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Use of Enhanced Lateral Drainage Geotextiles in a Pavement Founded on Expansive Clays

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ABSTRACT

Expansive clay soils are a major source of distress in pavements founded on them, responsible for billions of dollars' worth of damage every year in the United States alone. Moisture migration in clays is directly responsible for the volumetric changes in expansive clays, which cause the pavement distresses, typically in the form of longitudinal cracks. Newly developed enhanced lateral drainage geotextiles aim to minimize expansive clay-related damages by providing in-plane enhanced drainage to control the differences in the moisture content (and consequently differential volume changes) within the clay soil. In order to evaluate the performance of enhanced lateral drainage geotextiles in a pavement section founded on expansive clays, eight 500 ft (152 m) long test sections were constructed along State Highway 21 (SH-21) near Bastrop, Texas, USA, in 2013. Four different geotextiles were installed, including one with enhanced drainage capabilities, two with conventional woven geotextiles, and one with a conventional nonwoven geotextile. Each test section was equipped with sensors to monitor moisture within the expansive clay subgrade. Regular site visits were conducted after construction of the sections to retrieve moisture data and conduct condition surveys to document pavement distresses. Additionally, total station surveys were conducted to monitor vertical displacements and resulting fluctuations in the shrink/swell behavior of the soil. Results indicate that enhanced drainage geotextiles facilitate equilibrating the moisture content within the underlying subgrade soils, unlike conventional geotextiles that did show significant differences in subgrade moisture content within the pavement section.

1. INTRODUCTION

Expansive clay soils are considered one of the most common instigators leading to distresses in pavements. The annual cost of expansive clay related damage in the United States alone is over US$9 billion (Zhao et al., 2014). This value exceeds the average annual cost of damages caused by other natural hazards including earthquakes, hurricanes, and floods combined (Jones and Holtz, 1973). A likely reason for the high damage costs related to expansive clays is that approximately one-fourth of the United States is underlain with expansive clays (Olive et al., 1989).

Multiple methods exist for remediating or minimizing expansive clay related damage. Methods include lime stabilization, moisture conditioning the soil, removing and replacing the expansive soil, and using geosynthetic reinforcement (Wise and Hudson, 1971). Each of these methods may work to varying degrees of success on a case by case basis. However, it is important to note that the damage caused by expansive clays is a direct result of differential moisture movement (i.e., uneven distribution of moisture) within the clay soil (Zornberg et al., 2012). Therefore, in order to limit damage resulting from expansive clays, a mitigation method that allows for better moisture control can be considered.

A new category of geotextile has been developed to provide in-plane enhanced drainage (IPED). This geotextile may serve as a subsurface drainage layer for pavement structures to control the moisture migration in an expansive clay subgrade. Additionally, the geotextile may provide reinforcement to stiffen the overall structure of the pavement (Roodi, 2016). The main objective of this paper is to assess the suitability of IPED geotextiles to mitigate expansive clay related damage to pavements. To reach the objective of this study, an instrumented pavement section founded on an expansive clay was constructed along State Highway 21 (SH-21) in Bastrop, Texas. Multiple test sections were constructed using both conventional and enhanced drainage geotextiles to compare their behavior. Data collected in this field study includes soil moisture, precipitation, distresses from pavement condition surveys, and elevation profiles from total station surveys. The results from each of these data sources will be analyzed and discussed in this paper to assess the ability of conventional and enhanced drainage geotextiles to minimize expansive clay damage in pavements.

2. BACKGROUND

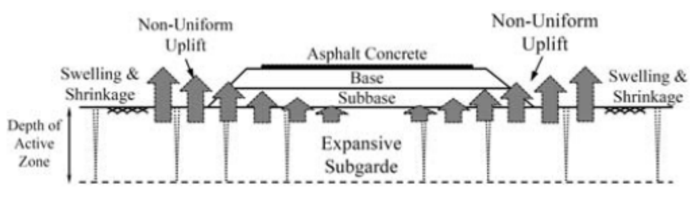
2.1 Expansive Clay Soils in Pavements

Expansive clay soils are soils that will swell upon wetting and shrink upon drying. Typically, the expansive nature of a soil is classified by the plasticity index (PI). Soils with low swelling potential will have a PI in the range of 0 to 15, medium swell potential soils will have a PI of 10 to 35, high swell potential soils will have a PI of 20 to 55, and very high swell potential soils will have a PI of 35 and above (ASTM D4829).

The main distress associated with pavements founded on expansive clays is environmentally induced longitudinal cracks near the shoulders of pavements. Figure 1 shows a typical pavement section founded on expansive clays. Damages induced by expansive clay are identified by multiple parallel longitudinal cracks near the pavement shoulders.

Figure 1. Typical longitudinal cracks related to expansive clays in pavements

The mechanism instigating expansive clay related pavement distress is induced by seasonal wet and dry cycles. The environmental moisture variations due to these rainy or dry periods may lead to different values of moisture content in the center of a pavement than at the shoulder. As shown in Figure 2a, the shoulder of a typical pavement will have more access to moisture from the environment. On the other hand, it is unlikely that moisture will migrate to the center of the pavement. Therefore, the edges of the pavement will shrink and swell due to moisture fluctuations, while the center of the pavement will not. Cyclic wet and dry seasons cause the pavement to swell during moist conditions, and shrink during dry periods. This repetitive shrink-swell behavior creates a non-uniform uplift between the center and shoulder of the pavement. As shown in Figure 2b, this differential settlement creates zones of high stresses that manifest into longitudinal cracks (Roodi & Zornberg, 2012). During particularly long periods of drought, multiple parallel significant longitudinal cracks may occur due to the severe shrinking of the soil in the pavement shoulders (Zornberg et al., 2010).



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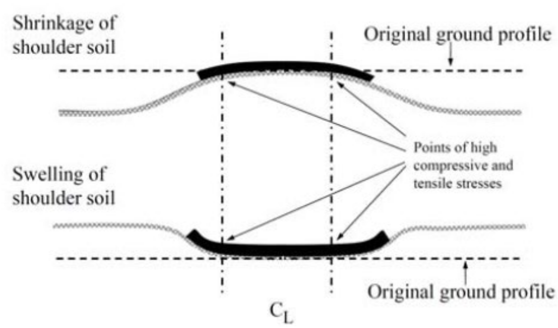

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Figure 2. Diagram of pavements founded on expansive clays (Roodi & Zornberg, 2012), (a) non-uniform uplift caused by uneven moisture distribution, (b) zones of high stresses where longitudinal cracks appear.

2.2 Subsurface Pavement Drainage

The addition of moisture to pavements can be detrimental, therefore, drainage systems can be implemented in pavement designs to remove excess moisture from a pavement structure. The most common pavement drainage method is an aggregate drainage layer. In this case, a certain thickness (typically at least a few inches) of select aggregate is placed as a sub-base across the entire subgrade. A major issue with using drainable base is cost. Drainable base costs an average of $40/ton compared to about $12/ton for regular base aggregate (costs are estimated using average aggregate costs and the method outlined in USDA, 2011). An additional cost associated with drainable base is transporting it to sites if it is only available in certain areas. Besides cost, an aggregate drainage base has the added potential problem of losing some of its thickness over time if the aggregates start penetrating into the subgrade soil. The loss in thickness of the aggregate base layer will reduce the overall structural number of the pavement.

Geosynthetics can play a role in providing proper drainage for a pavement. Instead of using a drainable aggregate, an alternative would be to utilize a geosynthetic drainage layer. When performing a drainage function, geosynthetics act as a drain to transport moisture out of the less permeable pavement soils. A geosynthetic pavement drainage system typically consists of a horizontal geocomposite drain placed directly beneath the pavement to laterally divert moisture that penetrates the pavement surface through in-plane drainage. Geocomposite edge drains are located on the shoulders of the pavement and direct moisture into geopipes that will in turn carry the moisture away from the pavement. Typical geosynthetics that provide drainage are geotextiles, geonets, geocomposites, and geopipes.

The importance of drainage in pavements is often overlooked by designers which focus on building a strong, high quality pavement, but may be lacking in drainage features. Unfortunately, moisture trapped under a pavement will exacerbate pavement distresses by increases in pore pressures and softening the subgrade soil. A properly designed geosynthetic drainage system can eliminate most issues related to inadequate pavement subsurface drainage. Also, while a typical pavement drain has a relatively thick aggregate drainage layer, a geocomposite drainage system is much simpler, which could allow for a reduction in cost of materials and construction time. Similarly, the geocomposite drain system is self-contained, requiring minimal design effort. The installation procedure is also much faster than that of an aggregate drain, as the simple unrolling of a geosynthetic encompasses most of the entire procedure (FHWA, 2008).

Even though drainage layers have been considered for use as a sub-base layer across the entire pavement section, such alternatives are only rarely implemented due to concerns of high cost, constructability, and potential aggregate loss with time. And although uncommon, geocomposite drainage layers consisting of conventional geotextiles and a core geonet have been adopted within roadway systems. However, both granular and geocomposite drainage layers provide lateral drainage only under saturated conditions (Azevedo, 2013) and not under the most typical unsaturated conditions.

2.3 In-Plane Enhanced Drainage Geosynthetics

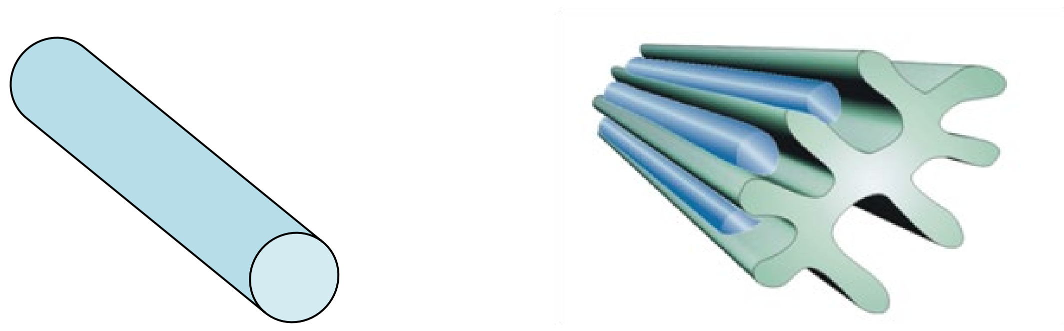
In general, applications that require the function of in-plane drainage with geosynthetics involve a geocomposite drainage net. Typical drainage nets are composed of a geonet sandwiched between two layers of nonwoven geotextiles. However, conventional nonwoven and woven geotextiles can fail to perform as efficient in-plane drainage layers. This is because conventional geosynthetic drains are really only suitable for managing flow under saturated soil conditions, while unsaturated conditions are commonly prevalent in pavement systems.

Previous versions of enhanced drainage geosynthetics have been utilized to remove excess water from rainfall infiltration or capillary barriers from pavements by laterally diverting moisture. Both the Terram Frost Blanket (Jay, 2002) and the Geocomposite Capillary Barrier Drain (Henry and Stormont, 2002) were reported to successfully mitigate frost heave in pavements in cold climates. The two geosynthetics are similar in structure, consisting of a geonet sandwiched between two special nonwoven geotextile transport layers to compose a drainage geocomposite. The capillary barrier created by the geocomposites in addition to their lateral drainage function was able to suppress capillary rise of groundwater, ice lens growth and subsequent heave, subgrade saturation and softening during spring thaw, and pavement damage caused by traffic loads. During the summer months, the geocomposites perform the function of laterally diverting moisture accumulation above them even under unsaturated conditions.

Recent developments have led to the creation of geotextile products that allow for improved drainage capabilities while also providing reinforcement. These new types of products are termed in-plane enhanced drainage (IPED) geotextiles and allow drainage even under unsaturated conditions. An in-plane enhanced drainage geotextile combines the functions of a nonwoven and woven geotextile to provide both the proper flow capacity for drainage as well as being able to transmit water along its length.

The enhanced drainage capacity of the IPED geotextile utilized in this study is provided by special grooved nylon fibers woven into the geotextile. Figures 3a and 3b display both a typical fiber present in standard geotextiles and a grooved cross-section that would be present in an IPED geotextile, respectively. The nylon fiber was developed with a unique grooved cross-section. The unique fiber cross-section shown in Figure 3b has deep grooves that allow for water to be carried by channels along the longitudinal axis of the fiber. The nylon fabric is both hydrophilic and hygroscopic. That is, the nylon will pull water from the surrounding soil as well as provide a conduit for the moisture along its channels. The channels provide some moisture storage as well, but since the channels are not large, their main function is to transport any absorbed water laterally. The channel width between the grooves is approximately 8 µm to prevent clogging from larger particles. Each grooved yarn is bundled into a strand of approximately 150 fibers.

The grooved fibers shown in Figure 3b can be substituted for the standard monofilament fibers in a conventional woven geotextile. In this case, the drainage capability of the woven geotextile is increased by allowing for transmission along its voids as well as through the grooved yarns as well. Additionally, if the IPED geotextile is woven and is rated for reinforcement, then the in-plane drainage layer may also provide the function of reinforcement at the same time.



a) b)

Figure 3. Geotextile fiber cross-sections, (a) typical monofilament fiber and (b) grooved cross-section to allow moisture transmission along the fiber.

Multiple case histories of recently constructed pavements designed with IPED geotextiles are presented in Zornberg et al. (2017). The selected case histories highlighted different applications where an enhanced drainage material may be particularly beneficial to mitigate moisture related pavement distresses due to high water tables, capillary rise, frost heave, expansive clays, and surface infiltration. Each case history was monitored throughout and after construction, with results indicating that the use of an IPED geotextile improves the pavement performance.

3. METHODOLOGY

3.1 Objectives

The objective of this study was to construct multiple test sections along a pavement founded on expansive clays to observe how an IPED geotextile may reduce the consequences associated with the shrink-swell behavior of the expansive clay subgrade soil in comparison to conventional geotextiles. The mechanism for mitigating shrink-swell related damage in pavements is associated with the ability for the IPED geotextile to transport water along its plane. Figure 4 illustrates the effect of placing an IPED geotextile at the interface of the base layer and an expansive clay subgrade. Theoretically, the geotextile is able to homogenize the distribution of water along its entire length. Accordingly, while moisture variations may still occur closer to the pavement edge, the IPED geotextile may facilitate migration of moisture under unsaturated conditions, resulting in a comparatively uniform moisture distribution across the width of the pavement structure. In the subgrade, this improved uniform moisture distribution will minimize differential vertical movements in the pavement and thus mitigate the development of longitudinal cracking. That is, while an IPED geotextile may not prevent a soil from shrinking or swelling, the shrink-swell behavior is expected to be uniform which will reduce the differential movements that lead to cracking.

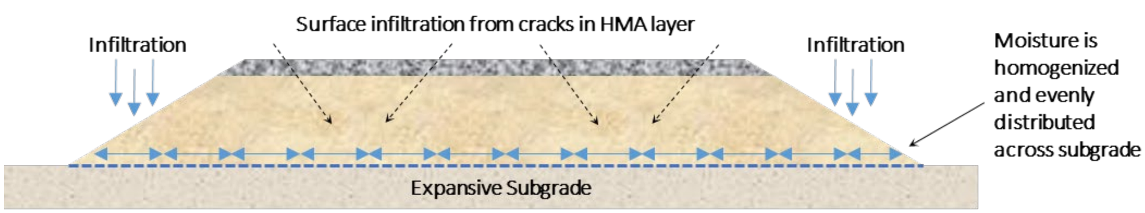


Figure 4. Moisture homogenization in expansive clay subgrade by IPED geotextile

3.2 Site Location and Pre-Construction Performance

The test sections for this study were incorporated into the rehabilitation of a 6 mile (10 km) stretch of Texas State Highway 21 (SH-21), just north of Bastrop, Texas, USA. The location of the site is approximately 40 miles east of Austin, Texas. The test sections are located approximately 1.5 miles (2.4 km) south of the intersection of SH-21 with US-290.

The SH-21 pavement is founded on an expansive clay subgrade and was rehabilitated by the Texas Department of Transportation (TxDOT) in 2013. Prior to rehabilitation, the road had been subject to continued maintenance operations.

Yet, rating of this road's pavement performance conducted by TxDOT prior to the 2013 rehabilitation still revealed inadequate performance. The study found that 26% of the road was performing well, 32% of the road had edge cracking, 38% of the road had patches and level-ups, and 4% of the road had longitudinal cracks within the inner and outer lanes. The poor performance of the road had been evident for many years, with multiple attempts at maintenance unable to halt the deterioration of the road. Extensive longitudinal and edge cracking was prevalent along the highway in 2012.

3.3 Soil Characterization

A comprehensive characterization of the subgrade soil was conducted on samples taken from the site prior to construction of the test sections. Atterberg limit tests revealed an average liquid limit (LL) of 58, plastic limit (PL) of 17, and a calculated PI of 41. This classifies the clay as having a high to very high swell potential. The USCS classification was confirmed to be a highly plastic clay (CH). Tests conducted on the clay samples determined a specific gravity of 2.784 and a sulfate content of 1,288 ppm (relatively low sulfate content). Various permeability tests conducted in a flexible wall permeameter test per ASTM D5084 indicate an average saturated hydraulic conductivity value in the range of $1x10^{-8}$ cm/s. X-ray diffraction tests confirmed the presence of montmorillonite in the mineralogy of the clay.

3.4 Pavement and Test Section Design

A pavement design was developed by TxDOT to rehabilitate this poorly performing section of SH-21. A cross-section of the reconstructed pavement in the test section area is shown in Figure 5. The rehabilitation plan called for milling the top 3 in (76 mm) of the existing pavement, partially excavating to the exterior white line, and widening of the existing shoulder. Following completion of the excavation process, a 9 ft (2.75 m) geotextile was placed on the shoulder of the pavement, and overlain by base aggregate (gravel between 3/8 to 3 in [9.5 to 76 mm] diameter). Design limitations did not allow the geotextiles to span the entire width of the pavement. At two locations within the base aggregate layer, biaxial geogrids were placed as shown in Figure 5. To complete the pavement, 6 in (152 mm) of cement treated base was added, followed by a 3 in (76 mm) thick layer of hot mix asphalt (HMA), and topped off with a thin overlay mixture.

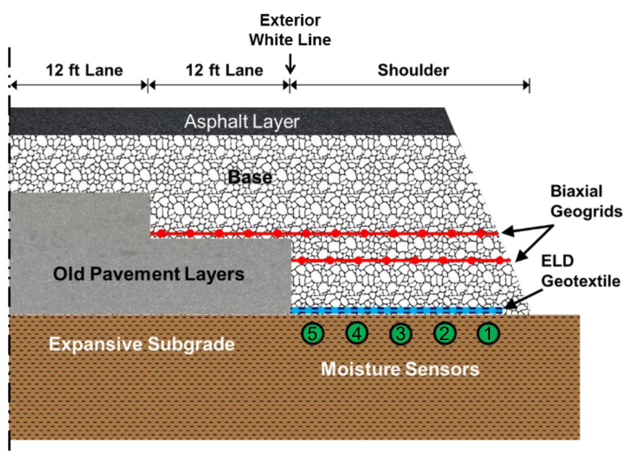


Figure 5. Reconstructed SH-21 cross section showing moisture sensor locations

Since the drainage and cyclic volumetric changes of the pavement were of major concern, The University of Texas at Austin suggested the evaluation of multiple test sections to TxDOT. The test sections would allow for the investigation of the nature of moisture changes in the subgrade material and its direct impact on volumetric changes and pavement degradation. A total of eight 500 ft (152 m) test sections were created to evaluate the impact of four different types of geotextiles on the performance of pavements founded over expansive clays. The geotextiles evaluated were a standard nonwoven geotextile separator, two types of woven high strength reinforcement geotextile, and a woven IPED geotextile. Each geotextile was 9 ft long and placed solely in the shoulder of the pavement above the subgrade as shown in Figure 5. The specific function for the geotextiles used in this project are listed in Table 1.

Table 1. Geotextiles included in testing program

Geotextile	Geotextile Functions
GT1	Separation
GT2	Separation, Reinforcement
GT3	Separation, Reinforcement
GT4	Separation, Reinforcement, Drainage

All geotextiles utilized in this study are currently available products with manufacturer reported properties provided in Table 2. The geotextile designated as a control is GT1. GT1 is a standard nonwoven product composed of polypropylene fibers and is used solely as a separator. While GT1 has relatively high puncture and tear resistance to withstand installation damage, it would not be suitable as a reinforcement geotextile. Two other geotextiles were implemented to provide the functions of separation and reinforcement. The first geotextile is the woven GT2, which is also composed of polypropylene. GT2 is not suitable for drainage since it has little to no storage space for water in the geotextile. Instead of drainage, GT2 is used for reinforcement purposes since it has high ultimate tensile strength per ASTM D4595. The woven geotextile GT3 is very similar in composition to the geotextile GT2. In fact, both geotextiles have the same polypropylene fibers in the machine direction. The difference between the geotextiles is that the GT3 product has a higher tensile strength capacity than the GT2 product, as it has additional fibers in the cross-machine direction.

Table 2. Manufacturer reported geotextile properties

Geotextile Property	Test Method	Unit	GT1	GT2	GT3	GT4
Apparent Opening Size	ASTM D4751	mm	0.18	0.6	0.43	0.43
Weight	ASTM D5261	g/m^2	271	475	450	575
Thickness	ASTM D5199	mm	1.8	1.25	1.5	1.65
Transmissivity	ASTM D4491	L/min/m^2	3870	1222	3056	1194
Permittivity	ASTM D4491	sec^{-1}	1.1	0.4	1	0.4
Cross-Plane Hydraulic Conductivity[1]	ASTM D4491	cm/s	0.198	0.05	0.15	0.07
Porosity[1]	—	—	0.835	0.582	0.670	0.617
Ultimate Tensile Strength	ASTM D4595	kN/m	—	70.0	—	78.8

[1] Properties calculated based on manufacturer reported properties

As described in the background section, the woven IPED geotextile GT4 can provide the functions of separation, reinforcement, and drainage. Compared to GT2, the geotextile GT4 has a very similar composition. In fact, both geotextiles have the exact same polypropylene fibers. The main difference between the geotextiles is that GT4 replaces some of the transverse polypropylene fibers with nylon. Not only are the polypropylene fibers replaced, however, but more nylon strands are added per inch, making GT4 a denser geotextile than GT2. The nylon fibers are bundled into strands of approximately 150 wicking fibers. The polypropylene is hydrophobic so it will not absorb water. Instead, the pattern of the weave and the polypropylene itself will help guide the water laterally along with the nylon fibers.

It should be noted that the original TxDOT design specified a separator geotextile (GT1) and geogrids as shown in Figure 5. No other changes were allowed or made to the pavement section other than simply substituting GT1 with other geotextiles in the test sections. As shown in Figure 6, each geotextile was 9 ft (2.7 m) wide and placed only in the pavement shoulder area, in accordance with the planned rehabilitation project, where the subgrade was exposed in this portion of pavement only. A control section with no geotextile or geogrid was not permitted in any test section.

Figure 6 shows the layout of the test sections along SH-21. In total, there are eight sections, and each section is 500 ft (152 m) in length. A repeat section for each geotextile was constructed along the eastbound side of the highway for reliability purposes. The eastbound section of the highway was only constructed with the control geotextile GT1.

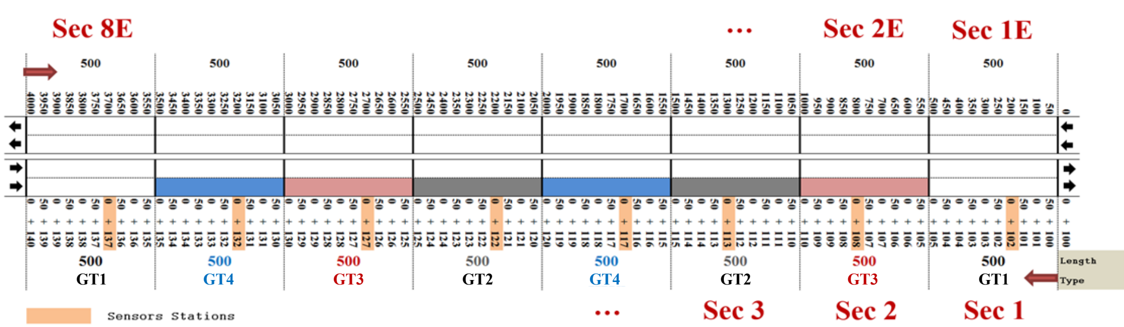


Figure 6. SH-21 test section layout

3.5 Moisture Sensor Installation and Test Section Construction

As part of the evaluation program, moisture sensors were installed in the subgrade at the center of each 500 ft (152 m) long test section to monitor the performance of the geotextiles. These moisture sensors allowed monitoring of changes in moisture content in the subgrade along the road shoulder, where moisture fluctuations were expected to be highest. A horizontal array of sensors was installed 5 cm below the top of the subgrade to evaluate the hydraulic performance of the various geotextiles. The approximate location of the sensor array is displayed in Figure 5.

Two different types of capacitance type moisture sensors were installed in each test section. The array featured a total of five sensors manufactured by Decagon Devices. Four of the five sensors were ECH2O EC-5 sensors, while the middle sensor in the array was a 5TE sensor. The main difference between the sensors is that the EC-5 sensor only provides volumetric moisture content data, while the 5TE sensor records volumetric water content, temperature, and electrical conductivity. All sensors were attached to Em50 dataloggers through 3.5 mm stereo jacks with data recorded hourly.

The test sections were constructed in January 2013. Prior to installation of the moisture sensors, the shoulder of the pavement was excavated to the subgrade and compacted per the project specifications. A shallow trench was excavated to install the moisture sensors below the top of the subgrade. The sensors were installed approximately 2 ft (0.61 m) apart. Once the sensors were installed, the trenches were backfilled and recompacted to the same level as the surrounding soil. Geotextiles were installed above the subgrade by unrolling the product rolls in each test section. After placement of the geotextiles, a layer of base gravel was placed immediately above the geotextiles. Construction continued following the design shown in Figure 5 until all layers of the pavement were installed.

4. RESULTS

4.1 Moisture Sensor Data

Moisture sensor data was collected every hour and stored in the datalogger. Bi-monthly site visits were conducted to collect the moisture data and inspect the pavement. The raw moisture sensor data was found to be sensitive to seasonal temperature fluctuations and a temperature correction was applied based on weather station data. Also, the data from the 5TE sensor in datalogger Port 3 was generally discarded for all sections. It was found that the 5TE sensor recorded drastically lower moisture contents compared to all of the other sensors (EC-5). This issue was apparent in many of the test sections. A soil specific sensor calibration was conducted for this study, however, the results were inconsistent when applied to the raw data. It was concluded that a sensor specific calibration should have been performed instead.

The horizontal moisture sensor array data is shown in the form of moisture profiles. This approach involves taking the average moisture content in a given month for each sensor and plotting horizontal moisture profiles over time. In this manner, the change in moisture content beneath the subgrade at a given time can be visualized. The horizontal moisture profiles for a conventional geotextile section are shown in Figure 7a. The results in this figure show that the moisture content in these sections was rather non-uniform, typically with the highest value toward the pavement outer shoulder edge (sensor 1) and lowest value closer toward the inner portion of the pavement (sensor 5). In fact, the difference in volumetric moisture content between the shoulder edge and the inner pavement reached values as high as 15%.

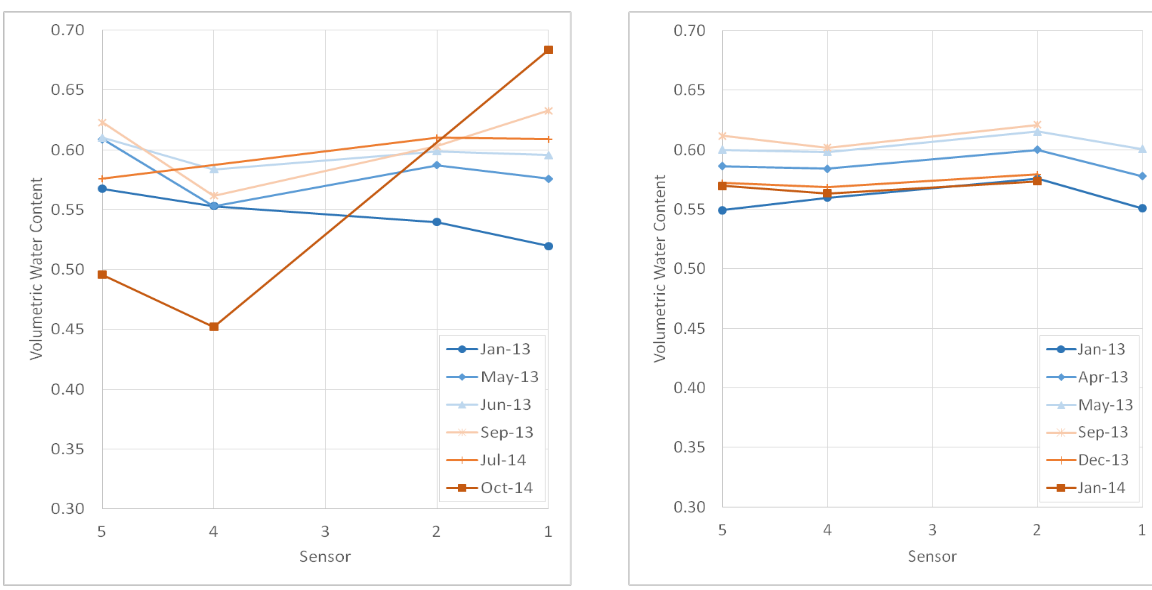


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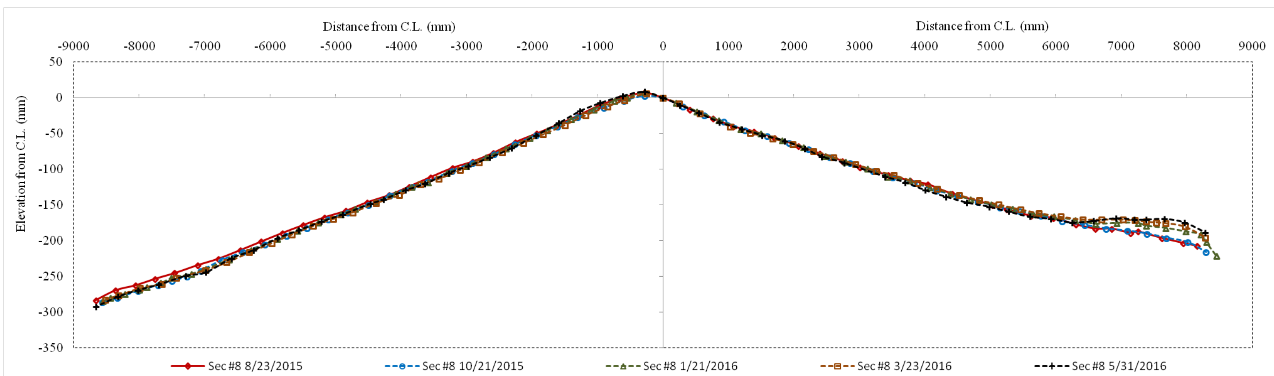
Figure 7. Moisture content along SH-21 shoulder, (a) Conventional geotextile section and (b) IPED geotextile section.

Figure 7b displays moisture profiles for a test section in which an IPED geotextile was used. For IPED geotextile sections, moisture content remained relatively uniform over time and across the entire width of the shoulder. Even though changes in moisture content were expected over time because the monitoring period included reasonably wet and dry seasons, the changes were fairly similar across the various monitored locations. Consequently, moisture content distribution remained reasonably uniform at any given time. In this case, the difference in volumetric moisture content between the edge and the center of the pavement remained around 3%.

4.2 Total Station Data

Total station surveys were initiated in August 2015 to monitor any fluctuations in the shrink-swell behavior of the soil. The surveys involved measuring the surface elevation of the pavement at each section near the location of the moisture sensor array with a total station as outlined in Roodi et al. (2016). By repeating the survey every two months at the same location, a record of changes in the pavement surface profile could be observed. Due to safety concerns, permanent markings were not able to placed along the width of the road inside the lanes. Instead, a rope with marked 1 ft (305 mm) intervals was placed across the width of the road at the profile measurement location. While the survey points in the inside lanes were not taken at the exact same location each time, permanent markings on the shoulder provided a few constant survey points. Considering that most of the potential heave or shrink of the pavement was expected to occur in the shoulder, this method was deemed acceptable. Also, survey results showed that even with the slightly different survey points, consistent surface profiles were recorded. Figure 8a and 8b show typical pavement surface profiles for conventional geotextile sections and IPED geotextile sections taken on five different dates over the course of about a year. The profiles show the progression of heave in the pavement shoulder over time. For each profile, the westbound lane corresponds to a negative distance from the pavement center line, while the eastbound lane corresponds to a positive distance from the center line.



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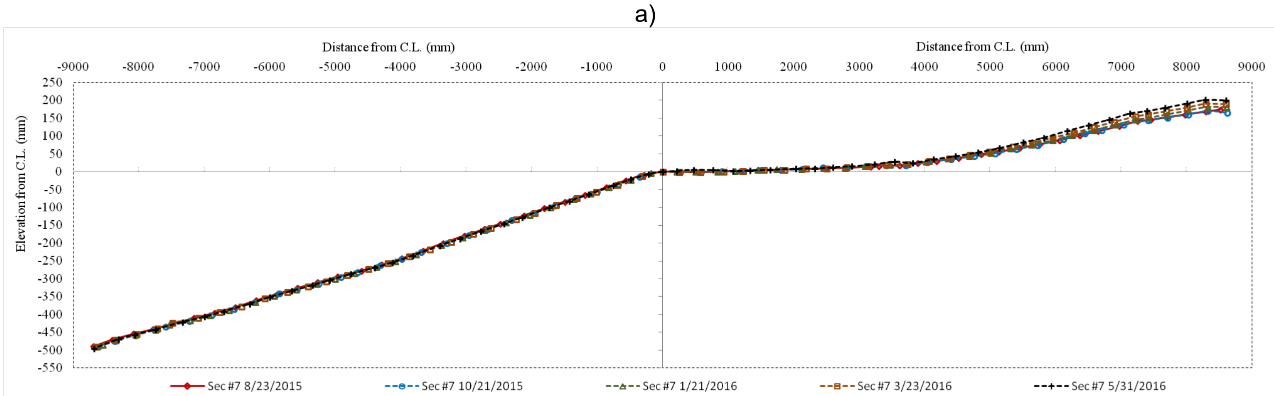

b)

Figure 8. Typical total station survey results, (a) Conventional geotextile section and (b) IPED geotextile section.

5. DISCUSSION

One of the main objectives of this project was to compare the moisture content distribution in sections with conventional geotextiles and sections with IPED geotextiles. Results from the horizontal moisture content profiles constructed with

GT4 (Sections 4 and 7) showed a uniform trend in moisture distribution in the subgrade in those sections. Section 4 started out with generally uniform moisture content, and maintained a similar distribution throughout the recorded data period. When the moisture content values did change for Section 4, all of the sensors in the horizontal array generally recorded the same increase or decrease in water content. This was reflected in the moisture content profiles through a vertical shift in the data. On the other hand, the initial moisture content distribution for Section 7 was highly non-uniform, with an approximately 9% moisture difference between all sensors. However, over time, the difference steadily decreased to 5%, appearing to be on track to becoming uniform. Results from the test sections constructed with conventional geotextiles GT1, GT2, and GT3 did not show any tendencies of homogenizing the moisture content beneath the geotextiles in the subgrade. For those sections, the moisture contents varied inconsistently in the subgrade.

To further illustrate the moisture content differences between each geotextile, Figure 9 was prepared displaying the range of moisture contents beneath each geotextile in the subgrade. The figure shows the average difference in the moisture contents between the five sensors in each section, along with the minimum and maximum observed difference over time. From this plot, it is clear that the IPED geotextile GT4 has the smallest range of moisture content distributions compared to the other geotextiles. This is indicative that the IPED geotextile may have been able to homogenize the moisture content in the subgrade, as hypothesized. On the other hand, the large range of moisture contents observed in the sections with conventional geotextiles leads to the conclusion that these geotextiles are unable to influence the moisture content distribution in the subgrade soils.

Unfortunately, many of the moisture sensors stopped recording moisture data or were reporting faulty data. Therefore, moisture data was only collected for up to two years. It was hypothesized that the sensors may have malfunctioned for multiple reasons. The first explanation is that the sensors may not have been adequate to handle the stresses induced by the overlying soil and traffic. In this project, there were approximately 32 inches of compacted base and asphalt overlying the sensors. The stresses induced by the overlying material and vehicular traffic may have been enough to crack the sensor body. Alternatively, since the moisture content in the subgrade was relatively high, there is the possibility that moisture seeped into the probe head (Bandaranayake et al., 2006). The probe head contains the electrical parts for the probe and could cause sensor failure if exposed to moisture. The manufacturer recommended the installation of sensors with epoxy coated probe heads to prevent moisture infiltration and add durability to the sensors. Finally, it is possible that the sensors could have been damaged with the movement of expansive clays. It was difficult to insert the probes into the subgrade as the subgrade material was very stiff. It is possible that the prongs were not installed completely straight or were bent over time with soil movement. If the prongs on a probe are not parallel to each other, this may have led to the sensors that did not completely fail, but continued to report faulty data.

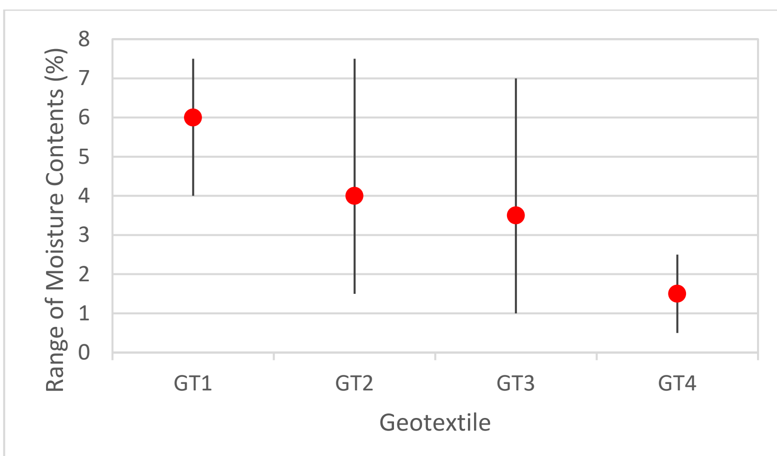

Figure 9. Range of moisture contents for each geotextile

Even without additional moisture data, the total station survey data provides further evidence of the homogenization of moisture contents beneath the pavement subgrade in the IPED geotextile sections. Profiles for both Section 4 and 7 with GT4 show that the entire pavement shoulder moves uniformly with time. Since total station surveys began in 2015, the shoulders of Sections 4 and 7 were at a consistently higher elevation upon each subsequent survey. Considering that 2015 and 2016 have been abnormally wet years in the area, it is consistent with the nature of expansive clays that the soil may swell under these wet conditions. A few sections with conventional geotextiles also exhibited signs of soil heave. In particular, Section 8 with GT1 showed significant swelling in a portion of the shoulder area. Unlike the sections with the IPED geotextile however, the swelling observed in the shoulder of Section 8 was non-uniform.

The total station surveys show evidence that the expansive clay subgrade along the SH-21 pavement is exhibiting the characteristic shrink-swell behavior. However, the addition of the geogrids in the shoulder is likely contributing to a reduction in environmentally induced cracks along the pavement. Continued condition surveys over time may record further evidence of expansive clay cracking if it eventually occurs.

6. CONCLUSIONS

The main objective of this study was to evaluate the performance of an enhanced drainage geotextile in comparison to conventional geotextiles, installed in a pavement founded on expansive clays. Accordingly, eight 500 ft long test sections were constructed on a pavement founded on expansive clays along State Highway 21 in Bastrop, Texas, USA in 2013. Four different geotextiles were installed, including one with enhanced drainage capabilities, and three different conventional geotextiles. Due to design limitations, the geotextiles were only installed in the pavement shoulder and did not span the entire width of the pavement. Each test section was equipped with an array of sensors to monitor the moisture distribution beneath the expansive clay subgrade.

The enhanced drainage geotextile utilized in this study was fabricated with special fibers allowing it to transport water along its plane. An important objective was to assess whether the enhanced drainage geotextile would be able to reduce the consequences of environmentally induced longitudinal cracking due to expansive clays. The enhanced drainage geotextile would be expected to achieve this goal by homogenizing the moisture beneath the subgrade. While an IPED geotextile was not expected to prevent a soil from shrinking or swelling, its use was aimed at obtaining a uniform shrink-swell behavior, which may reduce the differential movements that lead to cracking.

Continued monitoring of moisture content throughout several seasons revealed a clear trend in moisture content distribution across the width of the instrumented sections. Similar trends were observed in the moisture content data obtained from the various sections in which conventional geotextiles (both woven and non-woven) were used. Typical moisture distribution for conventional geotextile sections showed that the moisture content in these sections was non-uniform, typically with the highest value toward the pavement shoulder edge and lowest value toward the inner portion of the pavement. In some cases, the maximum difference in volumetric moisture content distribution beneath the geotextile reached values as high as 15%. Differences in moisture content across the width of the pavement may eventually result in differential settlements and, ultimately, in longitudinal cracks.

In one of the sections with enhanced drainage geotextiles, it was observed that the moisture distribution remained relatively uniform over time throughout the entire width of the shoulder. Even when the magnitude of the moisture content changed, the change was uniform throughout the profile, shifting the entire moisture content by a similar amount. The maximum difference between the moisture content distribution was approximately 3%. In another section with the enhanced drainage geotextile, the moisture content distribution started out highly non-uniform and appeared to be on the path to equilibrating before sensors in the section malfunctioned.

Total station surveys were utilized to monitor any fluctuations in the elevation of the pavement surface due to the shrink-swell behavior of the soil. Results confirmed that both test sections constructed with enhanced drainage geotextiles swelled uniformly along the shoulder. On the other hand, some sections with conventional geotextiles showed differential swelling along the shoulder. Ultimately, the moisture sensor and total station data obtained at SH-21 demonstrates the effectiveness of enhanced lateral drainage at homogenizing moisture content distribution across pavement sections in locations characterized by the presence of expansive clay subgrades.

For future pavement sections with enhanced drainage geotextiles it is recommended that an enhanced drainage geotextile is installed across the entire width of the pavement.

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