Chip Seal for Uniform Usages Across the Districts of NMDOT

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16. Abstract

Chip seals are a cost-effective pavement preservation treatment widely used by the New Mexico Department of Transportation (NMDOT) to extend pavement life and improve surface performance. Despite their extensive application, NMDOT has not previously adopted a standardized design procedure or construction specification, resulting in variability across districts. This research reviewed current practices, analyzed performance trends using Pavement Management System (PMS) data, and developed a formal design methodology tailored to New Mexico's conditions. The Modified Kearby method, documented in AASHTO R 102-22, was selected as the most suitable design approach based on its practicality and compatibility with available resources. Laboratory testing of 13 aggregate sources, including reclaimed asphalt pavement (RAP), revealed significant variability in material properties and application rates, confirming the need for project-specific design. Validation through two field projects demonstrated strong agreement between laboratory-designed and field-applied rates, supporting adoption of the method. PMS analysis showed that chip seals generally perform well, with minimal bleeding and acceptable aggregate retention. Service lives average six to eight years, consistent with current practice.

The study recommends adopting the Modified Kearby method, implementing statewide specifications, integrating PMS data into project selection, and constructing pilot test sections in each district during initial implementation. These measures will improve consistency, optimize material usage, and enhance long-term performance of chip seal treatments across New Mexico.

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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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for 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 ABBREVIATIONS

Item	**Definition**
AADT	Annual Average Daily Traffic
CTM	Circular Texture Meter
DFT	Dynamic Friction Tester
FHWA	Federal Highway Administration
FY	Fiscal Year
HFE100P	High Float Emulsion 100 with Polymer
HPMS	Highway Performance Monitoring System
IDI	Individual Distress Index
IRI	International Roughness Index
LA	Los Angeles
MUTCD	Manual on Uniform Traffic Control Devices
NMAS	Nominal Maximum Aggregate Size
NMDOT	New Mexico Department of Transportation
NCAT	National Center for Asphalt Technology
OCI	Overall Condition Index
PCR	Pavement Condition Rating
PMS	Pavement Management System
QA	Quality Assurance
QC	Quality Control
RAP	Reclaimed Asphalt Pavement

EXECUTIVE SUMMARY

Chip seals are among the most cost-effective pavement preservation treatments, widely used by the New Mexico Department of Transportation (NMDOT) to extend pavement life and improve surface performance. Despite their extensive application across the state, NMDOT has not previously adopted a standardized design procedure or construction specification for chip seal treatments. Current practices rely heavily on district-level experience, resulting in variability in material application rates and operational procedures. This research was undertaken to review existing practices, evaluate performance trends, and develop a formal design methodology and implementation framework tailored to New Mexico's unique geographic and operational conditions.

The study began with a comprehensive literature review of national and international chip seal design methods, construction practices, and performance outcomes. Fourteen design approaches were analyzed based on simplicity, practicality, repeatability, and compatibility with available resources. The Modified Kearby method, documented in AASHTO R 102-22, was selected as the most suitable design procedure for NMDOT due to its systematic approach and ease of implementation. This method determines binder and aggregate application rates through material characterization, board testing, and correction factors for traffic and surface conditions.

Current NMDOT practices were assessed through interviews, field observations, and analysis of Pavement Management System (PMS) data. Findings indicate that chip seals generally perform well, with minimal bleeding and acceptable aggregate retention. Early performance results show improved Pavement Condition Ratings (PCR) after treatment, although most pavements were treated below the recommended threshold for minor preservation. Long-term trends reveal that PCR values decline steadily, returning to pretreatment levels within six to eight years, consistent with NMDOT's current seven-year reapplication cycle.

Laboratory testing was conducted on 13 aggregate sources, including two reclaimed asphalt pavement (RAP) sources and 11 virgin aggregates, to determine material properties such as gradation, specific gravity, flakiness index, and abrasion resistance. Application rates calculated using the Modified Kearby method ranged from 9.8 to 31.7 lbs/yd^2 for aggregate and 0.17 to 0.91 gal/yd^2 for emulsion, confirming significant variability among sources and reinforcing the need for project-specific design. Validation through two field projects demonstrated strong agreement between laboratory-designed and field-applied rates, with aggregate rate differences under 5% and emulsion rates within the calculated range.

The study concludes that the Modified Kearby method is appropriate for statewide implementation and recommends adopting formal specifications to standardize construction practices. Additional recommendations include integrating PMS data into project selection, promoting RAP utilization for sustainability and cost savings, and constructing pilot test sections in each district during the initial implementation phase to validate design procedures under local conditions. These measures will improve consistency, optimize material usage, and enhance long-term performance of chip seal treatments across New Mexico.

CHAPTER 1. INTRODUCTION

Chip seals are widely recognized as an effective and economical pavement preservation treatment, particularly for asphalt-surfaced roads. Their primary function is to seal the pavement surface against moisture infiltration and oxidation, improve skid resistance, and mitigate minor surface distresses such as cracking and raveling. The process involves applying a layer of asphalt binder followed by a uniform distribution of aggregate chips, which are then embedded using pneumatic rollers. The simplicity of this method allows for implementation by local maintenance crews with minimal equipment, making it a cost-effective solution for state departments of transportation, including the New Mexico Department of Transportation (NMDOT).

Although chip seals are currently used as the primary preventive maintenance treatment throughout New Mexico, NMDOT has not yet adopted formal guidelines for project selection or treatment design. Additionally, there is no standardized specification for chip seal applications. These treatments are performed in-house, with each district operating its own crew. While official guidelines are lacking, districts generally adhere to similar construction practices that align with commonly accepted national standards.

Given the diverse conditions across New Mexico's pavement network, there is a clear need to develop formal procedures and criteria for chip seal design and construction. NMDOT divides the state into six districts (Figure 1), each characterized by unique geographic and environmental features. The state's varied landscape—including high deserts, rugged mountains, and river valleys—significantly influences transportation infrastructure and maintenance requirements within each district.

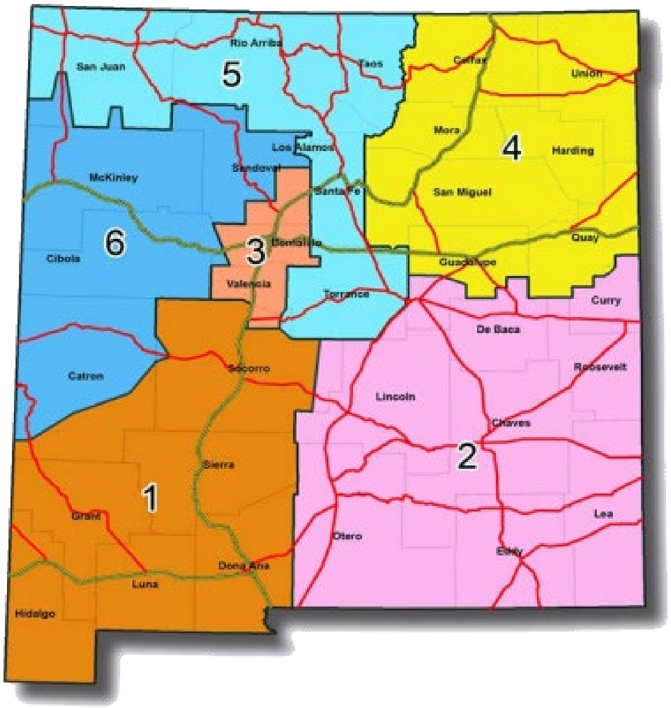

Figure 1. NMDOT Transportation Districts.

Climate and traffic conditions further complicate maintenance strategies across districts:

- **District 1 (Deming and surrounding area):** Covers Catron, Doña Ana, Grant, Hidalgo, Luna, Sierra, and Socorro counties. Characterized by arid high-desert plains, mountainous regions, and the Rio Grande Valley. The dry climate and sensitive desert ecosystems influence construction and water management practices.

- **District 2 (Roswell and surrounding area):** Includes Chaves, Curry, De Baca, Lea, Lincoln, Otero, and Roosevelt counties. Dominated by the Chihuahuan Desert and flat plains, this district supports significant oil and gas activity. Infrastructure must accommodate industrial traffic and rural agricultural needs.

- **District 3 (Albuquerque and surrounding area):** Comprises Bernalillo, Torrance, and Valencia counties. Encompasses Albuquerque and the Rio Grande Valley, with floodplains, mesas, and mountain ranges. Urban growth and traffic congestion require careful planning to balance infrastructure and environmental concerns.

- **District 4 (Las Vegas and surrounding area):** Serves Colfax, Guadalupe, Harding, Mora, Quay, San Miguel, and Union counties. Features high plains and mountain foothills, with a rural focus on agriculture and ranching. Seasonal weather and sparse population shape maintenance priorities.

- **District 5 (Santa Fe and surrounding area):** Covers Los Alamos, Rio Arriba, Santa Fe, San Juan, and Taos counties. High-altitude conditions and heavy snowfall present significant challenges for winter maintenance and road safety. Steep terrain increases erosion risks, requiring climate-adaptive design.

- **District 6 (Grants/Milan and surrounding area):** Includes Catron, Cibola, McKinley, Sandoval, and San Juan counties. Known for rugged terrain, tribal lands, and the Four Corners area. High-desert climate with extreme temperature swings and low precipitation affects pavement longevity.

To address these challenges and improve the performance and consistency of chip seal applications statewide, this research project aims to:

- Evaluate current NMDOT chip seal practices, including materials and application rates, and assess their impact on performance using available pavement management system (PMS) data.

- Develop a formal chip seal design procedure that accounts for local materials and geographic conditions across New Mexico.

- Provide guidance to NMDOT to support adoption of standardized chip seal practices across the state.

These objectives guided the development of a comprehensive framework for chip seal design, construction, and implementation, tailored to New Mexico's unique environmental and operational conditions.

This technical report documents the research effort. CHAPTER 2, presents a summary of the literature review. CHAPTER 3 reviews current chip seal practices across the state. CHAPTER 4 provides an overview of pavement condition data from NMDOT's pavement management system. CHAPTER 5 describes the development of the chip seal design method. Finally, CHAPTER 6 presents major conclusions and recommendations.

CHAPTER 2. SUMMARY OF LITERATURE REVIEW

The successful implementation of chip seal treatments depends not only on their cost-effectiveness and simplicity but also on a nuanced understanding of the factors that influence their performance. A comprehensive review of existing literature reveals a wide range of practices, design methodologies, and performance outcomes across different regions and climates. This chapter synthesizes key findings from national and international studies to inform the development of standardized chip seal procedures for New Mexico. It highlights the importance of project selection, material compatibility, climate adaptation, and construction quality—each of which plays a critical role in ensuring long-term pavement preservation. The insights gathered here serve as a foundation for the research tasks outlined in this study and guide the formulation of design and construction recommendations tailored to NMDOT's diverse operating conditions. The complete findings from the literature review can be found in Appendix A.

2.1. Project Selection Factors

2.1.1 Existing Pavement Condition

One of the most influential factors in determining the success of a chip seal treatment is the condition of the existing pavement at the time of application. Pavements must be structurally sound, with chip seals best suited for addressing non-structural distresses such as minor cracking, weathering, raveling, and oxidation (Lee & Shields, 2010). Studies have shown that treatments applied to pavements in good condition yield longer service lives and better performance outcomes. For instance, Eltahan et al. (1999) and Jalali & Vargas-Nordcbeck (2021) found that chip seals applied to pavements in good condition had significantly lower failure probabilities and higher survival rates. Visintine et al. (2015) reported that chip seal life expectancy decreased by 31% and 62% when applied to pavements in fair and poor conditions, respectively.

2.1.2 Traffic

Traffic volume also influences chip seal longevity. Chip seals generally perform best on low- to moderate-volume roads where traffic moves consistently with minimal stopping and turning. High traffic volumes, especially in urban environments, introduce challenges that can compromise treatment performance. Frequent braking, turning, and acceleration increase the likelihood of aggregate dislodgement, leading to premature raveling and reduced service life. Additionally, chip seals can generate increased road noise due to their coarse surface texture, which may be undesirable in residential areas or corridors with significant pedestrian and bicycle activity. This has led to user complaints and limited the use of chip seals in densely populated zones (Shuler et al., 2011; Donavan & Janello, 2023).

To mitigate these issues, agencies have adopted several strategies. One approach is the use of smaller aggregate sizes, which can reduce surface roughness and noise levels while improving chip retention under dynamic traffic conditions. Another common practice is the application of a fog seal over the chip seal to lock in aggregate, enhance surface cohesion, and reduce noise. In some cases, agencies opt for combination treatments, such as cape seals (chip seal followed by a slurry seal or micro surfacing), which provide a smoother finish suitable for urban settings.

These adaptations allow chip seals to be used more effectively in areas with higher traffic volumes or sensitive land uses, expanding their applicability while maintaining performance and public acceptance.

2.1.3 Climate

Climate plays a critical role in chip seal performance. High temperatures increase the risk of bleeding, while cold climates expose treatments to freeze-thaw cycles and snowplow damage. Polymer-modified binders have shown improved performance in cold climates (Aktas & Karasahin, 2013). Baladi et al. (2017) found that chip seals improved pavement performance across various climate zones, though the magnitude of improvement varied.

2.2. Materials and Design Methods

Chip seal performance is heavily dependent on the quality and compatibility of materials, as well as their corresponding application rates. A successful chip seal relies on the proper pairing of asphalt binder and aggregate, both of which must be selected based on local availability, climate conditions, and traffic demands.

2.2.1 Materials

Asphalt binders used in chip seals are typically either hot-applied paving-grade asphalt or emulsified asphalt. Emulsions are preferred in cooler or humid climates due to their ease of handling and better adhesion properties. These binders may be modified with polymers or recycled tire rubber to enhance elasticity and resistance to bleeding or cracking (Caltrans, 2007). The binder type and residual asphalt content are critical inputs in the design process, especially when using emulsified asphalt.

Aggregates must be clean, durable, and ideally single-sized, with a cubical shape and minimal fines to ensure proper embedment and retention. The most commonly used sizes range from ¼ inch to ½ inch, with less than 5% passing the No. 4 sieve. Aggregates with high flakiness or poor abrasion resistance can lead to premature failure. In some cases, reclaimed asphalt pavement (RAP) has been successfully used as a chip seal aggregate, offering sustainability benefits when properly processed and tested.

2.2.2 Design Methods

Several design methods have been developed to determine the optimal binder and aggregate application rates. Traditional methods such as the McLeod and Modified Kearby approaches rely on empirical relationships and correction factors for traffic and surface conditions. These methods aim to achieve a one-stone thick aggregate layer with 50–70% embedment, balancing chip retention and minimizing bleeding. More recent approaches incorporate performance-based testing and advanced technologies such as 3D laser profiling and image analysis to improve accuracy and account for field variability (Adams, 2014; El Hachem, 2019; Kumbargeri, 2019).

Table 1. Summary of Design Methods

Design Method	Features	Required Inputs
Hanson	Based on aggregate least dimension and binder viscosity	Aggregate size, binder properties, surface condition
Kearby and Modified Kearby	AASHTO R 102-22 standard; uses board test to determine aggregate rate	Board test results, aggregate unit weight, specific gravity, traffic correction factors
McLeod and Modified McLeod	Empirical method based on aggregate least dimension and embedment depth	Aggregate gradation, loose unit weight, flakiness index, traffic volume, surface condition
Spain	Emphasizes strict aggregate quality; involves well-defined binder selection	Aggregate quality (fractured faces, flakiness), binder type and viscosity
New Zealand	Performance-based; considers aggregate packing and binder rise	Aggregate shape and size, binder properties, traffic, climate
Austroads	Standardized sprayed-seal design (AP-T68/310/236) with dual-layer guidance	Traffic, texture depth, pavement dry-back, voids, aggregate shape
South Africa	Hybrid method drawing on UK and Austroads; includes climate, gradient factors	Traffic, ALD, texture depth, binder grade, climate, pavement temperature
United Kingdom	Surface dressing design with traffic, surface hardness, skid resistance focus	Traffic category, surface hardness, geometry, skid resistance needs, seasonal data
North Carolina State University	Digital imaging assesses aggregate embedment and shape	High-resolution images, software, material properties
Michigan State University	Lab testing focused on retention and binder durability	Aggregate gradation, binder tests (e.g., sweep, bond strength), traffic
University of Texas at Austin	3D laser scanning to measure embedment and texture in the field	3D profile data, aggregate and binder properties
France	Employs bituminous binders (either emulsified or cut-back) closely coupled with graded aggregates to form wearing courses	Binder type and rate, aggregate size & grading, structure selected based on traffic

The selection of a design method should consider the availability of input data, local material properties, and the desired level of precision. For example, the Modified Kearby method, recently adopted as AASHTO R 102-22, provides a standardized framework that can be adapted to New Mexico’s conditions. Regardless of the method used, the design process must ensure that the binder and aggregate rates are sufficient to achieve proper embedment without causing bleeding or aggregate loss.

2.3 Laboratory and Performance Testing

Laboratory and field testing are essential components of chip seal design and evaluation, providing the data needed to ensure that selected materials and construction practices will result in durable, high-performing treatments. These tests help agencies assess material quality, predict field performance, and refine design parameters to suit local conditions.

2.3.1 Material Properties

Aggregate testing focuses on properties that influence chip retention, embedment, and long-term durability. Standard tests include gradation analysis (AASHTO T 27) to ensure appropriate particle size distribution, Los Angeles abrasion (AASHTO T 96) to measure resistance to wear, and flakiness index (FLH T 508) to evaluate particle shape. Aggregates with low flakiness and high angularity are preferred, as they interlock more effectively and resist dislodgement under traffic loads. The percentage of fractured faces (AASHTO T 335) is also critical, with higher values indicating better mechanical interlock and improved performance.

Asphalt binder testing is equally important, particularly for emulsified binders commonly used in chip seals. Tests such as AASHTO T 59 determine the residue content after curing, which affects the binder's ability to hold aggregate in place. Viscosity and elasticity tests (AASHTO T 316 and T 315) assess the binder's flow characteristics and resistance to bleeding or cracking. Polymer-modified binders may undergo additional rheological evaluations to ensure they can withstand extreme temperature variations and traffic stresses.

2.3.2 Performance Testing

Performance testing simulates real-world conditions to evaluate how chip seals will behave once in service. The sweep test (ASTM D7000) is widely used to measure aggregate retention by simulating the abrasion caused by traffic. The binder bond strength test assesses the adhesive properties between the binder and aggregate, especially under moisture exposure, which is critical for preventing stripping and early failure. The boiling water test provides a quick assessment of moisture susceptibility, while visual inspections of aggregate embedment help verify proper construction practices.

Surface texture and friction characteristics are also evaluated using tests such as the sand patch test (ASTM E965), circular texture meter (CTM), and dynamic friction tester (DFT). These tests are crucial for ensuring adequate skid resistance and safety, particularly on high-speed or high-traffic roadways.

Field validation complements laboratory testing by confirming that design assumptions hold true under actual conditions. The board test, used in the Modified Kearby method, helps determine the appropriate aggregate application rate by simulating field coverage. Advanced technologies such as 3D laser profiling and image analysis are increasingly employed to assess aggregate embedment and surface texture with high precision, offering valuable insights for refining design and construction practices.

2.4 Construction Practices and Specifications

The success of chip seal treatments is highly dependent on proper construction practices and adherence to well-defined specifications. Even when materials and design are optimized, poor execution during construction can lead to premature failure, reduced service life, and increased maintenance costs. Best practices in chip seal construction include thorough surface preparation, calibrated equipment, appropriate weather conditions, and timely rolling and sweeping.

Surface preparation is the foundation of a successful chip seal. The existing pavement must be clean, dry, and free of loose debris, oil, or moisture. Any structural deficiencies should be addressed prior to treatment, as chip seals are not intended to correct underlying pavement failures. Tack coats or fog seals may be applied to improve adhesion, especially in areas with polished or oxidized surfaces (Shuler et al., 2011).

Equipment calibration is critical to ensure uniform application of both binder and aggregate. Distributors must be capable of applying the binder at the specified rate and temperature, typically between 60°F and 65°F for emulsified asphalt to ensure proper curing and bonding. Pneumatic tire rollers are used immediately after aggregate application to embed the chips into the binder layer. Rolling should be performed in multiple passes to achieve the desired embedment depth, typically between 50% and 70% (TxDOT, 2010).

Weather conditions play a significant role in chip seal performance. Construction should be avoided during periods of rain, high humidity, or extreme temperatures. Emulsified binders require adequate warmth and dry conditions to cure properly. Agencies often specify minimum ambient and surface temperatures for application, with 60°F being a common threshold.

Sweeping is typically performed the day after application to remove loose aggregate and prevent windshield damage or loss of skid resistance. Some agencies conduct follow-up inspections to assess embedment depth and binder coverage, often by extracting individual chips and visually evaluating their coating.

Specifications provide a standardized framework for ensuring quality and consistency across projects. The AASHTO Guide Specifications for Highway Construction (2020) offer detailed guidance on emulsified chip seal construction, including materials, equipment, surface preparation, application procedures, quality control, and acceptance criteria. These specifications are increasingly adopted and adapted by state DOTs to suit local conditions.

In addition to traditional specifications, some agencies are incorporating performance-based elements, such as minimum skid resistance values or maximum allowable chip loss, to better link construction quality with long-term outcomes. These approaches encourage contractors and maintenance crews to focus not only on meeting procedural requirements but also on achieving measurable performance targets.

2.5 Summary

The body of literature reviewed underscores the multifaceted nature of chip seal performance, highlighting the critical roles of project selection, material compatibility, climate adaptation, and construction quality. While chip seals offer a cost-effective solution for pavement preservation, their success is highly dependent on context-specific factors such as traffic volume, environmental conditions, and existing pavement distress levels. The evolution of design methodologies—from empirical approaches to advanced performance-based techniques—reflects a growing emphasis on precision and durability. Moreover, standardized testing and construction specifications are essential to ensure consistency and long-term effectiveness. These insights provide a strong foundation for developing tailored chip seal practices in New Mexico, guiding the subsequent phases of this research toward establishing formal design procedures, construction specifications, and project selection criteria that address the state's unique geographic and operational challenges.

CHAPTER 3. REVIEW OF CURRENT PRACTICES IN NEW MEXICO

Chip seal is a key pavement preservation strategy in New Mexico, particularly for rural and low-volume roads. NMDOT) has developed a robust chip seal program that combines in-house operations with contractual services, supported by statewide planning and performance monitoring. Five of the six districts routinely utilize this treatment, while District 3 (Albuquerque metropolitan area) does not perform chip seal treatments due to its urban environment. This chapter summarizes the current chip seal practices within five districts (D1, D2, D4, D5, and D6) throughout New Mexico.

3.1. Program Structure and Planning

NMDOT manages approximately 31,000 lane miles, including interstates, U.S. routes, and state highways. Pavement preservation is primarily funded through state resources, and route selection is guided by the Pavement Management System (PMS), which monitors pavement conditions statewide. While PMS identifies candidate routes, districts independently determine the preservation method.

All districts follow a similar procedure for identifying pavements suitable for chip seal treatment. Each districts is subdivided into several contiguous sectors, and maintenance patrols annually assess these sectors to identify pavements exhibiting conditions appropriate for chip sealing. While the overall approach is consistent, each district independently determine which types of pavement distress warrant treatment. In general, all districts prioritize chip seal for pavement sections with cracking and moisture infiltration. Most districts also consider oxidation, reduced skid resistance, and raveling as additional indicators. Selection is largely based on experience instead of using specific severity or extend criteria. Districts generally target placing chip seals on a seven-year cycle.

Chip seal operations follow a seasonal cycle from March to October, with planning beginning in October of the prior year. Preparatory activities include route selection, chip stockpiling, equipment calibration, and crew training. During the off-season, crews perform other maintenance tasks and attend the annual Chip Seal Conference, which emphasizes safety, material handling, and application techniques while fostering inter-district collaboration and quality improvement (Romero, 2022).

3.2 Materials

NMDOT utilizes emulsion-based chip seals, which are classified as minor preservation treatments. The binder used across all districts is High Float Emulsion (HFE-100P), with application rates ranging from 0.32 to 0.58 gal/yd^2, adjusted based on pavement condition.

Aggregate sizes range from 3/8 in. to ½ in. Sources include virgin aggregates as well as RAP. RAP utilization lowers material costs, and minimizes environmental impacts by diverting millings from stockpiles and landfills. Previous research by Tarefder & Ahmad (2017) demonstrates that chip seals constructed with RAP perform comparably to those using virgin chips in terms of shear strength, skid resistance, and texture depth, while offering up to 37% cost savings over the life cycle. Virgin aggregates are typically applied at 18–28 lbs/yd^2. When RAP millings are used, application rates increase to 28–33 lbs/yd² due to their irregular shape and residual binder.

Currently, no standardized chip seal design method has been adopted; material application rates are determined based on experience, involving several critical factors. Weather conditions, particularly temperature and humidity, directly affect emulsion curing and chip embedment, requiring adjustments to shot rates during cooler or wetter periods. Pavement surface characteristics, such as texture depth, oxidation level, and crack severity, influence binder demand—rougher or more porous surfaces typically require higher emulsion rates to achieve adequate coverage. Traffic volume and loading also play a role; high-volume routes may need increased binder and chip quantities to ensure durability under wheel loads. Aggregate properties, including size, shape, and cleanliness, further impact application rates, as irregular or dusty chips can reduce adhesion and require higher binder application. When RAP millings are used, additional considerations include their residual binder content and gradation variability, which often lead to higher aggregate spread rates compared to virgin chips (Romero, 2022; Tarefder & Ahmad, 2017).

3.3. Operational Practices

NMDOT is one of the few states with dedicated in-house chip seal crews, averaging 18 members per district, and supported by patrol units for preparatory work such as crack sealing and patching. These crews operate a full complement of equipment—including asphalt distributors, chip spreaders, pneumatic-tire and steel wheel rollers, brooms, and loaders—allowing NMDOT to perform chip seals without complete dependence on external contractors. This approach provides flexibility in scheduling, ensures rapid mobilization during the chip seal season, and promotes consistency in application practices.

The chip seal season typically runs from March through October, although the timeframe may vary by district due to differences in climate, elevation, and resource availability. Districts in southern New Mexico (D1 and D2), where temperatures warm earlier and remain higher for longer periods, often begin chip seal operations as early as April and extend into September. In contrast, northern districts with cooler climates (D4, D5, and D6) typically restrict chip seal work to May through August to ensure adequate curing of emulsions and proper chip embedment. These variations are critical because low temperatures or unexpected precipitation can compromise binder performance and lead to premature failures. District-specific adjustments to scheduling allow crews to optimize weather conditions, minimize risks, and maintain quality standards across diverse geographic regions.

Before construction, districts inspect pavement conditions and perform the necessary work to prepare the roadways. Districts coordinate with patrols at least six months in advance to perform a series of tasks to ensure the pavement is clean, stable, and ready for sealing. These tasks typically include brooming the surface to remove dust and debris, cleaning shoulders, and addressing vegetation encroachment. Cracks wider than ¼ inch are sealed well in advance to allow adequate curing and prevent binder loss. Potholes and localized failures are repaired through patching or blade patching, and ruts leveling. Districts also calibrate equipment and may use test strips to verify application rates prior to full-scale operations. These preparatory steps are critical to achieving uniform binder coverage, proper chip embedment, and long-term performance of the chip seal

Chip seal construction follows a structured sequence beginning with the implementation of a traffic control plan in accordance with the Manual on Uniform Traffic Control Devices (MUTCD), including signage, flaggers, and pilot vehicles to maintain safety. Minor adjustments are made based on traffic conditions, lane configurations, and site characteristics. Once the work zone is secured, the pavement surface is broomed to remove dust and debris. The asphalt binder is then applied at the specified rate using a distributor truck, ensuring uniform coverage across the lane. Immediately after binder application, aggregate chips are spread using a chip spreader, followed by rolling with pneumatic-tire rollers and steel wheel rollers to embed the chips into the binder. While pneumatic rollers provide uniform seating without damaging aggregate, static rollers can cause aggregate breakdown if not carefully managed. Multiple roller passes are performed to achieve proper embedment, typically between 50% and 70%. After compaction, excess loose aggregate is swept from the surface to reduce windshield damage and improve ride quality. In some cases, a fog seal may be applied as a finishing step to lock in chips and provide additional waterproofing.

3.4 Program Scale and Costs

In Fiscal Year (FY) 2025, NMDOT completed chip seal treatments on 39 routes, including 35 state (NM) routes, 2 US routes, and 2 frontage roads. These projects covered approximately 1,000 lane miles at an average cost of $13,040 per lane mile, resulting in a total program cost of about $13 million. This amount includes labor, equipment, and material costs. Table 2 shows a detailed cost breakdown.

Table 2. Breakdown of Costs for NMDOT's Chip Seal Program in FY 2025 (Gallegos, 2025)

Labor	$1,341,844
Equipment	$2,214,312
Materials	$9,504,736
Total	$13,060,891
Cost per lane mile	$13,040

Figure 2 illustrates the total program costs and lane miles chip sealed from 2021 to 2025. The data show that the program's budget has increased over the past two years, enabling NMDOT to achieve its target of treating approximately 1,000 lane miles annually.

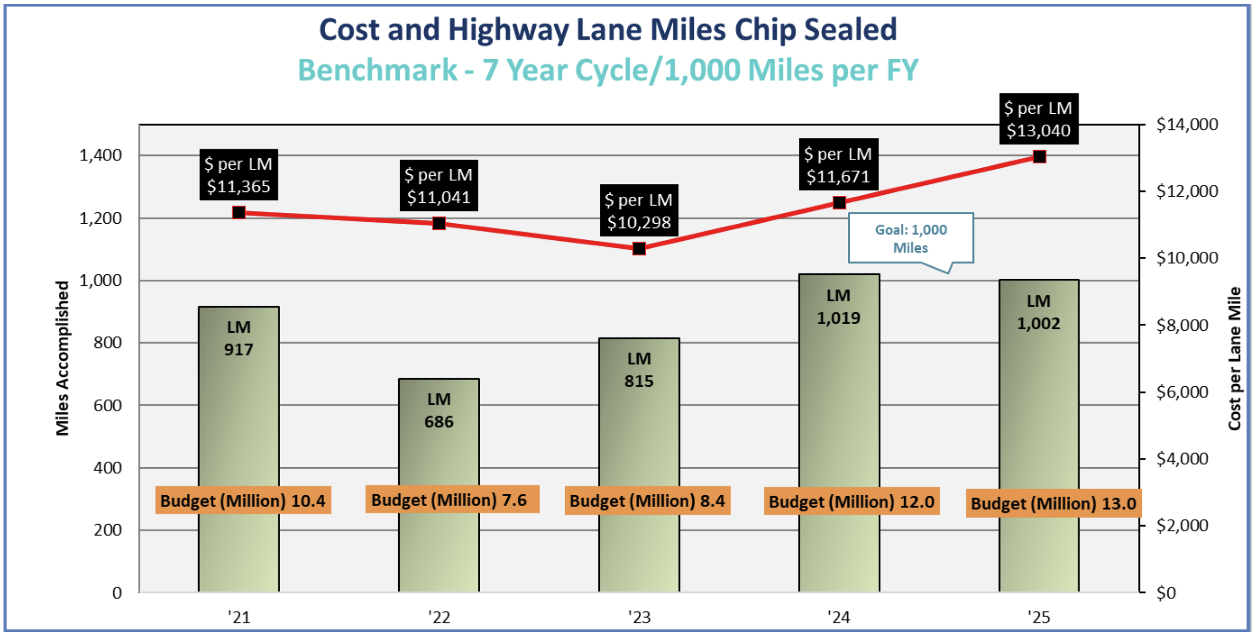

Figure 2. Total costs and miles treated under NMDOT's chip seal program during 2021-2025 (Gallegos, 2025).

3.5 Challenges

Despite the success of NMDOT's chip seal program, several challenges impact efficiency, quality, and long-term sustainability. Funding remains the most significant constraint, as preservation needs consistently exceed available resources, and inflation has further reduced purchasing power. Staffing shortages compound these issues, with critical vacancies in pavement design engineering and maintenance crews limiting the ability to plan and execute projects effectively. Inspection staff are also stretched thin, as construction activities consume resources needed for maintenance oversight. Equipment limitations present another obstacle; aging chip seal machinery frequently breaks down and lacks modern technology, reducing productivity and quality control. Additionally, lack of construction specifications or guidance documents, presents a difficulty for standardization across the state (Gallegos, 2025).

This project focuses on reviewing and enhancing chip seal practices across New Mexico by establishing guidance that promotes a standardized approach to design and construction. To support this effort, Appendix B includes a proposed draft construction specification intended to help implement uniform processes statewide. Additionally, Chapter 5 outlines the development of a chip seal design methodology tailored for NMDOT.

CHAPTER 4. REVIEW OF PAVEMENT MANAGEMENT SYSTEM DATA

Pavement condition data from NMDOT's Pavement Management System (PMS) were analyzed to assess the performance of chip seal treatments and identify potential issues associated with current practices. This analysis provided insight into the suitability of the material application rates currently determined by experience and supported the integration of these findings into a more systematic and data-driven design process.

4.1 Common Durability Issues

Chip seals, while effective as a pavement preservation treatment, are susceptible to two primary performance issues: aggregate loss and bleeding/flushing. Both problems can occur early in the life of the treatment, sometimes immediately after construction, and significantly impact skid resistance and overall functionality.

4.1.1 Aggregate Loss

Aggregate loss refers to the dislodgement of chips from the binder, leaving exposed asphalt and reducing surface texture. Initial chip loss often occurs soon after construction and is typically linked to factors such as low residual binder application rates, excessive aggregate application, premature breaking of the emulsion before chips are embedded, dusty or wet aggregates, improper binder distribution, and allowing traffic on the roadway too soon (Transit New Zealand, 2005; VDOT, 2012). Progressive aggregate loss can also develop over time due to binder aging and oxidation, particularly in high-stress areas such as intersections, curves, and steep grades where turning, braking, and acceleration are frequent. Once aggregate loss begins, it tends to accelerate rapidly because surrounding chips lose support, creating slick surfaces with poor skid resistance (Transit New Zealand, 2005).

4.1.2 Bleeding and Flushing

Bleeding and flushing are related but distinct issues involving excess binder rising to the pavement surface. Bleeding typically occurs during or shortly after construction when the binder is still in liquid form. It manifests as asphalt sticking to tires and aggregate, causing tracking and chip pick-up. Common causes include excessive binder application, inappropriate binder type, high temperatures, heavy traffic, and construction deficiencies such as uneven binder distribution (Senadheera et al., 2007). Bleeding is a cumulative process where excess asphalt fills aggregate voids and migrates upward under traffic and heat, creating a slick surface prone to safety hazards.

Flushing, on the other hand, occurs after the binder has cured and the pavement has been in service for some time. It is often associated with gradual aggregate wear and mat densification, which reduce surface voids and allow binder to dominate the surface texture. While a flushed pavement may still provide some sealing function, it compromises skid resistance and can soften and bleed under hot weather conditions (Transit New Zealand, 2005). Both bleeding and flushing are exacerbated by high temperatures, heavy traffic, and inadequate design or construction practices.

Preventing these failures requires careful material selection, accurate determination of binder and aggregate application rates through proper design methods, and adherence to best construction practices. These measures help maintain the balance between aggregate embedment and binder coverage, reducing the likelihood of early distress and extending the service life of chip seals.

4.2 NMDOT's PMS Database

NMDOT employs a comprehensive PMS to monitor and evaluate pavement condition across its network. Condition data are collected through automated distress surveys and processed into indices that support decision-making for maintenance and preservation treatments. These indices quantify both overall pavement health and individual distress types, including raveling and bleeding, which are critical indicators for chip seal performance.

4.2.1 Overall Condition Measurement

The PMS calculates an Overall Condition Index (OCI) to represent the general health of each pavement section. The OCI is derived by combining structural and environmental distress indices, which aggregate related distress types. The Structural Index captures load-related distresses such as fatigue cracking, rutting, and patch deterioration, which affect the pavement's ability to carry traffic loads. The Environmental Index reflects surface-related distresses caused by aging and weathering, including raveling, oxidation, and bleeding.

Both indices are calculated by converting distress severity and extent into Individual Distress Indices (IDIs), which are then aggregated into composite scores. The OCI is derived by combining these two indices, providing a single measure of overall pavement condition on a scale from 0 to 100, where 100 indicates excellent condition and 0 represents severe deterioration.

In addition to OCI, NMDOT computes a Pavement Condition Rating (PCR) for reporting purposes. PCR integrates the OCI with the Roughness Index (RI), which is based on International Roughness Index (IRI) measurements collected by profilometer-equipped survey vehicles. The PCR uses a weighted formula (80% OCI and 20% RI) to provide a balanced measure of structural integrity and ride quality. Table 3 shows NMDOT's pavement condition categories based on PCR and suggested treatment options.

Table 3. NMDOT's Pavement Condition Categories

PCR Range	Condition	Suggested Treatment
86-100	Very Good	Monitor – none to minor preservation, fog seals or other surface coats
66-85	Good	Major preservation, overlays – to minor rehabilitation, thin mill and inlay
51-65	Fair	Minor to major rehabilitation – mill and inlay between 2.5 and 5 inches
46-50	At Risk	Minor to major rehabilitation
26-45	Poor	Major rehabilitation 5 inches deep to PPC, FDR
0-25	Very Poor	Reconstruction

4.2.2 Measurement of Raveling and Bleeding

Raveling and bleeding are monitored as individual distress types due to their significant influence on surface texture, skid resistance, and overall safety.

Raveling, often associated with aggregate loss and surface weathering, is recorded by extent and severity (low, medium, high) during distress surveys. The PMS converts these observations into an Individual Distress Index using severity coefficients and extent percentages. This index quantifies the degree of surface degradation and feeds into the Environmental Index, which influences OCI calculations and treatment recommendations.

Bleeding, characterized by excess asphalt binder rising to the surface, is similarly assessed by severity and extent. The PMS applies the same IDI methodology to bleeding data, ensuring consistent evaluation across all distress types. Bleeding indices are critical for identifying sections where chip seals may have failed due to over-application of binder or inadequate aggregate embedment.

Both raveling and bleeding indices are quantified on a scale from 0 to 100, where 100 represents no distress and 0 indicates severe deterioration.

4.2.3 HMPS Condition Data

In addition to its own performance metrics, NMDOT collects pavement condition data for the Highway Performance Monitoring System (HMPS), a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the Nation's highways. The HMPS supports a data driven decision process within FHWA, the DOT, and the Congress. The collected data supports federal reporting, funding allocation, and performance monitoring for the entire U.S. highway system.

The HPMS performance measures for flexible pavement are cracking (percent), rutting depth (inches), and IRI (in/mi). Table 4 shows the condition categories established for each measure.

Table 4. HPMS Performance Measures and Condition Categories

Pavement Condition	IRI (in/mi)	Rutting (in)	Cracking (%)
Good	<95	<0.20	<5
Fair	95 – 170	0.20 – 0.40	5 – 20
Poor	>170	>0.40	>20

4.3 NMDOT's Trends

To better evaluate the effectiveness of chip seal practices across New Mexico, a comprehensive list of projects completed between 2016 and 2025 was compiled. Condition data for 2-mile pavement segments collected between 2018 and 2024 were extracted from NMDOT's Pavement Management System (PMS) to support detailed performance analysis.

4.3.1 Pretreatment Condition

Figure 3 shows the distribution of the PCR values for the year before chip seal application across districts. District 6 stands out with the highest median PCR (around 75), indicating generally good pavement conditions, while District 5 has the lowest median (around 40), suggesting poorer conditions overall. District 2 exhibits relatively high and consistent ratings, with a narrow interquartile range, whereas Districts 1 and 4 have moderate medians (around 50) and wider spreads, reflecting more variability in pavement quality. Both District 1 and District 5 have several high outliers, meaning some roads were in good to very good condition despite lower overall medians. District 6 also shows the widest range, including some very high ratings, reinforcing its strong pavement performance compared to other districts. Overall, almost all pavements were treated well past the recommended threshold for minor preservation (PCR range 86-100).

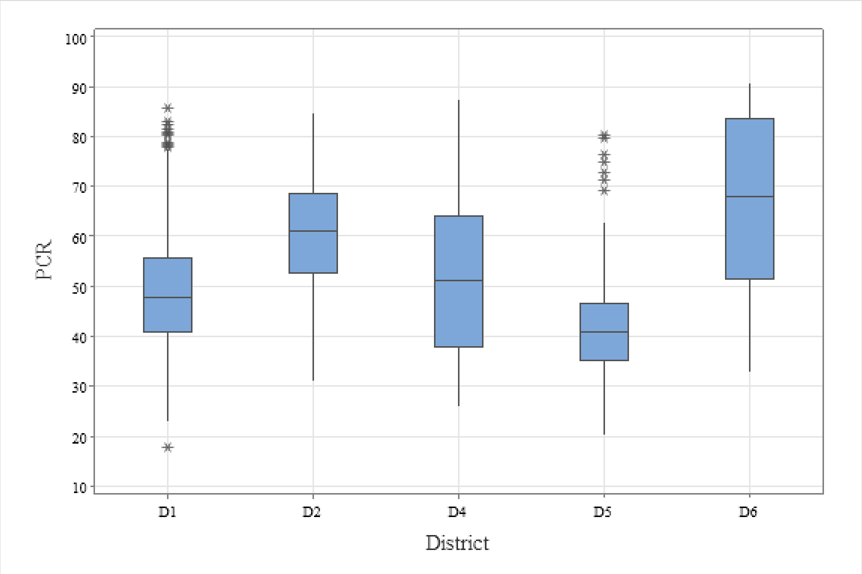

Figure 3. Pavement Condition Rating (PCR) before chip seal application.

Despite the PCR values before treatment being generally lower than the recommended range, the deterioration is primarily driven by environmental factors, while the pavements remain structurally sound. Figure 4 compares the Structural Index and the Environmental Index prior to chip seal application across all districts. Overall, Structural Index values are consistently higher than the Environmental Index values in every district. Structural Index medians range roughly from the mid-80s to near 100, indicating strong structural integrity, while Environmental Index medians fall between about 45 and 65. This reflects damage caused by aging and environmental exposure, conditions that chip seals are specifically designed to address.

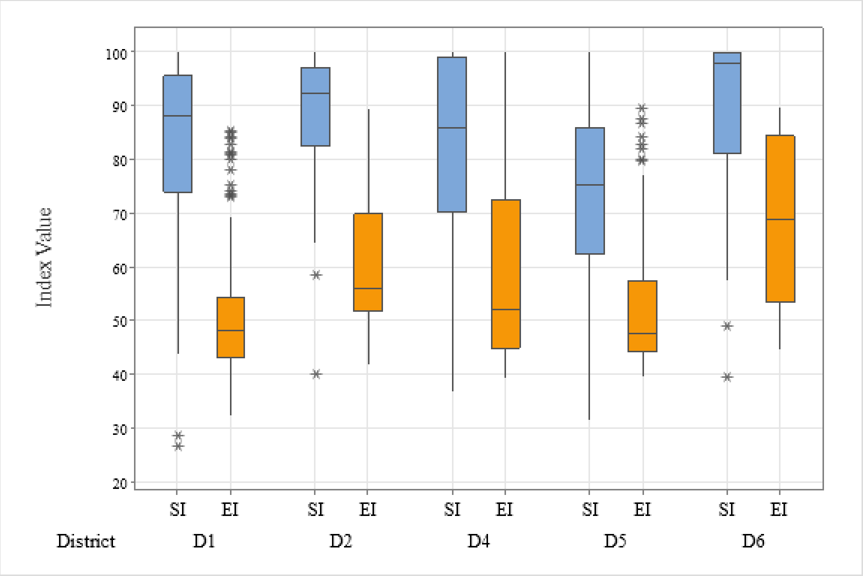

Figure 4. Structural Index (SI) and Environmental Index (EI) before chip seal application.

Although HPMS data is primarily used for federal reporting rather than integrated into NMDOT's decision-making process, the performance metrics prior to treatment (Figures 5–7) provide useful insights. For cracking, most pavement sections were treated while in the "Good" to "Fair" category, with median values below 10%. However, multiple outliers indicate that some sections were in "Poor" condition at the time of treatment, suggesting localized deterioration. In general, chip seals are most effective when applied to pavements with "Good" to "Fair" cracking conditions. It is important to note that HPMS cracking data represents the percentage of fatigue-type cracking of all severity levels within wheel paths relative to the total section area; additional cracking outside wheel paths may have been present.

For rutting and roughness, the results show that most pavements were in Fair condition or worse when treated. Rutting depth medians ranged from 0.22 to 0.25 inches, except for District 6, which had a median of 0.14 inches. IRI medians exhibited greater variability across districts, ranging from 143 to 243 in/mi. These findings indicate that pavements selected for chip seal treatments often had significant rutting and roughness issues, which cannot be addressed with chip seals.

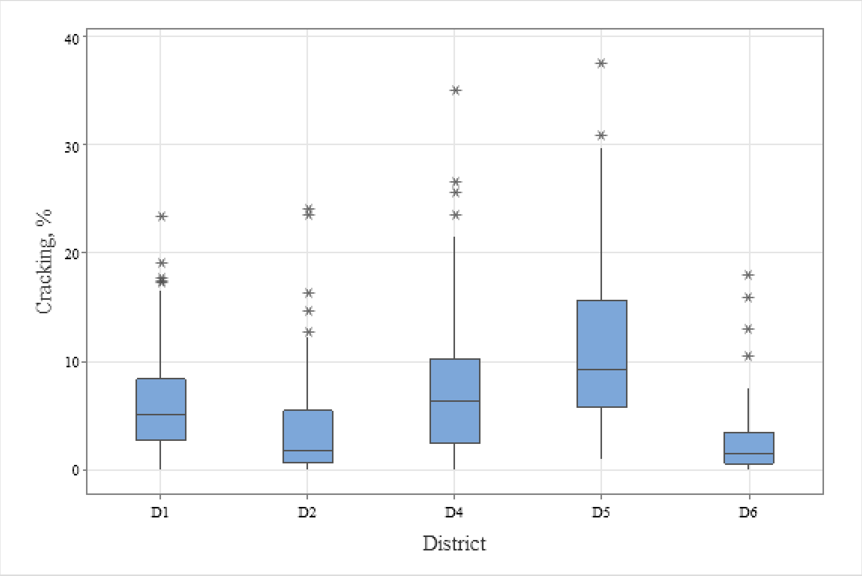

Figure 5. Cracking percentage before treatment.

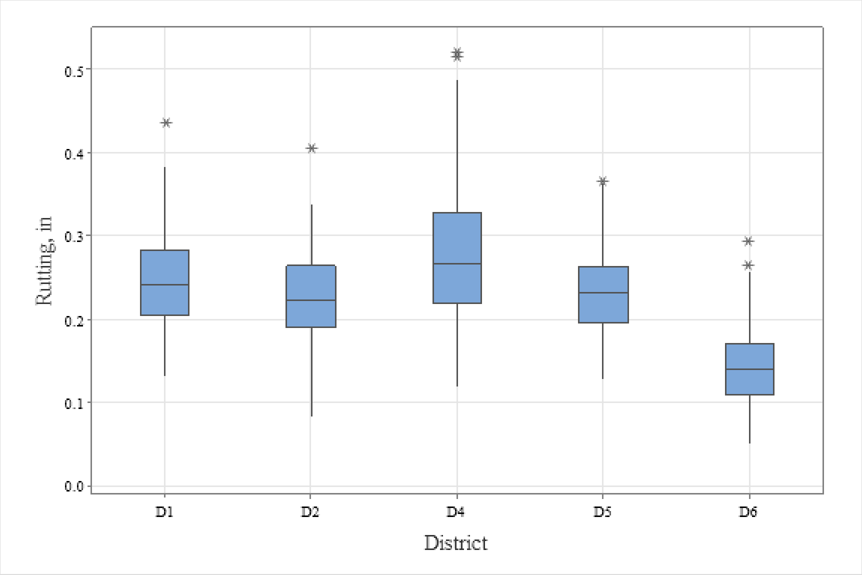

Figure 6. Average rut depth before treatment.

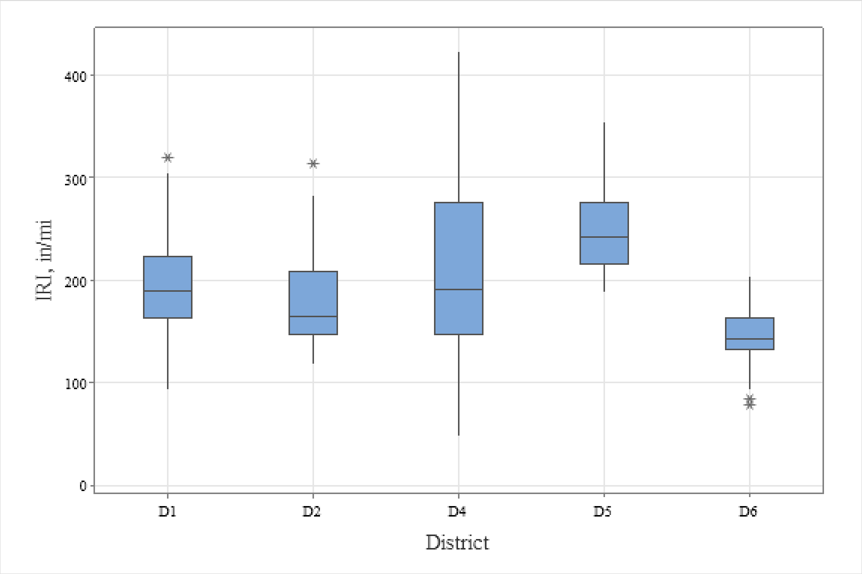

Figure 7. Average roughness (IRI) before treatment.

4.3.2 Early Performance

The early performance of chip seals (within the first year) is primarily evaluated by the occurrence of aggregate loss and bleeding. Aggregate loss can begin just hours after traffic control is removed, and if more than 10% of the applied aggregate is lost, the treatment is considered unacceptable. Common causes include incorrect application rates—either too much aggregate or too little binder—as well as excess dust, changes in aggregate gradation, or adverse weather conditions such as unexpected cold or rain. Premature removal of traffic control before the binder has adequately set can also lead to early failures. Bleeding typically results from excessive asphalt application or aggregate embedment into the substrate. These issues cannot be corrected without applying an additional seal, underscoring the importance of proper design, calibration, and construction practices during initial application (Shuler et al., 2011).

Figure 8 illustrates the Bleeding Index and Raveling Index for chip seals after one year of service. Bleeding performance is excellent in all districts, with medians near 100 and very narrow interquartile ranges, suggesting minimal migration of binder to the surface. In contrast, raveling indices show more variability and medians in the mid to upper 80s. While these results suggest aggregate loss is more frequent than bleeding or flushing, the high values for both indices are not indicative of early failures related to design or construction.

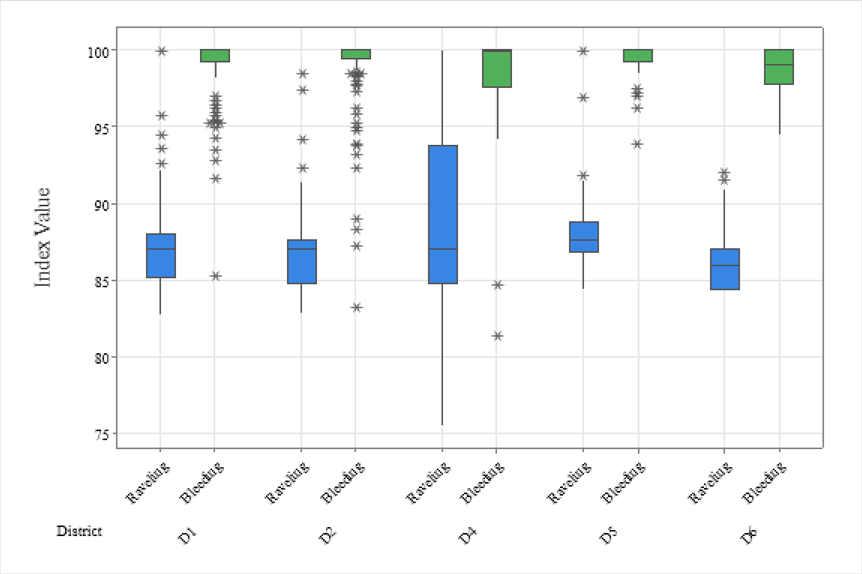

Figure 8. Raveling Index and Bleeding Index after the first year of service.

The PCR values after the first year of service are shown in Figure 9. Performance varies significantly among districts. District 6 stands out with the highest median PCR (around 82), placing most pavements in the “Good” category (66–85) and close to “Very Good” (86–100), indicating strong preservation results. District 4 also shows relatively high performance, with a median near 70 and a wide interquartile range extending into the “Very Good” category, though variability suggests inconsistent outcomes. Districts 1, 2, and 5 have lower medians (roughly 58–65), falling in the “Fair” range, which typically requires minor to major rehabilitation. Outliers in D2 and D5 indicate some pavements performing better than the median, but overall these districts show weaker results compared to D4 and D6. These findings suggest that while chip seals improved conditions, most districts remain below the “Very Good” threshold, and additional preservation or rehabilitation may be needed in lower-performing areas.

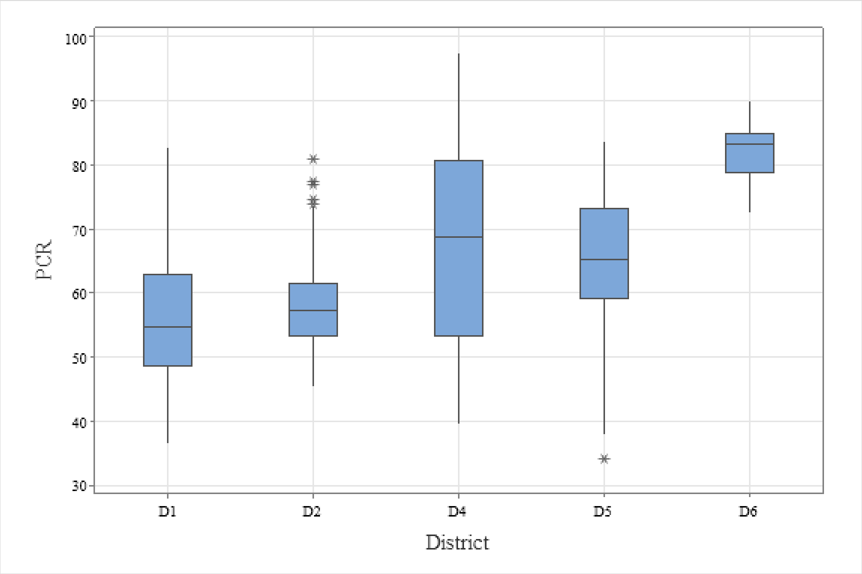

Figure 9. PCR values after the first year of service.

4.3.3 Long-Term Performance

The long-term performance trends reveal similar behavior among the districts. After treatment application, PCR values decline steadily over time, as shown in **Error! Reference source not found.**, eventually reaching levels comparable to the pretreatment condition within six to eight years. A notable observation is the apparent improvement in condition during the first year compared to year zero, which occurs in nearly every district. This increase may be attributed to additional preservation activities, such as fog seals, that were not recorded during the initial condition survey. Additionally, sudden increases in PCR later in the chip seal life cycle may reflect other maintenance or rehabilitation activities that were not documented in the PMS database.

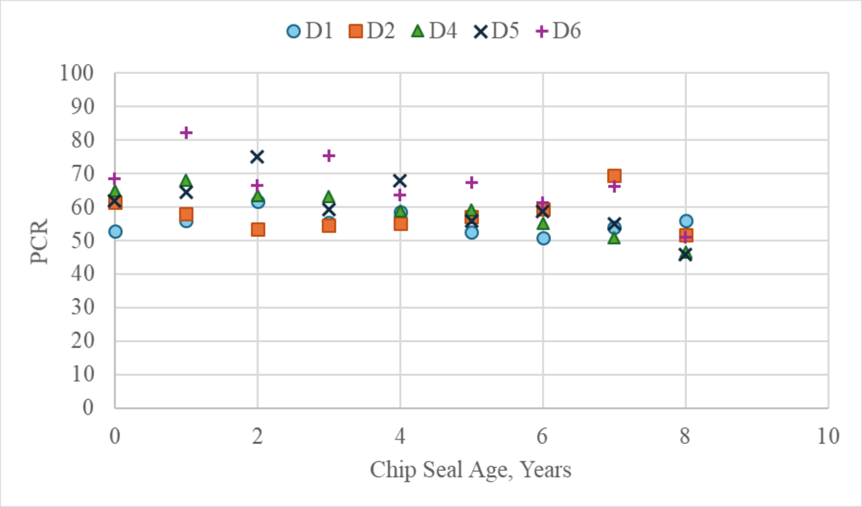

Figure 10. Average PCR by district.

Similar trends were observed when data was grouped by functional classification, as shown in Figure 11. PCR values remain relatively stable during the early years following chip seal application, then decline more rapidly, reaching levels comparable to pretreatment conditions within six to eight years. No significant differences in performance were identified based on functional classification.

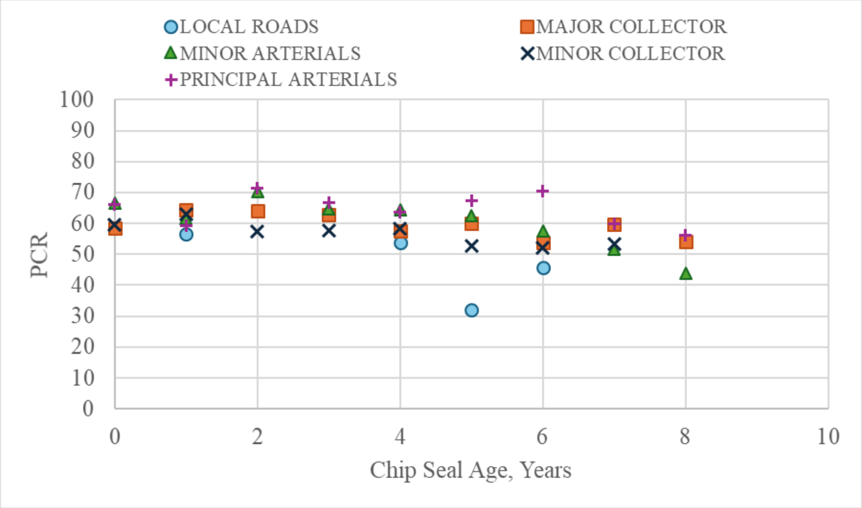

Figure 11. Average PCR by functional classification.

The observed chip seal service lives of six to eight years align with current NMDOT practices, which target reapplication of chip seal treatments approximately every seven years. However, improving treatment timing by selecting pavements in better initial condition could help maintain a higher level of service throughout the entire cycle. This concept is illustrated in Figure 12, which shows the relationship between the PCR from the previous survey year and change in PCR compared to the current year (ΔPCR). In general, pavement sections that had a high PCR value (>80) showed a moderate decrease by the next survey year (typically a two-year period). As condition worsens, deterioration accelerates and becomes more variable, affecting treatment durability.

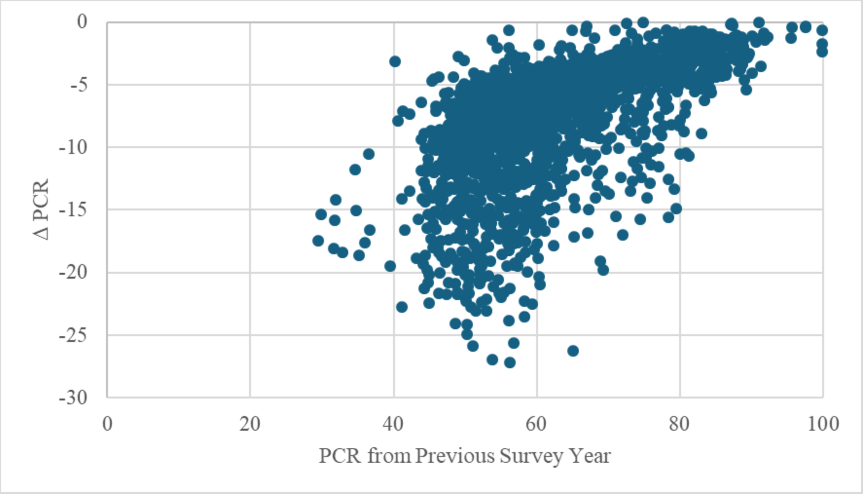

Figure 12. Change in PCR as a function of previous condition.

4.4 Summary

Analysis of NMDOT’s PMS data revealed that most pavements were treated well below the recommended threshold for minor preservation, with deterioration primarily driven by environmental factors rather than structural deficiencies. Early performance results indicate that bleeding is rarely an issue, while raveling shows slightly more variability, though overall distress levels remain low with no major issues resulting from current design or construction practices. After one year of service, PCR values improved across all districts, with Districts 4 and 6 showing the strongest results, while others remained in the “Fair” to “Good” range. Long-term trends demonstrate a steady decline in PCR, returning to pretreatment levels within six to eight years, consistent with NMDOT’s current practice of reapplying chip seals approximately every seven years. These findings suggest that optimizing treatment timing and targeting pavements in better initial condition could extend service life and maintain higher performance throughout the treatment cycle.

CHAPTER 5. DEVELOPMENT OF CHIP SEAL DESIGN METHOD

As stated in Chapter 2, there are presently 14 chip seal design methodologies utilized globally. The research team conducted a comprehensive review and comparison of these approaches, evaluating them on criteria such as simplicity, practicality, efficiency, accessibility of testing equipment, test repeatability, and specification availability. After this evaluation, the modified Kearby method, documented in AASHTO R 102-22, was selected as the most suitable approach for NMDOT.

The method was validated using local materials from all five districts that have implemented chip seals as minor preservation treatments. The research team obtained representative emulsified asphalt and aggregate samples from each district to perform chip seal designs using the modified Kearby method. The calculated material application rates were compared to the actual application rates currently used in New Mexico, discussed in Chapter 3. From this comparison, the research team was able to determine that the application rates being currently used based on experience are considered adequate according to a formal design procedure. However, to account for specific local conditions, the team also examined the PMS information obtained to evaluate possible correlations between application rates and chip seal performance. As discussed in Chapter 4, common modes of failure, such as aggregate loss or bleeding, were not identified in the data, indicating that the proposed design procedure could be adopted without the need for additional modification.

5.1. Introduction to the Modified Kearby Method

The modified Kearby method determines material application rates through three main steps, as outlined below.

5.1.1 Characterization of Raw Materials

According to AASHTO M 340-22, aggregates and emulsified binders used in chip seal treatments must meet specific requirements. Thus, it is important to characterize these materials before determining their application rates. Table 5 summarizes the required tests, parameters, and standards. As shown, the emulsified asphalt residue (R), loose unite weight (W), and bulk specific gravity (G) are required for the further calculation of material application rates. The remaining aggregate tests are performed to ensure aggregate quality, and include sieve analysis, flakiness index, fractured faces, and Los Angeles (LA) abrasion. The specific chip seal aggregate requirements in accordance with AASHTO M 340-22 are summarized in Table 6 and Table 7.

Table 5. Summary of Raw Material Tests

Material Type	Test Name	Test Parameters	Test Standard
Emulsion Binder	Emulsion residue test	Emulsified asphalt residue (*R*)	AASHTO T59
Aggregate	Specific gravity test	Bulk specific gravity (*G*)	AASHTO T84/T85
	Loose unit weight test	Loose unit weight (*W*)	AASHTO T19M/T19
	Sieve analysis test	Passing percentage	AASHTO T 27
	Flakiness test	Flakiness index	FLH T508
	Fracture faces test	Fracture face percentage %	AASHTO T 335
	Los Angeles (LA) abrasion test	LA abrasion loss %	AASHTO T 96

Table 6. Gradation Requirements for Chip Seal Aggregate

Sieve Size (mm)	A	B	C	D *Class I Only
19.00	100%	-	-	-
12.50	90-100%	100%	-	-
9.50	5-30%	90-100%	100%	100%
4.75	0-10%	5-30%	90-100%	0-65%
2.36	-	0-10%	5-30%	0-15%
1.18	0-2%	-	0-10%	0-10%
0.600	-	0-2%	-	-
0.300	-	-	0-2%	0-6%
0.075	0-1%	0-1%	0-1%	0-3%

Table 7. Fracture and Abrasion Requirements for Chip Seal Aggregate

Property	Class I	Class II	Class III
Fractured Faces (1+), min	70%	85%	95%
Fractured Faces (2+), min	60%	80%	90%
Flakiness Index Value, max	35%	30%	25%
LA Abrasion, max	40%	35%	30%

Note: Class I is less than 500 annual average daily traffic (AADT); Class II is 501-5000 AADT; and Class III is greater than 5000 AADT.

5.1.2 Determining Aggregate Application Rate using the Board Test

The board test is used to determine the aggregate application rate in four steps:

- Step 1: Weight the empty board of known dimensions.
- Step 2: Spread aggregate evenly in a single stone-thick layer.
- Step 3: Weight the board and aggregate and calculate the aggregate weight by subtracting the empty board weight.
- Step 4: Calculate the quantity of chips (*Q*), also known as the aggregate application rate, by dividing the aggregate weight by the board area.

Figure 13 illustrates the board test setup.

(a) **(b)**

Figure 13. Illustration of Board Test: (a) Empty Board; (b) Board Filled with Aggregate.

5.1.3 Determining Emulsified Binder Application Rate

The emulsified binder application rate, or emulsified asphalt quantity (*A*), is calculated using Equation 1, which incorporates material test results, board test data, and correction factors for traffic (*T*), and pavement surface condition (*V*) . Additionally, the percent embedment (*e*) is a function of average mat depth (*d*), and can be obtained from the figure in AASHTO R 102-22.

$$A = \frac{\left\{5.61e \times d \times \left[1 - \frac{W}{62.4G}\right] T\right\} + V}{R} \tag{1}$$

Where:

A = emulsified asphalt quantity, gal/sq yd
5.61 = constant for converting the units to gal/sq yd
e = percent embedment from Figure 1 in AASHTO R 102-22
d = average mass depth, 1.33Q/W
Q = quantity of chips from the board test, lb/sq yd
W = dry loose unit weight of chips, pcf
62.4 = unit weight of water, pcf
G = dry bulk specific gravity of chips
T = traffic correction factor from Table 1 in AASHTO R 102-22
V = pavement surface correction factor from Table 2 AASHTO R 102-22
R = emulsified asphalt residue expressed as a decimal

5.2. Characterization of Chip Seal Materials

In this project, the research team collected 13 aggregate sources used for chip seal treatment across New Mexico, including two RAP sources and 11 virgin aggregates. The results of all 13 aggregate sources, assessed through the tests mentioned above, are presented in the tables below.

Table 8 presents the specific gravity and loose unit weight results. Note that the theoretical maximum specific gravity (G_{mm}) and bulk specific gravity (G_{sb}) were measured for RAP and virgin aggregate sources, respectively. As illustrated, the majority of specific gravity measurements ranged from 2.414 to 2.665. However, two virgin aggregate sources from District 4 had values of 1.825 and 2.825. Meanwhile, most aggregates had unit weights between 79 and 90 pcf. The Mount Dora source is lighter, with a unit weight of 51.6 pcf .

Table 8. Specific Gravity and Loose Unit Weight Results

Aggregate Source	Material Type	G_{sb}/G_{mm}	Unit Weight (pcf)	District #
I-10 Exit 55	RAP	2.414	79.33	District 1
JCT US 380/US 70	Virgin Aggregate	2.615	82.51	District 2
D2-5B	Virgin Aggregate	2.589	85.95	
Mount Dora	Virgin Aggregate	1.825	51.60	District 4
Capulin Pit (Field)	Virgin Aggregate	2.825	89.41	
Four Corners Aztec	Virgin Aggregate	2.629	83.51	District 5
Chavez Farms	Virgin Aggregate	2.665	85.82	
Taos Gravel	Virgin Aggregate	2.572	84.57	
Black Rock Belen	Virgin Aggregate	2.657	85.62	
Russell Sand and Gravel (Field)	Virgin Aggregate	2.617	84.11	
Vernon Hamilton	Virgin Aggregate	2.574	86.87	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	2.586	82.90	
Mesita Millings	RAP	2.614	82.38	

Table 9 presents the gradation results. The majority of aggregate sources were classified as either "A" or "B," with the exception of Mount Dora, which was classified as "D." Additionally, most aggregate sources had a nominal maximum aggregate size (NMAS) of 1/2 inch or 3/8 inch except for Chavez Farms, which was 3/4 inch. Note that the sieve analysis of two RAP sources was conducted on dry RAP particles, which is also known as black rock gradation analysis.

Table 9. Gradation Results

Aggregate Source	Material Type	NMAS	Category	District #
I-10 Exit 55	RAP	1/2"	B	District 1
JCT US 380/US 70	Virgin Aggregate	3/8"	B	District 2
D2-5B	Virgin Aggregate	3/8"	B	
Mount Dora	Virgin Aggregate	3/8"	D	District 4
Capulin Pit (Field)	Virgin Aggregate	1/2"	B	
Four Corners Aztec	Virgin Aggregate	1/2"	A	District 5
Chavez Farms	Virgin Aggregate	3/4"	A	
Taos Gravel	Virgin Aggregate	1/2"	A	
Black Rock Belen	Virgin Aggregate	3/8"	B	
Russell Sand and Gravel (Field)	Virgin Aggregate	1/2"	B	
Vernon Hamilton	Virgin Aggregate	1/2"	B	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	1/2"	B	
Mesita Millings	RAP	1/2"	A	

Table 10 presents the fractured face results. Most of the aggregate sources were categorized as Class III, while the Taos Gravel aggregate was classified as Class II.

Table 10. Fracture Face Results

Aggregate Source	Material Type	Fracture, 1 Face (%)	Fracture, 2 Faces (%)	Category	District #
I-10 Exit 55	RAP	99.03	97.00	III	District 1
JCT US 380/US 70	Virgin Aggregate	99.68	98.35	III	District 2
D2-5B	Virgin Aggregate	100.00	99.59	III	
Mount Dora	Virgin Aggregate	100.00	100.00	III	District 4
Capulin Pit (Field)	Virgin Aggregate	99.89	99.58	III	
Four Corners Aztec	Virgin Aggregate	99.88	99.44	III	District 5
Chavez Farms	Virgin Aggregate	99.83	99.64	III	
Taos Gravel	Virgin Aggregate	93.92	88.09	II	
Black Rock Belen	Virgin Aggregate	100.00	99.99	III	
Russell Sand and Gravel (Field)	Virgin Aggregate	98.63	97.33	III	
Vernon Hamilton	Virgin Aggregate	99.67	98.52	III	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	99.95	98.77	III	
Mesita Millings	RAP	99.94	99.58	III	

Table 11 presents the flakiness index results. Most aggregate sources had a value of less than 25%, which was classified as Class III. However, the Mount Dora and Black Rock Belen aggregates were classified as Class I and Class II, respectively. The results indicated that most aggregate sources had low proportion of thin flaky particles.

Table 11. Flakiness Index Results

Aggregate Source	Material Type	Test Results (%)	Category	District #
I-10 Exit 55	RAP	6.56	III	District 1
JCT US 380/US 70	Virgin Aggregate	12.32	III	District 2
D2-5B	Virgin Aggregate	13.42	III	
Mount Dora	Virgin Aggregate	35.20	I	District 4
Capulin Pit (Field)	Virgin Aggregate	21.11	III	
Four Corners Aztec	Virgin Aggregate	15.01	III	District 5
Chavez Farms	Virgin Aggregate	3.39	III	
Taos Gravel	Virgin Aggregate	10.85	III	
Black Rock Belen	Virgin Aggregate	27.12	II	
Russell Sand and Gravel (Field)	Virgin Aggregate	23.81	III	
Vernon Hamilton	Virgin Aggregate	2.44	III	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	16.24	III	
Mesita Millings	RAP	18.08	III	

Table 12 presents the LA abrasion loss results. Most aggregate sources had a loss of less than 30%, which was classified as Class III. However, the Vernon Hamilton aggregate was classified as Class II with an LA abrasion loss value of 34.36%.

Table 12. LA Abrasion Loss Results

Aggregate Source	Material Type	LA Abrasion Loss (%)	Category	District #
I-10 Exit 55	RAP	14.79	III	District 1
JCT US 380/US 70	Virgin Aggregate	25.26	III	District 2
D2-5B	Virgin Aggregate	25.47	III	
Mount Dora	Virgin Aggregate	30.01	III	District 4
Capulin Pit (Field)	Virgin Aggregate	12.89	III	
Four Corners Aztec	Virgin Aggregate	21.56	III	District 5
Chavez Farms	Virgin Aggregate	22.82	III	
Taos Gravel	Virgin Aggregate	20.40	III	
Black Rock Belen	Virgin Aggregate	22.00	III	
Russell Sand and Gravel (Field)	Virgin Aggregate	26.49	III	
Vernon Hamilton	Virgin Aggregate	34.36	II	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	22.98	III	
Mesita Millings	RAP	18.02	III	

5.3. Validation of Selected Chip Seal Design Method

The material application rates were determined for all 13 aggregate sources, as summarized in Table 13. Aggregate application rates ranged from 9.8 to 31.7 lbs/yd^2, while emulsion rates varied widely from 0.17 to 0.91 gal/yd^2, demonstrating significant variability depending on aggregate properties, traffic levels, and pavement conditions. These results confirm that it is not appropriate to rely on standard values to establish material application rates.

Table 13. Summary of Material Applicate Rates

Aggregate Source	Material Type	Aggregate Application Rate (lbs/sq yd)	Emulsion Application Rate (gal/sq yd)	District #
I-10 Exit 55	RAP	13.1	0.17 - 0.40	District 1
JCT US 380/US 70	Virgin Aggregate	22.9	0.40 - 0.67	District 2
D2-5B	Virgin Aggregate	19.0	0.27 - 0.52	
Mount Dora	Virgin Aggregate	9.8	0.26 - 0.51	District 4
Capulin Pit (Field)	Virgin Aggregate	19.0	0.27 - 0.52	
Four Corners Aztec	Virgin Aggregate	21.1	0.34 - 0.61	District 5
Chavez Farms	Virgin Aggregate	31.7	0.59 - 0.91	
Taos Gravel	Virgin Aggregate	21.2	0.32 - 0.58	
Black Rock Belen	Virgin Aggregate	21.3	0.33 - 0.59	
Russell Sand and Gravel (Field)	Virgin Aggregate	21.0	0.35 - 0.60	
Vernon Hamilton	Virgin Aggregate	23.8	0.42 - 0.70	District 6
C&E Concrete Tinaja Pit	Virgin Aggregate	18.0	0.24 - 0.48	
Mesita Millings	RAP	21.3	0.35 - 0.61	

To validate the method, two field projects, NM 325 (District 4) and NM 514 (District 5), were selected. Field application rates were measured during construction and compared with laboratory-designed rates. Table 14 provides details for each of the projects, and Figures 14 and 15 show an overview of the site conditions.

Table 14. Description of Field Projects

Project Details	NM 325	NM 514
Location	District 4	District 5
Aggregate source	Capulin Pit	Russell Sand & Gravel
Aggregate size, in	½”	½”
Emulsion type	HFE-100P	HFE-100P
AADT range, vpd	100 – 250	<100
Functional class	Major collector	Minor collector
Surface condition	Slightly pocked, porous, oxidized	Slightly pocked, porous, oxidized
Date visited	6/26/2025	9/11/2024

Figure 14. Existing conditions in NM 325 project.

Figure 15. Existing conditions in NM 514 project.

Application rates were checked in the field by placing tarps or roofing felt samples of know dimensions over the pavement and letting the equipment apply the materials, as shown in Figure 14. Rates were checked along the transverse profile of the pavement for emulsion, and on both wheel paths for aggregate. Material samples were also obtained and sent to the National Center for Asphalt Technology (NCAT) laboratory to determine the material application rates using the selected method.


(a) (b)

Figure 16. Field verification of application rates: a) Emulsion; b) Aggregate

Table 14 summarizes the field and laboratory application rates for the two selected projects. The aggregate application rates determined in the laboratory were marginally lower than those measured in the field, with a variance of less than 5%. In addition, the field emulsion application rates fell within the range calculated in the laboratory. Overall, the material rates determined using the selected method were consistent with those derived from practical experience. Furthermore, PMS data indicated that the previous chip seal projects designed based on experience performed well, showing no significant bleeding and raveling issues. Therefore, the chosen method is considered appropriate for implementation by NMDOT.

Table 15. Lab Design Rates Vs. Actual Field Rates

Field Project	Aggregate Application Rate (lbs/yd^2)		Emulsion Application Rate (gal/yd^2)	
	Field Rate	Lab Rate	Field Rate	Lab Rate
NM 514 (District 5)	22.0	21.0	0.60	0.33-0.60
NM 325 (District 4)	19.5	19.0	0.33	0.27-0.52

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This research evaluated current chip seal practices in New Mexico and developed a standardized design approach tailored to NMDOT's operational and environmental conditions. The study included a comprehensive review of national and international design methods, analysis of NMDOT's Pavement Management System (PMS) data, and laboratory validation using local materials.

Key findings are summarized below:

- PMS data indicate that chip seals generally perform well, with minimal bleeding and acceptable levels of aggregate loss. Early performance results show improved PCR after treatment, although most pavements were treated below the recommended threshold for minor preservation. Long-term trends reveal that PCR values decline steadily, returning to pretreatment levels within six to eight years, consistent with NMDOT's current seven-year reapplication cycle.

- Analysis of 13 aggregate sources, including RAP and virgin aggregates, demonstrated significant variability in material properties such as specific gravity, gradation, flakiness index, and abrasion resistance. Laboratory design results confirmed that aggregate application rates ranged from 9.8 to 31.7 lbs/yd^2, while emulsion rates varied from 0.17 to 0.91 gal/yd^2, depending on aggregate characteristics, traffic levels, and pavement conditions. These findings underscore the need for project-specific design rather than reliance on standard values.

- The Modified Kearby method, documented in AASHTO R 102-22, was selected as the most suitable design approach for NMDOT based on its practicality, repeatability, and compatibility with available resources. Validation through two field projects showed strong agreement between laboratory-designed and field-applied rates, with aggregate rate differences varying by less than 5% and emulsion rates within the calculated range. These results confirm that the method aligns with current practices and can be implemented without major adjustments.

Although NMDOT has developed a robust chip seal program, current practices are based on experience and empirical data. Implementing formal guidelines will improve consistency, optimize material usage, and enhance long-term performance.

Implementation of the proposed design method can be deployed through the construction of pilot test sections to further validate the research findings. By monitoring these sections for early performance indicators such as aggregate retention and bleeding/flushing, and documenting lessons learned, NMDOT can refine statewide guidelines and training programs. NMDOT currently participates in the pooled fund study *TPF-5(522) National Partnership to Improve the Quality of Pavement Preservation Treatment Construction & Data Collection Practices*, which was developed to assist state and local agencies in reviewing and developing treatments which can advance their pavement preservation programs. The scope of this study includes constructing pavement preservation test sections incorporating established AASHTO standards to validate and verify existing construction practices. This presents an ideal opportunity for NMDOT to construct test sections under the technical guidance of the TPF-5(522) research team, which includes the National Center for Asphalt Technology, the National Center for Pavement Preservation, the Federal Highway Administration, and industry members (FP^2). Monitoring and analysis of the test sections is also supported by the study, which can assist NMDOT in determining the expected life extension more accurately and refine pavement management practices. A full implementation plan is provided in Appendix C.

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APPENDIX A. LITERATURE REVIEW

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1. BACKGROUND

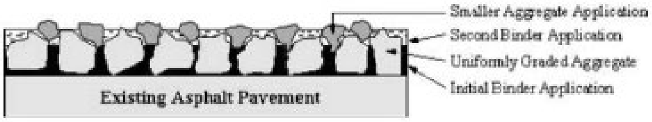
Chip seals are one of the most popular preservation treatments for asphalt pavements due to their ability to seal the existing road surface from moisture damage and oxidation, improve skid resistance, seal minor cracks, and delay deterioration. They consist of a uniform spray application of an asphalt binder followed by a uniform application of aggregate coat cover which is then rolled with pneumatic tire rollers to achieve the desired embedment. This simple process can be conducted using local maintenance personnel with minimal equipment requirements, making it a cost-effective option *(1)*.

There are several types of chip seals that may be used depending on the existing conditions *(2-5)*:

- **Single chip seal:** A spray application of asphalt binder (emulsified or hot-applied) followed by an application of aggregate chips, preferably one stone layer thick. It is the most common type of chip seal and is used for normal situations where no special considerations would indicate that a special type of chip seal is warranted.
- **Multiple chip seal:** Two or more consecutive applications of a single chip seal with decreasing aggregate size for each layer. For example, in a double chip seal the first chip seal is constructed with aggregate one sieve size larger than the second chip seal. Multiple chip seals are used in high-stress situations where a harder wearing and longer lasting surface treatment is needed, such as areas with a high percentage of truck traffic or on steep grades.
- **Single chip seal with choke stone (racked-in seal):** A single chip seal with crushed fine aggregate applied to the surface of the chip seal prior to rolling. The choke stone provides an interlock between the aggregate particles of the chip seal and prevents them from dislodging before the binder is fully cured. This option is used to lock the larger pieces of aggregate with the smaller aggregate in areas where there are large numbers of turning movements.
- **Cape seal:** An application of a chip seal followed by a slurry seal or micro surface. These are very robust treatments and provide a shear resistance comparable to that of asphalt.
- **Inverted seal:** A double chip seal where the larger-sized aggregate is placed on top of the smaller-sized aggregate. These types of seals are used to repair or correct an existing surface that is bleeding or to restore uniformity to surfaces with variation in transverse surface texture.
- **Sandwich seal:** A chip sealing technique that involves one binder application sandwiched between two separate aggregate applications. Sandwich seals are particularly useful for restoring surface texture on raveled surfaces.
- **Geotextile-reinforced seal:** A chip seal placed over a geotextile that has been carefully rolled over a tack coat. This practice can enhance the performance of a conventional chip seal over extremely oxidized or thermal cracked surfaces.

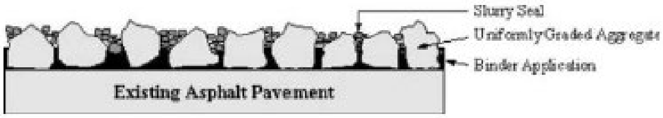
Figure 1 shows conceptual diagrams of the different types of chip seals described above. Other variations of these designs may be used in the field.

Single chip seal.



Double chip seal.

Racked-in seal.



Cape seal.

Inverted seal.

Sandwich seal (dry matting).

Geotextile-reinforced seal.

Figure 1. Types of chip seals ***(2)***

2. FACTORS AFFECTING PROJECT SELECTION

Chip seal performance depends on many variables, such as traffic, materials, construction practices, and initial condition of the pavement. Typically, performance lives range from 3 to 7 years for single course applications, while multiple applications can increase pavement life by up to 10 years *(6-9)*. Single-course applications are the most common process and have been successfully used on all pavement types. However, they could present potential disadvantages such as vehicle damage, tire noise, and roughness. Multi-layer applications are used when substantially higher sealing ability is required. They also reduce the risk of dislodgement of the larger aggregates and damage from traffic and snow plows and provide a quieter surface *(4)*.

2.1 Existing Pavement Condition

Ensuring the durability and effectiveness of chip seals starts with selecting adequate candidates for treatment. Chip seals are not intended to add structural capacity to the road or address major issues. As with any preservation treatment, the existing pavement must be structurally sound. However, the presence of non-structural minor cracking (less than ¼”) can be addressed early on to prevent further deterioration. Other distresses such as weathering, reveling, bleeding, and polished aggregate can also be corrected with a chip seal *(10)*.

Peshkin et al. *(8)* developed evaluation matrices to be used in the preliminary identification of feasible preservation treatments for existing asphalt pavements. These matrices identify how appropriate each treatment is for a given application in terms of how well it addresses a particular distress and corresponding severity level. Tables 1 through 3 summarize the authors’ recommendations for single and double chip seals.

Table 1. Feasibility Matrix for Preliminary Identification of Candidate Preservation Treatments for Asphalt-Surfaced Pavements (Window of Opportunity and Surface Distress) ***(8)***

Preservation Treatment	Window of opportunity		Distress Types and Severity Levels (L = Low, M = Medium, H = High)				
			Surface Distress				
			Raveling/ Weathering	Bleeding/ Flushing	Polished Aggregate	Segregation	Water Bleeding/ Pumping[a]
	PCI/ PCR	Age (yr)	L/M/H	-	-	L/M/H	-
Chip seal: Single							
Conventional	70-85	5-8	◉●◉	○	●	●◉○	◉
Polymer modified	70-85	5-8	○◉◉	×	●	◉◉○	○
Chip seal: Double							
Conventional	70-85	5-8	○◉◉	×	◉	◉◉○	×
Polymer modified	70-85	5-8	○○◉	×	◉	○◉○	×

Note: ● = Highly recommended; ◉ = Generally recommended; ○ = Provisionally recommended; × = Not recommended

[a] Porous surface mix problem.

Table 2. Feasibility Matrix for Preliminary Identification of Candidate Preservation Treatments for Asphalt-Surfaced Pavements (Cracking Distress) ***(8)***

Preservation Treatment	Distress Types and Severity Levels (L = Low, M = Medium, H = High)				
	Cracking Distress				
	Fatigue / Long. Wheel Path/ Slippage	Block	Transverse Thermal	Joint Reflection	Longitudinal/ Edge
	L/M/H	L/M/H	L/M/H	L/M/H	L/M/H
Chip seal: Single					
Conventional	◉××	●◉○	●◉○	●◉○	◉◉○
Polymer modified	◉○×	●◉◉	●◉◉	●◉◉	◉○×
Chip seal: Double					
Conventional	◉○×	●◉◉	●◉◉	●◉◉	●◉◉
Polymer modified	●◉○	●●◉	●●◉	●●◉	●◉◉

Note: ● = Highly recommended; ◉ = Generally recommended; ○ = Provisionally recommended; × = Not recommended

Table 3. Feasibility Matrix for Preliminary Identification of Candidate Preservation Treatments for Asphalt-Surfaced Pavements (Deformation Distress and Surface Characteristics Issues) *(8)*

Preservation Treatment	**Distress Types and Severity Levels (L = Low, M = Medium, H = High)**				**Surface Characteristics Issues**		
	Deformation Distress						
	Wear/ Stable Rutting[b]	**Corrugation / Shoving**[c]	**Bumps/ Sags**	**Patches**	**Ride Quality**	**Friction**	**Noise**
	L/M/H	**L/M/H**	**L/M/H**	**L/M/H**	**-**	**-**	**-**
Chip seal: Single							
Conventional	◉○×	○○×	○○×	◉◉○	○	●	×
Polymer modified	◉○×	○○×	○○×	◉◉○	○	●	×
Chip seal: Double							
Conventional	●◉○	◉○×	◉○×	●◉◉	◉	◉	○
Polymer modified	●◉○	◉○×	◉○×	●◉◉	◉	◉	○

Note: ● = Highly recommended; ◉ = Generally recommended; ○ = Provisionally recommended; × = Not recommended

[b] Rutting primarily confined to asphalt concrete surface layer and largely continuous in extent.

[c] Corrugation/shoving primarily asphalt concrete surface layer mix problem and frequent in extent.

Caltrans developed a similar matrix to guide the selection of appropriate binder/chip seal combinations for addressing various distress mechanisms (Table 4). In general, conventional chip seals are used on structurally sound pavements with minimal cracking. Polymer-modified emulsion (PME) chip seals are used to correct raveling and pavement oxidation. Binders such as asphalt rubber and polymer-modified (PG) asphalts may be used to address specific distress modes. Pavements with extensive cracking, structural failures, and deformation distresses are not good candidates for chip seal application *(3)*.

Table 4. Binder/Chip Seal Combinations for Addressing Specific Distress Mechanisms *(3)*

Binder/ Chip seal Combination	**Raveling**	**Aged Pavements**	**Bleeding/ Flushing**	**Load Associated Cracks**	**Water Proofing**	**Climate Associated Cracks**	**Heavy Traffic Volumes**	**Stone Retention**	**Improve Skid Resistance**
PME/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Double	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Sand	Yes	Yes	No	No	Yes	No	No (light)	Yes	No
PG/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PG/Double	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PG/Sand	Yes	Yes	No	No	Yes	No	No	Yes	No
AR/SAM	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Rejuvenating Emulsion/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes

Note: PME = Polymer-modified emulsion; PG = Performance graded asphalt binder; AR = Asphalt rubber; SAM = Stress absorbing membrane

Previous studies have emphasized the importance of existing pavement condition and its impact on the performance and life extension of the treated pavement. Eltahan et al. *(11)* used data from the LTPP SPS-3 experiment to estimate the probability of failure of several preservation treatments with respect to the original condition at application time. The results indicated that placing the treatment while the pavement is in good condition results in better performance. For chip seals, the probability of failure after 6 years was 25%, 25%, and 32% for pavements in good, fair, and poor condition, respectively. Jalali and Vargas-Nordcbeck *(12)* obtained similar findings when analyzing a subset of data from the Pavement Preservation Group (PG) Study, a long-term research effort conducted by NCAT in partnership with MnROAD. It was determined that under warm climate and low traffic volume conditions, chip seals had higher survival probabilities (between 7% and 32% depending on chip seal type) when placed on pavements in good condition.

Visintine et al. *(13)* estimated that under good conditions, the expected life of a chip seal was on average 7 years; however, that estimate was reduced by 31% when the pavement was treated while in fair condition, and by 62% if the pavement had fallen to the poor condition prior to treatment application. Rajagopal *(14)* analyzed data derived from the Ohio Department of Transportation's (ODOT) Pavement Management Information System to evaluate the effectiveness of chip seals. ODOT uses the pavement condition rating (PCR), a composite index of several distresses, to express pavement condition on a 0-100 scale, with a pavement having no distresses assigned a value of 100. The study concluded that chip seals provided maximum benefits when applied on pavements with a PCR in the range of 66 to 80.

Labi and Sinha *(15)* studied the effectiveness of seal coating treatments in terms of present serviceability index (PSI) using data from the Indiana Department of Transportation. Treatment benefits were calculated as performance jump (or PJ, the instantaneous elevation in performance upon maintenance) and deterioration reduction rate (DRR) to capture both short and long-term effects. Pavements in relatively poor condition generally exhibited higher performance jumps but lower reductions in their rates of deterioration. Conversely, pavements in relatively good condition experienced lower performance jumps but had greater reductions in their deterioration rates, implying greater benefits over extended periods of time.

In addition to sealing the pavement surface and protecting it against raveling and oxidation, chip seals can delay cracking propagation. Hall et al. *(16)* examined data from the LTPP flexible pavement maintenance study and found that chip seal sections exhibited considerably less cracking than the control sections, although an increasing trend in cracking over time was evident. Test sections constructed under the PG Study in both warm and cold climates also exhibited significantly less cracking compared to untreated sections in similar pretreatment condition *(17, 18)*. Lui et al. *(19)* evaluated the performance of chip seals applied on Kansas highways from 1992 to 2006 and found that transverse and fatigue cracking significantly decreased after chip seal application.

Although chip seals typically do not have an immediate impact on ride quality, they have been found to be effective in reducing the deterioration rate in terms of roughness progression. Brenes-Calderón and Vargas-Nordcbeck *(20)* studied the effect of chip seals on the international roughness index (IRI) deterioration rate for test sections in cold regions. The results indicated that the treatments were able to reduce long-term roughness progression associated with the presence of transverse cracking and tenting. Mamlouk and Dosa *(21)* used data from the Long-Term Pavement Performance (LTPP) program and found that chip seals increased pavement lives in terms of ride quality by 24%-32%, 18%-25%, and 0%-14% for smooth, medium, and rough pavements, respectively. A study, conducted on 51 chip sealed pavement sections in Louisiana concluded that chip seals had a negligible influence on instantly improving the roughness condition of the pavements, however, on a long-term basis chip seals provided a deterioration rate reduction of 3.22 units/year in the roughness index (RFI) *(22)*. Similarly, Mousa et al. *(23)* found that although chip seals offer a slightly immediate roughness improvement, they reduce roughness deterioration rate and the deterioration of overall pavement condition by an average of 4.7 units/year in terms of the pavement condition index (PCI).

2.2 Traffic

Chip seals can be successfully constructed in roadways with different functional classifications and traffic volumes. In most cases, these treatments are applied on roadways with low to moderate traffic volumes, due to the increased chance of windshield damage during and shortly after construction as traffic volume and speed limits increase. Roads with high traffic and high speed can still be chip sealed if measures are taken to minimize this risk, such as increasing the amount of residual asphalt binder, washing the aggregate to remove dust, using high float emulsions, or pre-coating the chips with asphalt binder *(24)*. Double seals or seals with choke stone have a lower potential for chip loss and may be preferred under high traffic volumes. The application of a fog seal to a fresh chip seal can also improve aggregate retention, but care should be taken due to a temporary reduction in pavement friction *(4)*.

Bolander *(25)* summarized the expected longevity of single and multi-layer chip seals as a function of traffic and determined that roadways with average daily traffic (ADT) under 100 vehicles per day (vpd) had expected service lives of up to 15 years, while the range of expected lives was significantly reduced for ADTs between 100 and 500 vpd (Table 5). A survey of agency chip seal practices in the U.S. showed that chip seals on local and collector roads have higher service lives compared to arterial and interstate highways. Similarly, chip seals were reported as being more effective in rural areas where traffic is predominantly low-volume *(26)*.

Table 5. Chip Seal Longevity *(25)*

Treatment Type	Expected Longevity (yrs)	
	< 100 ADT	100 to 500 ADT
Single chip seal	4 to 12	3 to 6
Multiple chip seal	5 to 15	5 to 7

Other factors should be considered during project selection. For instance, rural settings are generally more appropriate, as traffic tends to move more consistently with less stopping and starting. Urban environments are more challenging due to frequent turning, stopping, and starting, in addition to more difficult conditions for traffic control and lane closures. Loss of cover aggregate and subsequent bleeding in cul-de-sacs are common problems encountered in urban areas. However, this is a result of poor construction practices and can be avoided through the use of proper techniques. In most cases, the binder is not placed properly, causing it to break before the chips are applied and/or rolled and making it nearly impossible to achieve the desired embedment. In addition, leaving too much overlap when applying the binder can result in excessive application in certain areas, resulting in bleeding and scuffing as vehicles stop and turn *(24)*.

Peshkin et al. *(8)* provided guidance on treatment use on high-traffic-volume roadways. Chip seals were generally recommended for high traffic conditions (AADT > 5,000 vpd for rural roads, and AADT > 10,000 vpd for urban roads), and were expected to have a performance period of 4 to 6 years for single seals and 6 to 8 years for double seals.

Another consideration may be the increased noise and rougher texture resulting from chip seal application which may affect both vehicle occupants and nearby residents. This may limit their use in residential areas or roadways with significant bicycle traffic due to user complaints *(4)*. One strategy that can be used to reduce noise is to design the chip seals with smaller-sized aggregates. Donovan and Janello *(27)* studied the noise performance of different chip seal test sections with chip sizes ranging from 6.35 to 9.53 mm (1/4 to 3/8 in). It was concluded that by controlling the aggregate size to be 9.53 mm, chip seal pavements can be at the lower limit of about 104 dBA, as measured by the on-board sound intensity (OBSI) method. The use of chip sizes between 6.35 and 7.94 mm resulted in noise levels in the range of 101 to 102 dBA, comparable to the upper range of other asphalt surfaces.

Alternatively, a slurry seal or micro surface can be applied over the chip seal to provide a quieter, smoother riding surface. While this practice will result in a more robust, durable treatment, there are additional time and cost considerations that must be taken into account.

2.3 Climate

Climate also plays a significant role in chip seal performance *(28-30)*. High temperatures increase the potential of bleeding/flushing of the asphalt through the aggregate. In addition, chip seals placed in areas with shallow groundwater table conditions can prevent water from escaping upwards through the cracks by evaporation and trap moisture within the pavement structure, accelerating moisture damage *(31)*.

Chip seals in cold climate conditions are subject to freeze–thaw cycles and physical damage from snow and ice removal operations that may lead to premature deterioration. Aktas and Karasahin *(32)* found that polymer modification of neat asphalt cement improved aggregate retention performance in chip seals subjected to cold temperatures.

Baladi et al. *(33)* studied the impact of various treatments on pavement performance across four climatic regions. Chip seals appeared to improve pavement performance in all regions in terms of IRI, rut depth, and cracking, but the improvement varied from about 1 to 5 years, as seen in Table 6.

Table 6. Impact of seal coat on pavement performance compared with the control sections (years) *(33)*.

Condition or Distress Type	**Climatic Region**			
	Wet-Freeze	**Wet-No Freeze**	**Dry-Freeze**	**Dry-No Freeze**
IRI	2	4	1	-4
Rut depth	3	3	5	9
Alligator cracking	2	2	-1	1
Longitudinal cracking	-2	2	4	7
Transverse cracking	2	1	1	5

3. TREATMENT DURABILITY

Although proper project selection is essential to treatment effectiveness, there are also materials selection, design, and construction factors that can directly affect the performance and durability of the treatment. Common issues encountered in chip seals are aggregate loss and bleeding/flushing, and they can occur very early in the life of the treatment, sometimes immediately after construction. Both of these issues result in texture loss and affect the functionality of the treatment in terms of skid resistance.

Aggregate loss occurs when the applied aggregate does not adhere to the binder. Some chip loss happens soon after construction and may be caused by *(34, 35)*:

- Low residual binder application rates
- Excessive application of cover aggregate
- Emulsion breaking before the chips are applied or rolled

- Dry or dusty aggregate
- Wet weather affecting binder characteristics during and after sealing
- Improper asphalt distribution
- Allowing fast traffic on the roadway too soon

Chip loss can also develop progressively over the service life of the seal due to binder aging and oxidation. The damage is accelerated in high-stress areas such as those subjected to high speed, turning, heavy braking and acceleration, up or downhill sections, etc. Once chip loss starts it can increase very rapidly because of a lack of support from the surrounding chips, leaving a very slick surface of exposed binder with low skid resistance *(34)*.

Bleeding and flushing are similar types of issues where the binder in the chip seal rises to the surface. Although both terms are often used interchangeably, there are functional differences between the two distresses *(36)*. Bleeding typically occurs during the chip seal construction process when the pavement is first opened to traffic, while the asphalt is still in liquid form. Bleeding asphalt sticks to aggregate and tires and causes tracking. The chip seal aggregate can also be picked up, leaving an exposed, slick surface.

Bleeding may be caused by binder issues (too much binder, wrong binder type), environmental conditions (temperature, humidity), traffic effects (heavy traffic, high volume traffic), and construction deficiencies. Excess asphalt binder fills the voids in the aggregate mat and then moves upward to the pavement surface under traffic and with heat expansion in a non-reversible, cumulative process (Figure 2).

(a) Seal Coat Aggregate Particles Embedded in Asphalt Binder with Sufficient Voids Between Particles

(b) Asphalt Binder Migrated to the Surface of Seal Coat Aggregate Causing Insufficient Voids Between Particles

Figure 2. Relationship between aggregate voids and bleeding/flushing *(36)*.

Conversely, flushing occurs on pavements where the asphalt has already cured and is solid or semi-solid. A flushed pavement has typically been in service for at least a full winter/summer season but is still holding its seal and is able to perform at least one critical aspect of its function. Progressive flushing due to wearing down of aggregate is common during the typical life cycle of a properly-constructed seal coat. In hot weather, a flushed surface may soften and bleed *(34)*.

These treatment failures can be prevented by selecting appropriate materials, determining material application rates required for the specific site conditions through proper design methods, and implementing best practices during the construction process. These topics are discussed in the following sections.

4. MATERIALS

As mentioned previously, chip seals require the application of asphalt binder and cover aggregate. The asphalt binder seals the existing pavement surface, and bonds the aggregate particles to the existing pavement. The aggregates provide a good skid-resistant surface while being resistant to polishing, durable against abrasion effects, and resistant to the disintegration caused by weathering *(2)*. These materials must meet basic requirements and be selected according to the conditions expected in the field.

4.1 Asphalt Binder

The two main binder types used for chip seal operations are hot-applied and emulsified asphalts. Selecting between these options depends largely on environmental factors. Harder hot-applied binders are more appropriate to prevent bleeding in hot weather while emulsions are more effective when the expected conditions are low ambient temperatures, high humidity, or damp aggregate and pavement surfaces.

Performance-graded hot-applied binders are selected to meet expected climatic conditions as well as aging considerations with a certain level of reliability. They may be modified if the project requires additional performance and durability. The asphalt must be heated to a point where it is pumpable and suitable for application through a distributor truck, which can be a safety concern. Chip seals constructed with hot-applied binders can be opened to traffic early but require more rolling energy and are more sensitive to moisture in the aggregate particles *(1-3)*.

Emulsified asphalts are composed of asphalt, water, and emulsifier, and in some cases, they may contain polymer. Emulsions can be anionic (negative charge) or cationic (positive charge) depending on the chemistry created by the emulsifying agent. Cationic emulsions typically perform better in chip seals because they are less sensitive to weather, inherently have antistripping qualities, and are electrostatically compatible with more types of aggregate. High float emulsions are also used in chip seals, especially in situations where the local aggregate is excessively dirty or dusty. Common emulsion grades used in chip seals include RS-2, RS-2h, HFRS-2, CHFRS-2P, CRS-2, CRS-2h, CRS-2P (SBS), and CRS-2L (LM) *(1-3)*.

4.2 Cover Aggregate

Chip seal aggregate must be clean, durable stone such as granite, slag, limestone, or other high-quality aggregate. The shape and quality of the aggregate directly affect chip seal performance. Desired aggregate characteristics include *(1-3, 24, 37)*:

- **Size and Gradation:** Ideally, chip seals should consist of single-sized aggregate to help produce a constant embedment rate and improved aggregate retention, surface friction, and drainage capabilities of the seal. The nominal size aggregate of the aggregate is selected based on traffic, surface condition, and type of chip seal. Larger-sized aggregates are generally more durable and less sensitive to variations in the binder rate but can present a higher vehicular damage risk if they are not properly embedded and swept. Also, as previously discussed, larger aggregate particles result in increased noise.
- **Shape:** More cubical aggregate particles provide better interlock and are more resistant to rolling and displacement by traffic than rounded particles. A crushed aggregate with 100% fractured faces is recommended.
- **Cleanliness:** Dusty aggregates prevent the particles from bonding with the asphalt, causing extensive chip loss. To prevent this, the amount of fines in the aggregate source (material passing the #200 sieve) should be limited to a maximum of 1%.
- **Toughness and Soundness:** Aggregates must be able to resist abrasion and degradation to prevent the particles from breaking up and dislodging, which increases the potential for windshield damage and flushing. Aggregates must also be non-polishing to maintain the chip seal's skid resistance.

The requirements for chip seal aggregates are outlined in AASHTO M 340-22 *(38)* and include percentage of fractured faces, Los Angeles Abrasion, and Flakiness Index, as shown in Table 7. The limits vary depending on the expected traffic level, with higher quality requirements for chip seals subjected to higher traffic volumes.

Table 7. Fracture and Abrasion Requirements for Chip Seal Aggregates *(38)*

Property	**Chip Seal Class**		
	I	**II**	**III**
Fracture, 1 Face, % min	70	85	95
Fracture, 2 Faces, % min	60	80	90
Los Angeles Abrasion, max % loss	40	35	30
Flakiness Index Value, max %	35	30	25

Note: Class I is less than 500 AADT; Class II is 501–5,000 AADT; and Class III is greater than 5,000 AADT.

Aggregate selection is usually based on local availability and cost. Igneous, metamorphic, sedimentary, and manufactured aggregates have all been successfully used for chip sealing. The use of lightweight aggregate can significantly reduce windshield damage claims thanks to the lower specific gravity of the stone. Lightweight synthetic aggregate has also demonstrated a superior ability to retain its skid resistance; however, lightweight aggregates are generally more expensive than natural aggregates and may have high water absorption *(2)*.

5. CHIP SEAL DESIGN METHODS

The mix design process determines material application rates such that the resulting cover coat will be one-stone thick and the aggregate particles will have the proper embedment in the binder layer to ensure good chip retention. As previously discussed, aggregate embedment directly affects treatment performance. If it is insufficient, it will result in aggregate loss that can lead to windshield damage and, in general, reduce the service life of the chip seal. Conversely, high embedment will cause bleeding or flushing, and potential loss of skid resistance.

This section comprehensively reviewed the current chip seal design methods all over the world, especially focusing on the determination of the aggregate application rate (AAR) and binder application rate (BAR) or emulsion application rate (EAR). In total, 14 different chip seal design methods were included in this literature review, shown as follows:

- Hanson Design Method
- Kearby and Modified Kearby Design Method
- McLeod and Modified McLeod Design Method
- Spanish Design Method
- New Zealand Design Method
- Austroads Design Method
- South African Design Method
- The United Kingdom (British) Design Method
- French Design Method
- North Carolina State University (NCSU) Performance-based Design Method
- Michigan State University (MSU) Performance-based Design Method
- The University of Texas at Austin (UT Austin) Design Method

5.1 Hanson Design Method

The first chip seal design procedure, widely known as the Hanson Design Method, was proposed to determine the application/spread rates of materials (i.e., aggregate and binder) for a single-layer chip seal treatment using one-sized aggregate and liquid asphalt, particularly cutback asphalt *(39)*. This method was developed based on the average least dimension (ALD) of the aggregate spread on the pavement. The ALD represents the average height of the aggregate particles when they are spread as a single layer with least dimensions vertical. As shown in Figure 3, Hanson observed that the percentage of voids between aggregate particles was approximately 50% when the aggregate was dropped on the pre-sprayed asphalt layer from a chip spreader. Theoretically, the voids between the aggregate were expected to be reduced to 30% and 20% after initial rolling and trafficking, respectively. The material application rates are calculated such that the binder fills 65 to 70% of the voids between aggregate particles, depending on aggregate type and traffic.

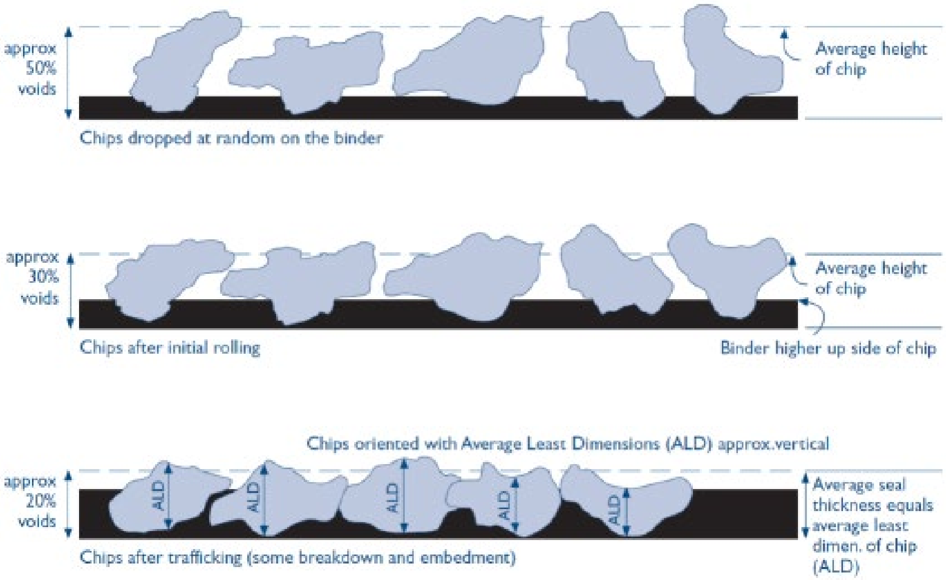


Figure 3. Change in Voids between Aggregate Particles with Chip Seal Construction Sequences ***(40)***

5.2 Kearby and Modified Kearby Design Method

Kearby *(41)* developed the first chip seal design procedure in the United States, which recommended the use of a uniformly graded aggregate by outlining eight grades of aggregate based on gradation and associated average spread ratios. Different from the Hanson method, the AAR is determined through the board test and loose unit weight test (ASTM C29), which depends on not only the aggregate size (i.e., ALD) but also aggregate unit weight, specific gravity, percent of voids, shape, size, and gradation. In the board test, a certain amount of aggregate is spread to fully cover an area of one square yard to achieve a single aggregate layer (i.e., one stone in depth), and the weight of the used aggregate is recorded. The aggregate spread ratio (SR) and the average mat thickness (d) are calculated based on the board and loose unit weight test results. Subsequently, the AAR is calculated based on the aggregate specific gravity (G) and d.

In addition, the BAR is determined based on the desired embedment depth (E) and the voids in the aggregate (V). E is the height of the binder that embeds a desired portion of d, shown in Figure 4, and the V is determined based on the unit weight test (ASTM C29). Note that if emulsified binder is used, the BAR should be divided by the residual asphalt content of the emulsion (R) to obtain the EAR.

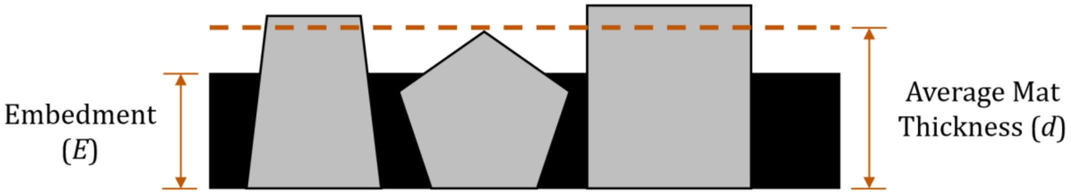


Figure 4. Illustration of the Average Mat Thickness and Aggregate Embedment Depth *(40)*.

To simplify the design process, Kearby *(41)* developed a nomograph (Figure 5) to help the designer determine the BAR with the inputs of average size of aggregates, the percent embedment depth, and the percentage of voids between aggregates. Kearby also pointed out that the computations alone cannot produce satisfactory results and that certain existing field conditions require visual inspection and engineering judgment to select the quantities of asphalt and aggregate. The specific recommendations related to the existing substrate surface, traffic, aggregate properties, aggregate shape, and aggregate gradation can be found in the original study.

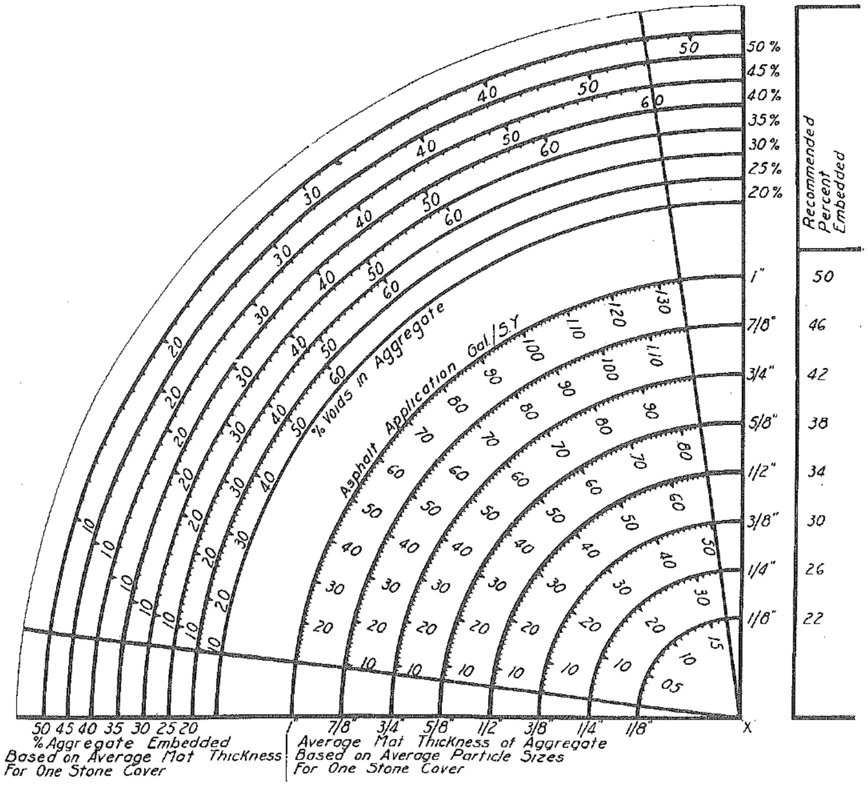


Figure 5. Kearby's BAR Nomograph *(41)*

Further studies were conducted to modify the original Kearby design method focusing on the determination of BAR, which included correction factors for traffic, substrate surface condition, season, and on-site temperature *(42-44)*. Note that the calculation of AAR was kept the same as the original Kearby method. If emulsion/cutback binder was used for chip seal treatment, the calculations were further modified to consider the seasonal and on-site temperature effect.

The recently adopted AASHTO R 102-22 *Standard Practice for Emulsified Asphalt Chip Seal Design* is based on the Kearby method. The application quantity of aggregate chips is determined based on the board test, and the quantity of emulsified asphalt is estimated by calculating the amount of asphalt needed to fill the voids between the chips to a specific embedment depth, considering traffic volume and substrate surface condition. The application of 5 to 10% excess aggregate is recommended during construction to reduce the potential for chips to be picked up by the pneumatic roller.

5.3 McLeod and Modified McLeod Design Method

The McLeod design procedure was derived from the Hanson concepts with some modifications *(45)*, which was later adopted by the Asphalt Institute MS19 and Asphalt Emulsion Manufacturers. Similar to the Hanson Design Method, the McLeod method was developed based on the ALD of the aggregate chips spread on the pavement, but it was designed for graded aggregate instead of single-sized aggregate. Thus, the ALD of the graded aggregate is calculated based on the gradation and aggregate shape instead of manually measuring a large amount of aggregate samples *(46, 47)*.

The aggregate information required to determine the AAR includes ALD, voids in the loose aggregate, specific gravity, and waste during construction. The additional information required to determine the BAR/EAR is residue content of emulsion/cutback, aggregate absorption, traffic volume factor, and substrate texture factor. Specific information related to the different factors can be found in the original study *(45)*.

In the Hanson and McLeod design methods, the final void content between the aggregate particles was expected to be 20%, but other studies found that the final void content was higher than 20%, and a value of 40% was recommended *(48, 49)*. The lower value of 20% obtained by Hanson was caused by testing relatively soft aggregates using a steel roller compactor, which resulted in aggregate breakdown during rolling and compaction. Thus, the McLeod design equations were further modified to reflect the higher void content *(50)*. Using a larger value (i.e., 40%) for the final void content in the McLeod design equations results in a lower AAR and a higher BAR than the previous values.

5.4 Spanish Design Method

Chip seal treatments have been used Spain since the 19th century, and the standard chip seal design procedures were developed in 1988. Two empirical methods were commonly used throughout Spain to determine the AAR and BAR, including the Centre de Recherches Routiers (CRR) and Linckenheyl methods *(51)*. For the CRR design method, the AAR is determined based on the aggregate size and gradation, and the BAR is calculated based on AAR, substrate surface texture, and aggregate type. In the Linckenheyl method, both AAR and BAR are determined based on the aggregate size and gradation.

5.5 New Zealand Design Method

New Zealand first adopted the Hanson method as its chip seal design procedure, and later modified it to consider the effects of traffic and existing surface texture on BAR *(34)*. Currently, New Zealand still uses the Hanson Method to determine the AAR.

Later, additional investigations found that the total volume of voids (V_V) was significantly higher than 20% after compaction, and the voids decreased with further traffic compaction during service *(52)*. The study further indicated that the ratio between V_V and ALD linearly correlated with the traffic in a half-log scale.

In the Hanson design method, it was assumed that 60 to 70% of the V_V was filled by residual binder. However, the New Zealand method found that the residual binder that fills 35% of V_V was enough to prevent the premature chip loss after monitoring many chip seal projects. Thus, the volume of the binder (V_B) shown in Figure 6 should be 35% of V_V.

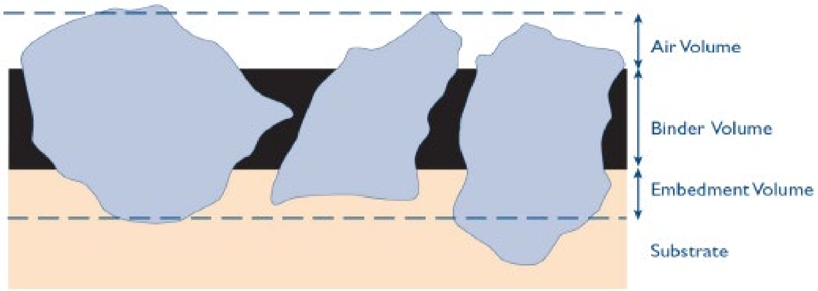


Figure 6. Components of the Volume of Voids in Aggregate Particles *(40)*.

In addition, New Zealand further adjusted the volume of binder considering that more binder was required to fill the existing surface texture, but it was assumed that 30% of the surface texture already was filled by the aggregate. Thus, only 70% of surface texture (i.e., MTD) needs to be added to ALD to increase the BAR. Furthermore, five site-specific adjustments were considered for the determination of BAR, namely: soft substrates, absorptive surface, steep grade, chip shape, and urban and/or low traffic volumes. Thus, the final BAR was determined by combining V_B and the abovementioned five adjustments.

5.6 Austroads Design Method

Austroads is a collaboration between the Australian and New Zealand Road Transport and Traffic departments. The current Austroads design method (i.e., Australian design method) originated from the Hanson design methodology, and the modifications were made based on field trials *(53)*. One major finding from the field trials was that the initial voids in the aggregates varied from 40% to 60% instead of a single value of 50% assumed in the Hanson method, which depends on traffic, aggregate size, gradation, and shape. Similar to the Hanson method, the BAR is determined when 50 to 65% of the height of the cover aggregate is filled by the residual binder two years after construction. First, the basic BAR is determined based on the ALD and the design voids factor (V_F), and the V_F depends on the aggregate shape, total traffic volume, and the heavy vehicles proportion, and site location (e.g., slow moving lanes, climbing lanes, stop/start location).

In addition, $\text{BAR}_{\text{Basic}}$ is further revised to determine the final/design BAR based on the emulsion factor (*EF*), polymer factor (*PF*), and corrections for substrate texture, embedment, absorption into substrate, absorption into aggregate. Similar to the Hanson design method, the AAR is determined based on the ALD and traffic.

5.7 South African Design Method

The South African method was incorporated in the specification of Design and Construction of Surfacing Seals published by the South African National Roads Agency SOC Ltd (SANRAL) *(54)*. The South African method derived from the Hanson method. In the South Africa method, the AAR was determined with a nomograph based on the ALD and the aggregate flakiness index, shown in Figure 7.

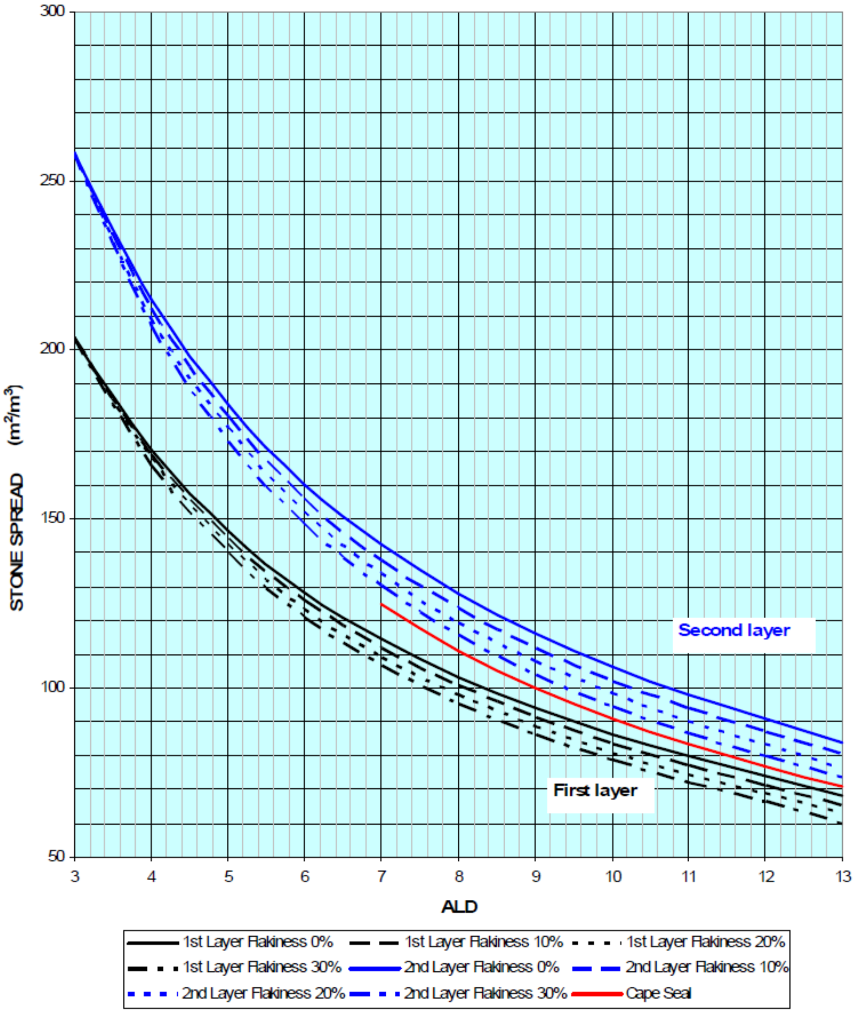


Figure 7. SANRAL's Nomograph to Determine AAR *(54).*

Similar to the Hanson method, the BAR/EAR is determined based on Hanson's concept of partially filling the voids in the aggregate with residual binder. The South African design method specifies that when there is no stone embedment into the existing surface, the minimum amount of voids to be filled with binder to prevent stone loss is 42%, shown in Figure 8. In addition, it is specified that 0.7 mm of texture depth is required to provide adequate skid resistance. In the South African method, the percentage of void content in the aggregate layer is a function of the effective layer thickness (ELT), and the ELT is determined based on ALD.

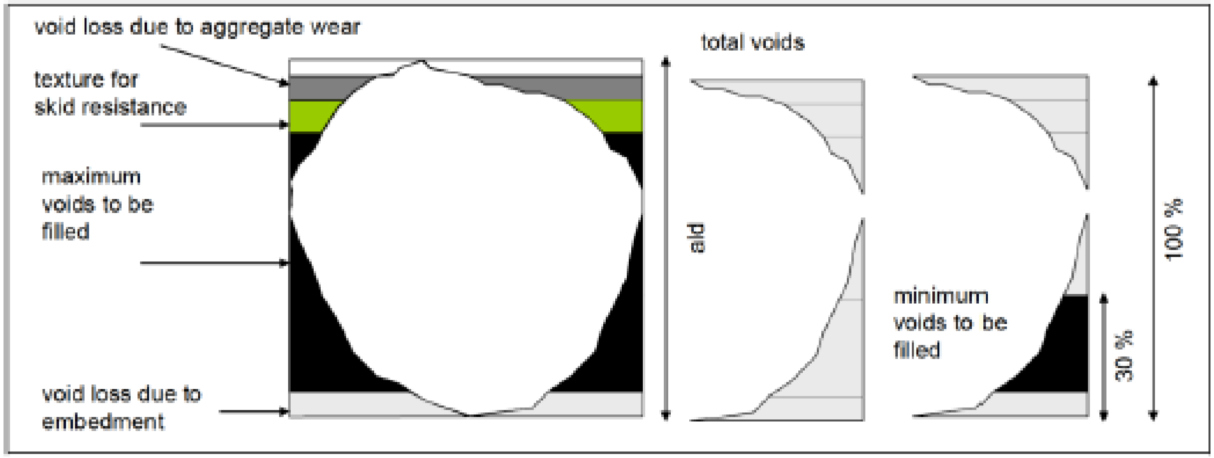


Figure 8. Components of Voids in Aggregates *(54)*.

To determine the BAR in the South African method, the first step is to obtain the embedment of chips into the substrate surface based on the traffic and ball penetration test results. Subsequently, the basic BAR is determined based on the embedment depth and the potential texture depth. The nomographs used to determine the basic BAR are shown in Figure 9. After determining the basic BAR using the nomograph, the site-specific conditions should be considered to further adjust the binder quantity to meet the requirements, including the existing surface texture, climate, slow moving and channelized traffic, and aggregate spread rate. The specific tables or nomographs used to adjust the basic BAR can be found in the specification of Design and Construction of Surfacing Seals published by SANRAL *(54)*.

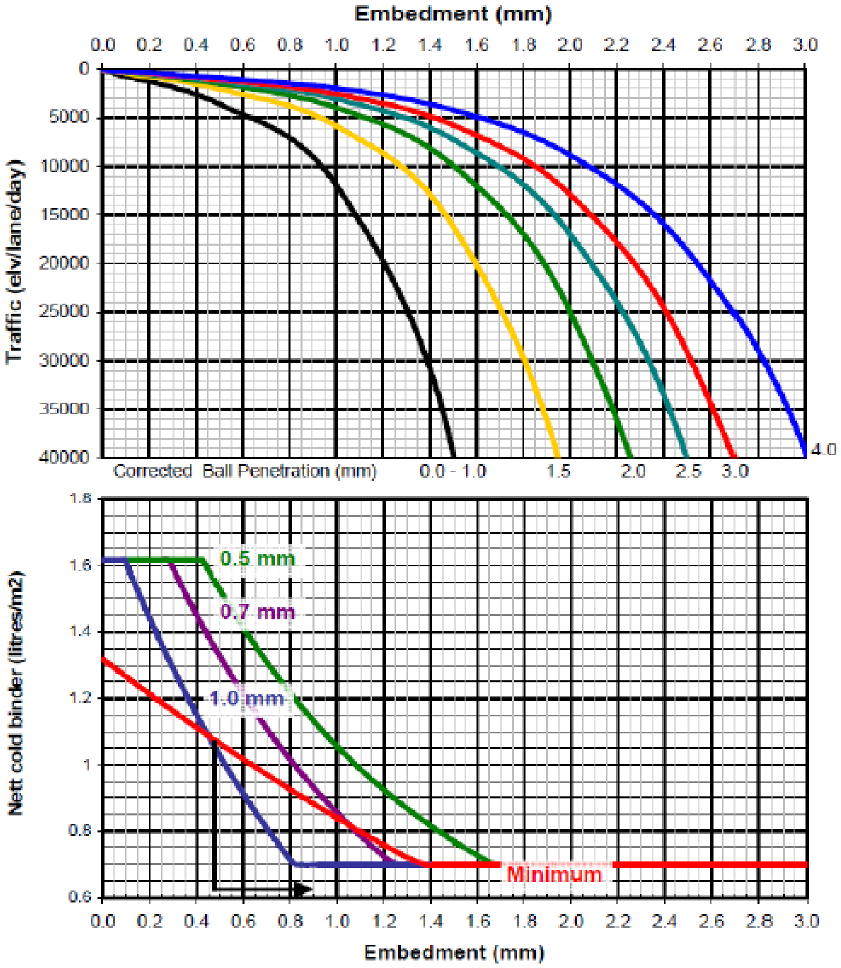


Figure 9. SANRAL's Nomograph to Determine Basic BAR *(54).*

5.8 The United Kingdom (British) Design Method

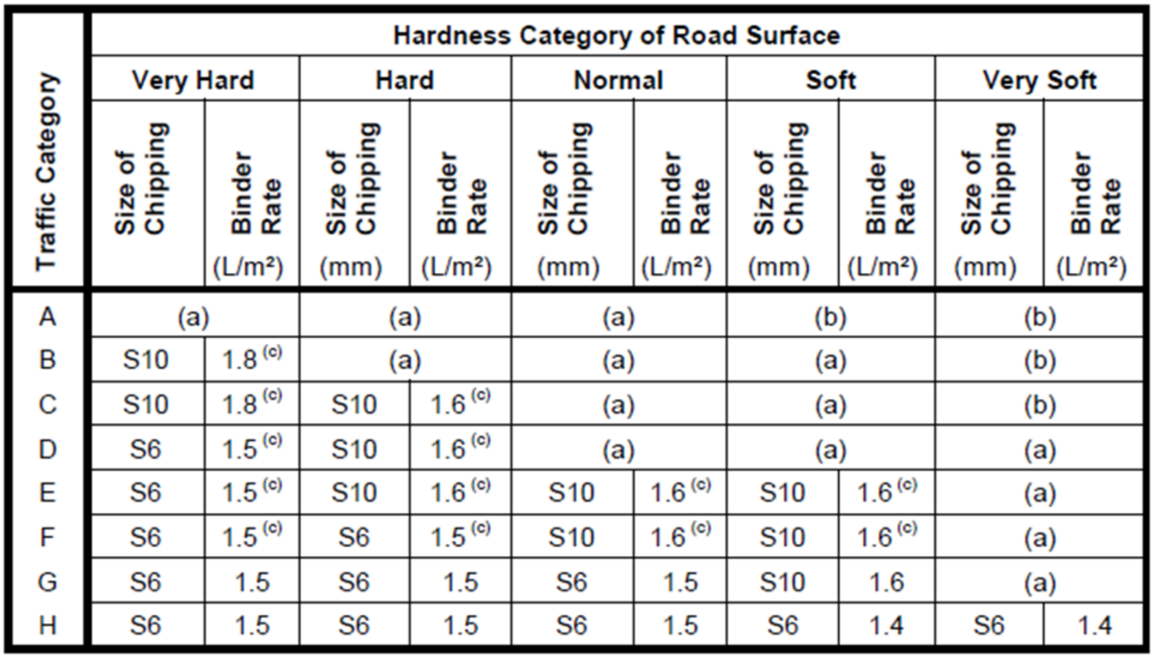
The British design method is described in the Design Guide for Road Surface Dressing, which is also known as ROAD NOTE 39 *(55)*. Prior to the chip seal design, a computer design program based on decision trees is used to determine if the current roadway conditions are suitable for chip seal treatment with a series of inputs including traffic level, road hardness, substrate surface conditions, and site geometry, skid-resistance requirements, and weather conditions. Afterwards, a four-step procedure is conducted to determine the material application rates including: 1) select binder type based on the road traffic category and construction season; 2) select aggregate size based on the road traffic and hardness of existing surface; 3) determine the AAR based on aggregate size, shape, and relative density; 4) determine the BAR based on aggregate size and shape, existing surface condition, and the aggregate embedment depth with traffic. The AAR must be sufficient to cover the pre-sprayed binder film with a spread rate to achieve 100 to 105% shoulder to shoulder coverage, and the guidance for estimating AAR is shown in Table 8.

Table 8. Recommended AAR in British Design Method *(55)*

Nominal Size of Chipping	Range of AAR	
	(kg/m^2)	(m^2/tonne)
2.8/6.3 mm	8 - 11	125 -91
6.3/10 mm	10 -14	100 -71
8/14 mm	12 -16	83 -62

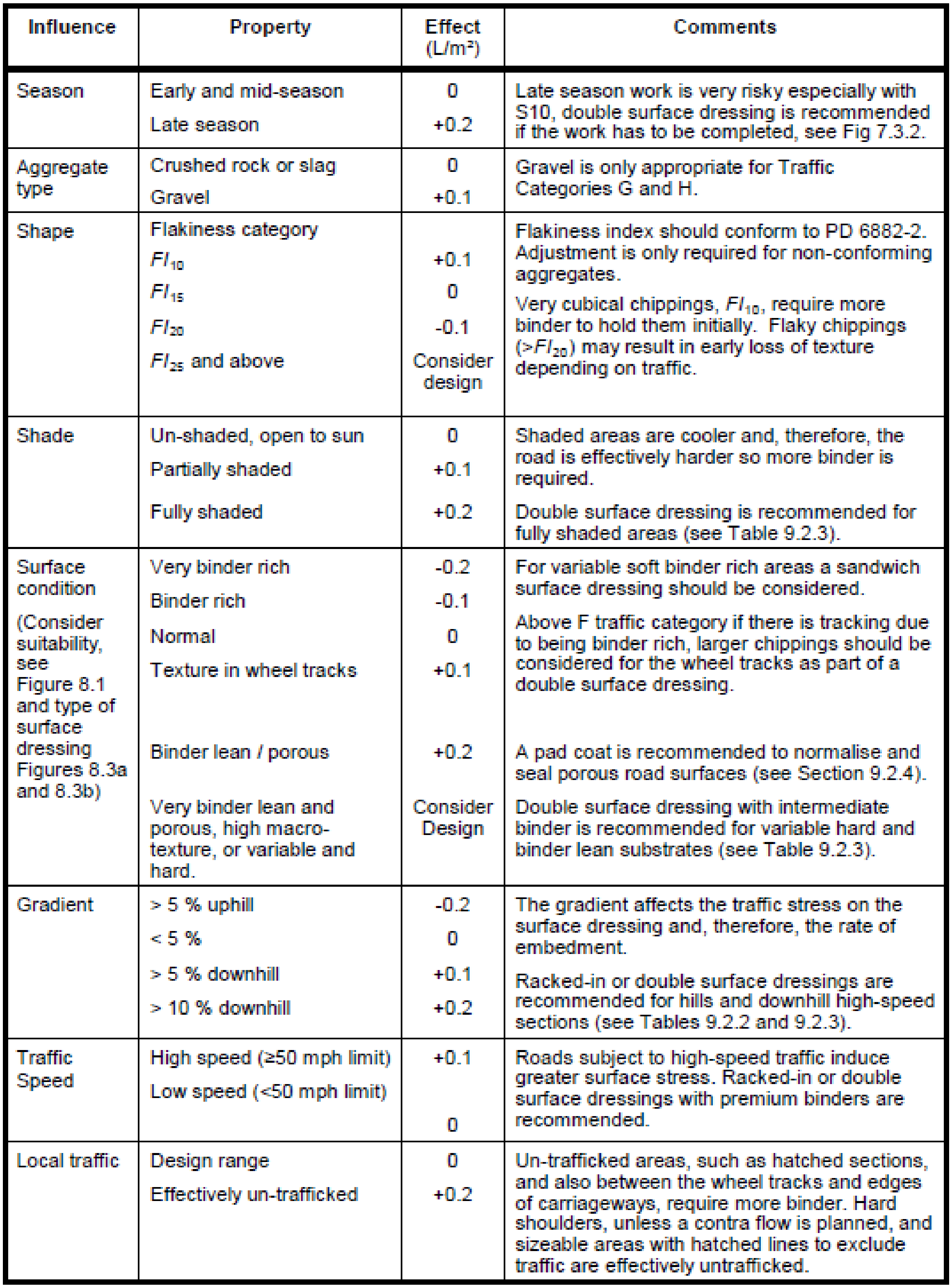
Meanwhile, the recommended BAR in the British method was also summarized in Table 9. Afterwards, the BAR is further adjusted based on the secondary factors including season, aggregate type, shape, shade, surface condition, gradient, traffic speed, and local traffic, shown in Table 10.

Table 9. Recommended BAR in the British Design Method *(55)*



Traffic Category	Hardness Category of Road Surface									
	Very Hard		Hard		Normal		Soft		Very Soft	
	Size of Chipping	Binder Rate (L/m²)	Size of Chipping (mm)	Binder Rate (L/m²)	Size of Chipping (mm)	Binder Rate (L/m²)	Size of Chipping (mm)	Binder Rate (L/m²)	Size of Chipping (mm)	Binder Rate (L/m²)
A	(a)		(a)		(a)		(b)		(b)	
B	S10	1.8 (c)	(a)		(a)		(a)		(b)	
C	S10	1.8 (c)	S10	1.6 (c)	(a)		(a)		(b)	
D	S6	1.5 (c)	S10	1.6 (c)	(a)		(a)		(a)	
E	S6	1.5 (c)	S10	1.6 (c)	S10	1.6 (c)	S10	1.6 (c)	(a)	
F	S6	1.5 (c)	S6	1.5 (c)	S10	1.6 (c)	S10	1.6 (c)	(a)	
G	S6	1.5	S6	1.5	S6	1.5	S10	1.6	(a)	
H	S6	1.5	S6	1.5	S6	1.5	S6	1.4	S6	1.4

Table 10. BAR Correction for Secondary Factors in British Design Method *(55)*



Influence	Property	Effect (L/m²)	Comments
Season	Early and mid-season Late season	0 +0.2	Late season work is very risky especially with S10, double surface dressing is recommended if the work has to be completed, see Fig 7.3.2.
Aggregate type	Crushed rock or slag Gravel	0 +0.1	Gravel is only appropriate for Traffic Categories G and H.
Shape	Flakiness category FI_{10} FI_{15} FI_{20} FI_{25} and above	 +0.1 0 -0.1 Consider design	Flakiness index should conform to PD 6882-2. Adjustment is only required for non-conforming aggregates. Very cubical chippings, FI_{10}, require more binder to hold them initially. Flaky chippings (>FI_{20}) may result in early loss of texture depending on traffic.
Shade	Un-shaded, open to sun Partially shaded Fully shaded	0 +0.1 +0.2	Shaded areas are cooler and, therefore, the road is effectively harder so more binder is required. Double surface dressing is recommended for fully shaded areas (see Table 9.2.3).
Surface condition (Consider suitability, see Figure 8.1 and type of surface dressing Figures 8.3a and 8.3b)	Very binder rich Binder rich Normal Texture in wheel tracks Binder lean / porous Very binder lean and porous, high macro-texture, or variable and hard.	-0.2 -0.1 0 +0.1 +0.2 Consider Design	For variable soft binder rich areas a sandwich surface dressing should be considered. Above F traffic category if there is tracking due to being binder rich, larger chippings should be considered for the wheel tracks as part of a double surface dressing. A pad coat is recommended to normalise and seal porous road surfaces (see Section 9.2.4). Double surface dressing with intermediate binder is recommended for variable hard and binder lean substrates (see Table 9.2.3).
Gradient	> 5 % uphill < 5 % > 5 % downhill > 10 % downhill	-0.2 0 +0.1 +0.2	The gradient affects the traffic stress on the surface dressing and, therefore, the rate of embedment. Racked-in or double surface dressings are recommended for hills and downhill high-speed sections (see Tables 9.2.2 and 9.2.3).
Traffic Speed	High speed (≥50 mph limit) Low speed (<50 mph limit)	+0.1 0	Roads subject to high-speed traffic induce greater surface stress. Racked-in or double surface dressings with premium binders are recommended.
Local traffic	Design range Effectively un-trafficked	0 +0.2	Un-trafficked areas, such as hatched sections, and also between the wheel tracks and edges of carriageways, require more binder. Hard shoulders, unless a contra flow is planned, and sizeable areas with hatched lines to exclude traffic are effectively untrafficked.

5.9 French Design Method

Chip seal treatments are widely used in France for the purpose of sealing the existing pavement and enhancing the skid resistance *(56, 57)*. The major factors influencing AAR and BAR include exiting surface condition, on-site geometry, traffic, site agglomeration, section exposure, climate region, and the construction time. In the French method, polymer modified binder is commonly used to ensure durability, and the aggregate used is selected based on the Los Angeles Abrasion test, Micro-Deval test, and Polish Stone Value (PSV) results. Similar to the Spanish method, the AAR and basic BAR/EAR are determined based on a gradation parameter of *d/D*, where *D* is the smallest sieve opening (in mm) that has a percent passing greater than or equal to 85%, and *d* is the largest sieve opening (in mm) with a percent passing of less than 15%. According to the French design method, the recommended AAR is determined as shown in Table 11.

Table 11. Recommended AAR and Basis BAR/EAR in the French Method *(56)*

Gradation *d/D*	**AAR (L/m^2)**	**Basic BAR/EAR**	
		Cutback BAR (kg/m^2)	**EAR (kg/m^2)**
4/6	6-7	1.05	1.30
6/10	8-9	1.35	1.75
10/14	11-13	1.60	2.15

Subsequently, the basic BAR/EAR is further corrected to better enhance durability and efficiency considering the site-specific conditions, which include traffic, substrate surface conditions, alignment, region altitude, climate, aggregate size and shape, binder category, and construction time. The specific correction details were summarized in Table 12. Note that the existing road surface is required to be pretreated for improvement before the application of chip seal if the accumulation of corrections is more than 35% or less than -20%.

Table 12. Recommended BAR/EAR Correction in the French Method *(56)*

Parameter			Correction of Dosage (%)
Traffic (HV/ln/day)	T0	> 750	-15
	T1	300 – 750	-12
	T2	150 – 300	-8
	T3+	100 – 150	-5
	T3-	50 – 100	0
	T4	25 – 50	+5
	T5	< 25	+10
		No HV	+12
Environment		Very Sunny	-5
		Sunny	-2
		Normal	0
		Shady	+5
		Very Shady	+10
Profile		Flat & Straight	0
		Sloping & Straight	-5
		Flat & curvy	+2
		Sloping & Curvy	-2
Existing Texture	Very rough	MTD > 1.7	+18
	Rough	MTD > 1.2	+12
	Not that rough	MTD > 0.8	+6
	Smooth not bleeding	MTD < 0.8	0
	Tendency to bleed	MTD < 0.8	-5
	Bleeding	MTD < 0.8	-10
Porosity and Permeability		Permeable	+5
		Impermeable	0
Hardness or rigidity		Not Punch-able	0
		Punch-able	+7
Construction Time		**April/May**	**0**
		June/July/August	**0**
		Starting September	**+5**
Binder Category		Cutback with Mineral Oil	+3
		Modified Cutback	+1
		Cutback with vegetable oil	-3
		Emulsion @65%	+6
		Emulsion @69%	0
		Modified emulsion @69%	0
Gradation		Normal (as guided)	0
		Finer	-5
		Coarser	+5
Flakiness		>15%	-4
		<10%	+4
		Normal Range	0
Region		Hot	-4
		Moderate	0
		Cold	+4
Altitude		< 500m	0
		500 – 1000m	+2
		> 1000 m	+4

5.10 NCSU Performance-based Design Method

North Carolina State University (NCSU) developed a performance-based chip seal design method where the AAR/EAR are determined through four major steps:1) aggregate analysis, 2) volumetric calculations, 3) detailed 3-D laser profiler scan test; and 4) corrections based on existing surface condition and aggregate absorption *(58)*. A flowchart summarizing the chip seal design framework in shown in Figure 10.

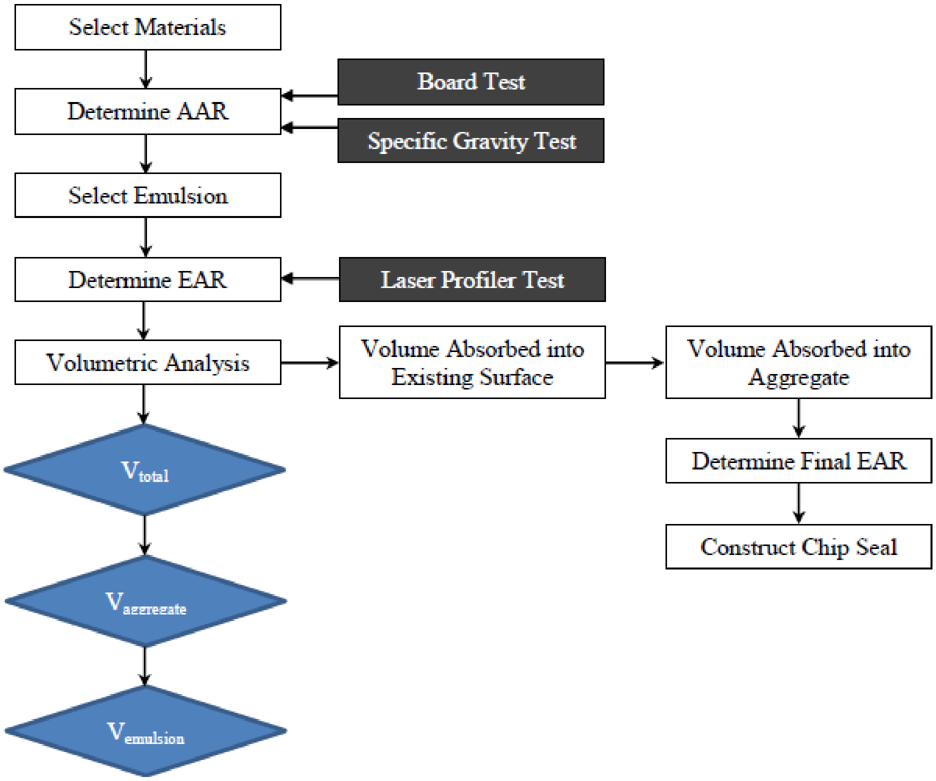


Figure 10. NCSU Design Framework *(58).*

As presented, the AAR was determined based on the board test and specific gravity test results, which was the same as the Kearby method. Note that the board test was conducted using a smaller board (i.e., 1 ft × 1.67 ft) instead of the original board (3 ft × 3ft) to reduce the test variability. Then, the 3-D laser profiler test was performed on the aggregate during the board test to obtain the total layer volume (V_{total}), shown in Figure 11. As presented, the V_{total} was the area between the bottom of the board (i.e., blue line) and the surface of the profiler view (i.e., red line). Subsequently, the volume of the air (V_{air}) in aggregates was calculated by subtracting the aggregate volume ($V_{aggregate}$) from the total volume.

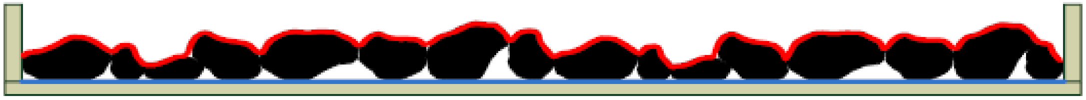


Figure 11. Schematic of Aggregate Board Test using 3-D Laser Profiler *(58)*.

In addition, it was assumed that the estimated embedment is approximately 50% by filling all the available voids in the chip seal, as shown in Figure 12. Note that embedment is defined as the emulsion height divided by the aggregate height. In this case, the air volume is considered as the basic emulsion volume, which was further adjusted based on the absorption of aggregate and existing pavement surface. Lastly, the BAR needs to be further adjusted based on engineering experience considering the on-site effects of aggregate penetration and steep grades.

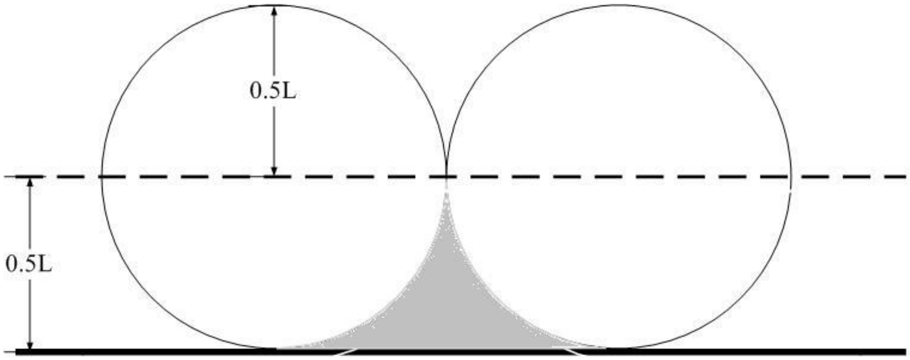


Figure 12. Illustration of 50% Embedment Concept *(58)*.

5.11 MSU Performance-Based Design Method

The aggregate in an ideal chip seal should be embedded adequately into the binder and aligned along its flattest side to ensure the durability of the chip seal treatment *(59)*. However, all the existing design methods assume that the ideal aggregate alignment and embedment will be achieved in the field during construction, which is not considered during the design process. To address this shortcoming, Michigan State University (MSU) developed a performance-based design procedure that addresses primary distresses (i.e., aggregate loss and bleeding) and directly considers aggregate orientation and embedment during the design process *(60)*. The MSU design framework presented in Figure 13 includes three steps: 1) determine AAR using image analysis; 2) select preliminary BARs based on the aggregate loss results; 3) determine the BAR based on the bleeding test results.

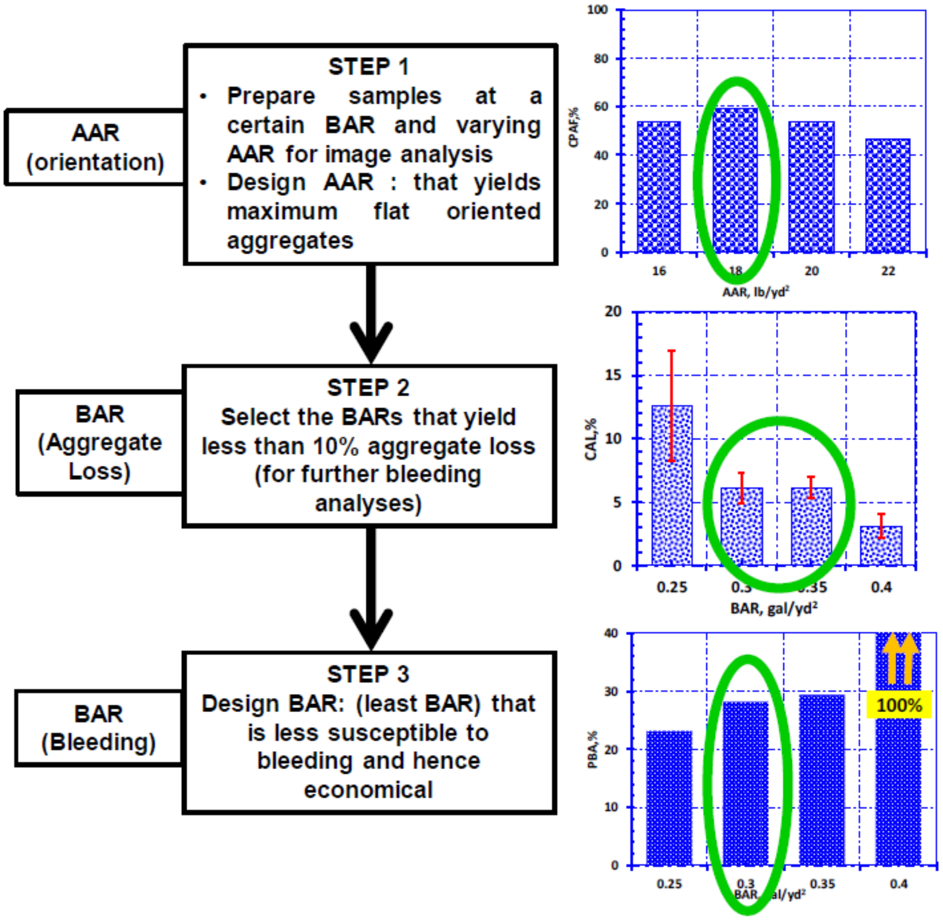


Figure 13. MSU Design Framework *(60).*

In this method, image analysis is first conducted on chip seal specimens prepared with various AARs at one selected BAR, and the optimum AAR is determined when the highest cumulative percentage of aggregates lying on the flattest side (CPAF) is achieved. The CPAF is calculated as the ratio between the number of the aggregate lying on the flattest side and the total aggregate number in the image. In the image analysis, the orientation angle of the aggregates (*θ*) is defined as the angle between the major axis and the horizontal axis, and aggregates with an angle of 20º and less are considered to be lying on the flattest side on the pavement substrate, as illustrated in Figure 14. After determining the optimum AAR, the specimens are prepared with multiple BARs at the optimum AAR, and the aggregate loss and bleeding performance of all the chip seal specimens are characterized using the sweep test (ASTM D7000) and modified Hamburg Wheel Tracking (HWT) test. For the bleeding characterization, the image analysis is conducted on the HWT specimens after 3,000 passes, and the parameter percent binder area (PBA) is calculated as the ratio between the black area (i.e., bleeding area) and the total area. In general, specimens with higher PBA are more susceptible to bleeding. Lastly, the minimum BAR that meets both aggregate loss (< 10%) and bleeding (< 30%) criteria is selected as the optimum BAR.

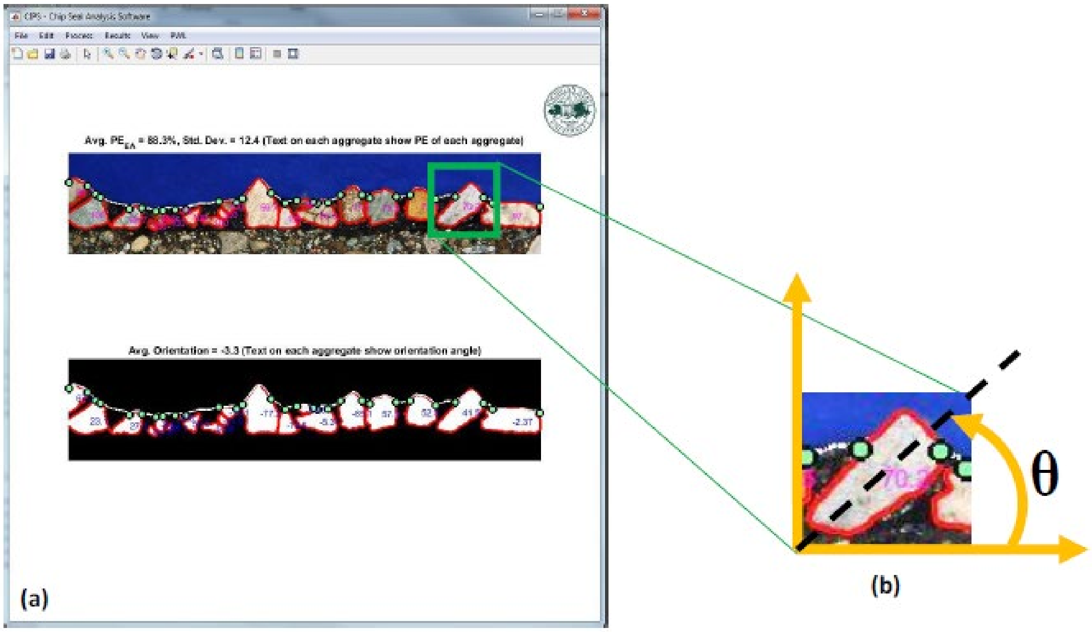


Figure 14. Illustration of Aggregate Orientation in the Image Analysis *(60).*

The research compared the BAR and AAR between this performance-based design method with three other widely used design procedures, shown in Table 13. As indicated, the AAR and BAR results determined based by modified McLeod method seemed comparable to this performance-based design method.

Table 13. Comparison of BAR and AAR among Different Chip Seal Design Methods *(60)*

Design Method	BAR (gal/yd^2)	AAR (lb/yd^2)
Modified Kearby	0.16	11.8
McLeod	0.19	23.8
Modified McLeod	0.38	18.8
Performance-based Design	0.30	18.0

5.12 UT Austin Design Method

Currently, most of the chip seal design methods determine the basic AAR and BAR based on the volumetric analysis (i.e., total volume of aggregate layer, air volume, binder volume, and embedment volume) and then further modify the rates based on the on-site conditions that usually are highly non-homogeneous. However, most of the on-site corrections are empirical and biased based on the judgment and experience of the site engineer. To mitigate the bias from data collection and on-site adjustment, the University of Texas at Austin applied 3-D laser technology throughout the chip seal design and construction to provide more precise and accurate estimates *(40)*. The findings from the UT Austin method can be applied to the existing design methods and allow the agencies to continue using the current design method with minimum modifications.

As discussed previously, the ALD is determined either by manual measurement or calculation based on the aggregate gradation and properties *(39, 46, 47)*. In this method, the ALD is measured using 3-D laser technology, which is faster, more accurate, and more reliable than the abovementioned methods. Subsequently, a composite model was developed to predict the aggregate coverage based on the AAR. The aggregate coverage is the ratio between the area covered by aggregate and the total area, which is determined by conducting image analysis on the 3-D laser profiler. This composite model is later used to determine the AAR based on given aggregate coverage.

Among the different design methods, the total volume of voids in aggregate layer (V_{Total}) is commonly defined as the volume of voids in aggregate (V_{Agg}) without considering the existing voids in the surface texture (V_{ES}), shown in Figure 15. In this method, the V_{Total} is revised through adding the V_{ES} and V_{Agg} together, and the V_{ES} is obtained by directly measuring the existing surface texture using 3-D laser device in this method. Thus, the revised V_{Total} can be directly used in the design equations of other design methods to improve the accuracy of surface condition correction.

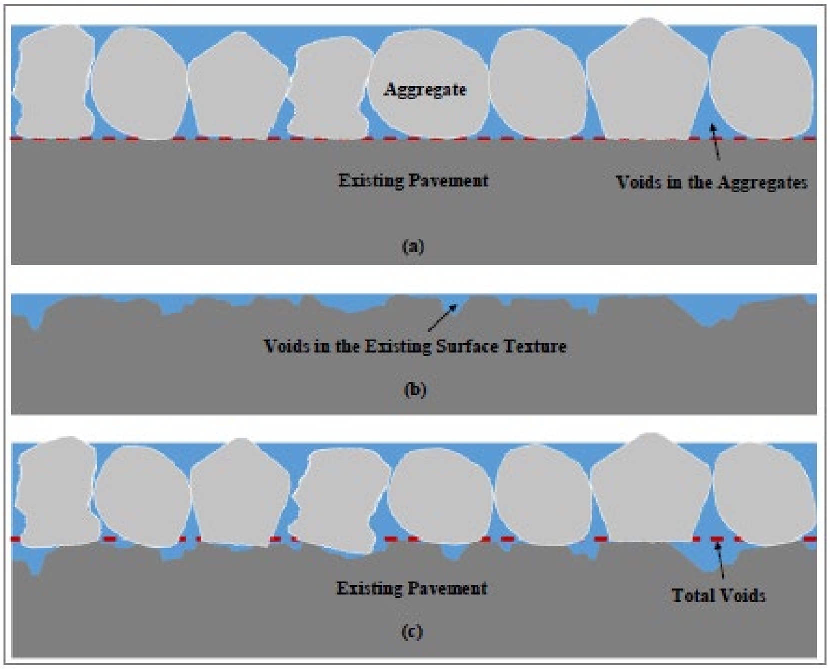


Figure 15. Effects of Existing Surface Texture on the Total Air Voids *(40)*.

5.13 Summary

As discussed, several design methods were identified in this review. Some of the methods are purely empirical and provided the foundation for the more modern design approaches. In general, the inputs require some knowledge of aggregate characteristics, and in most cases, corrections are applied to account for specific site conditions. Table 14 summarizes the required inputs and corrections factors for each of the methods discussed.

Table 14. Summary of Design Methods

Design Method	Required Inputs	Correction Factors
Hanson	Aggregate average least dimension (ALD) Aggregate bulk specific gravity (G)	None
Kearby and Modified Kearby	Loose unit weight of aggregate (W) Aggregate bulk specific gravity (G) Quantity of aggregate from the board test (Q) Desired embedment percentage (e) Residual asphalt content (R)	Traffic, substrate surface condition, season, and on-site temperature
McLeod and Modified McLeod	Aggregate median particle size (M) Flakiness Index (FI) Loose unit weight of aggregate (W) Aggregate bulk specific gravity (G) Aggregate absorption (A) Residual asphalt content (R)	Aggregate wastage from traffic whip-off, substrate condition
Spain	Smallest sieve opening that has a percent passing higher or equal to 90% (D) Largest sieve opening with a percent passing of less than 10% (d)	Road surface texture, aggregate type
New Zealand	Aggregate average least dimension (ALD) Mean texture depth from sand patch test (MTD) Average daily traffic (ADT) Percentage of heavy commercial vehicles (p)	Surface texture, traffic, grade, chip shape
Austroads	Aggregate average least dimension (ALD)	Aggregate shape, traffic, substrate texture, embedment, absorption into substrate, absorption into cover aggregate
South Africa	Aggregate average least dimension (ALD) Flakiness Index (FI)	Surface texture, climate, slow moving and channelized traffic, aggregate spread rate
United Kingdom	Road traffic category Hardness category of road surface	Season, aggregate type, shape, shade, surface condition, gradient, traffic speed, local traffic

France	Smallest sieve opening that has a percent passing higher or equal to 85% (D) Largest sieve opening with a percent passing of less than 15% (d)	Traffic, substrate surface conditions, alignment, region altitude, climate, aggregate size and shape, binder category, construction time
North Carolina State University	Aggregate weight from the board test ($W_{aggregate}$) Aggregate density ($r_{aggregate}$)	Surface condition, aggregate absorption
Michigan State University	Image analysis of specimens prepared with various AARs at one selected BAR	Results from aggregate loss and bleeding tests
University of Texas at Austin	Aggregate average least dimension (ALD) measured with 3-D laser technology Aggregate density ($r_{aggregate}$)	None

6. LABORATORY TESTS

There are a number of laboratory tests that can be conducted on the individual material components as well as the chip seal system to ensure compatibility, durability, and good performance are achieved. Some of them are included in the current AASHTO standards; however, there are other options available that could be considered during the development of new design methods.

6.1 Aggregate Tests

Table 15 summarizes the aggregate tests used in chip seal design, including the test standard, description, and measured parameters. The aggregate tests highlighted with green are included under AASHTO M 340-22 *Standard Specification for Materials for Emulsified Asphalt Chip Seal* and AASHTO R102-22 *Standard Practice for Emulsified Asphalt Chip Seal Design* and the results are used as either inputs to determine the material application rates, or as quality requirements for the aggregate. Additional tests used in other chip seal design methods described in Chapter 5 and in various research studies are also shown.

Table 15. Summary of Aggregate Tests used for Chip Seal Design

Standard	Test Description/Aggregate Properties	Test Parameters
AASHTO T27	Sieve Analysis of Fine and Coarse Aggregates	Size and Gradation
AASHTO T84/85	Specific Gravity of Coarse/Fine Aggregates	Specific Gravity (G) & Absorption (Abs%)
AASHTO T19	Unit Weight and Voids in Aggregates	Unit Weight and Voids
FLH T508	Coarse Aggregate Flakiness	Flakiness Index Value (%)
AASHTO T335	Coarse Aggregate Angularity	Percentage of Fracture (%)
AASHTO T96	Coarse Aggregate Toughness	Los Angeles Abrasion Loss (%)
ASTM D4791	Coarse Aggregate Shape and Texture	Flat, Elongated, or Flat and Elongated Particles Percentage (%)
AASHTO T327	Coarse Aggregate Abrasion Resistance	Micro-Deval Abrasion Loss (%)
AASHTO T104	Aggregate Soundness	Sulfate Soundness Loss (%)
AASHTO T278/279	Aggregate Skid/Polish Resistance	Aggregate Polish Value (PV)
AASHTO T112	Aggregate Cleanliness	Deleterious Materials Percent (%)
AASHTO T381	Aggregate Image Measurement System (AIMS)	Gradient Angularity (GA), Texture or Microtexture (TX), Sphericity (SP), and Form 2D

6.2 Asphalt Binder Tests

Table 16 summarizes the tests for emulsions and asphalt binders. The tests highlighted in green are used to characterize the emulsified binder for chip seal design under AASHTO M 340-22. The remaining tests have been recommended by others as quality tests for the emulsified asphalt or to evaluate different rheological properties of the asphalt binder residue.

Table 16. Summary of Asphalt Binder/Emulsified Asphalt Tests Used for Chip Seal Design

Standard/Reference	Test Description/Binder Properties	Test Properties/Notes
AASHTO M140	Emulsified Asphalt	Emulsion Grade
AASHTO M208	Cationic Emulsified Asphalt	Cationic Emulsion Grade
AASHTO M316	Polymer Modified Emulsified Asphalt	Polymer-Modified Emulsified Asphalt Grade
AASHTO T302	Polymer Content of emulsified asphalt residue and binders	Polymer Content
AASHTO T59	Standard Method of Emulsified Asphalts Testing	Composition, Consistency, Stability, Residue Examination, Specific Gravity, Ash Content, Solubility, Penetration, Ductility, Float Test, and Coating Test
AASHTO M320	Performance-graded Asphalt Binder	Performance Grade Criteria
AASHTO T315	Rheological Properties of Asphalt Binders (DSR)	Complex Modulus (G*) and Phase Angle (δ)
AASHTO T313	Flexural Creep Stiffness of Asphalt Binders (BBR)	Creep Stiffness (S) and m-value
AASHTO T316	Viscosity of Asphalt Binders	Viscosity
AASHTO T391	Linear Amplitude Sweep (LAS) Test	Binder Fatigue Performance Parameter N_f and Strain Level
AASHTO T350	Multiple Stress Creep and Recovery (MSCR) Test	Average Percent Recovery (R) and Nonrecoverable Creep Compliance (J_{nr})
AASHTO TP123	Elastic Recovery Test with DSR	Yield Energy and Elastic Recovery
Islam et al. *(61)*	Strain Sweep from 1 to 15% Strain Level at 25°C	Shear Stress at Failure and Yield Energy

6.3 Chip Seal Performance Tests

As mentioned earlier, the main concerns for chip seal performance relate to raveling/adhesion, bleeding, friction, and texture/embedment properties. Performance tests are typically not required as part of the design; however, there are test procedures available capable of measuring some of the critical properties that affect field performance. Table 17 shows tests found in the literature that could be implemented to assess chip seal performance in the laboratory and in the field.

For raveling, the sweep test (ASTM 7000) was the most commonly used in chip seal design and performance evaluation studies. The boiling water test, surface free energy test, binder bond strength (BBS) test, and the pneumatic adhesion tension (PAT) test were typically used to characterize the compatibility between the aggregate chips and asphalt binder (i.e., adhesion). Many studies evaluated the bleeding performance of chip seals in the laboratory using the modified loaded wheel test (LWT), and bleeding performance was quantified using image analysis to calculate the percentage of area occupied by the asphalt binder after loading *(60)*. Three friction tests were included in Table 17, with the locked-wheel skid trailer

(LWST) test being applicable for field testing only. In addition, the 3D laser device, circular texture meter (CTM), and sand patch test were commonly used to characterize macrotexture, which could be further used to calculate the embedment depth for a known aggregate ALD.

Table 17. Summary of Chip Seal Performance Tests

Chip Seal Performance Parameter	Test Name/Description	Standard/Reference
Raveling/Aggregate Loss/Adhesion	Sweep Test	ASTM 7000
	Vialit Adhesion Test	EN 12272-3 2003
	Texas Aggregate Retention Test	Tex-216-F
	Pennsylvania Aggregate Retention Test	Kandhal and Motter *(62)*
	Flip-over Test	Lee and Kim *(63)*
	Three-scale Model Mobile Load Simulator (MMLS3) Test	Lee et al. *(64)*
	Accelerated Chip Seal Simulation Device (HSKSC) Test	Aktas and Karaşahin *(32)*
	Frosted Marble Test	Howard et al. *(65)*
	Australian Aggregate Pull-out Test	Senadheera et al. *(66)*
	Plate-stripping Test	Australia Roads and Maritime Services (RMS) Test Method T230
	Boiling Water Test	ASTM D3625
	Surface Free Energy test	Alvarez et al. *(67)*
	Binder Bond Strength (BBS) Test	Moraes et al. *(68)*
	Pneumatic Adhesion Tension (PAT) Test	ASTM D4541
Bleeding	Three-scale Model Mobile Load Simulator (MMLS3) Test	Lee et al. *(64)*
	Accelerated Chip Seal Simulation Device (HSKSC) Test	Aktas and Karaşahin *(32)*
	Modified Loaded Wheel Test (LWT)	ASTM D6372
Friction	Dynamic Friction Tester (DFT) Test	ASTM E1911
	British Pendulum Tester (BPT) Test	AASHTO T278
	Locked-wheel Skid Trailer (LWST) Test	AASHTO T242
Texture/Embedment Depth	Three-dimensional (3D) Laser Profiler Test	Adams and Kim *(69)*; Cui et al. *(70)*; Pourhassan et al. *(71)*
	Circular Texture Meter (CTM) Test	ASTM E2157
	Sand Patch Test	ASTM E965

7. CONSTRUCTION

Following best practices during construction, along with proper project selection and treatment design, is necessary to ensure good chip seal performance. Chip seal construction is highly variable, particularly with practices common in North America *(72)*. Often, chip seal construction relies on experience instead of engineering principles, and agencies have limited knowledge of other agencies' successful chip sealing practices *(2)*. Agencies reporting superior chip seal performance, as shown through their detailed specifications, are able to consistently replicate successful chip seals by paying more attention to the details of construction and transferring detail to either construction contracts or in-house maintenance procedures *(73)*.

7.1 Equipment

The use of state-of-the-art equipment is critical to the success of chip seal treatments *(74)*. Construction of chip seals requires four main types of equipment *(1-4)*:

Distributor Truck

The function of the distributor truck is to apply the binder uniformly and in specified quantities. Binder distributors are essentially heated asphalt tanks with spraying equipment mounted on a truck (Figure 16). These include spray bars and nozzles, sometimes including parallel spray bars, or wheelpath bars, to allow for variable application rates across the lane.

Figure 16. Distributor Truck.

Each spray bar has evenly spaced nozzles. The asphalt tank is insulated and a heating system with a circulation pump is used to maintain asphalt viscosity. Burners for the heating system are located at the back of the tank while the circulation pump circulates the asphalt in the tank, maintaining a uniform temperature. Finally, the asphalt distributor includes controls and gauges used for controlling the application rate. Typical gauges on the distributor include tachometers, devices for measuring volumes, pressure gauges, and a thermometer. Most distributors today have computerized systems meant to regulate the pressure of the material to adjust for variable speeds and to allow operators to make swift adjustments *(2)*.

Aggregate Spreader

The aggregate spreader is used to apply a uniform aggregate cover at a specified rate over the freshly sprayed binder. Aggregate spreaders should be self-propelled and have a continuous feed feature (Figure

17). Self-propelled machinery has belt conveyors leading to a spreading hopper. The spreaders also have adjustable discharge gates with a discharge roller at the bottom of the gate. Controls are computerized and make automatic adjustments to the chip spreading rate to compensate for the variable speed. Dump trucks for aggregate should be sufficient to avoid interruption in aggregate supply and compatible with the aggregate spreader *(2)*.

Figure 17. Aggregate spreader.

A level of required quality is created by specifying the required features of both the asphalt distributor and the aggregate spreader, ensuring that only qualified equipment constructs the treatment. Thus, equipment specifications are vital to the success and performance of chip seal treatments *(73)*.

Rollers

Rollers orient and embed the aggregate into the binder, and help achieve aggregate interlock *(2)*. A minimum of three to four rollers has been mathematically proven to be required to achieve maximum production while maintaining even coverage of a 12-foot lane *(73)*. A self-propelled pneumatic roller capable of operating in both forward and reverse is recommended for all chip seal work (Figure 18). Steel rollers have been used on some chip seals with success; however, they could potentially crush the aggregate chips that cannot withstand the high stress imparted at the steel roller-chip interface and if used, should be limited to 5 tons. Rollers should not be operated in vibratory mode *(75)*.

Figure 18. Pneumatic Roller.

Brooms

Brooms are used to clean the existing road surface prior to chip seal construction as well as to remove excess aggregate after the constructed chip seal has cured. Brooming is done using rotary brooms with nylon or steel bristles or with vacuum mobile pickup brooms (Figure 19). Vacuum brooms are preferred in urban or residential areas for environmental reasons *(75)*.

Figure 19. Rotary broom (left) and vacuum broom (right).

7.2 Calibration

Qualified personnel are responsible for maintaining calibrated equipment. Several calibration checks should be performed regularly on the binder distributor, such as calibrating the spray bar to ensure each nozzle has the correct application rate and checking the spray bar height. Similarly, the aggregate spreader must also be maintained and calibrated routinely. The gates must be checked to ensure the spreader is evenly distributing the material across the roadway. One of the major causes of excess or inefficient aggregate is an improperly calibrated aggregate spreader *(2)*.

7.3 Construction Process

The construction process typically adheres to the following sequence *(2, 3, 35)*:

- Surface preparation
- Binder application
- Aggregate spreading
- Rolling
- Sweeping

The construction process is illustrated in Figure 20. Additional details are provided in the following sections.

a) Binder Application

b) Spreading of Aggregate

c) Rolling

d) Sweeping

Figure 20. Construction process for chip seals *(75)*.

Road Surface Preparation

Preparing the surface for treatment includes repairing all holes and depressions with a patch, crack sealing, leveling of bumps, waves, and corrugations, removal of excess asphalt, and a complete surface cleaning *(2)*. Agencies reporting excellent/good condition chip seals with excellent/good performance emphasize crack sealing prior to placement of the chip seal *(73)*. All patching materials and crack sealing must cure before placement of the chip seal. Ideally, patching should be completed no less than six months before the chip seal and crack sealing should be completed no less than three months before the chip seal *(2)*.

Application

Once all of the equipment is prepared and ready, the binder distributor begins spraying asphalt. Binder is sprayed across the entire width of the treatment in a uniform manner. On chip seal projects, the nozzles on the spray bars are set in such a way as to provide double- or triple-coverage of the roadway surface with emulsion, ensuring complete coverage.

The binder distributor sets the pace of all other equipment and minimal distance should be maintained between the distributor and the aggregate spreader. It is also recommended to have at least two to three loaded aggregate trucks ready to load the aggregate spreader to maintain adequate and efficient aggregate coverage of the asphalt. The aggregate is then spread evenly over the entire area covered by asphalt.

Care should be taken to ensure that the aggregate application rates provide the optimum amount of aggregate. If too much aggregate is spread, clean-up and sweeping efforts are increased. However, when too little aggregate is spread, the space between aggregate particles is too large to cause the asphalt to rise high enough to secure the aggregate in place, resulting in aggregate loss. Small areas with too little aggregate can be fixed by using a drag broom or a hand rake, redistributing the already spread aggregate. A drag broom or hand rake should always be used immediately for areas of the chip seal treatment where the aggregate is uneven, non-uniform, or irregular *(2)*.

Rolling and Sweeping

Aggregate chips must be rolled to ensure adequate embedment prior to the breaking of the emulsion, therefore, rollers must be able to keep up with the distributor truck and chip spreader and provide enough passes to embed the chips *(4)*. Rolling operations should always be planned prior to the treatment and communicated clearly between all involved members *(2)*.

Sweeping can generally be done after 30 minutes for hot-applied chip seals, and within 2 to 4 hours after application for emulsion-based chip seals. During a multi-layer chip seal operation, excess aggregate must be swept off between coats.

7.4 Weather Restrictions

When chip sealing, it is ideal to have weather conditions in which temperatures are high and sustained, humidity is low, and wind is at a minimum. Traditionally, the restrictions placed on temperatures for paving chip seals include a minimum ambient temperature and a maximum pavement temperature, ensuring that the emulsion does not break too quickly to efficiently place aggregate. As the specified ambient temperature increases, the chip sealing season becomes shorter. However, the performance of the treatment increases as the specification temperature increases *(73)*. Generally, it is specified that the ambient temperature should be at least 50 °C when using emulsions and at least 70 °C when using hot-applied binder *(2)*.

Pavement surface temperatures are also critical because the temperature on the pavement surface affects the viscosity of the emulsion or asphalt and break time of the emulsion. However, there is no general consensus on the maximum pavement temperature. The Asphalt Institute recommends at least 70 °C to ensure appropriate adhesion between the binder, aggregate, and pavement surface *(2)*.

Chip seals should also never be constructed when rain is likely, which could cause the chip seal to fail. If, in the case of an unexpected rainstorm, the treatment is exposed to rain, aggregate should be spread over the asphalt layer, covering the already placed binder. All other asphalt application should cease so as to not expose the treatment more. Finally, wind can aid the construction process or cause damages. Wind will speed up the breaking of the emulsion, allowing for a quicker brooming or sweeping and allow opening to traffic sooner. However, if it is windy enough, the spray from the nozzles may be diverted, leading to non-uniform binder application *(2)*.

7.5 Quality Assurance and Quality Control

The only way to determine if the materials used in design are the same materials used on site is to perform quality control testing *(2)*. A study of State Departments of Transportation (DOTs) with excellent chip seal programs reveals a strong correlation between aggressive quality control programs and chip seal treatment success *(74)*. Common material tests conducted during construction include *(2, 4, 76)*:

- **Aggregate sieve analysis:** Significant variations in the chip gradation can occur due to segregation or degradation during transport and stockpiling. Aggregate gradation should be checked to ensure the material does not deviate from the target design gradation by more than the established tolerances.
- **Moisture content:** Aggregate moisture content should be measured at the beginning and end of the day for: 1) calculating aggregate spread rate, and 2) determining when sweeping can occur and when traffic control can be removed.

- **Asphalt Tests:** There are several tests that can be run on the asphalt emulsion, but those that relate to bleeding or aggregate loss in chip seals are viscosity, penetration, elastic recovery, and particle charge. For performance graded binders, testing in accordance to AASHTO M320 or M322 should be conducted to verify that the binder meets specifications.

In addition, chip seal embedment is typically checked by pulling several chips out of the binder and visually estimating the amount of embedment. Tests like the sand patch test (ASTM E965) have been recommended for measuring surface texture and calculating the percent embedment; however, they have not been widely adopted for quality assurance.

7.6 Inspection

Inspectors assigned to projects must be familiar with the materials, equipment and the application process of chip seals. Local conditions and specific project requirements should be considered when determining the parameters of field inspection *(1)*. Typical areas of concern include *(76)*:

- Weather conditions (temperature and rain)
- Equipment calibration
- Cleanliness of roadway
- Material quantities/ application rates
- Binder or emulsion temperature
- Timeliness of emulsion and aggregate laydown, and rolling
- Proper signage and traffic control
- Quality of materials

8. SPECIFICATION REVIEW

A review of current State Departments of Transportation (DOTs) practices revealed that most state agencies (41) have standard specifications or special provisions for chip seal construction. The terminology varies among the states, with the treatment being called chip seal, seal coat, or bituminous/asphalt surface treatment. Most DOTs use emulsion-based chip seals rather than hot-applied binder chip seals.

In addition, AASHTO Guide Specifications for Highway Construction cover emulsified asphalt chip seal construction in Section 406. This guide specification provides information needed for owners or contractors and can easily be adopted and/or modified by any agency. The main sections covered in the AASHTO guide specifications contain requirements similar to those found among the state DOTs and are summarized below:

- **Equipment:** The specifications include requirements for the asphalt distributor, aggregate spreader, rollers, and brooms. All equipment should be self-propelled, and the asphalt distributor and aggregate spreader must be computerized. Some states allow the use of steel wheel rollers (for example, Kentucky allows the use of steel wheel rollers on slopes).
- **Calibration:** Proof of calibration is required to assure the correct material quantities are being applied. Generally, the calibration is performed prior to the beginning of the project (AASHTO specifies no earlier than five days prior to chip seal operations). Few DOT specifications (11) specifically mention equipment calibration or provide details on when it should be completed.
- **Preconstruction Meeting:** Conducting a preconstruction meeting is important to discuss topics such as construction process, quality control plan, mix design, materials control, materials measurement, equipment calibration, traffic control plan, equipment/process overview, inspection, test strip, unique project conditions, project documentation, and expectations. However, only two states (Arizona and Michigan) specifically list a preconstruction meeting requirement for chip seal projects.
- **Surface Preparation:** Surface preparation includes cleaning the existing pavement, protecting utilities, and removing thermoplastic pavement markings. These items are common among the specifications reviewed, with most focusing on removing all foreign materials prior to binder application.
- **Application:** Treatment application addresses weather limitations, test strips, application of materials, longitudinal and transverse joint construction methods, rolling and sweeping operations, traffic control, and protection of motor vehicles. In some instances, application of a fog seal following chip seal application is included as well.
- **Quality Control:** Specifications on quality control should outline the roles for quality staff, testing facilities, stockpile management, calibration, and workmanship. DOT specifications generally lack this level of detail.
- **Acceptance:** Agency acceptance activities include inspection overview, materials acceptance testing, and final inspection recommendations. Most commonly, sampling is specified to determine aggregate gradation, but tests on aggregate quality characteristics, moisture content, and binder properties are also specified by some agencies. Although as discussed throughout this document, aggregate embedment is critical to chip seal performance, very few agencies clearly state a requirement for percent embedment. Arizona specifies at least 70% (80% on high elevation areas), Pennsylvania calls for 50% or more before requiring a fog seal, Utah requires 70% after rolling operations, and Wyoming has a required range of 65 to 75%.

While chip seal specifications are very variable among states, the AASHTO guide specification can be a good starting point for agencies wishing to implement a new specification. In addition, agencies with successful chip seal programs tend to have more detailed specifications, proven to lead to good performing treatments.

9. SUMMARY

An intensive literature and practice review was conducted as part of this task. It is evident that successful chip seal projects begin with proper candidate selection, and that performance can be affected by many different factors relating to specific site conditions, as well as materials selection and design. There are various design methods available and selecting a specific approach (or developing a new one) may depend on availability of the required information and desired simplicity. While efforts have been made to improve the design with the aid of technological advances, some of the oldest methodologies are still used successfully.

Chip seal construction can also affect treatment quality and subsequent performance significantly. It is important to monitor construction operations closely to ensure that materials, equipment, and processes meet expectations. Communication between all parts involved is important, along with clearly outlined specifications.

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APPENDIX B. DRAFT SPECIFICATION

SECTION XX
EMULSIFIED ASPHALT CHIP SEAL

XX.1 DESCRIPTION

Construct a single-application chip seal on a prepared existing surface. Emulsion chip seal is an application of an emulsified asphalt binder covered with an application of clean graded aggregate to an existing asphalt surface. The emulsified asphalt binders may be modified with various polymers such as latex, tire, and natural rubbers. Aggregate must be durable, consisting of crushed stone, gravels, or manufactured aggregates varying in size from $^5/_8$ in. to a minimum of $^1/_4$ in.

XX.2 MATERIALS

Provide materials as specified below:

A. *Emulsified Asphalt.* Emulsified asphalt for chip seal shall meet the requirements of AASHTO M 140, M 208, or M 316.

B. *Aggregate.* Chip seal aggregate shall conform to the requirements specified in AASHTO MP 27, Section 6.1, Tables 1 and 2.

C. *Mix Design.* Design the chip seal to determine aggregate spread rate and emulsified asphalt application rate using a design method such as that described by AASHTO PP 82.

XX.3 CONSTRUCTION

A. Equipment. Furnish the following equipment or equivalent:

1. *Asphalt Distributor.* The asphalt distributor shall be self-propelled with a ground speed control device interconnected with the emulsified asphalt pump such that the specified application rate will be supplied at any speed. The asphalt distributor shall be capable of maintaining the emulsified asphalt at the specified temperature. The spray bar nozzles shall produce a uniform double or triple lap application fan spray, and the shutoff shall be instantaneous, with no dripping. All nozzles shall be oriented at the same angle between 15 and 30 degrees using the wrench supplied by the distributor manufacturer. Each asphalt distributor shall be capable of maintaining the specified application rate within ±0.015 gal/yd^2 for each load.

2. *Aggregate Spreader.* A self-propelled mechanical-type aggregate spreader with a computerized spread control, capable of distributing the aggregate uniformly to the required width and at the designed rate shall be used.

3. *Pneumatic-Tire Rollers.* A minimum of three self-propelled pneumatic-tire rollers capable of ballast loading, either with water or sand, to allow the weight of the machine to be varied from 6 to 8 tons to achieve a minimum contact pressure of 80 lb/in.^{2} shall be used. The alignment of the axles shall be such that the rear-axle tires, when inflated to the proper pressure, can compact the voids untouched by the front-axle tires. All tires shall be as supplied by the roller manufacturer. Width of the rollers shall exceed 60 in.

4. *Steel-wheel rollers.* If used, steel rollers should be limited to 5 tons. Vibration shall not be used if the rollers are so equipped.

5. *Brooms.* Motorized brooms with a positive means of controlling vertical pressure shall be used to clean the road surface prior to spraying emulsified asphalt. Plastic bristle brooms are required to remove loose aggregate after rolling.

6. *Trucks.* Unless otherwise approved, use trucks of uniform capacity to deliver the aggregate. Provide documentation showing measurements and calculation in cubic yards. Clearly mark the calibrated level. Truck size may be limited when shown on the plans.

B. *Equipment Calibration:*

Provide proof of calibration of the asphalt distributor and the aggregate spreader. Conduct calibration no earlier than five days prior to chip seal operations. Submit the results of the calibration procedure to the Engineer.

C. *Preconstruction Meeting.* Coordinate a preconstruction meeting prior to construction with the Engineer to discuss the following topics:

1. Construction process;
2. Quality control plan; required to be submitted;
3. Mix design; required to be submitted;
4. Materials control;
5. Materials measurement;
6. Equipment calibration; required to be submitted;
7. Traffic control plan;
8. Equipment/process overview;
9. Inspection;
10. Test strip;
11. Unique project conditions;
12. Project documentation; and
13. Expectations.

D. *Road Surface Preparations:*

1. *Cleaning Pavement.* Clean the roadway surface by sweeping no more than 30 min prior to application of the emulsified asphalt and aggregate. However, this 30-min window may be extended if authorized by the Engineer in cases where extending the time does not jeopardize a clean surface prior to chip seal operations. Sweep the pavement with a motorized broom to remove loose material. Clean depressions not reached by the motorized broom with a hand broom. Clean the outer edges of the pavement to be sealed including an adjacent paved shoulder.

2. *Protecting Accessories.* Cover utility castings (e.g. manholes, gate valve covers, catch basins, sensors) to prevent coating with emulsified asphalt. Suitable covering includes plywood disks, kraft paper, roofing felt, or other approved methods. Remove the protective coverings before opening the road to traffic.

3. *Stripe Removal.* Thermoplastic pavement markings shall be removed by grinding or other approved methods prior to chip seal operations. Other pavement markings may be left in place.

E. *Application:*

1. *Weather Limitations.* Construct chip seal per the following conditions:

a. Ambient and pavement surface temperatures shall be 50°F and rising.

b. Application of the chip seal shall be only during daylight hours.

c. Suspend chip sealing if the pavement surface temperature exceeds 140°F.

d. The road surface shall be dry to damp.

2. *Test Strip.* Construct a test strip on or near the project site. Construct the test strip under similar placement conditions of time of day, temperature, and humidity as expected for the duration of the project. The test strip shall be a minimum of 500 ft in length and shall be constructed with the job mix proportions, materials, and equipment to be used on the project. Adjustments to the mixture formula shall be permitted provided they do not exceed the values stated in the mix design. The Agency shall evaluate the test strip to determine whether project specifications are met. If specifications are not met, additional test strips will be constructed until specifications are met, at no additional cost to the Agency.

3. *Application of Emulsified Asphalt:*

   Apply the emulsified asphalt at the rate determined by the design. This rate shall be within ±5 percent of the chip seal design rate. After applying the emulsified asphalt, place the cover aggregate at the design application rate. Adjust the rate of application, if necessary, so that some emulsified asphalt can be seen between the aggregate chips, but not so much that aggregate chips adhere to the pneumatic rollers. Inspect the aggregate in the wheel paths for proper embedment. Embedment shall be 50 to 60 percent after rolling. Make additional adjustments to the rate of application during the project, if needed.

   The temperature of the emulsified asphalt at the time of application shall be above 120°F (50°C).

   The longitudinal construction joint for a single-course chip seal must coincide with the painted lane line or the outside edge of the shoulder. There shall be no overlap of the longitudinal construction joint for a single-application chip seal.

4. *Application of Cover Aggregate.* Provide uniformly moistened aggregates that are damp at the time of placement. Damp aggregates shall be saturated but surface dry with

approximate moisture content between 1 and 3 percent depending on the aggregate absorption capacity.

The speed of the spreader shall be restricted to prevent the aggregates from rolling over. Starting and stopping of the spreader should be minimized. The edges of the aggregate applications shall be sharply defined. Previously used aggregates from sweeping may not be returned to the stockpile or the spreader for reuse.

5. *Transverse Paper Joints.* When beginning a new application of the chip seal transversely abutting the previously placed chip seal, use a transverse paper joint so excess asphalt and chips are not placed at the joint. The transverse paper joint shall be formed by placing 36-in. wide kraft paper on top of the previously applied chip seal so the edge of the paper aligns with the joint that will be formed when the previously placed chip seal meets the newly applied chip seal. The asphalt distributor shall begin applying emulsified asphalt by starting the application on top of the kraft paper. After the asphalt distributor moves forward and over the joint, the paper shall be removed.
6. *Rolling Operations.* Complete the first roller pass as soon as possible but not longer than 2 min after applying the aggregate. Proceed in a longitudinal direction at a speed less than or equal to 3 mph. Three complete roller passes of the aggregate chips are required as a minimum. One pass is defined as the roller moving over the aggregates in a single direction. Ensure the rolling is completed quickly enough to embed the aggregate, before the emulsified asphalt breaks, and no longer than 15 min after the emulsified asphalt is sprayed. Position the rollers in echelon so the entire width of the pavement lane is covered in one pass of the rollers. If desired, final rolling may be accomplished using the steel-wheel roller in one pass.
7. *Sweeping.* Excess aggregate shall be swept off the new surface in accordance with Table XX.3-1.

TableXX.3-1. Sweeping Sequence

Chip Seal Class[a]		
I	**II**	**III**
Within 24 h after rolling	No later than the following morning	Before traffic is allowed without traffic control

[a] Class I is less than 500 annual average daily traffic (AADT), Class II is 501 to 5000 AADT, and Class III is greater than 5000 AADT.

Do not sweep embedded aggregate until at least 85 percent of the total moisture present in the chip seal has evaporated or aggregates may become dislodged. The Contractor shall dispose of the surplus cover aggregate in a manner satisfactory to the Agency. In no case shall the excess aggregates swept from the surface exceed 10 percent of the total amount placed. If this quantity is exceeded, work shall cease until an adjustment is made to reduce the spread rate to be within tolerances.

8. *Traffic Control*

Traffic may be allowed onto the fresh chip seal after rolling is completed and before sweeping in accordance with Table XX.3-2. Before allowing traffic on the newly placed chip seal, ensure that at least 85 percent of the total moisture present in the chip seal has evaporated or aggregates may become dislodged.

TableXX.3-2. Timing for Traffic

Chip Seal Class[a]		
I	**II**	**III**
Traffic controlled with speed limit signs	Traffic controlled with pilot cars	Traffic controlled with pilot cars

[a] Class I is less than 500 annual average daily traffic (AADT), Class II is 501 to 5000 AADT, and Class III is greater than 5000 AADT.

9. *Fog Seal*

If, in accordance with the plans, a fog seal is applied to the surface of the completed chip seal, spray the fog seal after sweeping and before placement of permanent pavement markings, but not sooner than 24 h after final rolling.

10. *Sequence of Work:*

Construct the chip seal so that adjacent lanes are sealed on the same day when possible. If the adjacent lane(s) has not been sealed, sweep all loose aggregate from the unsealed lane(s) before traffic is allowed on the surface without traffic control.

Permanent pavement markings shall not be placed for 24 h after placing the chip seal when no fog seal is applied.

If fog seal is used, the permanent pavement markings shall not be placed before three days have elapsed for waterborne pavement marking or ten days for other types of markings.

F. *Quality Control*

QC activities shall include monitoring, inspection, sampling, and testing. The minimum materials QC requirements and frequencies required are listed in Tables XX.3-3 and XX.3-4.

Table XX.3-3. Minimum Aggregate QC Requirements

Process Control Test	Test Method	Minimum Frequency
Gradation[a]	AASHTO T 11 or AASHTO T 27	Prior to construction for design, then once per day of placement and every change of source
Unit Weight	AASHTO T 19M/T 19	Prior to construction for design, then every change of source
Bulk Specific Gravity	AASHTO T 85	Once, prior to construction for design, then every change of source
Aggregate Absorption	AASHTO T 85	Once, prior to construction for design, then every change of source
L.A. Abrasion	AASHTO T 96	Once, prior to construction for design, then every change of source
Soundness	AASHTO T 104	Once, prior to construction for design, then every change of source
Deleterious Material	AASHTO T 112	Once, prior to construction, then every change of source
Fractured Faces	AASHTO T 335	Once, prior to construction, then every change of source
Flakiness Index	FLH T 508	Prior to construction for design, then every other day of placement or change of source
Application Rate	Truckload Yield Check, Tarp on Roadway	Once at startup each production day

[a] Aggregate samples will be taken at the project stockpile site using AASHTO R 90 Method B. Gradation test results should be provided within 24 hours.

Table XX.3-4. Minimum Asphalt Emulsion QC Requirements

Process Control Test	Test Method	Minimum Frequency
Tests on Emulsion[a]		
Viscosity	AASHTO T 59 or T 382	Once per 200 tons of material placed
Temperature	N/A	Once delivery tanker
Particle Charge	AASHTO T 59	Prior to loading emulsion distributor
Demulsibility	AASHTO T 59	Once per 200 tons of material placed
Sieve	AASHTO T 59	Once per 200 tons of material placed
Storage Stability	AASHTO T 59	Once per 200 tons of material placed
Residue[b]	AASHTO R 78	Once per 200 tons of material placed
Application Rate	Computer Printout, Volumetric Measurement, Plate on Roadway	Once at startup each production day, then each 500 tons of aggregate placed
Tests on Residue		
Solubility	AASHTO T 44	Once per 200 tons of material placed
Penetration	AASHTO T 49	Once per 200 tons of material placed
Ductility	AASHTO T 51	Once per 500 tons of material placed
Ash Content	AASHTO T 111	Once per 200 tons of material placed
Elastic Recovery	AASHTO T 301	Once per 500 tons of material placed
MSCR, Jnr, % Recovery	AASHTO T 350	Once per 500 tons of material placed

[a] A material certification from the supplier shall be provided with each delivery tanker. Asphalt emulsion samples will be taken at the point of delivery from the delivery tanker using AASHTO R 66.

XX.4 MEASUREMENT

The Engineer will measure work acceptably completed as specified below:

A. *Emulsified Asphalt.* Emulsified asphalt will be measured for chip seal by volume at 60°F.

B. *Aggregate.* Aggregate will be measured based on the area of pavement surfaced.

APPENDIX C. IMPLEMENTATION PLAN

IMPLEMENTATION PLAN

PURPOSE AND OBJECTIVES

The purpose of this implementation plan is to establish a standardized approach for chip seal design and construction across all New Mexico Department of Transportation (NMDOT) districts. By adopting a formal design methodology and uniform specifications, NMDOT aims to improve consistency, optimize material usage, and enhance the long-term performance of chip seal treatments statewide.

This plan seeks to achieve the following objectives:

1. **Adopt the Modified Kearby Method (AASHTO R 102-22)**

   Implement a systematic design procedure for determining binder and aggregate application rates based on material properties, traffic conditions, and pavement surface characteristics.

2. **Develop and Implement Statewide Specifications**

   Establish uniform construction specifications for chip seal treatments, including material requirements, application procedures, and quality control standards.

3. **Integrate Pavement Management System (PMS) Data into Project Selection**

   Use PMS condition data to identify candidate routes, prioritize pavements in good condition for treatment, and improve timing of preservation activities.

4. **Construct Pilot Test Sections in Each District**

   Validate the design methodology under local conditions through pilot projects, monitor early performance indicators, and refine guidelines based on field results.

5. **Provide Training and Capacity Building**

   Equip NMDOT staff and maintenance crews with the knowledge and tools needed to implement the standardized design and construction practices effectively.

SCOPE

This implementation plan applies to all NMDOT districts that perform chip seal treatments and covers the full range of activities required to standardize design and construction practices statewide. The scope includes adoption of the Modified Kearby method for determining binder and aggregate application rates, development of uniform construction specifications, and establishment of a material testing protocol to ensure quality and consistency. It also encompasses the integration of design and performance data into the Pavement Management System (PMS) to support data-driven project selection and long-term monitoring. Pilot test sections will be constructed in each district to validate the design method under local conditions, and lessons learned will inform statewide rollout. Training programs, quality assurance measures, and continuous improvement processes are included to ensure successful implementation and sustainability of the standardized approach.

KEY COMPONENTS

The implementation of standardized chip seal practices across NMDOT will focus on five core components, as described below.

Design Method Adoption

To ensure consistency and accuracy in chip seal applications across all NMDOT districts, the Modified Kearby method, as documented in AASHTO R 102-22, will be formally adopted as the statewide design procedure. This method provides a systematic approach for determining binder and aggregate application rates based on material properties and site-specific conditions.

While the design procedure, material specifications, and test procedures are documented in various AASHTO standards, the development of a comprehensive design manual that outlines the step-by-step process is recommended. A standardized Excel-based calculator has been created as part of the study to simplify computations and ensure uniformity across districts.

Training will be a critical component of adoption; district engineers and maintenance crews will receive hands-on instruction through workshops, annual conferences, and online modules, ensuring proficiency in both design and field verification.

Construction Specifications

To achieve uniformity and quality in chip seal applications statewide, it is recommended that NMDOT adopt standardized construction specifications aligned with AASHTO guidelines and tailored to New Mexico's conditions. These specifications will define requirements for surface preparation, binder and aggregate application, rolling, and post-construction activities. These specifications will provide a consistent framework for all districts, reducing variability and improving long-term performance of chip seal treatments.

Material Testing Protocol

A robust material testing protocol is essential to ensure that chip seal designs are accurate and tailored to local conditions. Before determining application rates, all aggregates and emulsified binders must undergo standardized laboratory testing in accordance with AASHTO specifications. Aggregate testing will include sieve analysis for gradation, bulk specific gravity, and loose unit weight to support design calculations, as well as flakiness index, fractured faces, and Los Angeles abrasion tests to confirm durability and shape requirements. Emulsified binders will be tested for residue content and viscosity to verify compliance with performance standards. These tests will be conducted by certified regional laboratories with established turnaround times to prevent project delays. A formal sample submission process will be implemented, requiring districts to collect representative material samples and submit them with detailed source information. Test results will be documented in a centralized database accessible to design engineers and integrated into the Pavement Management System (PMS) for long-term performance tracking. This protocol ensures that every chip seal project is based on verified material properties, reducing variability and improving treatment durability across all districts.

Pilot Test Sections

To ensure successful statewide implementation of the Modified Kearby method and standardized construction practices, NMDOT will initiate pilot test sections in each district during the first phase of deployment. These pilot projects will serve as controlled environments to validate design procedures under local material, traffic, and climate conditions. Each district will select representative routes based on Pavement Management System (PMS) data and current preservation needs. For each pilot, laboratory-designed application rates for binder and aggregate will be compared against field-applied rates, with adjustments documented to refine design templates and specifications. Performance monitoring will begin immediately after construction, focusing on early indicators such as aggregate retention, bleeding, and embedment depth, followed by periodic evaluations at one-year and three-year intervals. Data collected from these pilot projects will be integrated into PMS and analyzed to confirm the effectiveness of the design method and construction specifications. Lessons learned will inform statewide training programs and specification updates, ensuring that full-scale implementation is based on proven practices tailored to New Mexico’s diverse conditions.

PMS Integration

Integrating chip seal design and performance data into the Pavement Management System (PMS) is critical for data-driven decision-making and continuous improvement. The PMS will be updated to include key design parameters such as aggregate and binder application rates, material properties, and correction factors used in the Modified Kearby method. This linkage will allow NMDOT to track the relationship between design inputs and field performance over time, enabling refinement of specifications and treatment strategies. Project selection criteria will also be aligned with PMS indicators, prioritizing pavements with high structural integrity but declining environmental condition scores, ensuring chip seals are applied at the optimal point in the deterioration curve. Performance monitoring will include early distress indicators such as raveling and bleeding, as well as long-term Pavement Condition Rating (PCR) trends, which will be analyzed to validate service life expectations and improve treatment timing. By embedding design and performance data into PMS workflows, NMDOT can enhance predictive modeling, optimize resource allocation, and maintain a consistent statewide approach to pavement preservation.

Initial implementation will include pilot projects in each district to validate the method under local conditions and compare design-based application rates with current practices. Lessons learned from these pilots will inform refinements to the guidelines before full-scale deployment. Finally, design data will be integrated into the Pavement Management System (PMS) to enable performance tracking and continuous improvement, ensuring that the adoption of the Modified Kearby method enhances consistency, optimizes material usage, and improves long-term pavement performance statewide.

ROLES AND RESPONSIBILITIES

Clear roles and responsibilities are essential for successful implementation of standardized chip seal practices. The NMDOT Research Bureau will lead the program, providing oversight, coordinating guideline development, and ensuring alignment with statewide pavement preservation objectives. District Engineers will be responsible for applying the Modified Kearby design method, managing material testing requests, and verifying compliance with design protocols. District Maintenance Crews will execute construction activities, including surface preparation, binder and aggregate application, rolling, and sweeping, while adhering to the new specifications and quality control requirements. The Pavement Management System (PMS) Team will integrate design and performance data into the PMS database, enabling data-driven project selection and long-term monitoring. External technical partners, such as the National Center for Asphalt Technology (NCAT) and pooled fund study participants, will provide technical guidance, training, and support for pilot project validation. Quality Assurance staff will conduct inspections during construction to confirm adherence to specifications, and NMDOT's Training Academy will coordinate with subject matter experts to develop and deliver workshops, online modules, and field manuals to build capacity across all districts. This collaborative structure ensures accountability and consistency throughout the implementation process.

TIMELINE

The implementation will follow a phased approach over a 24-month period to allow for gradual adoption and refinement. Phase 1 (0–6 months) will focus on developing statewide specifications, design manuals, calculation templates, and training materials. During this phase, NMDOT will also identify certified laboratories and establish material testing protocols. Phase 2 (6–18 months) will involve constructing pilot test sections in each district, validating design procedures under local conditions, and monitoring early performance indicators such as aggregate retention and bleeding. Lessons learned during this phase will inform adjustments to specifications and training programs. Phase 3 (18–24 months) will complete the statewide rollout, integrating design and performance data into PMS workflows and ensuring all districts adopt the Modified Kearby method and standardized construction practices. Annual progress reports will be prepared to document achievements, challenges, and recommendations for continuous improvement beyond the initial implementation period.

TRAINING AND CAPACITY BUILDING

Training is a critical component of successful implementation. NMDOT will leverage its existing Training Academy and Technician Training and Certification Program (TTCP) to deliver targeted instruction on the Modified Kearby design method, standardized construction specifications, and quality assurance procedures. Training will include hands-on workshops for district engineers and maintenance crews, focusing on material testing, board test procedures, and field verification of application rates. These sessions will be supplemented by online modules, quick-reference guides, and video demonstrations to ensure accessibility and consistency across all districts. The annual Chip Seal Conference will incorporate dedicated sessions on design methodology, equipment calibration, and best practices for chip seal construction. By embedding training into existing programs and providing ongoing support, NMDOT will build the technical capacity needed to sustain uniform chip seal practices statewide.

PERFORMANCE METRICS

To measure the success of this implementation plan, NMDOT will track key performance indicators (KPIs) throughout the rollout. Metrics will include the percentage of projects designed using the Modified Kearby method, variance between laboratory-designed and field-applied application rates (targeting less than 5%), and compliance with standardized specifications. Early performance indicators such as aggregate retention and bleeding will be monitored within the first year, while long-term metrics will focus on Pavement Condition Rating (PCR) trends and service life extension compared to baseline practices. Additional measures will include training completion rates, number of certified personnel, and integration of design data into PMS workflows. These metrics will be reported annually to evaluate progress, identify areas for improvement, and ensure accountability.

RISK MANAGEMENT

Implementing standardized chip seal practices across a statewide network involves several potential risks, including funding constraints, staffing shortages, and equipment limitations. Inflationary pressures may impact material costs, while vacancies in engineering and maintenance positions could delay project execution. Aging equipment may reduce productivity and compromise quality control. To mitigate these risks, NMDOT will adopt a phased implementation strategy, prioritize high-impact routes, and leverage pooled fund resources for technical support and cost-sharing opportunities. Contingency plans will include cross-training personnel to address staffing gaps and scheduling flexibility to accommodate equipment availability. Continuous monitoring of risks and proactive adjustments will ensure that implementation remains on track and that statewide adoption of standardized chip seal practices is achieved without compromising quality or performance.

INTEGRATION WITH TRANSPORTATION POOLED FUND TPF-5(522)

NMDOT, as a partner agency in TPF-5(522), will integrate pooled fund resources throughout implementation. Led by the Minnesota Department of Transportation (MnDOT), TPF-5(522) focuses on improving the quality of pavement preservation treatment construction and data collection by providing: (1) preconstruction technical support and training (virtual); (2) on-site construction support for test sections; (3) standardized performance monitoring and reporting; and (4) guidance to harmonize specifications and practices using AASHTO standards. Contractors include Auburn University/NCAT and the National Center for Pavement Preservation, who will support New Mexico's pilot sections and statewide adoption with technical oversight and data protocols. NMDOT will nominate projects to this research program, coordinate sponsor meetings, and ensure PMS linkages so New Mexico data contribute to national life-extension curves and best practices.