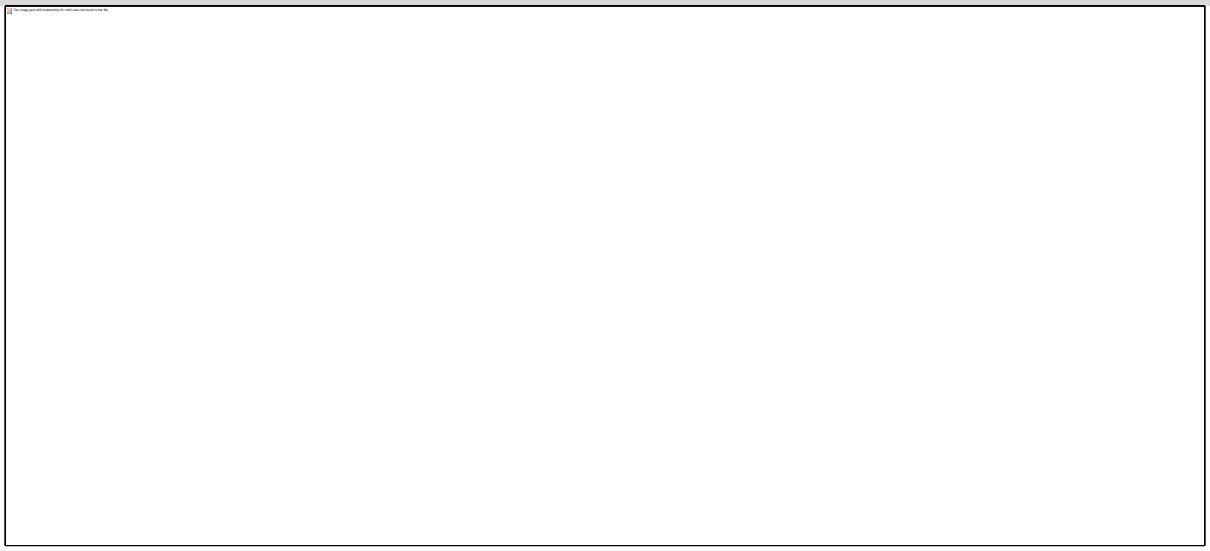
#	Answer		Response	%
1	0-50 Lane Miles		38	86%
2	51-100 Lane Miles		2	5%
3	100+ Lane Miles		4	9%
	Total		44	100%

13. Drag and drop each item to rank your top applications for Slurry Seals from 1 (most common) to 4 (least common).



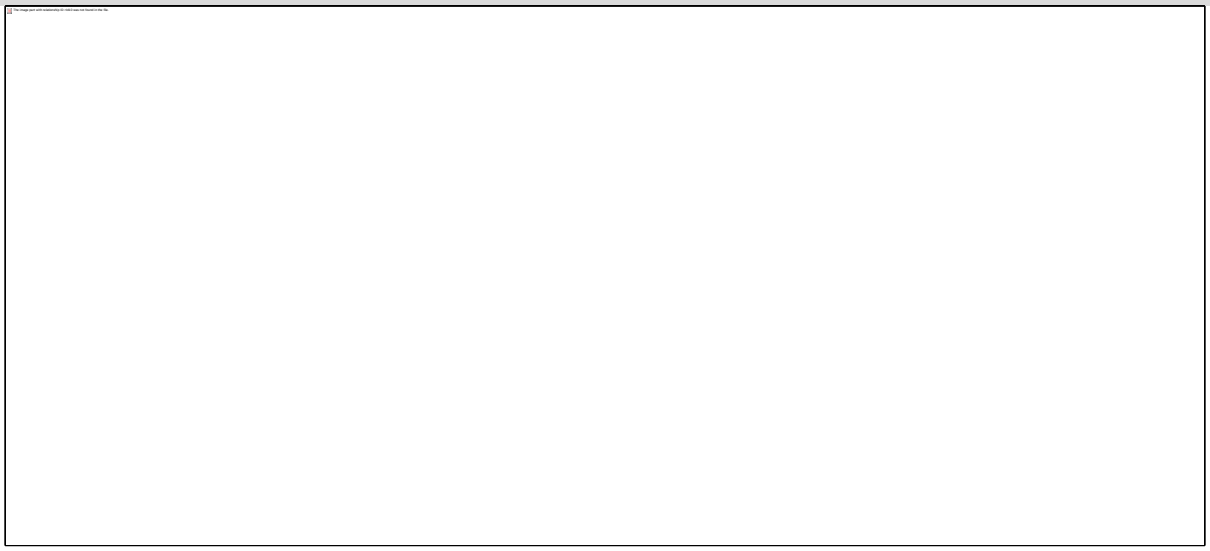
#	Answer	1	2	3	4	Total Responses
1	Preventive maintenance	11	11	2	2	26
2	Preventive maintenance	10	11	4	1	26
3	Final surface as part of minor rehabilitation	3	4	18	1	26
4	Final surface as part of major rehabilitation	2	0	2	22	26
	Total	26	26	26	26	-

14. How many years has your agency been using Thin Lift Asphalt Overlay treatments?



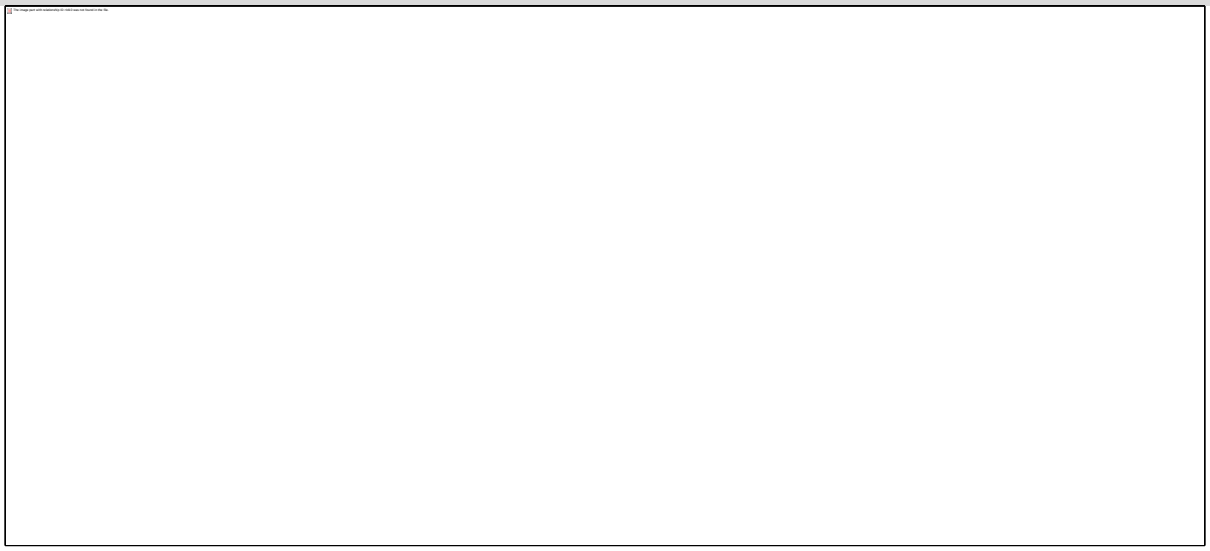
#	Answer		Response	%
1	0-10 Years		28	44%
2	11-20 Years		16	25%
3	20+ Years		20	31%
	Total		64	100%

15. Approximately how many lane miles of Thin Lift Asphalt Overlay treatment do you contract/construct a year?



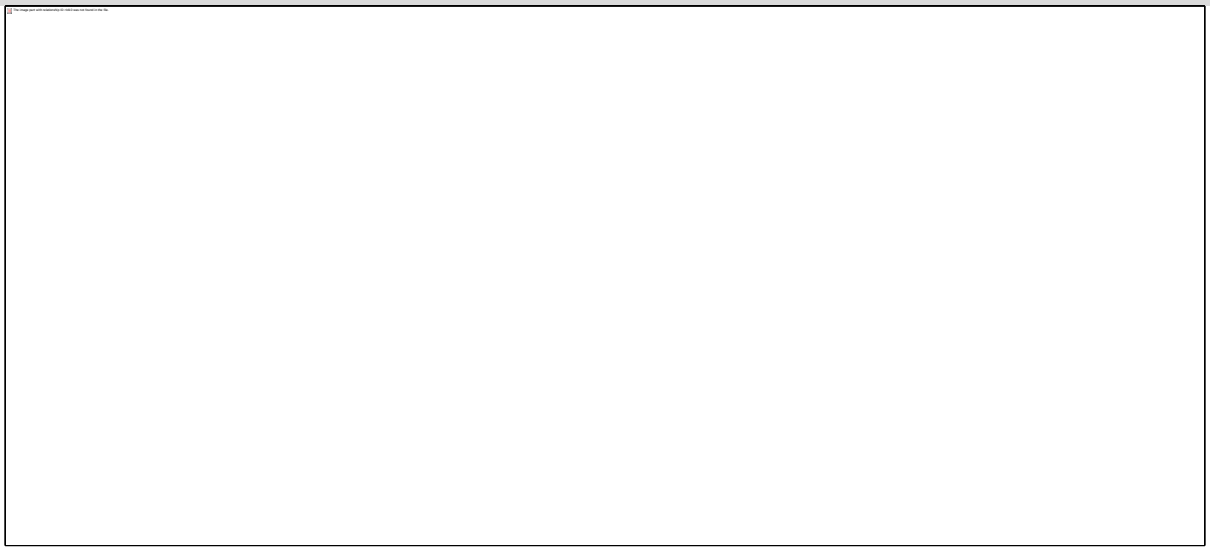
#	Answer		Response	%
1	0-50 Lane Miles		50	78%
2	51-100 Lane Miles		7	11%
3	100+ Lane Miles		7	11%
	Total		64	100%

16. Drag and drop each item to rank your top applications for Thin Lift Asphalt Overlays from 1 (most common) to 4 (least common).



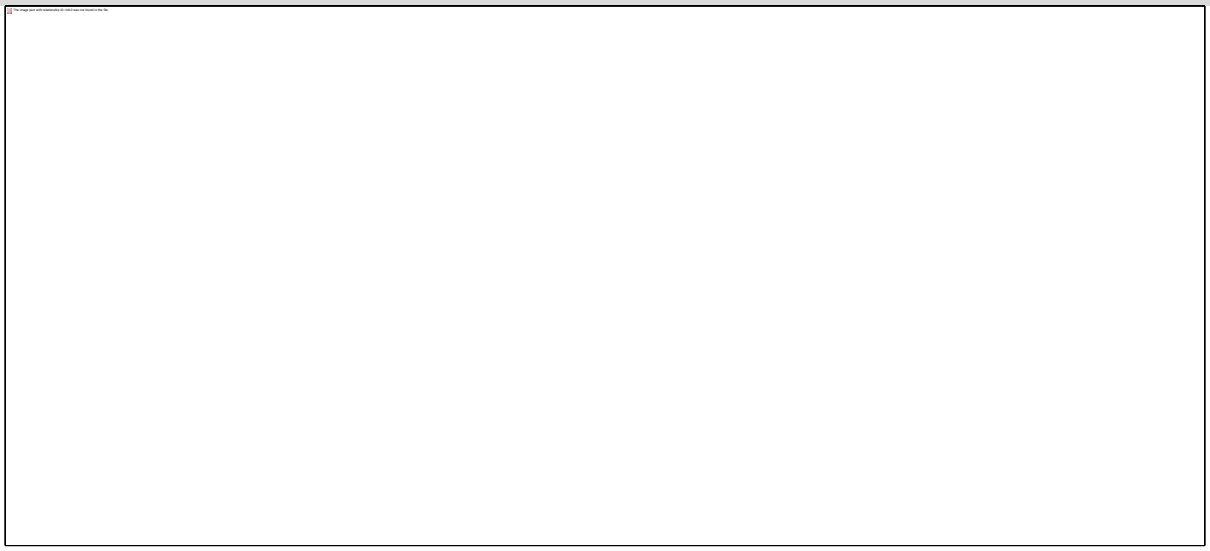
#	Answer	1	2	3	4	Total Responses
1	Preventive maintenance	8	22	12	9	51
2	Preventive maintenance	24	10	10	7	51
3	Final surface as part of minor rehabilitation	15	13	19	4	51
4	Final surface as part of major rehabilitation	4	6	10	31	51
	Total	51	51	51	51	-

17. Does your company construct any of the following pavement treatments?



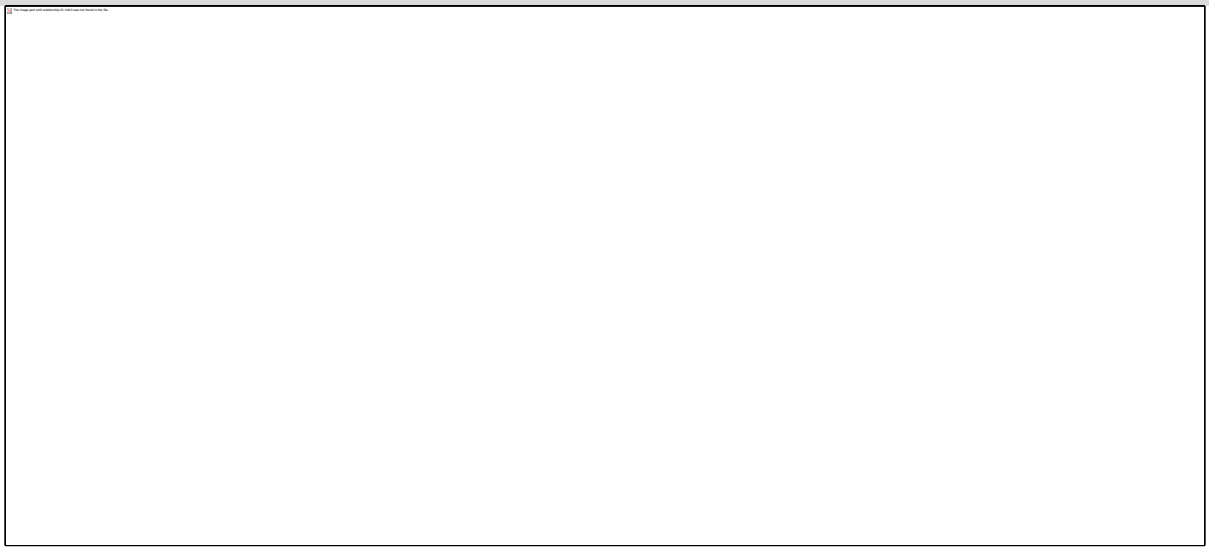
#	Question	Yes	No	Total Responses	Mean
1	Slurry Seal	18	37	55	1.67
2	Micro Surfacing	15	40	55	1.73
3	Chip Seal	22	33	55	1.60
5	Thin Lift Asphalt Overlay	37	18	55	1.33

18. How many years has your company been constructing Chip Seal treatments?



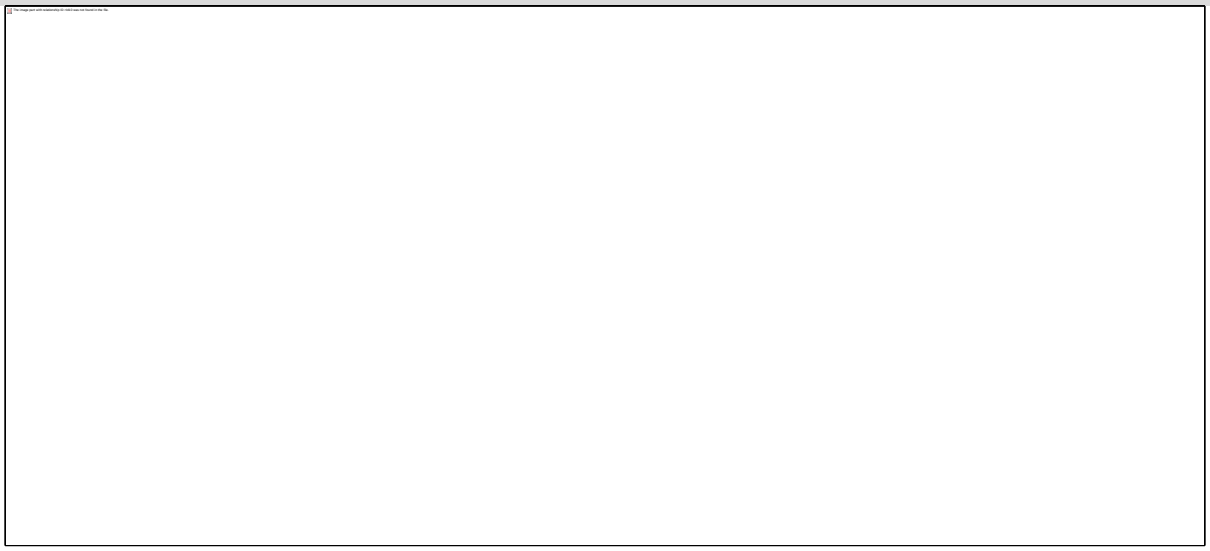
#	Answer		Response	%
1	0-10 Years		3	20%
2	11-20 Years		2	13%
3	20+ Years		10	67%
	Total		15	100%

19. Approximately how many lane miles of Chip Seal treatment do you construct a year?



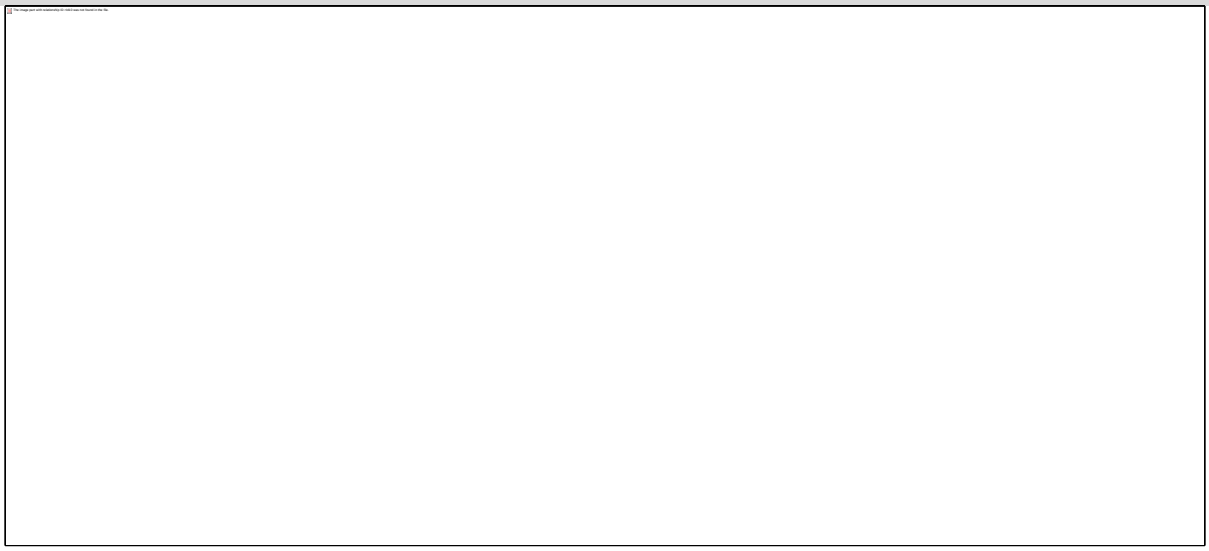
#	Answer		Response	%
1	0-50 Lane Miles		4	27%
2	51-100 Lane Miles		4	27%
3	100+ Lane Miles		7	47%
	Total		15	100%

20. How many years has your company been constructing Micro Surfacing treatments?



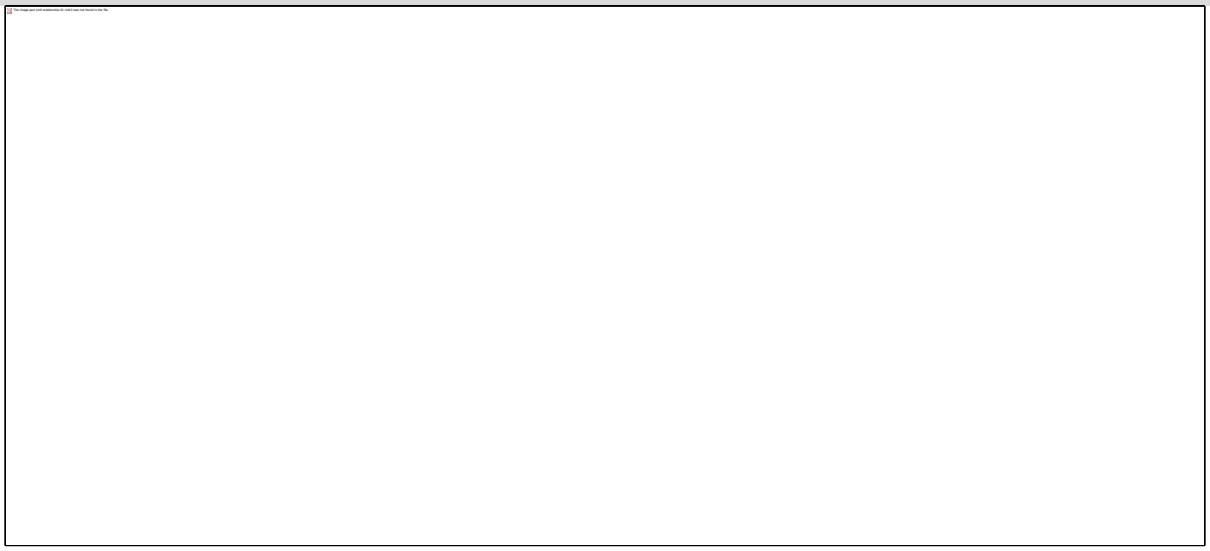
#	Answer		Response	%
1	0-10 Years		1	11%
2	11-20 Years		1	11%
3	20+ Years		7	78%
	Total		9	100%

21. Approximately how many lane miles of Micro Surfacing treatment do you construct a year?



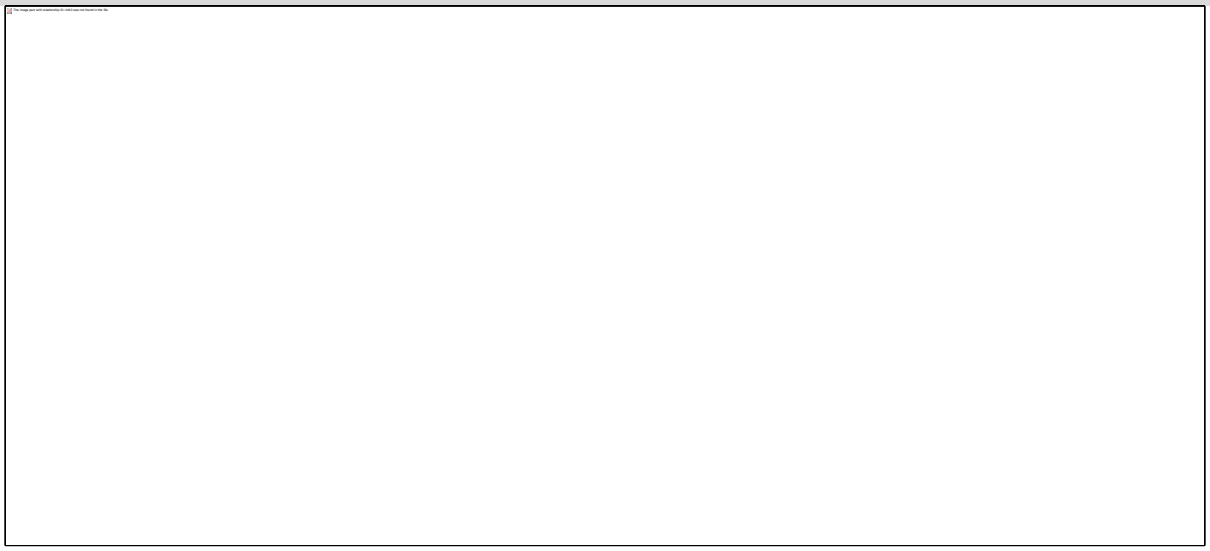
#	Answer		Response	%
1	0-50 Lane Miles		1	11%
2	51-100 Lane Miles		2	22%
3	100+ Lane Miles		6	67%
	Total		9	100%

22. How many years has your company been constructing Thin Lift Asphalt Overlay treatments?



#	Answer		Response	%
1	0-10 Years		17	55%
2	11-20 Years		3	10%
3	20+ Years		11	35%
	Total		31	100%

23. Approximately how many lane miles of Thin Lift Asphalt Overlay treatment do you construct a year?



#	Answer		Response	%
1	0-50 Lane Miles		17	57%
2	51-100 Lane Miles		6	20%
3	100+ Lane Miles		7	23%
	Total		30	100%

A.2 TIER 2 SURVEY RESULTS

AGENCY REPONSES

What are your primary selection criteria for using a pavement preventive maintenance treatment?				
	In Accordance With MR&R	**Pavement's Age**	**Poor pavement Condition**	**Other**
Chip Seal	4	5	5	3
Slurry Seal	3	1	2	2
Microsurfacing	2	2	4	2
Thin Asphalt Overlay	2	1	3	2
Other (includes formal selection processes, pavement condition software analysis, regular application, available funding and traffic levels)				

Do you currently have a mix design process that you refer to when designing a treatment?				
	No mix design/ Contractor handles	**Developing**	**Have and use**	**Other (no answers available)**
Chip Seal	4	0	5	0
Slurry Seal	3	0	3	0
Microsurfacing	2	0	4	0
Thin Asphalt Overlay	3	0	3	0

Do you currently have standard construction specifications?				
	No standard specs	**Developing**	**Have special provisions/standards**	**Other (includes use of industry specs and other states' specs)**
Chip Seal	1	1	7	0
Slurry Seal	0	0	5	1
Microsurfacing	0	0	5	0
Thin Asphalt Overlay	0	0	5	1

Is the treatment application/construction being done by agency or qualified contractor crew?					
	50/50 Agency/ Contractor	**5/95 Agency/ Contractor**	**10/90 Agency/ Contractor**	**100% Contractor**	**100% Agency**
Chip Seal	4	0	0	5	0
Slurry Seal	0	0	0	6	0
Microsurfacing	1	0	0	4	0
Thin Asphalt Overlay	2	0	0	4	0

If a combination of both agency and contractor crews is used, approximately how many projects/or lane-miles (%) are done by agency versus contractor crew?						
	50/50 Agency/ Contractor	**5/95 Agency/ Contractor**	**10/90 Agency/ Contractor**	**100% Contractor**	**100% Agency**	**Other**
Chip Seal	1	1	1	2	1	1
Slurry Seal	0	0	0	5	0	0
Microsurfacing	0	1	0	3	0	0
Thin Asphalt Overlay	0	1	1	3	0	1

Have you noticed a difference in the early performance (e.g., early failures) between those that are done by an agency crew or a contractor crew?				
	Difference with Agency Crew	**Difference with Contractor Crew**	**Little/ No Difference**	**Other (includes materials & climate related differences)**
Chip Seal	2	1	1	1
Slurry Seal	0	0	2	0
Microsurfacing	0	0	0	1
Thin Asphalt Overlay	1	0	1	1

Have you noticed a difference in the overall long-term performance between those that are done by an agency crew or a contractor crew?				
	Difference with Agency Crew	**Difference with Contractor Crew**	**Little/ No Difference**	**Other**
Chip Seal	2	0	1	0
Slurry Seal	0	0	0	0
Microsurfacing	0	0	0	0
Thin Asphalt Overlay	1	0	1	0

What percent of your projects have problems with early failure (within 1-2 years) vs. late-stage performance loss, regardless whether the work has been done with the agency crew or the contractor crew?			
	Mostly Early-Stage*	**Mostly Late-Stage**	**Other (includes low occurrence of significant failures and lack of information)**
Chip Seal	3	4	0
Slurry Seal	2	2	1
Microsurfacing	2	2	0
Thin Asphalt Overlay	3	3	1

What are the primary distresses that your preventive maintenance treatments have experienced in the past?						
	Chip Loss	**Rutting**	**Bleeding**	**Ravelling**	**Cracking**	**Other (delamination, plow damage segregation)**
Chip Seal	6	0	7	2	0	1
Slurry Seal	0	0	1	2	1	4
Microsurfacing	0	0	2	2	1	5
Thin Asphalt Overlay	0	1	1	3	4	2

What do you think might have caused the early distresses and do you have supporting information that you can share?						
	Incorrect project selection	**Materials/ mix design issues**	**Climate/ temperature**	**Poor Workmanship**	**Poor Construction**	**Other**
Chip Seal	1	5	6	2	3	3
Slurry Seal	1	1	2	0	1	2
Microsurfacing	1	1	2	1	1	3
Thin Asphalt Overlay	0	3	3	2	1	2
Other includes early-traffic opening, winter damage, poor surface prep, lack of experience and underlying pavement distresses.						

Do you think early failures are related to different climatic conditions in your state?				
	Yes	**No**	**Maybe**	**Other**
Chip Seal	5	2	1	0
Slurry Seal	2	2	0	0
Microsurfacing	3	1	0	0
Thin Asphalt Overlay	2	2	0	0

What key aspects of *proper construction* do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?						
	Equipment calibration	**Personnel cert.**	**Verification of materials/ application rates**	**Surface prep**	**Fog Seal**	**Other**
Chip Seal	6	3	7	2	1	2
Slurry Seal	2	2	4	3	0	2
Microsurfacing	3	1	5	2	0	1
Thin Asphalt Overlay	1	4	3	5	0	5
Other includes crack sealing, using pre-coated chips, small-truck chip spreaders, good inspection, proper surface/air temperatures, test strips and tack coats						

What types of asphalt binders/emulsions do you specify?		
	Hot—PG, rubber-modified binders	**Cold—polymer/latex-modified emulsions**
Chip Seal	5	6
Slurry Seal	0	5
Microsurfacing	0	5
Thin Asphalt Overlay	6	0

Do you have an established Quality Assurance program?			
	No program	**In development**	**Have and use**
Chip Seal	1	1	6
Slurry Seal	0	0	5
Microsurfacing	0	0	5
Thin Asphalt Overlay	0	0	6

Who performs Quality Control for materials?			
	Contractor	**Consultant**	**Other (binder testing only, a 50/50 mix of contractor/consultant QC)**
Chip Seal	5	0	2
Slurry Seal	5	0	0
Microsurfacing	4	0	1
Thin Asphalt Overlay	6	0	0

Who performs Quality Control for Inspection including equipment?			
	Contractor	**Consultant**	**Other (QC non-requirements and test-strip-only requirements)**
Chip Seal	7	0	1
Slurry Seal	5	0	0
Microsurfacing	5	0	0
Thin Asphalt Overlay	6	0	0

Who performs the Acceptance for materials?			
	Agency	**Consultant**	**Other**
Chip Seal	8	0	0
Slurry Seal	5	0	0
Microsurfacing	5	0	0
Thin Asphalt Overlay	5	0	0

Who performs the Acceptance for Inspection including equipment?			
	Agency	**Consultant**	**Other (80/20 agency/consultant split)**
Chip Seal	6	1	1
Slurry Seal	3	1	1
Microsurfacing	4	0	1
Thin Asphalt Overlay	5	0	1

Does your Quality Assurance program include an independent assurance (IA)?			
	Yes	**No**	**Other**
Chip Seal	5	2	0
Slurry Seal	4	2	0
Microsurfacing	3	1	0
Thin Asphalt Overlay	5	1	0

Does your independent assurance (IA) require any of the following?				
	Lab Accreditation	**Personnel cert.**	**Proficiency Samples program**	**Other**
Chip Seal	4	4	2	1
Slurry Seal	3	3	2	0
Microsurfacing	2	2	2	1
Thin Asphalt Overlay	4	3	2	1
Other (includes applicability to material suppliers and no requirements for IA)				

What areas of your Quality Assurance program do you see need improvement?					
	Materials	**Inspection**	**Better Communication**	**Training**	**Other**
Chip Seal	2	1	1	6	1
Slurry Seal	0	0	1	2	3
Microsurfacing	1	0	1	4	2
Thin Asphalt Overlay	0	2	1	3	2
Other (includes updating specs, continuous improvement and in-place validation)					

CONTRACTOR RESPONSES

Does your company conduct or contract with a consulting firm for QC testing or inspection, including equipment?			
	For Materials	**For Inspection**	**Other (includes inspection by agency, inspection with supplier and in-house)**
Chip Seal	1	1	2
Slurry Seal	2	0	2
Microsurfacing	2	1	3
Thin Asphalt Overlay	0	1	4

How many early failures (within 1-2 years) have you experienced over the last five years?		
	Mostly Early (Not necessarily a high amount of failures)	**Other (Includes no early failures, or insufficient data answers)**
Chip Seal	2	2
Slurry Seal	2	2
Microsurfacing	3	1
Thin Asphalt Overlay	3	2

What are the primary distresses that your preventive maintenance treatments have experienced in the past?					
	Chip Loss	**Rutting**	**Ravelling**	**Bleeding**	**Other**
Chip Seal	4	1	0	2	2
Slurry Seal	1	0	3	0	2
Microsurfacing	0	0	2	0	2
Thin Asphalt Overlay	1	1	0	0	2
Other (includes cracking, delamination, aggregate wear and mix loss)					

What you think caused the early distresses that you've identified and do you have supporting information that you can share?						
	Poor project selection	**Materials/ mix design issues**	**Climate/ temperature**	**Poor workmanship**	**Poor construction**	**Other**
Chip Seal	2	3	2	1	0	2
Slurry Seal	1	3	3	1	1	1
Microsurfacing	1	2	2	1	1	1
Thin Asphalt Overlay	3	1	1	0	0	1
Other (includes application rates and surface prep)						

Do you think early failures are related to different climatic conditions across the state?				
	Yes	**No**	**Maybe**	**Other (includes traffic considerations and binder/emulsion types)**
Chip Seal	0	0	3	1
Slurry Seal	2	0	1	1
Microsurfacing	1	0	1	1
Thin Asphalt Overlay	1	1	1	1

What key aspects of proper construction do you notice tend to result in a successful performance with a given pavement preventive maintenance treatment?						
	Equipment	**Personnel certification**	**Verification**	**Surface prep**	**Fog Seal**	**Other**
Chip Seal	2	1	4	3	0	4
Slurry Seal	2	1	4	2	0	4
Microsurfacing	1	1	3	2	0	2
Thin Asphalt Overlay	2	3	4	3	0	2
Other (includes climate/temperature adjustments, tack coat, test strips, management and post construction)						

What areas of the specifications do you see need improvement?				
	Mix design change(s)	**QC/Assurance program**	**Construction practices**	**Other**
Chip Seal	2	1	2	2
Slurry Seal	1	1	1	4
Microsurfacing	1	1	1	3
Thin Asphalt Overlay	1	1	2	4
Other (includes non-self-regulation of suppliers, smaller number of project elements, changes to application rate standards and qualified 3rd-party entities)				