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Advantages and Applications of Enhanced Lateral Drainage in Pavement Systems

J.G. Zornberg, The University of Texas at Austin, Austin, Texas, USA, zornberg@mail.utexas.edu
B. Odgers, Tencate Geosynthetics, Pendergrass, Georgia, USA, b.odgers@tencate.com
G.H. Roodi, The University of Texas at Austin, Austin, Texas, USA, hroodi@utexas.edu
M.M. Azevedo, The University of Texas at Austin, Austin, Texas, USA, mazevedo87@utexas.edu

ABSTRACT
Geosynthetics have been used in pavement systems to perform functions of separation, filtration, and reinforcement. However, significant additional benefits could result if the additional function of lateral drainage were also provided. Recent advances have involved the development of geotextiles with enhanced lateral drainage, which allow drainage even under conditions of reverse gradient. This paper highlights the potential benefits of enhanced lateral drainage, including: (1) Lateral drainage in pavements with a high water table, (2) Protection of roadways against frost-heave induced deterioration, (3) Protection of roadways against swelling and shrinkage of expansive subgrades induced by seasonal moisture content changes, and (4) Minimization of moisture accumulation within base course materials. The moisture migration mechanisms and relevant case histories are presented, with emphasis on the rationale for selection of the pavement layout. Overall, this paper illustrates multiple opportunities for improved pavement performance when enhanced lateral drainage is considered in the design.

1. INTRODUCTION

Geotextiles have been one of the most commonly used types of geosynthetics in civil engineering applications, having the characteristic of being able to fulfill, often simultaneously, a wide range of functions. In pavement systems, geotextiles have primarily been used for one or more of the following six applications: subsurface drainage, separation, stabilization, permanent erosion control, sediment control, and paving fabric (Figure 1) (AASHTO M 288, Shukla and Yin 2006).

In a subsurface drainage application (Figure 1a), the geotextile layer fulfills the primary function of filtration. In this application, the geotextile layer is placed against a soil to allow for long-term flow of water into a subsurface drain system while also retaining the in-situ soil. Geotextile filtration properties are a function of the in situ soil gradation, plasticity, hydraulic conditions, and geotextile opening size.

When used for the function of separation (Figure 1b), the geotextile minimizes mixing of an aggregate cover material with subgrade soil. The aggregate cover material can be the subbase layer, the base layer, or select embankment. In this application, the main function of geotextile is that of separation of two dissimilar materials whereas the water seepage or filtration through the geotextile is not a critical requirement. Under AASHTO M288-96, this application is limited to soils that either initially or seasonably have a California Bearing Ratio (CBR) ranging from 3 to 8. On the other hand, in the stabilization application (Figure 1c) the geotextile layer is used for pavement structures constructed over soils with a CBR ranging from 1 to 3. This is applicable mostly in wet, saturated conditions due to a high groundwater table or due to prolonged periods of wet weather. In this condition, the geotextile is required to provide the dual functions of separation and filtration. In some installations, the geotextile can also provide the function of reinforcement. The beneficial reinforcement function of a geotextile may be needed only for a short period of time, because as the weak subgrade consolidates, its shear strength increases and may reach the adequate level for future loadings. Yet, this process may result in large deformations that may exceed the limitations of paved roads. Therefore, a stabilizer geotextile in paved roadways has been used mostly as a working platform which serves as an alternative to excavation, removal, and backfilling of the weak subgrade.

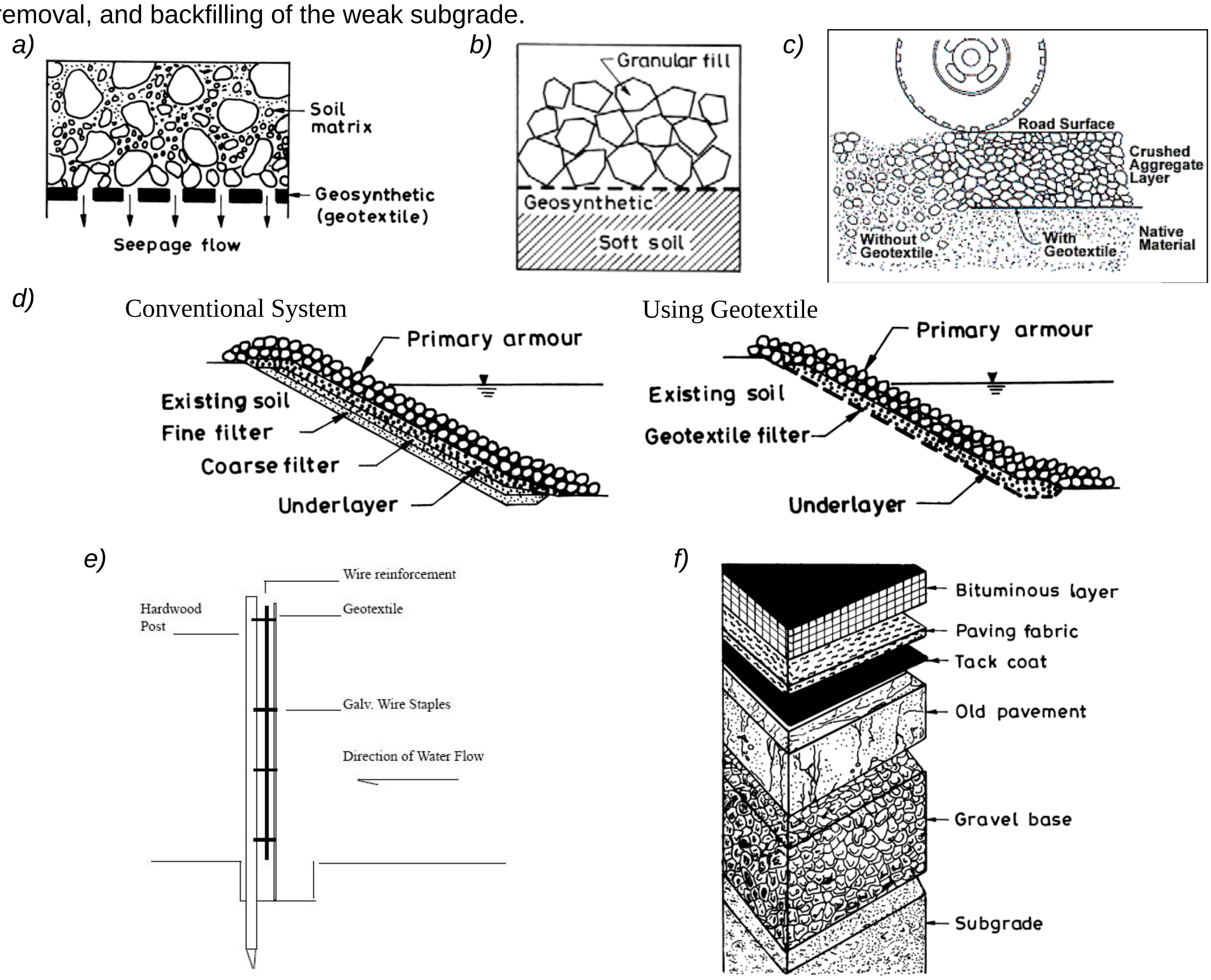

Figure 1. Conventional applications of geotextiles in pavement systems: a) Subsurface Drainage; b) Separation; c) Stabilization; d) Permanent Erosion Control; e) Temporary Silt Fence ; f) Paving Fabric (Shukla and Yin 2006)

Geotextiles can also be used to prevent migration of soil particles caused by erosive forces induced by flowing water, wind, and gravity. As illustrated in Figure 1d, a conventional revetment system consisting of layers of coarse and fine granular material can be replaced by a single layer of geotextile, while performing the same function. The hydraulic conductivity of the geotextile fabric should be adequate to prevent the hydraulic uplift pressures that would cause instability of the permanent erosion control systems. Sediment control (or temporary silt fence) is another application area for geotextiles. The function of a temporary silt fence is to filter and allow settlement of soil particles from sediment-laden water. The purpose is to prevent eroded soil from being transported off a construction site by water runoff (AASHTO M 288) (Figure 1e).

As shown in Figure 1f, in a paving fabric application, geotextile layers have been used beneath asphalt overlays. The geotextile layer is often saturated with hot mix asphalt or a tack coat to form a waterproofing and stress relieving membrane interlayer within the pavement structure. The waterproofing capability helps prevent infiltration of moisture into the pavement system, which is particularly beneficial where the road is founded on moisture sensitive subgrades. On the other hand, the stress-relieving capability has been reported to prevent or delay the development of reflective cracking in the overlay.

Significant research has been conducted on the use of geotextiles and geogrids as basal reinforcement in pavement systems (e.g. Zornberg et al. 2012, Roodi and Zornberg 2012). In this application, the geosynthetic layer is placed beneath or within the base or subbase layer, and provides reinforcement through three possible mechanisms: lateral restraint, increase in the bearing capacity, and tension membrane support (Holtz et al. 1998). However, the aforementioned mechanisms require different magnitudes of deformation in the pavement system to be mobilized. The “increased bearing capacity” and “tensioned membrane support” mechanisms would be activated only after significant rutting has developed (e.g. in unpaved roads). For the case of surfaced pavements, “lateral restraint”, which can be mobilized in relatively smaller deformations, is considered to contribute the most to the improved performance of geosynthetic-reinforced pavements.

Limited research has been conducted on the in-plane drainage capability of geotextiles in pavement applications. Yet, significant benefits would be expected if this additional function were provided. Recent advances in the development of geotextiles with enhanced lateral drainage are particularly promising, as they may allow the lateral drainage to occur even under conditions of reverse gradient (e.g. induced by differential settlements). The enhanced lateral drainage could be provided by specially designed wicking fibers inserted as part of the manufacturing process of geotextiles. Wicking fabrics have previously been utilized in geocomposite capillary barrier drains and frost blankets (Henry and Stormont 2002, Jay 2002) to remove excess water from pavements due to rainfall infiltration or capillary barriers. The excess moisture was removed by diverting it laterally. In both cases, the geosynthetic layer consisted of a geonet sandwiched between two special nonwoven geotextile transport layers to form a drainage geocomposite. The purpose of this article is to highlight the potential benefits of enhanced lateral drainage of woven geotextiles in pavement design, which may lead to adequate pavement behavior under conditions that would otherwise be significantly compromised without lateral drainage.

2. ENHANCED LATERAL DRAINAGE CONCEPT

The in-plane drainage function of geosynthetics is typically achieved by using geonets and geocomposites. However, geotextiles can in some cases also provide such a function. Due to the large void space in its structure, a thick, non-woven, needle-punched geotextile would be able to transmit comparatively high volumes of liquid. In a woven geotextile, in-plane drainage could be offered by the void spaces created by the crossed-over yarns. Enhanced lateral drainage involves maximizing the in-plane drainage capacity of geotextiles by facilitating the transmission of the liquid not only through the void spaces but also through the yarns themselves.

As illustrated in Figure 2, conventional woven geotextile fibers can be substituted by special wicking fibers with a unique cross-section. The special fiber cross-section is deeply grooved which allows the narrow channels between the grooves to transmit the liquid along the longitudinal axis of the fiber. Furthermore, instead of using hydrophobic polypropylene fibers, the wicking fibers are manufactured from nylon materials which are both hydrophilic and hygroscopic. Accordingly, the nylon conveys water from the surrounding soil as well as provides a conduit for the moisture along its channels. Nylon naturally provides these two functions, but additives have been found to enhance them. The channels main function is to transport any absorbed water laterally (Azevedo 2012). Geotextiles with enhanced lateral drainage are desirable, as they may allow lateral drainage to occur even under conditions of reverse gradient (e.g. induced by differential settlements).

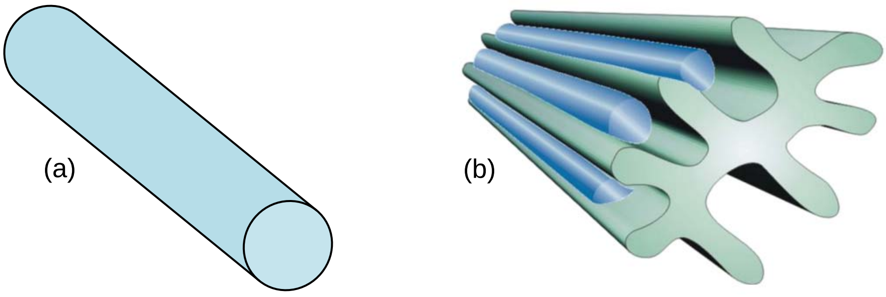

Figure 2. Geotextile fiber shapes: a) Standard cylindrical fibers; b) Grooved cross-section of the wicking fibers

allowing enhanced lateral drainage (F.I.T. 2011)

3. APPLICATIONS OF ENHANCED LATERAL DRAINAGE IN PAVEMENT SYSTEMS

This section summarizes the advantages of incorporating enhanced lateral drainage capacity in specific situations involving pavement projects.

3.1 Lateral drainage in pavements with a high water table

Upward movement of water from comparatively shallow water tables may lead to problems not only in cold regions, but also in arid or semi-arid areas. The problems associated with changing water table in cold regions are often associated with the frost-heave phenomenon (which will be discussed subsequently). On the other hand, changing water table may also lead to problems in arid or semi-arid regions such as undesirable dissolution of salts and their transportation to the ground surface. Application of the enhanced lateral drainage mechanism may control the impact on structures due to changes in the water table. As illustrated in Figure 3, a geotextile with enhanced lateral drainage could be incorporated to carry excess water to drain pipes outside the pavement area. This would protect the road foundation from weakening induced by rising water.

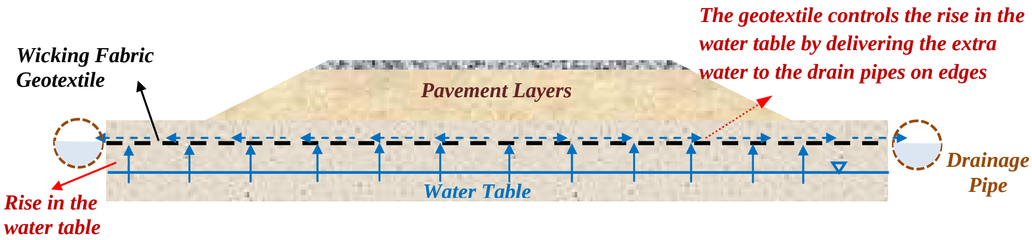

Figure 3. Advantage of the enhanced lateral drainage mechanism in controlling capillary rise from a high water table

3.2 Minimizing the accumulation of moisture within the base course material

Conventional drains in pavement systems are designed to convey water under saturated conditions. Specifically, to mobilize the capacity of drains, the flow should be saturated, resulting in the development of positive pore water pressure within the road structure. The positive pore water pressure could lead to weakening of pavement layers and reduction of the resistance of the road against rutting, cracking, and other types of failure. However, the water flow in pavement systems is often unsaturated. The unsaturated flow cannot be drained effectively by conventional drains due to formation of capillary barriers. Capillary barriers are formed when two porous materials with differing hydraulic conductivities are in contact with one another. The capillary barriers increase the moisture storage around the contact area by forming a temporary barrier at the interface of the two materials (Zornberg et al., 2010). The enhanced lateral drainage mechanism can help reduce or eliminate the moisture accumulation created by a capillary barrier as well as drain the accumulated water out of the pavement structure (Figure 4).

3.3 Protection of roadways against frost-heave deterioration

Geotextiles have also been used to create a capillary barrier in pavements to prevent the capillary rise of water which can cause frost heave (Henry, 1996). Water in fine-grained soils such as silt or clay has been reported to rise from the groundwater table or an aquifer via capillary action by as much as 9-27 meters (Blades and Kearny, 2004). In frost-susceptible soils, the water forms ice lenses in void spaces in the frozen subgrade which will cause frost heave and crack pavements. Moreover, during the spring thaw, the melting ice lenses will cause the ground to become excessively saturated and traffic loads will further deteriorate the pavement. By placing a geotextile or coarse-grained soil below the plane of freezing subgrade, a capillary barrier will stop the capillary rise of water from infiltrating the frost-susceptible zone. However, there will still be moisture accumulation below the geotextile since they are usually unable to laterally drain away the excess water. So while the issues associated with frost heave may have been mitigated, there are numerous additional issues resulting from excess moisture in pavement subgrades and base courses (Christopher et al. 2006). An example of one such issue is the softening of the subgrade soil which will cause pavement deformation with traffic loading.

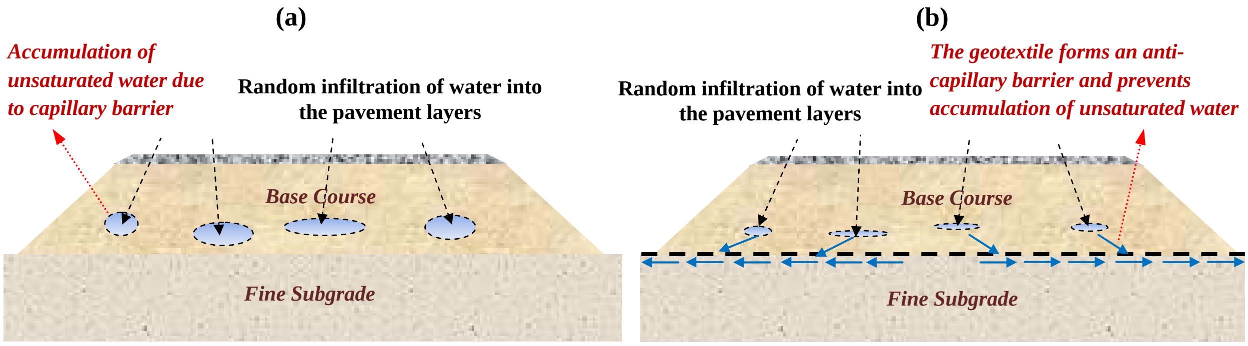

Figure 4. Advantage of the enhanced lateral drainage mechanism in minimizing the moisture accumulation: a) without the geotextile; b) with the geotextile

The use of a geotextile with enhanced lateral drainage capability in frost-heave susceptible areas may not only form a capillary barrier to prevent the rise of groundwater into the frost zone, but may also transmit the accumulated water to the edges of the pavement (Figure 5). Therefore, the potential for damage caused by freeze-thaw cycles and any damage caused by the accumulation of water around the geotextile layer can be minimized.

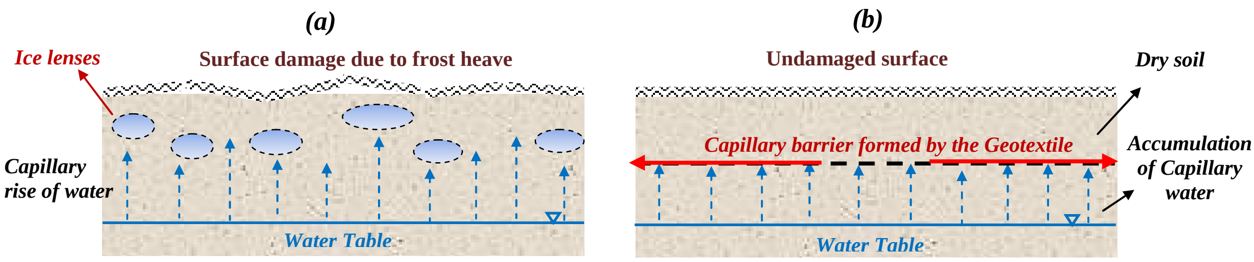

Figure 5. Advantage of the enhanced lateral drainage mechanism in mitigation of damages caused by frost-heave deterioration: a) without the wicking fabric geotextile; b) with the wicking fabric geotextile

3.4 Protection of roadways against swelling and shrinkage of expansive subgrades

An additional concern related to excess water in pavements is the moisture migration into the subgrade which may cause differential settlement in expansive clay soils. Expansive clays are found in many places around the world, being especially problematic in Texas, USA. Pavements founded on expansive clays are exposed to noticeable heave during the wet season and shrinkage in the dry season. Moisture generally seeps into the shoulders of the pavement which causes the soil below the shoulders to swell more than under the center of the road. In addition, infiltration of precipitation through pavement surface flows into the pavement layers and subgrade soil not only weakens the road structure, but also exacerbates the differential deformations induced by swelling and shrinkage of the subgrade. Significant longitudinal cracks are developed when the subgrade dries and settles unevenly inducing tensile stresses in the flexing pavement (Zornberg et al. 2012, Roodi and Zornberg 2012).

As illustrated in Figure 6, the use of a geotextile with enhanced lateral drainage may help remove moisture out of the pavement structure as well as balance the non-uniform distribution of moisture in the subgrade, which is the main source of the differential settlements.

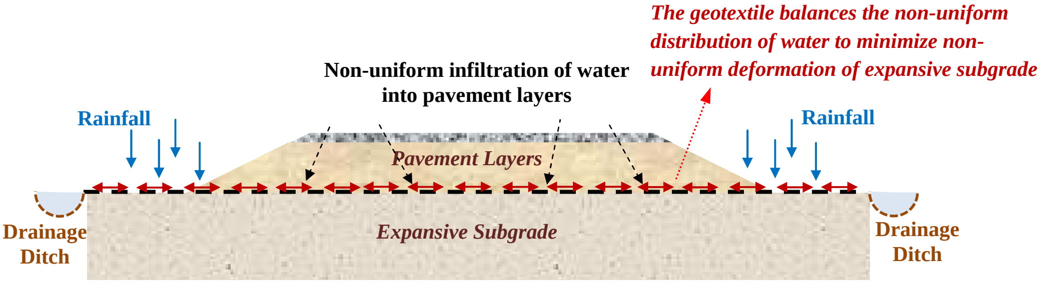

Figure 6. Advantage of the enhanced lateral drainage mechanism in mitigation of damages caused by swelling-shrinkage of expansive subgrades

4. CASE STUDIES

4.1 Differential Settlement Control in Expansive Clay Subgrades, SH21 Highway, Texas, USA

As a part of the Texas Department of Transportation (TxDOT) State Highway Improvement Plan, a stretch of approximately 9.65 km (6 miles) of State Highway 21 was planned to be rehabilitated. This portion of SH21 has shown a poor performance for many years. Even though numerous maintenance operations have been performed during the course of years to improve the quality of the road, the road suffered from various distresses at abundant spots which suggested a very poor riding quality. The main distresses observed included major longitudinal and edge cracking, vertical deformation, rutting, and faulting. Specifically, the edge of the road showed a large number of wide and deep longitudinal cracks with faulting which could not be prevented by sealing or using additional thickness in the asphalt layers (Figure 7).

Figure 7. Sample distresses found on SH21 road before the rehabilitation plan

The road was founded on a highly plastic subgrade soil with a plasticity index value exceeding 35% ,an indication of a highly expansive clay. The improvement plan involved full excavation of the outer lane of the road to the subgrade, widening the shoulder of the road using a gentler slope, using a nonwoven geotextile as a separation agent on top of the subgrade soil, and using geogrid layers within the reconstructed base and subbase layers of the road. Since the lateral drainage and seasonal swelling and shrinkage of the expansive subgrade were of significant concern in that area, The University of Texas at Austin proposed an evaluation involving eight test sections constructed with four different types of separator geotextiles. The selected geotextiles included: 1) a generic nonwoven geotextile which was conventionally used by TxDOT in that area; 2) a high strength wicking fabric woven geotextile; 3 and 4) two high strength woven geotextile manufactured with non-wicking fabric. As shown in Figure 8, a series of moisture and temperature sensors were installed in a trench beneath the geotextiles within the subgrade soil to allow for monitoring the change in the moisture content of the subgrade across the outside land and shoulder of the road. Monitoring the moisture sensor readings along with the observation of the performance of the road will provide valuable insights into the potential benefits of the wicking fabrics in enhancement of the hydraulic and/or mechanical performance of the road.

a)

b)

c)

d)

Figure 8. Rehabilitation of SH21 road: a) Excavation of the old road to the subgrade level; b) Installation of the moisture and temperature sensors in the subgrade; c and d) Installation of the wicking fabric geotextiles and other non-wicking fabric geotextiles

4.2 Subgrade Frost Heave Control in the Dalton Highway, Alaska, US

The Alaska Department of Transportation was involved in a project where a problematic road section was reinforced with a geotextile with enhanced lateral drainage capacity (Figure 9). The test section is located in a section of the Dalton Highway known as Beaver Slide, which is mostly unpaved and receives significant truck traffic. Indeed, this road is the only route for ground transportation between Prudhoe Bay and the city of Fairbanks. The section experiences significant annual degradation due to frost heave phenomenon with ensuing soil softening during spring thaw. Previous rehabilitation methods, including the use of a geocomposite layer, have been unsuccessful.

a) b) c) d)

Figure 9. The Dalton Highway Project: a) Sample traffic on the road; b) Installation of the first layer of geotextile; c)Installation of the second layer of the geotextile; d)Installation of moisture sensors (Tencate 2012)

Figure 10. Performance of the wicking fabric geotextile in the Dalton Highway project

Excavation of the existing road confirmed that an organic tundra layer was approximately 1.2 to 1.5 m (4 to 5 feet) below the road surface. Frozen soil was also encountered along with water from the high ground water table. Upon excavation of the test section, two layers of the geotextile were installed 45 cm (18 inches) apart with the bottom geotextile directly on the subgrade, which is approximately 1.5 m (5 ft) from the road surface (TenCate, 2012). Twenty two moisture and temperature sensors were placed in a grid-like pattern above and below the geotextiles (Figure 9d). The sensor leads were all bundled together and buried in a trench that led to a data collection unit on the side of the road. The sensors readings were monitored for one year by the researchers at the University of Alaska Fairbanks and employees of the Alaska Department of Transportation. Collected sensor data revealed the minimization of ice lens formation since the geotextiles were able to transport water across the highway. The sections of Beaver slide that included geotextile support appeared to be in very good shape while adjacent highway sections were nearly impassable. Figure 10 interestingly demonstrates the effectiveness of the wicking fabric geotextile in draining water out of the road section. In this figure, a clear contrast between the color of the materials located above and below the geotextile is observed. The soil placed above the geotextile looks relatively dry, whereas the soil placed below the wicking fabric looks relatively wet. This highlights the impact of the geotextile layer in draining the water out of the shallow layers as well as cutting off the capillary rise of water in the deeper layers. Additionally, the woven geotextile provides a reinforcement function that the previously mentioned geocomposites are unable to provide. This is because the geocomposites are comprised of a geonet and nonwoven geotextiles, which have much less tensile strength than a woven geotextile.

4.3 Subgrade Differential Settlement Control and Base Reinforcement, Lechería, Mexico

A pavement section was constructed over a high plasticity clay embankment in Lechería, Mexico (Figure 11). The main concern of the project was the change in the clay properties when exposed to future contact with water, which may lead to differential settlement of the road. In addition, the owner intended to minimize the amount of aggregate materials used for construction of the section. A wicking fabric geotextile was used in this project to fulfill both purposes: 1) to reduce differential settlement of the plastic clay by balancing non-uniform distribution of moisture; 2) to reinforce the base course of the road section which allows for a thinner base layer.

(a) (b) (c)

Figure 11.The Mexico Project: a) High Plasticity Clay Subgrade; b) Installation of the high strength wicking fabric geotextile; c)Construction of the base layer

As illustrated in Figure 12, a high strength wicking fabric geotextile was placed on top of the subgrade soil. This geotextile helps reduce the vertical flow of water and dissipate the flow in the horizontal direction. At the edges, the geotextile was connected to a French drain composed of a perforated pipe wrapped around with a geotextile filter and gravel materials. Also, the geotextile was designed to reinforce the base layer, so that the thickness of the base layer would be a minimum of 38 cm (15 inches). The performance of these sections is currently being monitored.

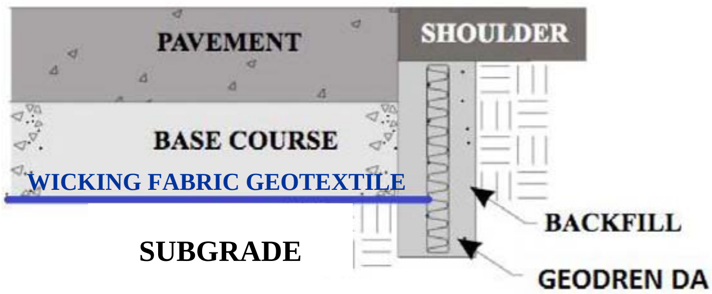

Figure 12. The designed road section in the Mexico project

5. CONCLUSIONS

Recent advances in the manufacturing of woven geotextiles have led to incorporation of specially designed wicking fibers with unique cross sectional shapes. This cross section is deeply grooved, allowing the narrow channels between the grooves to transmit the liquid along the longitudinal axis of the fibers. This provides the geotextile with enhanced capacity of in-plane (lateral) drainage. The geotextiles with enhanced lateral drainage capability may benefit applications in pavement systems such as lateral drainage in pavements with a high water table, protection of roadways against frost-heave deterioration, protection of roadways against swelling and shrinkage of expansive subgrades induced by seasonal change in moisture content, and minimizing the accumulation of moisture within the base course material. In these applications, the geotextiles with enhanced lateral drainage capacity can offer the traditional functions of separation, reinforcement, and filtration, as well as improved drainage capacity in the lateral direction. The advantages and mechanisms involved in the aforementioned applications were discussed in the paper. Three case studies involving wicking fabrics in Texas and Alaska, US, and Lechería, Mexico illustrate specific pavement projects that benefited from enhanced in-plane drainage. Data on the behavior of these projects, as collected so far, indicates successful opportunities for continued use of enhanced lateral drainage in pavement projects.

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