

## **CONTROL OF REFLECTIVE CRACKING IN CEMENT STABILIZED PAVEMENTS**

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### **Abstract**

Cracks occur in flexible (asphalt) pavements for various reasons. Some cracks are indicative of failure in the pavement, such as fatigue cracking or cracking due to base failure. Other cracks, such as reflective cracks from cement-stabilized pavement bases, are mainly cosmetic in nature and do not reduce the pavements smoothness or serviceability. However, if wide cracks (greater than 6 mm) occur, they can result in poor load transfer and increased stress in the pavement, eventually leading to performance problems.

Several factors contribute to the cracking and crack spacing in a cement-stabilized base including material characteristics, construction procedures, traffic loading, and restraint imposed on the base by the subgrade. With regard to material characteristics, the type of soil, cement content, degree of compaction and curing, and temperature and moisture changes directly influence the degree of shrinkage.

There are a number of preventative measures and design concepts that can be used to minimize shrinkage cracking in the cement-stabilized base, and to reduce the potential that base cracks will reflect through the asphalt surface. Methods of controlling reflective cracking include proper construction and curing of the stabilized base, reduction of crack size through the use of “pre-cracking”, and relief of stress concentrations through the use of flexible layers in the pavement structure.

### **1. Introduction**

A cement-stabilized base provides excellent support for asphalt surfaces. The stabilized base material is stronger, more uniform and more water resistant than an unstabilized base. Loads are distributed over a larger area and stresses in the subgrade are reduced. The use of cement stabilized bases such as soil-cement, cement-treated aggregate base, or full-depth recycling actually reduce the occurrence of base and subgrade 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.

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- 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 cracks that develop are not the result of a structural deficiency, but rather a natural characteristic of cement-stabilized bases. The surface cracks tend to follow the same pattern as the cracks in the base, and are referred to as “reflection” cracks. This document examines the reason for the crack reflection, and discusses different design and construction procedures that can control the occurrence of these cracks.

Three conditions must occur in order for reflection cracking to happen:

1. Cracks in the base layer must be wide enough to generate stress concentrations in the asphalt surface.
2. There is no method available to relieve the stress concentrations.
3. The asphalt is brittle enough to crack due to the upward propagation of the stress concentration.

In most cases, reflection cracks are narrow (less than 3 mm) and will not adversely affect the performance of the pavement (Fig 1). However, wider cracks (Fig 2) can result in a rough riding surface and deterioration of the pavement. Wide cracks create an environment for water infiltration and subsequent pumping of the underlying subgrade. A number of studies [1-5] confirmed that problems in the stabilized base were a result of shrinkage cracks and water infiltration causing loss of aggregate interlock at the crack, layer separation and localized deterioration of the pavement along the crack.



Fig.1. Narrow reflection crack



Fig. 2. Wide reflection cracks

## 2. Reasons for Shrinkage Cracking

Several factors contribute to the cracking and crack spacing in a cement-stabilized base including material characteristics, construction procedures, traffic loading, and restraint

imposed on the base by the subgrade. With regard to material characteristics, the primary cause of cracking is due to drying shrinkage of the cement-stabilized base. The degree of drying shrinkage is affected by the type of soil, degree of compaction and curing, cement content, and temperature and moisture changes.

### **2.1 Soil Type**

Studies [6-8] have shown that cement-stabilized fine-grained soils (e.g. clays) exhibit greater shrinkage than cement-stabilized granular soils. Although stabilized clay soils develop higher total shrinkage than granular soils, the cracks are typically finer and more closely spaced, often of hairline variety spaced 0.6 to 3.0 m (2 to 10 ft) apart. Granular soils produce less shrinkage but larger cracks spaced at greater intervals, usually 3.0 to 6.1 m (10 to 20 ft) [6].

Fine-grained soils have larger surface areas than granular soils and typically require higher moisture contents for compaction purposes. In addition, cement contents for fine-grained soils are generally 2 to 5 percent higher than granular soils in order to achieve adequate durability and strength. Both these factors contribute to higher moisture contents for cement-stabilized fine-grained soils and consequently higher drying shrinkage.

### **2.2 Compaction**

The effect of compaction on shrinkage characteristics of cement-stabilized material has also been documented [7, 9, 10]. A well-compacted mixture reduces shrinkage potential because the soil/aggregate particles are packed tightly together resulting in reduced voids. Bhandari [10] reported that compacting cement-stabilized soil at modified Proctor effort reduced shrinkage by more than 50% compared to stabilized soil compacted to standard Proctor density. In addition, optimum moisture contents at modified Proctor compaction are typically less than at standard Proctor compaction, which also helps to reduce shrinkage.

Figure 3 shows that increasing the density and reducing the moisture content can reduce shrinkage. The least amount of shrinkage is obtained for the stabilized material at the highest density and lowest moisture content. Many project specifications accept minimum densities of 95% of standard Proctor compaction. Also, specifications may allow the moisture content to be up to 2% above optimum. When minimizing shrinkage cracking is an important criterion, the allowable lower densities and higher moisture contents may need to be reconsidered. Some designers are requiring up to 98% of modified Proctor compaction and moisture contents not to exceed the optimum moisture content.

Another consideration is the method of compaction. Laboratory tests have indicated that samples compacted by vibratory (impact) compactors shrink more than by static loading or kneading compactors [11]. Where shrinkage cracking may be a concern, the use of sheepsfoot or pneumatic-tire rollers may be preferred over vibratory rollers.

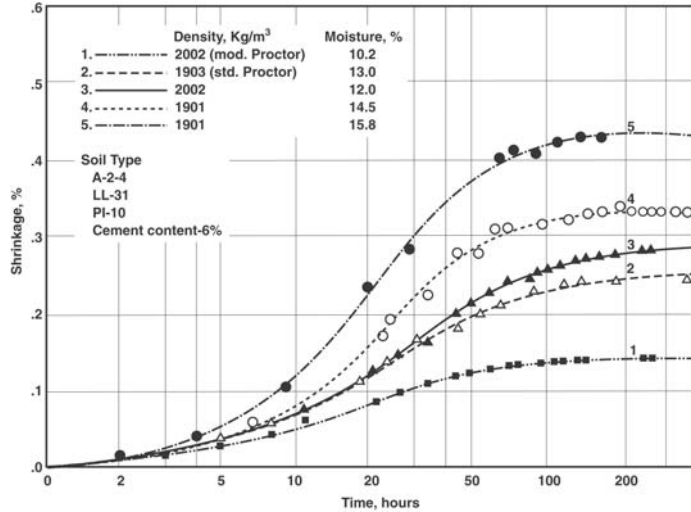


Fig. 3. Effect of density and moisture on shrinkage [7]

### 2.3 Curing

Studies [7,8] indicate that prolonged curing had limited benefit to the ultimate drying shrinkage. Curing delayed but did not appreciably reduce shrinkage. In some cases the total shrinkage was slightly less and other cases slightly more. George [7] reported that as the clay content increased, the tendency to shrink decreased with moist curing. As more and more soil reacted with cement, the shrinkage due to clay itself decreased. Although prolonged curing could increase shrinkage slightly due to higher proportion of cement hydration product, the net effect appeared to be a decrease in the overall shrinkage.

The obvious benefit of prolonged curing is the higher compressive and tensile strength compared with air-dried stabilized material. In another study by George [12], the researcher reported on the effect of curing conditions on the crack pattern of stabilized soil. The study concluded that prolonged curing resulted in narrower crack widths and crack spacings that were more than twice the distance of standard-cure specimens. According to the researcher, the larger crack spacing of the prolonged-cure specimens could be attributed to enhanced strength gain and reduced drying shrinkage.

### 2.4 Cement Content

Cement hydration contributes less to shrinkage than does many other factors. In fact, for soils that exhibit volume change without cement, increasing cement will decrease total shrinkage [6]. However, excessive amounts of cement can exacerbate cracking in two ways: First, increased cement contents cause greater consumption of water during hydration, thus increasing drying shrinkage. Also, 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.

Figure 4 shows the results of increasing cement content on shrinkage of various soils. Except for the non-plastic sandy (A-3) soil, shrinkage is initially reduced with the addition of a small amount of cement, but increases steadily as the cement content increases. The figure also shows that the optimum proportion of cement for minimum shrinkage is lower than that required for freeze/thaw durability. Therefore, to minimize the effect of cement content on shrinkage, it is important not to exceed the cement content required for adequate durability.

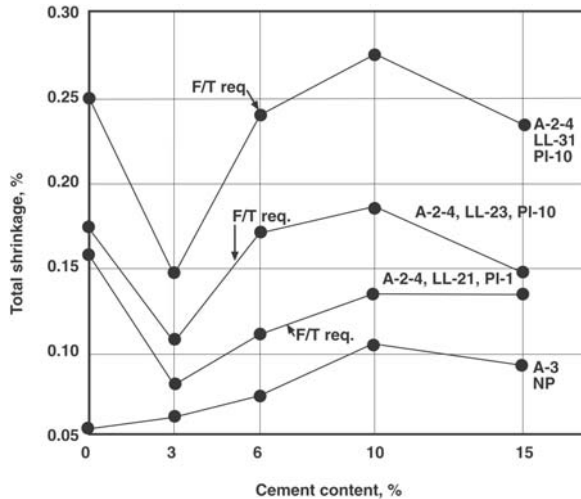


Fig. 4. Effect of cement content on shrinkage [Adapted from reference 7]

### 3. Methods to Control Reflective Cracking

Methods of controlling reflective cracking basically fall into the categories of: 1) reducing the width of cracks in the stabilized base, and 2) providing for stress relief at the base-surface interface

#### 3.1 Pre-cracking

Minimizing crack width with proper construction and curing procedures, as discussed in the previous sections, will eliminate much of the potential for wide cracks. Another method to reduce crack width is a relatively new procedure called “pre-cracking”, where hundreds of tiny micro-cracks develop instead of single transverse cracks.

Originally reported in Austria in 1995 [13] the method has been successfully tried on several projects in the United States. The procedure involves several passes of a large vibratory roller over the cement-stabilized base one to two days after final compaction. This introduces a network of closely spaced hairline cracks into the cement-stabilized material, which acts to relieve the shrinkage stresses in the early stages of curing, and provides a crack pattern that will minimize the development of wide shrinkage cracks. In addition, since the pre-cracking is performed shortly after placement, the “micro-

cracking” will not impact the pavement’s overall structural capacity as the cracks will heal and the cement-stabilized material will continue to gain strength with time.

Scullion [14] reported on a demonstration project involving several streets in a new residential subdivision in Texas. Three separate street sections were constructed using the pre-cracking technique with an adjoining fourth street built in conventional fashion and used as a control section. The pavement design of all four streets consisted of 150 mm (6 in.) of lime-stabilized subgrade, 150 mm (6 in.) of cement-stabilized base, and 50 mm (2 in.) of hot-mixed asphalt surfacing. The specified minimum design strength of the cement-stabilized layer was 3.4 MPa (500 psi) at 7-days.

The three sections were pre-cracked either one or two days after construction using a 10.9 tonne (12 ton) vibratory roller with the vibrator set on the maximum amplitude and traveling at a slow walking speed of about 3.2 kph (2 mph). Changes in the base stiffness were monitored before and after rolling. The average base stiffness decreased by approximately 30% after two passes of the roller and another 15 to 20% after two additional passes. Additional stiffness measurements with a Falling Weight Deflectometer (FWD) were made after 6 months for all three pre-cracked sections. The results showed that the stiffness measurements equaled or exceeded the initial stiffness measurements before cracking, indicating the sections continued to gain strength with time (see chart of deflection measurements in Fig. 5).

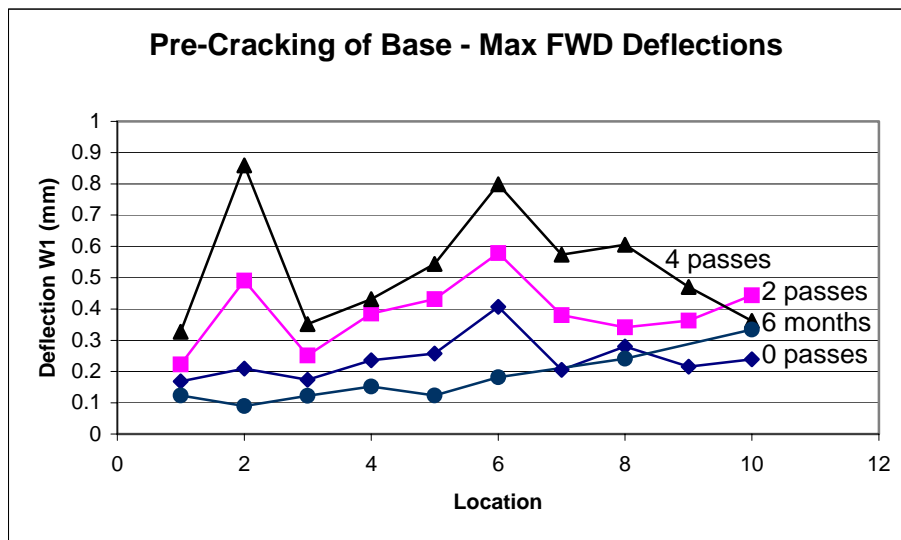


Fig. 5. Deflection measurements for pre-cracked base [Adapted from reference 14]

The most important result of the study is depicted in Table 1, showing that the amount of cracking was greatly reduced in all three pre-cracked sections compared to the controlled non-pre-cracked section. Visual observations after approximately one year indicated additional cracking in the pre-cracked sections, but still considerably less than the control section.

Table 1: Summary of shrinkage cracking six months after surfacing

Street	Crack length in meters per 30 meters of pavement (223 m <sup>2</sup> )
Salzburg Court	1.9
Von Trapp	1.1
Neuburg Court	0.7
Control Section	8.2

### 3.2 Stress Relief

Another method of reducing the potential for reflection cracking is to relieve the stress concentrations that result from cracks in the cement-stabilized base. Figure 6 illustrates three examples of pavement designs that will reduce the stresses that cause reflection cracks:

1. A bituminous surface treatment (chip seal) between the stabilized base and the asphalt surface. The additional flexibility of the surface treatment layer will help to reduce stress concentrations. This surface treatment also provides an excellent temporary surface during construction for traffic control.
2. A geotextile between the stabilized base and surface, or between the asphalt binder and wearing courses. Similar to the surface treatment, the geotextile provides flexibility and acts to intercept cracks without letting them pass through the material.
3. A 50 mm to 100 mm (2 to 4 in.) layer of unbound granular material between the stabilized base layer and the asphalt surface. This use of a “sandwich” or “inverted” pavement design adds additional structure to the pavement, and will prevent the propagation of cracks through to the surface layer.

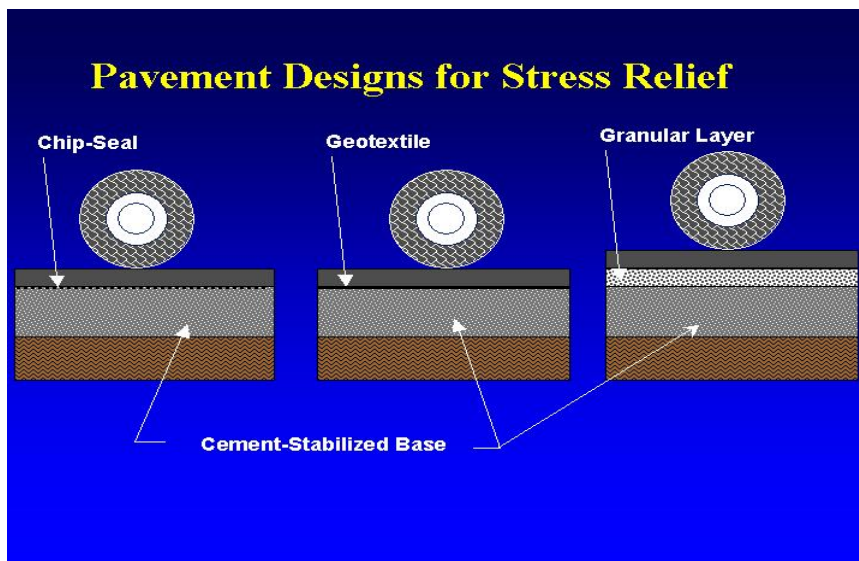


Fig. 6. Pavement designs for stress relief

#### 4. Conclusion

Although the potential exists for reflection cracking when a cement-stabilized base is used in a pavement structure, proper construction and design techniques can minimize the potential that the pavement will be adversely affected. Proper construction practices to minimize drying, pre-cracking soon after construction, and designing for stress relief are all valid methods that will reduce or eliminate the formation of reflection cracks in cement-stabilized bases.

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