Zornberg, J.G., and Gupta, R. (2009). “Reinforcement of Pavements over Expansive Clay Subgrades.” Proceedings of the *Seventeenth International Conference of Soil Mechanics and Geotechnical Engineering*, Alexandria, Egypt, 5-9 October, pp. 765- 768.

Reinforcement of pavements over expansive clay subgrades

Renfort des trottoirs au-dessus des argiles expansibles

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ABSTRACT

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. This paper describes a third application of basal reinforcement of pavements, namely, the mitigation of longitudinal cracks induced in pavements constructed over highly plastic, expansive clay subgrades. This includes information showing that: (i) geogrid reinforcement has precluded the development of longitudinal cracks in pavement sections located in projects where unreinforced sections have shown significant cracking, (ii) longitudinal cracks are ‘shifted’ beyond the reinforced pavement zone, avoiding their development within the pavement itself, and (iii) that current specifications, which often rely on geogrid properties defined in isolation, are insufficient to fully characterize the reinforcement requirements for reinforced pavement project. Overall, the field observations highlight the significant benefits associated with the use of geogrids in pavements over expansive clay subgrades, although there is still the need for more rationale design methodologies.

RÉSUMÉ

Le renfort basique des systèmes de trottoir a été employé aux fins de : (i) augmentater de la durée de vie du trottoir tout en maintenant l'épaisseur de la couche de base, et (ii) diminuner l'épaisseur de la couche de base tout en maintenant la durée de vie du trottoir. Cet article décrit une troisième application du renfort basique des trottoirs, à savoir, la réduction des fissures longitudinales induites en trottoirs construits au-dessus plastique dur, sous-grades expansibles d'argile. Ceci inclut des informations démontrant que : (i) le renfort de geogrid a exclu le développement des fissures longitudinales dans des sections de trottoir situées dans les projets où les sections non renforcées ont montré la fissuration significative, (ii) les fissures longitudinales glissé au dessus, continué au delà `au delà de la zone renforcée de trottoir, évitant leur développement dans le trottoir lui-même, et (iii) que les caractéristiques courantes, qui se fondent souvent sur des propriétés de geogrid définies en isolation, sont insuffisantes pour caractériser entièrement les conditions de renfort de renforcement du. De façon générale, les observations sur le terrain ont souligné les avantages significatifs liés à l'utilisation des geogrids sur les au dessus des sous grades expansibles d'argiles dans les trottoirs, bien qu'il reste le besoin de plus de méthodologies de conception de raisonnement.

Keywords: Geosynthetics, reinforcement, expansive clays, subgrade, pavements

1 INTRODUCTION

Base reinforcement results from the addition of a geosynthetic at the bottom or within a base course to increase the structural or load-carrying capacity of a pavement system by developing tensile stresses within the geosynthetic reinforcement. The two traditional benefits reported for reinforced pavements include: (1) improvement of the pavement service life and/or; (2) obtaining equivalent pavement performance with a reduced structural section. Base reinforcement could also be thought to provide a safety factor on the pavement load-carrying capacity, or weaker subgrade to account for pavement design inaccuracies.

The use of geosynthetics in roadways has involved multiple functions. While geotextiles have been used to provide separation, filtration, and lateral drainage, geogrids have often been used when the primary function is reinforcement. The mechanisms by which geosynthetics provide reinforcement include the following:

- Lateral Restraint, which minimizes lateral spreading of the base and subbase aggregates thereby providing confinement leading to: (i) increase in modulus of the base aggregate; (ii) improved vertical stress distribution on subgrade; and (iii) reduced shear strain along the top of the subgrade.
- Tensile Membrane Support, which develops if high strains are mobilized.
- Increased Bearing Capacity, which may develop by constraints imposed in the development of failure surfaces through the subgrade.

Among the various mechanisms, the primary mechanism associated with base reinforcement in flexible pavements is lateral restraint or confinement (Holtz et al. 1998). The improvement to the pavement system provided by geosynthetic reinforcement has been measured by a TBR or BCR ratio:

- TBR (Traffic benefit ratio): A ratio of the number of load cycles on a reinforced section to reach a defined failure state to the number of load cycles on an unreinforced section, with the same geometry and material constituents, to reach the same defined failure state. TBR is sometimes termed traffic improvement factor (TIF).
- BCR (Base course reduction): The percent reduction in the reinforced base or subbase thickness from the unreinforced section thickness, with the same material constituents, to reach the same defined failure state.

A number of studies have been conducted to quantify the effectiveness of geogrids in pavements (Al-Qadi 1997; Berg et al. 2000; Fanin 1996 and Perkins and Ismeik 1997a, 1997b). While field observations point to the good performance of geosynthetic-reinforced pavements, the actual properties governing the contribution of geosynthetics to the pavement reinforcement

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doi:10.3233/978-1-60750-031-5-765

have not been clearly identified. This had led to controversial design guidelines and post-construction evaluation criteria for these systems.

A new application of basal reinforcement of pavements has been used in Texas, USA, with the purpose of mitigating the development of longitudinal cracks in pavements constructed over expansive clays. Figure 1 shows the development of a longitudinal crack on a farm-to-market road (a low traffic volume road) in central Texas. The crack shown in the figure initiated below the pavement structure and has propagated to the surface. This pattern of cracking is typical of volumetric changes associated with expansive clays. Figure 2 shows the layout of a geogrid-reinforced pavement system as used by the Texas Department of Transportation (TxDOT) in the case of expansive clay subgrades. Geogrid-reinforcement has often been used in combination with lime or cement stabilization.

In summary, the use of currently available empirical methodologies based on traffic benefit ratio (TBR) or base course reduction ratio (BCR) cannot be directly applied for design of pavements which have problems due to longitudinal cracking. Specifically, their applicability for conditions typical of pavements involving expansive clay subgrades needs reevaluation. This paper summarizes lessons learned from the performance evaluation of recent projects involving pavement reinforcement projects over expansive clays.

Figure 1. Typical longitudinal crack developed on pavements over expansive clays.

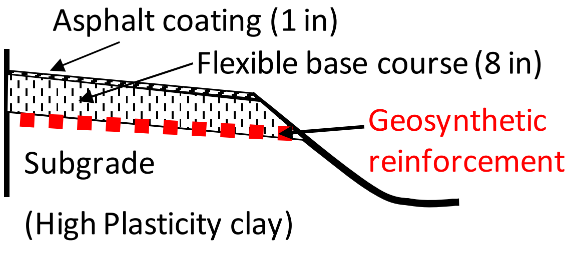

Figure 2. Typical pavement cross-section of a low-volume road in central Texas using reinforcement for mitigation of cracks induced by expansive subgrades.

2 MECHANISMS OF LONGITUDINAL CRACK DEVELOPMENT

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. Yet, volumetric changes associated with seasonal moisture variations have led to pavement heave during wet season and shrinkage during dry season. As mentioned, experience within Texas Department of Transportation (TxDOT) has indicated that these cyclic movements cause considerable damage in form of longitudinal cracks. Stabilization of the pavements over such soft subgrades in Texas has been attempted by lime treating (Petry and Little 2002) and, more recently, by reinforcing them with geogrids.

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 3 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 3a). 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 3b). In this case, heave occurs in the vicinity of the shoulder area, but not in the vicinity of the pavement central line. As shown in Figure 3, 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. They also have been reported to often partly close during the wet season.

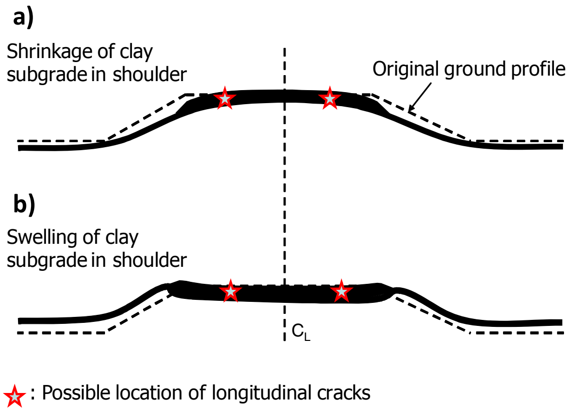

Figure 3. Mechanisms of pavement deflection over expansive clay subgrades: (a) settlements during dry season, (b) heave during wet season.

3 FIELD EVALUATION

A survey regarding the impact of expansive clays and the potential design approaches was recently conducted (Zornberg et al. 2008). Out of 35 projects reported involving high plasticity clays, 30 of them reported problems due to pavement cracking. Even though guidelines for use of geogrid reinforcements are not well established, geosynthetics were reported to have been used in 26 of these projects in order to address the performance problems. Among the various geosynthetic reinforcements, biaxial geogrids were the preferable reinforcement type. Yet, geotextiles and glass grids have also been used in some of the projects. The results obtained from the preliminary survey are compiled in Table 1.

Many of the projects in which geosynthetics were used involved pavements in the Forth Worth–Dallas area. This location is known to have problems with clays of high plasticity. In general, the geosynthetic reinforcements were placed in the pavement during construction, but no post-construction performance evaluation was conducted. In summary, while the survey revealed growing experience on the use of geosynthetic reinforcements in pavements over expansive clays, there was neither well defined design guideline nor material selection criteria. Several of the projects were revisited for post-construction evaluation, and important lessons learned from this experience are documented in the following sections.

Table 1. Survey of projects involving pavements over expansive clays

	Yes	*No*
Cracking problems were observed on pavements over high PI subgrades	88%	12%
Additional problems were observed due to the low bearing capacity	94%	6%
Geosynthetic reinforcements were used in recent projects or repairs	73.5%	26.5%

4 LESSON 1: GEOSYNTHETIC REINFORCEMENTS HAVE PREVENTED THE DEVELOPMENT OF LONGITUDINAL CRACKS

One of the projects evaluated as part of this study provided conclusive evidence of the beneficial effect of geosynthetic reinforcement placed over expansive clays. This project involves FM 1915 located in Milam County, Texas. In 1996, an extensive network of longitudinal cracks was observed in over a 4 km stretch of the pavement section. Accordingly, the pavement was reconstructed with 0.25 m of lime treated subgrade and an asphalt seal coat on top. Due to the presence of clays of high plasticity in the subgrade, the use of reinforcement was considered involving a layer of geogrid at the interface between the base and subgrade. In order to evaluate the actual effect of the geogrid on the required base course thickness, two geogrid reinforced sections were constructed. The first section (Section 1) included a 0.20 m-thick base course, while the second section (Section 2) involved a 0.127 m-thick base course underlain by the same geogrid. In addition, a control (unreinforced) section was constructed with a 0.20 m-thick base course. The details of each test section are summarized in Table 2.

Table 2. Characteristics of the test sections at FM 1915

	Section 1	*Control section*	*Section 2*
Reinforcement	Geogrid	No Geogrid	Geogrid
Base course thickness, m	0.20	0.20	0.127
PI	49	37	37
Total length of section, km	1.26	1.34	1.31

While falling weight deflectometer (FWD) testing was conducted to try to quantify the pavement performance, a clear evaluation was obtained based on condition surveys and visual inspection of the pavement. Specifically, the control section was found to develop significant longitudinal cracks only after a few months of use. On other hand, the two geogrid-reinforced sections were found to perform well, without any evidence of longitudinal cracking. While the actual mechanisms that led to the improved performance of the geogrid-reinforced sections are still to be fully defined, it is clear that an important lesson can be learned from this field experience: geosynthetic reinforcements have prevented the development of longitudinal cracks over expansive clays while unreinforced sections over similar clays have shown significant cracking. Figure 4 illustrates the extent of the three experimental sections and details the performance of the three sections.

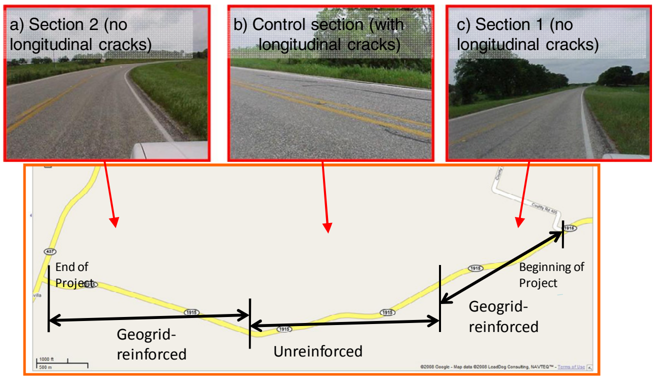

Figure 4. Comparison of the performance of pavement sections over expansive clays (FM 1915): (a) Geogrid-reinforced Section 2; (b) unreinforced control section; (c) Geogrid-reinforced Section 1.

5 LESSON 2: GEOSYNTHETIC REINFORCEMENTS HAVE RELOCATED CRACKS BEYOND THE REINFORCED-PAVEMENT AREA

A second project evaluated as part of this study provided additional evidence of the reinforcement mechanism. This project involves a geogrid-reinforced section in FM 542, located in Leon County, Texas, USA. In March 2005, a road closure was schedule, including repair of the main pavement section. The shoulder road was also to be improved to serve as an alternative traffic lane. Accordingly, the shoulder involved a lime stabilized subgrade, a flexible base, and one course of surface treatment. A geogrid was placed at the subgrade-base interface.

To the surprise of the field inspectors, longitudinal cracks were observed in the shoulder section of the pavement, even before it being opened to traffic. Specifically, longitudinal cracks developed at a distance of 3 ft (1m) from the edge of the shoulder. Accordingly, a forensic investigation was conducted to evaluate the reasons for premature failure of the geogrid-reinforced pavement. A trench was excavated to expose a vertical cut of the cracked portion of the pavement. The excavation up to the subgrade level revealed that the geogrid reinforcement was missing under the deteriorated portion of the pavement. The evaluation indicated that the contractor had used a shorter geogrid roll and, consequently, the geogrid did not cover the entire portion of the pavement. The longitudinal crack developed exactly at the edge of the shorter-than-specified geogrid reinforcement. Figure 5 shows a view of the bottom of the excavated trench, indicating the edge of the 3 m-wide roll, rather than the specified 4.2 m-wide roll. While this incident was unfortunate in the sense that the contractor had to reconstruct portions of the road, it provided additional evidence of the reinforcement effect of geosynthetics when placed over expansive clays. Specifically, the use of geosynthetic reinforcement relocated cracks, which may have developed within the pavement area, to a zone beyond the reinforced area.

6 LESSON 3: CURRENT SPECIFICATIONS HAVE LED TO INCONSISTENT PAVEMENT PERFORMANCE

A third project evaluated in this study reveals the lack of our current understanding regarding the geogrid properties governing the performance of geogrid-reinforced pavements. This project involves FM 1774, a road located in Grimes County, Texas, USA. In August 2002, 14.68 km of the road were reconstructed. During reconstruction, the existing road was regraded and leveled to have 0.25 m of cement-lime stabilized subgrade, 0.18 m of flexible base, and one course of asphalt surface treatment. Site investigation and soil testing indicated the presence of high plasticity clays (PI=40) in the subgrade. Accordingly, these locations were reinforced with a geogrid layer placed at the subgrade-base interface. However, two different geogrid manufacturers bid on the project, both with geogrid products that satisfied the project material specifications. This included a polypropylene Geogrid A and polyester Geogrid B.

During the summer of 2004, longitudinal cracks were observed to develop in the pavement sections reinforced with Geogrid B, while pavement sections reinforced with Geogrid A were observed to continue to perform adequately. Upon excavation for forensic evaluation of the early developed longitudinal cracks, it was evident that Geogrid B had failed at their junction (i.e. the bonded portion of the geogrid where the longitudinal and transverse ribs intersect), as shown in Figure 6. The material properties of the two geogrids used in this project are listed in Table 3, along with the recommended values defined by project specifications.

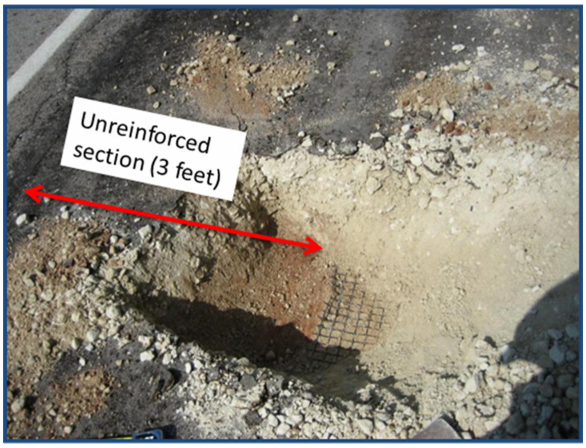

Figure 5. View of edge of geogrid reinforcement, directly underneath longitudinal crack.

Figure 6. Separation of longitudinal and transverse ribs at junctions of Geogrid B at FM 1774

The geogrid B has lower junction efficiency than Geogrid A. The junction efficiency is defined as the ratio between the strength of the junction and the rib tensile strength. However, it should be noted that Geogrid B was considered to meet the specifications because the actual junction strength was comparatively high (the low junction efficiency was result of the fact that Geogrid B had a particularly high tensile strength).

Ultimately, it is clear that the currently available specifications based on tensile properties of the geogrid (both ribs and junction) may not be adequate to identify the geogrid properties that govern the performance of geogrid-reinforced pavements over expansive soils. This indicates the need for additional material characterization specifically mechanism based testing approach to provide insight into the actual causes of the differences in performance of various geosynthetics, when used in pavement applications.

Table 3. Comparison of geogrid properties with specifications given by TxDOT

	Geogrid A	*Geogrid B*	*Recommended*
Aperture Size, mm	35	43	25-50
% Open Area	75 %	74 %	70% min.
Tensile Modulus at 2% Strain , kN/m	215	385	200-300
Ultimate T. Strength, MD, kN/m	26	44	-
CMD, kN/m	21	25	-
Junction Strength, kN/m	22.5	11	-
Ave. Junction Efficiency	93 %	35 %	70% min.

7 CONCLUSIONS

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

- 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, and
- Available geosynthetic specifications and testing methods for pavement reinforcement require additional investigation to identify the actual parameters governing the system performance.

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