Performance of Soil-Cement and Cement-Modified Soil for Pavements: Research Synopsis

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Introduction

This publication summarizes the findings on an extensive laboratory testing study to identify new approaches for evaluating the performance of soil-cement materials such as cement-modified soil (CMS) and cement-treated base (CTB) in pavements. Objectives of this project included:

- Developing laboratory testing procedures to select the optimum cement content for CMS and CTB that satisfies strength and durability criteria
- Investigating new laboratory tests for durability and moisture susceptibility of CMS and CTB
- Comparing the effectiveness of cement and lime in reducing the plasticity and increasing the strength of high plasticity index (PI) soils
- Evaualting the performance of cement slurry application compared to dry application

The complete research report is available as *Evaluating the Performance of Soil-Cement and Cement-Modified Soil for Pavements: A Laboratory Investigation*, by Tom Scullion, Stephen Sebesta, John P. Harris, and Imran Syed, Portland Cement Association (PCA) publication RD120.

The main focus of this research was to evaluate alternatives to strength-based design procedures. When designing for soil-cement base pavement applications, it is important to optimize both the strength and durability requirements in order to minimize the effect these properties have on shrinkage and cracking. Too strong a base may result in undesirable shrinkage cracking. New test procedures were evaluated to more quickly and economically correlate the strength, durability, and shrinkage of soil-cement. The intent is that long-term performance will be improved by optimizing rather than maximizing cement contents while maintaining adequate durability. This study included the use of a simple laboratory shrinkage test to assess if soil-cement materials would be prone to severe shrinkage cracking. Other tests were conducted to determine if the materials will be prone to durability and moisture-related deterioration.

Today, most agencies use unconfined compressive srength (UCS) as the primary factor in determining the required minimum cement content for soil-cement materials. Unfortunately, there are no widely accepted industry standards for UCS, which leads to a wide range of 7-day strength requirements, from 200 to 800 psi. Additionally, strength alone is no guarantee of satisfactory long-term performance. Other characteristics such as durability and shrinkage, as they relate to reflective cracking in the pavement surface, play an important role in overall pavement performance.

A common practice is to overstabilize soil-cement base material in the belief that the stronger the material, the more durable and long lasting it will be. However, current research has shown that this line of thinking is flawed and that the selection of the "optimal" cement content is preferred in order to achieve a balance between strength and performance.

"...recent research has indicated that 'over-stabilizing' and achieving a high 7-day compressive strength actually can be detrimental to long-term performance of a cement-stabilized base."

As mentioned previously, UCS is the most widely referenced property for the mix design of soil-cement materials. However, the overall goal should be to arrive at a soil-cement design that has acceptable strength and durability criteria while also minimizing shrinkage cracking. Lower 7-day compressive strengths in the order of 200 to 300 psi are acceptable if, and only if, the durability criteria also are met. Some materials may require 7-day strengths of 400 psi in order to provide adequate durability.

Testing Protocol

This study employed a series of testing procedures to evaluate the effect of differing cement contents on the performance-related engineering properties of three common aggregate base materials—

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caliche, recycled concrete, and river gravel. Each of these materials was tested with the addition of both Type I and Type IP (pozzolan) portland cement at 1.5%, 3.0%, and 4.5% by dry weight. A testing protocol and corresponding acceptance criteria were established that included the following:

- A minimum 7-day UCS ranging from 200 to 450 psi
- A maximum 21-day dielectric value of 10 as determined by the Tube Suction Test described below
- A maximum 21-day beam shrinkage value of 250 in/in microstrain
- A minimum retained strength of 100% following initial failure through autogenous healing

Tube Section Test

The current durability tests for soil-cement materials include the wet/dry (ASTM D559 or AASHTO T135) and freeze/thaw (ASTM D560 or AASHTO T136) tests, which take about one month to run. There is also a PCA "shortcut" test procedure for sandy soils (see Reference 1) that can be used to determine the cement content for durable soil-cement. Although this procedure takes only one week, it typically results in the use of a higher cement content than necessary. Recently, the Texas Transportation Institute has been evaluating a new test procedure called the Tube Suction Test (TST) in order to provide a simpler and quicker test procedure for determining the durability of both unstabilized and stabilized materials.

The TST operates by measuring the capillary rise and surface dielectric values of the test specimens. During the test, the capillary rise of moisture is monitored with a dielectric probe (see Figure 1), which measures the dielectric properties at the surface of the sample. The dielectric is the measure of the unbound or "free" moisture within the sample. High surface dielectric readings indicate suction of water by capillary forces and can be an indicator of a non-durable base material that will not perform well under saturated or freeze/thaw cycling conditions. In addition to being simple and quick, the TST has the added benefit of eliminating operator error, inherent in both the wet/dry and freeze/thaw durability tests.

"...the Tube Suction Test can serve as a reliable substitute for traditional durability testing."

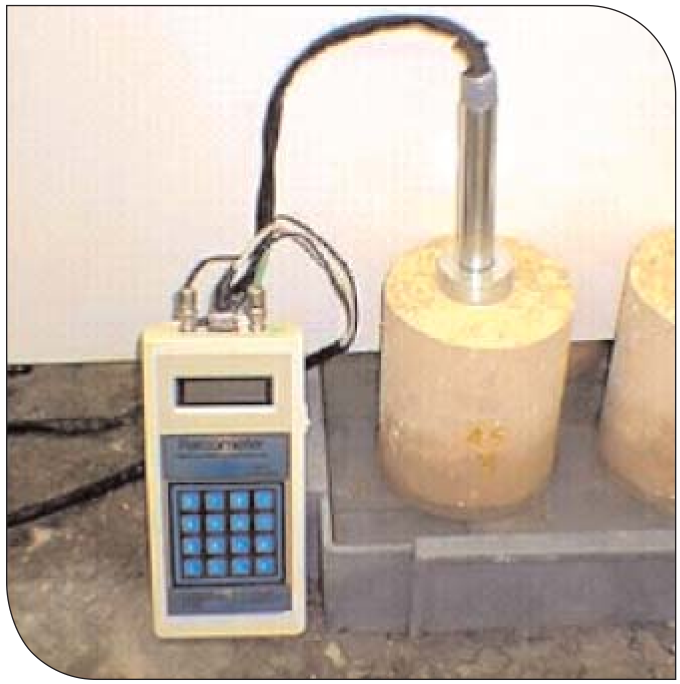

Figure 1 – Soil-cement base specimens in the TST.

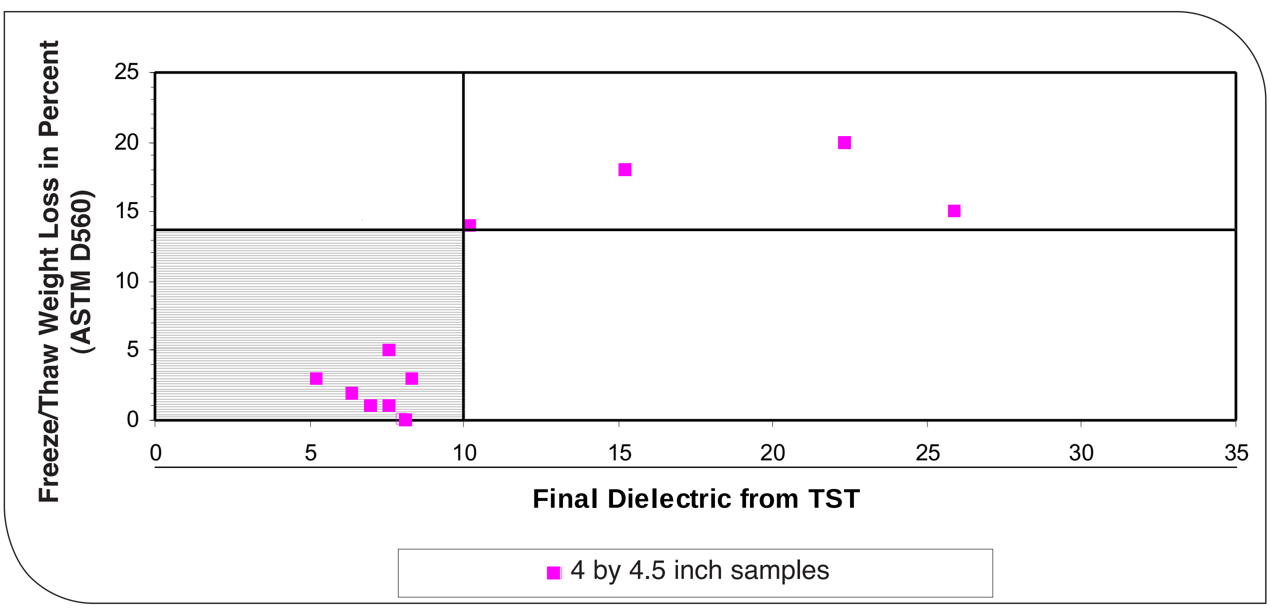

Figure 2 – Comparing TST results with freeze/thaw durability test results. Note: Shaded area is the acceptance region.

Figure 2 shows that the results from the TST were reliable for predicting whether a soil-cement material would pass the freeze/thaw durability test. All of the results from these specimens are either in the lower left or upper right quadrant, indicating that if the material passed the TST, it likewise passed the PCA acceptance criteria based on the freeze/thaw test procedure (ASTM D560).

Shrinkage/Strength Relationship

The major performance problems found with stabilized materials are related to shrinkage cracking. Fine, widely spaced shrinkage cracks are typically cosmetic in nature and not a structural problem, but, in some cases, these cracks have a tendency to become wider and more closely spaced. Wide shrinkage cracks can result in the following:

- Moisture infiltration into the subgrade causing pumping and loss of support for the stabilized layer above
- Faulting of the stabilized layer due to loss of subgrade support
- Moisture-induced deterioration of the stabilized layer at the joint, causing a widening of the crack and joint raveling
- Loss of aggregate interlock at the crack

The shrinkage of stabilized materials results from the loss of water through evaporation and from the hydration process. The severity of shrinkage of stabilized materials is influenced in part by material properties and mix design proportions. For instance, fine-grained materials tend to exhibit greater shrinkage than coarse-grained materials. Final crack widths are mainly dependent upon the ultimate shrinkage strain and crack spacing. This ultimate shrinkage is one of the most important characteristic properties of stabilized materials. Typically, efforts to minimize shrinkage cracking have focused on material selection, mix design, use of additives, curing, and construction techniques.

The effect of UCS on beam shrinkage tests is an important consideration in the design of soil-cement base pavements because it provides both an indication of load resistance and durability. Many materials tested produced a bowl-shaped graph when shrinkage is plotted against UCS, as shown in Figure 3. The general feeling is that the higher the UCS, the better the material properties. However, as Figure 3 indicates, there exists an optimum strength that will produce the minimum shrinkage and the optimum strength varies depending upon soil type.

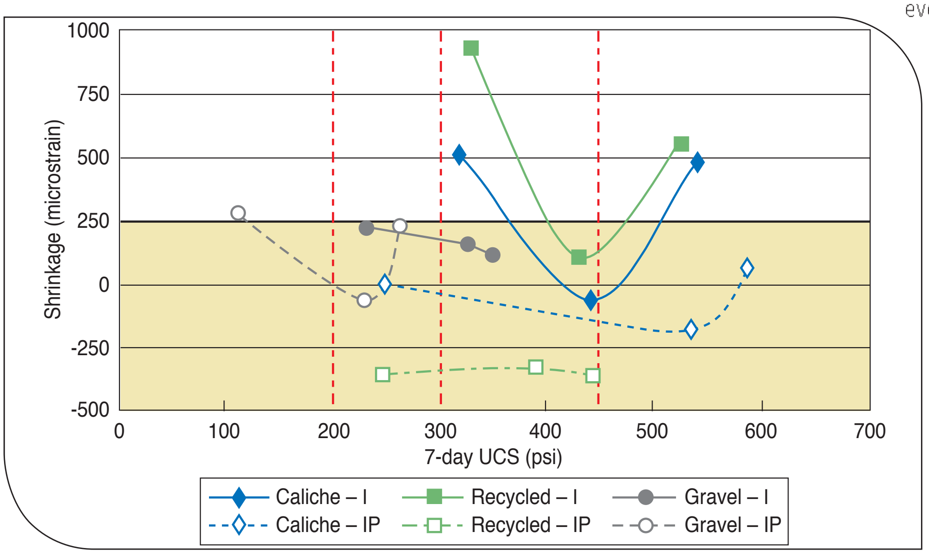

Figure 3 – 7-day UCS vs. beam shrinkage. Note: Shaded area is the acceptance region.

Autogenous Healing

Similar to concrete, soil-cement has autogenous healing properties—the ability to continue to generate cementitious compounds after cracking—that improve strength and bond cracks. Tests were conducted to show the ability of soil-cement to regain strength after initial failure.

"...for all aggregates and cement types and contents, the rehealed specimens retained 121% of the 7-day strength..."

One of the reasons for investigating autogenous healing was to demonstrate that soil-cement has significant reserve binding capacity that enables it to generate new cementitious bonds, even after some of the initial bonds have failed. This is the situation that would occur if a completed soil-cement base was deliberately overloaded and cracked by re-rolling with a vibratory roller 24 to 48 hours after completion. It is postulated that much of the initial shrinkage stress would be relieved through a distributed network of hairline cracks, resulting in significantly reduced propensity for wide shrinkage cracks and subsequent reflective cracking. Initially, some of the cementitious bonds would fail, and, immediately following post-rolling, the soil-cement would have a lower strength. However, as the autogenous healing tests suggest, all of the initial strength would be regained and exceeded. In this testing, all of the 7-day strength was regained, even beyond the time frame of 24 to 48 hour post-rolling. This implies that if post-rolling were to be performed on a soil-cement base, then the 7-day minimum UCS noted in a specification should be achieved and exceeded by the post-rolled section. More information on this type of "precracking" or "microcracking" can be found in Reference 2.

Cement-Modified Soil (CMS)

This study evaluated the effects of modification using both cement and lime on two different soils referred to as FM 20 and FM 1343. The soils were mixed (using both dry and slurry applications), compacted, cured, and tested in the laboratory for UCS and TST comparisons.

Atterberg limits were determined for the untreated soils as well as for each soil when stabilized with 3%, 6%, and 9% cement (all Type I); 3% and 6% lime; and 3% cement with 3% lime. Testing confirmed that portland cement was just as effective at reducing the PI as lime, which Figure 4 clearly illustrates.

"...cement was just as effective at reducing the Plasticity Index as lime."

Effect of Slurry Application

Some noteworthy findings about cement slurry application include:

- Samples made using cement slurries had better properties than those made by mixing the dry cement into the dry or moist soil.
- Slurry mixing times up to four hours were found not to have a major impact on the final strengths of the cement-stabilized soils.
- Additional testing found that cement slurry remained workable for up to 30 minutes after mixing was discontinued.

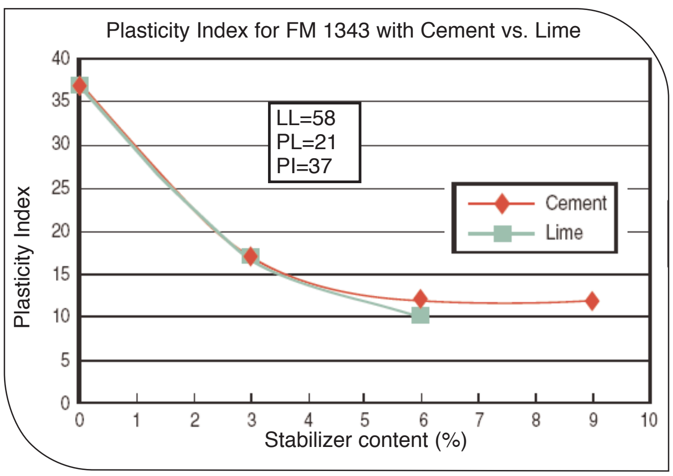

Figure 4 – PI of soils after being stabilized with both cement and lime.

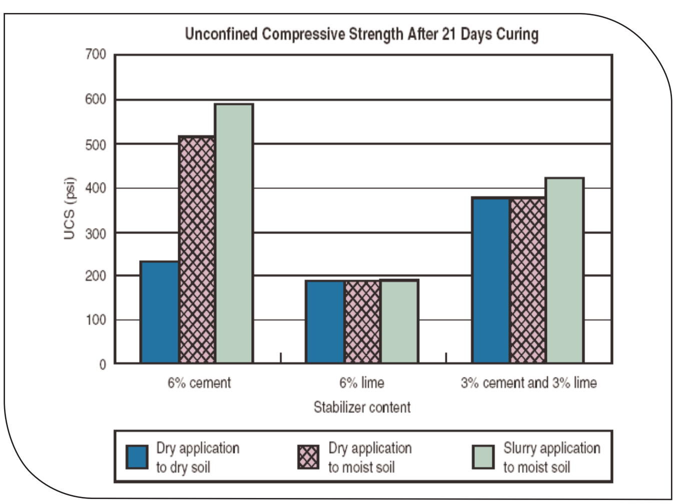

Figure 5 – UCS for FM 20 soil after 21 days curing time.

Tests were conducted to evaluate the performance of stabilizers applied to the soil in either dry or slurry form. Figure 5 presents UCS results for different preparation methods. For both the stabilized specimens containing 6% lime and those with a blend of 3% cement and 3% lime, the results are essentially the same for all types of preparation methods.

Conclusion

In summary, the methodology of selecting stabilizer type and content based on more than a simple 7-day UCS test appears beneficial. As a minimum, it is recommended that a moisture susceptibility test, such as the TST described in this study, be included in the selection criteria.

References

1. *Soil-Cement Laboratory Handbook*, EB052, PCA, 1992
2. *Precracking of Soil-Cement Bases to Reduce Reflection Cracking,-Field Investigation,* by T. Scullion, Transportation Research Record 1787, 2002

More Information

PCA offers a broad range of resources on soil-cement applications for pavements. Visit our Web site at **www.cement.org/pavements** for design and construction guidelines, technical support, and research on cement-modified soils, cement-treated base, and full-depth reclamation.

For local support, tap into the cement industry's network of regional groups covering the United States. Contact information is available at **www.cement.org/local.**

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