Field performance of geosynthetic reinforced pavements over expansive clay subgrades

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ABSTRACT:
Expansive soils in semi-arid and arid regions of Texas are subjected to moisture fluctuations due to seasonal variation causing large volumetric changes. These ground movements are observed in the form of heave during wet season and shrinkage during dry season. Experience in the Texas Department of Transportation (TxDOT) has shown that these cyclic movements lead to considerable damage in form of longitudinal cracks on the pavement structures. Traditionally the problems related to flexible pavements over expansive soils have been addressed by removing these soils or by lime treating the subgrade layer. The use of geosynthetic reinforcements, both geogrids and geotextiles, is proposed in this study to minimize the development of longitudinal cracks in such pavements. Specifically, this paper describes the construction and monitoring results on a comprehensive field program involving 32 pavement test sections with various combinations of reinforcements. The field program includes moisture sensor profiles, which were installed in both horizontal and vertical direction below the pavement during its construction. The information obtained from these sensors is complemented with condition surveying measurements in order to track and evaluate the development of cracks in the different test sections. The preliminary results from this monitoring program demonstrated that the use of geosynthetic reinforcements can significantly help in mitigating the longitudinal cracks associated with volumetric changes in expansive clay subgrades over flexible pavements.

1 INTRODUCTION

Basal reinforcement of pavement systems has been used for the purposes of: (i) increasing the lifespan of a pavement while maintaining the thickness of the base course, and (ii) decreasing the thickness of the base course while maintaining the lifespan of the pavement. A third application of basal reinforcement of pavements, namely, the mitigation of longitudinal cracks induced in pavements constructed over highly plastic, expansive clay subgrades has been proposed (Gupta 2009, Zornberg et.al 2008, Zornberg and Gupta 2009).

The mechanisms leading to the development of the classical longitudinal cracks are expected to be due to tensile stresses induced by flexion of the pavement during settlements caused during dry seasons. Figure 1 illustrates the envisioned mechanism that leads to the development of longitudinal cracks. During the dry season, there is decrease in the moisture content of the soil in the vicinity of the pavement shoulders (Figure 1a). This leads to settlements in the shoulder area, but not in the vicinity of the central line of the pavement, where the moisture content remains approximately constant throughout the dry season. On the other hand, during the wet season, the moisture content in the soil in the vicinity of the pavement shoulder increases (Figure 1b). In this case, heave occurs in the vicinity of the shoulder area, but not in the vicinity of the pavement central line.

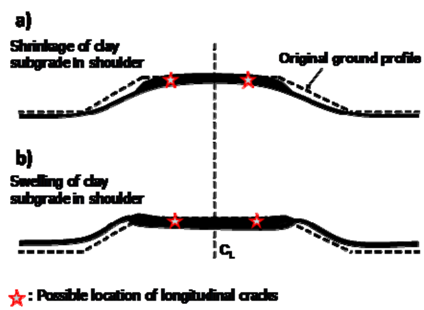

Figure 1: Mechanism of longitudinal crack development on pavements over expansive clays

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The cracks are developed in the region where the moisture front advancing and retreating from the shoulders reaches its maximum penetration under the pavement. Longitudinal cracks have been reported to occur towards the end of dry seasons, which is consistent with this envisioned mechanism.

The construction of pavements over expansive clays in regions such as central Texas has often led to poor performance due to development of longitudinal cracks induced by moisture fluctuations. These environmental conditions are generally not fully evaluated as part of the design of pavements, which focuses more directly on traffic conditions. In the current study, stabilization of these pavements over expansive clay subgrades in Texas has been attempted by reinforcing them with geosynthetics. This paper summarizes the results of field study including moisture monitoring and conditioning survey conducted to quantify the mechanism of longitudinal cracking and effect of geosynthetic reinforcement in mitigating these cracks over flexible pavements

2 FIELD TEST SITE

Texas Farm-to-Market Road No.2 (FM 2) is located in the Grimes County i.e. in southeast part of Texas as shown in Figure 2a below. The total length of the road is 6.4 miles of which 2.4 miles lie towards the west of State Highway 6 (SH 6) at Courtney and rest 4 miles continues eastward and ends at FM 362 as shown in Figure 2b. The test sections were constructed in the portion of the road lying between SH6 and FM 362. The test site was part of a highway maintenance and rehabilitation project. The state DOT supervised the construction of a geosynthetic reinforced low volume road at FM 2 in Bryan district of Texas.

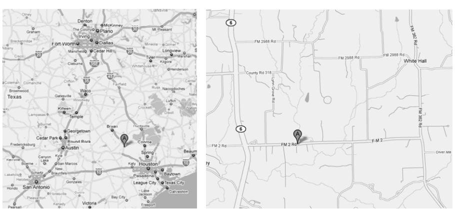

Figure 2: FM 2 section details (a) distance from major cities in Texas (b) SH6 and FM 362 end of the road

The field testing program included unreinforced and reinforced sections. The reinforced section further consisted of one of the three types of geosynthetic reinforcements i.e., geogrid type 1 (G1) or geogrid type 2 (G2) or a geotextile (G3). The unreinforced section with no reinforcement was labeled as G0. Further, each of the above sections was constructed over lime-treated and non lime-treated base course. Therefore, 8 such sections were constructed. For comparative evaluation, each of the eight different test sections had four repeats, thus a total of 32 test sections as shown in Figure 3 (4 reinforcement types x 2 stabilization approaches x 4 repeats) were constructed in FM2.

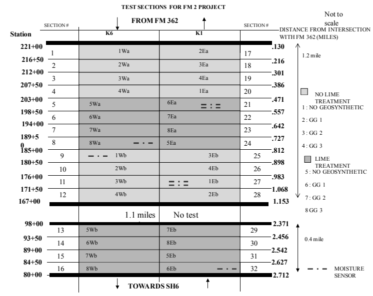

Figure 3: Layout of test sections at FM 2

3 FIELD MONITORING USING MOISTURE SENSORS

A strong linkage between moisture migration and longitudinal cracking has not been well established in the literature. Accordingly, it was decided to investigate the migration of moisture under the pavement in order to assess the likelihood of differential shrinkage and swelling between the center and edges of the pavement. The moisture sensors used in this study to infer the gravimetric water content at particular locations in the subgrade were ECH_20 sensors, obtained from Decagon, Inc., (Gupta et. al, 2008) as shown in Figure 4a below. They were attached to the Onset data logger which was powered by standard alkaline batteries as shown in Figure 4b.

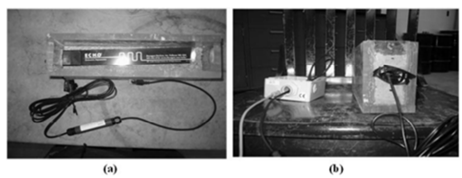

Figure 4: Instruments used in field study (a) Moisture sensor (b) Data logger

In a flexible pavement, the low hydraulic conductivity of the asphalt seal coat (<10^{-9} m/s) causes the precipitation falling onto the pavement surface to runoff into the drainage ditch. Therefore, the drainage ditch was assumed to be the primary infiltration pathway into the subgrade in this study. Furthermore, the secondary source of water entry into the subgrade was identified as the seepage through the slope of the pavement during runoff. Both these sources of water entry along with cross-section of pavement are shown in Figure 5a. Based on above sources, four possible pathways of moisture migration into the subgrade were envisioned as: (1) Horizontal seepage through the slope, (2) vertical seepage through the slope, (3) horizontal seepage through the pheratic surface and, (4) vertical seepage through the ditch in the ponded water and are as shown in Figure 5b. Thus, it was decided to install horizontal and vertical moisture profiles along the pavement cross section to capture the above pathways. Furthermore, the centre line of the pavement was assumed as the no flow boundary condition for design purposes. Thus, the horizontal array of sensors was limited to the center line of the pavement and the vertical array of sensors to the depth of two feet below the pavement.

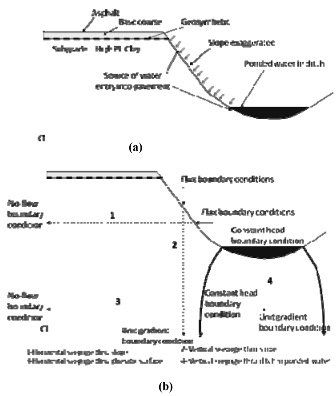

Figure 5: Moisture migration below pavement (a) Sources of water entry (b) Flow boundary conditions

An array of four moisture sensors was installed at a given cross-section below the pavement. For horizontal profile, the moisture sensors were placed at a distance of 2m from each other beginning from the center of the pavement leading towards the edge of the pavement as shown in Figure 6a. Vertical moisture sensors were installed in the ditch, close to the edge of the pavement. They were placed at a distance of 150mm, 300mm, 450mm and 600mm below the pavement in the subgrade layer as shown in Figure 6b.

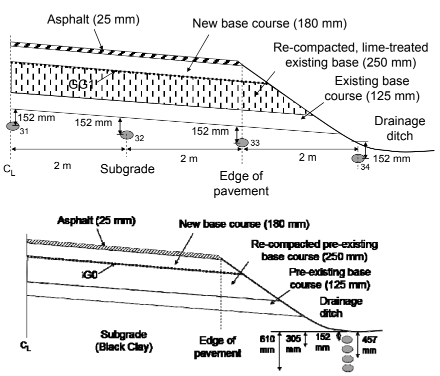

Figure 6: Moisture sensor (a) Horizontal profile (b) Vertical profile below the pavement at FM 2 site

The monitoring results for the horizontal array at Station 84 are shown in Figure 7a. After December 2005, the moisture sensor 34 showed significant fluctuations in water content, ranging from 16% to 46% whereas the water content inferred by the three sensors under the road did not vary and was close to 30%. The isochrones were drawn for moisture time histories for all the four sensors as shown in Figure 7b. This graph indicated that the moisture variation was limited to the edge of the pavement while the center of the pavement remained at the constant moisture content.

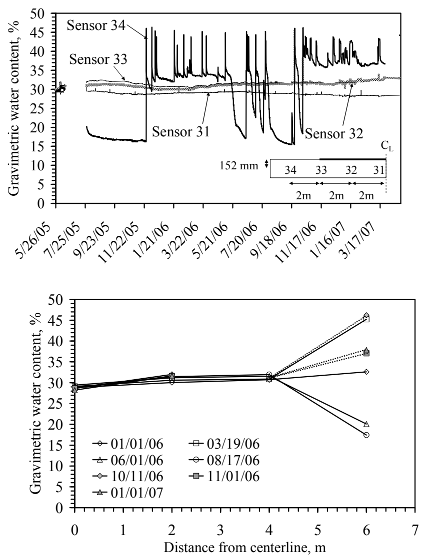

Figure 7: Horizontal moisture data from four sensors at Station 84 (a) Time series (b) Isochrones

The vertical arrays of sensors were installed in the drainage ditch at Stations 184 one year after the installation of the horizontal array of sensors at Station 84. The time series for the moisture sensors at Station 184 are shown in Figure 8. The water content at this location was observed to vary between 26% and 43%, indicating that wet conditions prevailed at the location for the duration of monitoring as the shrinkage limit of the soil was 13%. All the sensors showed change in water content over time, though the topmost sensor had the maximum daily fluctuation in readings..

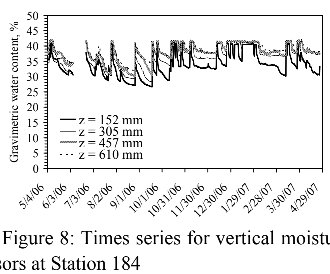

Figure 8: Times series for vertical moisture data from four sensors at Station 184

The preliminary results of moisture monitoring indicated that the zone of moisture fluctuation below the pavement is limited to 2m in horizontal direction and 0.3 m in vertical direction close to the edge of the pavement. Further, the center of the pavement remains at the constant moisture level as observed after construction.

4 FIELD MONITORING USING CONDITION SURVEYING

The distress due to environmental loading on the pavement was visually documented using the condition surveying. The procedure involved walking the entire length of the test sections followed by tracking the nature and progress of cracks over time. Since the reconstruction of FM2 road, eight conditions surveys were performed. The surveys were performed in August and November of 2006; February, May and November of 2007; April and August of 2008; and May of 2009. From the first survey (May 2006) to the fifth survey (November 2007) no significant longitudinal cracks were observed. This can be attributed to the relatively new construction of the pavement. However, since the survey in April 2008, longitudinal cracks were noticed. Initially, the cracks developed in the ditch and unpaved portion of the pavement close to the edge and then widened over time as shown in Figure 9. Over the course of time, these cracks were observed to reach close to the pavement.

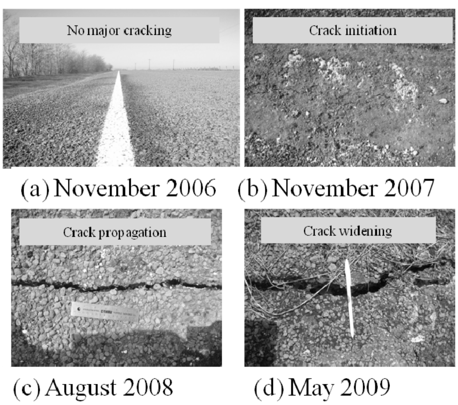

Figure 9: Development of crack on the site over time

Two significant observations were made. In sections having reinforcement (with or without lime treatment), these cracks were observed to be outside the pavement, near the outer end of the shoulder, and the traveled away from the road as shown in Figure 10a. On the other hand, cracks in the two control sections (i.e. the sections with no reinforcement and no lime treatment) started to move from the shoulder into the pavement as shown in Figure 10b. The number of cracks developed on the edge of the pavement was highest in the control sections. Thus, a clear distinction between the performances of the control and reinforced sections were established. But still, since the construction the pavement has been subjected to few moisture cycles all the reinforced section seemed to perform well.

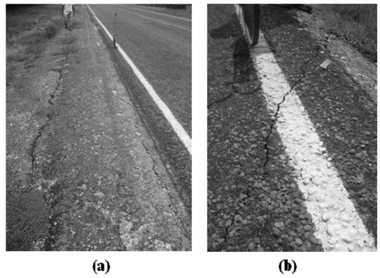

Figure 10 Difference in cracking pattern observed for (a) Reinforced section (b) Unreinforced section at site

5 CONCLUSIONS

Field evaluation of geosynthetic-reinforced pavements constructed over expansive clays indicated:

- The presence of moisture fluctuation in terms of wet and dry seasonal cycles at the site. Data from moisture sensors showed a zone of moisture fluctuation close to the edge of the pavement. These moisture fluctuation were primary cause of longitudinal cracking in the expansive clays
- The longitudinal cracking occurred three years after the pavement was open to traffic. Further, the pattern of cracking was different for reinforced and unreinforced sections.
- Geosynthetic reinforcements can be used to effectively minimize the development of longitudinal cracks.
- Geosynthetic reinforcements can effectively relocate possible longitudinal cracks beyond the reinforced zone

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