Effect of geosynthetic reinforcements on mitigation of environmentally induced cracks in pavements

G.H. Roodi & J.G. Zornberg,
The University of Texas, Austin, Texas, USA

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ABSTRACT: Volumetric changes in expansive clay subgrades result in the development of longitudinal cracks in pavements across the state of Texas, USA. To mitigate the longitudinal cracks, Texas Department of Transportation (TxDOT) has been using two mitigation approaches: Geosynthetic basal reinforcement and lime (or cement) stabilization. TxDOT reconstructed in 2006 a farm-to-market road in Grimes County, Texas. The rehabilitated road included 32 sections with different cross sections. Specifically, 17 of the road sections were reinforced with 3 types of geosynthetics, while 5 of the road sections remained unreinforced. In addition, approximately half of the sections were lime treated, while the other half was not. Field monitoring data has been collected throughout the life of the project. The analyses presented in this paper focus on the performance of the geosynthetic reinforcements as a technique to mitigate the development of longitudinal cracks during seasonal changes. In particular, the performance of the reinforced and unreinforced sections has been evaluated before and after a record-long dry season. The geosynthetic-reinforced sections were found to perform significantly better than the unreinforced sections. While the average level of longitudinal cracks in the unreinforced sections was recorded up to 41%, the longitudinal cracks in geosynthetic-reinforced sections were found to be significantly smaller or inexistent.

1 INTRODUCTION

Expansive soils have a major source of damages to different structures in the US and around the world. These structures include foundations, pipes, buildings, roads, airports, walls, and other facilities. Jones & Holtz (1987) and Jones & Jones (1987) have reported that the annual damage to the structures in the US from expansive soils have been 9 billion dollars. Their studies show that more than half of the annual damage occurred in highways and streets. This is partly due to the small surcharge of roadway structures which makes them more susceptible to damages from heaving.

Although numerous laboratory research studies have been conducted to predict the behavior of expansive soils, the field behavior of expansive clays is affected by several factors, which may affect the applicability of the laboratory results. Of the most important factors precluding the use of laboratory results to field studies is moisture conditioning of the soil. While the moisture conditioning of small soil specimens in the lab is under strict control, access to water for expansive soils in the field is very uncertain (Coduto 2001). This uncertainty is due to: (1) the uncontrolled climate conditions in the field and (2) the effect of soil structure and soil layering. The uncertain climate conditions in the field affect the supply of inflow water into the soil (through precipitation and surface drainage) and the outflow water from the soil (through evaporation and transpiration). On the other hand, the presence of fissures in the soil structure and the presence of granular lenses within soil layering often affect the water infiltration or drainage of outflow water (Coduto 2001).

Several remedies have been attempted to mitigate the effect of expansive clays on structures. However, none of these techniques represent a universal solution for construction over expansive clays. Holtz (1969) categorized these remedies as: (1) Replacing the expansive clays by non-expansive soils to the depth of influence of expansive clays, (2) Ponding the expansive soil area before construction, (3) Minimizing expansion by moisture-density control, (4) Stabilizing with chemicals, and (5) Structural modifications. However, each of these approaches may have limitations, especially in sites with significant depth of moisture changing.

A relatively recent method for mitigation of the adverse impact of the expansive soils on pavement structures is geosynthetic reinforcement, which is the focus of this paper. A field experiment has been conducted by the University of Texas at Austin to investigate the performance of a farm to market road constructed in Texas. The road was constructed on an expansive subgrade and geosynthetic reinforcements and lime treatment were used to protect the road against the environmentally-induced cracks in pavement. The remainder of this paper is organized as follows: After a brief description of expansive clays in Texas, the field program is described. The results of recent condition surveys (Surveys #14 and #17), which were performed before and after a record-long dry season are also presented. Specifically, the difference between the performance of the geosynthetic reinforced sections and the unreinforced sections are illustrated in terms of occurrence of environmentally induced longitudinal cracks.

2 EXPANSIVE CLAYS IN TEXAS

Detrimental effect of swelling has been reported in montmorillonite-rich clays in which the bonding between clay particles comparatively weak. Montmorillonite clays are abundant in many areas across the US, but not all these areas are susceptible to damages from expansive clays. Expansive clays need to experience a change in the moisture content to swell or shrink. In a humid climate, where precipitation occurs frequently over the summer months and winter months, the moisture content of soil remains reasonably constant. In contrast, in arid or semi-arid climates, where distinguished wet seasons and dry seasons occur, the moisture content in the active zone of the expansive soils could change dramatically. This condition can be found in many areas around the world, including South America, Africa, Australia and India (Das 2007), as well as many areas in the US, such as Colorado, Southern California, Nevada, Oklahoma, and Texas (Coduto 2001, Das 2007, Thornwaite 1948).

Expansive soils are dominant in Southern and Central Texas (Thornwaite 1948). O'Neil & Pourmoayed (1980) have reported the depth of seasonal variation in soil moisture, referred to as the Depth of Active Zone (DAZ), for different cities in Texas. They have reported the DAZ from 5 to 10 ft (1.5 to 3 m) in Houston, Southern Texas, from 7 to 15 ft (2.1 to 4.2 m) in Dallas, and from 10 to 30 ft (3 to 9 m) in San Antonio, Central Texas. However, the DAZ can be affected by various parameters. For example, removal of surface vegetative layer can reduce the transpiration rate. Also, construction on the ground surface can limit the access to water for expansive soils. Specifically, construction of slab-on-grade structures or impervious pavement surface can block the direct inflow of water into the soil and also limit the loss of surface moisture. Therefore, the depth of active zone is expected to be less under these types of structures. In contrary, in heavily fissured clays, water can move into and out from deeper layers and the DAZ may increase. Therefore, the DAZ is hard to determine and is one of the major sources for uncertainty in swelling analysis (Coduto 2001).

Texas Department of Transportation (TxDOT) has been using two approaches to minimize the detrimental effects of expansive soils. The first method is chemical stabilization using lime (or Cement). Lime is one of the most common additives for soil stabilization in the US. According to Miller (2004), in 2003 the USA used more than 1.6 million tons of lime for soil stabilization.

The second method that TxDOT has use to improve the performance of pavements over expansive clays is mechanical stabilization using geosynthetic reinforcements. Two types of geosynthetics, geogrids and geotextiles, have been extensively used for reinforcement of pavement layers. These reinforcement layers have been placed in various locations within or directly adjacent to the pavement system layers. Perkins et al. (2005) have reported the potential reinforcement locations and the benefits of using reinforcement in each location as followings:

- Within or at the bottom of the asphalt concrete layer: In this location, application of reinforcement can reduce rutting, fatigue cracking, reflective cracking, and frost heave cracking.
- Within or at the bottom of the aggregate layer (base or subbase layer): In this location, reinforcement can reduce surface deformation and dynamic deformation of the pavement along with reduction in fatigue cracking.
- Over the subgrade: In this location, the geosynthetic reinforcement can increase the bearing capacity of the subgrade and provide a working platform for construction traffic.

The improvement mechanisms attributed to the use of geosynthetic reinforcement have been discussed by several researchers (e.g. Koerner 2005, Perkins & Ismeik 1997). These mechanisms include: (1) Lateral Restraint (2) Improved Bearing Capacity and (3) Tensioned Membrane Effect. However, not all of these mechanisms can be realized in pavements systems. The tensioned membrane effect and the improved bearing capacity mechanism can be only considered in the cases that high surface deformation is permitted, e.g. in unpaved roads.

In this study, the effect of geosynthetic reinforcement on mitigation of environmentally induced cracks in pavement is discussed. The environmental load studied in this paper is caused by swelling and shrinkage of expansive subgrades. The mechanism involved in application of geosynthetics in the environmental load is different from the mechanism described for traffic loads. As shown in Fig. 1, construction of a relatively impervious pavement structure over expansive soil restrains the access to water for the area located beneath the center of the road. However, the shoulder areas have unrestrained access to water. Consequently, while the shoulder areas can freely swell and shrink with the change in the moisture, the center area experiences little change in the moisture and little swelling and shrinkage. Therefore, the edges of the pavement structure bending downward during dry seasons and upward during wet seasons (Fig. 2). Cyclic wet and dry seasons result in a nonuniform uplift loading applied to the pavement structure, and, consequently, a differential movement between the center line and the edges. This leads to points of high compressive stress in the wet seasons and high tensile stress in the dry seasons, and, subsequently, generates longitudinal cracks in the pavement. Application of geosynthetics can redistribute the nonuniform uplift load such that the points of high stress move from the paved area to the shoulder areas (Zornberg et al. 2012, Zornberg & Gupta 2009).

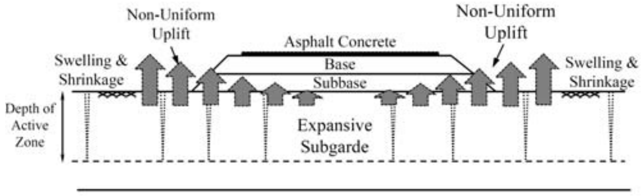

Fig. 1. Mechanism of loading from expansive subgrade on the pavement structure.

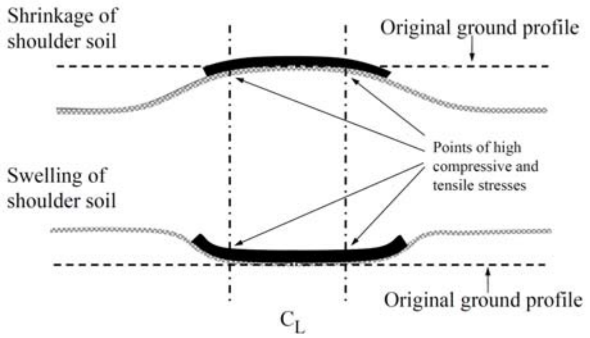

Fig. 2. Conceptual model for generating environmentally induced longitudinal cracks in pavements (Ranjiv et al. 2008).

3 RECONSTRUCTION OF FARM TO MARKET ROAD 2 IN GRIMES COUNTY, TEXAS

32 road test sections, located on Farm to Market road 2 (FM2), were reconstructed in 2006 using three techniques for protection against the effect of the existing expansive subgrade: (1) using lime stabilized subbase, (2) using geosynthetic reinforcements between base and subbase, and (3) using combination of lime stabilized subbase and geosynthetic reinforcements between base and subbase. Specifically, 17 of the road sections were reinforced with three different types of geosynthetics, while 5 of the road sections remained unreinforced. In addition, approximately half of the sections were lime treated, while the other half was not. The three geosynthetic products used in this project included two geogrids (GG1 and GG2) and one geotextile (GT). A comprehensive monitoring program was performed to evaluate the performance of the test sections under environmental loading. This program included:

- Performing non-destructive tests including Rolling Dynamic Deflectometer (RDD) and Falling Weight Deflectometer (FWD) to evaluate changing in the mechanical properties of pavement layers (Joshi & Zornberg 2011, Joshi 2010, Gupta 2009)
- Installing moisture sensors in horizontal and vertical arrays, as shown in Fig. 3, to study the moisture migration pattern under the pavement (Gupta 2010, Gupta et al. 2008)

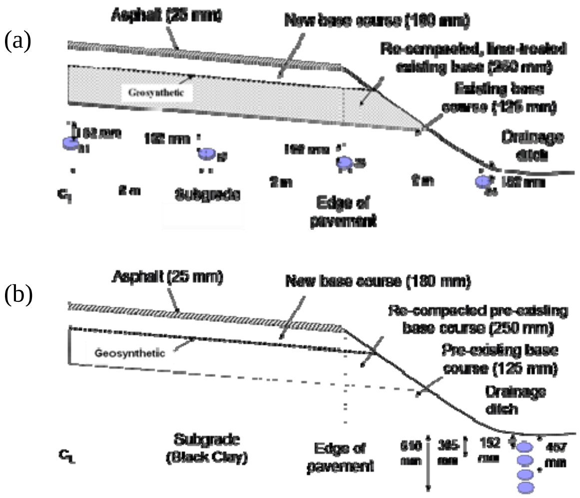

Fig. 3. Moisture sensors installed to study the migration of moisture (a) moisture sensors in a horizontal array beneath the pavement structure (b) moisture sensors in a vertical array in the edges of the road (Gupta et al. 2008).

- Monitoring environmental conditions including precipitation, humidity and temperature at the site to investigate the effect of the environmental changing in the performance of the road sections (Gupta 2010)
- Periodic conditions surveys to identify and quantify the distresses involved in each section and determine the condition of the pavement surface (Zornberg et al. 2012).

In this study, the performance of the unreinforced sections (Control sections) is compared to sections with Geosynthetic reinforcements. The comparison is on the basis of the visual condition surveys performed in 2010 and 2011 before and after a record-long dry season.

4 COMPARISON OF THE PERFORMANCE OF THE CONTROL SECTIONS VERSUS THE GEOSYNTHETIC REINFORCED SECTIONS

A total of 18 conditions surveys have been conducted from the reconstruction of the road sections in Jan. 2006 to the date of preparing this paper. The surveys have been conducted mainly on the basis of the instructions recommended by the TxDOT Pavement Management Information System, Rater's Manual, described by Zornberg et al. (2012). In this paper, the performance of unreinforced (Control) sections is compared to the performance of the geosynthetic reinforced sections (GG1, GG2, and GT) from Survey #14, conducted in Nov. 2010, to Survey #17, conducted in Sept. 2011.

Survey #14 conducted after almost 5 years (1556 days) of the opening of the FM2 road. During this period of time, the FM2 road has experienced several cycles of wetting and drying. Therefore, it could be assumed reasonable that at the time of Survey #14, the unreinforced (control) sections started to reveal different performance than the reinforced sections. Moreover, FM2 experienced a significant cycle of wetting and drying between Survey #14 and Survey #17. Fig. 4 shows the precipitation data collected from Oct. 2009 to Sept. 2011from a nearby weather station. As shown in this figure, the FM2 site had continuous wet months from Oct. 2009 to Sept. 2010, a period of 11 month. On the contrary, the road experienced a relatively dry season from Oct. 2010 to Sept. 2011, a period of 11 month. While the total precipitation between Oct. 2009 to Sept. 2010 was 54in (almost 5 in/month on average), the total precipitation between Oct. 2010 to Sept. 2011 was 16 in (less than 1.5 in/month on average).

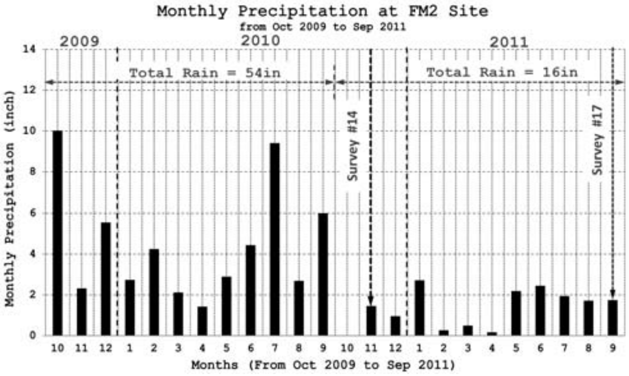

Fig. 4. Precipitation Data at the FM2 site from Oct. 2009 to Sept. 2011.

Results of condition Surveys #14 and #17 for longitudinal cracks in the pavement are presented in Figures 5 and 6. Since TxDOT PMIS Rater's Manual ignores cracks narrower than 3 mm, results presented in these figures involve only cracks wider than 3 mm.The numbers on the vertical axis are longitudinal cracking percentage. These numbers are measured in terms of linear feet of cracking per each 100 ft of the road. The horizontal axis addresses the section numbers for unreinforced (Control) and geosynthetic reinforced sections (GG1, GG2, and GT):

- 5 Unreinforced sections (Control): Sections #1, 10, 20, 26, and 27
- 4 Geogrid1-Reinforced sections (GG1): Sections #2, 9, 17, and 28
- 3 Geogrid2-Reinforced sections (GG2): Sections #3, 11, and 18
- 4 Geotextile-Reinforced sections (GT): Sections #4, 12, 19, and 25

The average longitudinal cracking percentage for each group is also calculated and shown with a white bar at the end of each group.

Fig. 5 shows the rate of longitudinal cracking in Survey #14. As indicated in this figure, except for three control sections and one GT section, the percentage of longitudinal cracking was less than 3%. At this point of time, the road sections had passed a long period of wetting months. However, from a month before Survey #14, the road started to experience a long period of drying months. Consequently, a significant change in longitudinal cracking was expected in Survey #17. The results for Survey #17 are presented in Fig. 6. As seen in this figure, most of the sections showed increase in the percentage of longitudinal cracking. While four of the Control sections showed over 38% increase in the longitudinal cracking, one Control section experienced 6% increase in the percentage of longitudinal cracking. On the other hand, of the 11 geosynthetic reinforced sections, only three demonstrated an increase more than 38%. The rest of the geosynthetic reinforced sections had less than 26% increase in the percentage of longitudinal cracking. More specifically, three of the GG1 sections, i.e. Sections #9, 17 & 28, showed 0 or 1% change in the longitudinal crack at the end of the dry season.

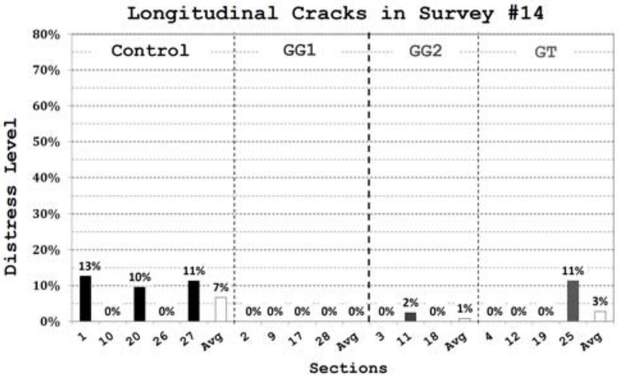

Fig. 5. Results of condition Survey #14 for longitudinal cracks in unreinforced and geosynthetic reinforced sections.

In Fig. 7, the average percentages of longitudinal cracking in each group of sections are compiled from Survey #14 to Survey #17 to evaluate the performance of the sections over time. The horizontal axis of this graph is the life of the road, in days, from reconstruction of FM2 in 2006. This axis starts at 1550 days, which is the time of Survey #14, to 1880 days, which is the time of Survey #17. The vertical axis shows the average percentage of longitudinal cracking. By studying this graph, it is obvious that on average all types of geosynthetic reinforcement had significant effects on mitigation of environmentally induced cracks in pavements. While the average percentage of longitudinal cracking in Survey #14 was 7 % in Control sections, this average was less than 1% in GG1 and GG2 sections, and less than 4% in GT sections. In Survey #17, after a long period of drying, the average percentage of longitudinal cracking in Control sections grew to 41%. However, this average was 10%, 24%, and 25% in GG1, GG2, and GT sections, respectively.

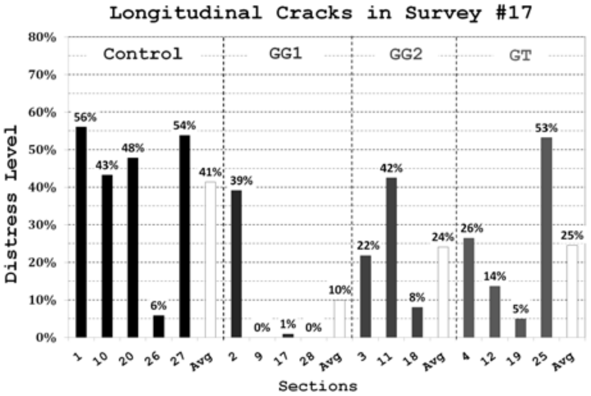

Fig. 6. Results of condition Survey #17 (after the dry season) for longitudinal cracks in unreinforced and geosynthetic-reinforced sections.

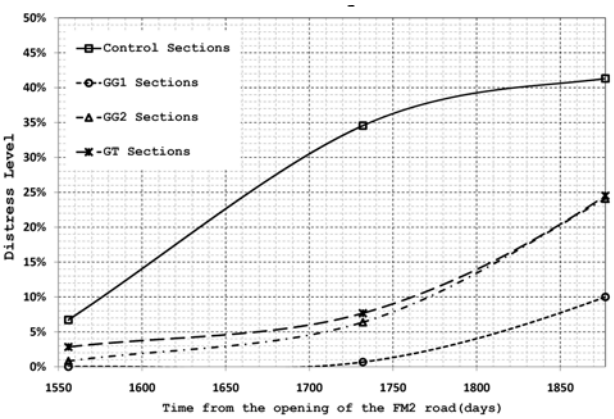

Fig. 7. Behaviour of unreinforced (Control) sections and geosynthetic-reinforced sections over time (Survey #14 to #17).

The performance of the two of the sections, Sections #1 and #17, are compared in Fig. 8, and Table 1. These sections are located adjacent to each other: Section #1(an unreinforced section) in the west lane and Section #17 (a GG1 reinforced section) in the east lane. This comparison can minimize uncertainties initiated by subgrade soil profile, topography, traffic, or environmental conditions, and exclusively address the effect of geosynthetic reinforcement inclusion in the road section. Fig. 8 shows the general view of both sections. As seen in this figure and in Table 1, the reinforced section (Section #17) performed significantly better than the unreinforced section (Section #1). While Section #1 shows up to 56% of longitudinal cracks after the dry season, this percentage found to be less than 1% in Section #17. Moreover, the reinforced section showed lower values in rutting measurement and in the amount of shoulder cracking.

Table 1. Comparison of the performance of Sections #1 and #17 after the dry season.

Layout	Section Number	Rutting			Patching	Cracking		
		Shallow	Deep	Severe		Transverse	Longitudinal	Shoulder
		% AREA			% AREA	No. / 100' STA. (%)	Linear ft/100' STA. (%)	Linear ft/100' STA. (%)
CONTROL	1	12%	10%	0%	0.0%	0.2%	56%	11%
GG1	17	0%	0%	0%	0.0%	0.0%	1%	4%

Fig. 8. Behaviour of unreinforced (Control) sections and geosynthetic reinforced sections over time (Survey #14 to #17).

5 SUMMARY AND CONCLUSIONS

Texas Department of Transportation, TxDOT, has used two main techniques to mitigate environmentally induced cracks in pavement structures caused by swelling and shrinkage of expansive subgrades: (1) stabilization of subbase with lime (2) use of geosynthetic reinforcement between base and subbase of the pavement structures. As part of an experimental project to evaluate the performance of the two techniques, TxDOT reconstructed 32 road test sections in a farm to market road, the FM2 road, using combinations of lime stabilization and three types of geosynthetic reinforcements. Five of the road sections were reconstructed without any treatment, which are referred to as Control (unreinforced) sections. 11 sections were reconstructed using three types of geosynthetic reinforcements including four sections with Geogrid type 1 (GG1), three sections with Geogrid type 2 (GG2) and four sections with Geotextile (GT). The rest of the sections were reconstructed either with only subbase lime stabilization or with combination of subbase lime stabilization and reinforcement with each of the three geosynthetics. A comprehensive monitoring program was conducted to evaluate the performance of the road sections. The results of the monitoring program were presented in a number of previous publications by the authors. In this paper, the performance of the Control sections was compared to the performance of the geosynthetic reinforced sections after a record-long dry season. The major findings of this comparison can be summarized as follows:

- Before the dry season, the percentage of longitudinal cracking was below 13% in all sections. Specifically, this percentage was negligible in 3 of the Control sections and 8 of the Geosynthetic reinforced sections.

- After the dry season, the percentage of longitudinal cracking grew in almost all sections. However, the increase in the Control sections was more significant than the Geosynthetic reinforced sections.
- While four of the Control sections showed over 38% increase in the percentage of the longitudinal cracking, one of the Control sections showed only 6% increase in the longitudinal cracking. On the other hand, 8 of the Geosynthetic reinforced sections showed less than 26% increase in the percentage of longitudinal cracking. Specifically, three of the GG1 sections had zero or 1% change in the longitudinal cracking.
- While the average level of longitudinal cracks in the unreinforced sections was recorded up to 41% after the dry season, the longitudinal cracks in geosynthetic-reinforced sections were found to be 10%, 24%, and 25% in GG1, GG2, and GT sections, respectively.
- The performance of Sections#1(unreinforced) and Section#17 (GG1 reinforced), which are located adjacent to each other in opposite lanes, were compared. This comparison showed that once the uncertainties from other factors, such subgrade soil profile, topography, traffic and environmental conditions, are minimized, the geosynthetic reinforced section performed significantly better than the counterpart unreinforced section.

Overall, the results of this experimental study showed that the geosynthetic reinforcements are effective in mitigation of environmentally-induced cracks in low volume roads.

6 ACKNOWLEDGEMENTS

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