TTI: 0-6989

Texas Seal Coat Design Method

Technical Report 0-6989-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/0-6989-R1.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-20/0-6989-R1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle TEXAS SEAL COAT DESIGN METHOD		5. Report Date Published: March 2020
		6. Performing Organization Code
7. Author(s) Darlene C. Goehl, Cindy Estakhri, and Eun Sug Park		8. Performing Organization Report No. Report 0-6989-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project 0-6989
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: September 2018–November 2019
		14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Update Seal Coat Application Rate Design Method
URL: http://tti.tamu.edu/documents/0-6989-R1.pdf

16. Abstract

Seal coat is a layer of asphalt binder with a layer of aggregate applied over a pavement. The purpose of a seal coat is to seal the pavement from air and water intrusion while providing the safety benefits of maintaining sufficient friction over the seal coat's design life. With an investment of over $300,000,000 annually, it is imperative to construct a high-quality project. To achieve quality construction, it is important to establish and adjust the application rates for the binder and aggregate based on the materials being used, traffic and existing roadway conditions. This project produced guidelines for improvements to rate design procedures that will help engineers and inspectors make better decisions resulting in successful projects.

17. Key Words Seal Coat, Application Rate, Aggregate, Binder	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 72	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TEXAS SEAL COAT DESIGN METHOD

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Project 0-6989
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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Darlene C. Goehl, P.E. #80195.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The author thanks Ross Taylor, Bryan Wilson, Stephen Sebesta, Darrin Jensen, Wade Odell, Enad Mahmoud, Arash Motamed, Eric Lykins, Jerry Peterson, Jace Lee, James Robbins, Magdy Mikhail, Sergio Cantu, and Shannon Ramos.

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CHAPTER 1. INTRODUCTION

HISTORY

Seal coat has been an important pavement treatment for the Texas Department of Transportation (TxDOT) since the Texas Highway Department was established in 1917. In fact, the earliest Specification and Contract book of 1918 contains ITEM 8, “Bituminous Surface Treatment” [1]. TxDOT historically has relied on its engineers to determine application rates. The earliest guidance found for TxDOT engineers was a reference to the Manual Series No. 12, “Asphalt Surface Treatments and Asphalt Penetration Macadam,” published by the Asphalt Institute and “Supplement to Volume 29 of the Proceedings of The Association of Asphalt Paving Technologists.” Currently, guidance for application rates can be found in TxDOT’s “Seal Coat and Surface Treatment Manual.” Surface treatment, surface dressing, chip seal, and seal coat are some of the many names used to refer to the method of placing a single layer of binder and a single layer of aggregate. The term *seal coat* will be used throughout this report.

Nationally and internationally, it is a consensus that the first documented seal coat design method was by Hanson in 1935, followed by Kearby in 1953, and McLeod in the 1960s. Work in the 1980s modified the Kearby method for use in Texas [2].

BASICS OF SEAL COAT

The purpose of a seal coat is to seal the pavement from air and water intrusion while providing the safety benefits of maintaining sufficient friction over the design life of the seal coat. Please refer to Figure 1 for an example of a single layer of asphalt binder with a single layer of aggregate applied over an existing pavement. Multiple layers may be used; however, each seal coat is placed as a single layer.

Figure 1. Seal Coat.

TxDOT invests over $300,000,000 annually in seal coats for both new construction and as a preventive maintenance treatment. TxDOT maintains 80,444 centerline miles of the state highway system and seal coat is one of the main methods used for preventive maintenance. According to the Federal Highway Administration, “Applying a pavement preservation treatment at the right time (when), on the right project (where), with quality materials and construction (how) is a critical investment strategy for optimizing infrastructure performance" [3].

To achieve quality construction, it is imperative to establish and adjust the application rates for the binder and aggregate based on the materials being used and existing roadway conditions. Some typical construction defects related to rate design are flushing, bleeding, and aggregate (rock) loss. Please refer to Figure 2 for examples of defects.

Figure 2. Seal Coat Defects.

Flushing and bleeding are the upward movement of asphalt resulting in the formation of a film of asphalt on the roadway surface [4]. Many use the terms bleeding and flushing interchangeably. For this report, bleeding is considered a more severe condition than flushing. Both affect the texture of the surface and are further defined as:

- Flushing has a pavement texture less than 0.05 in. and greater than or equal to 0.035 in., measured in accordance with Tex-436-A and can be visually detected.
- Bleeding has a pavement texture less than 0.035 in., measured in accordance with Tex-436-A and can be visually detected.

Rock loss, which is often referred to as shelling, occurs when the aggregate loses its bond with the binder and is dislodged from the pavement surface. Many times, rock loss leads to flushing and bleeding. Rock loss can occur when the following occurs:

- The binder is too stiff for a weather condition.
- The asphalt rate is too light.
- Too much time elapses between the asphalt shot and rock placement.
- Water is trapped in an existing pavement and then sealed. The water will turn into a vapor and rise when heated resulting in possible rock loss problems or delamination of the seal coat [4].

In practice, TxDOT uses experience to determine seal coat application rates during construction and rarely uses a design procedure. Unfortunately, the experience level is variable, and loss of experienced personnel can lead to increased problems until experience is gained. During plan, specification and estimate (PS&E) development, designers usually set an average rate. This is a reasonable approach since the materials sources are not known. The construction specification allows adjustment for field conditions during construction; however, some do not want to assume the risk of setting rates or changing rates designated on the PS&E. The perception between how the plan rates are established and what the actual construction application rates should be can lead to disputes on projects.

A design procedure can reduce risk and result in better performing seal coat projects. The goal of this research project is to produce guidelines for improvements to rate design procedures that will help engineers and inspectors make better decisions resulting in successful projects.

CHAPTER 2. DESIGN METHODS

OVERVIEW

The literature review found that there are numerous design methods to determine seal coat application rates. These included the following:

- Hanson Method. [5]
- Modified Kearby Method. [6]
- McLeod Method. [6]
- TxDOT Brownwood District Method. [7]
- Asphalt Institute Method. [8]
- Kansas Department of Transportation. [9]
- Arizona Test Method 819. [10]
- Pennsylvania references Bulletin 27, Appendix E. [11]
- Minnesota references the Minnesota Seal Coat Handbook, MN/RC-2006-34. [12]
- Austroads Sprayed Seal Design Method. [13]
- New Zealand Method. [14]
- South African Design Method. [15]

Many of the design methods are based on the concepts of Hanson's original method [5], summarized below:

- Method was based on 2/3 embedment of the stone in the binder to leave a non-skid, non-glare surface to handle the wear and stress imposed by traffic.
- The percentage of voids after placement but before rolling is approximately 50 percent, after rolling is reduced to 30 percent, and after traffic is reduced to 20 percent.
- The volume of voids has a relationship to the amount of binder required. The binder rate should be designed so that between 65 percent and 70 percent of the voids, after traffic compaction, are filled with binder.
- After traffic compaction, the average depth of aggregate is approximately equal to the average least dimension (ALD) of the aggregate used.

The objective in designing the rates is that the resulting seal will not have too much binder so that it flushes or bleeds in the summer; however, there is enough binder to prevent rock loss over the winter.

EVALUATION

After reviewing several design methods, six methods were selected for a thorough evaluation and comparison to TxDOT's methods and experience. The design methods evaluated in detail where the following:

- Modified Kearby.
- McLeod.
- TxDOT Brownwood District Method.

- Austroads Sprayed Seal Design Method.
- New Zealand Method.
- South African Method.

Table 1 contains a summary of the factors that influence the design and the method that addresses those factors. The table only includes the factors that are in at least one of the methods reviewed. Table 2 contains a summary of the laboratory and field tests needed to perform the design methods.

Table 1. Factors Influencing Application Rate Design Methods.

	Design Methods					
Factors	**Modified Kearby**	**McLeod**	**BWD District**	**Austroads**	**New Zealand**	**South Africa**
Binder Type	x	x	x	x	x	x
Aggregate						
ALD calculated		x		x	x	x
ALD measured				x		
ALD estimated	x		x			
Percent Embedment calculated	x	x	x			
Percent Embedment assumed		x		x	x	x
Aggregate Shape (Flakiness Index)		x		x	x	x
Aggregate Spread Rate estimated		x		x	x	x
Aggregate Spread Rate from Test	x		x			x
Surface Condition Described	x	x	x	x	x	x
Surface Hardness measured				x	x	x
Surface Texture described	x	x	x			
Surface Texture Measured				x	x	x
Traffic	x	x	x	x	x	x
Heavy Trucks				x	x	x
Steep Grades					x	x
Intersections, Slow moving, etc.				x		x
Climatic Conditions				x		
Climate - Time of Year	x				x	x
Shaded Areas						x
Double/Multiple Seal Coats				x	x	x

Table 2. Testing for Design Methods.

Laboratory Tests	Design Methods						TxDOT	
	Modified Kearby	McLeod	BWD District	Austroads	New Zealand	South Africa	Requires	Has Test Method
Loose Unit Weight	x	x	x					x
ALD calculated		x		x	x	x		
ALD measured				x	x			
Gradation		x	x					x
Flakiness Index		x		x	x	x	x	x
Bulk Specific Gravity	x	x	x					x
Board Test	x		x					
Modified Tray Test						x		
Absorption		x						x
Field Tests								
Surf Texture (Sand Patch)				x	x	x		x
Surface hardness (Ball Pen)				x	x	x		
Condition (Observation)	x	x	x					

There are several factors that affect the success of a seal coat. Those factors include material properties, material combinations, traffic and existing pavement condition, and climate.

Materials

Material Properties

The binder properties that affect the application rate are application temperature, residual asphalt for cutback and emulsions, and types of modifiers (polymers, tire rubber, and latex). In general, modified binders can be applied at a slightly heavier rate due to the stiffness characteristics with changing temperatures. The modifiers are designed to allow the binder to be stiff enough at high temperatures to avoid flushing and stay elastic at low temperatures to retain the aggregate.

The aggregate properties that affect the application rate are size, shape, and absorption properties. Size and shape are the critical factors since the binder rate design is dependent upon the average mat thickness and available void space. Figure 3 shows aggregate retained on the same sieve from a top and side view. Figure 4 shows the dimensions of a single aggregate particle. Material that is considered the same size can have significantly different thickness. The more variable the thickness, the more difficult to determine a rate that will hold the taller particles through the winter without causing flushing around the shorter pieces.

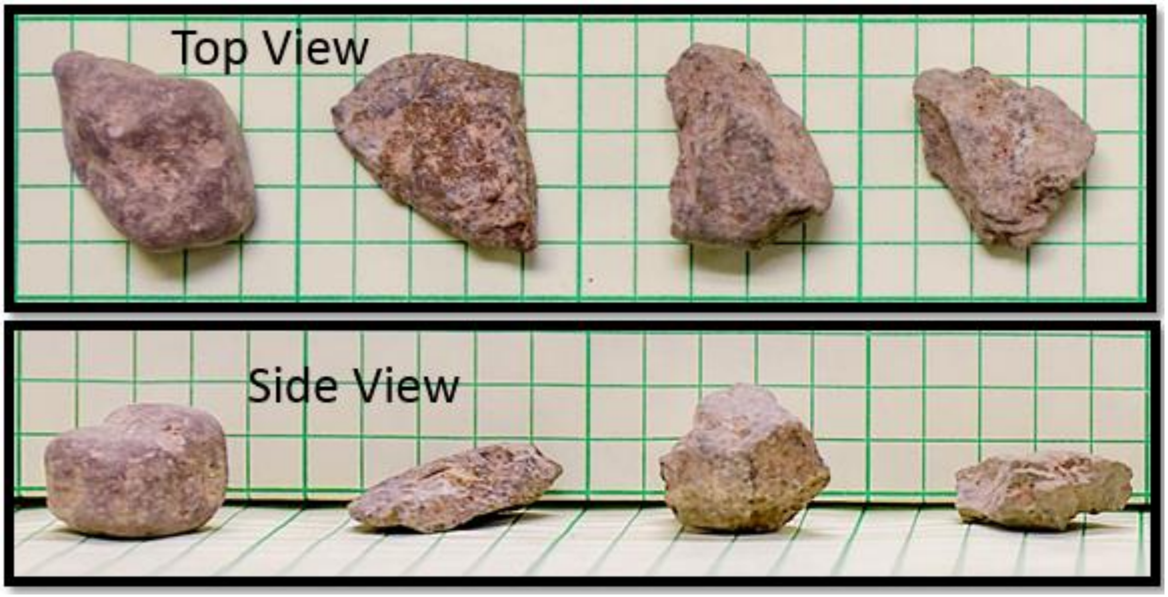

Figure 3. Grade 4, Aggregate Shape.

***Length (L)*—maximum dimension of the particle.**

***Width (W)*—maximum dimension in the plane perpendicular to the length.**

***Thickness (T)*—maximum dimension perpendicular to the length and width.**

Figure 4. Aggregate Dimensions.

Material Combinations

Material combinations in this discussion are the binder and aggregate. In general, it is recommended that precoated aggregates be used with asphaltic concrete binders. The precoating improves adhesion by removing dust and allowing the precoat material to bond quickly to the hot applied binder. Precoating is not required with emulsions or cutback binders due to the benefits of the binder's interaction with the aggregate. Both the type of aggregate and porosity will increase the break time for emulsions. Precoated aggregate can be used with emulsions or cutbacks; however, one of the drawbacks is that it will take longer for the emulsion to break, develop adhesion, and become stable enough to open to traffic since the aggregate to binder interaction is inhibited by the asphalt coating.

The space that the seal coat occupies on the pavement surface consists of the volume occupied by the aggregate, binder, and air voids. The aggregate spread rate is determined based on the size and shape of the aggregate and is typically expressed as a volume (cubic yard) of aggregate that will cover an area (square yard) of the pavement surface. The volume remaining (i.e., that not occupied by the aggregates) is available for binder. The binder application rate is determined from the embedment depth of the aggregate into the binder (thickness of binder) and the available void space (space that is not aggregate) and is expressed as a volume of binder (gallon) that will cover an area (square yard) of the pavement surface. Please refer to Figure 5, which is a graph of the aggregate mat from a line laser measurement.

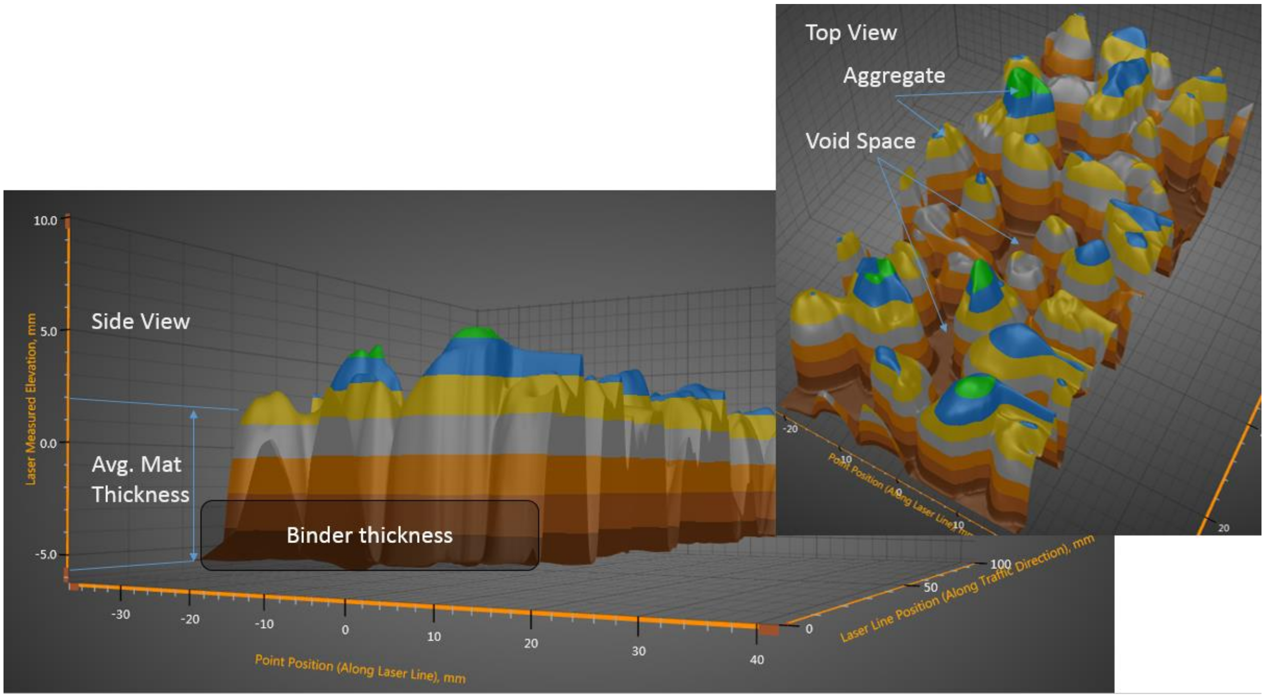

Figure 5. Seal Coat Volume.

Adjustments must be made based on the conditions to ensure the design embedment is achieved. The hardness, texture, and absorptive properties of the existing pavement and the traffic loading have the greatest effect on the embedment depth.

Traffic

The traffic affects the application rate by continuing to orient and embed the aggregate into the binder and potentially the existing pavement surface. After the aggregate is placed, it is rolled to embed and orient the aggregate; however not all aggregate during initial construction is oriented to its flattest side or embedded to its maximum depth. Over time and as pavement temperatures increase, continued rolling by traffic will dislodge partially embedded aggregate, reorient the aggregate to its flattest side, and force additional embedment. The additional embedment will depend on how much initial embedment into the binder was achieved, the hardness of the pavement surface before the seal was placed, the time to first frost (initial time that the binder is more flexible), the volume of traffic, and weight of the traffic. New Zealand estimates that the usual additional rolling time by traffic is 100 days, based on the time the first frost [14].

In order to adjust the application rates based on further embedment caused by traffic, the traffic volume including the percentage of trucks needs to be known. When significant changes in traffic volumes occur, rates should be designed according to each traffic condition. For example, shoulders or turn lanes verse a travel lane. Additionally, the type of trucks is important. For example, is the roadway in an energy sector or heavy industrial area?

Climate

The climate contains several factors that affect a seal coat. As discussed in the traffic section, the time to first frost is a factor for the embedment. Figure 6 is a map of Texas indicating the TxDOT districts, color coded by seal coat season, and the date of first frost [16]. Table 3 shows the number of days before the first frost, including the minimum number and average number of days until the first frost. Based on weather data, 134 days on average is reasonable for Texas, with the minimum of approximately 50 days. If this is used for design purposes, the number of days should be looked at regionally instead of statewide.

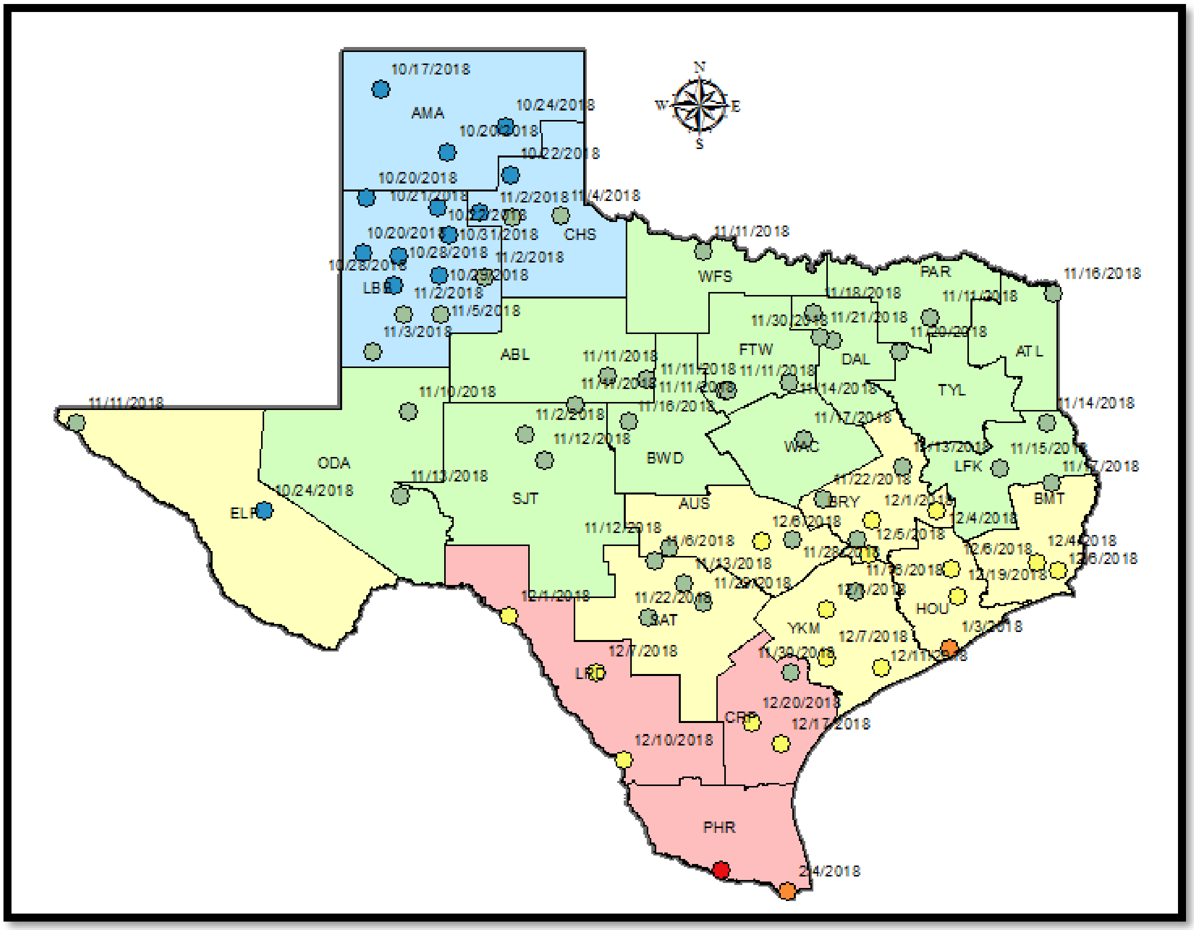

Figure 6. Texas Date of First Frost.

Table 3. First Frost.

District	Seal Coat Season		~Date of First Frost (Day-Month)	Timeframe		
	Begin (Day-Month)	End (Day-Month)		Days from Begin SC Season to 1st Frost	Days from End SC Season to 1st Frost	Avg. days to 1st Frost
Amarillo	15-May	31-Aug	17-Oct	155	47	101
Childress			21-Oct	159	51	105
Lubbock			20-Oct	158	50	104
Abilene	1-May	31-Aug	11-Nov	194	72	133
Atlanta			16-Nov	199	77	138
Brownwood			11-Nov	194	72	133
Dallas			18-Nov	201	79	140
Fort Worth			11-Nov	194	72	133
Lufkin			14-Nov	197	75	136
Odessa			10-Nov	193	71	132
Paris			11-Nov	194	72	133
San Angelo			2-Nov	185	63	124
Tyler			20-Nov	203	81	142
Waco			17-Nov	200	78	139
Wichita Falls			11-Nov	194	72	133
Austin	1-May	15-Sep	12-Nov	195	58	127
Beaumont			17-Nov	200	63	132
Bryan			13-Nov	196	59	128
El Paso			24-Oct	176	39	108
Houston			6-Dec	219	82	151
San Antonio			6-Nov	189	52	121
Yoakum			16-Nov	199	62	131
Corpus Christi	1-Apr	30-Sep	30-Nov	243	61	152
Laredo			1-Dec	244	62	153
Pharr			4-Feb	309	127	218
Average Days				200	68	134

The weather forecast, short and long term (time of year) which includes the ambient temperature, and sky conditions (overcast, sunny, etc.) can affect the application rates. Shaded areas will also affect the temperature of the area being sealed. Shaded areas tend to have a pavement surface temperature similar to the ambient temperature while other areas can be significantly hotter due to heating from the sun. For example, in the summer a typical measured pavement surface temperature may be 145°F while the ambient temperature is in the high 90s. When the binder cools quickly, optimum embedment may not be achieved, which could lead to rock loss in the winter. However, ideally this should be remedied through construction practices instead of rate adjustments.

Existing Pavement Geometry

The existing pavement geometry in combination with the traffic can affect the stability of the seal coat. The wheel load forces at intersections, on grades, and in curves can damage the seal coat. Refer to Figure 7 for an example of seal coat damage at an intersection. On grades, flushing tends to occur due to the loading characteristics of heavy vehicles traveling slower. The flushing is more extreme when there is a stopped condition along or at the end of the grade.

Figure 7. Damage at Intersections.

Existing Pavement Condition

Moisture in the existing pavement can lead to debonding issues with the new seal coat; however, this will not affect the rate, just whether or not it is appropriate to seal at that time. At one time, the Atlanta District used a method to evaluate condensation on a plastic sheet to determine a go/no-go scenario to allow the seal coat to be constructed. This is the same method that TxDOT uses to determine thermoplastic striping application and can be found in Item 666, “Retroreflectorized Pavement Markings.”

The existing pavement properties that affect the application rate are the texture, hardness, and absorption. The existing texture can be measured with Tex-436-A, “Sand Patch Method.” Only three of TxDOT’s current specifications have texture requirements, Item 354, “Planing and Texturing Pavement,” Item 360, “Concrete Pavement” and Item 422, “Concrete Superstructures.” Please refer to Table 4 for the specification limits. Based on this information and the testing performed in research project 0-5833, the recommended minimum texture depth of seal coats in Texas should be an average of 0.05 in. with no readings below 0.035 in. Please refer to Table 5 for the texture measurement results from project 0-5833 [17].

Table 4. Texture Requirements.

Item	Texture Depth (in.)	
	Minimum	Correct if texture is less than
354	0.05	
360	0.04	0.03
422	0.035 (avg.)	0.02

Table 5. Project 0-5833 Texture Tests [17].

Roadway	Sand Patch Results Mean Texture Depth		Roadway	Sand Patch Results Mean Texture Depth	
	WP (in.)	OWP (in.)		WP (in.)	OWP (in.)
FM 696	0.085	0.098	US 190	0.067	0.093
FM 696	0.037	0.084	US 190	0.082	0.094
FM 908	0.031	0.084	US 190	0.072	0.096
FM 908	0.085	0.127	SH 153	0.040	0.074
FM 819	0.047	0.078	FM 3425	0.042	0.060
FM 819	0.059	0.099	US 283	0.039	0.065
FM 2457	0.031	0.090	US 283	0.041	0.075
FM 2457	0.016	0.056	FM 2134	0.090	0.141
SH 147	0.076	0.115	FM 2134	0.094	0.119
SH 147	0.053	0.055	SH 6	0.050	0.074
SH 147	0.024	0.094	FM 2689	0.053	0.101
SH 147	0.057	0.070	FM 2689	0.137	0.154
SH 103	0.031	0.100	Average of all Locations	0.057	0.093
SH 103	0.053	0.111	Min	0.016	0.055
SH 103	0.053	0.110	Max	0.085	0.127

Description	WP (in.)	OWP (in.)
Severe Flushing (Bleeding) of Grade 3 Seal Coat	0.031	0.100
Moderate to Severe Flushing (Bleeding) of Grade 3	0.031	0.090
Moderate Flushing of Grade 3 Seal Coat	0.041	0.074
Mild to Moderate Flushing of Grade 3	0.039	0.074
Mild Flushing of Grade 3 Seal Coat	0.036	0.084
Slight Color Difference in Wheel Path of Grade 4 Seal Coat	0.084	0.126
No Color Difference in Wheel Path of Grade 4 Seal Coat	0.084	0.098

There are not established procedures in Texas for the impact of the existing texture on the rate design other than historical visual estimates. These visual estimates are used in conjunction with other pavement conditions.

South Africa, New Zealand, and Australia use the sand patch method for texture and measure pavement hardness with a ball penetration test [18]. Laser measured macrotexture is also allowed when correlated to the sand patch method. TxDOT does not have test methods to determine the hardness or absorptive properties of the pavement surface. These factors are estimated based on a visual assessment. The hardness of the existing surface will impact how much additional embedment can be anticipated by traffic loading. The texture effects the rate by impacting the amount of available void space for the new binder to occupy. Highly absorptive material, such as old dry oxidized hot mix, will require an increase in rate, while low absorptive material may lower the rate.

At this time, TxDOT uses a visual evaluation to adjust the rates for the existing pavement condition. Please refer to Figure 8 for some examples of surface conditions. Measuring these properties will lead to more accurate adjustments.

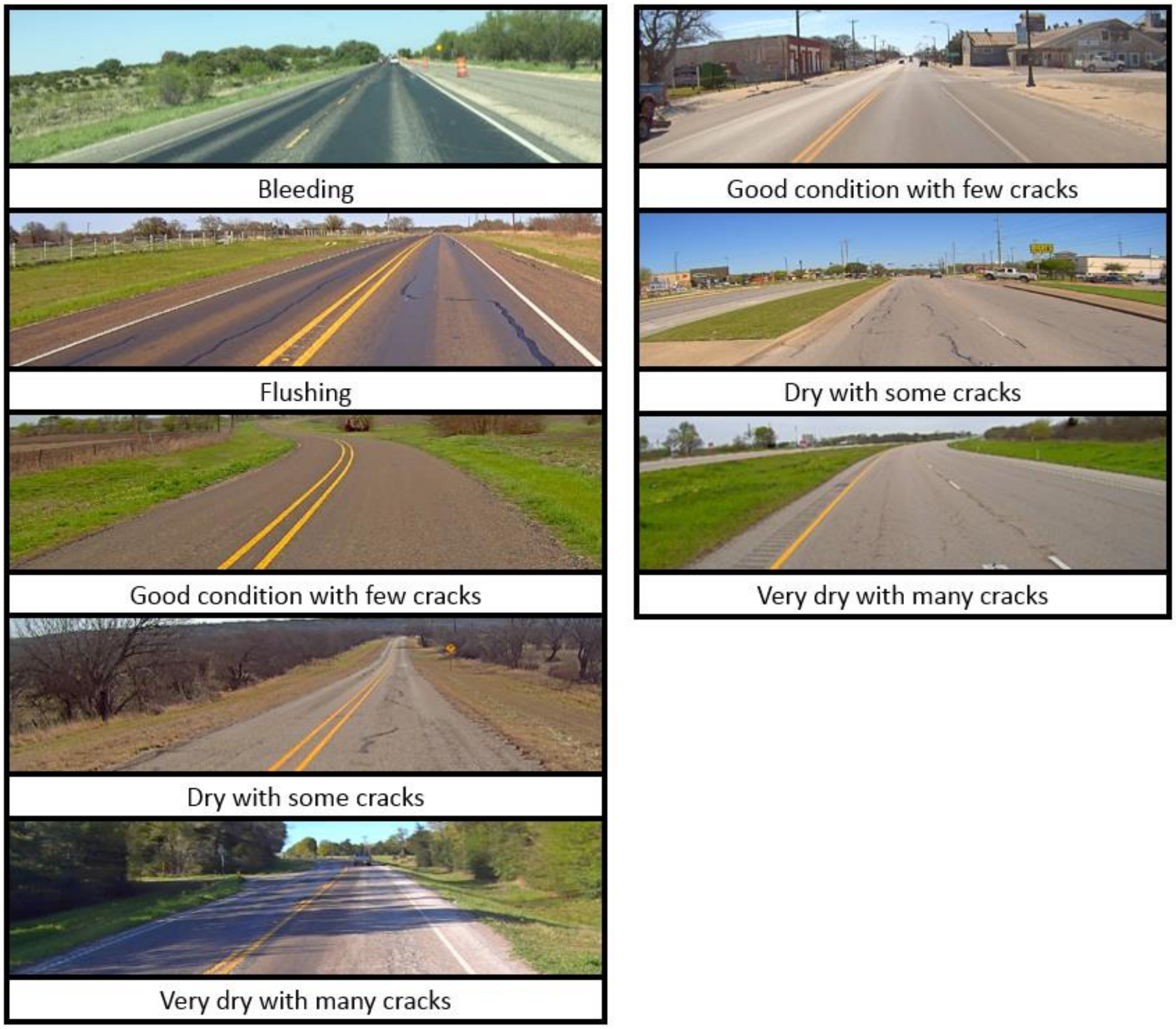

Figure 8. Existing Surfaced Roadways, Pavement Condition.

Multiple Seal Coats

Multiple seal coats refers to a multilayer system of individual seal coats placed within a short timeframe, usually the same day. The South Africa, Austroads, and New Zealand design methods discuss multiple seal coat applications. All design each seal individually. They do not discuss using less material because it is a multiple seal coat. The amount of material needed for each seal is design based on the materials being used and the condition of the surface that seal is being placed onto. For example, on a double seal coat the materials and quality of construction of the first course seal coat will affect the rates needed on the second course of the double seal coat. Because of this, those methods recommend certain aggregate size combinations be used. In general, it is recommended that the larger aggregate is below the smaller aggregate so that the smaller aggregate fits into the spaces between the larger aggregate and locks into place. However, when the seal coat is used as a prime seal, a grade 5 aggregate is used first.

COMPARISON

Each of the design methods was performed with two scenarios and aggregate grades 3, 4, and 5. The grade 4 aggregate included a crushed limestone and synthetic (lightweight) aggregate. The same binder, AC15P, was the assumed for all scenarios. This resulted in a total of eight different designs per method. Table 6 contains the factors influencing the design for each scenario. Note that both English and metric units are shown, due to the requirements of the international design methods.

Table 6. Comparison Scenario.

	Scenario 1	**Scenario 2**	**Units**
Factor	**Value**	**Value**	
Wastage Factor	5	n/a	**%**
ADT	1001	1001	Veh/day/lane
Trucks	10	25	%
Texture depth (Existing)	n/a	0.074 (1.87)	In. (mm)
Existing Surface	assume grade 4 existing seal coat		
Surface Condition	n/a	slightly flushed, smooth nonporous surface	
Alignment of Roadway	n/a	Slow moving traffic on uphill grade	
Final texture depth designed	n/a	7	mm
Ball penetration	n/a	1	mm

The design results for the aggregate spread rates and binder application rates is shown in Table 7 along with TxDOT typical rates based on district experience.

Table 7. Average Application Rates.

Grade	3			4						5		
	Average of Crushed Limestone			Lightweight			Average of Crushed Limestone			Average of Crushed Limestone		
		Sc 1	Sc 2		Sc 1	Sc 2		Sc 1	Sc 2		Sc 1	Sc 2
	Ag SR	Binder Rate	Binder Rate	Ag SR	Binder Rate	Binder Rate	Ag SR	Binder Rate	Binder Rate	Ag SR	Binder Rate	Binder Rate
Design Methods	**sy/ cy**	**gal/ sy**	**gal/ sy**	**sy/ cy**	**gal/ sy**	**gal/ sy**	**sy/ cy**	**gal/ sy**	**gal/ sy**	**sy/ cy**	**gal/ sy**	**gal/ sy**
Modified Kearby	98	0.31	0.28	124	0.26	0.23	143	0.20	0.17	214	0.13	0.10
McCloud	61	0.28	0.25	72	0.24	0.21	89	0.19	0.16	130	0.13	0.10
Brownwood	98	0.35	0.31	124	0.33	0.29	143	0.24	0.20	214	0.17	0.13
Austroads	89	0.41	0.37	111	0.35	0.32	129	0.29	0.26	193	0.22	0.20
New Zealand	74	0.39	0.38	93	0.35	0.34	107	0.28	0.28	161	0.20	0.20
South Africa	82	0.33	0.35	101	0.19	0.22	110	0.17	0.21	148	0.11	0.15
TxDOT District Historic Rates												
Pharr District [19]	90	0.36					120	0.32		135	0.25	
Brownwood & Abilene Districts [6]		0.37						0.32			0.22	
Bryan District	115	0.38		125	0.36		130	0.33		135	0.20	

Aggregate Spread Rates

The modified Kearby had the lightest spread rates while the McCloud method had the heaviest. In general, the modified Kearby spread rates are in line with what occurs on TxDOT projects since they are developed from a board test. The board test is subjective based on the person's impression of what does a good rate look like when running the test. However, with the modified Kearby method, a theoretical spread rate can be determined based on the mat thickness. The theoretical spread rate was used in the comparisons.

Binder Application Rates

The binder application rates varied significantly between design methods including when adjustments for various conditions were applied. The closest design rates to typical rates used by TxDOT were from the Austroads and New Zealand design methods.

CONCLUSIONS

While there are many good methods, no one method provides rates typical to current TxDOT practices. Therefore, a Texas design procedure is proposed that uses concepts from all the methods reviewed including TxDOT best practices.

CHAPTER 3. TEXAS DESIGN PROCEDURE

GENERAL

The seal coat design objective is to determine and aggregate and binder rate so that over the life of the seal coat, it seals the pavement from air and water intrusion while providing the safety benefits of maintaining sufficient friction. To determine the target rates, the aggregate and binder properties should be determined along with the factors that influence the design rate. The design procedure was based on the following concepts:

- Aggregate is spread in a uniform layer of one particle thickness, with the least dimension near vertical and the particles have no or minimal contact with each other.
    - Average mat thickness of the aggregate must be representative of the aggregate being used. [13]
- Aggregate spread rate determines the void space in the seal coat layer. The void space has a direct impact on the amount of binder required, therefore a failure to achieve, within practical limits, the design aggregate spread rate will result in the design binder application rate being incorrect [13].
    - Void space is typically 40–60 percent after rolling and trafficking orients the aggregate [13].
- Initial binder depth should be a minimum of 30–40 percent of the height of the aggregate particle (percent embedment) after initial rolling and trafficking, this will increase to between 50–65 percent (i.e., 1/2–2/3) about two years after construction [13].
    - The percent embedment should be varied to optimize requirements such as final surface texture and maximum seal life. Factors to adjust the design embedment are included in the design method.
    - The adjustment factors in the design were developed to account for the conditions that would ultimately affect the embedment depth. Many of these adjustments are subjective, but more research will lead to measurable adjustments replacing the estimated values. The factors are based on the following:
        - Aggregate size and shape.
        - Existing pavement texture.
        - Hardness of existing pavement.
            - Aggregate particles may penetrate (embed) into the existing pavement, depending on the properties of the pavement [13].
        - Absorptive properties of existing pavement.
            - Binder may be absorbed into the existing pavement surface and, sometimes, by the aggregate [13].
        - Traffic volume.
        - Percent trucks.
        - Time of year.
- Application rates determined by this method are expressed in gal per sq. yd. of residual binder at the standard reference temperature of 60°F, then adjusted based on the application temperature and emulsifier or cutback content.
    - The temperature adjustment factor tables are based on the assumption that the specific gravity was greater than 0.967. Other binders may be used with lower specific

    gravity, but the temperature to volume conversion will need to be adjusted for that material using TxDOT's "Asphalt Binder Temperature-Volume Corrections" [20].

- The following material information was used:
  - Unit weight of water is 62.4 lb per cu. ft.
  - Asphalt at 60°F with a specific gravity of 1.02 is:
    - 63.648 lb per cu. ft.
    - 8.508 lb per gal.
    - 7.48 gal. per cu. ft.
    - 5.61 gal.-in. per sq. yd.
- Multiple layer seal coats are defined as layers placed immediately after one another (placed the same day or within the minimum cure days of each layer).
- Variable rates are defined as transverse rates that vary across the pavement width being sealed. Variable rates are placed on pavement with an existing seal coat surface that is flushed or bleeding. The variation in rates is between 15 and 32 percent higher outside the wheelpaths than in the wheelpaths. The following situations are not recommended for transverse variable rates [17]:
  - When a grade 5 aggregate is being used.
  - When shooting emulsions on full super-elevated curves.
  - On new construction.
  - On shoulders and other minimal-traffic locations.
  - In continuous left-hand turn lanes where traffic patterns are random.
  - In intersections where the side street also carries considerable traffic volume.

Appendix A contains additional information about the aggregate theoretical spread rate. Examples of the target application rates based on the Texas Design Procedure are in Appendix B. Proposed construction specifications can be found in 0-6989-P1 Appendix A. The procedure and proposed specifications reference existing and proposed TxDOT test methods. While test methods exist for many of the material properties, some new test methods will need to be developed and are included in 0-6989-P1 Appendix B.

SEAL COAT (SINGLE OR MULTIPLE LAYER)

This method is for a single layer seal coat but may be used for multiple layer seal coats. For multiple layer seal coats, each layer should be designed as a single seal coat with the subsequent layer taking into account the properties of the layer just placed.

The proposed design procedure will be in the format of a test method. The test procedures needed to perform the rate design are identified in the list below and referenced by that name in the procedure:

- Tex-2XX-F, "Seal Coat Aggregate Average Mat Thickness."
- Tex-2XX-F,"Texas Seal Coat Design Method."

The following sections outline the procedure to develop the target application rates.

Aggregate Spread Rate

Use the following procedure to determine the target aggregate spread rate. At a minimum, the procedure should be performed for each source and grade of aggregate used on the project:

1. Obtain a representative aggregate sample in accordance with Tex-221-F. Sample a minimum of 55 lb of aggregate.
2. Determine the size and shape of the aggregate.
   2.1. Place a representative sample of processed aggregate in oven and dry to constant weight at a minimum temperature of 230 ± 9°F (110 ± 5°C). Dry the limestone rock asphalt or precoated aggregate to constant weight at a temperature of 140 ± 5°F (60 ± 3°C). Cool to room temperature.
   2.2. Determine the Dry Loose Unit weight in accordance with test method Tex-404-A.
   2.3. Sieve the sample in accordance with Tex-200-F, Part I, using a 7/8 in., ¾ in, 5/8 in., 1/2 in., 3/8 in., ¼ in., No. 4, and a No. 8 sieve.
   2.4. Determine the average mat thickness in accordance with Tex-2XX-F, “Average Mat Thickness.”
   2.5. Calculate the theoretical spread rate using equation 1. Note: Appendix A contains additional information about the theoretical spread rate.

$$\mathbf{S = \frac{36}{T_m}}$$

Equation 1: Theoretical Spread Rate

Where:

S = Theoretical Spread Rate in sq. yd. per cu. yd.
36 = Conversion Factor.
T_m = Average Mat Thickness, in.

3. Spread Rate Visual Analysis.
   3.1. Place the representative sample at the theoretical spread rate on a test area. The test area is made from wood or other sturdy material with a minimum size of 0.25 sq. yd.
      3.1.1. Calculate the weight of material needed for the visual analysis of the spread rate using Equation 2.

$$W_B = \frac{27 \times Uw \times B_t}{S}$$

Equation 2: Theoretical Board Test

Where:

W_B = Weight of Aggregate, lb per sq. yd.
S = Theoretical Spread Rate in sq. yd. per cu. yd.

27 = Conversion Factor.
U_w = Dry Loose Unit Weight of aggregate in lb per cu. ft.
B_t = Test area in sq. yd.

3.2. Visually evaluate whether or not the theoretical spread rate is acceptable. An acceptable spread rate should be one particle thick on the flattest side covering the full area of the board.
3.3. Remove or add material until the acceptable visual spread rate is achieved.
3.4. Weigh the material on the board.
3.5. Determine the target spread rate.
  3.5.1. Calculate the adjusted target spread rate in sq. yd. per cu. yd. using Equation 3.

$$S_T = \frac{27 \times Uw}{\frac{Wa}{B_t}}$$

Equation 3: Target Spread Rate

Where:
S_T = Target Spread Rate in sq. yd. per cu. yd.
Wa = Adjusted Weight of Aggregate on board, lb.
27 = Conversion Factor.
Uw = Dry Loose Unit Weight of aggregate in lb per cu. ft.
Bt = Test area in sq. yd.

4. Field Adjustments.
  4.1. Verify the spread rate by randomly sampling and testing the aggregate stockpiles following Step 3.
  4.2. When problems occur during construction, adjust the rate until visually acceptable and repeat steps 1 through 3 to determine what caused the need for adjustment and monitor those changes.
  4.3. If a significant change in aggregate size and or shape occurs, follow steps 1 through 3 to establish a new spread rate.

Binder Application Rate

Use the following procedure to determine the target binder application rate. At a minimum, the procedure should be performed for each combination of binder, source and grade of aggregate used for seal coat on the project:

1. Obtain the most recent binder test report from Materials and Test Division for each of the specified binders being used on the project.
2. Obtain the quantity of crumb rubber in percent from the A-R binder design.
3. Determine Aggregate effect on binder rate.
  3.1. Determine the average mat thickness in accordance with Tex-2XX-F, “Average Mat Thickness.”

3.2. Determine the dry loose unit weight in lb per cu. ft. in accordance with Tex-404-A.
3.3. Determine the specific gravity and absorption in accordance with either Tex-403-A (natural aggregate) or Tex-433-A (lightweight aggregate).
3.4. Determine the flakiness index (FI) of the aggregate in accordance with Tex-224-F.

4. Determine the available voids on the pavement using Equation 4.

$$V = 1 - \frac{Uw}{(62.4 \times G)}$$

Equation 4: Voids

Where:

V = Volume of Voids, percent (expressed as a decimal).
62.4 = Unit Weight of Water, lb per cu. ft.
U_w= Dry Loose Unit Weight of aggregate, lb per cu. ft.
G = Dry Bulk Specific Gravity of the Aggregate.

Note: Use formula results when a heavy spread rate is anticipated, and for a usual spread rate, use V=55 percent.

5. Determine the design embedment based on traffic data and aggregate shape and size.

5.1. Obtain current traffic counts in annual daily traffic and convert to vehicles per day per lane. For a 2-lane roadway, this value will typically be the annual daily traffic divided by 2.

Note: When there is a significant change in the traffic, develop rates based on the various traffic conditions. For example, the rate on a shoulder will be higher than the rate in the lane since traffic is lower on the shoulder.

5.2. Determine the design embedment percentage of the aggregate using Table 8 and Table 9.

Table 8. Design Embedment.

	AC, Modified AC, Emulsion and Cutback					
FI	≤8%	≤8%	≤8%	>8%	>8%	>8%
Aggregate Grade	**Gr 3**	**Gr 4**	**Gr 5**	**Gr 3**	**Gr 4**	**Gr 5**
Traffic (v/d/l)	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**
0–50 SHLD	41	40.5	40.5	37	36.5	36
51–100	40	39.5	39.5	36	35.5	35
101–250	39.5	39	39	35.5	35	34.5
251–400	39	38.5	38.5	35	34.5	34
401–600	38	37.5	37.5	34	33.5	33
601–800	37.5	37	37	33.5	33	32.5
801–1000	37	36.5	36.5	33	32.5	32
1001–1500	36.5	36	36	32.5	32	31.5
1501–2000	36	35.5	35.5	32	31.5	31
2001–3000	35.5	35	35	31.5	31	30.5
>3000	35	34.5	34.5	31	30.5	30

Table 9. Design Embedment, A-R Binders.

	A-R Binders					
FI	≤8%	≤8%	≤8%	>8%	>8%	>8%
Aggregate Grade	**Gr 3**	**Gr 4**	**Gr 5**	**Gr 3**	**Gr 4**	**Gr 5**
Traffic (v/d/l)	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**
0–50 SHLD	52.5	51.5	51.5	47	46.5	46
51–100	52	51	51	46.5	46	45.5
101–250	51.5	50.5	50.5	46	45.5	45
251–400	50.5	49.5	49.5	45	44.5	44
401–600	49.5	48.5	48.5	44	43.5	43
601–800	49	48	48	43.5	43	42.5
801–1000	48	47	47	42.5	42	41.5
1001–1500	47.5	46.5	46.5	42	41.5	41
1501–2000	47	46	46	41.5	41	40.5
2001–3000	46	45	45	40.5	40	39.5
>3000	45.5	44.5	44.5	40	39.5	39

6. Determine the residual binder based on the aggregate size and shape at 60°F, using Equation 5.

$$\mathrm{R} = 5.61 \times \mathrm{V} \times \mathrm{D_e} \times \mathrm{T_m} \times (1 + \mathrm{C_r})$$

Equation 5: Residual Binder at 60°F

Where:

R = Residual Binder at 60°F in gal per sq. yd.
5.61 = conversion factor, gal per (in-sq. yd.) .
V = Volume of Voids, percent (expressed as a decimal).
D_e = Design Embedment, percent (expressed as a decimal).
T_m = Average Mat Thickness, in.
C_r = Crumb Rubber content, percent (expressed as a decimal)

7. Adjust the binder rate based on the application temperature with Equation 6. Use the volume correction factors from TxDOT internal excel worksheet, "Asphalt Binder Temperature-Volume Corrections" [20]. The factors for the typical application rates of binders with an assumed asphalt specific gravity of 1.02 at 60°F can be found in Table 10, Table 11, and Table 12.

$$\mathrm{A} = \frac{\mathrm{R}}{\mathrm{Ft}}$$

Equation 6: Temperature Adjustment

Where:

A = the Binder application rate adjusted for application temperature, gal per sq. yd.
F_t = the temperature correction factor from Table 10, Table 11 and Table 12 or TxDOT's "Asphalt Binder Temperature-Volume Corrections."
R = the Residual Binder rate, gal per sq. yd.

Table 10. Application Temperature Volume Correction Factors for Emulsion Binders.

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]
120	0.98500	**150**	0.97750
120	0.98500	**141**	0.97975
121	0.98475	**142**	0.97950
122	0.98450	**143**	0.97925
123	0.98425	**144**	0.97900
124	0.98400	**145**	0.97875
125	0.98375	**146**	0.97850
126	0.98350	**147**	0.97825
127	0.98325	**148**	0.97800
128	0.98300	**149**	0.97775
129	0.98275	**150**	0.97750
130	0.98250	**151**	0.97725
131	0.98225	**152**	0.97700
132	0.98200	**153**	0.97675
133	0.98175	**154**	0.97650
134	0.98150	**155**	0.97625
135	0.98125	**156**	0.97600
136	0.98100	**157**	0.97575
137	0.98075	**158**	0.97550
138	0.98050	**159**	0.97525
139	0.98025	**160**	0.97500
140	0.98000		

Table 11. Application Temperature Volume Correction Factors for Cutback Binders.

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]
125	0.97747	**151**	0.96857
126	0.97713	**152**	0.96823
127	0.97679	**153**	0.96789
128	0.97644	**154**	0.96755
129	0.97610	**155**	0.96720
130	0.97576	**156**	0.96686
131	0.97541	**157**	0.96652
132	0.97507	**158**	0.96618
133	0.97473	**159**	0.96584
134	0.97438	**160**	0.96550
135	0.97404	**161**	0.96516
136	0.97370	**162**	0.96482
137	0.97336	**163**	0.96448
138	0.97301	**164**	0.96414
139	0.97267	**165**	0.96380
140	0.97233	**166**	0.96346
141	0.97199	**167**	0.96312
142	0.97164	**168**	0.96278
143	0.97130	**169**	0.96244
144	0.97096	**170**	0.96210
145	0.97062	**171**	0.96176
141	0.97199	**172**	0.96142
142	0.97164	**173**	0.96108
143	0.97130	**174**	0.96074
144	0.97096	**175**	0.96040
145	0.97062	**176**	0.96006
146	0.97028	**177**	0.95972
147	0.96993	**178**	0.95939
148	0.96959	**179**	0.95905
149	0.96925	**180**	0.95871
150	0.96891		

Table 12. Application Temperature Volume Correction Factors for Hot Applied Binders.

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]	[°F]	[60°F]	[°F]	[60°F]
300	0.91871	332	0.90826	364	0.89791	396	0.88765
301	0.91838	333	0.90794	365	0.89759	397	0.88733
302	0.91806	334	0.90762	366	0.89727	398	0.88701
303	0.91773	335	0.90729	367	0.89694	399	0.88669
304	0.91740	336	0.90697	368	0.89662	400	0.88637
305	0.91707	337	0.90664	369	0.89630	401	0.88605
306	0.91675	338	0.90632	370	0.89598	402	0.88573
307	0.91642	339	0.90599	371	0.89566	403	0.88541
308	0.91609	340	0.90567	372	0.89534	404	0.88510
309	0.91576	341	0.90534	373	0.89501	405	0.88478
310	0.91544	342	0.90502	374	0.89469	406	0.88446
311	0.91511	343	0.90470	375	0.89437	407	0.88414
312	0.91478	344	0.90437	376	0.89405	408	0.88382
313	0.91446	345	0.90405	377	0.89373	409	0.88350
314	0.91413	346	0.90372	378	0.89341	410	0.88319
315	0.91380	347	0.90340	379	0.89309	411	0.88287
316	0.91348	348	0.90308	380	0.89277	412	0.88255
317	0.91315	349	0.90275	381	0.89245	413	0.88223
318	0.91282	350	0.90243	382	0.89213	414	0.88192
319	0.91250	351	0.90211	383	0.89181	415	0.88160
320	0.91217	352	0.90178	384	0.89149	416	0.88128
321	0.91185	353	0.90146	385	0.89116	417	0.88096
322	0.91152	354	0.90114	386	0.89084	418	0.88065
323	0.91119	355	0.90081	387	0.89052	419	0.88033
324	0.91087	356	0.90049	388	0.89020	420	0.88001
325	0.91054	357	0.90017	389	0.88988	421	0.87969
326	0.91022	358	0.89984	390	0.88956	422	0.87938
327	0.90989	359	0.89952	391	0.88925	423	0.87906
328	0.90957	360	0.89920	392	0.88893	424	0.87874
329	0.90924	361	0.89888	393	0.88861	425	0.87843
330	0.90892	362	0.89855	394	0.88829		
331	0.90859	363	0.89823	395	0.88797		

8. Adjust the binder rate based on the pavement surface condition, traffic volume, and aggregate grade using Equation 7**.**

$$\mathrm{B = A + P + T_V + T_H}$$

Equation 7: Adjusted Residual Binder

Note: When there is a significant change in the pavement condition, develop rates based on the various conditions. For example, the rate on a fresh patch will be higher than the rate a section with flushed wheel paths.

Where:
B = Adjusted Residual Binder, gal per sq. yd.
A = the Binder application rate adjusted for application temperature, gal per sq. yd.
P = Pavement adjustment factor, gal per sq. yd., Refer to Table 13.
T_V = Traffic adjustment factor, gal per sq. yd., Refer to Table 14.
T_H = Heavy Traffic adjustment factor, gal per sq. yd., Refer to Table 15.

9. Compare the rates to a usual maximum and minimum rate based on the aggregate size, percent voids, and embedment to ensure the rate is in a reasonable range. Extreme conditions may require the rate to be outside the ranges, but caution should be used when outside the limits. The upper and lower limits can be found by using Equation 8 and Equation 9.

$$\mathrm{U}_L = \frac{5.61 \times \mathrm{E_{max}} \times 0.55 \times \mathrm{T_m}}{\mathrm{F_t}}$$

Equation 8: Upper Limit

$$\mathbf{L}_{\boldsymbol{L}} = \frac{\mathbf{5.61 \times E_{min} \times V \times T_m}}{\mathbf{F_t}}$$

Equation 9: Lower Limit

Where:
U_L = Residual Binder at the upper limit, gal per sq. yd.
L_L = Residual Binder at the lower limit, gal per sq. yd.
5.61 = conversion factor, gal per (in-sq. yd.).
0.55 = 55% Voids, percent (expressed as a decimal).
V = Volume of Voids, percent (expressed as a decimal).
E_{max}, = 0.50 for A-R (50% Embedment) or = 0.40 all other Binders (40% Embedment).
E_{min} = 0.40 for A-R (40% Embedment) or = 0.30 for all other Binders (30% Embedment).
F_t = the temperature correction factor from Table 10, Table 11, and Table 12 or TxDOT's "Asphalt Binder Temperature-Volume Corrections."
T_m = Average Mat Thickness, in.

Table 13. Pavement Surface Condition Adjustments.

Binder Rate Adjustment Factors for Pavement Surface Condition (existing or new pavement-wheel path conditions)				
Surface Type	**Surface Condition**	**Aggregate Grade**		
		Gr 3	**Gr 4**	**Gr 5**
		gal/sy	**gal/sy**	**gal/sy**
Asphaltic Concrete Pavement (ACP)	Very dry ACP with many cracks	0.08	0.06	0.05
	Dry ACP with some cracks	0.05	0.04	0.03
	Good condition ACP with few cracks	0.02	0.02	0.01
Seal	Very dry with many cracks	0.06	0.06	0.04
	Very Coarse Texture and Dry with few cracks	0.04	0.04	0.03
	Dry seal with few cracks	0.03	0.03	0.02
	Good seal with few cracks	0.00	0.00	0.00
	Flushed seal	−0.02	−0.02	−0.01
	Bleeding seal	−0.04	−0.04	−0.02
Patches	Dry or fresh patch	0.03	0.03	0.02
	Fogged patch	0.00	0.00	0.00
	Flushed patch	−0.03	−0.03	−0.03
Prime	Dry surface, light rate	0.02	0.02	0.02
	Penetrated well, good rate	0.00	0.00	0.00
	Waxy and wet, not penetrated well	−0.03	−0.03	−0.02
Base	Flex Base	0.04	0.03	0.02
	Stabilized Base	0.02	0.01	0
	Asphalt Stabilized Base	0.01	0	−0.01
Multiple Layer	1st Course on Base, Good Condition	−0.02	−0.02	−0.01
	1st Course on Base, Flushed	−0.04	−0.03	−0.02
	1st Course on Base, Bleeding	−0.05	−0.04	−0.03
Milled Surface	Smooth mill (micro-mill texture)	0.03	0.03	0.02
	Rough milled texture	0.08	0.06	0.05
	Milled Seal Coat, slightly flushed	0.03	0.03	0.02

Table 14. Traffic Volume Adjustments.

Binder Rate Adjustment Factors for Traffic Volume			
Current Traffic	**Aggregate Grade**		
Veh/Day/Lane	**Gr 3** **gal/sy**	**Gr 4** **gal/sy**	**Gr 5** **gal/sy**
0–50 (SHLD)	0.05	0.05	0.02
50–100	0.05	0.05	0.02
101–250	0.04	0.04	0.01
251–400	0.03	0.03	0.00
401–500	0.02	0.02	0.00
501–650	0.01	0.01	0.00
651–900	0.00	0.00	0.00
901–1500	−0.01	−0.01	−0.01
1501–2000	−0.02	−0.02	−0.01
>2000	−0.03	−0.03	−0.01

Table 15. Heavy Truck Traffic Adjustments.

Binder Rate Adjustment Factors for Truck Traffic			
Current Traffic	**Aggregate Grade**		
% Trucks	**Gr 3** **gal/sy**	**Gr 4** **gal/sy**	**Gr 5** **gal/sy**
≤ 15%	0.00	0.00	0.00
15.1%–30%	−0.01	−0.01	0.00
>30%	−0.02	−0.02	0.00

10. Adjust the rate based on time of year and percent residual binder for Emulsions and Cutbacks. Application rates for emulsions and cutbacks are determined from Equation 10 [21].

$$\mathrm{B_{ec}} = \mathrm{B} + \mathrm{K} \times (\frac{\mathrm{B}}{\mathrm{Ra}} - \mathrm{B})$$

Equation 10: Emulsion or Cutback Application Rate

Where:

B_{ec} is the recommended application rate of either the emulsion or cutback.
B is the adjusted residual binder rate from Equation 7.
K is the seasonal adjustment factor from Table 16.
Ra is the percent residual asphalt in the emulsion or cutback expressed as a decimal.

Table 16. Seasonal Adjustment Factors.

	Seasonal Adjustment Factor (K)	
Construction Time	**Emulsion**	**Cutback**
Spring	0.60	0.70
Summer	0.40	0.60
Fall	0.70	0.80
Winter	0.90	0.90

10.1. Compare the rates to a usual maximum and minimum rate based on the aggregate size, percent voids, and embedment to ensure the rate is in a reasonable range. Extreme conditions may require the rate to be outside the ranges, but caution should be used when outside the limits. The upper and lower limits can be found by using Equation 11 and Equation 12.

$$\mathrm{U}_{ec} = \mathrm{U}_{L} + \mathrm{K} \times (\frac{\mathrm{U}_{L}}{\mathrm{Ra}} - \mathrm{U}_{L})$$

Equation 11: Emulsion/Cutback Upper Limit

$$\mathbf{L}_{ec} = \mathbf{L}_{L} + \mathbf{K} \times (\frac{\mathbf{L}_{L}}{\mathbf{Ra}} - \mathbf{L}_{L})$$

Equation 12: Emulsion/Cutback Lower Limit

Where:

U_{ec} = Emulsion/Cutback rate at the Upper limit, gal. per sq. yd.
Lec = Emulsion/Cutback rate at the Lower limit, gal. per sq. yd.
U_L = Residual Binder at the upper limit, gal. per sq. yd.
L_L = Residual Binder at the lower limit, gal. per sq. yd.
5.61 = conversion factor, gal. per (in-sq. yd.).
0.55 = 55% Voids, percent (expressed as a decimal).
V = Volume of Voids, percent (expressed as a decimal).
E_{max}, = 0.50 for A-R (50% Embedment) or = 0.40 all other Binders (40% Embedment).
E_{min} = 0.40 for A-R (40% Embedment) or = 0.30 for all other Binders (30% Embedment).
F_t = the temperature correction factor from Table 10, Table 11, and Table 12 or TxDOT's "Asphalt Binder Temperature-Volume Corrections."
T_m = Average Mat Thickness, in.

TRANSVERSE VARIABLE BINDER RATES

Use the following procedure to determine the use of transverse variable binder application rates. At a minimum, the procedure should be performed for each combination of binder, source, and grade of aggregate used for seal coat on the project and as conditions change along the pavement.

1. Evaluate the existing pavement to determine if transverse variable rates are needed.
   - 1.1. Visual Evaluation.
     - 1.1.1. Evaluate the texture in the wheelpaths and outside the wheelpaths.
     - 1.1.2. When the wheelpaths are visually flushing or bleeding, consider the use of transverse variable rates.
   - 1.2. Texture Measurement.
     - 1.2.1. Use Tex 436-A to measure the texture in and outside the wheelpaths.
     - 1.2.2. Consider the use of variable nozzles when the difference in the Sand Patch Average diameter is greater than 0.79 inches (20 mm). [17]

2. Determining Transverse Variable Binder Rates.
    2.1. Determine the wheelpath rate following the procedure for determining the target binder values using the pavement adjustment factor based on the visual analysis of the wheelpath.
    2.2. Determine the rate outside the wheelpath following the procedure for determining the target binder values using the pavement adjustment factor based on the visual analysis outside of the wheelpath.

Note: Use the traffic range 0–50 SHLD for outside the wheelpath instead of the annual daily traffic (vehicles per day per lane).

3. Distributor Rates.
    3.1. Single Bar Distributor with variable nozzles.
        3.1.1. Obtain the calibration records for the distributor from the contractor showing the percent change in and outside the wheelpaths.
        3.1.2. Use Equation 13 to determine the average rate for the distributor computer and comparison to the strap of the tank.

$$D = \left(\left(\frac{N}{N_t}\right) \times I \times R_T\right) + R_T$$

Equation 13: Variable Nozzle Rate

Where:

D = the average application rate, gal per sq. yd.
N = Number of larger nozzles.
N_t = Total number of nozzles.
I = % increase in asphalt rate selected for outside of the wheel paths, expressed as a decimal.
R_T = Target design rate of asphalt application for the wheel paths in gal per sq. yd. (B or B_{ec}) from Equation 7 or Equation 10, gal per sq. yd.

    3.2. Use Equation 12 to determine the rate outside the wheelpath.

$$O_{wp} = R_T \times (1 + I)$$

Equation 14: Outside Wheelpath Rate

Where:

O_{wp} = the application rate outside the wheelpath, gal per sq. yd.
I = % increase in asphalt rate selected for outside of the wheel paths, expressed as a decimal.
R_T = Target design rate of asphalt application for the wheel paths (B or B_{ec}) from Equation 7 or Equation 10, gal per sq. yd.

- 3.3. Compare the rate outside the wheelpath to rate determined in 1.3. When the rate exceeds the rate from 1.3, consider not using the variable application since the rate may be too high and lead to other performance issues.
- 3.4. Multiple Bar distributors.
    - 3.4.1. Use the rates determined in 2.

REPORTING

Report the theoretical and target aggregate spread rate in square yard per cubic yard to the nearest whole number. Report the binder application rate in gallons per square yard to the nearest hundredth. When transverse variable binder application rates are used, report the wheelpath, outside the wheelpath, and distributor rates in gallons per square yard to the nearest hundredth. When conditions change, report the limits of the changes and the associated rates.

CHAPTER 4. RECOMMENDATIONS

SEAL COAT DESIGN METHOD

A design procedure can reduce risk and result in better performing seal coat projects. In this project, a seal coat application rate design procedure was developed based on national methods, international methods, and TxDOT experience. If implemented, this new procedure will help engineers and inspectors make better decisions resulting in successful projects.

In order to implement the new design procedure, new specifications and test methods are proposed. The design procedure was developed in a TxDOT test method format so that it could be referenced from the construction specifications. The test methods can be found in Appendix B in 0-6989-P1. Both method and performance specifications were developed and can be found in Appendix A in 0-6989-P1.

Rate Adjustments

Rate adjustments are needed when conditions change. Currently this is based on a visual inspection of the pavement. Future research is needed to replace the visual assessments with measurable methods. The visual assessments are used to identify the pavement hardness, absorption properties, and texture. The following future research should be considered:

- Texture:
  - Develop a method associating the texture depth reading and adjustments to the binder rate in the design method.
  - Develop a high-speed measuring method.
    - Recommend developing a laser-based system that can be collected at high speed so that traffic control will not be required to collect the data. This system will provide significantly more readings (data points) in a more efficient and safer manner than the current TxDOT test method, Tex-436-A, which is a spot specific test that requires a lane closure to perform.
  - Validate the criteria for the performance specification.
- Hardness:
  - Develop a test method to measure pavement hardness and the adjustments to the binder rate based on the hardness measurements.
  - When multiple layers of seal coats are placed the adjustments to the next seal should include an assumption that the seal coat binder just placed is tender or softer than a seal coat that has been in place for a long time. A measure of the hardness will be needed for this situation to develop the adjustments.
- Absorption—Develop a test method to measure pavement absorption and the adjustments to the binder rate based on the absorption measurements.

Traffic

Experience indicates that heavier slow-moving traffic leads to flushing and bleeding, but the levels are not quantified. Future research would include the effects of loading, speed, and pavement geometry on aggregate embedment depths and binder rates. This may also need to be tied to the binder stiffening timeframe and climate changes.

Materials

An extensive review of materials and material requirements was performed. Improvements can be made to the design procedure through additional material requirements.

For multiple seal coats, there is no consensus in the research for the best way to apply the binder rates for each layer, so further research is needed to develop recommendations for binder and aggregate application rates during construction when a layer is being placed immediately after another layer.

Aggregate

Continue performing the aggregate tests referenced in Item 302 and Item 316. The following are additional testing or modifications to an existing test method that are recommended for the design method:

- Gradation, Tex-200-F, Part I—For gradation, include use sieve sizes 7/8 in., ¾ in, 5/8 in., 1/2 in., 3/8 in., 1/4 in., No. 4, and a No. 8 to improve the correlation between gradation and mat thickness.
- Flakiness Index, Tex-224-F—Place a minimum testing frequency for the flakiness index so that it will become a test that is automatically generated into the sampling and testing plan in Sitemanager.
- New Test method: Tex-2XX-F, "Seal Coat Aggregate Average Mat Thickness."
  - This method will be used to determine the average mat thickness of the seal coat aggregate. Three methods are proposed. These include two ways to measure and one method to estimate from other tests.
    - Line Laser Method (measure).
    - Caliper Method (measure).
    - Correlation to gradation (estimate).
      - Additional research will be needed to validate and improve these methods.
- Develop precoating requirements.
  - Further research will be needed and is currently being proposed by the TxDOT Research and Technology Implementation division.
- When using multiple seal coats, further research is needed to develop a method to recommend aggregate size combinations, similar to the New Zealand chart.

Binder

Continue performing the binder tests referenced in Item 300 and Item 316. The following are additional testing or modifications to an existing test method that are recommended for the design method:

- Adopt the ASTM D4311 method for temperature volume correction based on binder type and application temperature or place the TxDOT worksheets [20] into a new test procedure.
- Move the requirements in Item 316 for Asphalt-Rubber binder to a separate item, to improve clarity for the unique requirements needed when using this type of binder.
  - Further research is needed to develop a method to add the volume of rubber (including binder absorbed by rubber) into the binder rate in the new design method.
- If a surface performance graded (SPG) binder is specified, consider:
  - Allowing a modifier type to be added to the SPG grade.
  - Adding the Elastic Recovery test to help indicate a modifier has been added.
- For use in multiple seal coat applications, further research is needed to develop recommendations for binder combinations.

IMPLEMENTATION

In order to implement the use of the new design procedure, it is recommended that workshops be developed. The workshops will train TxDOT engineers and inspectors to design the target application rates and make field adjustments to the application rates based on the new procedure.

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APPENDIX A. THEORETICAL AGGREGATE SPREAD RATE

The theoretical aggregate spread rate equation was derived from the equations in the Modified Kearby method [6] and from direct measurement of the average mat thickness.

The Modified Kearby design method assumes that the spread rate will mimic the loose unit weight when the material is spread one particle thick with the same void space. The spread rate from this method is shown in Equation 15. The Modified Kearby method then uses this information to estimate the mat thickness. The mat thickness estimation is shown in Equation 16. The issue with using this method to estimate the mat thickness is that the lighter the spread rate, the thinner the mat thickness. Figure 9 is an example of different spread rates using the same aggregate (Gr 4 Gravel source). The measured mat thickness was determined to be 0.285 inches. Based on Equation 17, the spread rate is 36/0.285 = 126 sq. yd. per 1 cu. yd. Approximately 15 percent of the weight was removed for a spread rate of 145 sq. yd. per 1 cu. yd. and then approximately 30 percent of the weight was removed for a spread rate of 165 sq. yd. per 1 cu. yd. If the board test performed in the Modified Kearby test was used to estimate the mat thickness, the resulting mat thickness would be 0.248 inches and 0.218 inches, respectively. Lighter spread rates resulted in smaller mat thickness and lower binder rates when in reality, more binder could be used due to increased void area as well as an actual mat thickness that is larger than what was estimated from the Modified Kearby formulas.

The theoretical spread rate can be found from combining Equation 15 and Equation 16 to derive Equation 17.

$$SR = 27 \times \frac{W}{Q}$$

Equation 15: Modified Kearby Spread Rate

Where:

SR is the Spread Rate in sq. yd. per cu. yd.
27 is conversion from cf to cu. yd.
W is the Dry Loose Unit Weight in pounds per cf.
Q is the weight of aggregate from the board test in lb per sq. yd.

$$d = 1.33 \times \frac{Q}{W}$$

Equation 16: Modified Kearby Mat Thickness

Where:

d is the mat thickness in inches
1.33 is a conversion factor (12 in per ft divided by 9 sf per sq. yd.).
W is the Dry Loose Unit Weight in pounds per sq. yd.
Q is the weight of aggregate from the board test in pounds per sf.

$$SR = 27 \times \frac{W}{Q} \rightarrow SR = 27 \times \frac{W}{(d \times W)} \times 1.33 \rightarrow$$

$$SR = \frac{36}{d}$$

Equation 17: Theoretical Spread Rate

Where:

SR is the Spread Rate in sq. yd. per cu. yd.
d is the mat thickness in in.
36 is a conversion factor.

Theoretical Spread Rate Typical Spread Rate Light Spread Rate

Figure 9. Gr 4 Gravel Spread Rates.

APPENDIX B. EXAMPLES OF THE TEXAS DESIGN PROCEDURE

Aggregate Spread Rate

Table B1: Aggregate Testing Information

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, lb per cu. ft	U_w	
Tex-2XX-F, “Average Mat Thickness”	Thickness, in.	T_m	
Tex-2XX-F,”Texas Seal Coat Design Method”	Board size, sq. yd.	B_t	

Theoretical Spread Rate

$$\boldsymbol{S = \frac{36}{T_m}}$$

$$\boxed{S = \frac{36}{\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_}$$

Where:
S = Theoretical Spread Rate, sq. yd. per cu. yd.
T_m = Average Mat Thickness, in.

Spread Rate Visual Analysis

$$W_B = \frac{27 \times \mathrm{Uw} \times B_t}{S}$$

$$\boxed{W_B = \frac{27 \times \_\_\_\_\_\_ \times \_\_\_\_\_\_\_}{\_\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_}$$

Where:
WB = Weight of Aggregate, lb per sq. yd.
U_w = Dry Loose Unit Weight of aggregate, in lb. per cu. ft.
Bt = Area of the board in sq. yd.

Adjusted Rate

$$S_t = \frac{27 \times Uw}{\frac{Wa}{B_t}}$$

$$\boxed{S_t = 27 \text{ x } \frac{\_\_\_\_\_\_\_\_}{\frac{\boxed{}}{\boxed{}}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_}$$

Where:
S_t = Target Spread Rate, sq. yd. per cu. yd.

Binder Application Rate

Table B2: Project Information

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	U_w	
Tex-2XX-F, “Average Mat Thickness”	Thickness, inches	T_m	
Tex-403-A or Tex-433-A	Specific Gravity	G	
Tex-224-F	Flakiness Index (FI)		
N/A - Traffic Data	Traffic Vehicles/Day/Lane		
T59 and/or T78	Residual Binder	Ra	

Available Void Space for Binder

$$V = 1 - \frac{Uw}{(62.4 \times \text{G})}$$

V = 1 - ______________ = ____________
(62.4 x _______)

Note: Use formula results when a Heavy spread rate is anticipated and for a usual spread rate, use V=55%.

Where:

V = Volume of Voids, percent (expressed as a decimal).
G = Dry Bulk Specific Gravity of the Aggregate.

Residual Binder Rate at 60°F

$$R = 5.61 \times V \times D_e \times T_m$$

R = Residual Binder at 60°F in gal/sy.
V = Volume of Voids, percent (expressed as a decimal).
D_e = Design Embedment, percent (expressed as a decimal), from Tables B3 and B4, percent is shown in the tables.

$R = 5.61 \times$ ____ $\times$ ____ $\times$ ___ $=$ ______

Table B3: Embedment

	AC, Modified AC, Emulsion and Cutback					
FI	≤8%	≤8%	≤8%	>8%	>8%	>8%
Aggregate Grade	**Gr 3**	**Gr 4**	**Gr 5**	**Gr 3**	**Gr 4**	**Gr 5**
Traffic (v/d/l)	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**
0–50 SHLD	41	40.5	40.5	37	36.5	36
51–100	40	39.5	39.5	36	35.5	35
101–250	39.5	39	39	35.5	35	34.5
251–400	39	38.5	38.5	35	34.5	34
401–600	38	37.5	37.5	34	33.5	33
601–800	37.5	37	37	33.5	33	32.5
801–1000	37	36.5	36.5	33	32.5	32
1001–1500	36.5	36	36	32.5	32	31.5
1501-2000	36	35.5	35.5	32	31.5	31
2001–3000	35.5	35	35	31.5	31	30.5
>3000	35	34.5	34.5	31	30.5	30

Table B4: A-R Binder Embedment

	A-R Binders					
FI	≤8%	≤8%	≤8%	>8%	>8%	>8%
Aggregate Grade	**Gr 3**	**Gr 4**	**Gr 5**	**Gr 3**	**Gr 4**	**Gr 5**
Traffic (v/d/l)	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**	**De (%)**
0–50 SHLD	52.5	51.5	51.5	47	46.5	46
51–100	52	51	51	46.5	46	45.5
101–250	51.5	50.5	50.5	46	45.5	45
251–400	50.5	49.5	49.5	45	44.5	44
401–600	49.5	48.5	48.5	44	43.5	43
601–800	49	48	48	43.5	43	42.5
801–1000	48	47	47	42.5	42	41.5
1001–1500	47.5	46.5	46.5	42	41.5	41
1501–2000	47	46	46	41.5	41	40.5
2001–3000	46	45	45	40.5	40	39.5
>3000	45.5	44.5	44.5	40	39.5	39

Adjust for Application Temperature

$$A = \frac{R}{\mathrm{Ft}}$$

$$A = \frac{\_\_\_\_\_\_}{\_\_\_\_\_\_} = \_\_\_\_\_\_\_\_$$

Where:

A = the Binder application rate adjusted for application temperature, gal per sq. yd.

F_t = the temperature correction factor from Table B5, Table B6, and Table B7 or TxDOT's "Asphalt Binder Temperature-Volume Corrections."

Table B5: Application Temperature Volume Correction Factors for Emulsion Binders

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]
120	0.98500	**150**	0.97750
120	0.98500	**141**	0.97975
121	0.98475	**142**	0.97950
122	0.98450	**143**	0.97925
123	0.98425	**144**	0.97900
124	0.98400	**145**	0.97875
125	0.98375	**146**	0.97850
126	0.98350	**147**	0.97825
127	0.98325	**148**	0.97800
128	0.98300	**149**	0.97775
129	0.98275	**150**	0.97750
130	0.98250	**151**	0.97725
131	0.98225	**152**	0.97700
132	0.98200	**153**	0.97675
133	0.98175	**154**	0.97650
134	0.98150	**155**	0.97625
135	0.98125	**156**	0.97600
136	0.98100	**157**	0.97575
137	0.98075	**158**	0.97550
138	0.98050	**159**	0.97525
139	0.98025	**160**	0.97500
140	0.98000		

Table B6: Application Temperature Volume Correction Factors for Cutback Binders

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]
125	0.97747	**151**	0.96857
126	0.97713	**152**	0.96823
127	0.97679	**153**	0.96789
128	0.97644	**154**	0.96755
129	0.97610	**155**	0.96720
130	0.97576	**156**	0.96686
131	0.97541	**157**	0.96652
132	0.97507	**158**	0.96618
133	0.97473	**159**	0.96584
134	0.97438	**160**	0.96550
135	0.97404	**161**	0.96516
136	0.97370	**162**	0.96482
137	0.97336	**163**	0.96448
138	0.97301	**164**	0.96414
139	0.97267	**165**	0.96380
140	0.97233	**166**	0.96346
141	0.97199	**167**	0.96312
142	0.97164	**168**	0.96278
143	0.97130	**169**	0.96244
144	0.97096	**170**	0.96210
145	0.97062	**171**	0.96176
141	0.97199	**172**	0.96142
142	0.97164	**173**	0.96108
143	0.97130	**174**	0.96074
144	0.97096	**175**	0.96040
145	0.97062	**176**	0.96006
146	0.97028	**177**	0.95972
147	0.96993	**178**	0.95939
148	0.96959	**179**	0.95905
149	0.96925	**180**	0.95871
150	0.96891		

Table B7: Application Temperature Volume Correction Factors for Hot Applied Binders

App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to	App. Temp.	Vol. Correction Factor to
[°F]	[60°F]	[°F]	[60°F]	[°F]	[60°F]	[°F]	[60°F]
300	0.91871	332	0.90826	364	0.89791	396	0.88765
301	0.91838	333	0.90794	365	0.89759	397	0.88733
302	0.91806	334	0.90762	366	0.89727	398	0.88701
303	0.91773	335	0.90729	367	0.89694	399	0.88669
304	0.91740	336	0.90697	368	0.89662	400	0.88637
305	0.91707	337	0.90664	369	0.89630	401	0.88605
306	0.91675	338	0.90632	370	0.89598	402	0.88573
307	0.91642	339	0.90599	371	0.89566	403	0.88541
308	0.91609	340	0.90567	372	0.89534	404	0.88510
309	0.91576	341	0.90534	373	0.89501	405	0.88478
310	0.91544	342	0.90502	374	0.89469	406	0.88446
311	0.91511	343	0.90470	375	0.89437	407	0.88414
312	0.91478	344	0.90437	376	0.89405	408	0.88382
313	0.91446	345	0.90405	377	0.89373	409	0.88350
314	0.91413	346	0.90372	378	0.89341	410	0.88319
315	0.91380	347	0.90340	379	0.89309	411	0.88287
316	0.91348	348	0.90308	380	0.89277	412	0.88255
317	0.91315	349	0.90275	381	0.89245	413	0.88223
318	0.91282	350	0.90243	382	0.89213	414	0.88192
319	0.91250	351	0.90211	383	0.89181	415	0.88160
320	0.91217	352	0.90178	384	0.89149	416	0.88128
321	0.91185	353	0.90146	385	0.89116	417	0.88096
322	0.91152	354	0.90114	386	0.89084	418	0.88065
323	0.91119	355	0.90081	387	0.89052	419	0.88033
324	0.91087	356	0.90049	388	0.89020	420	0.88001
325	0.91054	357	0.90017	389	0.88988	421	0.87969
326	0.91022	358	0.89984	390	0.88956	422	0.87938
327	0.90989	359	0.89952	391	0.88925	423	0.87906
328	0.90957	360	0.89920	392	0.88893	424	0.87874
329	0.90924	361	0.89888	393	0.88861	425	0.87843
330	0.90892	362	0.89855	394	0.88829		
331	0.90859	363	0.89823	395	0.88797		

Adjusted Binder Rate

$$B = A + P + T_V + \mathrm{T}_H$$

$$B = \underline{\qquad} + \underline{\qquad} + \underline{\qquad} + \underline{\qquad} = \underline{\qquad\quad}$$

Where:

B = Adjusted Residual Binder, gal per sq. yd.
P = Pavement adjustment factor, gal per sq. yd., Refer to Table B8.
T_V = Traffic adjustment factor, gal per sq. yd., Refer to Table B9.
T_H = Heavy Traffic adjustment factor, gal per sq. yd., Refer to Table B10.

Compare the rates to a usual maximum and minimum rate based on the aggregate size, percent voids, and embedment to ensure the rate is in a reasonable range. Extreme conditions may require the rate to be outside the ranges, but caution should be used when outside the limits. The upper and lower limits can be found by using the following equations.

$$U_L = \frac{5.61 \times E_{max} \times 0.55 \times \mathrm{T}_m}{\mathrm{F_t}}$$

$$UL = \frac{5.61 \times \underline{\qquad} \times 0.55 \times \underline{\qquad}}{\underline{\qquad\quad}} = \underline{\qquad\quad}$$

$$\boldsymbol{L_L} = \frac{\mathbf{5.61 \times E_{\boldsymbol{min}} \times V \times T_{\boldsymbol{m}}}}{\mathbf{F_t}}$$

$$LL = \frac{5.61 \times \underline{\qquad} \times \underline{\qquad} \times \underline{\qquad}}{\underline{\qquad\quad}} = \underline{\qquad\quad}$$

Where:

U_L= Residual Binder at the upper limit, gal per sq. yd.
0.55 = 55% Voids, percent (expressed as a decimal).
L_L = Residual Binder at the lower limit, gal per sq. yd.
V = Volume of Voids, percent (expressed as a decimal), from equation 10.4.
E_{max}, = 0.50 for A-R (50% Embedment) or = 0.40 all other Binders (40% Embedment).
E_{min} = 0.40 for A-R (40% Embedment) or = 0.30 for all other Binders (30% Embedment).

Table B8: Pavement Surface Condition Adjustments

Binder Rate Adjustment Factors for Pavement Surface Condition (existing or new pavement-wheel path conditions)				
Surface Type	**Surface Condition**	**Aggregate Grade**		
		Gr 3	**Gr 4**	**Gr 5**
		gal/sy	**gal/sy**	**gal/sy**
ACP	Very dry ACP with many cracks	0.08	0.06	0.05
	Dry ACP with some cracks	0.05	0.04	0.03
	Good condition ACP with few cracks	0.02	0.02	0.01
Seal	Very dry with many cracks	0.06	0.06	0.04
	Very Coarse Texture and Dry with few cracks	0.04	0.04	0.03
	Dry seal with few cracks	0.03	0.03	0.02
	Good seal with few cracks	0.00	0.00	0.00
	Flushed seal	-0.02	-0.02	-0.01
	Bleeding seal	-0.04	-0.04	-0.02
Patches	Dry or fresh patch	0.03	0.03	0.02
	Fogged patch	0.00	0.00	0.00
	Flushed patch	-0.03	-0.03	-0.03
Prime	Dry surface, light rate	0.02	0.02	0.02
	Penetrated well, good rate	0.00	0.00	0.00
	Waxy and wet, not penetrated well	-0.03	-0.03	-0.02
Base	Flex Base	0.04	0.03	0.02
	Stabilized Base	0.02	0.01	0
	Asphalt Stab Base	0.01	0	-0.01
Multiple Layer	1st Course on Base, Good Condition	-0.02	-0.02	-0.01
	1st Course on Base, Flushed	-0.04	-0.03	-0.02
	1st Course on Base, Bleeding	-0.05	-0.04	-0.03
Milled Surface	Smooth (micro-mill texture)	0.03	0.03	0.02
	Rough milled texture	0.08	0.06	0.05
	Milled Seal Coat, slightly flushed	0.03	0.03	0.02

Table B9: Traffic Volume Adjustments

Binder Rate Adjustment Factors for Traffic Volume			
Current Traffic	**Aggregate Grade**		
Veh/Lane/Day	**Gr 3**	**Gr 4**	**Gr 5**
	gal/sy	**gal/sy**	**gal/sy**
0–50 (SHLD)	0.05	0.05	0.02
50–100	0.05	0.05	0.02
101–250	0.04	0.04	0.01
251–400	0.03	0.03	0.00
401–500	0.02	0.02	0.00
501–650	0.01	0.01	0.00
651–900	0.00	0.00	0.00
901–1100	−0.01	−0.01	−0.01
1101–1500	−0.01	−0.01	−0.01
1501–2000	−0.02	−0.02	−0.01
>2000	−0.03	−0.03	−0.01

Table B10: Heavy Truck Traffic Adjustments

Binder Rate Adjustment Factors for Truck Traffic			
Current Traffic	**Aggregate Grade**		
% Trucks	**Gr 3**	**Gr 4**	**Gr 5**
	gal/sy	**gal/sy**	**gal/sy**
≤15%	0.00	0.00	0.00
15.1%–30%	−0.01	−0.01	0.00
>30%	−0.02	−0.02	0.00

Emulsion or Cutback Rate

$$B_{ec} = \_\_\_\_ + \_\_\_\_ \times \left(\frac{\_\_\_\_}{\_\_\_\_} - \_\_\_\_\right) = \_\_\_\_\_\_\_\_$$

$$B_{ec} = B + K \times \left(\frac{B}{R_a} - B\right)$$

Where:

B_{ec} = the recommended application rate of either the emulsion or cutback, gal per sq. yd.
K = the seasonal adjustment factor from Table B11.
R_a = the percent residual asphalt in the emulsion or cutback expressed as a decimal.

Table B11: Seasonal Adjustment Factors

	Seasonal Adjustment Factor (K)	
Construction Time	Emulsion	Cutback
Spring	0.60	0.70
Summer	0.40	0.60
Fall	0.70	0.80
Winter	0.90	0.90

$$\mathrm{U}_{ec} = \mathrm{U}_L + \mathrm{K} \times \left(\frac{\mathrm{U}_L}{\mathrm{Ra}} - \mathrm{U}_L\right)$$

$$U_{ec} = \_\_\_\_ + \_\_\_\_ \times \left(\frac{\_\_\_\_}{\_\_\_\_} - \_\_\_\_\right) = \_\_\_\_\_\_\_\_$$

$$L_{ec} = \_\_\_\_ + \_\_\_\_ \times \left(\frac{\_\_\_\_}{\_\_\_\_} - \_\_\_\_\right) = \_\_\_\_\_\_\_\_$$

$$\mathbf{L}_{ec} = \mathbf{L}_L + \mathbf{K} \times \left(\frac{\mathbf{L}_L}{\mathbf{Ra}} - \mathbf{L}_L\right)$$

Where:

U_{ec} = Emulsion/Cutback rate at the Upper limit, gal. per sq. yd.
Lec = Emulsion/Cutback rate at the Lower limit, gal. per sq. yd.
U_L = Residual Binder at the upper limit, gal. per sq. yd.
L_L = Residual Binder at the lower limit, gal. per sq. yd.

TRANSVERSE VARIABLE BINDER RATES

Determining Transverse Variable Binder Rates

Determine the wheelpath rate following the procedure for determining the target binder values using the pavement adjustment factor based on the visual analysis of the wheelpath.

Determine the rate outside the wheelpath following the procedure for determining the target binder values using the pavement adjustment factor based on the visual analysis outside of the wheelpath. *Note: Use the traffic range 0-50 SHLD for outside the wheelpath instead of the annual daily traffic (vehicles per day per lane).*

Single Bar Distributor with Variable Nozzles

$$D = \left(\left(\frac{N}{N_t}\right) xCxR_T\right) + R_T$$

$$D = \left(\left(\frac{\_\_\_\_}{100}\right) \times \left(\frac{\_\_\_\_}{100}\right) \times \_\_\_\_\right) + \_\_\_\_ = \_\_\_\_\_\_\_\_$$

Equation 11: Variable Nozzle Rate

Where:

D = the average application rate, gal per sq. yd.
N = Number of larger nozzles.
N_t = Total number of nozzles.
C= % increase in asphalt rate selected for outside of the wheel paths, expressed as a decimal.
R_T = design rate of asphalt application for the wheel paths (B or B_{ec}) from Part 2, gal per sq. yd.

$$OWP = R_T \times (1 + V)$$

Equation 12: Outside Wheelpath Rate

$$OWP = \_\_\_\_ \times (1 + \_\_\_\_) = \_\_\_\_\_\_\_\_$$

Where:

OWP = the application rate outside the wheelpath, gal per sq. yd.

Texas Seal Coat Design Method Example 1

Description		Description	
Binder	AC 20-5TR	Application Temp ˚F	375
Aggregate	GR 4	Time of Year	Summer
Traffic Data (Vehicles/Day/Lane)	1500	Trucks, %	12

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	88.3
"Average Mat Thickness"	Thickness, inches	T	0.237
Texas Seal Coat Design Method"	Board size, sy	B	
Tex-403-A or Tex-433-A	Specific Gravity	SG	2.633
Tex-224-F	Flakiness Index, %	FI	16
T59 and/or T78	Residual Binder, %	Ra	n/a

Pavement Condition:

Results:

Description	Value	Description	Value
			gal/sy
Design Voids % Note: Use formula results when a Heavy spread rate is anticipated and for a usual spread rate, use V=55%.	46.3	Pav. Surface Condition Adjustment	0.02
Residual Binder at 60˚F, gal/sy	0.23	Traffic Adjustment	-0.01
Temp Adjustment Factor	0.8944	Truck Adjustment	0.00
Binder rate adj for appl. temp., gal/sy	0.26	Adjusted Residual Binder	0.27
Aggregate Spread Rate, sy/cy	152	Wheelpath Rate	0.27

Texas Seal Coat Design Method Example 2

Description		Description	
Binder	CRS-2P	Application Temp ˚F	150
Aggregate	GR 4	Time of Year	Summer
Traffic Data (Vehicles/Day/Lane)	400	Trucks, %	20
Distributor Transv. Variation,%	20		

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	85.62
“Average Mat Thickness”	Thickness, inches	T	0.251
Texas Seal Coat Design Method”	Board size, sy	B	0.25
Tex-403-A or Tex-433-A	Specific Gravity	SG	2.645
Tex-224-F	Flakiness Index, %	FI	16
T59 and/or T78	Residual Binder, %	Ra	65

Pavement Condition:

Results:

Description	Value	Description	Value
			gal/sy
Design Voids %	48.1 use 55	Pav. Surface Condition Adjustment	-0.02
Residual Binder at 60˚F, gal/sy	0.27	Traffic Adjustment	0.03
Temp Adjustment Factor	0.9775	Truck Adjustment	-0.01
Binder rate adj for temp., gal/sy	0.27	Adjusted Residual Binder	0.27
K Factor	0.4	Wheelpath Rate	0.33
		Outside Wheelpath Rate	0.40
Aggregate Spread Rate, sy/cy	144	Binder Rate	0.36

Consider using variable nozzles since aggregate is shelling outside wheelpaths and wheelpaths are slightly flushed. Assume a 12-ft wide lane.

Texas Seal Coat Design Method Example 3

Description		Description	
Binder	RC 250	Application Temp ˚F	150
Aggregate	GR 5	Time of Year	Spring
Traffic Data (Vehicles/Day/Lane)	150	Trucks, %	5
Distributor Transv. Variation,%	20		

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	80.34
"Average Mat Thickness"	Thickness, inches	T	0.171
Texas Seal Coat Design Method"	Board size, sy	B	0.25
Tex-403-A or Tex-433-A	Specific Gravity	SG	2.439
Tex-224-F	Flakiness Index, %	FI	10
T59 and/or T78	Residual Binder, %	Ra	70

Pavement Condition:

Results:

Description	Value	Description	Value gal/sy
Design Voids %	46.8 use 55	Pav. Surface Condition Adjustment	0.0
Residual Binder at 60˚F, gal/sy	0.18	Traffic Adjustment	0.01
Temp Adjustment Factor	0.9689	Truck Adjustment	0.0
Binder rate adj for temp., gal/sy	0.19	Adjusted Residual Binder	0.20
K Factor	0.7	Wheelpath Rate	0.27
		Outside Wheelpath Rate	n/a
Aggregate Spread Rate, sy/cy	210	Binder Rate	0.27

Maintenance repair during the spring

Texas Seal Coat Design Method Example 4

Description		Description	
Binder	HFRS-2P	Application Temp ˚F	150
Aggregate	GR 3	Time of Year	Fall
Traffic Data (Vehicles/Day/Lane)	800	Trucks, %	6
Distributor Transv. Variation,%	20		

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	85.61
"Average Mat Thickness"	Thickness, inches	T	0.377
Texas Seal Coat Design Method"	Board size, sy	B	0.25
Tex-403-A or Tex-433-A	Specific Gravity	SG	2.642
Tex-224-F	Flakiness Index, %	FI	9
T59 and/or T78	Residual Binder, %	Ra	65

Pavement Condition:

Results:

Description	Value	Description	Value
			gal/sy
Design Voids %	48.1 use 55	Pav. Surface Condition Adjustment	0.03
Residual Binder at 60˚F, gal/sy	0.39	Traffic Adjustment	0.00
Temp Adjustment Factor	0.9775	Truck Adjustment	0.00
Binder rate adj for temp., gal/sy	0.40	Adjusted Residual Binder	0.43
K Factor	0.7	Wheelpath Rate	0.59
		Outside Wheelpath Rate	n/a
Aggregate Spread Rate, sy/cy	96	Binder Rate	0.59

Texas Seal Coat Design Method Example 5

Description		Description	
Binder	AC 15P	Application Temp ˚F	375
Aggregate	GR 3	Time of Year	Summer
Traffic Data (Vehicles/Day/Lane)	1500	Trucks, %	18
Distributor Transv. Variation,%	20		

Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	44
"Average Mat Thickness"	Thickness, inches	T	0.334
Texas Seal Coat Design Method"	Board size, sy	B	0.25
Tex-403-A or Tex-433-A	Specific Gravity	SG	1.5
Tex-224-F	Flakiness Index, %	FI	6
T59 and/or T78	Residual Binder, %	Ra	n/a

Pavement Condition:

Results:

Description	Value	Description	Value
			gal/sy
Design Voids %	53 use 55	Pav. Surface Condition Adjustment	-0.02
Residual Binder at 60˚F, gal/sy	0.38	Traffic Adjustment	-0.01
Temp Adjustment Factor	0.8944	Truck Adjustment	-0.01
Binder rate adj for temp., gal/sy	0.42	Adjusted Residual Binder	0.38
K Factor	n/a	Wheelpath Rate	0.38
		Outside Wheelpath Rate	n/a
Aggregate Spread Rate, sy/cy	108	Binder Rate	0.38

Texas Seal Coat Design Method Example 6

Description		Description	
Binder	AC 20-5TR	Application Temp ˚F	375
Aggregate	GR 4	Time of Year	Summer
Traffic Data (Vehicles/Day/Lane)	3200	Trucks, %	34
Distributor Transv. Variation, %	20		
Test Method	Description	Formula Symbol	Test Result
Tex-404-A	Dry Loose Unit weight, pcf	Uw	44
“Average Mat Thickness”	Thickness, inches	T	0.291
Texas Seal Coat Design Method”	Board size, sy	B	0.25
Tex-403-A or Tex-433-A	Specific Gravity	SG	1.5
Tex-224-F	Flakiness Index, %	FI	1
T59 and/or T78	Residual Binder, %	Ra	n/a

Pavement Condition:

Results:

Description	Value	Description	Value
			gal/sy
Design Voids %	53 use 55	Pav. Surface Condition Adjustment	0.06
Residual Binder at 60˚F, gal/sy	0.31	Traffic Adjustment	-0.03
Temp Adjustment Factor	0.8944	Truck Adjustment	-0.02
Binder rate adj for temp., gal/sy	0.35	Adjusted Residual Binder	0.36
K Factor	n/a	Wheelpath Rate	0.36
		Outside Wheelpath Rate	n/a
Aggregate Spread Rate, sy/cy	124	Binder Rate	0.36