SECTION 4
SINGLE AND MULTIPLE CHIP SEALS USING ASPHALT EMULSIONS

4.1 Scope

This guideline has been prepared for the benefit of those engaged in chip seal construction, to highlight items that are essential for achieving consistent, high quality results. It will present information on rapid setting RS or CRS, medium setting MS or CMS, and high float asphalt emulsions, cover aggregates, design practices that indicate the quantities of asphalt emulsion and cover aggregate to be applied, relevant construction equipment, and construction procedures that are required for successful single and multiple chip seals.

This section has been written as a guide only, and should be so employed. User specifications based on this guide should be adapted to job conditions, local usages and anticipated performance requirements.

4.2 Definitions

A single chip seal wearing surface consists of a uniform application of a rapid setting RS, HFRS, or CRS asphalt emulsion to a prepared surface followed by uniform application of cover aggregate which is then rolled.

A multiple chip seal continues this construction procedure by adding alternate uniform applications of asphalt emulsion and cover aggregate, followed by rolling each application of cover stone. Subsequently, a double chip seal consists of two alternate uniform applications of asphalt emulsion and cover aggregate, a triple chip seal consists of three alternate uniform applications of these materials, etc.

Chip seals are quite often referred to as seal coats when they are applied to an existing paved surface, and as surface treatments when they are applied to a prepared consolidated gravel, crushed stone, water bound macadam, stabilized soil, or similar base.

For multiple chip seals, the size of cover aggregate for each successive layer is normally about one-half that for the immediately preceding layer.

4.3 Applicable Documents

4.3.1 ASTM Documents

- *C29 Test Method for Unit Weight and Voids in Aggregate*
- C131 *Resistance to Degradation of Small-Size Course Aggregate by Abrasion and Impact in the Los Angeles Machine*
- D977 *Specification for Emulsified Asphalt*

- D1139 *Specification for Aggregate for Single or Multiple Bituminous Surface Treatments*
- D1369 *Practice for Quantities of Materials for Bituminous Surface Treatments*
- D2397 *Specification for Cationic Emulsified Asphalt*
- D2995 *Practice for Determining Application Rate of Bituminous Distributors*

4.3.2 AEMA Documents

- **A Basic Asphalt Emulstion Manual**

4.4 Asphalt Emulsions

The asphalt emulsions employed for chip seals may be either rapid setting anionic or cationic RS, HFRS, or CRS; ASTM specifications for anionic (RS, HFRS) emulsions are listed in D977 and for cationic (CRS) emulsions in D2397. Each of the rapid-setting asphalt emulsions may be modified with a polymer additive. Polymer-modified emulsions are generally used for chip seal of pavements that are subject to higher traffic volumes and require a tougher, more resilient surface course.

Rapid setting emulsions are the most commonly used asphalt emulsions used for chip seals. However, there may be certain applications where medium setting emulsions provide better performance.

Rapid setting emulsions should be selected where the chip seal will be exposed to traffic immediately after construction. By breaking or setting quickly, the asphalt cement in the emulsion is able to develop a strong bond with the cover aggregate, providing the chip seal with more resistance to the disintegrating forces of traffic. Fast traffic should never be allowed on newly constructed chip seals.

Graded aggregate seals (section 4.29) most often use medium-setting high float (HFMS-1 or HFMS-2) emulsion.

4.4.1 Cover Aggregates

There are four very important properties of cover aggregates; toughness or hardness, gradation or sieve analysis, particle shape, and voids in the loose weight condition. In addition, cover stone should be clean and free from coatings of dust or other foreign material, preferably less than 1.5 percent passing 0.075 mm (No. 200) sieve by the wash test.

4.4.2 Hardness

A Los Angeles abrasion rating of 25 maximum is sometimes stipulated for heavier traffic (more than 1,000 vehicles per day) while an L.A. rating up to 40 may be accepted for light traffic (under 500 vpd). However, locally available aggregates tend to be employed as cover materials regardless of the Los Angeles abrasion value. The advantage of a Los Angeles abrasion rating of 26 or less is that this usually ensures a tough aggregate with much less tendency to break up or wear away under the influence of traffic and climate.

4.4.3 Gradation

ASTM D1139 provides the gradation requirements for cover aggregates for single and multiple chip seals. The National Association of Australian Road Authorities specification requires cover aggregates that are more nearly one-size than those referred to in ASTM D1139. The Australian specification calls for 95% of the aggregate to be retained on two adjacent sieves in the standard series, and a maximum of 0.5% minus the 0.075 mm (No. 200) sieve. Because of the consistent excellence of chip seals in the State of Victoria, Australia, this target cover aggregate specification should be approximated or equaled wherever possible. These single-size cover aggregates are seldom available in North America and cover stone referred to in ASTM D1139 is generally used.

Figure 4-1 Average Least Dimension Illustrates the Average Least Dimension (ALD) of cover aggregate particles and their ultimate positioning after considerable traffic (the least dimension of each particle is vertical).

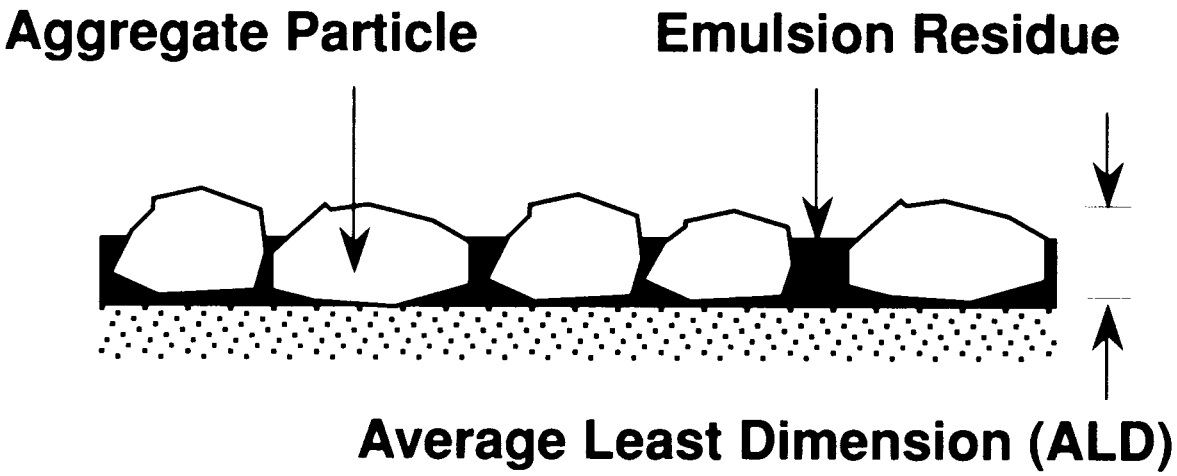

Figure 4-1 Average Least Dimension

4.4.4 Shape

The third important characteristic of cover aggregate is particle shape, which should preferably approach that of a cube or tetrahedron (pyramid). However, as illustrated by **Figure 4-1 Average Least Dimension**, most aggregate particles are thinner in one dimension than in the other two, and under traffic all cover aggregate particles tend eventually to lie on their flattest sides, which is their most stable position. Therefore, the average thickness of a chip seal is given by the average of the smallest dimension of a representative sample of cover aggregate particles, which is called their Average Least Dimension (ALD). Elongated particles, having a ratio of maximum to minimum dimensions greater than 4 to 1, should be limited to not more than 25%.

4.4.5 Voids

The voids in the cover stone is needed for one method of chip seal design and requires the use of ASTM C29 for determining the loose unit weight of the cover aggregate. From this information by knowing the aggregates' ASTM bulk specific gravity, the voids in the cover stone in the loose weight condition can be calculated.

4.5 Compatibility of Emulsion and Aggregate

Compatibility or affinity between an asphalt emulsion and an aggregate can be variable. If there is any doubt as to whether an anionic or cationic emulsion would be preferable with a given cover stone, your AEMA emulsion supplier should be consulted.

4.6 Chip Seal Design

4.6.1 General

There are two approaches to the design of chip seals. One approach is for organizations that do not have access to a laboratory, and are primarily interested in approximate quantities of asphalt emulsion and cover aggregate to be applied.

The second approach measures the physical properties of the actual construction materials and develops a scientific basis for aggregate and emulsion application. This approach will be precise and minimize both the risk of product failure and the use of unnecessary materials.

4.6.2 Background for Chip Seal Design

Any method of design for chip seals must be able to provide an answer to the following three questions:

1. How much asphalt emulsion will be applied in L/m^2 (gal/yd^2) measured at 15.6° C (60° F)?
2. How many kg (lb) of cover aggregate will be applied per m^2 (yd^2)?
3. What grade of asphalt emulsion should be selected?

Answering the third question first, generally speaking, RS-1 or CRS-1 type emulsions are used for smaller sizes of cover aggregate and for flatter surfaces, while HFRS-2, RS-2, or CRS-2 type emulsions are employed for cover aggregate of larger size and for highly crowned or sloping surfaces.

Therefore, RS-1 or CRS-1 type asphalt emulsions should be selected for cover stone up to 9.5 mm (3/8 in.) size and where crown or cross slopes are not steep enough to cause run-off. The quantity of RS-1 or CRS-1 type emulsion required for cover aggregates larger than 9.5 mm (3/8 in.) is usually so high that surface run-off could occur, and for these HFRS-2, RS-2 or CRS-2 type should be specified.

The -2h grades of the above asphalt emulsions may be used in warmer climates.

Consult your local AEMA emulsion supplier for selection criteria.

4.6.2.1 Other Considerations

When designing a chip seal, each of the following items should be examined and assessed. Whether the design is being done on a formal or very casual basis, more success will be achieved by focusing on and checking off each item before construction is permitted to begin.

- Traffic Volume — The optimum amount of asphalt binder to be applied must be increased by 40% as the traffic volume decreases from more than 2000 to less than 100 vehicles per day.
- Voids in the Cover Stone — Between different cover aggregates this can easily range from 0.16 to 0.20 of the volume of a chip seal, and can result in a difference in optimum asphalt requirements of 25 percent.
- ASTM Bulk Specific Gravity of Cover Stone — With all other factors equal, if the ASTM bulk specific gravity of a cover aggregate is higher than normal, more kg/m^2 (lb/yd^2) must be applied, and vice-versa.
- Aggregate Waste — Because of unevenness of spread and loss due to whip-off by traffic, more cover aggregate must be placed than will remain in a chip seal. The excess cover stone that must be applied for this reason can range from 2 to 10% depending on the efficiency of the chip spreader being employed.
- Percent Residual Asphalt — The asphalt emulsion requirement for a chip seal is based on the amount of residual asphalt in the emulsion. Asphalt emulsions for chip seal usually contain from about 60 to 70 percent of residual asphalt. Therefore, the same optimum residual asphalt content in a chip seal, 17% more asphalt emulsion with a residue of 60 percent should be applied than an emulsion with 70 percent of asphalt residue.
- Surface Texture of the Existing Pavement — The texture of a paved surface to which a chip seal is to be applied, can range from black due to some flushing or bleeding which can subtract as much as 0.27 L/m^2 (0.06 gal/yd^2) from the normal asphalt binder requirement for a chip seal, to a dry ravelled surface which can require up to an additional 0.40 L/m^2 (0.09 gal/yd^2). Therefore, the adjustment in asphalt emulsion application in terms of residual asphalt due to the wide difference in texture of the surface on which a chip seal is to be constructed, can range from 0 to 0.7 L/m^2 (0 to 0.15 gal/yd^2).

It should be clear that the ranges in quantities of asphalt emulsion and cover stone associated with the above items, can very easily make the difference between a poor, mediocre, and a highly successful chip seal. They also emphasize the need for a formal to chip seal design in which each of these items is evaluated, and point out the dangers in the common absence of any but the most casual and even complete lack of attention to the design of chip seals.

4.7 Single Chip Seal Design Without Access to a Laboratory

For organizations that do not have access to a laboratory for the precise design of chip seals, **Table 6-3 Quantities of Asphalt and Aggregate for Single Surface Treatments** in AEMA's **A Basic Asphalt Emulstion Manual** or ASTM D1369, provides a useful guide to the quantities of asphalt emulsion in L/m^2 (gal/yd^2) and cover stone in kg/m^2 (lb/yd^2) that should be applied for a single chip seal.

It should be clearly recognized that **Table 6-3 Quantities of Asphalt and Aggregate for Single Surface Treatments** provides guidance for selecting the quantities of asphalt emulsion and cover aggregate for average circumstances. It does not provide a precise method of design for the wide range of conditions that can occur on chip seal projects. For example, **Table 6-3 Quantities of Asphalt and Aggregate for Single Surface Treatments** does not specifically make provision for the wide differences in traffic volume, ALD, voids in the cover stone, in cover aggregate wastage loss, in texture of the surface to which a chip seal is to be applied, or in content of residual asphalt, that can occur from project to project. Each of which can have a major influence on the quantities of cover stone and asphalt binder that should be applied per unit area.

Consequently, while many organizations will probably continue to employ empirical guidance like**Table 6-3 Quantities of Asphalt and Aggregate for Single Surface Treatments** for establishing the quantities of asphalt emulsion and cover stone to be applied per unit area, or no tables at all, they should not be surprised when the resulting chip seals provide indifferent performance and have short service lives.

4.8 Multiple Chip Seal Design without Access to a Laboratory

The aggregate for each successive layer of a multiple chip seal should be approximately one-half the size of the aggregate for the immediately preceding layer. On this basis, organizations that do not have access to a laboratory for the precise design of chip seals, **Table 6-4 Correction for Surface Condition** and **Table 6-5 Quantities of Asphalt and Aggregate for Double Surface Treatment** in AEMA's **A Basic Asphalt Emulstion Manual** or ASTM D1369, provides a useful guide to the quantities of asphalt emulsion in L/m^2 (gal/yd^2) and cover stone in kg/m^2 (lb/yd^2) that should be applied for a multiple chip seal.

Again, **Table 6-4 Correction for Surface Condition** and **Table 6-5 Quantities of Asphalt and Aggregate for Double Surface Treatment** provide guidance for selecting the quantities of asphalt emulsion and cover aggregate for more or less average circumstances. They do not. provide a precise method of design for the wide range of conditions that can occur on chip seal projects. (See **Figure 4-2 Effect of Aggregate Particle Shape on Materials Quantities**)

4.9 Formal Chip Seal Design

The asphalt emulsion supplier should be consulted for a formal single or multiple chip seal design. The supplier has knowledge of local aggregate characteristics and construction practice. The supplier is also in the best situation to judge emulsion compatibility and formulation. Aggregates proposed for use on a chip seal project should be delivered to the emulsion supplier. Other useful information includes traffic count and road surface condition.

An inspection of the proposed roadway by the supplier may be recommended.

Figure 4-2 Effect of Aggregate Particle Shape on Materials Quantities Illustrates the effect of aggregate particle shape on materials quantities. Both aggregates are 0.5

inch as measured by sieve analysis. One is cubicle, the other is flat and elongated. Voids filled is 70% for both aggregates.

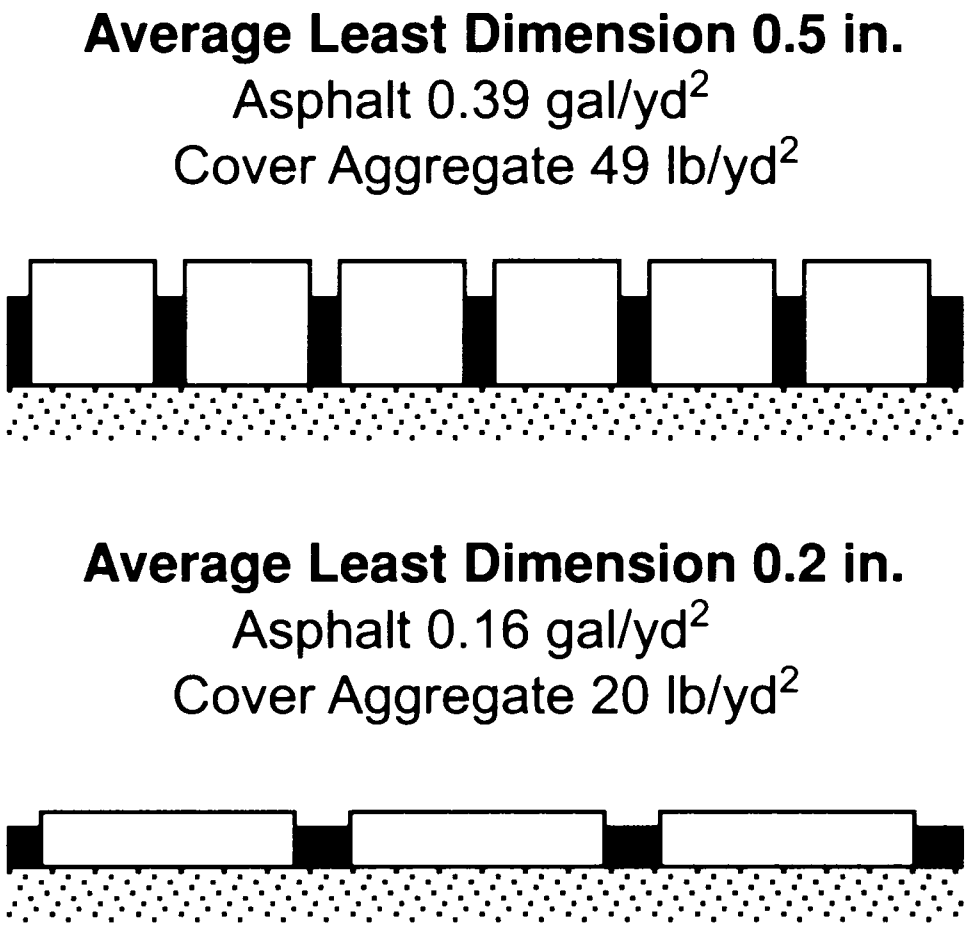

Figure 4-2 Effect of Aggregate Particle Shape on Materials Quantities

4.10 Basic Construction Equipment

The basic equipment for constructing a chip seal should include:

1. Asphalt distributor
2. Cover aggregate spreader, preferably of the mechanical self-propelled type
3. Rollers, preferably pneumatic-tired
4. Rotary power broom and other cleaning equipment
5. Broom drag
6. Cover aggregate haul trucks equipped with special hitches for attachment to aggregate spreaders

4.10.1 Emulsion Distributor

It is the principal function of the distributor to apply asphalt emulsion uniformly in both transverse and longitudinal directions at the specified rate in L/m^2 (gal/yd^2). Failure to do so can result in streaking in which too much and too little asphalt alternate every few inches across the road surface.

Streaking usually results from incorrect positioning of the nozzles in the spray bar, from different nozzle sizes in the spray bar, from incorrect spray bar height, from damaged or nicked spray nozzles, by forcing more or less than the optimum quantity of asphalt emulsion through each spray nozzle, or from attempting to spray asphalt emulsion at too low a temperature so that it cannot fan out properly from the spray nozzles, and even by inability of the control mechanism to fully open the spray nozzles in one or more sections of the spray bar.

To avoid streaking, each nozzle in the spray bar of the asphalt distributor should be turned to make the constant angle with the longitudinal axis of the spray bar that is recommended by the manufacturer. All nozzles in the spray bar should be of the same size. The spray bar height should provide double or triple overlap of the asphalt emulsion being applied by the spray nozzles as recommended by the manufacturer. The distributor should be able to spray asphalt emulsion within ±7.5 percent of the average application rate in the longitudinal direction and within ±10.0 percent of the average rate of application for any 4-inch width in the transverse direction. A very simple and practical method for checking the rate of application of asphalt emulsion in both the longitudinal and transverse directions is provided by ASTM D2995.

For satisfactory application of asphalt binder uniform pressure must be maintained in the spray bar. The optimum pressure discharges asphalt binder at a constant rate through each spray nozzle, (e.g., 15.1 L/min (4 gal/min)). Only at this constant rate of discharge does the asphalt emulsion fan out uniformly from each spray nozzle. Therefore, different rates of application of asphalt binder in L/m^2 (gal/yd^2) should be achieved by changing the forward speed of the distributor and not by changing the discharge rate in L/min (gal/min) from each spray nozzle.

Important accessory equipment for each distributor includes an accurate gauge, 150 mm (6 in.) in diameter or larger, to indicate pressure in the spray bar, an accurate tachometer to show pump speed in r/min, an accurate thermometer for registering the temperature of the asphalt emulsion in the distributor, a calibrated dipstick to enable liters (gallons) of asphalt binder per millimeter (inch) of depth to be read at any time, and a bitumeter that has been calibrated to accurately measure the distance traveled and the speed in m/min (ft/min) when spraying.

4.10.2 Cover Aggregate Spreaders

Cover aggregate spreaders may consist of tailgate spreaders, but to obtain a continuous and uniform rate of cover aggregate application, and to keep up with the asphalt distributor, they should preferably be of the mechanical self-propelled type.

Before use on any given job, a mechanical self-propelled chip spreader should be calibrated for the particular cover aggregate to be applied. The forward speed of the chip

spreader during calibration should approximate the speed required to remain close to the distributor. The object of calibration therefore, is the gate opening at this speed that results in the application of cover stone by the chip seal spreader at the rate specified.

Calibrating the aggregate spreader avoids the application of either too little or too much cover aggregate, either of which can be costly. Too little cover aggregate can result in shortened service life, while too much represents a waste of cover stone. Furthermore, there is a shortage of good quality cover aggregates in some areas. Consequently, by applying the correct quantity of cover stone per m^2 (yd^2) a vanishing valuable natural resource is being conserved.

4.10.3 Rollers

The objective of the rolling operation is to press the cover stone firmly into the asphalt emulsion. This improves particle embedment, promotes more thorough wetting and better adhesion between asphalt emulsion and cover aggregate, and achieves better cover stone interlock. For single chip seals, rollers should be of the pneumatic-tire type. No existing surface is entirely smooth, and because of their flexibility, pneumatic tires can reach down into small depressions and press the cover stone into the asphalt emulsion. Steel wheel rollers bridge over these depressions. Steel wheel rollers also tend to crush cover aggregate particles.

For multiple chip seals, while most rolling should be done with pneumatic tire rollers, at least one pass should preferably be made with a steel wheel roller immediately before the next layer is to be placed, and also on the final layer. This orients the cover stone particles into a flatter surface, which is desirable when constructing multiple chip seals.

For an average chip seal construction operation, a minimum of three rollers should be used on chip seal projects. Two rollers should be kept close to the chip spreader at all times so as to make the first pass of the roller over the cover aggregate before the emulsion breaks, while the third roller does the back-rolling.

4.10.4 Rotary Power Broom

A powerful rotary broom is needed to thoroughly clean the existing surface before a chip seal is applied.

A layer of dust tends to accumulate near the edges of an existing surface which can prevent good bond between the new chip seal and the old surface. For this reason this layer of dust should be carefully removed with a power broom.

By light brooming, the powered rotary broom should also be used to remove excess cover stone from a new chip seal preferably during the coolness of early morning immediately following the construction of the chip seal.

4.10.5 Broom Drag

The use of a broom drag immediately following the chip spreader is generally frowned upon. Nevertheless, even the most skillfully operated chip spreaders leave occasional

areas with insufficient cover aggregate and others with an excess. With some chip spreaders there is considerable unevenness of spread. Consequently, there is often need for a carefully operated broom drag to provide more uniform distribution of the cover stone. To obtain more evenness of spread, broom dragging may be particularly beneficial on the first layer of cover stone for a double surface treatment.

It needs to be emphatically stressed however, that the broom drag operation must avoid turning over any of the cover aggregate particles exposing their black undersides. These black surfaces stick to the wheels of traffic and initiate a snowballing effect by tearing out other stone particles to the detriment of the new chip seal. On any project where this is occurring in spite of careful broom drag operations, the broom dragging should be stopped immediately.

4.10.6 Cover Aggregate Trucks

To avoid costly delays in chip seal construction operations due to lack of cover stone an adequate number of haulage trucks should be provided.

Each haulage truck should be equipped with a suitable hitch for connection to the chip spreader. The trucks should be designed to avoid contact between the truck body and the chip spreader at all times and the truck body should be modified if necessary to empty cleanly and completely into the hopper of a self-propelled chip spreader. Spillage of cover aggregate onto the road surface when the truck is emptying into this hopper should not be tolerated.

4.11 Construction Operations

The sequence of construction operations is as follows:

1. Adequate preparation, repair, and thorough cleaning of the surface that is to receive the chip seal. Because they are invariably quite porous, new patches made with pre-mix material should preferably be made several weeks ahead of the chip seal.
2. Consideration of temperature and weather
3. Spraying the asphalt emulsion
4. Applying the cover aggregate
5. Rolling
6. Broom dragging if necessary to achieve more uniform cover aggregate distribution
7. Brooming off excess cover stone
8. Repeating this sequence of operations for each layer of multiple chip seal

4.12 General Considerations

It cannot be overemphasized that poor chip seals often result from poor construction practice in spite of the excellent quality of the asphalt emulsion and cover aggregate, and the competent design procedures employed.

Some chip seals lose much or most of the cover aggregate during the first winter. When the particles of cover aggregate thrown onto the shoulder are examined, very

often only a very small area of each particle has been blackened by asphalt. This provides evidence of lack of sufficient embedment during construction, which could result from a number of causes:

- The chip seal was constructed during cool weather late in the year. Therefore, the one month of warm weather traffic required to reorient them onto their flattest sides and properly embed the cover stone particles into the asphalt binder was not available before winter arrived.
- Not enough asphalt emulsion was applied.
- There was a long delay between the application of the emulsion and the application of the cover stone so that the emulsion had broken before the cover aggregate was applied.
- The emulsion being used was too fast breaking. The emulsion broke before the cover aggregate was applied in spite of well-coordinated chip seal construction operations.
- The rolling operation was inadequate, or the rollers may not have been ballasted, or were delayed so that the first roller pass was not made before the emulsion had broken.
- The skin of hard penetration grade asphalt that forms on the surface of an asphalt emulsion when it breaks, tends to prevent the development of adequate early adhesion between emulsion and cover aggregate when the cover stone is applied after the emulsion has started to break. Consequently, adequate rolling of chip seals made with asphalt emulsions should be crowded as closely to the chip spreader as possible, so that the first roller pass over the cover stone is made before the emulsion breaks.

4.12.1 Preparation of a Granular or Stabilized Base

The granular or stabilized base should be scarified if necessary, bladed, watered, and rolled to provide a surface that is uniform, firm, smooth, and that conforms to specified profile and cross section.

Immediately after this preliminary preparation, it should be primed with from 0.9 to 2.3 L/m^2 (0.2 to 0.5 gal/yd^2) of a suitable asphalt primer. Priming will be facilitated if the surface is damp, but the use of calcium chloride can hinder penetration of the primer. The grade of primer selected and the quantity to be applied should be completely absorbed into the surface in 24 hours, and depends very largely on the porosity of the surface.

If the primed surface is to be exposed to traffic for sometime, it should be protected by an immediate application of from 3.2 to 5.4 kg/m^2 (6 t o 10 lb/yd^2) of clean coarse sand.

The priming operation should be completed far enough ahead of the chip seal to enable the asphalt primer to cure. Depending upon local conditions and the season of the year, this could be from two to three days to two weeks.

Immediately before applying the chip seal, the primed surface should be broomed with a rotary power broom to remove all loose and foreign material. Hardened patches of mud or clay may have to be removed with a pick and shovel.

4.12.2 Preparation of a Paved Surface

The paved surface should be made as uniform as possible before a chip seal is applied. Consequently, all rich patches should be removed, and all holes, depressions, and other defective or distressed areas should be repaired. It cannot be overemphasized that unless a chip seal is constructed on a uniform surface, the appearance of the chip seal after several weeks of traffic will not be uniform.

New patches that have been made on the surface will be porous, and may absorb some of the asphalt emulsion applied for the chip seal. These should be sprayed with 0.45 L/m^2 (0.1 gal/yd^2) of SS-1h or CSS-1h emulsion that has been diluted 50 percent (1 + 1) with water, and covered with from 3.2 to 5.4 kg/m^2 (6 to 10 lb/yd^2) of clean coarse sand, for example bank sand, and opened to traffic for two weeks before chip sealing.

If the old pavement is noticeably porous, it may absorb some of the emulsion applied for a chip seal. A simple quick test for porosity of an existing surface is to apply to it a couple of drops of lubricating oil from the dipstick of an automobile. If the surface is porous it will absorb the oil almost immediately. If it is non-porous most of the oil will remain on the surface after 10 minutes. If the existing surface is porous, it should be sprayed with 0.45 L/m^2 (0.1 gal/yd^2) of SS-1h or CSS-1h emulsion that has been diluted 50 percent with water and covered with from 3.2 to 5.4 kg/m^2 (6 to 10 lb/yd^2) of clean coarse sand. An asphalt emulsion sand slurry seal can be substituted for the SS-1h or CSS-1h emulsion and sand.

If the old surface is severely pocked, see **Table 6-3 Quantities of Asphalt and Aggregate for Single Surface Treatments** in AEMA's **A Basic Asphalt Emulsion Manual**), it is probably so variable that it should be made uniform before a chip seal is applied. Again, the remedy is either 0.45 L/m^2 (0.1 gal/yd^2) of SS-1h or CSS-1h emulsion diluted 50 percent (1 + 1) with water and covered with 3.2 to 5.4 kg/m^2 (6 to 10 lb/yd^2) of clean coarse sand, or an asphalt emulsion slurry seal.

The purpose of each of these treatments is to obtain a uniform surface on which a chip seal is to be constructed. Each treatment should result in a uniform surface with a textural rating of smooth.

Immediately before any of these treatments is applied, and before a chip seal is constructed, the existing surface should be thoroughly broomed with a rotary broom to remove all dust and other foreign material. Hardened patches of mud or clay may have to be removed with a pick and shovel.

4.12.3 Temperature and Weather Restraints

The temperature of the surface on which a single chip seal is to be constructed should be not less than 10° C (50° F) and rising, and should be not less than 4° C (40° F) and rising for a double chip seal.

In addition, there should be a weather forecast that no rain is expected for a minimum period of 24 hours.

4.12.4 Spraying the Asphalt Emulsion

Five very important items that can be easily checked are:

1. Alignment of the nozzles in the spray bar
2. That all spray nozzles are of the same size, and are not nicked or otherwise damaged
3. That every spray nozzle is free from even partial clogging, is clean, and can spray normally
4. Height of spray bar above the road surface
5. Application temperature of the asphalt emulsion. The recommended ranges are:
   RS-1 27 to 85° C (80 to 185° F)
   RS-2 52 to 85° C (125 to 185° F)
   HFRS-2 52 to 85° C (125 to 185° F)
   CRS-1 52 to 85° C (125 to 185° F)
   CRS-2 60 to 85° C (140 to 185° F)

Unless the distributor has been calibrated for its ability to spray the specified quantity of asphalt emulsion uniformly over every 0.1 m^2 (yd^2) of surface, this should be checked. It is not enough to determine that the total gallons applied to a measured section of road surface is correct. This tells nothing about the uniformity of application centimeter by centimeter transversely across the sprayed width.

When necessary adjustments have been made, the distributor should be able to make a uniform application of asphalt emulsion at the rate specified. Before spraying begins, a line should be placed along one edge of the road as a guide. This line may consist of string or even suitably spaced small rocks. To protect concrete curbs in urban areas a removable shield may be attached to the pertinent end of the spray bar.

The distributor should not be permitted to start spraying until the chip spreader and loaded trucks are in line and ready to apply the cover stone, and rollers are ready to roll the cover stone immediately after it has been spread. Otherwise, the emulsion may break before the cover stone has been applied, or before the first pass of the roller over the spread aggregate has been made.

The asphalt emulsion should preferably be sprayed full width to avoid the need for a longitudinal joint in the center of the road that can be unsightly due to either too much or too little asphalt. and can also be a location for distress and even failure within the chip seal. When this is not possible. an inside strip of uncovered asphalt emulsion from 75 to 100 mm (3 to 4 in.) wide should be left when constructing the first half, to provide center joint overlap when the second half of the chip seal is placed. For a double surface treatment the center joint on the second layer should be displaced at least 150 mm (6 in.) from the center joint in the first layer.

To obtain smooth, well constructed transverse joints, the distributor should always begin and preferably stop spraying on a strip of kraft or building paper placed across the lane under construction at right angles to the direction of traffic.

4.12.5 Applying the Cover Aggregate

The gate opening and forward speed of the chip spreader, which should preferably be the same as the forward speed of the asphalt distributor should be adjusted to apply the number of kilograms of cover aggregate per square meter (lb/yd^2) indicated by the design requirement.

Truck loads of cover aggregate should be in position before any asphalt emulsion is applied. When spraying of asphalt emulsion begins. the chip spreader should follow within a distance of 15 to 50 m (50 to 150 ft). This distance is needed for a layer of asphalt emulsion of more uniform thickness to develop under the influence of gravity.

A self-propelled chip spreader should pull the truck, which should be in neutral gear.

Use of a tachometer assists in maintaining a uniform forward speed of the chip spreader.

Oversize cover stone particles and other foreign material can interfere with the uniform application of the cover aggregate by partially clogging the gate opening of the chip spreader. This can result in streaking, and should not be tolerated.

The cover aggregate should be preferably damp when applied, but should never be wet.

When cover aggregate is spilled on to the chip seal it should be removed with hand shovels. In small areas where not enough cover stone has been applied, broadcasting cover aggregate with hand shovels from a truck can be employed to make up the deficiency.

4.12.6 Rolling

Rolling should begin as soon as possible after the cover aggregate has been applied, and one pass of a roller should be made before the emulsion breaks.

On chip seal projects of average size, two pneumatic-tired rollers should be kept as close to the spreader as possible at all times, and should make one or two initial passes over the cover aggregate before the emulsion breaks. A third roller should apply the several roller passes required for back rolling.

Rolling should proceed from the outer edge to the center, with each pass overlapping the previous pass by one-half.

4.12.7 Removing Surplus Cover Aggregate

When designing the quantity of cover aggregate to be applied, some allowance must be made for loss of cover aggregate due to whip-off and unevenness of spread. Consequently, the quantity of cover aggregate applied exceeds by from 2 to 10 percent

the amount that will remain in the chip seal since this surplus aggregate can be thrown into the air by traffic and cause motor vehicle damage, it should be removed. This can be done by light brooming with a power broom during the cool morning after construction, when the asphalt binder is reasonably hard. Care must be taken to avoid turning over any of the cover aggregate particles embedded in asphalt.

4.12.8 Constructing Multiple Chip Seals

For the construction of multiple chip seals, the same sequence of operations is continued that has just been described for single chip seals, with the exception that one pass with a steelwheeled roller should preferably be made over each layer before the next layer is applied, and over the surface of the final layer.

All layers should be constructed the same day, or as soon thereafter as possible.

The center joint in each layer of a multiple chip seal should be displaced at least 150 mm (6 in.) from the center joints in the other layers. The distributor should be driven in opposite directions on successive layers. If there is any lack of uniformity of asphalt emulsion distribution from the spray bars, this procedure will ordinarily avoid the same fault occurring at the same location in superimposed layers.

4.12.9 Traffic Control for Newly Constructed Chip Seals

Traffic control by flagmen, barriers, or truck convoying is required to protect workmen, construction equipment, and motor vehicles, and to avoid damage to the chip seal as construction proceeds and during the critical period when the finished chip seal is first opened to traffic.

Preferably, all traffic should be kept off chip seals during their construction. This includes the construction equipment, which should be routed to the worksite from the direction opposite to that in which construction is progressing.

Newly constructed chip seals tend to be rather weak for two reasons:

1. Hanson, a New Zealand engineer who made the first authoritative study of chip seals, observed that the voids in the cover aggregate with which he was working were approximately 30 percent after rolling, but under warm weather traffic the voids eventually decreased to about 20 percent. Consequently, newly constructed chip seals are weak because at 30 percent voids the cover aggregate interlock is only partly developed.
2. An asphalt emulsion contains from 30 to 40 percent water, and some time is required after spraying for this water to leave the emulsion. As its water content decreases, the residual asphalt remaining becomes stronger and stronger with increasing ability to hold the cover aggregate in place against the dislodging tendencies of traffic.

During this weak period immediately following construction of a chip seal, fast moving traffic should not be permitted because it tends to tear out cover aggregate particles.

While traffic speeds can be partially controlled by barricades and flagmen, the most effective means is the assignment of a half-tonne (half-ton) truck to convoy traffic over the new chip seal at speeds that are low enough to avoid damaging it.

The length of time during which a newly constructed chip seal must be protected against high speed traffic depends upon existing conditions. It can vary from a few hours in hot dry weather, to one or more days in humid, cool, or wet weather.

4.12.10 Graded Aggregate Seals

For low volume roads, graded cover aggregates can be used in place of the normally more expensive one-size cover stone specified for standard chip seals. The aggregates should typically all be passing a 16.0 mm (5/8 in.) or 12.5 mm (1/2 in.) sieve, with from 60 to 70 percent passing a 4.75 mm (No. 4) sieve, with preferably not more than 6 percent passing a 0.075 mm (No. 200) sieve, and have a minimum sand equivalent of 45. The resulting seals tend to be several superimposed aggregate particles in thickness.

High Float Medium Setting Asphalt Emulsion (HFMS-1 and HFMS-2) are recommended for graded aggregate seals. They may contain from 0 to 10 percent of a petroleum solvent, which results in a softer distillation residue. These emulsions normally appear to develop a weak gel structure immediately after spraying which gives them greater resistance to flow on a banked or crowned surface.

A typical HFMS graded aggregate seal would require the application of a high float asphalt emulsion at the rate of 1.4 to 1.8 L/m^2 (0.30 to 0.40 gal/yd^2) to which from 16 to 22 kg/m^2 (30 to 40 lb/yd^2) of graded cover aggregate would be applied.

The speed of the aggregate spreader should be slow enough to avoid the formation of a wave or roll of HFMS emulsion of width greater than about 25 mm (1 in.) along the front of the layer of graded cover aggregate being applied. Otherwise, the aggregate tends to jump over this wave or roll, and this in turn can result in a ripple (bump) or series of ripples in the surface of the finished seal.

Self-propelled chip spreaders are designed to apply approximately single-size cover stone which is not susceptible to noticeable segregation. When graded cover aggregates are used, a system of baffles or augers should be added to the front hopper to prevent marked segregation of the aggregate into a series of alternating zones or sections of coarse and fine aggregate within the hopper itself, which can result in similar segregation of the graded cover aggregate in longitudinal streaks of coarse and fine cover aggregate in the finished seal.

After curing, any excess cover aggregate may be removed from the seal by light sweeping with a powered rotary broom.

4.13 Do's and Don'ts

A number of items will help to insure a successful chip seal project:

1. Never permit anionic and cationic asphalt emulsions to be mixed because this will cause each emulsion to break, leaving tanks or other equipment partially filled with semi-solid asphalt, and a difficult cleaning job.
2. Thoroughly wash out with diesel fuel any equipment in which an anionic emulsion has been used before using it for a cationic emulsion and vice versa.
3. At the end of each day, flush out with diesel fuel the pumping and spraying system on the asphalt distributor. This will avoid clogging, binding, or seizure if the asphalt emulsion otherwise left in this system should break.
4. Do not dilute a rapid setting HFRS, RS, or CRS emulsion with water. It is likely to break.
5. Do not allow an asphalt emulsion to either freeze or boil — it will break.
6. When pumping asphalt emulsions, keep the end of the discharge pipe submerged in emulsion to avoid entrapment of air and foaming. This may also cause an emulsion to break.
7. Avoid tight fitting pumps when pumping asphalt emulsion. They may bind and seize due to breaking of the emulsion.
8. Avoid excessive pumping or handling of asphalt emulsions, because this can result in a reduction of their viscosity.
9. Have a clear mental image of what an excellent chip seal looks like as a target for achievement.
10. For chip seals, tailor rapid setting emulsions to break after the first pass of a roller has been made immediately behind the chip spreader, which in turn should follow from 15 to 50 m (50 to 150 ft) after the distributor.
11. A lack of uniformity of texture in an old asphalt surface that is to be chip sealed will result in a lack of uniformity in the finished chip seal. Therefore, rich patches or flushed and bleeding areas should be repaired before a chip seal is applied. If an old pavement is dry and raveling and has a variable surface texture, it should be sprayed with 0.45 L/m^2 (0.1 gal/yd^2) of SS-1 or CSS-1 asphalt emulsion that has been diluted 50 percent with water, covered with from 3.2 to 5.4 kg/m^2 (6 to 10 lb/yd^2) of clean coarse sand, and exposed to traffic for two weeks, before a chip seal is applied. This will provide the old pavement with a more consistent surface texture, on which a more uniform chip seal can be constructed.
12. Since they tend to be porous and could absorb a portion of the asphalt emulsion applied, new patches on an old pavement should be placed several weeks before a chip seal is constructed, so as to obtain compaction and closing up by traffic.
13. The quantity of cover aggregate to be applied per unit area for a chip seal depends on the aggregate's Average Least Dimension, the void space between the cover stone particles, its ASTM bulk specific gravity and the allowance for loss due to whip-off and unevenness of spread.

14. The quantity of asphalt emulsion to be applied per unit area for a chip seal depends upon the Average Least Dimension of the cover aggregate, the volume of void space between the cover stone particles, the traffic volume anticipated, the texture of the surface on which the chip seal is to be placed, and the percent residual asphalt in the emulsion.
15. Any asphalt emulsion application is optimum for only one cover aggregate particle size. This is a strong argument for cover stone as nearly one size as possible.
16. Chip spreaders should be calibrated on each project to apply uniformly the quantity of cover aggregate per unit area that has been stipulated, and the asphalt distributor should have been calibrated to spray uniformly the specified quantity of asphalt emulsion per unit area.
17. Before starting to spray asphalt emulsion on any chip seal project, the nozzles in the spray bar should be checked for angle to the spray bar, for clogging, for damage, and for size. The spray bar height should be adjusted and then maintained either by a special mechanism for automatic adjustment, or by chaining or otherwise tying the frame to the axle.
18. Do not proceed with the construction of an asphalt emulsion chip seal if rain is impending within two hours after completion of the chip seal.
19. The asphalt distributor should not be permitted to start spraying until the chip spreader and loaded trucks are in line and ready to apply the cover stone, and pneumatic-tire rollers are ready to begin rolling the cover aggregate as soon as it has been spread. Otherwise, the emulsion may break before the cover stone is applied, or before the first pass of a roller over the newly spread cover aggregate has been made.
20. When constructing a chip seal in half-road widths a strip of uncovered asphalt emulsion 75 to 100 mm (3 to 4 in.) wide should be left along the inside edge when spraying the first half-width, for overlap when spraying the second half-width.
21. To obtain satisfactory transverse joints free from the common faults of bumps or of flushing and bleeding, the asphalt distributor should start spraying and should preferably stop spraying on a strip of Kraft or building paper placed across the construction lane at right angles to the direction of traffic.
22. For approximately a 50% increase in cost, a double chip seal can be constructed that will ordinarily provide three times the service life of a single chip seal.
23. When constructing a multiple chip seal, to avoid superimposing the same fault at the same location in consecutive layers, the asphalt distributor should be driven in the opposite direction on successive courses.
24. To minimize the damage of flying cover stone particles to motor vehicles, excess cover aggregate should be broomed from a newly constructed chip seal by light sweeping with a rotary power broom during the cool part of the morning following construction, when the asphalt binder is hardest.
25. To avoid damage by high speed traffic to a newly opened chip seal, control of traffic during this initial critical period is required. The most effective method is convoying traffic over the new chip seal with a half-tonne (half-ton) truck at a speed not exceeding 30 km/h (20 mph).