Discussion of "Long-Term Field Evaluation of a Geosynthetic-Stabilized Roadway Founded on Expansive Clays" by Gholam H. Roodi and Jorge G. Zornberg

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The authors have presented the results of a comprehensive case study involving several years of evaluating the behavior of a variety of pavement structures constructed on expansive soil using geosynthetics, chemically stabilized subbase courses, and subgrade soil typically used by the Texas Department of Transportation (TxDOT) to mitigate deformation associated with expansive soils. Through systematic monitoring of a large number of test sections along the roadway over a period of 9 to 10 years, the authors have determined that environmental longitudinal cracks in roadways built on expansive soils result from flexing of the pavement structure above the subgrade. This flexing results from shrinkage due to drying in dry periods and from swelling in wet periods. This recurring cyclic climate change results in overall differential vertical displacement between the road's edge and its centerline, leading to crack formation. According to the authors, geosynthetic inclusions in a roadway pavement structure provide a medium that, through its inherent physical characteristics, allows a shift in location of the longitudinal shoulder crack to the outside of the travel lane. They compare the crack locations in the control (nonreinforced) section with those in the reinforced section as shown in Fig. 10 of the original paper.

This observation is consistent with the transverse edge of the geosynthetic inclusion extending beyond the outside edge of the roadway shoulder as shown in a typical TxDOT design for geosynthetic-reinforced low-volume pavement over a treated subbase (Goehl 2013).

The authors, however, have not indicated the extent of the geosynthetic inclusion in the transverse direction beyond the roadway travel lanes where the inclusion should terminate for the longitudinal crack to be disposed outside of the travel lanes, except to indicate that the locations of crack formation outside of the travel lanes depend on the width of the inclusion being used. Determining or establishing the width of the inclusion used in a roadway pavement structure is important economically and practically for practitioners and/or jurisdictions engaged in design, construction, and maintenance of pavements on expansive soils.

When a roadway shoulder is paved, water infiltration in the pavement structure is restricted in comparison with much greater infiltration of a roadway with gravel shoulders unless temperature cracks are present in the asphalt-paved surface. In this case, the moisture movement across the shoulder toward the centerline is less. This suggests different design and rehabilitation strategies for geosynthetic inclusion for roadways with paved and unpaved shoulders.

In reviewing the literature on seasonal movements of impermeable covers such as roadway pavements or housing slabs on expansive soils, two papers of some relevance to the work under discussion are noted: Holland and Lawrance (1980) and Wray (1980). Holland and Lawrance presented information such as the schematic provided in Fig. 9 of the original paper and in Appendix 11 simplified relationships in determining the edge and central heave of impermeable covers on the surface of expansive surfaces. Wray analyzed the soil–structure interaction of stiffened slabs on ground over expansive soils and provided equations to determine the edge moisture variation distance and hence the edge lift and the center lift of the slabs. As Wray noted, of all design parameters, edge moisture variation distance is the most difficult to estimate but, from values reported by other researchers, it is most often expected to lie 2–5 ft measured inward from the transverse edge of the slab. In the typical TxDOT geosynthetic reinforced roadway section provided by Goehl (2013), the extent of geosynthetic reinforcement is 2 ft outside the outer edge of the roadway shoulder for low-volume pavements. For highways with paved shoulders, this suggests that geosynthetic reinforcement is likely to extend beyond the outer edge of the paved shoulders to prevent cracks in the shoulders. On the other hand, crack formation in the shoulders is not considered a serious problem for roadway rideability if the shoulders are used only for temporary stopping.

Based on the authors' conclusion that there is no need to use geosynthetic base stabilization along with chemical stabilization of the subbase, it is necessary to establish or recommend a most suitable approach to determine the location of environmental longitudinal cracks in flexible pavements, especially if the findings of other researchers for rigid covers for concrete slabs are inadequate.

The authors' observations and the possible inferences to be drawn are undoubtedly of value in the design, construction, and maintenance of pavement structures on expansive soils. A response from the authors on the discusser's comments would be much appreciated.

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The writers thank the discusser for his interest in their paper and for his valuable contributions. The discusser calls attention to important similarities and differences between designs of roadways and those of slab-on-ground foundations (both being comparatively lightly loaded structures) that are founded over expansive clay soils. The edge moisture variation distance is an important parameter to determine the deformed shape of the two lightly loaded structures when founded on expansive clay soils. However, the location of resulting damage (e.g., environmental longitudinal cracks) may not be defined only by the extent of the zone subjected to moisture variations. Although a deformability analysis of a slab-on-ground foundation over expansive clays may share similarities with an analysis of a pavement structure, several aspects make the analysis of the latter more complex. Specifically, unlike a concrete slab-on-ground structure that is composed of a single structural layer from bound materials, pavement structures involve multiple bound and unbound layers, all of which contribute to the structures' overall performance. Introducing a geosynthetic layer into the pavement structure does actually increase the complexity of such analysis. Therefore, while factors affecting the deformed shape of the ground surface under covers (e.g., seasonal heave, edge moisture variation distance) may be similar for the two lightly loaded structures, the resulting damage also depends on other characteristics of the two structures. Accordingly, lessons learned about damage to slab-on-ground foundations induced by expansive clay soils cannot be directly applied to roadways.

In the case of roadways, although numerous observations have confirmed that environmental longitudinal cracks induced by expansive clay subgrades often develop at the edge of a roadway, the actual location of such cracks may occur at locations within the roadway. In this closure, observations are provided on the performance of Texas roadways founded over expansive clay subgrades, with a particular focus on the extent of moisture changes from the road edge, the location of environmental longitudinal cracks, and selection of the adequate width of geosynthetic layers.

Observations Regarding Edge Moisture Variation Distance in FM2

To investigate the moisture migration pattern within the expansive clay subgrade in Farm-to-Market Road 2 (FM2) (the subject of the study presented in the original paper), moisture sensors were installed in vertical and horizontal arrays at several locations within the subgrade soil (Zornberg et al. 2008b). The moisture data collected from the horizontal sensor arrays were useful to assess the migration of water under the roadway, while the data acquired from the vertical sensor arrays allowed evaluation of moisture fluctuation in the active zone of the expansive clay subgrade. Fig. 1(a) shows the location of the four sensors in one of the horizontal moisture sensor arrays. The sensors were installed in a test section involving a geogrid-stabilized base over a lime-treated subbase. The outer sensor was installed under the drainage ditch located approximately 2 m beyond the pavement edge, while the other three sensors were evenly distributed under the paved lane.

The moisture data from the sensors in the horizontal array were collected after roadway reconstruction from January 2006 to January 2007. Isochrones defining horizontal moisture profiles are presented in Fig. 1(b). Evaluation of daily weather data from a station located in Hempstead, Texas, for the same period indicated episodes of intense rain between October 2006 and February 2007, while periods with only minor rainfall were observed in late spring and late summer 2006. Also, data from the same weather station indicated that relative humidity fluctuated from 50% to 92% while temperatures ranged from 0°C to 31°C (Zornberg et al. 2008b).

The data presented in Fig. 1(b) reveal significant fluctuations in soil moisture for the sensor installed under the drainage ditch. Specifically, soil moisture at this location ranged from 16% to 46%, with low values corresponding to comparatively dry periods and high values corresponding to rainy months. However, soil moisture at the three sensors installed under the roadway remained approximately constant (about 30% throughout the monitoring period). The monitoring data presented in Fig. 1(b) indicate that moisture variations did not extend beyond 2 m from the drainage ditch. This value is consistent with the typical range of edge moisture variation distance under slab-on-ground structures (i.e., 0.6–1.5 m) reported by Wray (1980).

Location of Environmental Longitudinal Cracks Observed in Central Texas

In this section, the writers initially summarize field observations of the location of environmental longitudinal cracks in roadways not stabilized by geosynthetics. This includes roadways where chemical stabilization of the subbase (a rigid cover) was adopted. Then, observations on the impact of geosynthetic stabilization of environmental crack locations are provided.

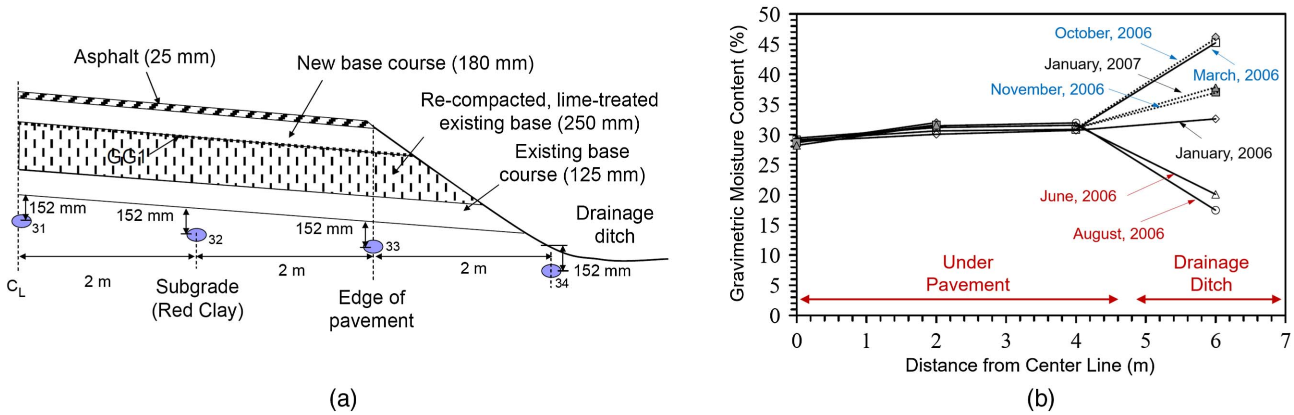

Fig. 1. Moisture sensors in the subgrade of a FM2 test section: (a) layout of horizontal moisture sensor array; and (b) moisture content isochrones. (Adapted from Zornberg et al. 2008b.)

Location of Environmental Longitudinal Cracks in Roadways without Geosynthetic Stabilization

The writers' observations on the performance of roadways founded on expansive clay subgrades in central Texas reveal that environmental longitudinal cracks generally initiate along the roadway edges within approximately 600 mm of the edge white stripes (Fig. 2). After such cracks develop, they provide additional pathways for moisture to enter and compromise the pavement's structural layers. These moisture pathways further contribute to moisture increase in the underlying expansive clay subgrade, ultimately triggering additional longitudinal cracks and uneven roadway deformations. Lime stabilization of subbase layers was found not to affect locations where environmental longitudinal cracks develop. However, as will be discussed subsequently in this closure, crack location may be affected by the adequate selection of geosynthetics to stabilize the base layer.

Location of Environmental Longitudinal Cracks in Geosynthetic-stabilized Roadways

Several cases have been reported in which geosynthetic base stabilization was successfully adopted to minimize the development of longitudinal cracks in roadways founded over expansive clay subgrades (Zornberg and Roodi 2020). However, inadequate design or construction of geosynthetic-stabilized roadway systems may result in the development of longitudinal cracks at unexpected locations. A case illustrating such situations occurred during construction of a detour lane on FM542, where geosynthetics of insufficient width ended up explaining the unexpected crack location (Zornberg et al. 2008a). An additional example is premature longitudinal cracking in a newly rehabilitated highway (SH-21) in Bastrop County, Texas. In this project, the construction joint between a newly constructed shoulder and the existing roadway structure resulted in a pavement discontinuity that was vulnerable to seasonal heaving and shrinkage due to the presence of an expansive clay subgrade. In this case, while the geosynthetic width beyond the edge of the pavement was adequate, longitudinal cracking developed along the construction discontinuity.

On the other hand, in adequately designed and constructed geosynthetic-stabilized roadways, as indicated in the original paper, environmental longitudinal cracks tend to develop beyond the stabilized area and often near the edge of the geosynthetic layers. To further address the important issues raised by the discusser, the writers conducted additional investigations to more accurately determine crack locations. These included a field investigation of

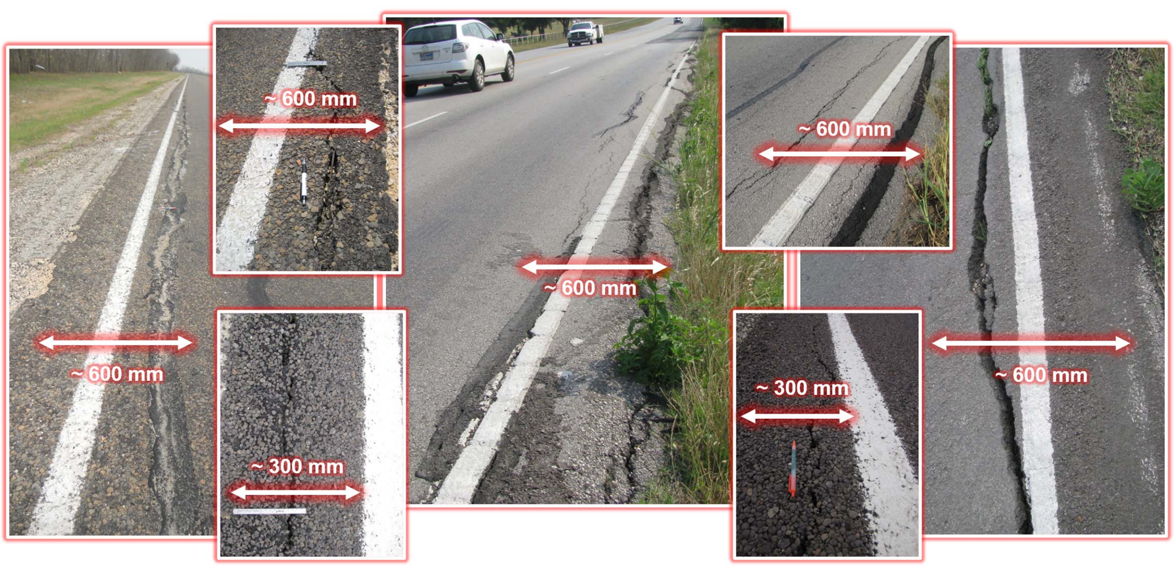

Fig. 2. Locations of environmental longitudinal cracks in central Texas roadways without geosynthetic stabilization founded over expansive clay subgrades.

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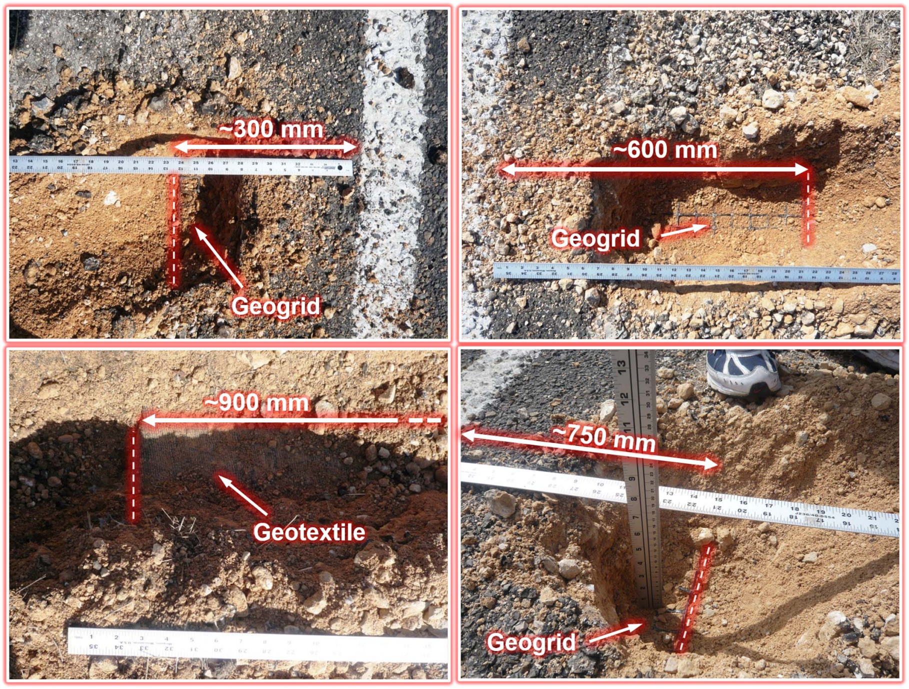

Fig. 3. Field observations of the extent of the geosynthetic width in FM2 test sections.

the geosynthetic width in several test sections of the project site presented in the original paper (i.e., FM2). Specifically, the edges in several geosynthetic-stabilized test sections in FM2 were excavated to confirm the location of the geosynthetic layer. As shown in Fig. 3, the extent of the geosynthetic layer beyond the edge white stripe ranged from 300 to 900 mm.

An additional case documenting the successful use of geosynthetic base stabilization in roadways founded over expansive clay subgrades involved FM1644 in Robertson County, Texas. Specifically, a test section including a geosynthetic-stabilized base was constructed along a stretch of FM1644 that had exhibited poor performance over the years. The reconstructed road profile included a 200-mm-thick cement-treated subbase and a 150-mm-thick base with a biaxial geogrid installed at the subbase–base interface. The images in Fig. 4, obtained during test section construction, confirm that the geosynthetic layer extended approximately 750 mm beyond the pavement edge.

Rigorous visual condition surveys were conducted over approximately five years to assess the performance of the geosynthetic-stabilized test sections and adjacent nonstabilized (control) test sections (Roodi 2016). Specifically, the location and extent of environmental longitudinal cracks were documented. The geosynthetic-stabilized test section exhibited significantly fewer cracks in the pavement than in the control sections, demonstrating the benefits

Fig. 4. Extent beyond road structural layers of geogrid in construction of the geosynthetic-stabilized base in FM1644.

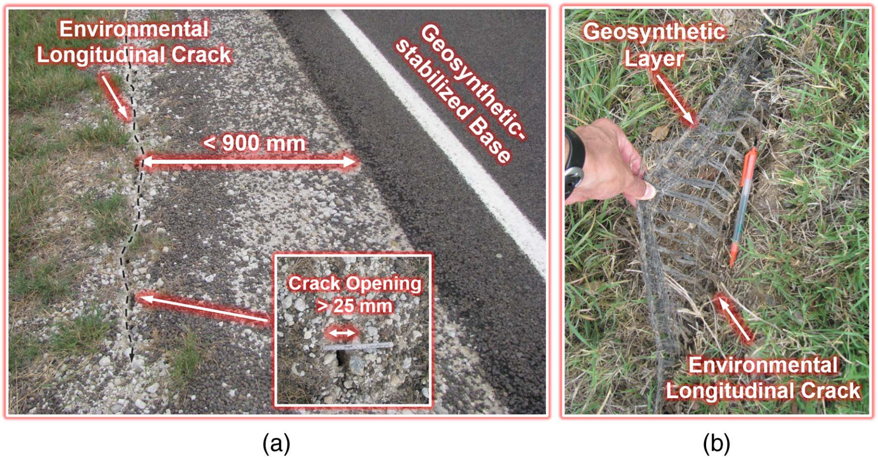

Fig. 5. Field investigation of environmental longitudinal crack outside the pavement: (a) crack location in the geosynthetic-stabilized section; and (b) exposed geogrid in the crack opening.

of geosynthetic stabilization. An additional evaluation during condition surveys involved documenting and investigating the environmental longitudinal cracks that had developed beyond the pavement. As shown in Fig. 5(a), severe longitudinal cracks were observed along the edge of the geosynthetic-stabilized section up to 900 mm beyond the pavement. The location of the longitudinal cracks corresponded to the documented edge of the geosynthetic layer during construction. Further investigation of these cracks indeed confirmed that the location of the edge of the geogrid was consistent with the location of these cracks [see the exposed geogrid material in the crack opening in Fig. 5(b)].

Concluding Remarks

Overall, the information presented in this closure suggests that, while factors causing the deformed shape of expansive clay subgrades under covers may be similar for roadways and slab-on-ground foundations, the responses of these structures are different. Specifically, the locations of environmental longitudinal cracks in pavements may not correspond to those determined for concrete slab-on-ground structures. However, the edge moisture variation distance for both structures may be comparable. In adequately designed and constructed geosynthetic-stabilized roadways, environmental longitudinal cracks tend to develop near the edge of the geosynthetic layer. Complementary field data, presented in this closure, indicate that successful geosynthetic-stabilized base roadways founded over expansive clay subgrades can have geosynthetic layers that extend approximately 750 mm beyond the paved edge.

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