

Role of Lime-Stabilized Subgrades in Minimizing Pavement Distress in Flexible Pavement Systems



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Role of Base and Subbase Layers in Flexible Pavement Structures

The Flexible Pavement Structure

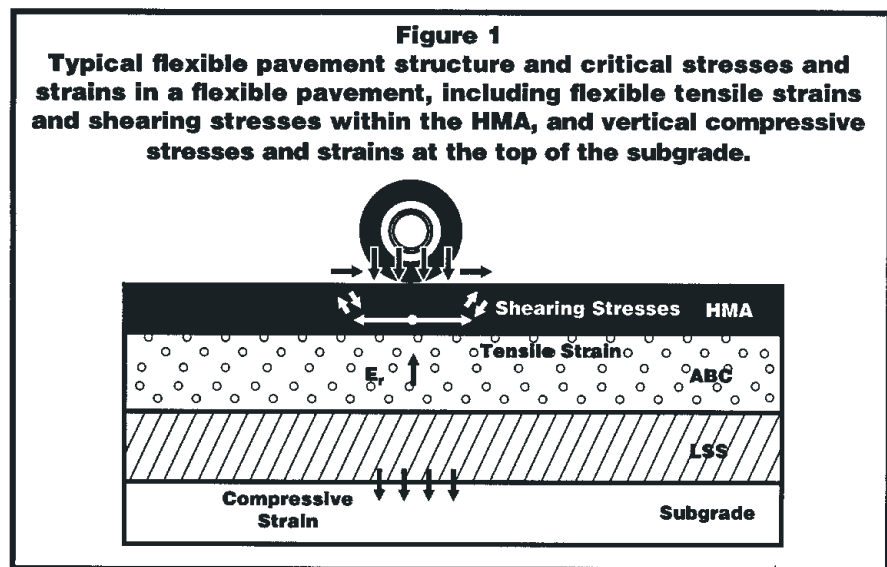
The typical flexible pavement system is comprised of a hot mix asphalt (HMA) surface layer and, generally, an aggregate base course. The base course is a major structural component of a flexible pavement system. Often, a subbase also is included in the pavement structural section. The subbase serves as a support layer for the base course, providing structural contribution to the pavement system. The base and subbase layers provide support for the overlying HMA pavement surface and protection for the underlying natural subgrade soils.

Figure 1 illustrates the components of a typical flexible pavement with a HMA surface layer, an aggregate base course (ABC) layer, and a lime-stabilized subgrade (LSS) layer. The lime-stabilized subgrade becomes a major structural component of the flexible pavement system, fulfills the role of a subbase, and can lower pavement life cycle costs. In some pavement system designs, the lime-stabilized subgrade has been successfully utilized as the base course layer directly beneath the HMA pavement surface.

Distribution of Loads and Stresses within the Flexible Pavement Structure

Figure 1 also illustrates the critical stresses induced in a flexible pavement system. The flexural tensile stresses and strains induced in the HMA by traffic are related to fatigue cracking. If these stresses and strains are too large, the result is a pavement with cracking of the HMA in the wheel

path. The shearing stresses in the HMA are related to distortion, shoving, or rutting within the surface layer. These stresses are induced by the vertical contact stresses of the wheel load as well as the rolling and braking surface shearing stresses. The vertical compressive stresses and strains within the granular bases, subbases, and subgrades are related to rutting and pavement roughness. The magnitude of the stresses and strains developed within the various pavement layers is dependent on the magnitude of the contact stresses of the wheel load, the thicknesses of the respective layers, and the relative stiffness or moduli of the various layers.



Because the magnitude of the stresses developed within the asphalt layer is influenced by the modulus (or stiffness) ratio between the surface and the base course, strengthening of the base or subbase is a method by which to minimize distress within the HMA. For example, by increasing the stiffness or modulus of a granular base by adding a stabilizer such as lime, the ratio of moduli between the HMA surface and the supporting base course is reduced. In other words, the increased stiffness of the base provides better

support for the surface. The net result is that both the tensile flexural stresses and the shearing stresses developed within the HMA are reduced. The reduction in flexural and shearing stresses reduces the potential to fatigue crack or deform.

The stiffness or modulus of granular bases is stress dependent. This means that as the stress or confinement within the granular base is increased the response modulus or stiffness increases. Development of a high-confining stress within the granular base can be achieved by enhanced support from the subbase or subgrade. Because lime stabilization of a native soil improves the consistency of the soil over a wide range of moisture contents, it lowers plasticity, reduces swell and volume change potential, and increases the strength of the subgrade. This means that a lime-stabilized subgrade can provide improved and more consistent support for the base compared to the unstabilized natural soil. The net result is a better structural response from the aggregate base and a reduction of the cracking and shearing stresses within the HMA. Strengthening and stiffening the base and subgrade layers through lime stabilization provides improved load-spreading capability of the pavement structure, providing protection of the natural subgrade from being over-stressed by traffic loading. This results in reduced potential for the pavement to develop roughness or deep layer rutting.

Characteristics of Lime-Stabilized Subbases that Enhance Structural Performance

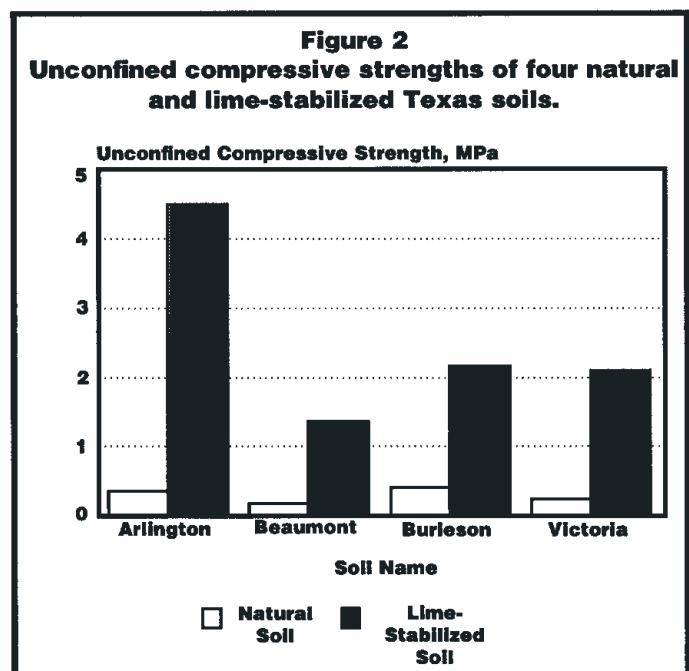
Shear Strength

Calcium hydroxide (lime) reacts with soils containing clay minerals to increase the shear strength of the soil. This reaction occurs as the high pH of the lime-soil-water mixture solubilizes silica and alumina from the clay mineral surfaces. The solubilized silica and alumina react with cal-

cium from the lime to form cementitious calcium silicate hydrate and calcium aluminate hydrate compounds that bind the soil particles together. This “pozzolanic” strength gain process continues to occur as long as calcium is available and soil silica and alumina are being solubilized. The reaction can continue to occur for years, although the majority of the reaction occurs within about one month for most soils under proper curing conditions.

The shear strength of lime-soil mixtures is measured indirectly by the unconfined compressive strength test (ASTM D 5102). Because soils vary in their pozzolanic reactivity with lime, the magnitude of developed shear strength varies among different soils. Unconfined compressive strengths in soils stabilized with lime typically range from about 700 kPa (100 psi) to over 7,000 kPa (1,000 psi).

Figure 2 shows the strength gain achieved through lime stabilization of four Texas soils. Each soil was shown to be reactive with lime, and a strength gain of at least 1,000 kPa



(150 psi) occurred with each soil following a 28-day curing period at 22°C (73° F). Thompson (1970) reported that with residual compressive strengths of 1,000 kPa (150 psi) or greater, lime-stabilized soils can function well as bases or subbases and enhance the structural performance of the pavement system. Thompson (1970) assigned AASHTO structural layer coefficients of 0.11 to lime-stabilized soils achieving an unconfined compressive strength of 1,000 kPa (150 psi) following 28-day cure at 22°C (73°F). Pavement designs incorporating structural contribution of lime-stabilized layers typically assign structural layer coefficients ranging from 0.10 to 0.20, depending on the amount of strength developed with curing.

Resilient Modulus

In order for the structural system to perform acceptably, the base and subbase layers must provide adequate support for the HMA surface and a load-distributing capacity expected to protect the underlying natural subgrade from being overstressed. The engineering property associated with these performance characteristics is the resilient modulus of the base. The resilient modulus is determined in accordance with AASHTO T-274 and is equal to the ratio of repeated stress to the measured total resilient or recoverable strain caused by the applied dynamic or cyclic load:

$$E_r = \frac{\sigma_{\text{repeated}}}{\epsilon_{\text{recoverable}}}$$

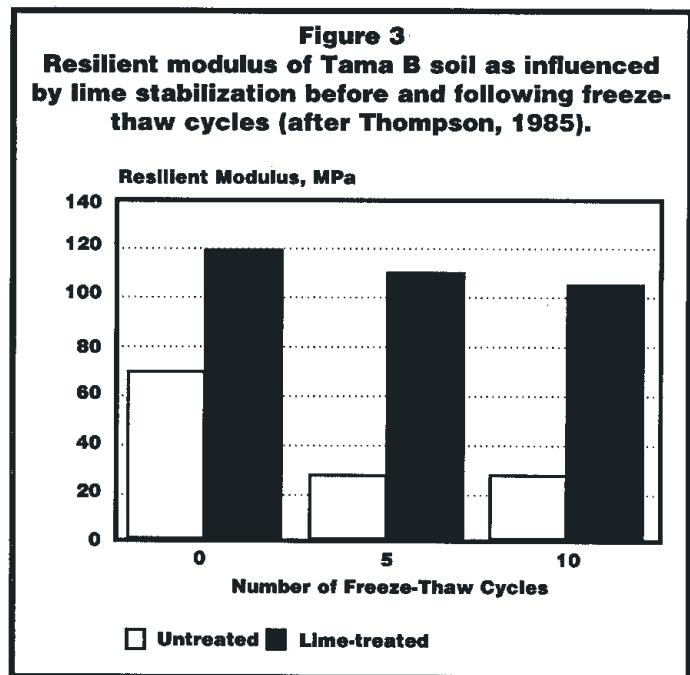
Where E_r is the value of the resilient modulus, σ_{repeated} is the repeated stress which simulates the stress level produced by a moving wheel, and $\epsilon_{\text{recoverable}}$ is the measured total resilient or recoverable strain induced as a result of the repeated stress.

Figure 3 presents typical lab resilient modulus data for an

Illinois soil tested by Thompson (1985). Note the four-fold improvement in modulus and the resistance to freeze-thaw damage provided by lime stabilization.

Perhaps a more revealing way to investigate the structural contribution of lime stabilization is through field testing. Non-destructive testing techniques such as the Falling Weight Deflectometer (FWD) are now being used extensively to determine in-situ properties of pavement layers. The FWD applies an impulse load to the pavement surface which simulates the actual movement of a wheel across the pavement. The FWD then measures the deflection basin caused by the impulse load. Using this deflection basin, actual, in-place resilient moduli of the pavement layers can be ascertained under realistic field conditions and within the actual pavement structure as opposed to within a fabricated laboratory sample.

Evaluation of in-place moduli of lime-stabilized pavement subgrades in Texas has revealed that the resilient modulus



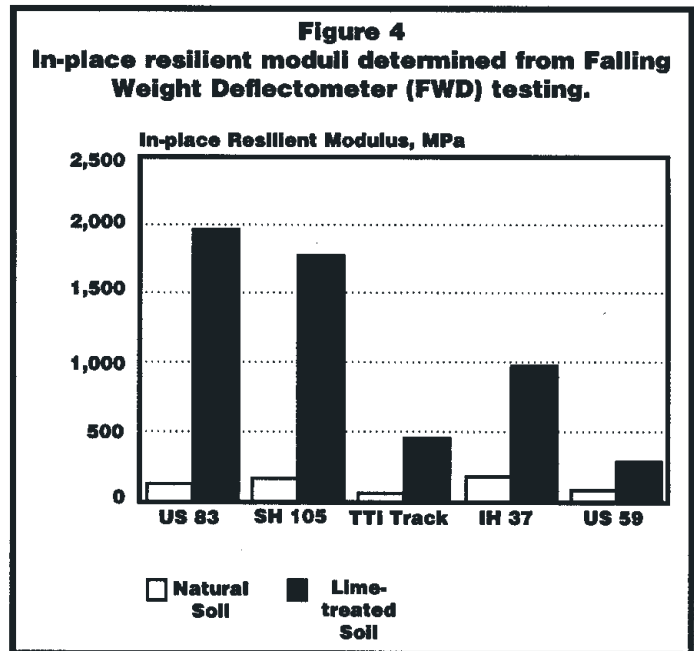
of the natural subgrade typically is increased by a factor of 10 to 50, with the majority of the increase approximately 10 to 20 times the original modulus of the natural subgrade. Figure 4 presents the resilient moduli measured for lime-stabilized subgrades in five Texas pavements and compares the native subgrade modulus with the lime-stabilized subgrade modulus.

The magnitude of resilient modulus increase caused by lime stabilization is often optimal for pavement performance. Studies have demonstrated that very stiff subbases or bases, i.e., where the in-place modulus is in excess of 7000 MPa (1,000,000 psi), often do not perform well and are subject to development of severe shrinkage cracks that propagate through the asphalt surface and result in pavement distress. On the other hand, subbase and base moduli in the range of 345 MPa (50,000 psi) to 7000 MPa (1,000,000 psi) have demonstrated excellent performance by providing good load spreading capacity without reflection cracking.

Example of the Use of Lime Stabilization to Enhance Performance

Little (1995) considered two pavement systems with regard to structural and life cycle cost analyses. Pavement “A” consisted of a 122.5-mm (5-inch) HMA surface and a 305-mm (12-inch) aggregate base placed over a clay subgrade with an average annual resilient modulus of 28 MPa (4000 psi). Pavement “B” consisted of exactly the same pavement layers except that the top 203-mm (8-inches) of the subgrade was lime-stabilized, boosting its average annual resilient modulus to 483 MPa (70,000 psi) based on in-place FWD evaluation. The addition of the 203-mm (8-inch) lime-stabilized layer had the following effects on pavement system performance:

1. The resilient modulus of the aggregate base course was



increased by 25%, increasing its AASHTO structural layer coefficient, a_2 , from 0.10 to 0.13. ...

2. The tensile strain and shearing stress developed within the HMA surface were reduced by 50% and 60%, respectively, increasing fatigue life by 400% and significantly improving the ability of the HMA to resist excessive shearing stresses that result in rutting and instability.
3. The compressive strain developed within the natural subgrade, that results in deep rutting and pavement roughness when excessive, was reduced by 35%, increasing the performance life by 1200%.
4. The predicted life cycle costs of pavement “B” were 10% lower than those of pavement “A” even though the first cost of pavement “B” was higher due to incorporation of the lime-stabilized subgrade.

Summary of Flexible Pavement Structural Enhancement Offered by Lime Stabilization of Natural Subgrades

Lime stabilization of subgrades can enhance pavement structural performance by:

1. Improving the physical and mechanical properties of the lime-stabilized subgrade compared to the unstabilized natural soil. These improvements result in reduced volume change potential for expansive clay soils, and substantially higher shear strengths and resilient moduli of the lime-stabilized soils as compared to the natural soils.
2. Improving the supporting capacity for the aggregate base which results in a better structural response of the aggregate base in terms of resilient modulus and the AASHTO structural layer coefficient. The result of the improved structural response of the lime-stabilized layer and the aggregate base is better protection of the natural subgrade from being over-stressed by traffic loads.
3. Improving the structural support of the HMA pavement surface, thus providing better resistance to flexural fatigue cracking and rutting.

References

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- Thompson, M. R., "Final Report—Subgrade Stability," FHWA-IL-UI-169, 1985.

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