Minimizing Reflective Cracking in Cement-Stabilized Pavement Bases

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ABSTRACT

Cracks occur in flexible (asphalt) pavements for a lot of different reasons. Some cracks are indicative of structural failure in the pavement, such as fatigue cracking, thermal cracking, or cracking due to base failures. Other cracks, such as reflective cracks, are mainly cosmetic in nature. They can be present for many years without the need for significant maintenance, yet they do not reduce the pavement's smoothness or ability to handle traffic.

The use of properly designed and constructed cement-stabilized bases can actually reduce the occurrence of failure-related cracking. Fatigue cracking is decreased because the stiff, stabilized base reduces vertical deflection and tensile strain in the asphalt surface. Base failures are decreased because cement stabilization helps keep moisture out of the base and improves base material performance in saturated or freezing conditions. In addition, subgrade failure is decreased because cement-stabilized bases spread traffic loads over wide areas and can span weak subgrade locations.

However, cement-stabilized bases can also be the source of shrinkage cracks in the stabilized base layer, which can reflect through the asphalt surface. Thankfully, there are a number of measures that can be taken to minimize the chance that cracks will occur in a cement-stabilized material. These techniques include selecting the proper materials, optimizing mix designs, following proper construction, compaction, and curing practices, providing a stress relief layer in the pavement structure, delaying final surface paving, and microcracking.

A well designed, constructed, and properly maintained cement-stabilized base will normally outlast several asphalt overlays, providing decades of low maintenance service. This paper will look at the types and causes of reflective cracking in cement-stabilized pavement bases and what techniques are available to minimize them for improved pavement performance.

INTRODUCTION

[1] Cracks occur in flexible (asphalt) pavements for a wide variety of reasons. There are three primary types of asphalt pavement cracking: load associated; non-load associated; and a combination of both [2]. Load associated cracking is due to the repeated application of heavy wheel loads, while non-load associated cracking is due to environmental factors such as volume or temperature changes in a pavement.

Some cracks are indicative of failure in the pavement, such as fatigue cracking, thermal cracking, or cracking due to base failure (Figure 1). Other cracks, such as reflective cracks (Figure 2) in cement-stabilized pavement bases, are mainly cosmetic in nature. They can be present for many years without the need for significant maintenance, yet they do not reduce the pavement's smoothness.

The use of cement-stabilized bases, such as soil-cement, cement-treated aggregate base, or full-depth reclamation, actually reduces the occurrence of failure-related cracking:

- Fatigue cracking, with its typical “alligator” pattern, is decreased because the stiff, stabilized base reduces vertical deflection and tensile strain in the asphalt surface.
- Base failure, and resultant cracking and potholes, is decreased because cement stabilization helps keep moisture out of the base and improves base material performance in saturated or freezing conditions.
- Subgrade failure is decreased because cement-stabilized bases spread traffic loads over wide areas and can span weak subgrade locations.

However, cement-stabilized bases can also be the source of shrinkage cracks in the stabilized base layer, which can reflect through the asphalt surface. The following questions are frequently asked regarding reflective cracking in cement-stabilized pavement bases.

WHAT IS REFLECTION CRACKING?

Cracks in the base layer, regardless of their cause, can result in stress concentrations and cracking in the asphalt surface layer. The surface cracks tend to follow the same pattern as the cracks in the base, and are referred to as “reflection” cracks (Figure 3).

Care must be taken in determining what mechanism is causing cracks in the asphalt surface. They can occur for a number of reasons, including poor construction, structural failure, asphalt aging, and temperature cracking among others [3]. The only way to be sure a crack in the surface of an asphalt pavement is reflecting a crack in the stabilized base layer below is to take a pavement core and visually see the crack in the same location in the base and asphalt layers.

DOES REFLECTION CRACKING OCCUR WITH ALL STABILIZED BASES?

Not always, but usually materials that have been treated with a stabilizer will experience some shrinkage through the natural processes of hydration and curing. Soil-cement and cement-treated aggregate bases will typically experience narrow transverse cracks at 2.4 to 6 meter intervals that will maintain structural integrity through aggregate interlock. In wide paving areas, such as multiple lane roadways or parking lots, the cracks may take on a bi-directional rectangular “block” pattern with the rectangular sides having widths of 2.4 to 6 meters or greater. These cracks may or may not be reflected through the asphalt surface. If they are reflected, the resulting asphalt crack will usually be narrow if the crack in the base is also narrow.

ARE REFLECTION CRACKS A PROBLEM?

Reflection cracks may or may not be a problem. If the cracks are narrow (< 3 mm), sufficient load transfer normally exists through aggregate interlock to keep the pavement structure functioning. Also, narrow cracks are usually tight enough that moisture intrusion into the base and/or subgrade layers is minimal and non-problematic. If the cracking causes no "tenting" or roughness, there is usually no need for any maintenance action.

However, if wide cracks (> 6 mm) occur at the pavement surface, they can result in poor load transfer and increased stress in the asphalt that will lead to deterioration of the structure. In addition, wider cracks in the surface provide an avenue for water to enter the pavement. This can result in pumping of subgrade material, faulting of the base, and increased pavement roughness. A "working" crack with moisture intrusion will also cause eventual deterioration of the base material, even though it is stabilized. Therefore, wide cracks in stabilized pavement bases should be avoided to ensure smooth pavements and long life.

WHAT CAUSES WIDE CRACKS?

Cracking in a cement-treated material is caused by volume change (shrinkage). This shrinkage can occur for a number of reasons, such as cement hydration, temperature change, and drying [4]. The greatest amount of shrinkage occurs early in the life of the pavement (within the first couple of months). When a pavement layer undergoes shrinkage, its movement is resisted by friction from the layer below, causing tension to build in the shrinking layer. Since cement-treated materials have limited tensile strength (especially before they have undergone much curing) the forces due to shrinkage can cause cracking. As previously noted, the cracks are not harmful to the pavement structure as long as they are narrow. Narrow cracks with good interlock may not reflect through the asphalt at all. And reflection of a crack through the asphalt, if it does occur, may occur rapidly (within a few months), or may be delayed for many years (especially in the case of narrow cracks and/or thick asphalt surface mats).

Studies have shown that wide cracks (> 6 mm) in cement-treated materials are due primarily to drying (water loss) shrinkage rather than hydration or temperature change [5]. Excessive cracking in cement-treated materials is caused by a number of factors:

- **Compacting material at high moisture levels (above optimum moisture content).** Moisture in excess of that needed for maximum density provides higher potential for shrinkage, since the material can undergo more drying.

- **Using a soil that contains a high percentage of clay.** Clay particles have a large surface area relative to their weight, so they hold a large amount of water, and have a high optimum moisture content. This is especially true if the clay particles have a very high surface area, such as montmorillonite.

- **Rapid moisture loss.** After a cement-treated material is placed, it immediately begins to lose moisture through evaporation unless proper curing procedures are followed. Moisture loss causes two problems: 1) the material dries quickly and will undergo more shrinkage, and 2) there may not be enough moisture to continue hydration of the cement (which will reduce the final strength).

- **Failing to achieve required compaction.** Poorly compacted materials have high void ratios, with more unrestricted space to undergo movement, thus resulting in higher shrinkage and wider cracks. A tight matrix of a well-compacted soil reduces the shrinkage potential because the soil/aggregate particles are packed densely together, with little room to undergo high shrinkage. Also, good compaction leads to better aggregate interlock and structural support if a crack does develop.

- **Using excessive amounts of cement in the stabilized mix.** Although cement hydration contributes less to shrinkage than does moisture loss, excessive amounts of cement can exacerbate cracking in two ways: Increased cement contents cause greater consumption of water during hydration, thus increasing shrinkage. More importantly, higher cement levels cause higher rigidity and excessive strength (both tensile and compressive). Higher tensile strength results in cracks which are spaced further apart, but because the material undergoes at least as much total shrinkage as a lower cement content material, the width of each individual crack is wider.

HOW CAN WIDE CRACKS BE MINIMIZED?

Hundreds of thousands of kilometers of roads with cement-stabilized bases have been constructed in all climates with excellent performance. There are a number of preventative measures that can be taken to minimize the chance that wide cracks will occur in a cement-stabilized material [6]:

- **Provide proper construction techniques.** As with any construction process, following the proper construction techniques and providing good quality control during field operations is paramount to achieving superior results. With cement-stabilized bases, a quality project relies on several important factors including the use of appropriate cement and moisture contents, thorough mixing, adequate compaction, and curing [7]. Additionally, the stabilization process must be accomplished within a reasonable time frame (within two hours of cement mixing) to ensure that the cement does not hydrate before final compaction is achieved [8 and 9].

- **Compact the cement-treated material at or slightly less than optimum moisture content.** Too much water in the soil-cement mix creates the potential for excessive drying, which can lead to wide shrinkage cracks. Optimum moisture content should be determined by developing a moisture-density curve from the standard Proctor procedure (ASTM D558). Ideally, the field moisture content during compaction should be within a range of zero to slightly below (minus 2%) optimum (Figure 4).

- **Reduce the percentage of clay in the treated soil.** Because clay holds more water and is compacted at a higher moisture content, the potential for shrinkage cracking is greater. Blending in granular, sandy materials can help reduce the clay percentage. However, the use of clay often cannot be avoided, and blending in additional materials may be costly. Therefore, if the stabilized material has a high clay content, monitoring the water content during compaction is especially important.

- **Proportion the proper amount of cement in the mix.** Enough cement should be added to the soil-aggregate mixture to achieve the desired engineering properties, but more than that amount is unnecessary, uneconomical, and can lead to additional cracking. Therefore, laboratory testing should be conducted to evaluate the engineering properties desired. This could include unconfined compression tests, freeze-thaw and/or wet-dry durability testing, and Atterberg Limits (liquid limit, plastic limit, and plasticity index). Typically, a 7-day unconfined compressive strength of 2.1 to 2.8 MPa provides good bearing capacity, durability, and shrinkage properties [10].

- **Use admixtures.** Various admixtures have been investigated for reducing the shrinkage potential of soil-cement. Among these are shrinkage-compensating cement, gypsum, water reducers, fly ash, and ground granulated blast-furnace slag. Admixtures often reduce water demand, aid in the mixing process, extend mixing time, and for many granular soils, provide a filler material that can effectively reduce the need for excess cement.

- **Provide a stress relief layer in the pavement structure.** Cracks in the base layer can cause stress concentrations in the asphalt surface. These stress concentrations lead to reflective cracks in the asphalt. Placing a flexible material between the base and surface layers will provide stress relief. This can be accomplished by using:

  - A bituminous surface treatment (chip seal) between the stabilized base and surface.
  - A geotextile fabric between the stabilized base and surface, or between the asphalt binder and surface courses.
  - A 50 to 100 mm layer of unbound granular material between the stabilized base layer and the asphalt surface.

  Good field performance in minimizing or eliminating reflective cracking has been achieved in each of the options noted above (Figure 5).

- **Take positive steps for curing immediately after final compaction.** The surface of the cement-treated layer must be kept moist until a permanent moisture barrier is in place. Normally, water trucks supply moisture to the pavement, although sprinkler systems can also be used. The compacted stabilized base should never be allowed to dry completely, even for a short period of time. Once a moisture barrier is placed, water curing can stop. The moisture barrier can be a curing compound, a bituminous emulsion prime coat, or even a chip seal.

- **Delay paving as long as practical following the placing of the prime coat.** If the final paving of the asphalt surface is delayed for a period of time (14 to 28 days), it allows more time for any shrinkage cracks to develop. Placing the surface after most of the shrinkage has occurred can result in fewer and/or thinner cracks in the asphalt layer, as the asphalt will tend to bridge the already-formed cracks. This strategy can be combined with proper curing techniques to delay final asphalt application if a combined chip seal and asphalt surface are used. The chip seal can be applied soon after the base is constructed (even the next day) to seal the surface and provide a durable surface for traffic. The asphalt course can then be placed many months (or even years) after the chip seal depending on the traffic and extent of surface wear.

- **Microcrack the pavement.** This method to reduce or eliminate reflection cracking has shown excellent results to date. The procedure is to apply loading to the soil-cement (using several passes of a vibrating roller) one to two days after final compaction. This introduces a network of closely spaced hairline cracks into the cement-treated material, which acts to relieve the shrinkage stresses early in its life, and provides a crack pattern that will minimize the development of wide shrinkage cracks. Furthermore, since microcracking is performed shortly after placement, the technique will not impact the pavement's overall structural capacity as the cracks will heal and the cement-treated material will continue to gain strength with time [11 and 12].

WHAT TO DO IF REFLECTION CRACKS DEVELOP?

Not all reflection cracks require maintenance. For low- to medium-volume roadways, narrow (< 3 mm) reflection cracks in the asphalt surface will likely not be a performance problem at all, and can be left alone.

If wider cracks develop (> mm), or if the pavement supports a high volume of traffic, sealing of the reflection cracks should be performed. Standard bituminous sealing compounds normally used with asphalt pavements will suffice to eliminate moisture intrusion into the base and subgrade levels. This should be sufficient to preclude maintenance problems such as raveling, pumping, faulting, and base deterioration.

If cracks in a stabilized pavement have deteriorated, more extensive repair procedures will be necessary. This may include milling the deteriorated joint and filling with appropriate repair materials, removing and replacing the base material at the crack location, and repair/filling of the subgrade if substantial pumping and moisture intrusion have occurred.

Usually proper construction procedures, crack minimization strategies, and maintenance sealing, if necessary, can eliminate requirements for significant maintenance. A well-designed and properly maintained cement-stabilized base will normally outlast several asphalt overlays, providing decades of low maintenance service.

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FIGURES

Figure 1 – Example of base failure cracking.

Figure 2 – Example of reflective cracking.

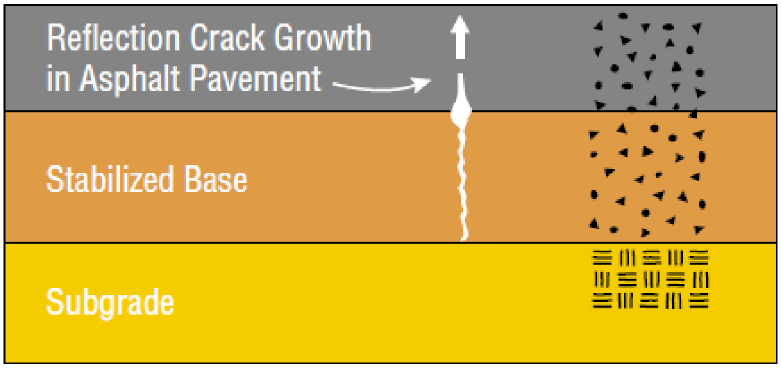

Figure 3 – Displacements in base layer can continue upwards through surface layer.

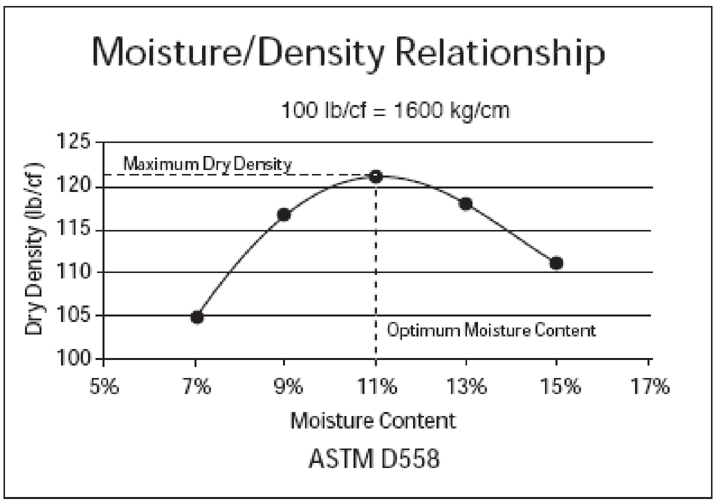

Figure 4 – Determining the Maximum Dry Density and Optimum Moisture Content.

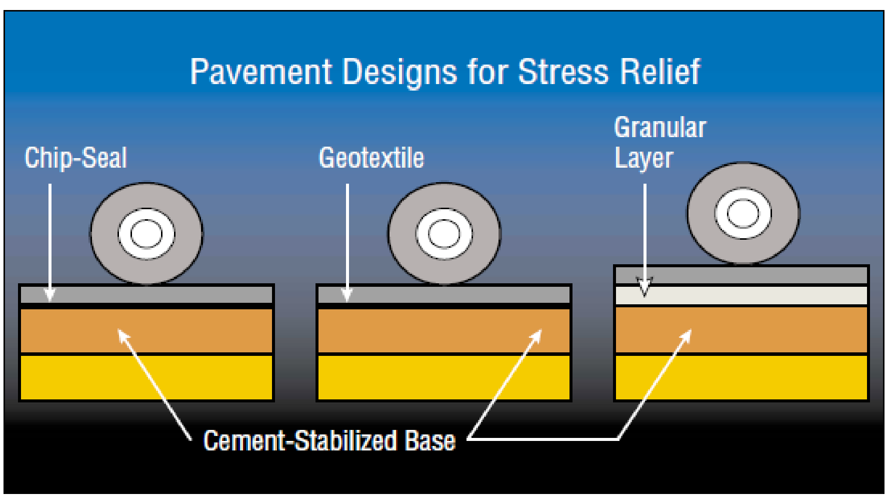

Figure 5 – Stress relief layers can be used to retard reflective cracking.