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Chemical versus Geosynthetic Stabilization used in Roadways

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Since the introduction of geosynthetics into transportation systems in the late 1970's, geosynthetics have been utilized in ever increasing variety of applications. With this heightened interest, due to their effectiveness and great benefit cost ratio, geosynthetics (including geotextiles, geocells and geogrids) are regularly used as part of roadway systems. Currently, owners and regulatory agencies have been questioned as to their position on geosynthetics as opposed to conventional techniques such as chemical stabilization. This white paper is intended to counterpoint the pros and cons associated with these techniques as they pertain to the topic of roadway stabilization.

When placing stone aggregate on fine-grained soils, there are two simultaneous mechanisms that tend to occur over time. One is that the underlying soil attempts to enter the voids of the aggregate, thereby ruining its drainage capability; the other is that the overlying aggregate attempts to intrude into the fine soil, thereby ruining the aggregate's strength. Unfortunately, the generation of "potholes" or roadway deterioration is a common occurrence as described in R. M. Koerner's, (2012) Designing with Geosynthetics text book.

GEOSYNTHETICS

Right from the start, geosynthetics have seen significant utilization in roadways. Geosynthetics are polymeric material that are applied into soils to provide filtration, drainage, separation, reinforcement, and stabilization of roadways. They have an endless range of type, size, style, and thickness to choose from based on site specific needs. As can be seen in the schematic diagram of Figure 1, geosynthetics can be used in several locations within the roadway. The location which we will address in this white paper is highlighted in yellow, where they are placed between the soil subgrade and the stone aggregate base.

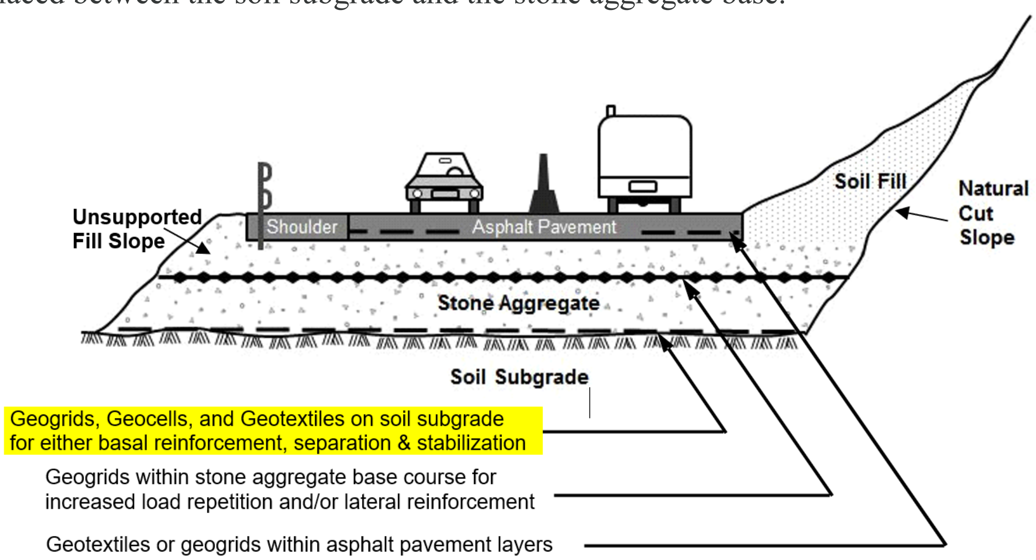


Figure 1, Schematic diagram of roadway cross section showing areas of geosynthetic use

Roads represent a tremendous opportunity for geosynthetics. This most widely used application generally focuses on soft soil subgrades. A stone base course (of varying types and thicknesses) is placed on top of the geosynthetic material. This application has triggered high-volume use and acceptance of geosynthetics by many state departments of Transportation (DOT's) since the 1970s, ASSHTO (1993).

The geosynthetic has tensile modulus mobilized via deformation of the soil subgrade. The yielding of the soil subgrade is the mechanism allowing for mobilization of its tensile properties of the geosynthetic. This deformation of the soil subgrade is critical and typically based on the ASTM D1883 California Bearing Ratio (CBR) of the soil subgrade. Typical threshold CBR values are given in Table 1 for both unsoaked and soaked conditions.

Table 1 - Recommended Soil Subgrade CBR Values to Distinguish Different Geosynthetic Functions in Roadway Applications, after Koerner (2012)

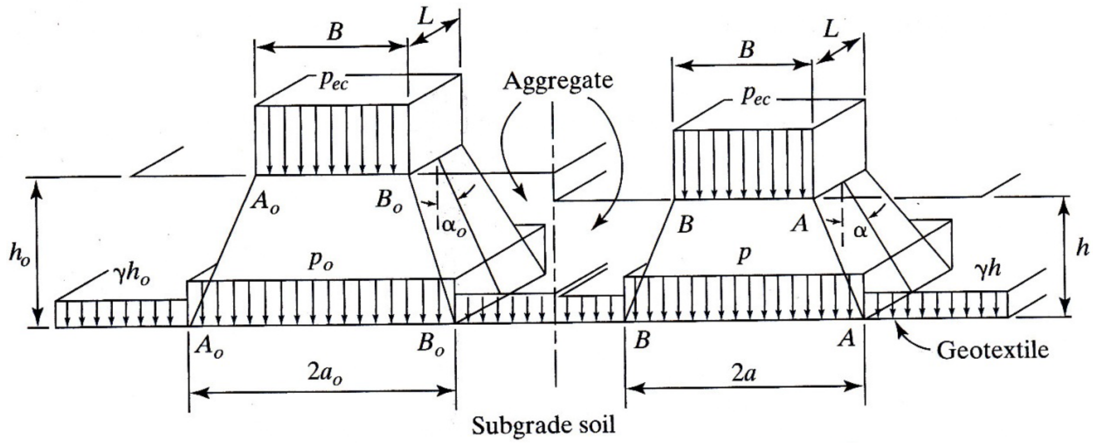
Geosynthetic Function(s)	CBR - Value	
	Unsoaked	Soaked
Separation (Firm)	≥ 8	≥ 3
Stabilization*	8-3	3-1
Reinforcement and Separation (Soft)	≤ 3	≤ 1

*a frequently used but poorly defined transition term that always includes separation, some unknown amount of reinforcement, and often filtration as well.

Irrespective of whether the road surface is unpaved or paved, the stone base will be placed directly on the soil subgrade. Depending on the site-specific circumstances, most notably the soil's stiffness and moisture content, a gradual movement of soil subgrade up into the gravel and the associated downward movement of the gravel into the soil subgrade occurs. Arresting this movement or migration is necessary to take advantage of the full-depth effect of the stone base course. Certainly, a geosynthetic placed at this interface to preserve the integrity of the boundary is a worthwhile goal.

All of the major geosynthetic manufacturers have a road design method for use with their particular geosynthetics. They usually compare CBR (or other soil strength values) versus stone base thickness savings with inclusion of the geosynthetic. In many cases, the geosynthetic provides greater savings in stone aggregate as the soil subgrade becomes weaker. Most manufacturers have a range of products available. The heavier and stronger the geosynthetics the greater stone savings are associated with it. Generally, the material's tensile modulus is used as the basis for design.

The design on which geosynthetics used in roadways is based follows the Giroud and Noiray (1981) geometric model shown in Figure 2. For a tire wheel load of pressure p_{ec} on a $B \times L$ area, which dissipates through h_o thickness of stone base without a geosynthetic and h thickness of stone base with the geosynthetic inclusion.



(a) Case without geosynthetic (b) Case with geosynthetic

Figure 2. Load distribution by aggregate layer (after Giroud and Noiray (1981)).

This geometry results in stress on the soil subgrade of p_o (without geotextile) and p (with geotextile) as follows:

$$p_o = \frac{P}{2(B + 2h_o \tan \alpha_o)(L + 2h_o \tan \alpha_o)} + \gamma h_o \tag{1}$$

$$p = \frac{P}{2(B + 2h \tan \alpha)(L + 2h \tan \alpha)} + \gamma h \tag{2}$$

where

P = axle load, and

γ = unit weight of the stone aggregate base.

Once you know the pressure exerted by the axle load through the aggregate and into the soil subgrade, shallow-foundation theory of geotechnical engineering can now be applied. Assumed throughout the analysis is that the soil is functioning in an undrained condition and thus its shear strength is represented completely by the cohesion (i.e., $\tau = c$). Thus, the tacit assumption is that the soil subgrade consists of saturated fine-grained silt and clay soils. Critical in this design method is the assumption that without the geosynthetic, the maximum pressure that can be maintained corresponds to the elastic limit of the soil.

It is important to recognize that in the previous design process the savings in stone aggregate can be directly compared to the cost of the geosynthetic and thus a benefit cost ratio can be calculated. It should be noted that the Giroud and Noiray (1981) procedure (above) has been revised and upgraded for specific geosynthetics by Giroud and Han (2004, 2012).

Geosynthetics are often placed directly on the soil subgrade to separate it from the overlying stone base aggregate. This twofold detrimental phenomena of loss of gravel and intrusion of soil subgrade ruins roadway foundations. According to AASHTO, the number one transportation infrastructure asset in most jurisdictions is the unbound aggregate within the roadway's foundation support layer. Demise of the roadway is the result of loss of the foundation layer which is a roadway structural failure. Jorenby and Hicks (2015) research showed that the foundation layer's strength dropped 50% when contaminated with 13% fines. Furthermore, they showed that there was a two order of magnitude drainage loss with only 8% fines introduction into the foundation layer. In all cases, geosynthetics preserve and strengthen the supporting layers of the roadway, creating a stabilized permanent road foundation.

The successful use of a geosynthetic in roadway applications requires proper installation. The four basic steps of proper installation include: subgrade preparation, geosynthetic placement, aggregate placement, and aggregate compaction. These steps are each described below in detail as outlined in works by Barenberg and Bender (1978), Carroll, Walls and Haas (1987) and IVG (2012) published in Germany.

SUBGRADE PREPARATION: Initially, the site should be cleared of tree stumps, large stones, and other sharp objects that could damage the geosynthetic. This step should be performed regardless of subgrade strength. Roadway subgrade preparation typically involves removal of all vegetation, roots, and topsoil.

GEOSYNTHETIC PLACEMENT: Two people can easily place a roll of geosynthetic on prepared subgrade. The geosynthetic should be rolled out onto the subgrade beginning at a point that allows easy access for construction equipment yet is consistent with the layout plan. Adjacent geosynthetic edges can be overlapped or sewn together based on the manufacturers recommendations. This decision is incumbent on whether the sewn seam must transfer significant tensile reinforcement to and from adjacent panels. Such is the case when the subgrade is very soft.

AGGREGATE PLACEMENT: Aggregate is placed and spread on the geosynthetic using conventional construction practices and equipment. Cover gravel can be shoveled or pins inserted to anchor the leading edge of the material in place, to prevent it from lifting during installation of the first aggregate lift. The aggregate is typically back-dumped onto the geosynthetic, as the truck should not drive directly on the deployed geosynthetic. The aggregate is then spread over the geosynthetic and tracked by a lightweight ground pressure bulldozer. Low ground pressure models (less than 7 psi (50 kPa)) are recommended for work on soft subgrades. Lift thickness should not be less than 6 inches (150 mm). That said, the first lift should be as thick as necessary to limit rutting to less than 4 inches (100 mm). During spreading, the bulldozer should blade up into the load by slightly tilting the dozer blade upward to prevent stressing the geosynthetic. The blade of the dozer should never be crowded downward while spreading aggregate over the geosynthetic. This procedure should be followed for each load until the geosynthetic is completely covered. The dozer operator can determine which areas may need additional aggregate for good stability by observing aggregate layer rutting. On very soft subgrades, care should be taken during aggregate placement to ensure that the geosynthetic has not moved up, out of position nor the subgrade overstressed. Over some very soft soil conditions, "mud waves" may appear during or after aggregate placement. Mud waves result from overstressing the subgrade during fill placement, causing the subsurface soil to move away and up from the loaded area. Mud waves are normally not a problem if they do not heave above the surface of the aggregate base.

Sudden stops or turns by equipment operating over the geosynthetic should be avoided. Under typical conditions, vehicles should not be allowed to drive directly on any geosynthetic. If space constraints make this impractical, the possible damage from direct vehicle contact should be evaluated on a test section prior to commencing construction. If the geosynthetic is damaged, such that it cannot fulfill project requirements (i.e., no longer meets or exceeds the project specification), the geosynthetic should be replaced by a higher survivability geosynthetic. If the geosynthetic is damaged during installation, the damaged section should be exposed and repaired.

AGGREGATE COMPACTION: The aggregate must be compacted as required by the project specifications. The aggregate should be initially compacted by "walking" the tracked bulldozer back and forth over the aggregate while waiting for the next aggregate load. Construction traffic will then compact the aggregate until reasonable stability is obtained. Final compaction is achieved by rolling the area with a vibratory compactor, first without vibration for several passes and then with full vibration. Any weak areas found during final compaction usually indicate inadequate aggregate thickness in those locations. Do not grade ruts down; simply fill with additional aggregate and compact to the specified density. This also applies to any future rut maintenance that might be required.

Geosynthetics can be used in most weather and temperature conditions. Adequate planning and preparation for each installation step will speed construction and ensure good performance. For more details on the design and performance of geosynthetic used in pavements, the following references are recommended: Al Qadi, et. Al. (2008), Hoppe, et. Al. (2019), Koerner (2000), and Zornberg and Gupta (2010). Table 2 recaps the pros and cons of using geosynthetic in roadways as stabilization.

Table 2 – Pros and Cons of Geosynthetic Stabilization

Advantages (Pros)	**Disadvantages** (Cons)
Compatible with all soil types Easily accessible and available Technique tried and true Often cost effective Can be installed in any weather	Susceptible to installation damage Requires QA/QC High upfront cost

CHEMICAL STABILIZATION

There are several types of chemical techniques to stabilize problematic subgrade soils for roadways. In general, they are broken down into the following four types: chlorides, polymers, pozzolanic (lime and or cement) and fly ash which will be discussed at length in this section of the white paper. It should be mentioned that several of these techniques may be used in concert with one another. Doing so may have synergistic affects toward the end of improving the overall strength of the soil subgrade. Chemical stabilization can be beneficial to a roadway in several ways. It generally strengthens the soil and keeps it intact over time, Makusa and Davis (2011).

Before we start discussing chemical stabilization types we need to ask, "which type of soil is best suited for each chemical stabilization type?" This question is asked knowing that the quality of the chemical stabilization will also depend on several variables, including but not limited to, the available effective surface area of the chemical, pulverization of the soil, degree and quality of mixing, degree of compaction, adequate moisture, and proper curing.

The first part of deciding what method of soil stabilization will be best for your application is understanding what type of soil you are dealing with. There are four main types of soil: sand, silt, clay and loam (mixture of sand, silt, and/or clay sometimes called till). Each soil has different characteristics and needs when being stabilized. Two of the biggest factors to consider when working on soil stabilization is the soil's plasticity and organic content. In all cases, lab tests are required to categorize the soil in question and determine the efficacy of the candidate chemical stabilization technique. In addition, if subgrade soils change on the project, multiple chemical stabilization techniques may be required to accommodate such variations. Much of the following information regarding chemical stabilization was obtained from the Puppala (2003) and Egloffstein (2009) references.

Chlorides

Chlorides are some of the most popular forms of chemical stabilization for subgrade soils. Magnesium Chloride and Calcium Chloride are most often used. Essentially, chlorides are salts and chloride soil stabilization works by trapping soil moisture in place. While the soil is very hard and strong when dry, the soil immediately loosens when water is applied. To maintain a hard and strong surface, chlorides will need to be reapplied to the surface after rain or snow events.

The decision between which salt to use is usually based on the availability. Both Magnesium and Calcium chloride come in a liquid or solid forms. For this application, you will need to use a water truck that can heavily dilute the salts prior to application onto the soil subgrade by spraying.

Chlorides can be applied in one of two ways. The most effective method is to apply the chlorides to the top 3 to 6 inches (75 to 150 mm) of the soil, mix it in, and then follow up with compaction. Another less effective method of application is to simply spray the top of the soil with the chloride. This method is quicker but does not produce the same results as when the chloride is mixed into the soil. Both techniques should result in a very hard surface, emitting little to no dust into the atmosphere.

Chloride soil stabilization has been used for decades and is still popular. Chloride stabilization is well known, tried and true, and often cost-effective. In addition to the fact that chloride stabilization requires reapplication after the surface becomes wet, a major downside is the environmental concerns. The amount of chloride introduced into the environment is extreme, which can have detrimental effects on plants and animals.

Table 3 – Pros and Cons of Chloride Chemical Stabilization

Advantages (Pros)	**Disadvantages** (Cons)
Compatible with all soil types Easily accessible Been around for decades Often Cost Effective	Not water resilient Needs constant reapplication Environmental concerns Salt is migratory, irritant, and corrosive

Polymers

Polymer soil stabilization is the method of adding synthetic or biopolymers to the soil to improve the overall physical and mechanical properties of the in-situ soil. Alumino-silicate based polymers are the most used synthetic polymer in geotechnical applications. Common biopolymers used in soil stabilization include cellulose, starch, chitosan, xanthan, curdlan, and beta-glucan. In both cases the polymer is gluing the soil particles together. Polymers are traditionally sold in liquid form and then diluted on site when the subgrade is prepared and ready for application. Again, it is better to mix the polymer into the soil subgrade rather than merely spraying it on the surface without mixing.

Unfortunately, not all synthetic polymers are environmentally friendly. Some pose both health and environmental concerns. In contrast, biopolymers tend to have less of a health and environmental risk but seem to be less effective on a per volume basis.

The lifespan and characteristics of polymers vary depending on the manufacture. However, traditional applications last 1 to 3 years with little maintenance. Most polymer applications create a low permeable surface for the life of the application. Polymer service life is greatly affected by the environment in which they are installed and exposed.

Table 4 – Pros and Cons of Polymer Stabilization

Advantages (Pros)	**Disadvantages** (Cons)
Compatible with all soil types Easily to apply Creates low permeability layer	Environmental concerns Short lifespan Requires large dose Mixing messy and residual disposal difficult

Pozzolanic

Lime and or cement soil stabilization are one of the most popular means of chemical stabilization techniques in the United States. This stabilization method is done by mixing lime or cement into the soil to increase its strength and resiliency. The percentage of lime or cement that gets mixed into the soil varies depending on the soil subgrade's characteristics. Often, the higher the plasticity, the more lime or cement will be needed. Commonly, lime and cement are grouped together since they have very similar properties and both function as a binder.

Lime occurs naturally, while Portland cement is manmade. Treating the soil with cement or lime is one of the most popular means of soil stabilization; this technique is most prevalent in paved roads. It is usually cost prohibitive to treat unpaved roads with cement. Geographical regions often dictate whether you use lime or cement to stabilize soil. Some regions have lime readily accessible, while others do not, making cement more cost-effective.

Lime or cement soil stabilization works by binding all the soil's particles together, which results in an increase of the soil's strength. Since this process calls for adding cement or lime to the soil, practically all soil types are compatible with this type of soil stabilization. Even though most soil types are compatible with lime and cement soil stabilization, the soil must be analyzed to ensure that the proper additive amount is being used. If too little of the additive is used, then the soil will not reach the desired strength. If too much lime or cement is used, then the soil could shrink and be susceptible to cracking.

One of the major benefits of lime or cement is the ability to use it on soil that is above optimum moisture. When using powdered lime or cement in conjunction with a moist soil, the soil will dry quickly, allowing you to compact the soil properly. While the powder method is desirable for applications with very wet soil, it does unfortunately have health concerns due to the powder being so fine that it can become airborne. This poses a safety risk to construction workers.

During the application of lime or cement to the soil, you will need to mix it thoroughly. It is important to keep the soil's moisture content as close to optimum as possible. Upon mixing the soil with lime or cement, the next step is to compact the soil per the project specifications, (i.e., 95% Standard Proctor.) Once the soil has been compacted, the soil subgrade will continue to cure for approximately 28 days.

Table 5 – Pros and Cons of Pozzolanic Stabilization

Advantages (Pros)	**Disadvantages** (Cons)
Permanent and long lasting Tried and true Compatible with most soil types Can achieve very high strengths Decreases soil's moisture content	Expensive Potential health concerns Only for paved roads Requires extensive soil tested pretreatment

FLY ASH

Fly ash soil stabilization is similar to lime or cement stabilization in principle but differs based on the product being used. Fly ash is a byproduct of coal which comes from coal-fired power plants. Traditionally, this byproduct was stored in landfills or ponds. Fly ash can be used as a bonding agent to increase the soil's strength. Just as cement and lime stabilization are primarily used for soil stabilization as the subbase to paved roads, fly ash's primary use is to treat the subbase of paved roads.

There are two main types of fly ash, Class F and Class C. Class C fly ash is pozzolanic. Once the fly ash is wet, it will harden because of its cementitious nature. Class F Fly ash is not pozzolanic, therefore it will need gypsum or calcium hydroxide to activate it. The type and characteristic of fly ash is dependent upon which type of coal from which the fly ash was derived.

Typically, fly ash reduces stabilization costs when compared to lime or cement because fly ash is essentially a waste product. Because fly ash is a dry additive, one large benefit of fly ash is that it can be used in soils above optimum moisture. The powder will absorb the moisture and lower the soil's moisture content, which is sometime very advantageous. Being a dry additive is also a disadvantage in the fact that the additive can be labor intensive to apply as well as a health concern to workers, since the powder possesses an inhalation risk. The cure time is another factor to consider when using fly ash. It sometime can be more that 28 days and may have an antagonistic affect on cement or lime stabilization.

Table 6 – Pros and Cons of Fly Ash Stabilization

Advantages (Pros)	**Disadvantages** (Cons)
Permanent and long lasting Compatible with most soil types Various types for different applications More cost effective than pozzolans Usable with high moisture content soils	Potential health and environmental concerns Availability Fly ash disposal is regulated Requires extensive soil tested pretreatment

With so many chemical stabilization categories and subcategories, choosing the right method can be challenging. It is beneficial to know about the different methods and various products that are available. To choose the best method for your project, consider the following:

- The type of soil
- Project type (paved or unpaved)
- Longevity of the project
- Budget
- Environmental concerns
- Health concerns for the installation risks

Chemical stabilization has been used successfully for decades. There are often regional contractors with excellent knowledge of what method works best with specific local soils. In such cases, no learning curve is required, and the project can be bid very competitively.

SUMMARY

This retrospective white paper on chemical versus geosynthetic stabilization used in roadway applications covers the topic in a concise manner but is referenced heavily. White paper #45 counterpoints the use of geosynthetics versus four very discrete chemical stabilization techniques. The method of point-counterpoint was highlighted in the text of the report in tables 2-6 with advantages versus disadvantages for each technique. This white paper focuses on specific design and performances-based criteria from field experiences which are summarized below in Table 7.

Table 7, Technical Equivalency Evaluation Based on Criteria to Address When Considering Stabilization of Roadway Subgrades

CRITERIA	Geosynthetic Superior	Chemical Stabilization Superior	Equivalency - Depends on Site or Product
Hydraulic			
Filtration	√		
Drainage	√		
Seepage	√		
Physical Mechanical			
Settlement			√
Stability			√
Bearing Capacity			√
Endurance			
Cracking	√		
Shink/Swell	√		
Freeze-Thaw	√		
Construction			
Puncture Resistance		√	
Subgrade Condition	√		
Ease of Placement	√		
Speed of Construction	√		
Availability of Materials	√		
Requirements for Water	√		
Sustainability	√		
Weather Constraints	√		
QA/QC Insurance	√		
Health Concerns	√		
Environmental Risks	√		

In short, it is believed that geosynthetics can enhance the performance of paved and unpaved roadways, parking lots, airports, loading docks, and storage areas through stabilization of the soil subgrade more effectively and at a better benefit cost than chemical stabilization methods. Geosynthetics help minimize rutting and improve performance of the roadway by combining several functions simultaneously. The geosynthetic serves as a permeable separation layer, preventing the aggregate and subgrade soils from intermixing while allowing the passage of water. They can be installed during most weather conditions and do not crack or shrink. It is our belief that geosynthetics are often superior (more versatile, longer lasting, greater benefit/cost, more sustainable (Miner and Davis (2011)), easier to construct etc.) options when compared to chemical stabilization of roadway subgrades.

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