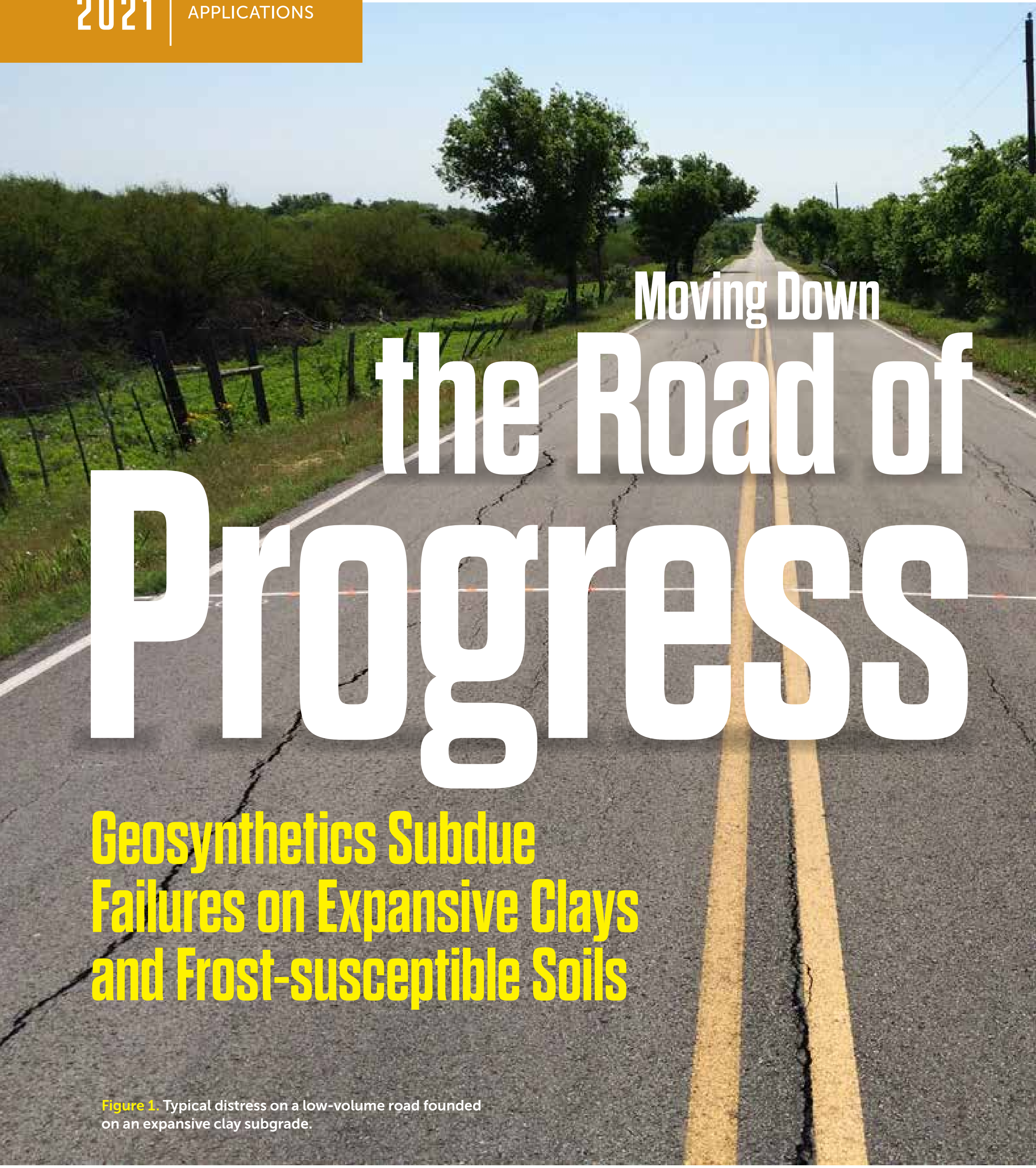

Moving Down the Road of Progress

Geosynthetics Subdue Failures on Expansive Clays and Frost-susceptible Soils

Figure 1. Typical distress on a low-volume road founded on an expansive clay subgrade.

By Jorge Zornberg, PhD, PE, F.ASCE, and Xiong Zhang, PhD, PE, M.ASCE

Using geosynthetics in roadway projects has provided sustainable alternatives for reconstruction and maintenance and now represents a significant portion of the total geosynthetics market. Geosynthetics can enhance roadway performance in relation to traffic loads and can address design objectives such as increasing the roadway design life or decreasing the thickness requirements of structural layers. Various geosynthetic types have been used to mitigate reflective cracking in structural asphalt overlays, stabilize unbound aggregate layers, reduce layer intermixing, reduce moisture in structural layers, and stabilize soft subgrades. Geosynthetics have also worked successfully on problems triggered by sources other than traffic loads — for example, on roadways founded on subgrade soils subjected to volumetric changes caused by the presence of expansive clay subgrades and frost-susceptible soils.

Expansive Soils

In the U.S. alone, $15 billion in annual total reported damages can be attributed to expansive soils. While not life-threatening compared to natural disasters, expansive soils constitute a natural hazard with an average annual cost exceeding that caused by floods, hurricanes, earthquakes, and tornadoes combined. Common across much of the central and southern U.S. and many other regions worldwide, expansive clays may trigger large volumetric changes that result in ground heave during wet seasons and settlements during dry seasons. Figure 1 depicts a common type of distress often referred to as "environmental longitudinal cracking." This one was observed on a low-volume road founded on an expansive clay subgrade in Texas, after being subjected to cyclic differential movements caused by varying moisture conditions.

Roadways constructed over expansive subgrades have been stabilized using lime treatment and, more recently, geosynthetics. In fact, while the Texas Department of Transportation (TxDOT) might be the U.S. transportation agency with the highest usage of geosynthetics in roadway stabilization projects, the agency's use of geosynthetics for more conventional stabilization design objectives, such as reducing the required base thickness due to traffic loads, has been limited. Instead, geosynthetic-stabilized base courses have been constructed in Texas, primarily to mitigate problems associated with expansive clay subgrades.

Frost-susceptible Soils

Frost-susceptible soils are soils with fine particles that promote capillary flow and undergo significantly detrimental ice segregation during freezing. Frost heave and thaw-weakening, also referred to as "frost action," lead to major pavement distress that can cause deterioration in surface roughness (ride quality) and cracks in the pavement structure. During winter, the downward advance of a freezing process in soils results in continuous migration of water to the freezing front. The migrated water subsequently freezes, forming ice lenses that cause the uplift of pavement structures, commonly known as "frost heave." During spring, thawing of the ice lenses results in a significant increase in soil moisture content. Because the underlying soils are still frozen and therefore act as a temporary barrier, water drainage away from the pavement structure may be significantly delayed. This results in yearly recurring springtime softening of the subgrade soils supporting the pavement. During this period, the pavement is poorly supported and highly vulnerable to imposed vehicle loads, often leading to a complete loss in bearing capacity and structural failure. Longitudinal cracking, potholes, and frost boils are a typical consequence of frost actions.

Roadway Distress Mechanisms Triggered by Subgrade Volume Changes

Cycles of wet and dry seasons may lead to significant changes in the moisture content of surficial subgrade soils (Figure 2). However, such changes are comparatively more significant near the pavement shoulders. Instead, moisture fluctuations in subgrade soils beneath the paved roadway centerline are markedly less affected by precipitation events, leading to a nonuniform distribution of moisture along the roadway cross-section. If the subgrade involves expansive clays, such nonuniform moisture changes result in nonuniform volumetric changes over the roadway cross-section.

Consequently, differential vertical movements between the edge and centerline of the roadway develop because of recurring wet and dry

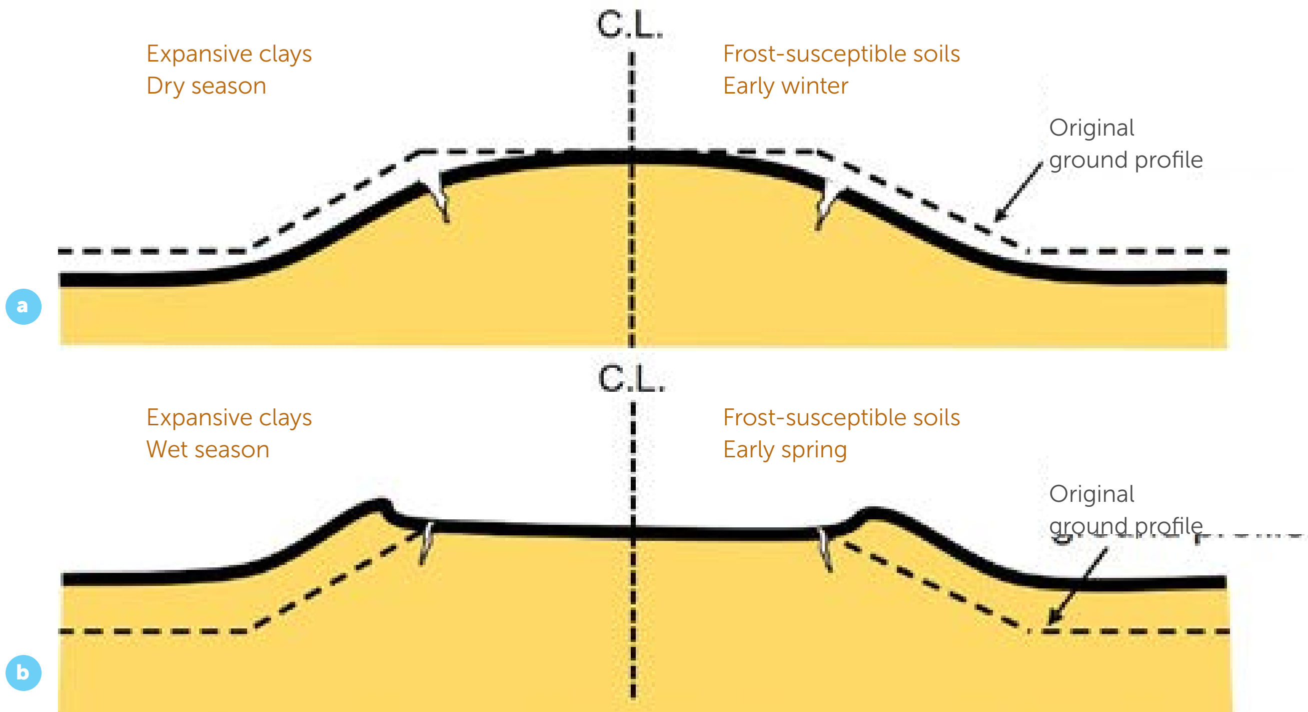

Figure 2. Schematic roadway profiles.

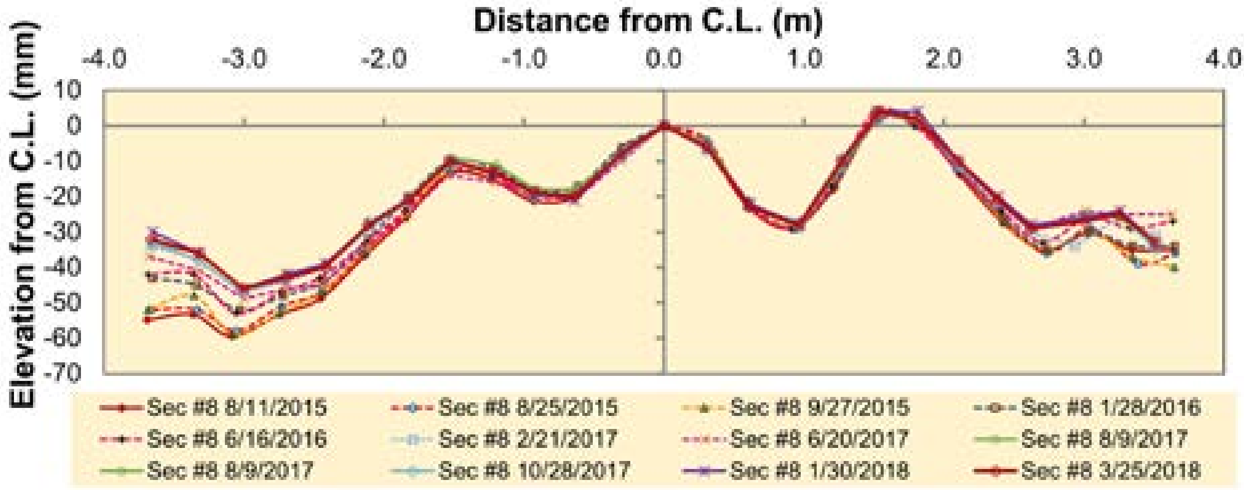

Figure 3. Differential vertical movements between the edge and centerline at a low-volume road founded on expansive clay subgrade shown in Figure 1.

seasons. Pavement shoulders will then settle in relation to the roadway centerline during dry seasons (Figure 2a) and show a relative heave during wet seasons (Figure 2b). Such differential movements induce flexure and, consequently, tensile stresses and associated distress in the roadway surface layer.

For example, the magnitude of differential vertical movements between the edge and centerline of the road (Figure 3) exceeded 1.2 in. over a three-year monitoring of vertical movements. Consistent with this mechanism, significant longitudinal cracks will often develop, particularly after sustained dry seasons (i.e., when tensile strains are the greatest). Longitudinal cracks may even partially close during wet seasons, although water will continue to infiltrate the damaged pavement surface. These longitudinal cracks are due to "environmental" loads rather than the "traffic" loads for which roadways are conventionally designed.

A pattern of shoulder differential vertical movements in relation to the road centerline, similar to that present in expansive clays, is also observed in cold regions. Figure 4 shows typical distress of a road in Alaska caused by nonuniform frost actions and, consequently, uneven vertical movements. The road surface in a pavement structure has distinctly different thermal characteristics in terms of heat absorption and release than the road shoulders, which may trigger differential frost heaving across the road section under cycles of warm-cold seasons. Common winter maintenance operations, such as removing the insulating snow from the roadway and depositing it on the road shoulders, further aggravate the situation by promoting freezing under the roadway and retarding it under the shoulders. For example, the reported annual average surface temperatures on Alaskan roads is approximately 32°F, while the average surface temperature on the road shoulders ranged from 35°F to 40°F. Accordingly, such differences in temperature changes lead in turn to nonuniform frost action and differential movements over the road cross-section. Longitudinal cracking at the center of the pavement often initiates due to transverse differential heaving when the induced tensile stresses in the pavement structure exceed the tensile strength. That is, the volume changes in frost-susceptible soils of cold Alaska show a similar pattern to the expansive soils in hot Texas! This makes frost heave another clear example of pavement distress caused by environmental rather than traffic loads.

Using Geosynthetics to Mitigate Roadway Distress

Geosynthetics have successfully mitigated problems with volumetric changes in the subgrade caused by moisture fluctuations in roadways founded on expansive clays or uneven freezing of frost-susceptible soils. In fact, as two case studies will illustrate, there are two mechanisms by which geosynthetics can mitigate problems of subgrade volume changes: 1) mechanical stabilization of the unbound aggregate layer, and 2) hydraulic control of subgrade moisture conditions. Geosynthetics can provide mechanical stabilization by distributing strains over a comparatively large area to minimize or prevent the generation of high local strains that trigger longitudinal cracks. Geosynthetics can provide hydraulic control by distributing moisture along the roadway subgrade soils to minimize or prevent moisture distributions that lead to differential vertical movements across a roadway.

Expansive Clay Mitigation

A 4.5-mile section of Farm-to-Market Road 2 (FM2) in Central Texas had

Figure 4. Image of typical longitudinal crack in Alaskan pavement.

been exhibiting significant ride quality problems with distresses characterized by the recurring development of longitudinal cracks. Reconstruction of a significant portion of FM2 was carried out to improve roadway conditions. The project entailed scarification, remixing, and compaction of the original base course to construct a 10-in.-thick subbase layer, subsequent construction of a 7-in.-thick new base layer, and final placement of a thin surface asphalt layer. Because the subgrade soils comprised highly expansive clays, the rehabilitation program involved chemical stabilization of the subbase and geosynthetic stabilization of the base with a geosynthetic placed at the subbase-base interface. Ultimately, the FM2 rehabilitation project evolved into a pilot program consisting of 1) geosynthetic-only stabilized base sections, 2) lime-only stabilized subbase sections, 3) combined geosynthetic- and lime-stabilized sections, and 4) control sections. In all, 32 test sections were constructed for the pilot program, which included four repeats each of the four design schemes.

The geosynthetics used included a polypropylene and polyester biaxial geogrid with similar aperture sizes and mechanical properties in both machine and cross-machine directions, and a polypropylene woven geotextile with a comparatively higher tensile stiffness. Performance evaluations of the FM2 test sections included condition surveys of road surface distress, with a focus on quantifying the extent and severity of longitudinal cracking. Quantifying the longitudinal cracking proved particularly revealing after a severe drought that occurred six years following reconstruction. Performance evaluations of the test sections showed that the geosynthetic-stabilized sections performed considerably better than the nonstabilized sections. On average, the test sections stabilized using the three geosynthetic types were found to exhibit approximately the same level of performance. In fact, the average length of environmental longitudinal cracks in the control sections was 65 percent of the section length compared to 21 percent in geosynthetic-stabilized sections. Figure 5 shows a section of FM2, following a 2011 drought, that includes a geosynthetic-stabilized section (left lane) and a nonstabilized (control) section (right lane). The difference in longitudinal crack development is definitive, as the sections (intentionally constructed along the same roadway stretch) have identical soil, weather, and traffic conditions.

Evaluation longitudinal cracking in control and lime-stabilized sections showed that lime stabilization of the subbase did not mitigate their development. Indeed, field data indicated that combining subbase lime treatment with geosynthetic stabilization was less effective than geosynthetic stabilization without lime treatment. This is because limited chemical stabilization may end up incorporating a rigid, yet brittle layer that does not tolerate the still-occurring soil differential settlements.

Frost-susceptible Soil Mitigation
Beaver Slide is on Dalton Highway 11 in north central Alaska, just 5 miles south of the Arctic Circle. Located on a downhill when heading north, the road gradient is approximately 11 percent, and the road prism is on a

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Figure 5. **Road conditions showing control section (right) and geosynthetic-stabilized base section (left).**

Figure 6. **Performance of wicking fabric at Beaver Slide test section on Dalton Highway: a) Before treatment (May 2010), and b) After treatment (May 2011).**

side hill embankment (3 ft on the west side and 9 ft on the east side). Each year, "frost boils" that usually appear in late April and remain throughout the summer (Figure 6a), have created extremely unsafe driving conditions and contributed to more frequent accidents. Conventional repairs, such as installation of French drains at a skew, had not worked adequately. The alternative option of replacing the road section with more adequate material only temporarily resolved local frost boils and moved the problem down slope.

In 2010, a then-new type of geotextile (i.e., "wicking" geotextile) was adopted to mitigate frost boils. The geotextile includes hydrophilic and hygroscopic nylon fibers that facilitate reducing the moisture of surrounding soils. More importantly, the multichannel cross-section of these fibers promotes enhanced water transport due to capillary action.

A 60-ft-long test section was constructed in an area where recurring "soft spots" had been reported. During construction, the original road section was first excavated to a depth of approximately 3.5 ft, and two layers of wicking geotextile were installed at depths of 2 and 3.5 ft respectively. Care was taken to ensure that the direction of the wicking fabric was along the transverse direction of the road section so water could be directed laterally toward the road shoulder. The test section was then backfilled with compacted materials from the excavation. Approximately 4 ft of the wicking geotextile were left exposed to the atmosphere to promote water loss from evapotranspiration. The test section was instrumented with moisture and temperature sensors.

Figure 6b shows the roadway's condition one year after treatment. As the figures show, the soil above the wicking geotextile remained unsaturated during the 2011 thawing period. Visual evidence and monitoring data have showed very good performance of the test section over the past 10 years. Neither soft spots nor frost boils developed in the test section treated with wicking geotextiles, while soft spots or frost boils were observed just beyond the upper and lower ends of the test section. Monitoring results have also revealed that water was flowing along the direction of the wicking geotextile to the shoulder of the pavement. The wicking geotextile has successfully eliminated frost heave and thaw weakening in the upper 3.5 ft. below the second layer of wicking fabric. The observed volumetric moisture contents indicate that the soils in the test section did not reach saturation. When the water supply from the underlying soils was cut off by the wicking geotextile, frost action was eliminated.

Thereafter, Alaskan transportation authorities have successfully used the same wicking geotextile on several other projects. In one case, wicking geotextile was used as substitute for shot rock (riprap) to improve problematic soft ground, resulting in a 34 percent price savings compared to the shot rock treatment alternative, and an 83 percent savings compared to the alternative treatment for an adjacent road section. The initial construction alone reduced costs by $2.5 million, a savings that could increase in the long run when the costs of remedial measures are added.

What's the Link Between Similar Problem Conditions in Texas and Alaska?

The impact on light infrastructure (e.g., roadways) of wet/dry weather cycles, combined with the presence of expansive clays in Texas, is analogous to the impact of above/below freezing condition cycles combined with the presence of frost-susceptible soils in Alaska. In both cases, weather cycles (of precipitation/temperature), combined with an abundance of soils prone to volumetric changes, trigger problematic differential vertical movements. For low-volume roads, they trigger distinctive longitudinal cracks induced by environmental loads rather than the traffic loads for which roads are designed. Roadway problems triggered by the presence of expansive clays or frost-susceptible soils may share common engineering solutions. Specifically, geosynthetics have been successfully used to address problems for both cases by providing either mechanical stabilization or moisture control. These observations lead us to believe geosynthetics may end up providing solutions to some of the oldest geotechnical problems related to the presence of problematic soils. GS

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