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MTI MINETA TRANSPORTATION INSTITUTE

Manual for Chip Seals

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California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY Chico

MINETA TRANSPORTATION INSTITUTE
California Pavement Preservation Center

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MANUAL FOR CHIP SEALS

R. Gary Hicks, PhD, PE
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Chip seals, also known as seal coats or surface treatments, are a valuable preservation treatment for roads which receive light to medium traffic; they have also performed well on higher-volume roadways and are usually placed on an existing asphalt pavement.
Chip seals are placed by spraying the pavement with a binder, either an asphalt emulsion or a hot applied binder, from a distributor truck, and then immediately applying a uniform application of a cover aggregate (chips or screening) using a self-propelled chip spreader. The aggregate is rolled as soon as possible to ensure embedment and adhesion of the aggregate to the fresh binder.
Chip seals can be placed in single or multiple layers, usually using 1/4 to 1/2 inch aggregates. On multiple chip seals, the binder and aggregate application process is repeated, with the aggregate size declining with each application. Only clean and well-crushed aggregates should be used in chip seals. They should only be placed in warm weather, and traffic needs to be controlled until the chips are well adhered to the pavement surface. Excess loose aggregate should be swept after placement in order to avoid windshield and vehicle damage.
This report presents the best practices for construction of chip seals, including scrub and Geosynthetic Reinforced Chip Seals (GRCS), and also includes guides for troubleshooting problems. It also includes information on the design of chip seals as well as guide specifications for both emulsion and hot applied chip seals.</td></tr>
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EXECUTIVE SUMMARY

Chip seals, also known as seal coats or surface treatments, are a valuable preservation treatment for roads which receive light to medium traffic; they have also performed well on higher-volume roadways and are usually placed on an existing asphalt pavement.

Chip seals are placed by spraying the pavement with a binder, either an asphalt emulsion or a hot applied binder, from a distributor truck, and then immediately applying a uniform application of a cover aggregate (chips or screening) using a self-propelled chip spreader. The aggregate is rolled as soon as possible to ensure embedment and adhesion of the aggregate to the fresh binder.

Chip seals can be placed in single or multiple layers, usually using 1/4 to 1/2 inch aggregates. On multiple chip seals, the binder and aggregate application process is repeated, with the aggregate size declining with each application. Only clean and well-crushed aggregates should be used in chip seals. They should only be placed in warm weather, and traffic needs to be controlled until the chips are well adhered to the pavement surface. Excess loose aggregate should be swept after placement in order to avoid windshield and vehicle damage.

This report presents the best practices for construction of chip seals, including scrub and Geosynthetic Reinforced Chip Seals (GRCS), and also includes guides for troubleshooting problems. It also includes information on the design of chip seals as well as guide specifications for both emulsion and hot applied chip seals.

I. INTRODUCTION

BACKGROUND

California passed Senate Bill 1 (SB-1) in 2018 to raise revenue for transportation infrastructure improvements through increased state gas and other taxes. Part of this money is being distributed back to the local agencies, which will be split between all cities and counties throughout the state. The purpose of this manual is to provide training for local agency staff so that they will have the ability to recognize their maintenance needs, be knowledgeable of maintenance strategies, and develop the most cost-effective strategies for preserving their aging hot mix asphalt (HMA) pavements.

Chip seals have been around since the 1920s. They were first used as a wearing course in the construction of low-volume roads. In the past several years, they have evolved into maintenance treatments that can be successfully used on both low and high-volume roads. The popularity of chip seals is a direct result of their low initial costs in comparison with thin hot mix overlays. Currently, with improved binders and equipment, considerable interest has been shown toward using chip seals in a wide range of applications on public roads, highways, local streets, and a multitude of other surfacing projects throughout the world. Chip seals have been accepted and incorporated into many maintenance programs as a cost-effective maintenance treatment.[1]

A chip seal is a surface treatment that consists of a layer(s) of asphalt binder (hot or emulsion) with a layer(s) of embedded cover aggregate. This treatment provides a new skid-resistant wearing surface, stops raveling, seals minor cracks, and retards further deterioration of the existing roadway. Common types of chip seals include:

- Single chip seals
- Double chip seals
- Scrub seals
- Geosynthetic reinforced chip seals (GRCS)
- Chip seal interlayers with a HMA overlay

Different binders can be used in chip seals, either cold or hot applied. Cold applied binders included modified and unmodified asphalt emulsions, normally rapid setting. Hot applied binders can be polymer modified asphalt cements, asphalt rubber, and rubberized asphalt such as polymer/crumb rubber blends. The appropriate binder type is selected based on pavement condition, volume and type of traffic, climate, aggregate properties, desired service life, and cost considerations.

PURPOSE

This manual is one of several designed to empower local agency staff, through training, to choose the right treatment at the right time to optimize their maintenance funds. Most local agencies have deferred road maintenance over many years, and there are thousands of miles of public roads that are currently in poor condition. With new funding being made available for maintenance and construction projects, the importance of proper road maintenance is paramount. Chip seals are just one type of many maintenance treatments that will preserve pavements until structural overlay or re-construction projects can be designed and funded. Chip seals extend the life of a pavement by the prevention of moisture intrusion into the base and subgrade. When properly designed and constructed, a chip seal is a cost-effective tool that provides improved life cycle benefits.

As mentioned above, chip seals are a generic term to describe treatments commonly referred to as:

- Seal coats
- Armor coats
- Surface treatments

It has been shown that chip seals provide improvements in performance and extend pavement life. Although an untreated asphalt pavement may still be adequate after several years of use, pavement deterioration has already begun and the application of a chip seal needs to be applied before significant deterioration has occurred.

ORGANIZATION OF THE MANUAL

This manual is one of three manuals addressing pavement preservation strategies: 1) Slurry Surfacing, 2) Chip Seals, and 3) Cape Seals. Besides project selection, types of chip seals (including scrub and GRCS) are described, as well as the design process for chip seals, construction, and troubleshooting guides. A reference list is also included, followed by the appendices, which include example specifications for emulsion chip seals, hot applied chip seals, and fog seals or flush coats; the appendices also include example specifications for scrub seals and GRCS as well as an example for chip seal design.

II. PROJECT SELECTION

WHEN SHOULD A CHIP SEAL BE USED?

The selection of a pavement for a chip seal project is based on the structural soundness of a pavement and the types of distress that are present. The ability of a treatment to address the current condition of a project is paramount in selecting an appropriate treatment. The main criteria addressed by the various chip seal types are:

- Conventional emulsion chip seals are used on structurally sound pavements with minimal cracking and restore skid resistance.

- Polymer-Modified Emulsion (PME) chip seals are used to correct raveling and pavement oxidation (especially in harsher climates) and restore skid resistance. Polymers also aid in bonding and early retention of chips.

- Hot chip seals (asphalt rubber and terminal blends) cure quickly, restore skid resistance on worn surfaces, and resist reflection cracking. They can be applied in cooler ambient temperatures and at night.

- Scrub seals are used to seal significant cracking using a rejuvenating emulsion binder.

- GRCS are geosynthetic reinforced chip seals which can be used when there is significant cracking.

- Hot binders such as asphalt rubber and polymer-modified (PG) asphalts may be used to address specific distress modes.

- Significant cracking, flushing, and base failures cannot be addressed with emulsion chip seals. However, they have been addressed with hot applied cape seals and multilayer treatments.

- Deformation, rutting and shoving cannot be addressed with chip seals of any kind.

The main advantages associated with chip seals include:

- Excellent Waterproofing: Chip seals provide sealing against water intrusion.

- Improved Skid Resistance: Chip seals provide good skid resistance

- Cost-Effective Treatments: Chip seals are typically cost-effective when properly placed on the right type of pavement. Hot chip seals will cost more than conventional emulsion-based chip seals.

- Good Durability: Chip seals wear well and can have long service lives.

- Ease of Construction: Chip seals are typically constructed rapidly and cause less disruption to the traveling public than do other treatments such as thin blanket overlays that take longer to construct.

The main disadvantages associated with chip seals include:

- Cure Time: Emulsion chip seals take several hours (depending on the climatic conditions) to reach a stage where they can tolerate unrestricted traffic.

- Flying Chips: Chip seals must be swept to remove excess stone and fog sealed to avoid broken windshields and vehicle damage.

- Rough surface: Bicyclists, roller bladers, and skateboarders find them too rough and noisy.

- Weather Considerations: Emulsion chip seals must be constructed during warm, dry weather and during the daytime only. Hot applied chip seals may be applied in cooler conditions and at night.

- Performance: Chip seals create a rougher surface and are generally not used for parking lots. Chip seals do not improve ride quality.

According to WSDOT, agencies in the United States generally place chip seals when there is some evidence of distress on the roadway.[2] The overall design approach includes the steps of evaluating and determining the following:[3]

- Surface condition
  - Texture
  - Type and extent of distress
- Traffic conditions: volume, speed, percentage of trucks, etc.
- Climatic and seasonal characteristics
  - Humidity and wind
  - Air temperature
  - Surface temperature
- Aggregate selection and availability
  - Type of aggregate
  - Aggregate properties

- Binder
    - Type
    - Hot versus cold applied
- Time available for construction operations

The use of chip seals has specific limitations. For example, chip seals should be used considering the following guidelines:[4]

- As a surface for light to medium traffic, at an average daily traffic (ADT) value of less than 30,000
- If using a conventional emulsion chip seal application, it should be used to treat only structurally sound pavements with minimal cracking
- Emulsion chip seals are used for raveling and pavement oxidation
- Rubberized chip seals cure fast and resist reflection cracking
- Full lane chip sealing is best for treating longitudinal and transverse cracking at a width less than 1/4 inch, and alligator cracking
- Emulsion chip seals should be placed when the ambient temperature is 65°F and the surface temperature is 85°F and increasing. Hot applied chip seals can be placed in cooler weather.

WHEN SHOULD A CHIP SEAL NOT BE USED?

Chip seals should not be used in the following:[5]

- Structurally deficient pavements
- Cracks greater than 1/4 inch width unless they are sealed; when using Asphalt Rubber, the chip seal can be placed over cracks up to 3/8 inch
- Large number of potholes
- Over fresh crack sealing and rutted pavements
- Areas subject to high turning stresses (e.g. parking lots, tight residential streets, and cul-de-sacs)
- Bike lanes when using the larger chip sizes (it is possible to produce good bike lanes with a 1/4 inch chip size)

- Where ride quality needs significant improvement
- In areas of severe distresses such as severe cracking, flushing, and base failures
- If the ambient temperature falls below 70°F before the treatment can cure; hot applied chip seals can be placed in cooler weather
- For emulsion chip seals, if there will be rain within 24 hours
- If there is too much wind
- On very hot days (>105°F).

If a project has significant distress, repairs such as crack sealing and patching need to be done prior to chip sealing. Best practices would be to place a pavement preservation treatment prior to the pavement reaching a PCI of less than 80. Figure 1 shows the PCI values from 0–100 and their corresponding pavement condition rating.

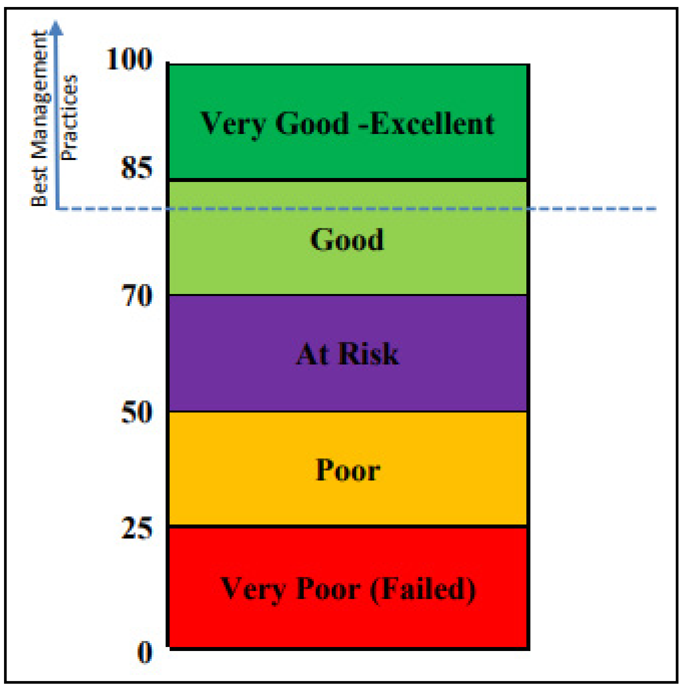


Figure 1. StreetSaver Pavement Condition Index Classifications

Source: County of Riverside Department of Transportation, 2014.

III. TYPES OF CHIP SEALS

Two broad types of chip seals are used in California and elsewhere: those using asphalt emulsions, and those using hot applied binders to secure the chips. These types are discussed in this chapter.

EMULSION CHIP SEALS

Types of Emulsion Chip Seals

There are several types of emulsion chip seals in use today. They include the following:

- Single Chip Seal: A single chip seal is an application of binder followed by an aggregate. This is used as a pavement preservation treatment and provides a new skid-resistant wearing surface, arrests raveling, and seals minor cracks. This is by far the most common type of chip seal used in California. Figure 2 illustrates this type of chip seal application.

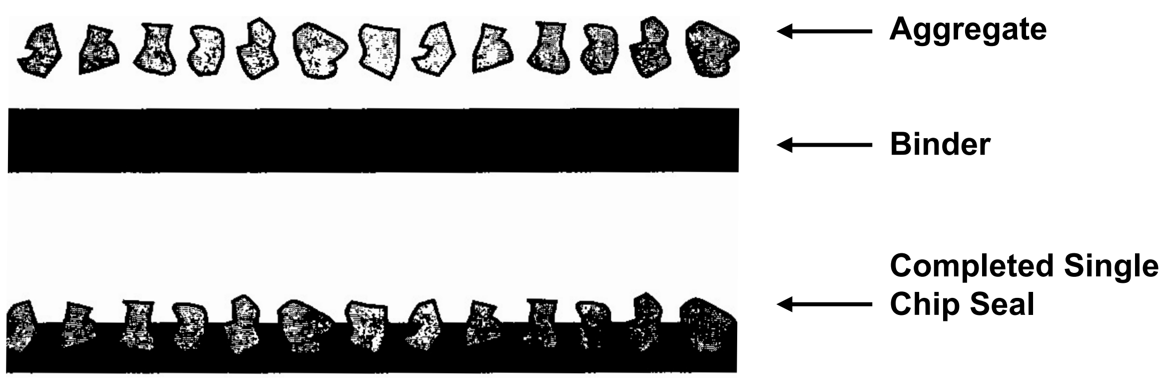


Figure 2. Single Chip Seal

Source: MTAG, 2008.

- Double Chip Seal: A double chip seal (or armor coat) is a built-up seal coat consisting of multiple applications of an asphalt emulsion binder and aggregate. A double chip seal consists of a spray application of binder, spreading a layer of aggregate, rolling the aggregate for embedment, applying an additional application of binder, spreading another layer of aggregate (approximately half the average least dimension of the base layer aggregate), and final rolling. Sweeping should be done between applications. This process may be repeated, as necessary, to build up a pavement's edges. Double chip seals are used where a harder-wearing and longer-lasting surface treatment is needed. Figure 3 illustrates a double chip seal application.

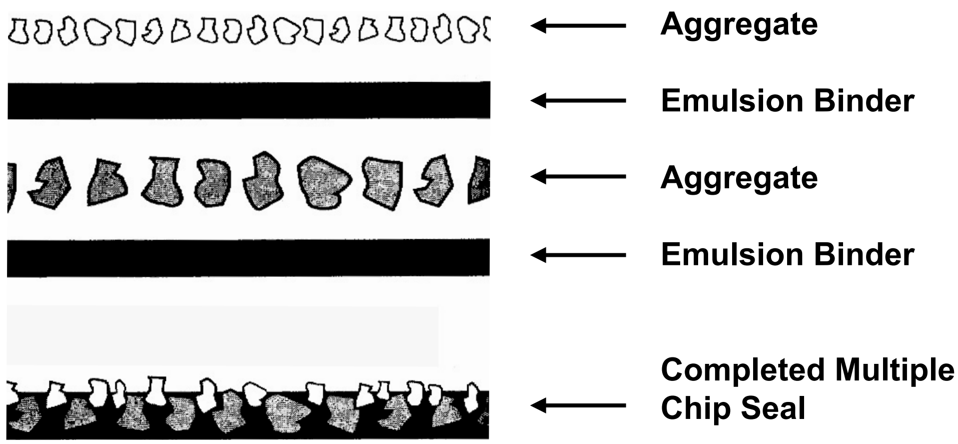


Figure 3. Double Chip Seal

Source: MTAG, 2008.

- Scrub Seals: A Scrub Seal uses a specialized polymer-modified rejuvenating emulsion (PMRE) as the chip binder in conjunction with an attached scrub broom that forces the emulsion into the cracks.

- Interlayer Applications: Paving fabrics followed by a chip seal have also been used in California. Now referred to as a GRCS, it is often used and specified by local agencies with excellent performance over moderately cracked pavements.

Types of Emulsions

Binder type varies according to the type of chip seal being used. Binder types include:

- Asphalt Emulsion: Asphalt emulsions are water-based products composed of a bituminous material uniformly emulsified with water and an emulsifying or stabilizing agent.

- Polymer modified emulsions (PME) contain a polymer and are available as Cationic Polymer-modified emulsions (PME), such as PMCRS-2 and PMCRS-2h. These are found in the Standard Specifications, Section 94 (Caltrans, 2018).

- Rejuvenating Emulsion: This emulsion is not only highly polymerized, which adds flexibility, toughness and durability to a chip seal: it also contains a recycling agent that rejuvenates the aged pavement surface. It also rejuvenates the aged surface of the walls of the cracks: therefore, it significantly aids in the sealing of the cracks. It is commonly used in scrub seals.

Table 1 lists common binder types and their suitable applications.

Table 1. Binder Type and Suitable Applications

Binder Type	Single	Multiple	Sand	Scrub	GRCS
Asphalt Emulsions	Yes	Yes	Yes	No	Yes
Rejuvenating Emulsions	Yes	No	Yes	Yes	No

Aggregates

Aggregates used for emulsion chip seals are usually single-sized (with a specified narrow gradation), of good quality, angular and clean. For chip seals, the best performance is obtained when the aggregate has the following characteristics:

- Single-sized
- Clean (dust-free), although PRME scrub seal applications can tolerate some dust
- Free of clay
- Cubical (limited flat and elongated particles)
- Fractured faces
- Compatible with the selected binder type
- Aggregates should be surface damp for emulsion use.

The specifics on the aggregates used including the gradations are discussed further in a later chapter.

HOT APPLIED CHIP SEALS

Types of Hot Chip Seals

The types of hot applied chip seals commonly used in California include the following:

- Single Chip Seal: A single chip seal is an application of hot binder followed by an aggregate.
- Double Chip Seal: A double chip seal (or armor coat) is a built-up seal coat consisting of multiple applications of binder and aggregate. As an example, a double chip seal consists of a spray application of binder, spreading a layer of aggregate, rolling the aggregate for embedment, applying an additional application of binder, spreading another layer of aggregate (approximately half the average least dimension of the base coat aggregate), and rolling once more. Sweeping should be done between applications. This process may be repeated, as necessary, to build up a pavement's edges. Double or multiple chip seals are used where a harder-wearing and longer-lasting surface treatment is needed

- Stress Absorbing Membrane (SAM) Seal: A SAM is a single chip seal in which a hot modified binder (normally asphalt rubber) is applied, followed by a layer of aggregate, plus rolling. Binder applications are much higher than those used for conventional emulsion chip seals. Generally, a SAM has been used with asphalt rubber (AR) binders.

- Stress Absorbing Membrane Inter-layer (SAMI): A SAMI is a membrane seal that is used to retard the rate of reflection cracking in new HMA overlays. It consists of an application of a hot modified binder followed by a layer of aggregate, spread and rolled. An HMA overlay is then placed over the membrane. If necessary, traffic may be allowed to operate on the SAMI prior to construction of the overlay.

Types of Hot Binders

The types of binders commonly used in California include the following:

- Performance Graded (PG) Asphalt: California is divided into different climate zones based on different climatic conditions. PG asphalt binders are selected to meet expected climatic conditions as well as aging considerations with a certain level of reliability. Hot polymer modified binders can be used wherever extra performance and durability are desired, typically at higher elevations and/or desert environments. Polymer modification is done at a refinery or at a binder storage tank terminal.

- Asphalt Rubber Binder: Binders modified with high levels of crumb tire rubber and a high natural rubber content material. These binders require special field blending equipment which adds to an increased cost. They are sprayed hot and require hot chips pre-coated with asphalt. Hot applied AR binders can be placed at cooler temperatures than emulsion binders and can be placed at night. They are the primary type of hot binder used in California.

- Terminal Blends: Binders modified with a minimum of 10% fine crumb rubber and a minimum of 3% polymer. These binders are sprayed hot and require hot applied pre-coated chips.

Table 2 summarizes the hot binder types and suitable applications. In the 2018 Caltrans standard specifications, the asphalt rubber chip seal is the only hot applied binder specified for chip seals.

Table 2. Binder Type and Suitable Applications

Binder Type	Single	Multiple	SAM/SAMI
PG graded asphalts-polymer modified	Yes	Yes	No
Asphalt Rubber	Yes	Yes	Yes
Terminal blend rubberized asphalt	Yes	Yes	Yes

Aggregates

Aggregates used for hot applied chip seals of good quality and meet the specified gradation. For chip seals, the best performance is obtained when the aggregate has the following characteristics:

- Single-sized (if possible)
- Clean
- Free of clay
- Cubical (limited flat and elongated particles)
- Fractured faces
- Compatible with the selected binder type
- Aggregates must be dry for use with hot binders

The aggregates used in these applications also are pre-heated and pre-coated with an asphalt binder to ensure better chip retention. The specifics of the aggregates used, including the gradations, are discussed further in a later chapter.

IV. DESIGN PROCESS FOR CHIP SEALS

Two broad approaches have been used to determine the application rates for the binder and aggregate used in chip seals, including scrub seals and GRCS. These approaches include the use of engineering judgment (or the historical approach) and the use of a more theoretical or engineered approach. Both of these approaches are discussed in this chapter.

HISTORICAL APPROACH

Many agencies rely on experience and judgment rather than engineering for the design of chip seals, considering the design process to be art rather than science. Gransberg, in his report on chip seal best practices, concluded that the past experience of the highway agency personnel appears to be the major factor for achieving chip seal success.

With this approach, the use of best practices in construction is critical, and the following considerations are important:

- Weather conditions during and after construction
- Surface preparation before beginning the work, such as crack sealing, repairing potholes, and dig outs of severe fatigue failures
- Traffic control during and after construction
- Application rates must be selected to fit site conditions
- A properly calibrated and adjusted spray bar, with properly positioned nozzles is critical to uniform application of the binder
- Condition of the aggregate chips is important: the binders will not adhere to aggregate that is too dusty or too wet
- The chip spreader should follow the distributor immediately after the binder is applied
- The rolling procedure should start immediately after the application of the chips to embed the chips in the binder
- Light sweeping with minimum downward pressure is necessary to remove the loose aggregate without dislodging the embedded chips after the binder has cured

In this approach, ranges of application rates for the binder and aggregate are usually specified and then the exact application rates are determined in the field on a project by project basis.

MATERIALS

Emulsion Chip Seals

Section 37-2.02 of Caltrans Standard Specification includes the materials and procedures to be used for applying asphaltic emulsion chip seals.[6] An asphaltic emulsion chip seal in California generally includes applying an asphaltic emulsion, followed by aggregate, and then a flush coat (or fog seal). This product is a light application of emulsion used to blacken the surface and help retain the rock. A double asphaltic emulsion chip seal is the application of an asphaltic emulsion followed by aggregate, applied twice in sequence and then a flush coat.

The aggregate gradation for an asphaltic emulsion chip seal must comply with the requirements shown in Table 3. Note that three sizes are available, with the 3/8 inch top seal being the most commonly used in California.

Table 3. Asphaltic Emulsion Chip Seal Aggregate Gradation

Quality characteristic	Test method	Requirement		
Gradation (% passing by weight) Sieve size:		3/8”	5/16”	1/4”
3/4”	California Test 202	--	--	--
1/2”		100	--	--
3/8”		85–100	100	100
No. 4		0–15	0–50	60–85
No. 8		0–5	0–15	0–25
No. 16		--	0–5	0–5
No. 30		--	0–3	0–3
No. 200		0–2	0–2	0–2

Section 37-2.03 of Caltrans Standard Specifications includes the materials and procedures for applying polymer-modified emulsion chip seals. A polymer-modified emulsion chip seal includes applying a PME followed by aggregate, and then a flush coat or fog seal. A double chip seal is the application of a PME followed by aggregate, applied twice in sequence and then a flush coat.

The specifications for PME binders given in Table 4 must include elastomeric polymer. A polymer modified asphaltic emulsion must be Grade PMRS2, PMRS2h, PMCRS2, or PMCRS2h.

Table 4. Polymer Modified Asphaltic Emulsion (Caltrans Section 94)

		Requirement			
		Anionic		Cationic	
Quality characteristic	Test method	Grade PMRS2	Grade PMRS2h	Grade PMCRS2	Grade PM-CRS2h
Saybolt Furol viscosity, @ 50°C (Saybolt Furol seconds)	AASHTO T 59	100–400	100–400	100–400	100–4,000
Storage stability test, 1 day (max., %)		1	1	1	1
Sieve test (max., %)		0.30	0.30	0.30	0.30
Demulsibility (min., %)		60[a]	60[a]	40[b]	40[b]
Particle charge[c]				positive	positive
Residue from distillation or evaporation (min., %)	AASHTO T 59[e]	65	65	65	65
Tests on residue from evaporation test:					
Penetration, 25°C	AASHTO T 49	100–200	40–90	100–200	40–90
Ductility, 25°C, (min., mm)	AASHTO T 51	400	400	400	400
Torsional recovery (min., %)	California Test 332	20			
or			65	65	65
Elastic recover, 25°C, min., %)[d]	AASHTO T-301	65			

[a] Use 35 ml of 0.02 N CaCl2 solution.
[b] Use 35 ml of 0.8% sodium dioctyl sulfosuccinate solution.
[c] Must comply with pH requirement of 6.7 max. under ASTM E 70 if the particle charge test is inconclusive
[d] Elastic recovery is defining test if conflict with torsional recovery
[e] Distillation is defining test if in conflict with evaporation; distillation temperature of 350°F

A polymer-modified asphaltic emulsion must also comply with Section 94 of the 2018 Caltrans Standard Specifications and the quality characteristic requirements as shown in Table 5.

Table 5. Polymeric Asphaltic Emulsion

Quality characteristic	Test method	Requirement
Penetration, 4°C, 200g for 60 seconds (min.)	AASHTO T 49	6
Ring and Ball Softening Point (min., °C)	AASHTO T 53	57

Aggregate acceptance is based on the Department's sampling and testing for compliance with the requirements shown in the following Table 6. This applies to both conventional and polymer-modified chip seals.

Table 6. Aggregate Gradation Acceptance Criteria

Quality characteristic	Test method	Requirement		
Gradation (% passing by weight) Sieve size:		3/8”	5/16”	1/4”
3/4”	California Test 202	--	--	--
1/2”		100	--	--
3/8”		85–100	100	100
No. 4		0–15	0–50	60–85
No. 8		0–5	0–15	0–25
No. 16		--	0–5	0–5
No. 30		--	0–3	0–3
No. 200		0–2	0–2	0–2

Hot Applied Chip Seals

Section 37-2.04 of Caltrans Standard Specifications also includes materials and construction procedures for applying asphalt rubber binder chip seals. The following are excerpts from that section.

“An asphalt rubber binder chip seal consists of applying hot asphalt rubber binder followed by hot aggregate pre-coated with an asphalt binder, followed by a flush coat or fog seal.

An asphalt rubber binder must be 79±1 percent by weight asphalt binder and 21±1 percent by weight of CRM. The minimum percentage of CRM must be 20.0 percent, and lower values must not be rounded up.

The CRM must be 75±2 percent by weight scrap tire crumb rubber and 25±2 percent by weight high natural scrap tire crumb rubber. In early projects, high natural from tennis balls was used, but this practice is not as common now.

An asphalt modifier and asphalt binder must be blended at the production site. An asphalt modifier must be from 2.5 to 6.0 percent by weight of the asphalt binder in the asphalt rubber binder. The asphalt rubber binder supplier determines the exact percentage. These modifiers are also referred to as extender oils.

If blended before adding CRM, the asphalt binder must be from 375 to 440°F when an asphalt modifier is added and the mixture must circulate for at least 20 minutes. An asphalt binder, asphalt modifier, and CRM may be proportioned and combined simultaneously.

The blend of an asphalt binder and an asphalt modifier must be combined with the CRM at the asphalt rubber binder production site. The asphalt binder and asphalt modifier blend must be from 375 to 440°F when the CRM is added. Combined ingredients must be allowed to react until there are two descending viscosities at temperatures from 375 to 425°F, except the temperature must be at least 10°F below the flash point of the asphalt rubber binder.”

After reacting, the asphalt rubber binder must comply with the requirements shown in Table 7.

Table 7. Asphalt Rubber Binder

Quality characteristic	Test method	Requirement
Cone penetration at 25°C (0.10 mm)	ASTM D217	25–60
Resilience at 25 °C (% rebound)	ASTM D5329	18–50
Softening point (°C)	ASTM D36	55–88
Viscosity at 375 °F (Pa•s x 10-3)[a]	ASTM D7741	1,500–2,500

[a] Prepare sample for viscosity test under California Test 388.

Maintain asphalt rubber binder at a temperature from 375 to 415°F. Stop heating unused asphalt rubber binder four hours after the reaction period. Reheating asphalt rubber binder that cools below 375°F is a reheat cycle. Do not exceed two reheat cycles. If reheating, the asphalt rubber binder must be from 375 to 415°F before use.

During reheating, you may add CRM. The CRM must not exceed 10 percent by weight of the asphalt rubber binder. Allow added CRM to react for at least 45 minutes. Reheated asphalt rubber binder must comply with the specifications for asphalt rubber binder.

Before pre-coating the aggregate with an asphalt binder, the aggregate for an asphalt rubber binder chip seal must comply with the gradation requirements shown in Table 8.

Table 8. Asphalt Rubber Binder Chip Seal Aggregate Gradation

Quality characteristic	Test method	Requirement	
Gradation (% passing by weight) Sieve size:		1/2”	3/8”
3/4”	California Test 202	100	100
1/2”		85–90	95–100
3/8”		0–30	70–85
No. 4		0–5	0–15
No. 8		--	0–5
No. 200		0–1	0–1

Scrub Seals

A scrub seal consists of a uniform application of a polymer-modified rejuvenating emulsion (PMRE) followed by a scrub broom mounted at the rear of the distributor truck which sweeps and floods the emulsion into pores and cracks in the pavement surface. This application is followed by a uniform application of aggregate, which is then rolled using a pneumatic tired roller. In California, this product is used by many local agencies, but Caltrans does not yet include scrub seals into their 2018 specifications. According to Caltrans, the PRME used for scrub seals should meet the specifications included in Table

9. The aggregate gradations used for the scrub seal are the same as used for conventional and polymer modified chip seals. Caltrans has constructed several scrub seal pilot projects and has developed non-standard special provisions (NSPP) for these projects, and they are included in Appendix B of this report.

Table 9. Polymer Modified Rejuvenating Emulsion

Quality characteristic	Test method	Requirement Grade PMRE
Saybolt Furol viscosity, @ 50°C (Saybolt Furol seconds)	AASHTO T 59	50–350
Storage stability test, 1 day (max., %)		1.0
Sieve (max., %)		0.3
Oil distillate (max., %)		0.5
Demulsibility (min., %)[a]		40
Particle charge		Positive
pH	ASTM E70	2.0–5.0
Residue from distillation or evaporation test[b] (min., %):	AASHTO T59[c]	65
Test on Residue:		
Viscosity @ 60°C, (P) (max.)	AASHTO T202[d,e]	5000
Penetration, 4°C, (dmm)	AASHTO T 49	40–70
Elastic Recovery, 25°C, (min., %)	AASHTO T301[f]	60

[a] If product is to be diluted, demulsibility is waived
[b] Distillation is defining test if conflict with evaporation
[c] Distillation temperature of 350°F
[d] If it is suspected that a sample may contain solid material, strain the melted sample into the container through a No. 50 (300 µm) sieve conforming to Specification E 11.
[e] Use an AI-200 glass capillary tube to run the test. If the viscosity is 4000 or above use an AI 400 instead.
[f] Elastic Recovery, Hour glass sides, pull to 20 cm, hold 5 minutes then cut, let sit 1 hour.

The rejuvenating agent must meet the requirements for quality characteristics shown in Table 10.

Table 10. Requirements for Rejuvenating Agent

Quality characteristic	Test method	Requirements
	Test on rejuvenating agent	
Viscosity, 60°C, cSt (centistoke)	ASTM D2170	50–175
Flash point, °C, (min.)	ASTM D92	193
Saturate (max., % by weight)	ASTM D2007	30
Asphaltenes (max.)	ASTM D2007	1.0
	Test on rejuvenating agent RTFOT Residue	
Weight change (max., %)	ASTM D2872	6.5
Viscosity ratio (max.)	ASTM D2170	3

Geosynthetic Reinforced Chip Seals (GRCS)

At the present time, neither Caltrans nor the Greenbook has a specification for GRCS, but the product is increasing in frequency of use by local agencies. This technique is intended for roads that have a sound structural section which do not deform under loads. The design and construction processes consist of the following steps:

- Applying hot liquid asphalt to the existing pavement and then applying a geosynthetic fabric. The fabric must be thoroughly saturated during rolling so that it is bonded to the existing surface.

- If the chip seal is not applied immediately, it is recommended that a light sanding be applied to prevent pickup from traffic. The application rate for the sand is 2–4 lbs./yd^2 and the maximum size aggregate is 3/8 inch.

- An emulsion chip seal is then applied to the sanded surface. This could be either a single or double chip seal. Hot applied chip seals with high melt fabric could also be considered but are not as widely used.

- The application rates for the chip seal would be similar to those recommended by Caltrans or the local agency.

Guide specifications from the AIA for these types of applications are given in Appendix B.

DETERMINATION OF APPLICATION RATES (BINDER AND AGGREGATE)

Emulsion Chip Seals

According to 2018 Caltrans Standard Specifications, emulsions must be applied within the application rate ranges shown in Table 11. This applies not only to conventional but also to polymer modified emulsions.

Table 11. Asphaltic Emulsion Application Rates

Aggregate gradation	Application rate range (gal/sq. yd.)
3/8”	0.30–0.45
5/16”	0.25–0.35
1/4”	0.20–0.30

For double asphaltic emulsion chip seals, the asphaltic emulsions must be applied within the application rates shown in Table 12.

Table 12. Asphaltic Emulsion Application Rates

Double chip seals	Application rate range (gal/sq. yd.)
1st application	0.30–0.45
2nd application	0.20–0.30

When applied, the temperature of the asphaltic emulsions must be from 130 to 180°F. Apply asphaltic emulsions when the ambient air temperature is from 65 to 110°F and the pavement surface temperature is at least 80°F. Do not apply asphaltic emulsions when weather forecasts predict the ambient air temperature will fall below 39°F within 24 hours after application.

For single chip seals, aggregate must be spread within the spread rate ranges shown in Table 13. For double emulsion chip seals, aggregate must be spread within the spread rate ranges shown in Table 14.

Table 13. Aggregate Spread Rates

Aggregate gradation	Spread rate range (lbs./sq. yd.)
3/8”	20–30
5/16”	16–25
1/4”	12–20

Table 14. Aggregate Spread Rates

Double chip seal	Spread rate range (lbs./sq. yd.)
1st application	23–30
2nd application	12–20

It is necessary to sweep and remove the excess aggregate on the first application before the second application of asphaltic emulsion.

For Scrub Seals, the NSSP from Caltrans requires that the PRME must be applied within the application rate ranges shown in Table 15 which is the same as for other chip seals. These values should be adequate to create a wave in front of the broom. If not, the application rate should be increased until a wave is observed.

Table 15. PRME Application Rates

Aggregate gradation	Application rate range (gal/sq. yd.)
3/8”	0.30–0.45
5/16”	0.25–0.35
1/4”	0.20–0.30

The PRME should be applied when the ambient air temperature is from 60 to 105°F and the pavement surface temperature is at least 80°F. Do not apply polymer-modified asphaltic emulsions when weather forecasts predict the ambient air temperature will fall below 39°F within 24 hours after application.

Aggregate gradations are the same as for the other chip seals, and the aggregate must be spread within the spread rate ranges shown in Table 16.

Table 16. Aggregate Spread Rates

Chip seal type	Spread rate range (lbs./sq. yd.)
3/8”	20–30
5/16”	16–25
1/4”	12–20

Application rates utilized by many agencies come from prior experience. When applying the treatment, 50–70 percent of the aggregate particles should be embedded within the asphalt. If asphalt emulsion is used, the aggregate particles must have 55–60 percent embedment within.[7] The ideal aggregate particle shape for chip seals is cubical with fractured faces.[8]

Hot applied chip seals

Hot applied chip chips have used asphalt rubber, performance graded binders, and terminal blends or a rubberized asphalt binder. The most widely used hot applied binder is asphalt rubber. The asphalt rubber binder is applied when the ambient temperature is from 60 to 105°F and the pavement surface temperature is at least 55°F. Do not apply the asphalt rubber binder unless enough aggregate is available at the job site to cover the asphalt rubber binder within two minutes. Intersections turn lanes, gore points, and irregular areas must be covered within 10 minutes.

Do not apply asphalt rubber binder when pavement is damp or during high wind conditions. If authorized, you may adjust the distributor bar height and distribution speed and use shielding equipment during high wind conditions. When applied, the temperature of the asphalt rubber binder must be from 385 to 415°F. Apply the asphalt rubber binder at a rate from 0.55 to 0.65 gal/sq. yd. You may reduce the application rate by 0.050 gal/sq. yd. in the wheel paths.

The aggregate is spread at a rate from 28 to 40 lbs./sq. yd. Do not spread the aggregate more than 200 feet ahead of the completed initial rolling.

ENGINEERED APPROACH

Because of the importance of chip seals as a preservation treatment, a great deal of work has been done recently to move to have a more engineered technical approach to chip seal. Early work by Hanson (1934–35) and McLeod (1969) formed the framework for this engineered approach. Materials improvements including the use of polymer-modified emulsions and rubberized asphalt hot binders, one-size chips and improved equipment have led to significant advances in constructing more reliable chip seals.

Additionally, significant research has been completed in recent years to improve the design and construction process for chip seals. This work is reported in NCHRP report 680 and includes the following products.[9]

- Modified Sweep Test and Critical Moisture Content: This is a lab test simulating rotary sweeping to determine the timing for sweeping and opening to traffic by monitoring the moisture content which corresponds to adhesion needed for chip retention.
- Field Consistency Test: This test uses a Wagner cup viscometer, a device used to measure the consistency of paints, to measure the consistency of emulsions from load to load.
- Pavement Texture: A correlation was developed between the sand patch test and the CT (circular texture) meter, the results of which can be used to adjust binder spray rates during construction.
- Residue Recovery and Describable Properties: The stirred can emulsion recovery (SCERR) is recommended for obtaining residue for measuring physical properties of the asphalt binder used in making the emulsion.
- Measuring Aggregate Embedment in The Field: Two methods were developed to ensure proper embedment of the chips into the binder. It is important to make sure that the chips are properly embedded between 50 to 70 percent.

Materials

The materials used for emulsion chip seals and hot applied chip seals are generally the same as described in Section 4.1. Similarly, the materials used for scrub seals and GRCS are the same as described in Section 4.1.

Mix Design Methods

Both the McLeod method and the method currently recommended by AASHTO are included in Appendix C and are used for emulsion chip seals. These are the most commonly used procedures in the United States. Engineered approaches are not yet available for hot applied chip seals.

McLeod Method

The McLeod Design Method is a proven approach to determine the application rates for chip seals. Factors and steps to consider in this approach include:

1. Determine aggregate gradation, bulk specific gravity, and percent absorption.

2. Determine median particle size.

3. Determine the flakiness index (FI) using the equation:

$$FI = \frac{(Weight\ of\ Flat\ Chips)}{(Weight\ of\ Sample)}$$

4. Determine the average least dimension (H) using results from step 2 and step 3. To calculate the upper and lower H use the maximum and minimum FI-value, respectively.

$$H = \frac{M}{1.139285 + (O.011506) * (\ FI)}$$

where H = the average least dimension

M = median particle size from sieve analysis.

Determine the loose unit weight of the aggregate (W).

$$W = \frac{Weight\ of\ Aggregate}{Volume\ of\ Cylinder}$$

5. Determine the voids in the loose aggregate (V). To determine upper and lower void values, use the maximum and minimum W-value, respectively.

$$V = 1 - \frac{W}{62.4\ G}$$

where G = specific gravity of the aggregate.

6. Determine the aggregate application rate. To determine the upper and lower aggregate application rate, use the maximum and minimum V-value as well as the

maximum and minimum H-value, respectively.

$$C = 46.8 * \left(1 - (0.4)(V)\right) * (H)(G)(E)\right)$$

where C = application rate

E = Wastage = 1.05

G = Specific Gravity of aggregate = 2.67

7. Determine the binder application rate.

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R}$$

where T = Traffic Factor found in Table 17

S = Surface Condition found in Table 18

Table 17. Traffic Factor (T)

Traffic factor				
Traffic Vehicles per day				
Under 100	100 to 500	500 to 1000	1000 to 2000	Over 2000
0.85	0.75	0.7	0.65	0.6

Source: Mahoney et al., 2014.

Table 18. Surface Condition (S)

Existing Pavement Texture	Correction, S
Black, flushed asphalt surface	-0.01 to -0.06
Smooth, nonporous surface	0
Slightly porous, oxidized surface	0.03
Slightly pocked, porous, oxidized surface	0.06
Badly pocked, porous, oxidized surface	0.09

Source: Mahoney et al., 2014.

AASHTO Method

In addition to the McLeod Design Method, the American Association of State Highway and Transportation Officials (AASHTO, 2016) has included a procedure similar to that of McLeod.

*The first step is to determine the design application rate for the aggregate chips. This is accomplished by f*abricating a board measuring 3 feet by 1.5 feet. A 3/4-inch-thick particle board works well for this item then attaching 1 inch by 2 inch pine wood strips to the edge of the board to create a raised edge. Weigh the completed board and record the weight in pounds. Place the chips to be used on the project on the board. The quantity will vary depending on the gradation, shape, and crushed content of the chips but should be no less than 5 lbs. and no greater than 25 lbs., so try to fit as many chips on the board within the confines of the edging as possible. The chips should not overlap and should be only one stone thick. Push the chips against the edge of the board. Place as many chips as possible onto the board until every gap is filled. Reweigh the board containing the chips in pounds. Subtract the weight of the empty board from the weight of the board with chips. Multiply this value by 2. This is the quantity of chips to be used on the chip seal in pounds per square yard. Record this quantity as *Q*.

The emulsified asphalt quantity is estimated by calculating the amount of asphalt needed to fill the voids between the chips to a specific embedment depth. That relationship is expressed as follows:

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

where:

A = emulsified asphalt quantity, gal/yd^2

5.61 = constant for converting the units to gal/yd^2

e = percent embedment from Figure 4 expressed as a decimal

d = average mat depth, 1.33 *Q*/*W*

Q = quantity of chips from the board test, lbs./yd^2

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 19

V = pavement surface correction factor from Table 20; and

R = emulsified asphalt residue, expressed as a decimal, e. g., 0.65 = 65 percent

The result of the calculation for Equation 1 is the estimated emulsified asphalt spray rate.

Table 19. Traffic Correction Factor, T

Chip Seal Class >		**I**		**II**		**III**
AADT >	<100	100–250	251–500	501–1000	1001–5000	>5000
Traffic Correction Factor, *T* >	1.20	1.15	1.10	1.05	1.00	[a]

[a] Greater than 5000 AADT has not been evaluated sufficiently to develop a recommended traffic correction factor.

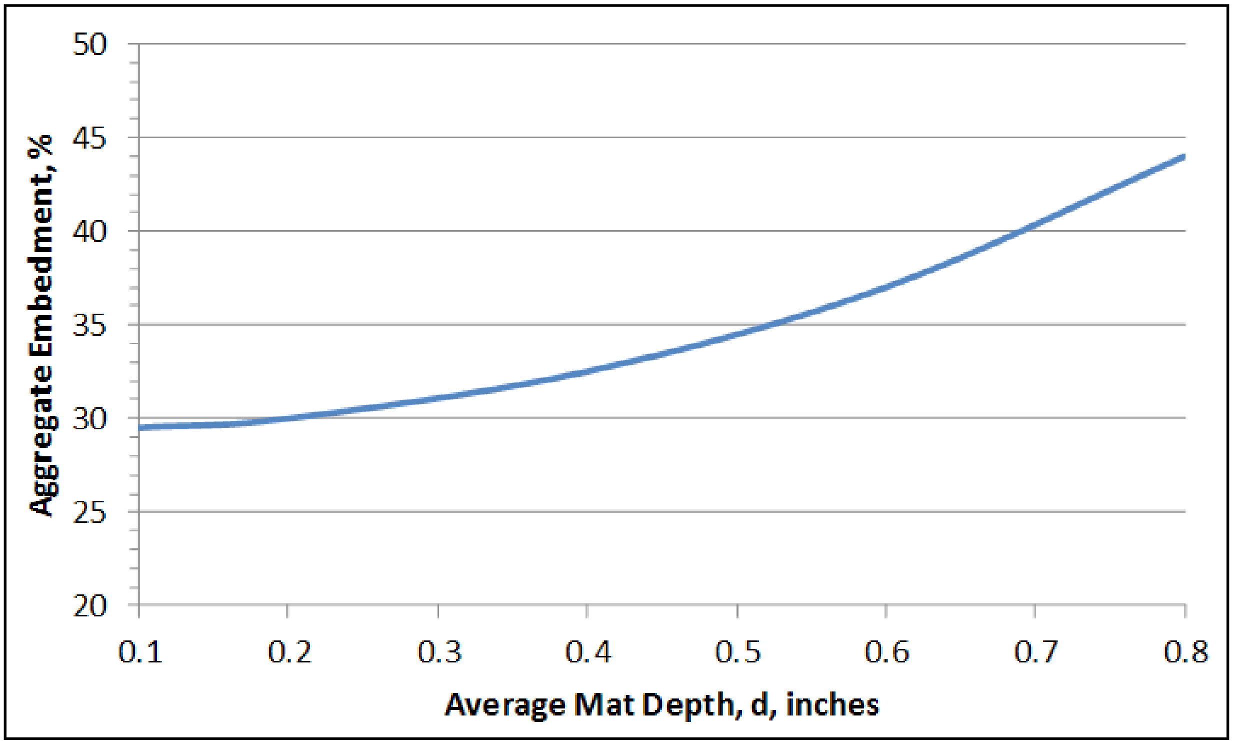


Figure 4. Aggregate Embedment, Percent, e (before Rolling)

Table 20. Substrate Surface Condition, V

Existing Surface Condition	**Correction Factor, *V*, gal/yd^2**
Flushed-bleeding[a]	-0.06
Smooth, non-porous[a]	-0.03
Slightly porous, slightly oxdized	0.00
Slightly pocked, porous, oxdized[b]	+0.03
Badly pocked, porous, oxdized[b]	+0.06

[a] A quantitative method using the Ball Penetration Test has also been reported in NCHRP Report 680.
[b] A quantitative method using the Sand Patch Test has also been reported in NCHRP Report 680.

More aggregate should be spread during chip seal construction with emulsified asphalt than is actually needed to produce a one-stone layer. This extra material is applied to aid in reducing the potential for chips to be picked up by pneumatic rollers during construction. The amount of excess material will vary, but it should be approximately 5 to 10 percent and never more than 10 percent. Adjustment up or down is necessary based on when the rollers begin to pick up the chips.

All design work should be carried out using aggregate either directly from the job site stockpile or equivalent material from the same source and having substantially the same material properties.

V. CONSTRUCTION

When constructing a chip seal, the following considerations are important:

- Weather considerations during construction can have a direct impact on performance. The weather should be warm and dry to promote proper binder setting and curing. Don't start work if rain is in the weather forecast.

- Install water pollution control items prior to beginning seal coat.

- Before beginning the seal coat, prepare and clean the existing surface. Fill any potholes and seal large cracks up to 1/4 inch for emulsion chip seals and 3/8 inch for AR chip seals.

- Traffic control is important. The traffic speed should be reduced or controlled until the binder sets, the rolling has been completed, and the first sweeping has occurred.

- Application rates must be selected to fit pavement surface conditions. The procedures identified in the prior chapter can be considered. Proper binder and application rates result in durable, long-lasting chip seals.

- The condition of the aggregate chips is important. Clean aggregate is necessary to ensure the binder will adhere to the aggregate. The chips are crushed and durable and often one-sized.

- A properly calibrated distributor spray bar is critical to a uniform application of the binder.

- The chip spreader should follow binder application as closely as possible and be applied on the binder almost immediately.

- The rolling procedure with complete coverage is critical to embed the chips and promote good bonding. The chips should be rolled immediately after spreading with a pneumatic tire roller.

- Light sweeping with minimum downward pressure is necessary to remove loose aggregate.

- After sweeping, an emulsified fog seal or flush coat may be applied to further lock down the chips. Caltrans sometimes uses san on this treatment in order to prevent pick-up.

- Apply temporary pavement striping before opening to uncontrolled traffic. Or apply temporary type markers before applying the binder.

Prior to construction, it is recommended that a preconstruction meeting be held within five days before the start of seal coat work at a mutually-agreed time and place with the engineer and a contractor's staff including:

1. Project superintendent
2. Project foreman
3. Traffic control foreman
4. Laboratory samplers and testers
5. Agency engineer or lead inspector

For smaller jobs, it may not be possible to get all the above-mentioned people to attend. In any case, be prepared to discuss:

1. Quality control testing
2. Acceptance testing
3. Seal coat placement
4. Proposed application rates for asphaltic emulsion or asphalt binder and aggregate
5. Training on placement methods (optional)
6. Checklist of items for proper placement
7. Unique issues specific to the project, including:
    - Weather
    - Storm water pollution control plan
    - Alignment and geometrics
    - Traffic control requirements
    - Haul distances
    - Presence and absence of shaded areas
    - Any other local conditions
    - Notifications to businesses and property owners as to when project will start and end

8. Contingency plan for equipment breakdowns, and traffic handling

9. Who in the field has authority to adjust application rates and how will adjustments be documented?

10. Schedule of sweepings

11. Agenda for safety meeting

EQUIPMENT

Types of Equipment Used

The types of equipment used for chip seals generally consists of the following:[10]

- Distributor Truck: The distributor truck 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 pressure 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 using the wrench supplied by the distributor manufacturer. Each pressure distributor shall be capable of maintaining the specified application rate within ±0.015 gal/yd^2 for each load. Obtaining a triple overlap from the spray bar is the most desirable arrangement because the emulsion application will generally be more uniform than with double overlap. However, when equipment is calibrated and set up properly very acceptable results have been obtained with double overlap.

- 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.

- Pneumatic-Tire Rollers: Use a minimum of three self-propelled pneumatic-tire rollers capable of ballast loading, with either 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 lbs./in^2. 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 tire. All tires shall be as supplied by the roller manufacturer. Width of the rollers shall exceed 60 inches. All tires are to be inflated to the same pressure.

  Note that steel-wheel rollers have been used as the final roller on some chip seals with success. The advantage is a more even final elevation. This produces fewer prominent chip edges extruding above the surface which can be susceptible to snow plow damage. The disadvantage of steel-wheel rollers is the potential for crushing of aggregate chips that cannot withstand the high stress imparted at the steel roller-chip interface. Therefore, if used, steel rollers should be limited to 5 tons. Vibration shall not be used if the rollers are so equipped.

- 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 chip sealing.

  Self-contained mechanical brooms of the pick-up type are preferred in urban or residential areas for environmental reasons, but push broom (or side broadcast) brooms are acceptable for cold applied chip seals in rural areas where chips being scattered off the roadway do not pose a hazard to pedestrians or vehicles. Contractors may collect the excess used chips and sell them.

- Trucks: Unless otherwise approved, use trucks of uniform capacity to deliver the aggregate. Provide documentation showing measurements and calculation in tons. Truck size may be limited when shown on the plans. The engineer should receive certified weigh tickets for each load delivered.

Calibration of Equipment

All equipment needs to be properly calibrated according to acceptable standards. The guides shown in Appendix A provide detailed instructions how to calibrate the distributor truck and the aggregate spreader for both emulsion and hot applied chip seals. This also applies to equipment for scrub seals and GRCS.

CONSTRUCTION PROCESS

The sequence of construction events for chip seals is as follows:

1. Project preparation
2. Protecting drainage inlets and utility boxes from seal coat
3. Weather conditions and traffic control
4. Review of water pollution control plan
5. Apply temporary markers before applying the binder if temporary striping will not be used
6. Binder application
7. Aggregate spreading
8. Rolling
9. Sweeping (Brooming) of excess aggregate
10. Flush coat or fog seal application
11. Application of temporary traffic striping

Figure 5 illustrates the construction process from project preparation through application of temporary traffic markings. Details of the construction process are provided in the following sections.

a) Binder Application **b) Spreading of Aggregate**

c) Rolling **d) Sweeping**

Figure 5. Construction Process for Chip Seals

Project Preparation

Preparation of the surface is critical to the performance of the chip seal. Areas of the pavement exhibiting structural failures (such as potholes and deteriorated patches) should be addressed by removal, patching, and fog sealing of the patched area. Avoid the use of cold mix for patching prior to applying the chip seal. Finally, the prepared surface must be clean, dry and free of any loose material before applying the binder. Preparation for a chip seal project typically includes:

- Notification of the residents
- Safety meeting with all on-site project personnel

- Milling of the surface (if there is extensive loose material, roughness, or areas of bleeding that must be removed)
- Crack sealing or filling of cracks (that are likely to reflect through the chip seal)
- Patching any deteriorated areas with dig-outs where required and fog seal patches
- Cleaning or sweeping any loose material from the pavement surface (such as areas of raveling)
- Removing pavement markers and thermoplastic markings; some painted stripes in good condition may also need to be removed.

If the patched areas or newly placed patches are generally more porous than the rest of the pavement, a fog seal or tack coat may be required prior to chip sealing. Known shaded areas that seldom get sunlight (i.e. under trees or bridge decks) may need a longer curing time with traffic control to prevent rock loss.

Specific recommendations should include the following:[11]

1. Cleaning Pavement. Clean the roadway surface by sweeping no more than 30 minutes prior to application of the asphalt emulsion and chips. However, this 30-minute 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 or a self-contained vacuum truck 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 any adjacent paved shoulder.

2. Protecting Accessories. Cover utility castings (manholes, gate valve covers, catch basins, sensors, etc.) 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 have to be removed if they could cause debonding.

A work site needs to contain a facility or staging area for storing aggregate and binder. Generally, binders are trucked directly from the manufacturer and off-loaded for use. However, situations arise when distance and weather create the need for off-site storage. The site should be chosen well in advance of project start-up. The aggregate stockpile should ideally be placed on a sloped and paved surface, but at least on a sloped surface to promote drainage of the stockpile. It should also ideally be protected from contamination with foreign material. Once stockpiled, the aggregate should not be moved until it is to be transported to the road being chip sealed. Following project completion, any remaining aggregate must be removed from the stockpile site and the site restored to its original condition.

Weather Conditions and Traffic Control

For emulsion chip seals, the weather should be clear and warm. In general, pavement surface temperatures should be 80°F and above, and the humidity should be 50% or lower. Wind may cause the emulsion spray to be diverted and compromise uniformity of application rate. A gentle breeze will assist in accelerating cure times for the emulsion binder. Any rainfall immediately before, during, or shortly after the construction of the PME chip seal will contribute to failure of the treatment. Extreme ambient air temperatures over 105°F are also cause to discontinue work. The actual requirements vary for different binder types and are included in the Caltrans 2018 specifications. Hot applied chip seals can tolerate cooler temperatures as long as the chips are spread promptly onto the hot binder.

For traffic control, the agency's Resident Engineer (RE) examines and approves the contractor's traffic control plan. The signs and devices used must match the traffic control plan and all workers must have all required safety equipment and clothing. After chipping, pilot cars should be used for between 2 and 24 hours or until the material is cured and swept to ensure that traffic speed is limited on the fresh chips to approximately 25 mph.

Application of the Binder

To ensure that the transverse joints are clean and sharp, chip seal passes should begin and end on felt paper or follow the specification requirements. Longitudinal joints may be made with an overlap. In this process, a wet edge (i.e., one without an application of aggregate) of 3 to 4 in (75 to 100 mm) is left (not in a wheel path) and the next run overlaps this wet edge. The chip distributor then covers the whole run to the pavement's edge. Figure 6 illustrates the layout of felt paper at the end of a project lane.

The spray distributor is the most important piece of equipment in the chip seal process. Its function is to uniformly apply the binder over the surface at the designed rate. Typically, spray distributors (boot trucks) are truck-mounted as shown in Figure 7, but trailer units have also been used. A distributor should have a heating, circulation, and pumping system, along with a spray bar, plus all necessary controls to guarantee proper application.

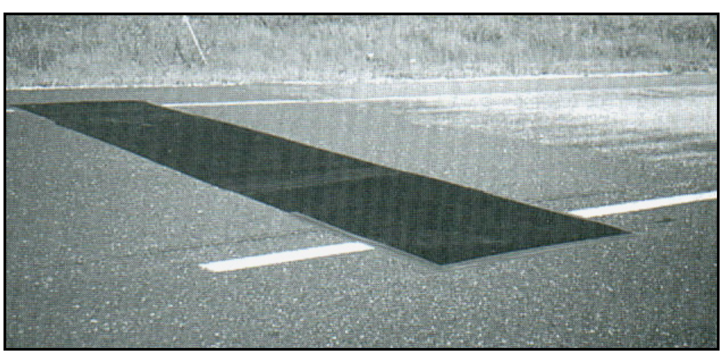


Figure 6. Start and Stop Passes on Roofing Felt (Transverse Joints)

Figure 7. Spray Distributor

The steps associated with preparing the distributor include:

- Calibrate the distributor by spraying a pre-weighed area of carpet (backed with a waterproof layer) and subtracting the initial weight from that of the sprayed carpet, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate. Another method is CT 339 for calibration of equipment.

- Blow the spray nozzles to ensure there are no blockages, and check the nozzle angles (see Figure 8) to ensure they spray at an angle 15 to 30 degrees from the spray bar axis. Often, the outer-most nozzles will be turned in to give a sharp edge with no over spray.

- Check the distributor bar's height. The height is usually set so that a double or triple uniform overlap is obtained, as illustrated in Figure 9.

- Check the distributor bar's transverse alignment to ensure it is closely perpendicular to the centerline of the pavement.

- Check the binder temperature to ensure it is in the appropriate range for proper application. Chip seal emulsion should be between 104 and 185°F (40 and 85°C), while the AR binder should be between 385 to 415°F.

- Distributor trucks for AR binder are usually equipped with a hood to filter emissions that is associated with the higher application temperatures for AR binder.

- Ensure an adequate supply of binder is available.

- Do not spread the binder too far in advance of the chip spreader.

- Check for proper embedment of the chips and adjust the application rate as necessary considering the pavement porosity/texture and aggregate size/quantity.

Figure 8 also shows details for nozzle and spray bar configurations.

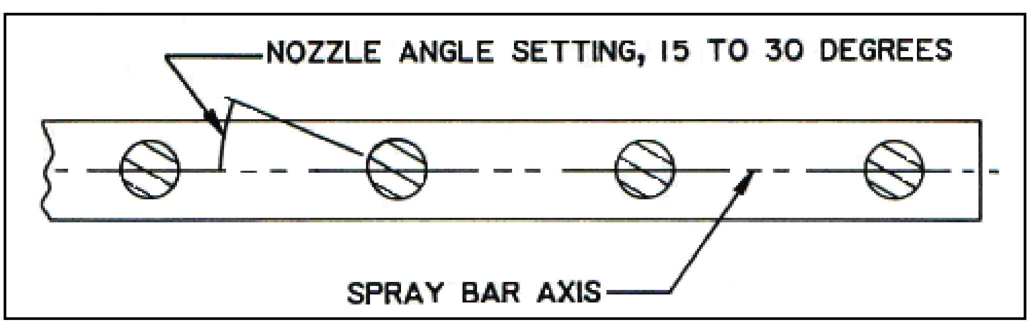


Figure 8. Spray Bar with Nozzle Arrangement

Note: (McLeod, 1969).

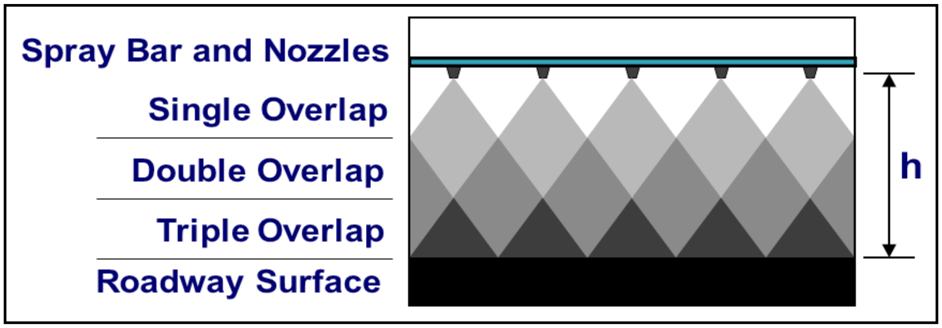


Figure 9. Spray Bar Height Arrangements

Visual checks should be made throughout the spraying process to ensure that the spray bars are clean and are spraying even fans. There should be no streaking of binder visible on the surface. If streaking occurs, the operation should be stopped to re-check proper functioning of the spray bar as well as proper binder temperature. The inspector should check application rates frequently. The application rate can be checked using the calibration method mentioned above or using the alternative method outlined in Chapter 7 (Field Considerations) of this report. The method above is recommended for equipment calibration, while the alternative method is appropriate for quick spot-checking during construction.

For scrub seals, the process is identical to that of a standard chip seal, with the exception of the towed scrub broom which is used to force the emulsion into cracks. The wave of emulsion carried by the scrub broom is a function of the amount of cracking in the roadway. Unlike with PME chip seals, cracks less than 1/2 inch do not need to be sealed prior to applying the surface treatment. Figure 10 shows the scrub broom in action and the wave of PRME necessary to flood and fill the cracks.

Figure 10. Scrub Seal Application

The GRCS construction process consists of the following steps:

- Place Geosynthetic Binder (Tack Coat): Hot paving asphalt for tack coat shall be applied between 290 and 350°F. The application rate of paving asphalt, including overlaps, shall normally be the minimum as specified by the manufacturer. This will vary with interlayer used. The application rate of the tack coat needs to be sufficient to ensure the geosynthetic is fully saturated with bitumen (liquid paving asphalt) and bonded to the existing surface, but not so heavy that there is free bitumen on the surface of the interlayer. This is a critical judgment decision that must be made as the project proceeds.

- Place Interlayer: The interlayer must be completely saturated with the tack coat immediately after the tack coat is placed. It is imperative that broom pressure be applied uniformly across the full width of the interlayer being placed. If paved shoulders are to receive the treatment, the interlayer shall be placed on shoulders before placing the interlayer on travel lanes. Longitudinal joints shall be placed in the same location as travel lane delineation (striping) when possible. When desired, the interlayer and the first layer of a double chip seal can be held back 4–6 inches from all valve covers and curbs to provide a smoother transition.

- Place Sand: Place sand if the construction of the chip seal is delayed.

- Rolling Operation (sanded and un-sanded operations): Rollers shall be pneumatic tired and should not exceed speeds of 5 miles per hour during all passes. Rolling should begin immediately behind [no more than 50 feet] the interlayer placement and/or the mechanical sand spreader (if sand is applied). Enough rolling has been done when the texture of the underlying pavement surface is visible on the surface of the interlayer. Sand shall be removed immediately prior to beginning chip seal operations.

- Place Chip Seal: Materials and placement requirements should conform to agency requirements. Chip seals can be placed as soon as the fabric placement is complete and appropriate sweeping has been completed.

The AIA specifications for this process are given in Appendix B.

Application of the Aggregate

Chip spreaders must be able to spread an even coating of aggregate over the entire sprayed surface. Figure 11 shows a typical chip spreader.

Figure 11. Chip Spreader

Prior to applying aggregate on a project, the following steps should be taken:

- Calibrate the spreader by spreading chips over a pre-weighed area of carpet and subtracting the initial weight from that of the carpet with chips spread onto it, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the spreader is applying the aggregate at the correct application rate. An alternate method is to use CT 339.

- Ensure all gates in the spreader open correctly.

- Ensure the spreader applies the aggregate uniformly over the surface.

- Ensure that the spreader is not leaving piles of aggregate and is not spreading too thick a layer. Too thin a layer of aggregate can result in the aggregate being crushed under rollers or by traffic, compromising the seal. Too thick a layer of aggregate can also result in the lever and wedge effect illustrated in Figure 12, which also compromises the performance of the seal i.e. rock loss.

- Ensure an adequate supply of aggregate is available prior to applying the binder.

- Ensure proper moisture content of aggregate for PME chip seals.

- Ensure recommended temperature range for hot applied chips.

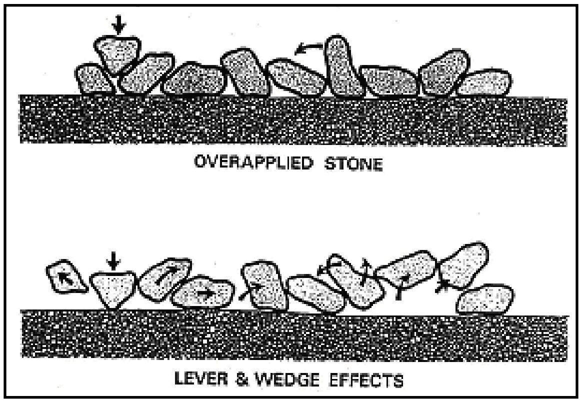


Figure 12. Lever and Wedge Effect
Source: South Australian DOT, 1995.

For emulsion chip seals, the application of aggregate should follow the binder application by no more than 90 seconds in order to obtain the best possible aggregate retention. A good visual check is that the spreader should be no more than 100 feet (30 m) behind the distributor truck. The first chip spreading pass is usually done against traffic to allow good centerline match up. The direction for spreading is chosen mostly to minimize truck movements on the fresh oil. For hot applied chip seals, the aggregate application should be immediate. The aggregate should also be hot and pre-coated with asphalt.

Visual checks of the spreading include checking that the aggregate does not roll or bounce when applied. The flow of aggregate should also be checked. If a wave of binder forms in front of the blanket of aggregate, the binder application may be too heavy. The scalping screen should also be checked for build-up of clay or other contaminants. If such contamination is heavy, it may be necessary to re-screen or reject the stockpile. The spread pattern should be even without ripples or streaks. If ripples or streams occur, the spreading gates may need to be lowered and the machine slowed down.

Haul trucks are responsible for providing a continuous supply of binder to the site and aggregate to the spreader. Haul trucks should be in good mechanical condition. Hydraulic leaks from haul trucks or any other equipment can compromise the seal binder. Single-axle trucks carry between 5 and 7 tons (4,500 and 6,350 kg), and trucks with tandem axles between 11 and 14 tons (9,000 and 12,700 kg). For this reason, trucks with tandem axles are the preferred choice. The increased capacity requires fewer hook-ups, resulting in less chance for spillage and a more efficient operation.

Tires on the trucks should be examined for binder pick-up. If pick-up occurs, it may severely damage the seal. Tires should be cleaned and sanded. Trucks should not drive on the new surface unnecessarily and should never brake sharply. When driving on the fresh mat, haul truck wheel paths should be staggered to assist in embedding the aggregate uniformly. When pulling away from the spreader, trucks should move smoothly and slowly to prevent wheel spin and mat damage. Trucks shall not be allowed to lose or dump chips when pulling away from the chip spreader. No sharp turning movements or high speeds should be allowed on a newly constructed chip seal.

Rolling

The function of the roller is to embed the aggregate into the binder and orient it into an interlocking mosaic. This is initially accomplished with pneumatic tired rollers as shown in Figure 13; compaction applied by traffic finishes the process. Rolling should be expedited in cooler weather to ensure proper embedment of the aggregate. Steel rollers are not normally recommended for chip seals because they can crush the aggregate. However, steel wheel rollers have been used to smooth out coarser chip seals.

The important variables when rolling chip seals are:

- Contact pressure
- Number of passes and pattern
- Speed
- Smoothness of tires
- Adequate number of rollers

Figure 13. Pneumatic (Rubber Tired) Roller

Rollers shall be pneumatictired typerface. A minimum of two pneumatictired rollers conforming to the provisions in Section 395.02, “Compacting Equipment,” shall be furnished.[12] Initial rolling shall consist of one complete coverage and shall begin immediately behind the spreader. Asphaltic emulsion and screenings shall not be spread more than 2,500 feet ahead of the completion of initial rolling operations. Secondary rolling shall begin immediately after completion of the initial rolling. The amount of secondary rolling shall be sufficient to adequately seat the screenings and in no case shall it be less than two complete coverages.[13] When two rollers are used, three passes are sufficient: one forward, one in reverse, and the final pass extending into the next section.

Sweeping

Sweeping is required before, after, and sometimes during the chip seal operation. Before applying the chip seal, the pavement must be swept clean of dust and debris. During a multi-coat sealing operation, excess aggregate must be swept off between coats. After the chip seal has been constructed, excess aggregate must be swept off to minimize whip-off by traffic.

Sweeping is done using towed rotary brooms with nylon or steel bristles or with self-propelled vacuum pickup brooms. Steel bristles should not be used on emulsion chip seals. The broom should not be worn and should not be operated in such a manner that it removes embedded aggregate. Figure 14 illustrates a typical sweeping operation.

Mobile pickup brooms are usually capable of picking up aggregate and storing it. Sometimes, so-called “kick brooms” are used. These brooms move the aggregate into a windrow so that it can be collected, but they often generate dust and may sweep aggregate into watercourses or gutters. Figure 15 illustrates a typical kick broom.

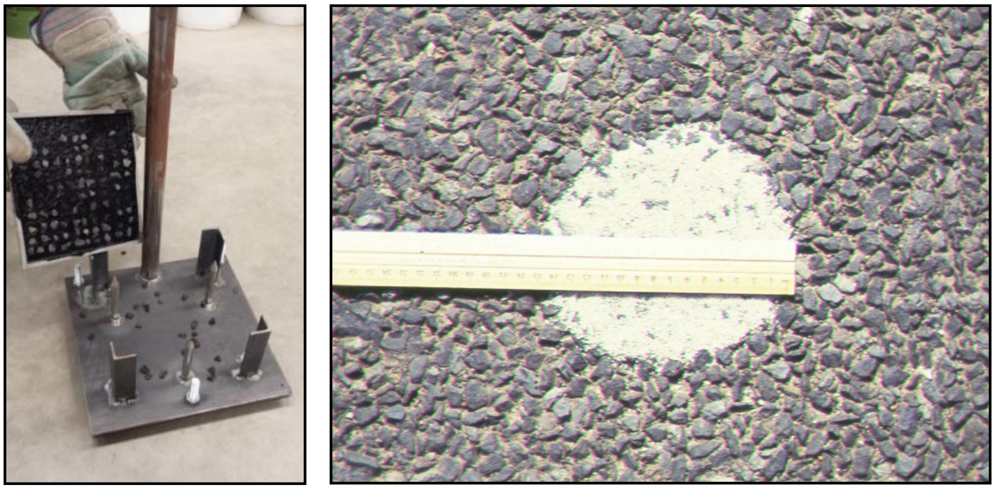
Sweeping can generally be done within 2 to 4 hours after sealing. Hot applied chip seals can be swept within 30 minutes, while conventional chip seals can be swept in 2 to 4 hours. A flush coat or fog seal is often applied after sweeping to eliminate further rock loss and improve durability prior to opening the pavement to uncontrolled traffic.

Figure 14. Sweeping Process, Shown on a Shoulder Seal

Figure 15. Kick Broom

Field Testing

Most tests of constructed chip seals are empirical and provide the user an indication of the additional adjustments that must be made on the job site. Though not used by Caltrans, the Sand Patch Test (ASTM E965) is useful for checking the condition of the original pavement and the final seal. The Sand Patch Test provides surface texture information for classifying surface type or examining seals with typical texture depths ranging from 0.04 to 0.1 in (1 mm to 2.5 mm), depending on the aggregate size. The field Vialet Test can be used to test the adhesion between the binder and the aggregate.[14] It involves dropping a 500 g steel ball onto a Vialet plate to determine the percentage of the materials retained on the plate. Figure 16 illustrates the Sand Patch and Vialet tests.



a) Vialet Test **b) Sand Patch Test**

Figure 16. Field Test Methods

WORKMANSHIP ISSUES

Emulsion Chip Seals

As far as workmanship issues, the following need to be monitored for emulsion chip seals:

- Longitudinal application rates
- Transverse application rates
- Asphalt transverse application uniformity
- Transverse joint construction technique
- Monitoring method for application rates
- Rolling operations detailing the roller pattern and number of passes and coverages
- Sweeping operations and schedule
- Method of controlling traffic

Hot Applied Chip Seals

The same items need to be monitored for hot applied chip seals as well as the temperature of the binder and the chip and the proper pre-coating of the chip.

SAFETY

As with all construction projects, safety is the Number One concern for pedestrians, bicyclists, motorists, contractors' personnel, and local agency inspectors. Chip seal projects have had some issues which are unique for this project type including loose rock, excess dust, and in the case of hot applied chip seals, severe burns and excessive emissions. As the design and construction engineer, there are many items regarding safety that you should be aware of.

Traffic Control

Another factor is that lane closures are always required for chip seal work, since traffic must be kept off of fresh chip seal until at least an initial break and cure has taken place. For the emulsion chip seals, the time required to cure will depend on climate factors such as air temperature, relative humidity and wind speed. Hot applied chip seals require a shorter cure period. If there are shady areas and cooler temperatures, cure time must be extended since these areas will take longer to cure. Since curing time can vary depending on the weather conditions, it is important that the contractor maintain the detours or traffic control until the chip seal is cured. Cure time may take several hours after placement. During this time, traffic must be restricted from the new chip seal surface. If a chip seal surface is open to traffic too soon, raveling may occur.

If this is an urban project, the first item that should be considered is detouring traffic. In a downtown situation, it is usually easy to close a street and move traffic over a block. Also, businesses and residences should receive notification of street closures ahead of construction. Business owners will often ask that the construction be done on a weekend or at night so that their normal business is not disrupted. If that is not possible, customers may have to walk by the construction zone. It is important for pedestrian safety to cordon off the work areas from the sidewalks and for flaggers to direct pedestrians who may want to cross the street. Decisions must be made ahead of construction to leave certain intersections open to traffic, and to determine how access to businesses and residences will be managed during construction. Construction signing for detours must be included in the contract plans.

If this is a rural two-lane road project, only one direction will be constructed at a time, with traffic control using a pilot car with flaggers to alternately allow traffic to be piloted in one direction at a time. After the chip seal is cured, traffic may be switched onto the new chip seal surface, and the opposing lane will be constructed. There are traffic control standards that must be adhered to during the construction and curing process.

Safety During Construction

It is important to be familiar with the equipment traffic patterns on the project and know what the 'NO ZONES' are. Figure 17 shows where these zones are. Drive through the project in the traffic queue if there is one-way controlled traffic. Observe the flow of equipment, i.e., the distributor truck and aggregate spreading machine direction and speed. Also, observe the haul trucks for the aggregate and the asphalt binder. The haul trucks supplying the aggregate spreader may back up at very high speeds and should have backup alarms. The Resident Engineer is usually in charge of enforcing the safety items on the project. All the equipment should be equipped with backup alarms.

The haul truck and the aggregate truck drivers have limited vision when backing up. With the limited vision, be sure to make contact with the truck driver before walking behind the truck. The driver will not be able to see who or what is behind his vehicle.

Many observations can be made from the vehicle, so don't stand in the construction zone unless sampling or performing tests. Assign an observer to watch traffic when the tester is unable to. Be sure to perform testing or sampling in a lane closure.

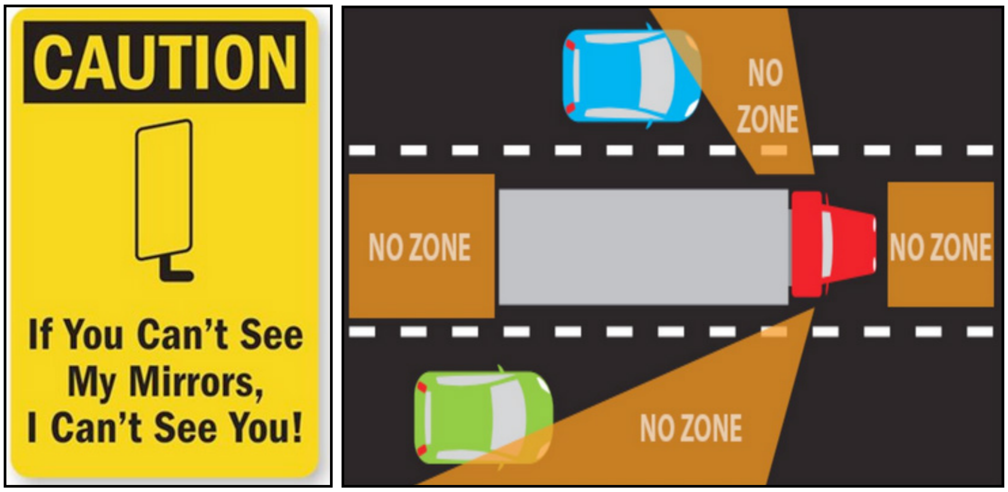


Figure 17. Mirrors and the No Zone

During construction, all construction personnel must wear safety vests, hard hats, and safety glasses when in active construction zones. All construction personnel must also wear long pants, and suitable shoes or boots. No sandals or shorts are allowed for construction personnel. If a worker is around a high level of noise, earplugs must be worn. Gloves should be worn by workers performing hand labor or handling hot materials. If the agency has a standard operating procedure (SOP) for this purpose, then it could be followed.

VI. QUALITY ASSURANCE, MEASUREMENT AND PAYMENT

Quality assurance establishes the core elements required to achieve quality materials and workmanship for construction projects as shown in Figure 18.[15] This has been accomplished to a great deal in hot mix asphalt, but it is just beginning for pavement preservation treatments. This chapter discusses the various elements of an overall QA program.

Figure 18. Core Elements of a Quality Assurance Program

When the various ingredients are applied following the design proportions, they produce chip seals that ultimately make up the new surface on the pavement. Obviously, high-quality materials and construction practices—and good quality control/quality assurance—will help maximize the smoothness, uniformity, skid resistance, and appearance of the chip seal. Quality control is critical during the construction process to achieve a uniform surface finish. The contractor is responsible for quality control, and the agency is responsible for quality assurance. If there is a difference in the testing results between the contractor and the agency, it may be necessary to go to dispute resolution. Independent assurance mediates the dispute resolution process, and monitors both laboratories during their re-testing of the materials.

CONTRACTOR QUALITY CONTROL PLAN

A written Quality Control Plan (QCP) needs to be developed to detail the contractor's QC program that meets the requirements of the specifications. The QCP shall be contract-specific and signed by the contractors' representative. Chip seal construction shall not begin or proceed without the Engineer's approval of the QCP and QC personnel present on the project. Failure to comply with these provisions will result in shutdown of the operations until such time as the contractor's operations are in compliance.

Unless the engineer accepts other documentation of the qualifications and/or responsibilities of the contractor's QC staff, the QC staff shall include the following as a minimum:

- QCP Administrator: The person with overall responsibility of the QCP.

- QCP Manager – The person is responsible for the execution of the QCP and liaison with the agency. This person shall be on the project and shall have the authority to stop or suspend construction operations.

- QC Technicians: The person(s) responsible for conducting QC tests and inspection to implement the QCP. QC technicians shall have Level 2 Aggregate Testing Certification from the American Concrete Institute (ACI) or other accrediting body approved by the Agency to ensure quality aggregates.

- Certified Crew Members: Three crew members (job foreman, aggregate spreader operator and asphalt distributor operator), at minimum, shall possess a valid chip seal certification and shall be on the project at all times the chip seal is being constructed. The chip seal certification is administered by the National Center for Pavement Preservation (NCPP) on behalf of AASHTO TSP[2] (Transportation Services Preservation Program). Although Caltrans does not currently require this certification, some local agencies and most contractors are following this practice.

CONTRACTOR QUALITY CONTROL DOCUMENTATION

The contractor is responsible for quality control (QC) sampling, testing, and documentation, and shall submit a QC plan including materials and procedures for verifying the quality of the chip seal aggregates and binder; measures to ensure placement of materials conforms to the contract documents; and measures and documentation to ensure the in-place end product conforms to the contract documents. The contractor's QC plan shall include but is not limited to sampling, testing, inspection, monitoring, documentation and submittals, and corrective action during transport, stockpiling, placement, and sweeping/cleanup operations.

The contractor's QC system should also address the following:

- Materials production processes

- Materials transportation and handling

- Field placement procedures

- Calibration and maintenance of equipment

- Activities (sampling, testing, and inspection) to maintain each process in control

- Means to make timely adjustments and corrections

SAMPLING AND TESTS TO RUN INCLUDING FREQUENCY (CALTRANS SPECS-2018)

Both contractor and agency need to establish a sampling plan prior to beginning work. An example of such a plan is shown in Table 21.

Table 21. Example of a Sampling Control Plan for Chip Seals

	Project Location
Product	**Producer's Emulsion**
Where	On site/Sampling Port
When	15 minutes after starting application
How much	Four 1/2 gallon plastic jugs
Who	Consultant Tester
Testing	Agency and/or Consultant Tester
	(List tests to be run)
Product	**Aggregate, Producer**
Where	Stockpile, or from equipment
When	Various times, once daily
How much	1 Bag, 20 pound ±
Who	Operator or Agency Inspector or Agency Tester
Testing	Agency or Consultant Lab for all aggregate specified characteristics
Tests	Engineer to order tests per project specifications

A consultant tester may be employed by either the contractor or the agency. Usually, the person sampling the product will take two or three samples, giving one to the agency and one to the contractor as a split sample. This is a good strategy in case there is a discrepancy on the test results. Even though the production product is tested before construction, there needs to be assurance that the product being delivered is verified to be of the same quality as the product that was submitted to the agency prior to construction.

AGENCY INSPECTION AND DOCUMENTATION

The agency has the responsibility to document the quality of the products being used in the construction processes used on their project. The agency's Resident Engineer is responsible for keeping daily diaries to document the construction process. Depending on the size of the project, there may also be an agency tester on the project responsible for the materials sampling. The agency tester may be a consultant tester or an agency employee. The tester should be certified in any and all of the tests that are being run, including sampling the products. It is recommended that the inspector go through the same certification process required for contractors, monitored by the National Center for Pavement Preservation (NCPP).

The materials test results are compared to the specifications to make sure that the materials are within the specified limits of each test specified and performed. Some out-of-specification products may be accepted to be left in place on the project, but with a pay deduction. This is often at the contractor's discretion. If the materials are too far outside of the specified limits, the engineer may order that the material be removed and replaced at the contractor's expense.

Overall, the primary objectives of agency acceptance are to:

- Assure the quality of all materials provided and placed by the contractor
- Determine the corresponding payment the contractor should receive

INDEPENDENT ASSURANCE

Independent Assurance (IA) is performed by the agency or designated agency personnel who are not directly responsible for project acceptance. It provides independent evaluation of the QC program and agency acceptance and their equipment, but it is not used to make a determination of work quality or acceptability.

Samples that have been maintained during the project in case of dispute are run as split samples. The IA effort is to determine why there was a difference in the test results, and to ensure consistent testing results between the laboratories. This is done so the dispute can be settled in a fair and equitable process.

Besides the appearance of the project, the materials need to be tested during construction. If two tests in a row fail, the work should be suspended until the contractor remedies the problem. If no problem can be identified, then re-testing needs to follow. Independent assurance processes may be used when the re-testing is being done between the two laboratories.

MEASUREMENT AND PAYMENT

If recorded batch weights for the binder and chips are printed automatically, the bid item for screenings will be measured using the printed batch weights, provided the following are applicable:

1. Total aggregate weight for screenings per batch is printed.
2. Total asphalt binder weight per batch is printed.
3. Each truckload's zero tolerance weight is printed before weighing the first batch and after weighing the last batch.
4. Time, date, mix number, load number and truck identification are correlated with a load slip.
5. A copy of the recorded batch weights is certified by a licensed weigh master and submitted to the engineer.

6. Weigh tags are produced at the hot plant where the screenings were stockpiled, heated, and coated.

Weigh slips, which include the printed batch weights, should be submitted no later than the morning after the delivery has been made. The same applies to the binder and the pre-coated aggregate determined by the contractor in the case of hot applied chip seals.

The contract unit prices, paid per ton for binder and for screenings, shall be considered as full compensation for furnishing all labor, materials, tools, equipment, guarantees, warranties and incidentals, and for doing all the work involved in installing chip seal, including but not limited to site preparation, cleanup, protecting utility and manhole covers, applying chip seal, repairs or corrections to application, street sweeping and all other incidental work required to complete the work as shown and specified.

As an alternative, the contractor could furnish the following warranty after completion of the work and prior to final payment:

> “The Contractor hereby warrants that all workmanship and all materials furnished under the contract comply fully with requirements of the Chip Seal specifications. If at any time within 2 years from the date of filing of the Notice of Completion, any unfaithful or defective work should appear which in the opinion of the agency is due to inferior materials or workmanship, the Contractor warrants are to perform whatever corrective work is necessary to remedy the defects immediately without cost to the agency. The agency will notify the Contractor in writing of the defects and the repairs to be made, and the Contractor will begin repairs within a mutually agreed time frame.”

VII. TROUBLESHOOTING GUIDE

This chapter provides information to assist construction personnel in troubleshooting problems with chip seals. The guide, along with a related table on problems and solutions, addresses common problems encountered during the construction of chip seal projects.

TROUBLESHOOTING GUIDES

In California, the most common problems with chip seals are rock loss or flushing after construction. Figure 19 depicts examples for rock loss and flushing. The troubleshooting guide presented in Table 22 identifies common problems for both emulsion and hot applied chip seals and their potential causes.

a) Rock loss **b) Flushing**

Figure 19. Rock Loss and Flushing

In addition to the troubleshooting guide in Table 22 while Table 23 lists some commonly encountered problems and some recommended solutions.

Table 22. Troubleshooting Chip Seal Problems

CAUSE	EXCESSIVE LOSS OF AGGREGATE	CRUSHING OF AGGREGATES	PICKUP OF BINDER	ADHESION PROBLEMS	RAVELING OF AGGREGATES	STREAKING OF BINDER	TRANSVERSE PATCHES	FLUSHING	FAILURE IN SHADE	POLISHING OF AGGREGATE	POOR MOSAIC OF FINISHED MAT
	PROBLEM										
Poor Traffic Control	•		•		•				•		•
Poor Equipment	•		•		•		•	•	•		•
Spray Temperature	•		•		•	•	•		•		•
Vehicle Speeds	•				•	•	•	•	•		•
Distributor Nozzles	•				•	•		•	•		
Climatic Conditions											
Cold Surfaces	•			•	•				•		•
Wet	•			•	•				•		•
Windy	•			•	•				•		•
Binder											
Wrong Binder	•		•	•	•	•		•	•		•
Too Little Binder	•			•	•				•		•
Too Much Binder			•					•			•
Aggregate											
Too Little	•		•					•			•
Too Much	•	•		•	•		•		•		•
Wet	•			•	•			•	•		•
Dirty	•			•	•				•		•
Quality	•	•		•	•				•	•	
Wrong Size	•				•			•	•	•	•
Pre-coat											
Too Little	•			•	•				•		
Too Heavy	•				•						

Table 23. Typical Problems and Recommended Solutions

PROBLEMS	SOLUTION
Streaking or Drill Marks in the Binder	Ensure emulsion or asphalt binder is at correct application temperature. Ensure the viscosity of the emulsion or asphalt binder is not too high. Ensure all the nozzles are at the same angle and not plugged. Ensure the spray bar is not too high or too low. Ensure the spray bar pressure is not too high or too low.
Exposed Emulsion After Chip Application	Ensure the chip spreader gate is not clogged or malfunctioning. Ensure the chip spreader is covering all the binder.
Excessive Chips/Many Chips with Small Amounts of Binder	Ensure the chip spreader gate is not malfunctioning or chipper head is not overloaded. Lower the chip application rate.
Uneven Chip Application	Re-calibrate the chip spreader; ensure all spreader gates are set the same.

PROBLEMS	SOLUTION
Binder on the Top of Chips	Ensure the chip spreader is not operating too quickly. Ensure trucks, rollers, and pilot cars are operating correctly at low speeds.
Chips Being Dislodged	Ensure the binder application is not too light. Ensure the chips are not dirty or dusty. Ensure the traffic or equipment speeds are not too high. Ensure sweeping does not occur before the emulsion is properly set.
Bleeding or Flushing	Ensure the binder application is not too high. This can occur in pavements that were rutted. Ensure the aggregate application is not too low.
After Sweeping, Loss of Chip at Centerlines	Check centerline procedure. Check binder application rate.
Excessive Splattering of the Binder	Lower the spray pressure.

FIELD CONSIDERATIONS

The following field considerations, as shown in Table 24, are a guide through the important aspects of performing a chip seal project. The various tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be carefully evaluated before, during, and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff. The field supervisor should be acquainted with its contents. Responses to the questions in these tables are not meant to form a report, but rather are intended to call attention to important aspects and components of the chip seal project process. Some information is product-specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

Table 24. Guide for Important Aspects of Chip Seal Projects

PRELIMINARY RESPONSIBILITIES	
Project Review	Is the project a good candidate for a chip seal? How much rutting is present? How much and what type of cracking exists? Is crack sealing needed? How much bleeding or flushing exists? Review project for bid/plan quantities.
Document Review	Bid Specifications Special Provisions Construction Manual Traffic Control Plan (TCP)
Materials Checks	Is the type of binder to be used compatible with the chips? Is the binder from an approved source (if required)? The binder and aggregate have been sampled and submitted for testing (if required)? All chips are close to the same size? The chips are clean and free of excess fines? The chips used with emulsions are in a surface-damp condition? Is the emulsion temperature within application temperature specification? For hot applied chip seals, is the binder temperature within specs? Where required, are the chips pre-heated and pre-coated to spec?
Surface Preparation	Is the surface clean and dry? Have all major pavement distresses been repaired and sealed? Has the existing surface been inspected for drainage problems? Have pavement markers been removed and temporary markers placed?

EQUIPMENT INSPECTIONS	
Broom	Are the bristles the proper length? Do not use steel bristles for emulsion chip seals. The broom can be adjusted vertically to avoid excess pressure? Are water misters operable?
Distributor	Is the spray bar at the proper height? Are all nozzles are uniformly angled 15 to 30 degrees from the spray bar? Are all nozzles working and free of clogs? Is the spray pattern uniform and does it properly overlap (double or triple)? Is the application pressure correct? Is the distributor properly calibrated and the correct size nozzle tips installed?
Chip Spreader	Do the spreader gates function properly and are their settings correct? Is the scalping screen in good condition? Is the chip spreader's calibration uniform across the entire chipper head? Are the truck hook-up hitches in good condition?
Rollers	What type of roller will be used on the project (pneumatic-tired roller recommended)? Do rollers meet weight requirements? Does the roller tire sizes, ratings, and pressures comply with the manufacturer's recommendations and specifications? Are the tire pressures the same on all tires? Do all tires have a smooth surface?
Haul Trucks	Is the truck box clean and free of debris and other materials? Is the truck hook-up hitch in working order? Is a truck box apron or extension required for loading the chip spreader?

WEATHER CONDTIONS	
Weather Requirements	Do the specifications describe a range of dates when chip sealing can be done? Air and surface temperatures have been checked at the coolest location on the project? Air and surface temperatures meet agency requirements? Are high winds expected? High winds can create problems with the emulsion application. Will the expected weather conditions delay the breaking of the emulsion? High temperatures, humidity, and wind will affect how long the emulsion takes to break. The application of emulsion should not begin if rain is likely within 24 hours.
DESIGN CONSIDERATIONS	
Determining Application Rates	Agency guidelines and requirements have been followed? Has a chip seal design been done? Is the surface oxidized or porous? More oil is applied to dried-out and porous surfaces. Is the traffic volume on the road low? More oil is applied on roads with low traffic volumes. Is the surface smooth, non-porous, or bleeding? Less oil is applied to smooth, non-porous, and asphalt-rich surfaces. Is the traffic volume on the road high? Less oil is applied on roads with high traffic volumes. Is there a salt and pepper appearance after the chips have been applied and swept?

	PROJECT INSPECTION RESPONSIBILITIES
Binder Application	Is roofing felt or building paper used to start and stop binder application? Is the binder within the required application temperature range? Does the application look uniform? Are any nozzles plugged? Is there streaking in the applied binder? Are application rates randomly checked? Is the speed of the distributor adjusted to match the chip spreader to prevent stop-and-start operations? Is the distributor stopped if any problems are observed?

	PROJECT INSPECTION RESPONSIBILITIES
Chip Application	Are enough trucks on hand to maintain a steady supply of chips to the spreader? The application starts and stops with neat, straight edges? Does binder application start and stop on building paper or roofing felt? The chip spreader follows closely behind the distributor when an emulsion is used and even closer for hot applied chip seals? The chip spreader travels slowly enough to prevent chips from rolling when they hit the surface? Are the chips clean and in a surface damp condition? No binder is on top of the chips? The application is stopped as soon as any problems are detected? Does the application appear uniform? Where required, do the pre-coated chips have a salt and pepper appearance and are they pre-heated? Check the percent chip embedment in the binder and adjust binder or chip application rate if required.

	PROJECT INSPECTION RESPONSIBILITIES
Traffic Control	The signs and devices used match the traffic control plan? The work zone complies with agency specs? Flaggers do not hold the traffic for extended periods of time? The pilot car leads traffic slowly—25 mph (40 kph) or less—over fresh chip seals? Signs are removed when they no longer apply? Any unsafe conditions are immediately reported to a supervisor?
Rolling	Are the rollers pneumatic tired type? The rollers follow closely behind the chip spreader? The entire surface is rolled with 3 coverages. Roller speeds kept at 5 mph (8–9 kph) maximum? The roller's first pass is on the meet line? Rollers do not drive on exposed emulsion? All stop, starts, and turns are made gradually?
Truck Operation	Trucks travel slowly on the fresh seal? Stops and turns are made gradually? Truck operators avoid driving over exposed binder? Trucks stagger their wheel paths when backing into the chip spreader? This helps to eliminate chip roll over and aids in rolling.
Longitudinal Joints	The meet line is only as wide as the spray from the end nozzle—about 8 in (20 cm)? The distributor lines up so that the end nozzle sprays the meet line? The meet lines are not made in the wheel paths? The meet lines are made at the center of the road, center of a lane, or edge of a lane? The meet lines are not left uncovered overnight?
Transverse Joints	All binder and chip applications begin and end on building paper or roofing felt? The building paper or roofing felt is disposed of properly?

PROJECT INSPECTION RESPONSIBILITIES	
Sweeping	Sweeping should not dislodge the aggregate. Sweeping begins as soon as possible, but not until sufficient bond has formed between the chip and the binder. Check with the binder manufacturer for their recommendation or refer to agency requirements. Are the proper bristles used? Which types of sweepers should be used? Are misters on mobile pickup brooms operating?
Opening the Chip Seal to Traffic	Traffic travels slowly—24 mph (40 kph) or less—over the fresh seal coat until the chip seal is swept and opened for normal traffic? Reduced speed limit signs are to be used when pilot cars are not used. Are pavement markings placed before opening chip seal to normal traffic? Are all construction-related signs removed when opening chip seal to traffic and traffic control is removed?
Clean Up	Is all loose aggregate from sweeping removed from the roadway? Are binder spills cleaned up?

APPENDIX A: SAMPLE SPECIFICATIONS

The sample specifications in this appendix were developed as part of NCHRP project 14-37. The specifications include ones for emulsion chip seals, hot applied chip seals, and fog seals which are often used with chip seals.[16]

A-1 EMULSION CHIP SEAL SAMPLE SPECIFICATION

The emulsion chip seal sample specification can be accessed through the following link:

https://www.csuchico.edu/cp2c/_assets/documents/specs/emulsion-chip-seal-sample-specification-1.pdf.

A-2 HOT APPLIED CHIP SEAL SAMPLE SPECIFICATION

The hot applied chip seal sample specification can be accessed through the following link:

https://www.csuchico.edu/cp2c/_assets/documents/specs/hot-applied-chip-seal-sample-spec-1.pdf.

A-3 EMULSION FOG SEAL SAMPLE SPECIFICATION

The emulsion fog seal sample specification can be accessed through the following link:

https://www.csuchico.edu/cp2c/_assets/documents/specs/fog-seal-sample-spec-1.pdf.

APPENDIX B: SPECIFICATIONS USED IN CALIFORNIA FOR SCRUB SEALS AND GRCS

B-1 SCRUB SEAL SAMPLE SPECIFICATION

The scrub seal sample specification can be accessed through the following link:

https://www.csuchico.edu/cp2c/_assets/documents/specs/scrub-seal-sample-spec-1.pdf

B-2 GRCS SAMPLE SPECIFICATION FROM ASPHALT INTERLAYER ASSOCIATION

The geosynthetic reinforced chip seal sample specification can be accessed through the following link:

https://www.csuchico.edu/cp2c/_assets/documents/specs/grcs-sample-specification-aia-1.pdf

APPENDIX C: MCLEOD DESIGN PROCEDURE WSDOT EXAMPLE

To determine how the McLeod Method matches with current WSDOT standard specifications application rates for chip seals, example calculations are shown in this appendix. Values and properties of aggregate were estimated from various sources.

For all calculations it was assumed:

- The traffic on the roadway is greater than 2,000 vehicles per day.
- The pavement surface is a slightly pocked, porous, and oxidized surface.
- The binder will be a CRS-2 emulsion with 65% residual asphalt.

A common aggregate blend used for WSDOT chip seal is the 3/8” - No. 4 gradation which is used to illustrate the calculations. The calculations are done via eight steps.

Step 1: Determine the aggregate gradation, bulk specific gravity and percent absorption

The following table below shows the results of percent passing for the case study.

Table C-1: Percentage Passing for WSDOT Design Example

Sieve Name	Maximum Percentage Passing	Minimum Percentage Passing
1”	100	100
3/4”	100	100
5/8”	100	100
1/2”	100	100
3/8”	90	70
No. 4	5	0
No. 10	2.95	0
No. 200	1.5	0

* Aggregate absorption assumed = 0%

Step 2: Determine the Median Particle Size

To determine median particle size, Table C-1 is plotted on a gradation chart. The Median Particle Size is determined by extending a horizontal line at 50 percent passing mark until it intersects the gradation curve. This vertical line is then projected and the median size is determined. For example, from this graph, an average aggregate size will be used which is 7.7 mm or 0.303”.

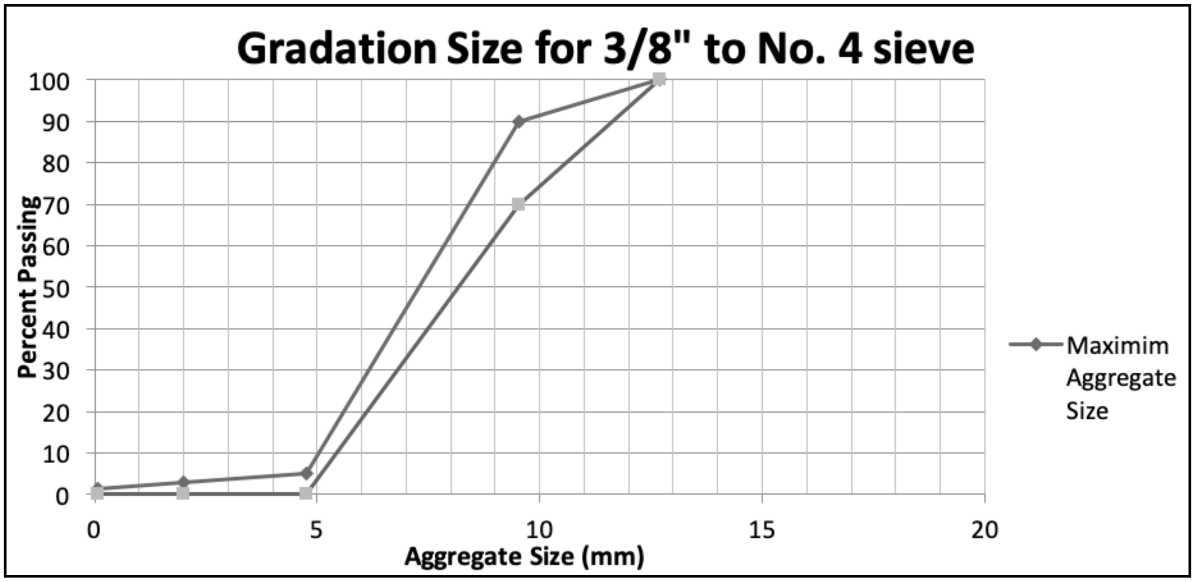


Figure C-1: Gradation Chart for Design Example

Step 3. Determine Flakiness Index (FI)

The aggregate used to determine the gradation is then broken down into the five following groups.

1. Passing the 1” sieve but retained on the 3/4” sieve.
2. Passing the 3/4” sieve, but retained on the 1/2” sieve.
3. Passing the 1/2” sieve, but retained on the 3/8” sieve.
4. Passing the 3/8” sieve, but retained on the 1/4” sieve.
5. Passing the 1/4” sieve, but retained on the No. 4 sieve.

Flakiness Index (FI) can be calculated by the following equation:

$$FI=\frac{(\text{Weight of Flat Chips})}{(\text{Weight of Sample})}$$

At the time these calculations were done, no Flakiness Index was available for WSDOT aggregate. Therefore, FI values were assumed. From a case study in Minnesota, the Flakiness Index was determined to be 28 percent. The aggregate used was a natural aggregate. WSDOT typically uses crushed rock, which provides more cubical aggregate; thus, we would expect an FI lower than 28 percent. From the BST review meetings (summarized in Appendices B through E), it was noted that rock quality does vary throughout Washington State, as expected, but it is generally of good quality. To represent a range of realistic FI values, test data from Idaho were used.[17] For their six districts, samples tested resulted in FI values, which ranged from 5 to 21%. Those will be used here. The value for Median Size Aggregate (M) is 0.303", as noted earlier.

Least average dimensions is calculated from the results of step 2 and step·3.

U.S. Customary Units

$$H = \frac{M}{1.139285+(0.011506)*(FI)}$$

Lower H

$$H = \frac{0.303\text{ in}}{1.1139285+(0.011506)*(21)} = \mathbf{0.224\ inches}$$

Upper H

$$H = \frac{0.303\text{ in}}{1.1139285+(0.011506)*(5)} = \mathbf{0.259\ inches}$$

Step 5. Determine the Loose Weight of the Aggregate (W)

Loose weight is determined by filling a metal cylinder with a volume of 0.50 ft^3 and then determining the weight of the material. From the Minnesota design example, a range of 80–100 lbs./ft^3 was noted. For the Idaho test data, the range of W for their six districts was 87 to 96 lbs./ft^3. The data from Idaho will be used as a range.

The Loose Unit Weight (W) was calculated by the straightforward relationship:

$$W = \frac{\text{Weight of Aggregate}}{\text{Volume of Cylinder}}$$

Step 6. Determine the Voids in the Loose Aggregate (V)

Once W is determined, voids are calculated as below. A specific gravity of 2.67 was assumed (as in the Idaho calculations):

U.S. Customary Units

$$V = 1-\frac{W}{62.4G}$$

Lower W

$$V = 1 - \frac{87\ \text{lbs/ft}^3}{(62.4)*(2.67)} = \mathbf{0.48}$$

Upper W

$$V = 1 - \frac{96\ \text{lbs/ft}^3}{(62.4)*(2.67)} = \mathbf{0.42}$$

Step 7: Application Rate

Now that the variables are all calculated, the application rate and binder design equation can be calculated including wastage (E) of 1.05 (whip-off) with G = 2.67:

Aggregate Application Rate in U.S. Customary Units

$$C = 46.8*(1-(0.4)(V))*(H)(G)(E))$$

Lower C

$$C = 46.8*\left(1-(0.4)(0.48)\right)*(0.224\text{in})(2.67)(1.05) = \mathbf{24\ lbs./yd^2}$$

Upper C

$$C = 46.8*\left(1-(0.4)(0.42)\right)*(0.259\text{in})(2.67)(1.05) = \mathbf{28\ lbs./yd^2}$$

Step 8: Binder Design Equation

The binder application rate is determined from the equation below and the variables calculated in the earlier example.

$$B = \frac{(2.244)(H)(T)(V)+S+A}{R}$$

*Variables T, S, and A are calculated from the traffic condition, surface condition, and aggregate absorption. Below are the tables where these factors can be found.

Table C-2: Traffic Factor (T)

Traffic factor				
Traffic Vehicles per day				
Under 100	100 to 500	500 to 1000	1000 to 2000	Over 2000
0.85	0.75	0.7	0.65	0.6

Table C-3: Surface Condition (S)

Existing Pavement Texture	Correction, S
Black, flushed asphalt surface	-0.01 to -0.06
Smooth, nonporous surface	0
Slightly porous, oxidized surface	0.03
Slightly pocked, porous, oxidized surface	0.06
Badly pocked, porous, oxidized surface	0.09

For this example: T =0.60, S = 0.06, and R = 0.65 (WSDOT SS 9-02). Aggregate absorption was considered to be 0.0 in this example.

Binder application rate in U.S. Customary Units

$$B = \frac{(2.244)(H)(T)(V)+S+A}{R}$$

Lower B

$$B = \frac{(2.244)(0.224)(0.60)(0.48)+0.06+0.00}{0.65} = \mathbf{0.32\,gal/yd^2}$$

Upper B

$$B = \frac{(2.244)(0.259)(0.60)(0.42)+0.06+0.00}{0.65} = \mathbf{0.32\,gal/yd^2}$$

Below in Table C-4 are the Median Particle Sizes for all three primary WSDOT chip seal bands. Using the same assumptions as for 3/8” and No. 4, the results for all three bands are shown in Table C-5.

Table C-4: Minimum and Maximum Median Particle Sizes for WSDOT Aggregate Sizes

	Median Particle Size		
	Minimum	Maximum	Average
5/8” - No. 4	0.378	0.417	0.398
1/2” - No. 4	0.299	0.346	0.322
3/8” - No. 4	0.283	0.323	0.303

Results

Below in Table C-5 are the results for typical WSDOT chip seal gradation bands using the McLeod Method. The Minnesota DOT recommends taking an average of (1) calculating the binder application rate by use of the Average Least Dimension and (2) the same calculation but done with the Median Particle Size. This table provides a starting point for selecting an acceptable binder application rate. These overall averages would then be about 0.46 gal/yd² for 5/8” - No.4, 0.37 gal/yd² for 1/2” - No.4, and 0.35 gal/yd² for 3/8”- No.4, all of which fall within the current WSDOT Standard Specifications range. The caveat is the various assumptions made: other assumptions would certainly produce different results which would not necessarily fit within the current specification ranges.

Table C-5: Results of McLeod Method Applied to WSDOT Aggregate

	McLeod Method			WSDOT SS 2014	
	(1) Emulsified Asphalt (gal/yd²)	(2) Emulsified Asphalt Averaged (gal/yd²)	Aggregate (lbs./yd²)	Emulsified Asphalt (gal/yd²)	Aggregate (lbs./yd²)
5/8” - No. 4	0.42	0.47–0.51	32–37	0.40–0.65	25–45
1/2” - No. 4	0.34	0.38–0.41	26–30	0.35–0.55	20–35
3/8” - No. 4	0.32	0.36–0.39	24–28	0.35–0.55	20–30

ENDNOTES

1. Douglas D. Gransberg and David M. B. James (2005), *NCHRP Synthesis 342 Chip Seal Best Practices* (Washington, D.C.: Transportation Research Board), 1–111.

2. Joe P. Mahoney, Megan Slater, Chris Keifenheim, Jeff Uhlmeyer, Tim Moomaw, and Kim Willoughby (2014), *WSDOT Chip Seals—Optimal Timing, Design, and Construction Considerations* (Olympia, WA: Washington State Transportation Center), 1–88.

3. Douglas D. Gransberg and David M. B. James (2005), *NCHRP Synthesis 342 Chip Seal Best Practices* (Washington, D.C.: Transportation Research Board), 1–111; Asphalt Institute, "Terminal Blend Asphalt Goes Mainstream-Now PG Graded," *Asphalt Magazine*, November 2008.

4. California Department of Transportation (2008), *Maintenance Technical Advisory Guide Volume I—Flexible Pavement Preservation*, *Second Edition* (Sacramento, CA: Office of Pavement Preservation Division of Maintenance).

5. Pavement Preservation Committee, Arizona Chapter (2013), *Chip Seal Guide for Application and Construction*, *1st ed.*, (Phoenix, AZ: Arizona Chapter, Associated General Contractors).

6. California Department of Transportation (2018), *Standard Specifications* (Sacramento, CA: California Department of Transportation), 439-489.

7. Asphalt Institute, Asphalt in Pavement Preservation and Maintenance, MS-16, Fourth Edition, Lexington, Kentucky, 2009.

8. Asphalt Institute, "Terminal Blend Asphalt Goes Mainstream-Now PG Graded," *Asphalt Magazine*, November 2008.

9. Scott Shuler, Anthony Lord, Amy Epps-Martin, and Denise Hoyt (2011), *NCHRP Report 680: Manual for Emulsion-Based Chip Seals for Pavement Preservation* (Washington, D. C.: Transportation Research Board of the National Academies).

10. Ibid.

11. Ibid.

12. California Department of Transportation (2018), *Standard Specifications* (Sacramento, CA: California Department of Transportation), 439-489.

13. Ibid.

14. B. Fraser and D. Cheng (2014), "Vialet Testing Results for Rubber Modified Seal Coat Project on CA SR 36, CP2C-2014-105," California Pavement Preservation Center.

15. Colin A. Franco and Todd Shields (2018), "Quality Assurance for Emulsion Treatments in Pavement Preservation," AASHTO ETF Webinar.

16. Scott Shuler, Anthony Lord, Amy Epps-Martin, and Denise Hoyt (2011), *NCHRP Report 680: Manual for Emulsion-Based Chip Seals for Pavement Preservation* (Washington, D. C.: Transportation Research Board of the National Academies).

BIBLIOGRAPHY

American Association of State Highway Transportation Officials (AASHTO). "Standard Practice for Emulsified Asphalt Chip Seal Design," 82–86. Washington, D.C.: 2016.

Anderson, K. W., Fraisure, C., Luhr, D., Russell, M., Uhlmeyer, J. S., Weston, J., and Willoughby, K. *Preventive Maintenance Study—Final Report*, Washington State Department of Transportation. Olympia, WA: 2018.

AGC, Pavement Preservation Committee, Arizona Chapter. *Chip Seal Guide for Application and Construction*, 1st ed. Phoenix, AZ: 2013.

Asphalt Institute, "Terminal Blend Asphalt Goes Mainstream-Now PG Graded," *Asphalt Magazine*, November 2008.

Asphalt Institute, MS-2, *Surface Treatments*.

Asphalt Interlayer Association, *Guide Specifications for Geosynthetic Reinforced Chip Seals,* 2018.

Austroads Sprayed Sealing Guide, AP-676/104, Austroads, Sydney, Australia, 2004.

Caltrans, Specifications for Bituminous Seals (Hot and Cold Applied), Section 37, 2018.

California Department of Transportation. *Maintenance Technical Advisory Guide Volume I—Flexible Pavement Preservation*, Second Edition, Office of Pavement Preservation Division of Maintenance. Sacramento, CA: 2008.

Cheng, D., Lane, L., and H. Zhou, Initial Performance Study by Caltrans SR 36 Rubberized Chip Seal Pilot Project, Proceedings, 2015 Rubberized Asphalt—Asphalt Rubber, October 2015.

FHWA. Information: Guidance on Highway Preservation and Maintenance. FHWA, Associate Administrator for Infrastructure, Washington, D.C.: 2016. Available at https://www.fhwa.gov/preservation/memos/160225.cfm.

Franco, C., and Shields, T., AASHTO ETF Presentation, Quality Assurance for Emulsion Treatment in Pavement Preservation. November 2018.

Fraser, B., and Cheng D., Vialet Testing Results for Rubber Modified Seal Coat Project on CA SR 36, CP2C-2014-105, California Pavement Preservation Center, May 4, 2014.

Hanson, F. M., "Bituminous Surface Treatments on Rural Highways," Proceedings of the New Zealand Society of Civil Engineers, Vol. 21, 1934–1935.

Gransberg D., James D. M. B. (2005). *NCHRP Synthesis 342 Chip Seal Best Practices*, Transportation Research Board, 1–111. Washington, D.C.: 2005.

Mahoney J. P., Slater M., Keifenheim C., Uhlmeyer J., Willoughby K., Moomaw T. *WSDOT Chip Seals—Optimal Timing, Design, and Construction Considerations*, Washington State Transportation Center, 1–88. Olympia, WA: 2014.

McLeod, N. W., “Seal Coat Design,” Proceedings of the Association of Asphalt Paving Technologists, Vol. 38, February, 1969.

Peshkin, D. Smith, K. L., Wolters, A. Krstulovich, J. Moulthrop J. Alvarado, C. “Definitions,” *Guidelines for the Preservation of High-Traffic-Volume Roadways*, Ed. 2, National Academy of Sciences, 2–3. Washington, D.C.: 2011.

Pierce L. M., Kebede N., *Chip Seal Performance Measures—Best Practices*, Applied Pavement Technology, Inc., 1–57. Urbana, IL: 2015.

Shuler, S., Lord, A., Epps-Martin, A., and Hoyt, D., “Manual for Emulsion-Based Chip Seals for Pavement Preservation,” NCHRP Report 680, Transportation Research Board of the National Academies, Washington, D. C.: 2011.

Way G. B., K. E. Kaloush, and K. P. Biligiri, Asphalt Rubber Standard Practice Guide, Rubber Pavements Association, October 2012.

TERMINOLOGY

- Cape Seal: This treatment is a combination of a chip seal followed by either a slurry seal or microsurfacing. The chip seal can be an emulsion or asphalt rubber chip seal. Cape seals typically increase the durability of the road and produce a smooth surface.

- Chip Seal: A bituminous binder is applied, followed by aggregate application and rolling to embed the aggregate into the binder.

- Corrective Maintenance: This maintenance type is conducted in response to defects that affect operations of a facility and integrity of pavement sections. This form of maintenance is also known as reactionary maintenance and can be conducted throughout the lifespan of a pavement. It is typically used to fix localized defects and return a pavement to an acceptable service quality. Maintenance activities include patching of potholes and replacement of concrete slabs.

- Distresses: Deterioration resulting from factors including the environment, construction and design practices, material selection, and loads on pavement. There are two distinct categories of distresses: functional and structural.

- Functional distress: Deterioration affecting the pavement's ability to serve its function of being a safe, smooth, and quiet surface for comfort while driving. Using preservation treatments, minor functional problems can be addressed as long as there are no structural problems.

- Structural distress: Deterioration resulting from excess weight and loading, lack of thickness and support for the pavement structure. Considerable deterioration does not allow for the distresses to be addressed using preservation treatments.

- Fog Seal: A light application of a diluted and slow-setting asphalt emulsion to the surface of an aged pavement surface. Sometimes used at a low cost to help lock in the chip seal aggregate and blacken the chip seal surface.

- Flush Coat: A final application of a fog seal taking place after brooming that serves to eliminate rock loss and improve durability prior to opening the pavement to uncontrolled traffic. In California, some agencies apply a light application of sand to prevent pick up under traffic.

- GRCS (Geosynthetic Reinforced Chip Seals) constitute a type of chip seal applied over an asphalt-impregnated geotextile to help prevent reflection cracks from the underlying layer.

- High-traffic-volume Roadway**:** Rural roadways have an ADT greater than 5,000 vehicles per day and urban roadways have an ADT greater than 10,000 vehicles per day.

- Major Rehabilitation: To extend the service of a pavement and/or improve load-carrying capabilities through structural enhancement.

- Microsurfacing: This treatment type relates to slurry seals; however, the main variation between the two is the quality of the materials. With this treatment, the polymer and asphalt residual content is greater than that of slurry seals, and the aggregate quality is better. In addition, the cost is greater than for slurry seals; however, the cure time is more time-efficient than slurry seals.

- Minor Rehabilitation**:** The distresses addressed are non-structural enhancements to improve the lifespan, reduce surface cracking and restore the pavement to serve its function. The distresses could be a result of environmental factors. These are typically referred to as pavement preservation techniques, occurring midway in a pavement's lifespan when the quality of the roadway begins to diminish.

- Pavement Condition Index (PCI): This index is most commonly used by the Metropolitan Transportation Commission (MTC) as a value ranging from 1–100 directly related to the condition of the pavement.

- Pavement Preservation: The practice of utilizing a cost-effective system that allows for tracking and recording to extend and enhance the quality and life of a pavement. In addition, preservation would serve as a way to improve safety and provide good ride quality. The system primarily focuses on preventive maintenance as a cost-effective way to treat roadways and improve the quality of the road.

- Paving Fabric or Geosynthetic: A sheet of non-woven petroleum-based material used in conjunction with chip seals or HMA overlays to provide additional support. Benefits roadway by minimizing water penetration, inhibiting reflective cracking, and increases pavement life.

- Performance Curve: Diagram that displays the relationship between time and a variable, such as the Pavement Condition Index (PCI) of road sections. The performance curves would detail the life and condition of a roadway before and after treatment application.

- Preventive Maintenance**:** Cost-effective strategy for treatment to roadway system accounting for ways to preserve the roadway and prevent deterioration in addition to improving or maintaining the condition of the roadway. This is typically performed early, before significant structural deterioration can appear. Some activities include joint sealing, crack sealing and filling, as well as utilizing chip seals and slurry seals.

- Routine Maintenance: Maintenance performed routinely to preserve the roadways' condition or to return the roadways to a proper level of service. Some maintenance activities include crack filling and/or sealing, as well as maintaining the drainage system, both of which are performed throughout a pavement's life.

- Scrub seal: A variation of the chip seal used when cracks are present as a form of distress. The PRME is applied to the road surface and broomed into the cracks, followed by the application of either a single or double chip seal.

- Surface Type: Surface type is the uppermost layer and is dependent on the type of material used, whether it is HMA or Portland Cement. The surface type also depends on the functional class (arterial, collector, residential).

- Treatment Category: Treatments with application times and objectives alike. For instance, one group of treatments is meant to hinder and prevent deterioration; however, other treatments would include maintenance, rehabilitation, and construction of roadways.

- Treatment Type: A certain treatment used to treat specific distresses on a roadway. These treatments would include chip seals, slurry seals, microsurfacing, HMA overlays, and diamond grinding. For some situations, treatment combinations are required to ensure quality performance of the roadway.

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AAPT	Association of Asphalt Paving Technologists
ADT	Average Daily Traffic
AEMA	Asphalt Emulsion Manufacturers Association
AGC	Associated General Contractors
AI	Asphalt Institute
AIA	Asphalt Interlayer Association
APWA	American Public Works Association
AR	Asphalt Rubber
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CalRecycle	California Department of Resources Recycling and Recovery
CCPIC	City and County Pavement Improvement Center
CP2C	California Pavement Preservation Center
DOT	Department of Transportation
FHWA	Federal Highway Administration
HMA	Hot Mixed Asphalt
IRI	International Roughness Index
ISSA	International Slurry Surfacing Association
LCCA	Life Cycle Cost Analysis
LCC	Life Cycle Cost
MSA	Maintenance Superintendents Association
MTAG	Maintenance Technical Advisory Guide developed by Caltrans
MTC	Metropolitan Transportation Committee
MTI	Mineta Transportation Institute
NDOT	Nevada Department of Transportation
PaveM	Caltrans Pavement Management System
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PME	Polymer Modified Emulsion
PMS	Pavement Management System
PMRE	Polymer Modified Rejuvenating Emulsion
TDA	Tire-Derived Aggregate
TRB	Transportation Research Board
UNR	University of Nevada, Reno
WSDOT	Washington State Department of Transportation

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Dr. DingXin (Ding) Cheng is a professor of the department of civil engineering at the California State University, Chico, director of the California Pavement Preservation (CP2) Center, and the director of the Tire Derived Aggregate Technology Center. He has worked actively with the CP2 Center since he joined the department of civil engineering of CSU Chico in 2006. He obtained his PhD in the areas of pavement materials and transportation from Texas A&M University in College Station, Texas in 2002. He worked in private industry for Parsons Brinckerhoff in Houston, TX before joining Chico State University. He has extensive experience in Hot Mix Asphalt (HMA) materials and pavement preservation on both asphalt and concrete pavements. He has more than 55 peer-reviewed publications related to pavement materials and preservation in Transportation Research Board, AAPT, ASCE, and other conferences. Ding has co-managed or managed more than $7 million research projects funded by California Department of Transportation (Caltrans), California Department of Resources Recycling and Recovery (CalRecycle), Metropolitan Transportation Commissions (MTC) of San Francisco Bay Area, and other agencies and industry leaders. He is a registered professional engineer in the State of Texas.

LEROSE LANE, P.E., SENIOR PAVEMENT PRESERVATION ENGINEER

Lerose Lane, P.E., is a Senior Pavement Preservation Engineer who has worked for the California Pavement Preservation Center (CP^2C) since August 2010. Her work includes observing pilot project construction for a wide variety of preservation strategies including Rubberized Chip Seals, Scrub Seals, Reconstruction with Rubberized Hot Mix Asphalt Concrete, and Double Chip Seals. Besides observing and evaluating construction and long-term performance of this wide variety of preservation strategies, she co-authors many of the technical reports regarding the construction phases and the follow up inspection reports. Most of these projects are Caltrans projects on California State Highways or Interstate Routes.

She graduated from CSU, Chico, in 1970 with a B.S. degree in Civil Engineering. Since that time, she has worked for UCD, City of Marysville, County of Tehama, and Caltrans in various capacities, including: District Materials Engineer, Office Chief in Design, Senior Construction Engineer, as well as Resident Engineer for a wide variety of projects. She has been a Professional Engineer in the State of California since 1975.

PEER REVIEW

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