Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 189 (2017) 298 – 306

Procedia Engineering

www.elsevier.com/locate/procedia

Transportation Geotechnics and Geoecology, TGG 2017, 17-19 May 2017, Saint Petersburg, Russia

Functions and applications of geosynthetics in roadways

Jorge G. Zornberg [a,*]

[a]*Professor, Department of Civil, Architectural and Environmental Engineering, the University of Texas at Austin, 301 E. Dean Keeton St. Stop C1700, Austin, Texas, 78712-0273, USA*

Abstract

Geosynthetics have been successfully used to fulfill a number of functions that contribute significantly to the good performance of roadways. They include the functions of separation, filtration, reinforcement, stiffening, drainage, barrier, and protection. One or more of these multiple functions have been used in at least six important roadway applications. The applications include the migration of reflective cracking in asphalt overlays, separation, stabilization of road bases, stabilization of road soft subgrades, and lateral drainage. This paper illustrates the mechanisms as well as key advances in each one of these multiple applications.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology

Keywords:

The geosynthetic products most commonly used in roadway systems include geotextiles (woven and non-woven) and geogrids (biaxial and multiaxial), although erosion-control products, geocells, geonets (or geocomposite drainage products) and geomembranes have also been incorporated in a number of applications. These various types of geosynthetics can be used to fulfill one or more specific functions in a variety of roadway applications. For example, geosynthetics have been in use since the 1970s to improve the performance of unpaved roads on soft subgrade soils. Beginning in the 1980s, geosynthetics were utilized to minimize reflective cracking in asphalt overlays as well as to improve the performance of base aggregate layers.

The terminology used in the technical literature to describe the various applications of geosynthetics in roadway systems and the functions of geosynthetics incorporated into roadway design has not been consistent. This is

* Tel.: +1-512-232-3595; fax: +1-512-471-6548.
E-mail address: zornberg@mail.utexas.edu

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology
doi:10.1016/j.proeng.2017.05.048

understandable, as the mechanisms that lead to roadway improvement in each application are complex and often intertwined. Consequently, a framework is presented in this paper that is expected to minimize inconsistencies regarding the terminology used when designing roadways using geosynthetics.

While strongly based on frameworks currently used for geosynthetic design [1], the refined framework proposed herein follows two key premises: (1) Different geosynthetic functions unequivocally correspond to different geosynthetic properties, and (2) Geosynthetic applications correspond to the different types of projects that can be implemented to achieve specific design goals. Each geosynthetic application may involve a single geosynthetic function or a combination of such functions to develop mechanical or hydraulic mechanisms aimed at enhancing the roadway performance.

Fig. 1 shows a paved road section with the location of possible geosynthetic layers and the various functions that these geosynthetics can fulfill. These functions include:

- Separation: The geosynthetic, placed between two dissimilar materials, maintains the integrity and functionality of the two materials. It may also involve providing long-term stress relief. Key design properties to perform this function include those used to characterize the survivability of the geosynthetic during installation.
- Filtration: The geosynthetic allows liquid flow across its plane, while retaining fine particles on its upstream side. Key design properties to fulfill this function include the geosynthetic permittivity (cross-plane hydraulic conductivity per unit thickness) and measures of the geosynthetic pore-size distribution (e.g. apparent opening size).
- Reinforcement: The geosynthetic develops tensile forces intended to maintain or improve the stability of the soil-geosynthetic composite. A key design property to carry out this function is the geosynthetic tensile strength.
- Stiffening: The geosynthetic develops tensile forces intended to control the deformations in the soil-geosynthetic composite. Key design properties to accomplish this function include those used to quantify the stiffness of the soil-geosynthetic composite.
- Drainage: The geosynthetic allows liquid (or gas) flow within the plane of its structure. A key design property to quantify this function is the geosynthetic transmissivity (in-plane hydraulic conductivity integrated over thickness).

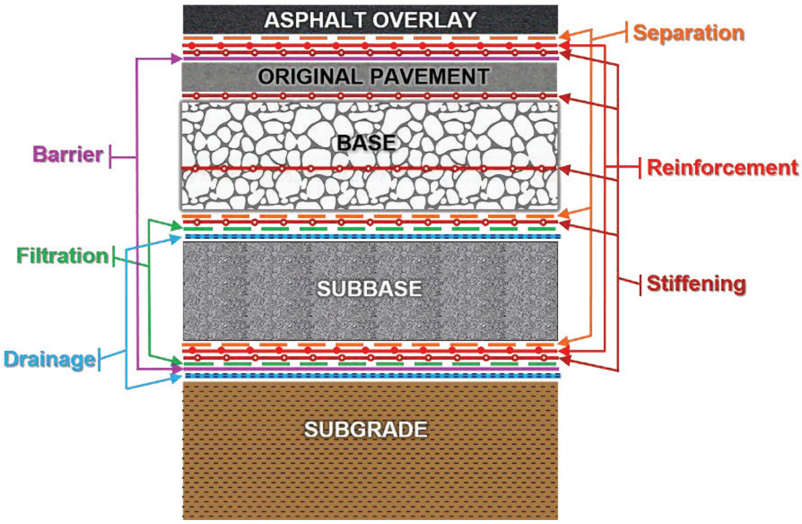

Fig. 1. Multiple functions of geosynthetics in roadway applications.

While comparatively less common in roadway applications, additional geosynthetic functions include:

- Hydraulic/Gas Barrier: The geosynthetic minimizes the cross-plane flow, providing containment of liquids or gasses. Key design properties to fulfill this function include those used to characterize the long-term durability of the geosynthetic material.
- Protection: The geosynthetic provides a cushion above or below other material (e.g. a geomembrane) in order to minimize damage during placement of overlying materials. Key design properties to quantify this function include those used to characterize the puncture resistance of the geosynthetic material.

Six of the seven functions listed above have traditionally been reported in the technical literature [1,2]. However, a seventh function – stiffening – is additionally considered in this paper. This addition is deemed appropriate to make a clear distinction on whether the mechanical inclusion (i.e. the geosynthetic) is used to develop tensile forces for the purposes of improving system stability or of controlling deformations. While both functions involve mechanical improvements, the properties required to fulfill them are distinctively different.

One or more of the seven aforementioned geosynthetic functions are used to enhance the roadway performance in the following five roadway applications: (1) mitigation of reflective cracking in asphalt overlays; (2) separation; (3) stabilization of road base; (4) stabilization of road subgrade; and (5) lateral drainage. This list is limited to applications of geosynthetics within a roadway section. Consequently, it does not include transportation applications aimed at enhancing the roadway performance but that involve components that are beyond the roadway section. Such applications, including trench drains, erosion control elements and surface water management features, are discussed by Holtz et al. [3,4] and Zornberg and Thompson [5].

Table 1 identifies a total of five roadway applications involving geosynthetics. For each of the five roadway applications, the table identifies the design objectives, relevant mechanisms, the primary and secondary geosynthetic function(s) involved in the application and the implications in roadway performance. A summary is provided next in this paper regarding each one of these roadway applications.

Table 1. Summary of roadway applications involving geosynthetics.

Application	Objective	Mechanism	Geosynthetic Functions		Implications in Roadway Performance
			Primary	Secondary	
Mitigation of reflective cracking in asphalt overlays	Retard or eliminate reflective cracking in asphalt overlays	Reduction of stress concentration in asphalt overlays in the vicinity of pre-existing cracks	Reinforcement	Stiffening Barrier Separation[1]	Reduced impact of degradation mechanisms in asphaltic layers that are caused (or accelerated) by water intrusion
Separation	Avoid contamination of aggregate base material with fine-grained subgrade soils	Minimized loss of aggregate particles into the subgrade and migration of fine-grade particles into the base layer	Separation	Filtration	Minimized time-dependent decrease in base layer thickness and in the quality of the aggregate base material
Stabilization of road bases	Minimize a time-dependent decrease in the modulus of the aggregate base material	Lateral restraint, which involves minimizing the time-dependent lateral displacements of aggregate base material	Stiffening		Minimized lateral displacements in the base aggregate material. This facilitates maintaining the original (comparatively high) aggregate confinement and, consequently, maintaining the original (comparatively high) aggregate modulus that results in a comparatively wide distribution of vertical loads and decreased base-subgrade contact stresses
Stabilization of road soft subgrades[2]	Increase the bearing capacity of subgrade soils	Development of membrane-induced tension under the wheel path and of soil-geosynthetic interface shear transfer beyond the wheel path	Reinforcement[2]	Stiffening Separation Filtration	Decreased vertical stresses in the subgrade under the wheel path, and beneficial redistribution of shear and normal stresses beyond the wheel path
Lateral drainage	Minimize the accumulation of moisture within the base and subgrade materials	Gravity-induced lateral drainage (for saturated conditions) and suction-driven lateral drainage (for unsaturated soil conditions)	Drainage (in-plane)	Filtration Separation	Minimized generation of positive pore water pressures (for saturated conditions) and decreased soil moisture content (for unsaturated conditions). This in turn avoids moisture-induced reduction of shear strength and modulus, both in the aggregate base and in the subgrade materials

Notes: [1] The “stress relief” reported as a possible mechanism in some applications is considered herein as a “separation” function.
[2] The same geosynthetic used for the application of “stabilization of road soft subgrades,” with reinforcement as primary function, also results in “stabilization of road bases.” Note that “stiffening” is the primary function of the geosynthetic in the latter application.

1. Mitigation of reflective cracking in asphalt overlays

The prevention of reflective cracking in asphalt overlays was one of the earliest applications involving geosynthetics in paved roads. Reflective cracks can occur in new flexible pavement overlays where pre-existing cracks are located within the old paved road. Reflective cracking may be triggered by bending and/or shear stresses induced by repeated traffic loads, as well as by tensile stresses caused by thermal variations [6]. Fig. (a) shows the development of stresses resulting from lateral movements induced by flexing of the paved road located directly below the traffic load. Such stresses may end up causing a reflective crack that propagates through the new pavement overlay, making it susceptible to early failure facilitated by moisture intrusion. Geosynthetics have been used to mitigate the early development of reflective cracks, through one or a combination of functions, including reinforcement, separation (or protection) and barrier [7]. Accordingly, the geosynthetic can act:

- By developing tensile forces in the vicinity of the crack tip, thereby reducing stresses and strains in the bituminous material. This reinforcement function has been achieved using polymeric, steel or glass grids.
- By providing a layer that allows horizontal deformations so that potentially large movements can develop without failure in the vicinity of pre-existing cracks. This mechanism has been referred to as stress absorbing membrane interlayer, often involving bitumen-impregnated non-woven geotextiles and can be characterized as a controlled de-bonding.
- By providing a hydraulic barrier function to waterproof the roadway structure, even after the reappearance of a crack in the road surface. This mechanism has also involved the use of bitumen-impregnated non-woven geotextiles.

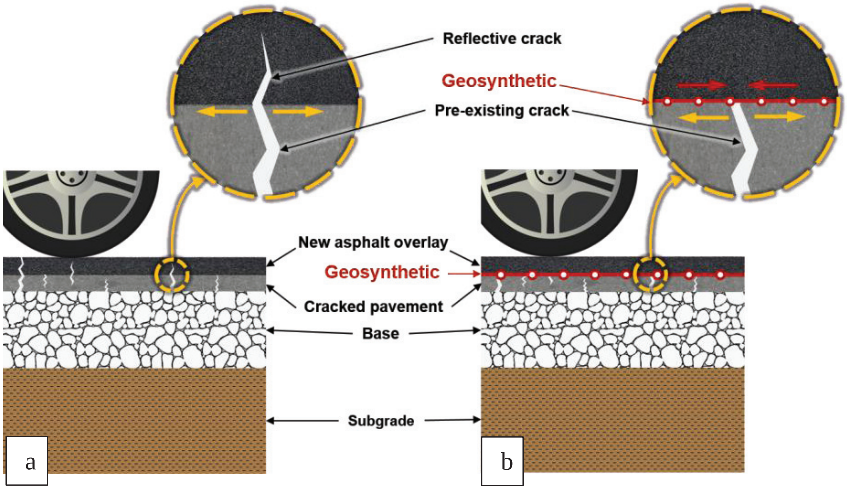

Fig. 2. Use of geosynthetics in mitigation of reflective cracking in asphalt overlays: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.

The use of a geosynthetic to fulfill a reinforcement function at the interface between the surface of an old pavement surface and a new overlay is shown in Fig. (b). The figure illustrates the geosynthetic tensile forces that can halt the progression of reflective cracking. Montestruque (2002) [8] conducted laboratory tests on reinforced and unreinforced asphalt concrete beams to investigate the use of geosynthetic reinforcement in pavement overlays. Geogrids and a non-woven geotextile were used as reinforcements. Results indicated better performance of the geogrid-reinforced specimens, as compared to the geotextile-reinforced and unreinforced specimens. More recently, Correia and Zornberg [9] reported that the use of geosynthetics as reinforcement in asphaltic layers can not only mitigate the development of reflective cracks, but can also increase the structural capacity of a paved road.

2. Separation

Geosynthetics were first used in roadway applications solely to fulfill the function of separation. In this application, a geosynthetic is placed between two layers of soil with different particle-size distributions. Indeed, a major cause of failure of roadways constructed over soft foundations is the contamination of aggregate base material with the underlying soft subgrade soil (Fig. (a)). Contamination occurs due to: (1) penetration of the aggregate into the weak subgrade due to localized bearing capacity failure under wheel-load induced stresses, and (2) intrusion of the fine-grained soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressure. Subgrade contamination results in inadequate structural support, which often leads to premature failure of the roadway. A geosynthetic placed between the aggregate and the subgrade can act as an effective separator by preventing mixing of the subgrade and aggregate base course.

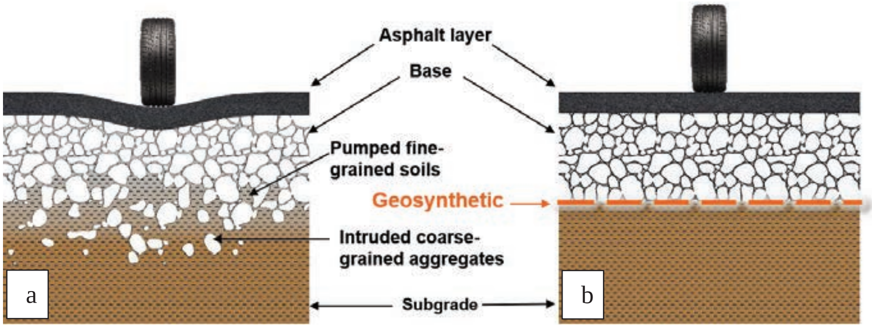

Fig. 3. Use of geosynthetics in separation: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.

Even a small amount of fines contaminating a granular layer can negatively affect its structural response, including a reduced shear strength, decreased hydraulic conductivity and increased frost susceptibility. Ultimately, a mix involving base aggregate material contaminated with fine-grained soils may essentially behave as the fine-grained soil itself. Consequently, the contamination effectively leads to a reduced base layer thickness and, ultimately, to a decreased road life. Use of a geosynthetic separator is comparatively inexpensive and may result in significant cost savings over the design-life of the roadway (Fig. (b)). Among the different types of geosynthetics, geotextiles have generally been used to achieve the function of separation. Design methodologies for the use of geosynthetics in separation applications are provided by Koerner [1] and Holtz et al. [3,4].

3. Stabilization of road bases

Base stabilization can be defined as the roadway application where geosynthetics are used to maintain the stiffness of the base aggregate materials. Stiffening is the primary (and sole) function leading to decreased lateral displacements within (and increased confinement of) the aggregate-geosynthetic composite. As stated previously, key design properties to fulfill this function involve those quantifying the stiffness of the soil-geosynthetic composite.

While the geosynthetic could be placed within the base layer, the typical placement location to facilitate constructability is at the interface between the base being stabilized and the underlying subgrade. As will be discussed in the subsequent section, this is also the location where geosynthetics are placed for subgrade stabilization. Consequently, it is possible that a geosynthetic used for base stabilization may also serve for subgrade stabilization. However, base stabilization can be achieved for a wide range of roadway deformations, including comparatively small levels consistent with those in paved roadways, while base stabilization requires mobilization of comparatively large roadway deformations, consistent with those that develop in unpaved roads.

Lateral displacement of aggregate particles occurring under repeated traffic loading is a mechanism that degrades the mechanical properties of the base aggregate. Such displacement is of particular significance in the lower portion of the base layer, directly below the wheel path, where tensile stresses are more prone to develop. Fig. (a) illustrates the lateral displacements that may develop within the base layer. The displacements result in decreased lateral stresses (i.e. decreased confinement) of the aggregate, which significantly impact the modulus of the base material. In a multi-layer pavement system, the main characteristic of the base layer is its comparatively high modulus, which widens the distribution of vertical loads and ultimately decreases the maximum vertical stresses acting at the base-subgrade interface. Traffic-induced degradation of the original modulus in the aggregate results in increasing contact pressures at the base-subgrade interface and eventually high rutting depths in the roadway structure.

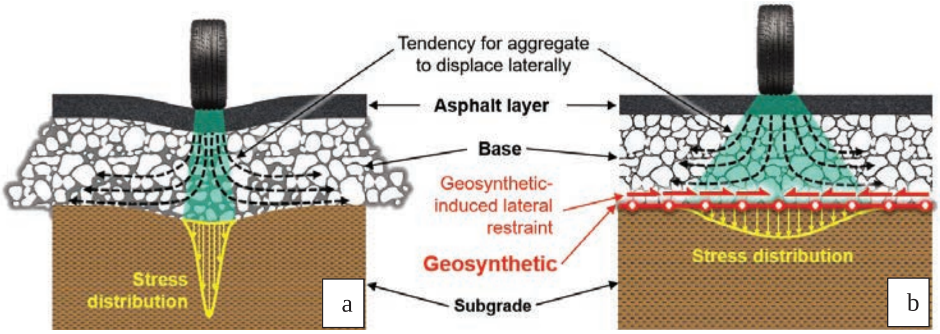

Fig. 4. Use of geosynthetics in stabilization of road bases: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.

Fig. (b) illustrates the restrain to lateral displacement provided by the geosynthetic inclusion. Interaction between the base aggregate and the geosynthetic results in transfer of shear stresses from the base material into tensile stresses in the geosynthetic. As a result, comparatively high interface shear transfer is needed to achieve stabilization of the base layer. In addition, the geosynthetic's own tensile stiffness also contribute to limit the development of lateral strains. Consequently, a geosynthetic with comparatively high stiffness is required to achieve stabilization of the base. Zornberg and Gupta [10] identified a parameter, the stiffness of the soil-geosynthetic composite, which accounts for both the interface shear strength at the soil-geosynthetic interface and the geosynthetic stiffness. The increased confinement provided by the geosynthetic layer in the base course material leads to an increase in the mean stresses, leading also to an increase in the shear strength of the aggregate. Both frictional and interlocking characteristics of the interface between the soil and the geosynthetic contribute to lateral restraint. Therefore, when geogrids are used to stabilize a road base, the geogrid aperture and base material particle sizes should be properly selected. On the other hand, when geotextiles are selected for base stabilization, proper interface frictional capabilities should be provided. As also illustrated in Fig. (b), the comparatively higher modulus of the geosynthetic-stabilized base results in a wide distribution of vertical traffic loads and in comparatively smaller vertical stresses acting at the base-subgrade interface.

4. Stabilization of road subgrades

Subgrade stabilization is defined herein as the roadway application involving the use of geosynthetics to increase the bearing capacity of soft subgrade soils. The functions of reinforcement, stiffening, separation, and filtration are involved in this application. Among these multiple functions, the reinforcement function leads to an increased bearing capacity of soft foundation soils while the stiffening function contributes to decreased lateral displacement within the base. Accordingly, a key design property for the reinforcement function is the geosynthetic tensile strength. It should be noted, though, that the stiffening function, which requires quantification of the rigidity of the soil-geosynthetic composite, is also relevant to complement stabilization of the subgrade with that of the base.

The geosynthetic is placed at the interface between the subgrade being stabilized and the overlying granular base. As previously indicated, it is then the case that a geosynthetic used for subgrade stabilization also provides stabilization to the overlying base material, as discussed in the previous section of this paper. This exemplifies use of a single geosynthetic for two applications: subgrade stabilization (to increase the subgrade bearing capacity) and base stabilization (to control lateral displacement of base material and consequently maintain a comparatively high base stiffness). However, subgrade stabilization involves the mobilization of comparatively large geosynthetic strains and the development of comparatively large rutting depths, which are consistent with those expected in unpaved roads. In contrast, base stabilization is mobilized for comparatively small geosynthetic strains and the corresponding small rutting depths, which are in line with those expected for paved and unpaved roads.

As illustrated in Fig. (a), the presence of a weak subgrade may lead to the development of localized (punching) shear failure in foundation soils, which creates significant deflections in the various overlying layers of the roadway. This is exacerbated by a comparatively narrow angle in the stress distribution within the base layer, which in turn results in a comparatively high contact pressure on top of the subgrade layer [11]. Fig. (b) illustrates the impact that incorporating a geosynthetic reinforcement can have on the bearing capacity of subgrade soils. The geosynthetic acts as a tensioned membrane, at least partly supporting the wheel loads. That is, the geosynthetic develops a concave shape so the acting tension includes a vertical component that directly resists the applied wheel load. More importantly, the vertical deflection and membrane-induced tension under the wheel path results in mobilization of soil-geosynthetic interface shear stresses in the portion of the road beyond the wheel path. The tension mobilized by the geosynthetic beyond the wheel path provides control of the subgrade heave between the wheel paths [11]. Ultimately, vertical restraint of the subgrade results in a surcharge that is applied beyond the loaded area. Such surcharge results in vertical restraint that may contribute significantly to an increased bearing capacity in subgrade soils. High deformations (i.e. high rutting depth), which are consistent with those acceptable only in unpaved roads, are required to mobilize this mechanism. Subgrade stabilization has been reported to be particularly applicable for projects involving subgrade CBR values below 3 [12] (Barksdale et al. 1989). In addition, stiffening of the base material yields a stress distribution characterized by a comparatively wide angle, leading to relatively low contact pressure on top of the subgrade layer. This is expected to change the shear failure from a localized (punching) shear mechanism in the unreinforced subgrade to a generalized shear mechanism in the reinforced subgrade.

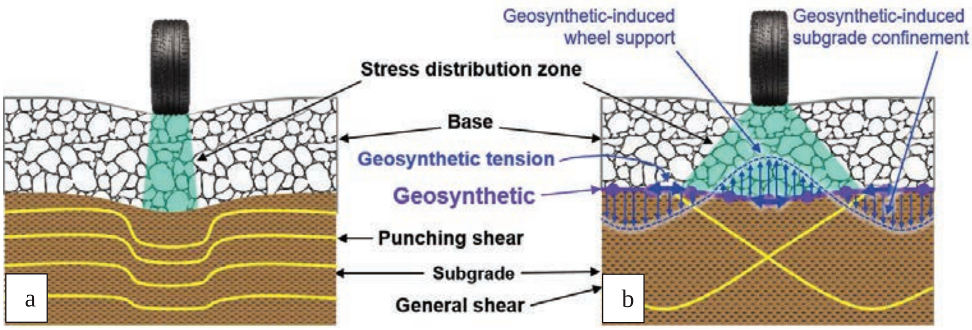

Fig. 5. Use of geosynthetics in stabilization of road subgrades: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.

Geosynthetics have often been used in subgrade stabilization applications to facilitate construction. If the subgrade soils are extremely weak, it may be virtually impossible to begin construction of the embankment or roadway without some form of stabilization. Geosynthetics have proven to be a cost-effective alternative to other foundation stabilization methods such as de-watering, excavation and replacement with select granular materials, utilization of thicker stabilization aggregate layers, or chemical stabilization [7,13]. The use of stabilizing geosynthetics enables contractors to meet minimum compaction specifications for the first few aggregate lifts. Even in cases where the stabilization application is primarily selected for initial construction, geosynthetics will provide long-term benefits and improve the performance of the road over its design-life.

5. Lateral drainage

The presence of moisture in both the base and subgrade layers of a pavement is detrimental, compromising the mechanical properties of these soils. Fig. (a) shows the impact on road performance of a moisture-induced decrease in modulus in both the base and subgrade layers. One way to quantify the impact of increased moisture is to evaluate its effect on the structural number (SN) in the design method proposed by the American Association of State Highway and Transportation Officials (AASHTO 1993). This method considers the pavement as a multi-layer elastic system, with the overall structural number reflecting the total pavement thickness and its resiliency to repeated traffic loading. The required SN for a project is selected so that the pavement will support anticipated traffic loads and experience a loss in serviceability no greater than that established by project requirements. The SN is penalized by a modifier, m, which accounts for the moisture characteristics of each pavement layer. This penalty can be sizable, with values for m ranging from as high as 1.4 for excellent drainage conditions to as low as 0.4 for poor drainage conditions. Or, stated more precisely, the structural capacity of a roadway with poor drainage conditions is as low as 29% (i.e. the ratio between the extreme modifiers) of that of a roadway with excellent drainage conditions. Designers often overlook the importance of lateral (internal) drainage in a roadway, focusing instead on building thick, high-quality material layers, while omitting good drainage features. Unfortunately, moisture trapped under a pavement will exacerbate pavement distresses by increasing pore pressures and softening the subgrade soil.

Fig. (b) illustrates the use of a geosynthetic with in-plane drainage capabilities. In this illustration, a horizontal geosynthetic drain was placed directly beneath the pavement, laterally diverting moisture that may have reached the base layer through downward infiltration, which may result from the presence of cracks in the pavement surface. The geosynthetic can also minimize moisture in the underlying subgrade soils, which may have reached high degree of saturation, for example, through capillary rise from a comparatively high water table.

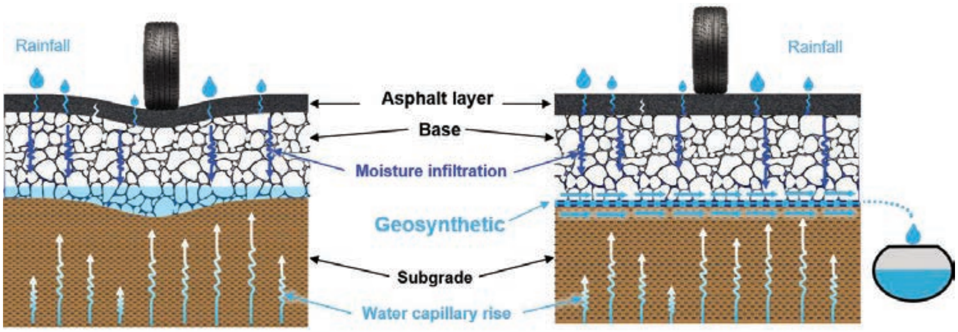

Fig. 6. Use of geosynthetics in improved internal drainage: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics

Conventional geosynthetic drains include geocomposite drainage products (a combination of geonets and geotextile filters) and geotextiles with comparatively high transmissivity. However, these conventional geosynthetic products can only provide gravity-induced lateral drainage, which is important when the soil adjacent to the geosynthetic has reached saturated conditions. Through advances in geosynthetic manufacturing, such as the development of geotextiles with enhanced lateral drainage (ELD), drainage under unsaturated conditions has also been made possible. Zornberg et al. [14] highlights the use of with ELD in a number of roadway situations, including: (1) enhanced lateral drainage of moisture migrating upward from a high water table, (2) enhanced lateral drainage of moisture infiltrating downward from the surface, (3) control of frost heave-induced pavement damage, (4) control of pavement damage caused by expansive clay subgrades, and (5) enhanced lateral drainage in projects involving soil improvement.

References

[1] R. M. Koerner, Designing with Geosynthetics, sixth ed., Vol. 1 and 2. Xlibris Corporation, 2012.
[2] J. G. Zornberg, B. R. Christopher, Chapter 37: Geosynthetics, In The Handbook of Groundwater Engineering, second ed., Jacques W. Delleur, CRC Press, Boca Raton, FL, 2006.
[3] R.D. Holtz, B.R. Christopher, R.R. Berg, Geosynthetic Engineering, Bitech Publishers Ltd., Richmond, British Columbia, Canada, 1997, pp. 452.
[4] R.D. Holtz, B.R. Christopher, R.R. Berg, Geosynthetic Design and Construction Guidelines, Report No. FHWA-NHI-07-092, U.S. Department of Transportation, Federal Highway Administration, Washington DC, 2008, pp. 612.

[5] J. G. Zornberg, N. Thompson, Guide for the Application and Selection of Geotextiles, Document 0-5812-P1, Center for Transportation Research (CTR), Austin, Texas, 2010, 16 p.
[6] J.W. Button, R.L. Lytton, Guidelines for Using Geosynthetics with HMA Overlays to Reduce Reflective Cracking, Report 1777-P2, Project Number 0-1777, Texas Department of Transportation, Austin, TX, 2003.
[7] S.W. Perkins, B.R. Christopher, N. Thom, G. Montestruque, L. Korkiala-Tanttu, A. Want, Geosynthetics in pavement reinforcement applications, Proceedings of 9th International Conference on Geosynthetics, Vol. 1, Guaruja, Brazil, 2010, pp. 165-192.
[8] G. Montestruque, Contribution to the development of a design method to retrofit pavements using geossinthetics in anti-reflexion cracks, 2002. Ph. D. Dissertation, Aeronautic Institute, Brazil.
[9] N.S. Correia, J. G. Zornberg, Mechanical response of flexible pavements enhanced with geogrid-reinforced asphalt overlays, Geosynthetics International. 2015 Dec 9;23(3):183-193.
[10] J. G. Zornberg, R. Gupta, Geosynthetics in Pavements: North American Contributions, Theme Speaker Lecture, 9th International Conference on Geosynthetics, Guarujá, Brazil, May, Vol. 1, pp. 379-400.
[11] J.P. Giroud, J. Han, Design method for geogrid-reinforced unpaved roads, I. Development of design method & II. Calibration and applications. Journal of Geotechnical and Geoenvironmental Engineering. 2004 Aug;130(8):775-797.
[12] R.D. Barksdale, S.F. Brown, F. Chan, Potential Benefits of Geosynthetics in Flexible Pavement Systems, National Cooperative Highway Research Program Report No. 315, Transportation Research Board, National Research Council, Washington DC, USA, 1989, 56p.
[13] B.R. Christopher, Cost savings by using geosynthetics in the construction of civil works projects, Proceedings of the 10th International Conference on Geosynthetics, 10ICG, Berlin, Germany, 2014 Sep 21-25 (CD-ROM).
[14] J. G. Zornberg, M. Azevedo, M. Sikkema, B. Odgers, Geosynthetics with enhanced lateral drainage capabilities in roadway systems, Transportation Geotechnics (in press), 2016.