# Performance of geocomposite membrane in pavement systems

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ABSTRACT: Geosynthetics are recognized as materials that may significantly improve the performance of flexible pavements when appropriately used. However, its contributing mechanism is still unclear. The pavement research at the Virginia Smart Road has been designed to better understand the geosynthetic mechanistic contribution. Twelve flexible pavement sections with different designs, wearing surfaces, and drainage capabilities were built and instrumented for stress and strain measurements in all layers as well as for environmental effects (temperature, frost, and moisture). A geocomposite membrane (a low modulus polyvinyl chloride [PVC] layer sandwiched between two woven geotextiles) was installed in two sections to quantify its effectiveness as a moisture barrier and as a strain energy absorber. Initial analysis of the collected data from embedded instruments showed the ability of the geocomposite membrane to significantly reduce the transversal tensile strain in the supporting layer. Although this behavior is coupled with greater deformation in the geocomposite membrane, the resulted deformation is recoverable.

## 1 INTRODUCTION

Modern traffic with greater numbers of vehicles and increased truck tire pressures and axle loads has detrimental effect on pavement systems. Although traditional materials performed satisfactorily on a wide range of roads in the past, recent dramatic failures have attracted the attention of public and media to the current status of the transportation infrastructure. To rehabilitate and maintain the crumbling transportation infrastructure, new materials and construction techniques have been recently introduced. Most of these materials were empirically used based on field experiences. Hence, the contribution of these new materials to the pavement or bridge systems has not been fully understood. Among the new materials utilized to improve pavement and bridge deck performance are geosynthetics. “Geosynthetics” is the collective term applied to thin and flexible sheets of synthetic polymer material incorporated in soils, pavements, and bridge decks (Donovan et al. 1999). As with any polymeric materials, geosynthetic properties are not only functions of temperatures and loading times that reflect their viscoelastic behavior, but they are also highly dependent on their chemical and topologic composition (i.e. amorphous or crystalline).

Since their introduction in the 1960s, the use of geosynthetics has experienced an incredible growth in different applications in civil engineering (Koerner 1994). Geosynthetics have been used for at least 80 specific application areas in geotechnical, transportation, and environmental engineering. Five distinct functions can be identified in pavement and bridge systems: reinforcement of a particular layer; separation (by maintaining the integrity of particular layers by preventing intermixing); drainage or filtration (by allowing the water to flow thereby dissipating pore water pressure while limiting soil movement); stress absorption; and a moisture barrier (by preventing water movement between layers). Geosynthetics are divided into six major categories: geotextiles, geogrids, geonets, geomembranes, geocells, and geocomposites, which combine the main function of different geosynthetics to obtain a multi-purpose system.

It is well documented that incorporation of a geotextile into the flexible pavement design can improve the pavement‘s performance and its service life when used as a separator over weak subgrade. Field evidence and laboratory testing suggest that both geogrids and geotextiles can improve the performance of flexible pavement systems constructed on weak soil (Al-Qadi et al. 1994). Moreover, some design practices suggest that the use of interface reinforcement systems provide substantial savings in HMA thickness, double the number of load repetitions to failure, and reduce permanent deformation in flexible pavement systems (Kennepohl et al. 1985). Unfortunately, many of the design practices are not supported by theoretical explanation and rely mostly on the pragmatic use of "Black Arts" than the real science. The idea that geosynthetics will result in better long-term performance of the pavement is too simple a view of a very complex situation. This paper illustrates the initiation of a new project that will reduce the gap between in-situ performances of geocomposite membrane and its properties and behavior mechanism. Preliminary data collected at the Virginia Smart Road illustrates the potential use of this material in pavement systems.

## 2 THE VIRGINIA SMART ROAD

The Virginia Smart Road located in Southwest Virginia is a unique, state-of-the-art, full-scale research facility for pavement research and evaluation of Intelligent Transportation Systems (ITS) concepts, technologies, and products. The Smart Road is the first facility of its kind to be built from the ground up with its infrastructure incorporated into the roadway. When completed, the Smart Road will be a 9.6-km connector highway between Blacksburg and I-81 in Southwest Virginia, with the first 3.2 km designated as a controlled test facility. One of its unique features is All Weather Conditions, a system that has the ability to generate or simulate different types of weather conditions. Seventy-five HKD Snow Towers are used to generate snow and rain conditions. The towers are able to produce snowfalls of up to 100 mm/hr and rainfall of up to 50 mm/hr. An underground conduit network (low power, two 100-mm conduits with four inner-ducts for communications, and several spare conduits for future expansion) with manhole access provides the medium for installing a power and data network. A fiber optic network serves as the backbone information network for the test bed. It will be used for the transmission of digital and analog data originating from on-site data acquisition systems to the control center which is used for remote monitoring and control of all the instruments embedded in the road. The construction of the Smart Road project has been made possible through cooperative effort of several federal and state organizations, including the Virginia Department of Transportation, The Virginia Transportation Research Council, the Federal Highway Administration, and Virginia Tech.

The flexible pavement part of the Smart Road test facility includes 12 (heavily instrumented) different flexible pavement sections. Each section is approximately 100 m long. Seven of the 12 sections are located on a fill, while the remaining five sections are located in a cut. Different layers are used in each section (all designations are in accordance with Virginia Department of Transportation specifications):

- Wearing surface: Seven types of wearing surface are used (SM-9.5A, SM-9.5A with high laboratory compaction, SM-9.5D, SM-9.5E, SM-12.5D, SMA-12.5, and open-graded friction course [OGFC]. Five of these seven mixes are SuperPave™ mixes. All mixes, with the exception of the OGFC, were constructed at 38-mm-thick. The OGFC was constructed at 19-mm-thick.
- Intermediate hot-mix-asphalt (HMA) layer: BM-25.0 at different thicknesses ranging from 100 to 244 mm.

- Three sections have the SuperPave™ SM9.5A fine mix placed under the BM-25.0 to examine the benefits of such a design on reducing fatigue cracking.
- Open-graded drainage layer [OGDL]: Out of the 12 sections, three sections were built without OGDL. Seven sections are treated with asphalt cement, and two are treated with Portland cement. The thickness of this layer is kept constant at 75 mm throughout the project.
- Cement Stabilized Subbase: 21-A cement-stabilized layer is used in 10 sections at a thickness of 150 mm.
- Subbase layer: 21-B aggregate layer was placed over the subgrade at different thicknesses with and without a geosynthetic.

The Smart Road offers a good opportunity to explore the effectiveness of geosynthetics as a moisture barrier and as a strain energy absorber. To achieve these objectives, a special geocomposite membrane, consisting of a low modulus polyvinyl chloride (PVC) geomembrane backed on both sides with polyester nonwoven geotextile reinforcement, was installed in two different sections. In section J, this geocomposite was installed underneath an asphalt treated drainage layer to test its effectiveness as a moisture barrier. In section K, the geocomposite membrane was installed underneath the surface mix to investigate its capability to relief stresses; a schematic of the layered system of each section is presented in Figure1.

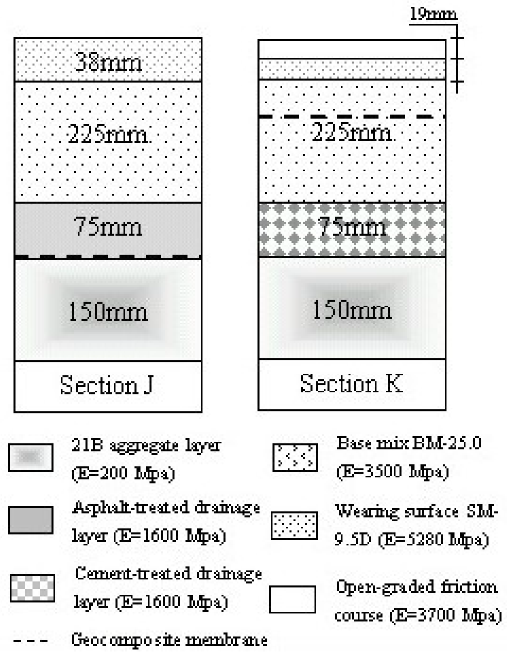

Figure 1. Pavement design (section J and K).

This geocomposite membrane has been successfully used as an impermeable material for dams, canals, reservoirs, and hydraulic tunnels (Scuero et al. 1997). While this geocomposite has been used on two bridge decks in Italy, it has never been used on any roads or bridges in the United States, except at the Virginia Smart Road pavement test facility.

More than 500 instruments were embedded in the road during construction to quantitatively measure the response of pavement systems to vehicular and environmental loading. For successful instrumentation strategy, at least two types of response (stress, strain or deflection) should be compared simultaneously. Therefore, strain and stress are carefully monitored along the depth of the pavement system. Also, climatic parameters, including temperature, base and subbase moisture, and frost depth are monitored at different depth along the pavement. The calibration and installation of the instruments at the Smart Road has been presented elsewhere (Al-Qadi et al. 1999).

## 3 GEOCOMPOSITE INSTALLATION

Installation of geosynthetic in pavements is a major source of damage for the material and, hence, may impact its potential effectiveness. The followed installation procedure used at the Smart Road was newly developed due to the lack of familiarity with the installation of such materials in roadways. The installation of the geocomposite membrane in section J (moisture barrier over a granular material) did not necessitate the use of a prime coat between the geotextile and the underneath layer. A prime coat would not be effective when applied to a granular material (21B) due to the nature of the surface that accumulates lots of loose aggregates and due to the fact that greater friction may exist between the geocomposite membrane and the aggregate layer when the prime coat is absent. Five rolls, 37-m-long and 2.05-m-wide each, were installed over the complete width of the road and 2.15-m into the shoulder. Figure 2 shows the layout of the geocomposite installation in section K.

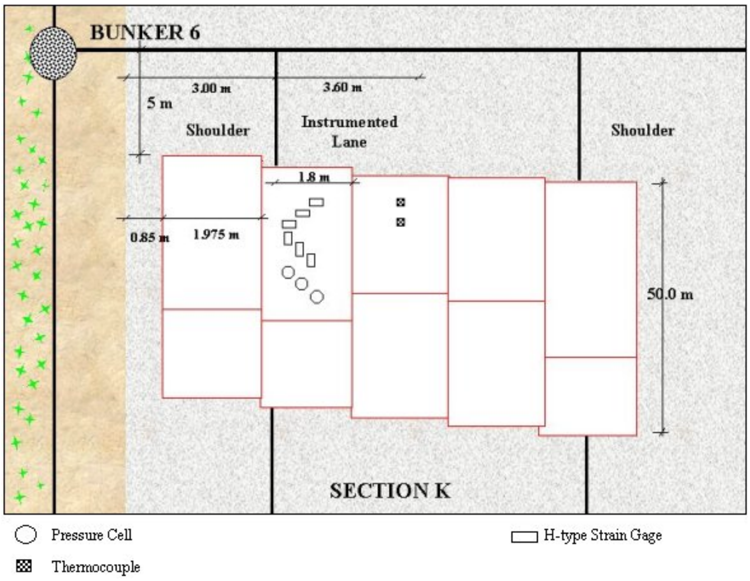


Figure 2. General layout of the geocomposite membrane installation in section K.

Transverse joints were planned to be staggered. An overlap of 85 mm was made at the transverse joints. The connection of the longitudinal joints was done by welding a 55 mm length at the edge of each roll by applying hot air to melt the uncovered PVC end. The welding was then carefully checked. Figure 3 illustrates the final product of the installation. The upper surface of the geocomposite membrane was primed using PG 64-22 asphalt binder at a rate of 1.5 kg/m$^2$. Seventy-five mm of asphalt treated drainage layer was then placed on top of the geocomposite membrane. Temperature and moisture sensors were placed on both sides of the geocomposite membrane, while three pressure cells (500 mm apart) were installed under the membrane. The installation of the geocomposite membrane in section K was slightly different than the previous procedure; it was installed after placing two lifts of BM-25.0. A tack coat was applied underneath the geotextile of the geocomposite membrane to prevent it from moving during installation of the upper layer, and to the top of the geotextile of the geocomposite membrane to minimize the absorption of liquid asphalt during construction of the upper HMA layer during construction. The required amount of tack coat was previously investigated and has been presented elsewhere (Donovan et al. 1999): A rate of 1.25 kg/m$^2$ was applied underneath the lower geotextile. After the installation of the geocomposite membrane and prior to applying the tack coat on top of it, a pneumatic-tired roller (PTR) was used to compact the geocomposite membrane to ensure good adhesion between the geocomposite membrane and the underneath layer. Tack coat was then applied to the upper geotextile of the geocomposite membrane at a rate of 1.4 kg/m$^2$ (see Figure 4), and another lift of BM-25.0 was applied followed by 19-mm-thick SM 9.5D and the OGFC layer.

Figure 3. Installation of the geocomposite membrane in section J showing the wedding process, staggered installation is also shown.

The presence of the embedded instruments in each section required extra-care during the geocomposite membrane installation to avoid any damage to the instruments. The installation of the instruments was very successful with a total loss of less than 10%. This number is very low when a loss of 50% is not unusual (Ullidtz 1987).

Figure 4. Applying tack coat on top of the geocomposite membrane

## 4 GEOCOMPOSITE STRUCTURAL EVALUATION

Structural evaluation of pavement using Falling Weight Deflectometer (FWD) was the first technique adopted to investigate the effectiveness of the geocomposite membrane. In this test, a force pulse is applied to the pavement system by dropping a weight on a specially designed set of springs. This produces an impact load with duration of 25-30 msec; surface deflections are measured and recorded by seven (or more) geophones at various distances from the loading point. A number of deflection basin parameters (e.g. radius of curvature, spreadability, deflection ratio, etc.), which are functions of deflection values at one or more sensors, were introduced to check the structural integrity of in-service pavements. Most of these parameters reflect one simple idea: the greater the deflection(s), the weaker the pavement system. This system is currently widely used at the network level to diagnose the structural integrity of in-service pavement.

Falling Weight Deflectometer (FWD) tests were conducted before and after the installation of the geocomposite membrane in both sections and periodically after construction. Figure 5 illustrates the measured deflection on top and below the geocomposite membrane in section J. As shown in this figure, the center deflection exhibits a very high jump due to the polymeric nature of the membrane. The load-deformation behavior of the geocomposite membrane is similar to that of a rubber band (i.e., increasing tensile strength with increased elongation, which may reach up to 300% of the original length for some materials, and the ability to recover to the initial state after removal of load). This elastic behavior is considered a desired property in pavement systems as it may reduce the potential of fatigue damages. It is important to note that the classical approach of assuming the less deflection, the stronger the pavement, may not be valid for the analysis of pavement systems incorporating geocomposite membranes. Due to the low modulus property of the geocomposite membrane, it may produce greater deformation under loading, but it has the capability to dissipate applied stresses.

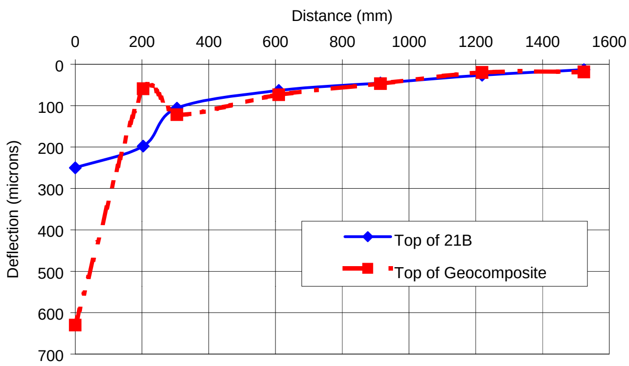


Figure 5. Falling weight deflectometer results on top and underneath the geocomposite membrane.

Figure 6 illustrates the same trend on top of the wearing surface after completion of the construction. To optimize the benefits of utilizing the geocomposite membranes in pavement systems, several parameters may need to be carefully evaluated including pavement thickness, geocomposite membrane location in pavements, geocomposite membrane thickness, and pavement loading.

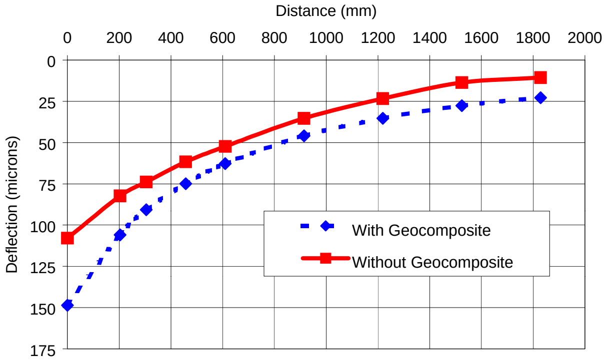


Figure 6. Falling weight deflectometer results for two pavement sections with and without geocomposite membrane.

## 5 GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) has been used for the last 30 years as a nondestructive evaluation (NDE) technique to evaluate and assess pavement structures and their performance. This technique is based on sending electromagnetic waves through the surveyed structure and then analyzing the reflected signal (Loulizi et al. 1997). Ground penetrating radar is periodically used to monitor water movement in the pavement sections at the Smart Road and to identify any significant changes in the pavement system profile. Figure 7 illustrates a scan taken at the pavement surface showing the geocomposite membrane (Section J). In this scan, the uniformity of the color refers to the absence of any abnormal spots (i.e. water accumulation, voids, etc.).

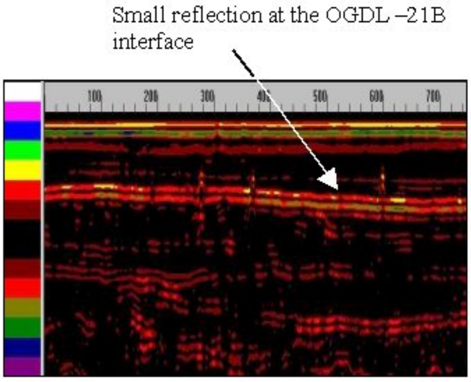


Figure 7. GPR survey on top of the geocomposite membrane in section J.

On the other hand, Figure 8 presents a scan taken for a similar pavement section but without the geocomposite membrane. As one may note in this case, a green area (represents large reflection due to moisture presence) appears at the interface between the drainage layer (OGDL) and the underneath layer (21B aggregate layer). This indicates that the 21B layer has high moisture content, which may not be desirable as it will reduce the resilient modulus of that layer and, hence, the structural capacity of the pavement system. This preliminary result raises some concerns about using a drainage layer without any particular precautions for the drained water. An effective geocomposite membrane layer may solve such problems by forming a water barrier preventing the saturation of underlying layers and forcing the water to drain laterally to a shoulder drain system.

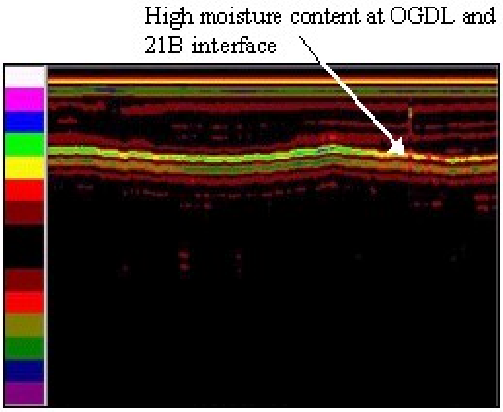


Figure 8. GPR survey on a section without geocomposite membrane.

## 6 INSTRUMENT RESPONSES

Due to the difficulty of measurements and the very high cost of road test facilities, very little can be known about the actual effects of geocomposite membranes on pavements subjected to dynamic loading. Although theoretical analysis using finite element and fracture mechanics has been previously conducted on the effectiveness of geosynthetics in pavements, it is virtually impossible to verify their contributions based on these studies without in-situ measurements of pavement layer responses. Figure 9 illustrates the measured vertical stress under the geocomposite membrane in section K and at the bottom of the BM-25.0. These responses correspond to two different axles: a single axle and a tandem axle. During this test, the speed was kept constant at 15 km/hr and the tire pressure at 724 kPa. As noticed from this figure, very high stress was measured underneath the geocomposite membrane (280.6 kPa) relative to the vertical stress at the bottom of the BM-25.0 layer (52.7 kPa).

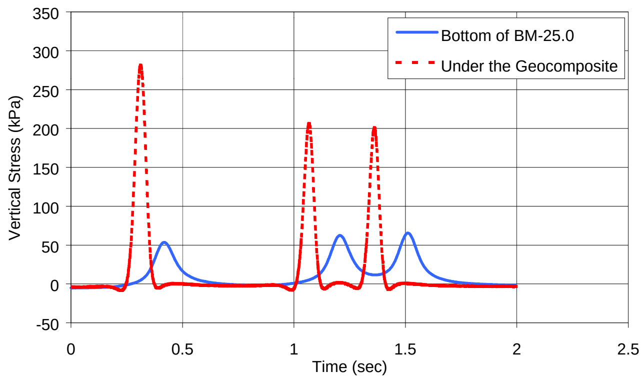


Figure 9. Vertical stress under the geocomposite membrane and at the bottom of the BM-25.0 layer.

Figure 10 illustrates the measured transversal strain in two locations: the first location is underneath the geocomposite membrane under 75mm of BM-25.0; the second location is in a regular section at the Smart Road under 150mm of BM-25.0. As noticed from this figure, the measured strain is approximately the same. The measured strains in both locations indicate that the geocomposite membrane may provide a substantial strain absorption, which results in a significant reduction in the transversal strain in the HMA layer.

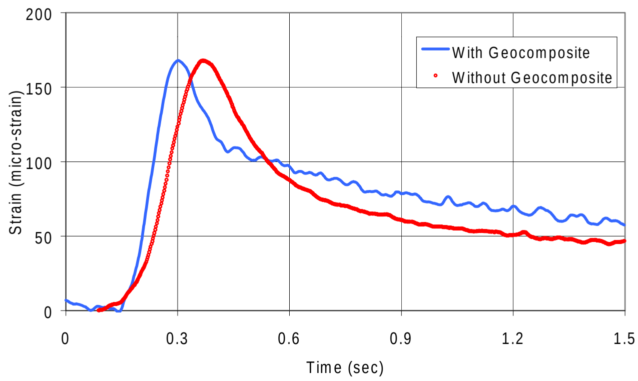


Figure 10. Measured transversal strain for two pavement sections with and without geocomposite membrane.

Measured stresses and strains were checked using a finite element model developed using ABAQUS (ABAQUS 1998). As expected, this simulation indicates that the generated strains and stresses on the geocomposite membrane are very high. In addition, the simulation indicates that the resulting deformation when using the geocomposite membrane is greater than without the membrane. This supports earlier findings based on the FWD results (Fig. 11).

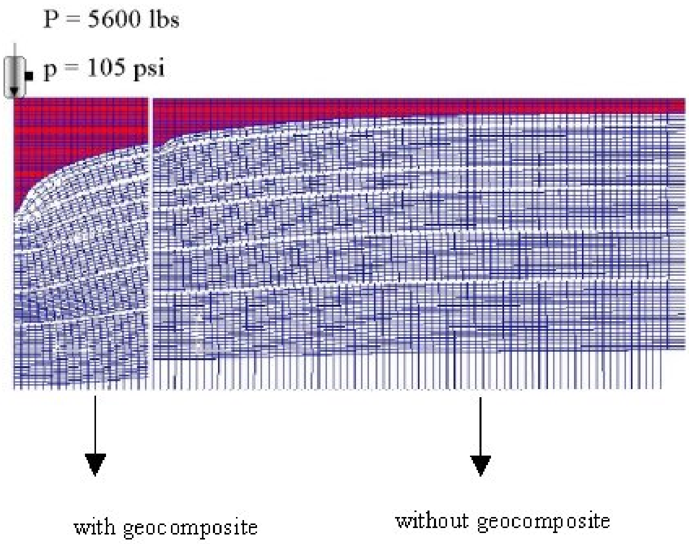


Figure 11. Comparison between the deformation for two pavement sections with and without geocomposite membrane.

To effectively enhance pavement performance, the geocomposite membrane should absorb a significant part of the generated tensile strain when installed at an interface. However, the geocomposite membrane would then exhibit large deformations due to the absorbed stresses. These deformations will be both vertical (due to the vertical load) and horizontal (due the absorbed stress).

## 7 CONCLUSIONS

To develop a fundamental understanding of how geosynthetics may contribute to the performance of flexible pavements under environmental and vehicular loadings, a full-scale instrumented facility may provide significant information as to the in-situ behavior of the paving materials and geosynthetic contribution. In addition, allow the verification of any theoretical analysis. This paper presents preliminary results as to the effectiveness of geocomposite membranes used in roads for the first time and tested at the Virginia Smart Road:

- Initial analysis of the collected data from embedded instruments showed the ability of the geocomposite membrane to significantly reduce the transversal tensile strain in the supporting layer due to its strain energy absorption capability.
- The FWD results indicate the ability of the geocomposite membranes to enhance the performance of a pavement system by allowing for greater “recoverable” deformations.
- The GPR results showed the ability of this type of geocomposite membrane to effectively enhance draining the water out of the pavement system laterally to the drainage system when installed underneath an open-graded drainage layer.

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