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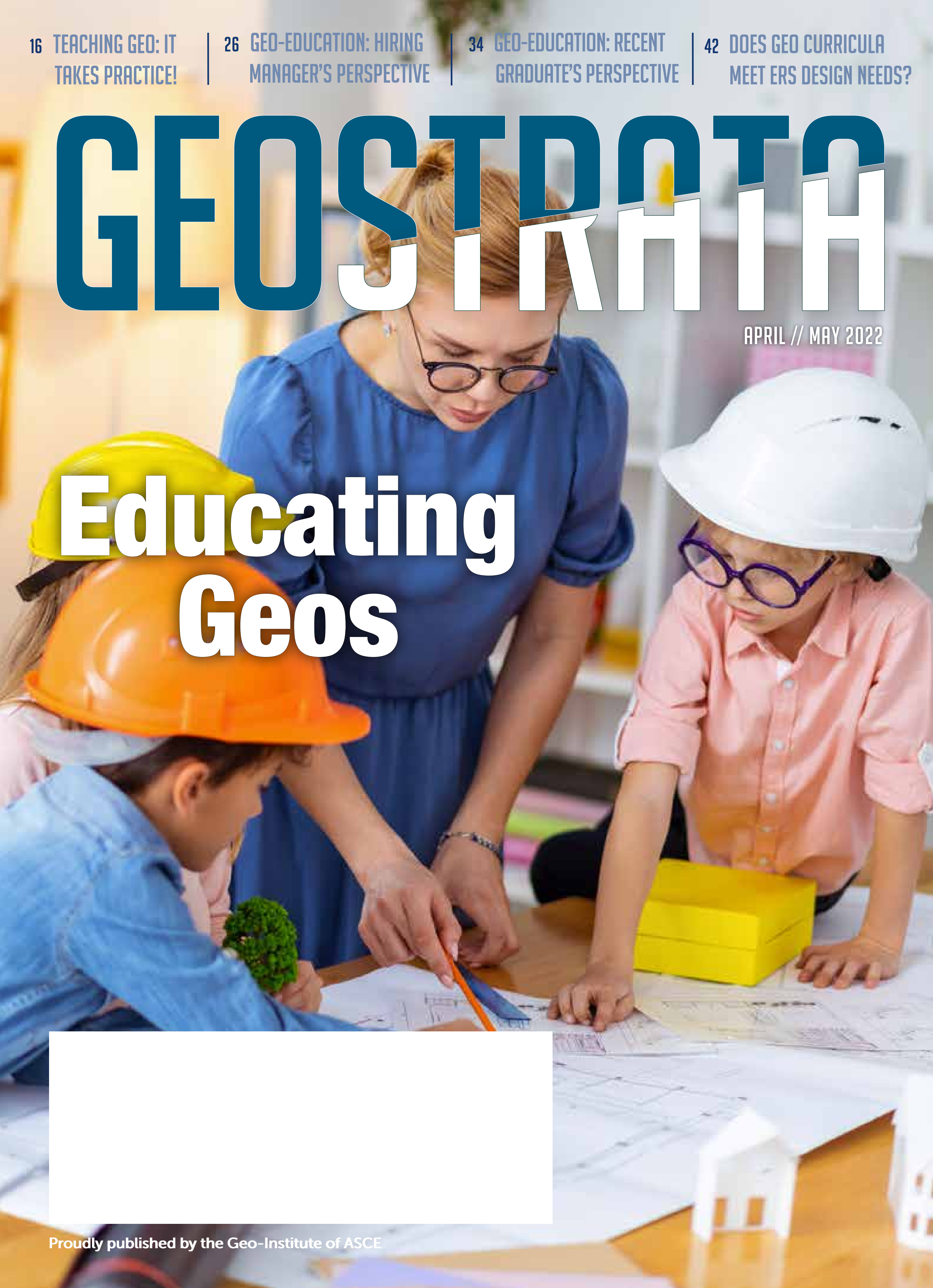

Educating Geos

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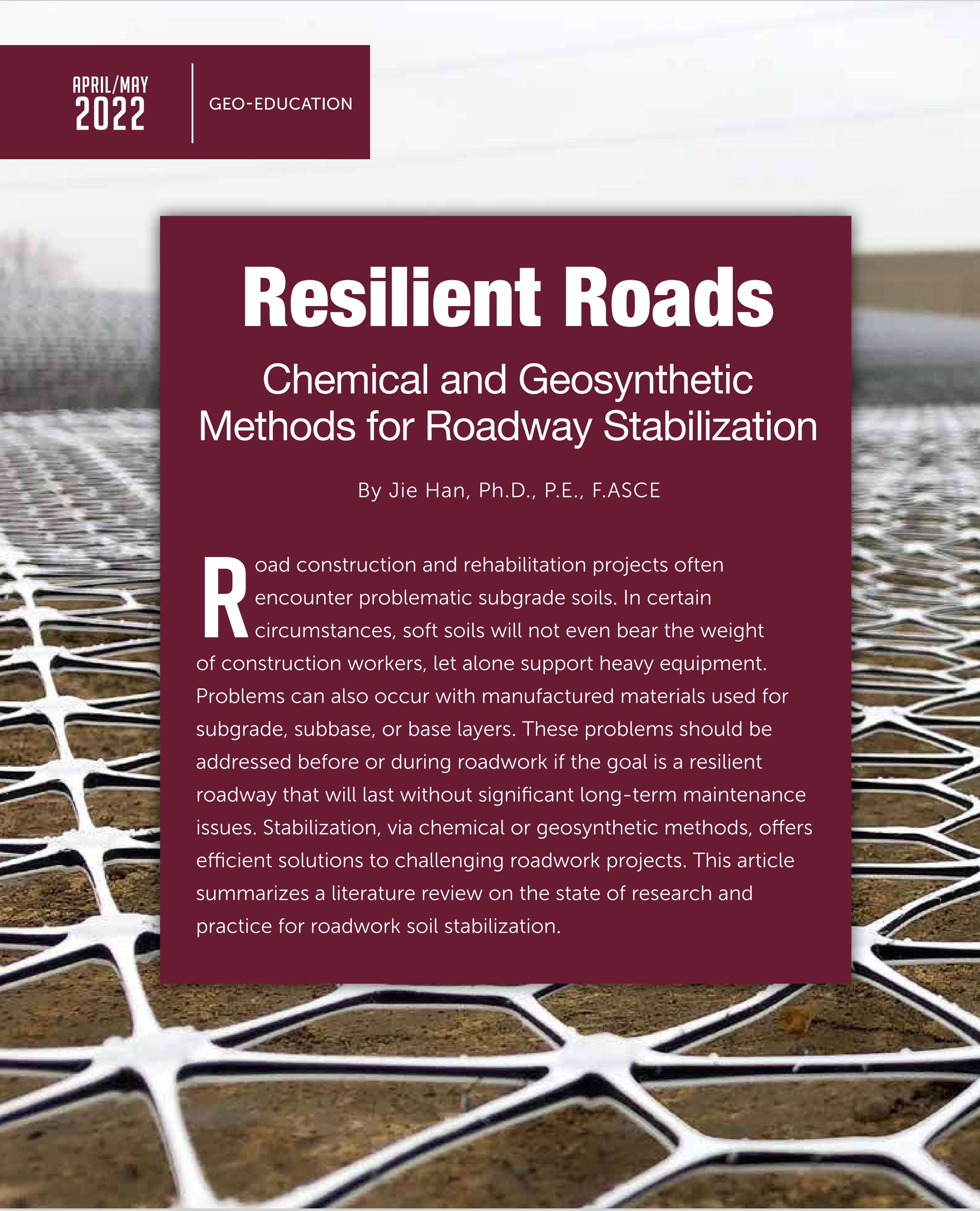

Resilient Roads

Chemical and Geosynthetic Methods for Roadway Stabilization

By Jie Han, Ph.D., P.E., F.ASCE

Road construction and rehabilitation projects often encounter problematic subgrade soils. In certain circumstances, soft soils will not even bear the weight of construction workers, let alone support heavy equipment. Problems can also occur with manufactured materials used for subgrade, subbase, or base layers. These problems should be addressed before or during roadwork if the goal is a resilient roadway that will last without significant long-term maintenance issues. Stabilization, via chemical or geosynthetic methods, offers efficient solutions to challenging roadwork projects. This article summarizes a literature review on the state of research and practice for roadwork soil stabilization.


Roadway stabilization.

Figure 1. Lime application and mixing during roadway subgrade stabilization.

Problems at Every Layer

Every layer of road construction, from subgrade to subbase to base, presents its own challenges, largely due to the materials used to create the layers. Natural or native soils, particularly soft clay and silt, loose sand, organic soil (including peat), expansive soil, collapsible soil (e.g., loess), and frozen soil, can be problematic to roadway construction — and of course, natural soils make up most of the subgrade in roads. Depending on the type of natural soil, common problems include low shear strength, high compressibility, large creep deformation, swell and shrinkage, hydraulic collapse, freeze and thaw, low permeability, liquefaction, fine migration, and erosion. These problems can crop up during construction and the lifespan of the roadway.

Subgrade Soils

Many of the problems that can occur with natural soils are related to water. Rainfall and groundwater-table rise saturate soil, making it unstable, lacking the strength to support a roadway. You can imagine what this means for heavy equipment on a road construction site, or for traffic on a busy roadway. Expansive soils, as the name suggests, can shrink or swell depending on the level of moisture, causing ground heave and significant cracks. Loess can experience "hydraulic collapse" (i.e., sudden settlement) when exposed to water, causing damage to the roadway. Cycles of seasonal freezing and thawing may cause durability problems, such as ground heave during winter and soil softening during spring. Natural soils may also be eroded due to running water from road surfaces when the road slopes, or ejection of water when traffic loading induces excess water pressure at the joints of or cracks in concrete pavements. With all of these challenges, natural soils frequently need to be stabilized to provide effective roadway support.

Subbase and Base Materials

Sands and aggregates (e.g., crushed stone aggregate) are two granular materials commonly used to form roadway subbases and bases. They tend to settle and move laterally under traffic loading, resulting in rutting and fatigue cracking of asphalt pavements. Granular bases with excessive fines can have freeze-thaw problems in cold regions.

Processed or manufactured geomaterials are produced from other materials, such as recycled and lightweight aggregate, and are also used as granular materials for the subbase and base layers in roads instead of sands and crushed stone aggregates. In recent years, recycled aggregates like asphalt-reclaimed pavement and recycled concrete have been increasingly used as base materials. These aggregates, however, can be sensitive to moisture changes and susceptible to freeze-thaw cycles. Variability is also a problem with recycled materials because they have been gathered from different pavements and contain different mixtures from past construction. They may contain particles with low durability that easily degrade under repetitive traffic loading or when subjected to freeze-thaw cycles. Stabilization is frequently needed to improve the performance and durability of these geomaterials.

Figure 2. **Regrading and compaction of lime-treated subgrade soil.**

Solutions for Stabilization and More Resilient Roadways

The goal of stabilization is to improve the short-term and/or long-term properties and performance of the materials in different layers of the roadway. Their short-term properties — strength and stiffness, for example — are often required for construction platforms and haul roads, ensuring vehicles get in and out quickly and safely. Their long-term performance, however, involves long-lasting strength, high durability, and low sensitivity to water and temperature changes, which ensures resilient roadways. Among many methods for stabilizing natural soils and geomaterials for roadways, chemical and geosynthetic stabilization are the most commonly used.

Chemical Stabilization

Typical chemical stabilization approaches for soil, such as the application of lime or Portland cement, have been used on construction sites and beneath roads because they make the soil stronger, stiffer, and thus able to bear higher loads. Chemical stabilization usually involves improving soil properties through chemical gel formation and bonding among soil particles, as well as reduction in the soil's susceptibility when interacting with water.

For example, the calcium in lime changes the minerals in the soil, producing stable calcium silicate and calcium aluminate hydrates. As a result, lime can reduce the swelling potential, liquid limit, and plasticity index of soil. It can also increase the soil's shrinkage limit and strength, and improve its workability and compactibility. Lime can strengthen the soil to the point where it can hold up for decades, assuming that enough lime is added and the pH of the soil continues to be at a high level during the in-service life of the stabilized soil.

Depending on the composition of cement and the mineralogy of the soil to be stabilized, a chemical reaction can occur between calcium hydroxide in cement and soluble silica and alumina present in clay, leading to stabilized particle structures through the formation of cement-clay bonds and the improvement of physical and mechanical properties.

Some benefits of chemical stabilization are:

- Reduced shrink/swell of expansive soils
- Increased strength and stiffness to provide short- and long-term support for pavement structures
- Reduced moisture susceptibility and migration
- Utilization of locally available materials or salvaged materials on pavement rehabilitation projects
- Reduced need for thick pavement layers
- The ability to provide a working platform for construction of subsequent layers by drying out wet areas and/or temporarily increasing strength properties

Most chemical stabilization leads to improved soil properties, but this improvement sometimes may be short-lived. Some studies have shown that premature failures of chemically stabilized subgrade happened in projects in the U.S. for one of two reasons: either the chemical additive lost its effectiveness over time, or it was ineffective for that specific soil. Lime, for example, works best for clay soils with a plasticity index greater than 15 percent, but it does not work well with silts and granular materials because those soils have limited aluminates and silicates with which the lime can react.

Executing the chemical stabilization process involves mixing natural

Figure 3. Roadway construction over geotextile.

soil with additives (Figure 1), followed by compaction. For lime stabilization, the lime must be hydrated before its application, and the lime-treated soil must be given sufficient time (from one to seven days) for the chemical reactions to change the material properties, or for the soil to "mellow." After the mellowing period, the soil should be remixed, graded, and compacted in place (Figure 2).

The local climate conditions must also be taken into account when using lime. Freeze-thaw cycles can cause lime-treated soil to lose strength. An ambient air temperature of 40°F or higher is required for the chemical reactions in lime stabilization, and lime cannot be applied to frozen soil. Also, dry lime should not be applied in the rain because it gets wet quickly and becomes difficult to spread uniformly, resulting in alkaline runoff if not properly protected.

Chemical stabilization may have short-term construction impacts on the nearby environment; for example, it can damage vegetation adjacent to a treated roadway. Best practices should be employed during construction to prevent the surrounding environment and water bodies from being exposed to large quantities of lime dust. The same applies to protecting workers from the dangers of lime dust. The U.S. Occupational Health and Safety Administration lists a variety of hazardous effects of working with lime, including the fact that dust from lime can severely irritate the skin, lungs, eyes, and mouth, requiring workers to take safety precautions.

Soils with sulfate contents greater than 0.3 percent can pose challenges for chemical stabilization. When calcium-based cement or lime additives are used to treat sulfate-rich natural soils, the calcium from the additives reacts with the sulfates in these soils and the free reactive alumina from the soils and/or additives to form a crystalline mineral known as ettringite. Ettringite minerals can undergo crystal growth and volume change due to hydration, leading to significant heaving. As a result, many state DOTs require sulfate measurements in soils as routine geotechnical site characterization for infrastructure projects. Because sulfates are rarely

Figure 4. Soil placement and compaction over geogrid.

distributed uniformly throughout a construction site, locating sulfate concentrations in isolated seams and pockets in the field is difficult, and the risk of problems is hard to avoid.

Chemically treated bases can provide relatively good support for pavements, if properly designed and installed, because they typically have high strength and stiffness. However, they may suffer from shrinkage cracking or durability issues when proper construction practices (e.g., laboratory mix design and microcracking during construction) are not implemented or followed.

Geosynthetic Stabilization

A geosynthetic is a synthetic product used to solve civil and geotechnical engineering problems in the ground. Geosynthetics, including geogrid, geotextile, and geocell, are successfully used to mitigate problems in road applications, mainly through physical, mechanical, and hydraulic stabilization. For example, a geotextile (Figure 3) can serve as a separator to keep subgrade and base materials apart so they maintain their individual properties (i.e., physical stabilization). For hydraulic stabilization, geosynthetics (also Figure 3) can help remove water in road layers so that the properties of subgrades and bases can be maintained or improved.

In mechanical stabilization, geosynthetics, such as geogrid, provide lateral restraint to granular bases so that their mechanical properties can be maintained or improved and their deformations under loading can be minimized. Lateral restraint is considered the most important mechanism for mechanical stabilization, so that the base stiffness is maintained or improved, and rutting of unpaved roads and rutting and fatigue failure of asphalt pavements are minimized.

Geogrids provide highly effective lateral restraint to granular bases through particle-aperture interlocking (Figure 4). Geotextiles provide lateral restraint through interface friction between a granular base and a geotextile surface, and geocells provide lateral restraint through closed confinement of infill material. Theoretically, geocells may provide the best lateral restraint to infill material, but their inclusion makes compaction more difficult, especially when tall geocells are used. In addition, geocells are typically more expensive than geogrids and geotextiles. Geosynthetics can stabilize all types of materials in subgrade and bases courses of the roadway.

Some benefits of geosynthetic stabilization include:

- Increased road resiliency and prolonged roadway service life
- The ability to provide working platforms over weak subgrade
- Minimization or prevention of intermixing of subgrade and base
- Reduced rutting and fatigue cracking by restraining movements of aggregate base, subbase, and subgrade (particularly with geogrids through particle-aperture interlocking)
- Minimized swell and shrinkage-induced cracking by expansive soils
- Mitigated freeze-thaw problems of base with fines
- Reduced need for thick pavement layers
- Increased use of recycled materials, such as recycled aggregates, reclaimed asphalt pavement, or recycled concrete

Placement of geosynthetics for road construction is relatively easy and quick. However, different geosynthetic products may require different special treatments. For example, when a geotextile is placed over a weak subgrade, its corners and edges should be anchored first by a pile of soil to restrain the geotextile as it settles under an earthen surcharge or load. Installation of a geocell panel also requires anchorage at its edge by stakes or steel rods. Stiff geogrid, because of its ability to bend while remaining stiff, can be rolled out directly with placement of fill without any anchorage.

When it comes to performance, geosynthetics provide short-term and long-term stabilization for roadwork, and can also be used to stabilize weak subgrade for construction platforms and/or haul roads on a construction site.

Before chemical and geosynthetic stabilization, it was common practice that the contractor would excavate and remove topsoil, deleterious debris, and unsuitable material from a site to reach the design subgrade elevation. For very soft soils, use of geosynthetics can take advantage of the strength provided by root mats that are left in place.

What's the Right Approach?

Chemical and geosynthetic stabilization methods can be used to improve the performance of roadways and the foundation that pavement structures bear on. Selecting a method for such improvement depends on many factors. Additional details, discussion of best practices, and case history examples for these methods can be found at *geoinstitute.org/geotechtools*.

Table 1 provides a side-by-side comparison of chemical versus geosynthetic stabilization for several factors. For instance, the construction process is fast with geosynthetics, while a chemical approach like lime stabilization is time-consuming and requires multiple steps (including laboratory testing to verify the effectiveness of a chemical binder for a given soil and determine the percent of the binder), lengthy construction time, possible weather delays, and curing time after placement. Certain soils and climates are not appropriate for a chemical stabilization approach, whereas geosynthetics have no such restrictions. Chemical stabilization can improve subgrade soil properties, while geosynthetic stabilization can improve subgrade soil behavior. Lime stabilization is generally effective in mitigating swell and shrinkage of expansive soil. Some studies have shown that geosynthetic stabilization is more effective than lime stabilization when swell and shrinkage of expansive soil are induced by road-edge moisture changes or differential movement. Plus, geosynthetics pose no environmental risk, a crucial consideration today. However, contractors and pavement engineers may be more aware of or have more experience with the use of chemical stabilization than with geosynthetic stabilization.

Chemical stabilization is limited to particular site conditions and project objectives, while geosynthetics can be used in all site conditions and to address any type of project objective, from pavement foundation support, drainage, constructability, and traffic support to long-term performance. Costs for both stabilization methods are site-specific, product-specific, and depend on different factors. Cost analysis, especially life cycle cost analysis, should be conducted to select an appropriate method in terms of performance and economy. Stabilization is essential because the damage from heaving, cracking, settlement, and other problems can cause considerable damage to roadways, requiring costly and time-consuming repairs or even replacement, not to mention road closures and related traffic delays.

In summary, both chemical and geosynthetic stabilization methods can improve performance, minimize problems, prolong life, and reduce cost of roadways so that they're more resilient and sustainable. To achieve the goal for resilient roads, these methods should be properly selected, designed, and implemented. GS

▸ **JIE HAN, Ph.D., P.E., F.ASCE**, is the Glenn L. Parker Professor of Geotechnical Engineering in the Civil, Environmental, and Architectural Engineering Department at the University of Kansas, in Lawrence, Kan., and treasurer of the G-I Board of Governors. His research has focused on geosynthetics, ground improvement, pile foundations, buried structures, and roadways. He can be contacted at *jiehan@ku.edu*.

	Chemical	Geosynthetic
Mechanisms	Alter chemical compositions and soil structures to improve soil properties	Provide lateral restraint, separation, filtration, and/or drainage to maintain or improve soil properties and behavior
Soil types	Applicable to most types of soils, except for organic soils and sulfate-rich soils	Applicable to all soil types, but more beneficial with weak and problematic soils
Benefits	Increase bearing capacity and stiffness, reduce rutting, mitigate moisture-related distresses, and prolong road life	Increase bearing capacity and stiffness, reduce rutting and cracking, mitigate moisture-related distresses, and prolong road life
Design	Mix design required based on testing and validation for given soil types and applications	In-ground full-scale testing and validation testing needed on specific products/ applications
Construction method	Blend chemicals into in-place or fill soils	Apply layer of geosynthetic in conjunction with granular fill or on-site soils
Equipment required	Specialized equipment needed to place and mix chemicals	Standard equipment or manual effort
Construction process	Mixing, grading, compaction, and mellowing	Move product into place, unroll and overlap (anchorage may be needed for geotextile and geocell)
Climate	Temperature > 40° to 50°F and no rain	No restriction
Post-construction traffic	Curing time required	Immediate after placement
Cause for road distresses	May induce shrinkage cracks and cause reflective cracks in asphalt pavements	None
Durability	Proper design and construction required to mitigate or consider freeze-thaw, wet-dry cycle, and shrinkage cracking effects on long-term performance	Proper design and product required to address clogging concerns for long-term drainage performance
Tolerable to differential movement	No	Yes
Recycling	Difficult to recycle treated granular base material	Relatively easy to recycle granular base material, but not geosynthetic
Environmental	Possible leaching	No environmental concern
Safety	Safety protection required during construction	Gloves and eye protection recommended
Cost	Site- and product-specific	Site- and product-specific
User awareness and experience	More	Less

Table 1. **Comparison of chemical versus geosynthetic stabilization.**