TECHNICAL NOTE

BENEFITS OF SUBGRADE STABILIZATION USING GEOSYNTHETICS VERSUS CHEMICAL STABILIZATION (LIME/CEMENT TREATED SOIL)

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INTRODUCTION

Construction of long lasting, economical pavement structures requires subgrade materials with good engineering properties. It is also critical that the subgrade materials maintain good engineering properties for the design life of the system; being able to withstand environmental effects, such as freeze/thaw, seasonal high moisture conditions and repeated dynamic loading. Subgrade preparation for pavement sections can be one of the most time-consuming aspects of roadway construction. Desirable properties the subgrade should possess to maximize the service life of the roadway section include: strength, drainage, ease and permanency of compaction, and permanency of strength. In many areas, the in-situ soils are high plasticity clays or other types of fine-grained soils, which are not satisfactory materials for use as a subgrade in pavement structure. These subgrade soils exhibit poor strength, moisture sensitivity, shrink/swell, freeze/thaw and load deformation properties and must be replaced or stabilized in some manner.

For centuries, removing the poor soil (or, at least a portion of the poor soil) and replacement with a higher shear strength soil or aggregate, i.e., “engineered/granular fill” has been the time tested and proven method to stabilize weak subgrades. Much time and expense have been expended over the years in utilizing this conventional form of *mechanical stabilization*. Geosynthetics have been used over the past several decades to enhance mechanical stabilization of subgrades and reinforce earth fills.

Another popular method of subgrade stabilization in use since the 1960’s is *chemical stabilization.* This is achieved through addition of lime, Portland cement, fly ash and/or other chemicals to the soil to change the chemical and physical properties of the subgrade.

This Technical Note provides a comparison of Mirafi® geosynthetics-reinforced mechanical stabilization versus chemical stabilization. Included are reviews of stabilization mechanisms that are involved, design methods and procedures, engineering properties of stabilized soils, and typical construction procedures.

CHEMICAL STABILIZATION

Chemical stabilization of subgrade soils can improve the short-term strength, bearing capacity, shrink/swell behavior and freeze/thaw characteristics. The two most common chemical stabilization treatments are lime and cement. *Lime* refers to Calcium Hydroxide (hydrated lime, slaked lime [$Ca(OH)_2$]) and Calcium Oxide (quicklime [CaO]), as well as the dolomitic variants of these high-calcium content limes. Hydrated lime is a fine powder, while quicklime is a more granular substance. Both heat-refined compounds created from Calcium Carbonate (limestone [$CaCO_3$]). Hydrated lime is safer to work with, as quicklime is more caustic. Several States have banned the use of quicklime due to safety concerns. *Cement* refers to Portland cement.

Lime Stabilization

1. *Mechanism*. Lime, in the form of quicklime or hydrated lime, is a strong alkaline base that reacts chemically with specific clay minerals. The reaction causes a base ion exchange, with calcium ions displacing sodium and hydrogen cations. There is generally a distinct reduction in plasticity and increase in strength.

1.1. When lime is added to the subgrade soil, hydration of the lime causes an immediate drying of the soil. The addition of lime provides an abundance of calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). These cations tend to displace other common cations such as sodium (Na^{+}) or potassium (K^{+}) in the clay particle via *cation exchange*. If the soil is plastic, there is an immediate reduction in its Plasticity Index (PI), generally due to the Liquid Limit (LL) decreasing and the Plastic Limit (PL) increasing. This also results in an increased optimum moisture content as well as an increase in soil pH, which also increases the cation-exchange capacity. This chemical reaction also changes the soil texture. Clay particles are arranged parallel to each other (like a stack of plates). As a result of the cation exchange, a clayey soil becomes more silty or sandy in behavior due to a process known as *agglomeration and flocculation*; where edge-to-face attraction occurs among the clay particles and they are rearranged (like a house of cards).

1.2. The remainder of the available chemical reaction (strength producing reaction) is a cementing or hardening action, in which lime reacts chemically with the available silica (Si^{2+}) and aluminum (Al^{2+}) cations (provided by the clay minerals), forming calcium silicates and aluminates. Clay, typically is a pozzolan as it is a source of both silica and alumina. Because this is a chemical reaction, pozzolanic strength gain is both time and temperature dependent. Temperatures need to be above 40°F (4.4°C) to maintain the pozzolanic reaction. The rate of pozzolanic reactions is slowed by low temperatures. Once the pozzolanic reaction stops, it will not restart.

2. *Non-reactive soils*. There are instances when the clay soil does not have adequate amounts of Si^{2+} and Al^{2+} ions for the pozzolanic reaction to occur. Subsequently, a pozzolan additive, such as *fly ash* is introduced to provide the silica and aluminum in order for the chemical reaction to take place. Fly ash is produced from the burning of pulverized coal in a coal-fired boiler. It is a fine-grained, powdery particulate material – grain size is generally similar to that of silt. Some types of fly ash are unsuitable for use in this application due to their high affinity for water molecules, thus creating the potential for the amended soil to swell. *See Section 3.5 below*.

3. *Durability.* Typically, short-term durability is not a concern for some lime applications (e.g., drying, plasticity reduction, textural change and immediate uncured strength gain to aid construction). This is applicable when the desired result is a short-term, proof-roll passing working platform. However, more permanent changes, such as a reduction in the swell potential of expansive clays or development of pozzolanic strength for structural strength can be adversely affected by the environment. Five (5) basic areas of concern that must be considered:

3.1. *Water.* Some lime-stabilized soils maintain some (70-85 percent) of their strength when exposed to water. However, many lime-stabilized soils exhibit poor strength retention when exposed to continued hydration. Consequently, testing of lime-stabilized soils for soaked strength retention is prudent.

3.2. *Freezing and Thawing.* When lime-stabilized soils are exposed to freezing and thawing, their volume typically increases and the strength decreases. There have been numerous studies since the 1960's into the effect of freeze-thaw on chemically stabilized subgrades. One of the most recent, “Effect of Freeze-Thaw Cycles on Performance of Stabilized Subgrade,” (Solanki, Zaman, Khalife, 2013). These studies consistently show a decrease in the unconfined compressive strength (UCS) of tested samples with an increase in the number of freeze-thaw cycles. Therefore, it is not a matter of *if* the lime-stabilized subgrade becomes completely degraded, but more a matter of *when* they will degrade. It should be noted the level of reduction in the UCS values is influenced by the type of soil as well as the type and amount of chemical additive used. Typically, lime stabilization samples last for about 120 freeze-thaw cycles.

3.3. *Leaching.* The development of calcium silicate (Ca_2SiO_4) and calcium aluminate hydrates (CAH_{10}, C_2AH_8, C_3AH_6) from the pozzolanic reactions are not typically affected by leaching. However, the other effects of lime stabilization due to reversible processes might be affected by extended leaching. For example, the cation exchange that reduces plasticity could be reversed if calcium cations are replaced during percolation of groundwater or infiltration of surface water. Studies have shown that continuous leaching effects negatively affect the stabilized soil’s physical engineering properties (i.e., Atterberg limits, permeability, strength and swell pressure). The magnitude of changes in physical and chemical properties is highly dependent upon the lime content of the mixture. Typically, soils stabilized with 6-7 percent lime demonstrated less changes, compared to greater changes at less than 6 percent lime.

3.4. *Carbonation.* Carbonation occurs when atmospheric carbon dioxide [CO_2] combines with lime to form calcium carbonate [$CaCO_3$]. If the pH of the lime-stabilized system drops sufficiently low, the calcium silicate and calcium aluminate hydrate cementing compounds may become unstable and react with the carbon dioxide to revert back to silica, alumna and calcium carbonate. These reactions are obviously detrimental to the lime-stabilized system’s long-term strength and durability. Potential problems of this nature can be minimized; by use of ample lime content; care in selection of materials to be stabilized (i.e., proper analysis and mix design); placement and compaction of the material to high density to minimize carbon dioxide penetration; prompt placement after mixing the lime with the soil; and adequate curing time (i.e., proper installation procedures and quality control measures during construction).

3.5. *Sulfate Attack.* If sulfates (SO_4^{2-}) are present in the soil or water (or additives like fly ash) where lime stabilization is used (recent studies indicate ≥ 0.3%), detrimental reactions resulting in large volume increases are likely to occur. The chemical reactions forming the cementitious compounds (calcium silicate and calcium aluminate hydrate) normally increase the strength, and reduce the plasticity and swell potential of the soil. However, when sulfates are present in the soil or water, they also participate in the chemical reaction and disrupt the normal long-term pozzolanic reactions of the stabilization process. This disruption results in the formation of ettringite [$Ca_6Al_2(SO_4)(OH)_{12} \cdot 26H_2O$] and thaumasite [$Ca_3Si(OH)_6(CO_3)(SO_4) \cdot 12H_2O$]; both minerals that are expansive in nature from absorption of water. Ettringite forms first and then transforms to thaumasite when the temperature drops below 60°F (15°C) and if there is sufficient carbonate and silica available in the system. Due to water absorption, these minerals can generate significant expansion (volumetric change over 200%). Once the formation of these minerals begins, the process does not stop until it runs its course.

4. *Mix Design.* The purpose of mix design for lime-stabilized soil is to achieve the desired change in soil properties at the minimum lime content that will maintain the desired level of durability. There are a number of specific mix design methods that have been developed by different organizations and they all specifically address;

    4.1. *The objective to be achieved:* PI reduction, texture change, swell reduction, immediate strength gain or long-term pozzolanic strength gain.

    4.2. *Durability*: The ability to maintain desired change in the stabilized soil properties over the time required.

    4.3. *Economics*: Minimum lime content to achieve the objective and maintain the required durability.

    4.4. *Subgrade Soil Characterization:* Conducting a proper mix design takes approximately 2 - 3 weeks, sometimes longer, and is dependent on the size of the project and how many subgrade soil types are involved. According to the National Lime Association (NLA), as well as FHWA and the Joint Departments of the Army and Air Force design manuals/methods, a typical mix design for a lime-stabilized soil application must include the following; if the soil is a candidate for lime stabilization. Generally, soil with at least 25% passing #200 sieve (P_{200}) and PI ≥ 10.

    4.5. Determine organic content of soil ≤ 1 percent.

    4.6. Soil pH needs to be 12.4

    4.7. Test the clay mineralogy of the soil to determine if there is swell potential with addition of chemical stabilization and/or if there is a necessity to add a pozzolan, such as fly ash.

    4.8. Test for presence of carbonates.

    4.9. Test for presence of sulfates (should be < 0.3%).

    4.10. Several test specimens must be prepared with varying additive concentrations for each type of soil. The specimens are cured and periodically tested for unconfined compressive strength. This process is conducted over a minimum of 2 - 3 days, but can take as long as 7 – 10 days.

5. *Construction*. There are four (4) basic steps in the chemical stabilization construction process.

    5.1. *Delivery and distribution of the lime and, when necessary, the pozzolan additive:* Lime is applied to the soil either dry or as a slurry. Dry hydrated lime dusts vary considerably and can become a serious environmental concern. As lime is very caustic, it poses eye, skin and inhalation hazards to workers and anyone in the vicinity of the working area. In addition, property damage to vehicles or structures is also a concern. Lime dust should be washed off chrome and painted surfaces immediately.

Using the slurry option reduces unwanted dusting. However, slurry is more expensive due to the additional equipment requirements and slower application rates. Furthermore, depending on the amount of lime and pozzolan required as a consequence of the required mix design(s), the slurry may become more difficult to pump. In addition, slurry is not practical to use in very wet soils or for soil drying applications.

5.2. *Mixing.* Lime stabilization will not be successful unless the soil and additives are properly mixed. Poor mixing with the subgrade soil is probably the leading cause of lime stabilization failure. Specialized equipment such as rotary mixers with tines are typically utilized to churn and till the subgrade where the chemical admixtures have been deployed. The mixing process includes adding water to the soil, as the moisture content typically needs to be increased to at least 5% above optimum moisture contents. Achieving a proper mix also relies heavily on determining and maintaining the as-designed lime content uniformly across the soil by controlling the spread rate. There are specific quality control procedures for these processes.

5.3. *Compaction.* The treated area must be compacted appropriately prior to curing to minimize evaporation loss. Excessive loss of moisture will adversely affect the chemical stabilization process. Conversely, there is also a concern from heavy rain, as excess moisture will also adversely affect the chemical reaction. Proper compaction of the treated area can help to seal the surface and reduce evaporation or intrusion of excess water.

5.4. *Curing.* Because the lime stabilization process is a chemical reaction, there are specific conditions which must be met in order for the process to occur. In addition to verifying the chemistry of the soil minerals and determining the type(s) and quantities of chemical additives required, achieving and maintaining the appropriate pH (12.4) and range of suitable temperatures in order for the chemical reaction to take place must be achieved. The cooler the temperature, the slower the chemical reactions will proceed. The temperature must be ≥ 40°F or the chemical reactions do not take place. Further, if the chemical reaction was to stop due to a drop in temperature, it will not restart if the temperature increases. The curing process takes a minimum of 2 – 3 days, but can take as much as 7 – 10 days, or more. Vehicles and equipment should be prevented from trafficking the treated area until the curing process is complete.

Cement Stabilization

Portland cement is a *hydraulic cement*, indicating it will harden and gain strength through chemical reactions with water. It is composed primarily of calcium oxides, silicates and aluminates that form a strong cementing paste when hydrated. Cement stabilization of subgrade soils is fairly straight forward. Portland cement contains excess lime and the lime generates the same chemical reactions discussed in the Lime Stabilization section above. However, Portland cement is more expensive than lime. The primary value for cement stabilization of subgrade soil is to create the strong cementitious bonds formed to tie the soil particles together into a cemented, coherent mass. Unlike lime stabilization, all the chemical components necessary for the development of calcium silicate and aluminate hydrate bonds are present in the Portland cement. No chemical contribution is necessary from the soil. Therefore, cement stabilization of subgrade soils does not depend on the mineralogy of the soil being stabilized.

However, because the chemical reactions and processes are the same as those in lime stabilization, cement stabilization is subject to the same durability issues/concerns as lime stabilization. The mix design and construction procedures are also very similar.

MIRAFI® GEOSYNTHETICS-REINFORCED MECHANICAL STABILIZATION

Mechanical Stabilization is simply improving selected engineering properties of a system through mechanical means. Undercutting and removing soft, weak, possibly wet or otherwise undesirable soils and replacing with an engineered fill, creating a Mechanically Stabilized Layer (MSL), is one type of Mechanical Stabilization. An engineered fill being material that is placed and compacted in accordance with approved design criteria in order to improve the ground for an intended use. The engineered fill is comprised of granular, non-organic soil. However, in most cases of mechanical stabilization, especially for roadways and pavements, the engineered fill is comprised of crushed stone aggregate. The use of Mirafi® geosynthetics in mechanical stabilization reinforces and enhances the performance of the crushed stone aggregate, thereby enabling the contractor to utilize less stone and less undercut while maintaining and/or improving the desired level of performance.

Geosynthetic stabilization and reinforcement are mechanical processes. The geosynthetic is placed on the subgrade or subbase, under or within aggregate layers and works with the soils and aggregate to create a reinforced composite section. This is achieved through the separation, filtration & drainage, and confinement functions provided by the geosynthetic. Soil chemistry is not usually involved.

Geosynthetics are delivered to the project site in ready to use rolls and can be installed quickly and easily. The material is deployed evenly over the subgrade simply by unrolling and then aggregate fill is placed, spread and compacted over top. Unlike chemical stabilization, specialized equipment is not required, a specialty contractor is not required (any earthwork contractor can install geosynthetics utilized for roadway stabilization / reinforcement applications) and there is no curing time or extended waiting period before the stabilized area can be trafficked. Construction can continue immediately after installation.

Commonly used roadway geosynthetic stabilization is applicable regardless of soil type, soil mineralogy, presence or absence of sulfates, water content or pH. A geosynthetic reinforced mechanical stabilization application is designed based on the in-situ soil strength. This can be accomplished via several standard of practice design methodologies, or even through a small test section conducted on site. In addition, there are no environmental concerns or safety concerns such as those associated with chemicals or airborne particles. Furthermore, Mirafi® geosynthetics can be installed in all weather conditions, including wind or cold and in populated area and near active traffic zones. Because the geosynthetic reinforced MSL is a composite section comprised of geosynthetic and aggregate, it is not degraded or otherwise adversely affected by freeze-thaw cycles, as are lime and cement stabilization applications.

The wide variety of geotextiles and geogrids available for stabilization and reinforcement applications insure geosynthetics are the right choice for any subgrade soil type and project loading conditions. TenCate Mirafi® manufactures and markets the most comprehensive line of geosynthetics in the industry, including geogrids, woven geotextiles and non-woven geotextiles, along with other specialty geosynthetics. All of these products can be used in subgrade stabilization, reinforcement or separation; individually or in combination with each other to improve subgrade support, roadway construction and pavement service life. Their use is not limited to certain soil types or soft soil conditions.

Summarized Comparison: Geosynthetic MSL vs. Chemical Stabilization

Geosynthetic MSL	Chemical Stabilization
Long-term strength & survivability	Short-term strength and survivability
No environmental concerns	Caustic – potential health & property damage
Quick & easy installation, regardless of weather or temperature	Time, weather & temperature dependent
MSL section can be determined by test section	Requires engineering analysis & design for appropriate application & installation
Not affected by soil minerology or chemistry	Dependent upon minerology, sulfate & iron oxides, organic content, pH, carbonates
No long-term degradation	Affected by long-term exposure to water, affected by freeze-thaw cycles
No specialized equipment required	Specialized equipment
No cure time – immediate trafficking	2 to 14 days cure time – no trafficking during cure time
Consistent results	Results can vary

The next time you encounter soft subgrade soils on your roadway or pavement project, first consider using geosynthetics for stabilization or reinforcement before attempting to overcome all the disadvantages and challenges of using lime or cement stabilization.

Contact your local TenCate Geosynthetics Mirafi® representative for technical support and product recommendations.