Case Histories on Geogrid Reinforced Pavements to Mitigate Problems Associated with Expansive Subgrade Soils

J.G. Zornberg, Department of Civil and Environmental Engineering, University of Texas, Austin, USA
R. Gupta, Department of Civil and Environmental Engineering, University of Texas, Austin, USA
J. Prozzi, Department of Civil and Environmental Engineering, University of Texas, Austin, USA
D. Goehl, Texas Department of Transportation, Texas, USA

ABSTRACT
Geosynthetic reinforcement of highway subgrades has been used in Texas, USA for the past ten years to mitigate the potential development of longitudinal cracks induced by volume changes in the subgrade soils. This paper describes a survey conducted of TxDOT projects to understand the present state of practice of geosynthetic reinforcement among various districts of Texas. Further, it describes the post construction performance of three pavement projects involving geosynthetic reinforcement. The results obtained in this study reinforce the benefits obtained through the use of geosynthetic reinforcement to mitigate volume changes in the subgrade material. At the same time, the results from this study also emphasize the current lack of understanding of the mechanical contribution of geosynthetic reinforcement to the pavement's structural performance and its resistance to environmental changes.

1. INTRODUCTION

Expansive soils in semi-arid and arid parts of Texas are generally 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 within Texas Department of Transportation (TxDOT) has shown that these cyclic movements cause considerable damage in form of longitudinal cracks to pavement structures founded on them. Stabilization of the pavements over such soft subgrades in Texas has been attempted by lime treating (Petry and Little 2002) and reinforcing them with geogrids.

Geogrids constitute a category of geosynthetics designed to function as soil reinforcement. In particular, geogrids have been used in numerous applications in transportation projects (Zornberg and Christopher 2000; Zornberg et al. 2001). Geogrids have a uniformly distributed array of apertures between longitudinal and transverse tension-bearing elements. The apertures allow direct contact between particles on either side of the installed sheet, which serves to increase the interaction between the geogrid and the backfill soil. Geogrids are typically composed of polypropylene, polyethylene, polyester, or coated polyester polymers. Numerous 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 1997). While the empirical observations of the performance of geosynthetic-reinforced subgrade layers are promising, the actual mechanisms governing the contribution of geosynthetics to the pavement stability have not been clearly identified. This had led to controversial results in the post-construction evaluation of the performance of these systems.

This paper describes a survey conducted to assess the usage patterns of geosynthetics in areas with weak and expansive subgrade throughout the state of Texas. Further, the field performance of three pavement projects involving base reinforcement was documented. In the first pavement project, longitudinal cracks were observed immediately after construction of the pavement, before it was even open to traffic. In second project, starkly different performance was observed for two sections reinforced with different geosynthetic products (selected using project-specific specifications). The third project showed consistent, good performance throughout the first two years of operation (*e.g.*, no pavement distress), although the results of field monitoring tests did not indicate a significant improvement in the stiffness of the subgrade. The lessons learned from these projects will be discussed in detail. The aspects of this project that are useful for planning instrumentation and monitoring of full scale field test sections are also discussed.

2. SURVEY DETAILS

2.1 Participating TxDOT districts

A survey in the form of a one page questionnaire was distributed to TxDOT district engineers. The survey forms were distributed in electronic format, and engineers were requested to send the completed form by email. The survey asked the engineers to report on their experience with expansive clays and the different solutions that the districts have used to construct pavements over such subgrade. The information obtained was analyzed at the University of Texas, Austin. Survey responses were obtained from 35 projects in 16 TxDOT districts. The number of projects reported based on participating county of each district is as shown in Table 1. No response was obtained from TxDOT districts of Childress, Amarillo, San Antonio, Corpus Christi, Houston, Brownwood, Waco, Tyler, and Laredo.

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Table 1 Number of projects from each county of participating TxDOT districts

S.NO.	County	District	Projects reported
1.	Fort Worth	Fort Worth	3
2.	Yoakum	Yoakum	1
3.	Williamson	Austin	1
4.	Hidalgo	Pharr	2
5.	Wichita	Wichita Fall	1
6.	Lubbock	Lubbock	1
7.	Jefferson	Beaumont	1
8.	Burnet	Austin	1
9.	Taylor	Abilene	1
10.	Angelina	Lufkin	1
11.	El Paso	El Paso	1
12.	Navarro	Dallas	1
13.	San Angelo	San Angelo	1
14.	Panola	Atlanta	4
15.	Titus	Atlanta	1
16.	Bowie	Atlanta	1
17.	Harrison	Atlanta	2
18.	Walker	Bryan	5
19.	Lamar	Paris	1
20.	Hunt	Paris	1
21.	Grayson	Paris	3
22.	Midland	Odessa	1

2.2 Analysis of survey results

Out of the 35 projects reported in the survey, 30 of the projects reported problems due to cracking of pavement over high plasticity clay, and 33 projects had problems due to pavement over weak subgrade. Analysis of the combined response indicates that that 85% of the pavements had problems due to both of above reasons. Geosynthetics were used in 26 projects to counteract these problems, and geogrids were the preferred geosynthetics. The results obtained from the preliminary survey are compiled in Table 2.

Table 2 Results obtained for survey conducted with TX-DOT

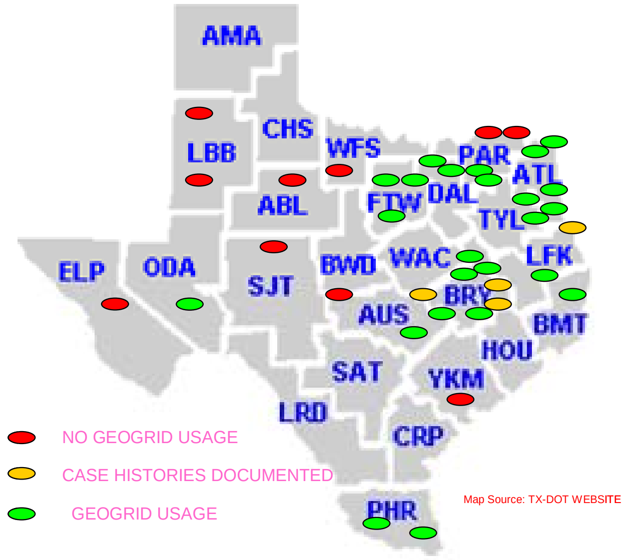
Response	Cracking problem over pavements with high PI clay	Problems with weak subgrade	Use of geosynthetic over pavements
Yes	88 %	94 %	73.5 %
No	12 %	6 %	26.5 %

2.3 Discussion of survey results

Based on the survey responses above, most cracking occurred in pavements that were constructed over clays of high plasticity. District engineers attributed this to the weak subgrade below the pavement. They had attempted to use geosynthetics in such cases to stabilize the weak subgrade. The geosynthetics products used in the projects ranged from geogrids (from more than one manufacturer), geotextiles to glass geogrids, although geogrids were the most widely used. A breakdown of the districts using geogrids is shown in Figure 1. Also, most of the projects in which geosynthetics were used in the pavement were in the Forth Worth–Dallas area. This location is known to have problems with clays of high plasticity.

For the majority of projects considered in this study, geosynthetics were placed in the pavement during construction and no post construction performance evaluation was conducted. This made quantification of the benefits of using geosynthetics in pavements difficult to assess. The geosynthetics were also used at various locations within the pavement (*i.e.*, at the base-subbase interface, within the base course, and within the asphalt). Further, based on the comments received on the survey forms, it was found that the engineers did not use a systematic specification to select a geosynthetic in a reinforced pavement project. There is currently a single TxDOT specification regarding the necessary material properties of geogrids used in reinforcement applications, although there is no similar specification for other geosynthetics. Further, the engineers had no guidance as to the best location for placement of the geosynthetics and how to place them in the pavement during construction.

In summary, the survey indicates that there is an experience base for the usage of reinforcement geosynthetics in pavements, but there are still no material selection criteria, suggested design methodology, or requirements for post-construction performance evaluation. Accordingly, three of the 35 projects listed in the survey were selected for post construction field monitoring.



Map Source: TX-DOT WEBSITE

Figure 1 Map showing usage of geosynthetics in Texas based on districts which responded to the survey

3. CASE HISTORY 1

3.1 Project description

FM 542 is located in Leon County, which is in the Bryan TxDOT district approximately 120 miles north of Houston, Texas. In March 2005, the road was planned for closure to replace its main section. The shoulder road was also to be improved to serve as an alternative traffic lane. Accordingly, the shoulder was constructed consisting of lime stabilized subgrade, a flexible base, and one course of surface treatment. A geogrid was placed at the subgrade-base interface.

3.2 Field observations

Longitudinal cracks were observed in the shoulder section of the pavement before it was opened to the traffic. Accordingly, a forensic investigation of the site was performed to establish the reasons for premature failure of the road. During visual inspection of the site, 50 mm-wide longitudinal cracks were observed close to the junction of the recently constructed shoulder and previous main road section. A backhoe was then used to excavate the asphalt and base course to expose a vertical section of the cracked portion of the pavement. The excavation indicated that there was no geogrid below the cracked portion of the pavement. Further, a borehole was made at this location with soil samples collected at 0.15 m intervals to a depth of 1 m. The top 0.5 m of soil was red colored sand underlain by light brown clay. The in-situ water content and plasticity index values at the time of excavation are summarized in Table 3. The subgrade is a clay of low plasticity. The water content of the soil compared to the plastic limit indicates that the soil is relatively dry, which may have been the cause of the observed cracking.

Table 3 Atterberg limit values for the soil samples collected at site

Depth of sample	Water content	Liquid limit	Plastic limit	Plasticity Index
(mm)	(%)	LL	PL	PI=LL-PL
0-150	9.7	17.7	14.1	3.6
150-300	17.7	23.6	19.0	4.6
300-450	13.7	23.3	20.0	3.3
450-600	20.3	37.1	23.2	13.9
600-750	24.3	38.5	24.1	14.4
750-900	24.8	43.8	31.1	12.7

3.3 Analysis and Results

The geogrid rolls supplied by the manufacturer were 3m wide, but the proposed lane was 4.2 m wide. The contractor had placed only one roll of the geogrid along the centerline of the road, leaving 1.2 m of unreinforced pavement near the edge of the road. While the section consisting of the geogrid was observed to still have good performance at the time of excavation, cracks were observed in the unreinforced section of the pavement. In fact, most of the cracks were observed at the junction of the unreinforced and reinforced section as shown in Figure 2 below. The shrinkage cracks were not observed to pass into the subgrade. This indicates the benefit of using geogrid-reinforced pavements instead of unreinforced pavements when constructing roads over expansive subgrade soils.

Figure 2 Longitudinal cracks in the unreinforced section of FM 542 pavement

4. CASE HISTORY 2

4.1 Project description

The second project investigated in detail is the FM 1774 road, located in Grimes county located 75 miles north of Houston, Texas. In August 2002, 14.68 km of the road were reconstructed, from SH 90 to FM 2445. During construction, 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 clay of high plasticity (PI=40) in the subgrade. To reinforce the pavement at these locations, an additional layer of geogrid was included in the pavement design, located at the subgrade-base interface. Two different geogrid types available on the market were found to satisfy the project specifications. The geogrids were labeled as geogrid 1 (polypropylene), and as geogrid 2 (polyester). A typical section of the geogrid reinforced pavement constructed at site was as shown in Figure 3.

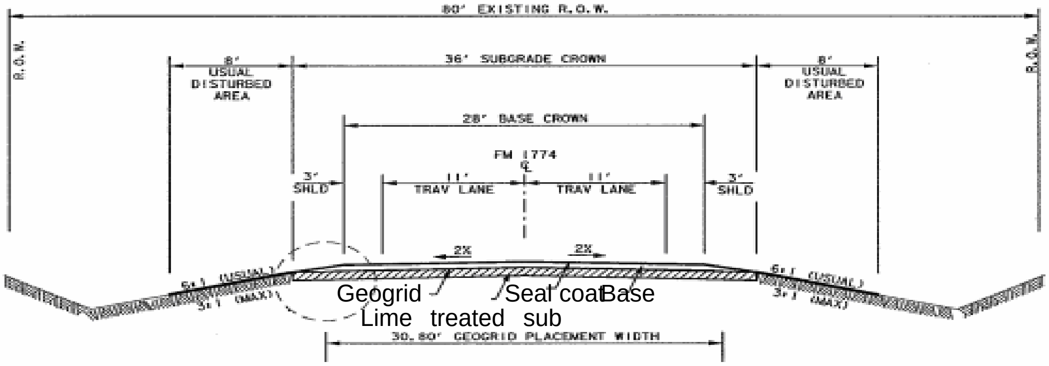


Figure 3. Typical geogrid reinforced pavement section at FM 1774

4.2 Field Observation

In summer 2004, longitudinal cracks were observed in a pavement section reinforced with geogrid type 2, while pavement section reinforced with geogrid type 1 was observed to still have satisfactory performance. Upon excavation of the cracked road section, it was observed that the geogrids had failed at their junction (the bond between the longitudinal and transverse elements of the geogrid). Longitudinal cracks and slippage at the junction of the geogrids in the pavement section reinforced with geogrid 2 are shown in Figures 4(a) and 4(b) respectively.

Figure 4.a) Longitudinal crack on the pavement reinforced with geogrid type 2 at FM 1774 (Bryan District) b) Slippage between longitudinal and transverse ribs at junction of geogrid type 2 at FM 1774 (Bryan District)

4.3 Material properties

The material properties of both the geogrids used in this project listed in Table 4, along with the recommended project specifications.

Table 4 Comparison of geogrid properties (type 1 and 2) with specifications given by TxDOT

Geogrid type	Geogrid type 1	Geogrid type 2	Recommended
Aperture size, cm (inch)	3.5 (1.4)	4.3(1.7)	2.5-5.0 (1.0-2.0)
% Open area	75 %	74 %	70% min
Tensile Modulus at 2% strain , lb/ft	15306	27450	14000-20000
Junction efficiency	94 %	35 %	90% minimum

4.4 Analysis and Results

Although geogrid type 2 has higher tensile strength in both the machine and cross-machine directions than geogrid type 1, geogrid type 2 had lower junction strength. The TxDOT specification for the use of geogrids in this project only included both geogrid index properties (e.g., aperture size, % open area) and performance properties (e.g., tensile modulus, junction efficiency, ultimate strength in machine and cross-machine direction). A preliminary review of the test results for geogrid type 1 (performing satisfactorily) indicates that the geogrid had a junction efficiency, defined as the ratio between the strength of the junction and the rib tensile strength, of 94%. However, the test results for geogrid type 2 (poor performance) had a junction efficiency of only 35 %. As specifications developed since the time of this project require 90% junction efficiency, the inadequate junction efficiency value could be inferred as being the potential cause for the difference in pavement performance.

However, closer inspection of the available test results indicated that the tensile modulus (at 2% strain) for geogrid type 2 in the poorly-performing section is approximately twice as high as that in the well-performing section. As the tensile modulus is a key property in the definition of the junction strength, this geogrid was unfairly penalized. This indicates the need for additional material characterization to provide insight into the actual causes of the differences in pavement performance. For example, the tensile modulus in the cross-machine direction is rarely specified, even though it is just as relevant as the tensile modulus in the machine direction. However, the tensile modulus in the machine direction is usually the only variable typically specified. Also, the time-dependent response of different polymers to sustained loading may lead to different strength values, especially if tensile tests are conducted at different strain rates. Accordingly there is need of having additional laboratory tests that will capture the geogrid mechanism and provide independent verification of the geogrid properties that can better predict its performance in the field. As per the current specification help to characterize the unconfined behavior of the geogrid, but no tests have been done to understand the behavior of geogrids when they are used

5. CASE HISTORY 3

5.1 Project description

FM 1915 is located in Milam County located 140 miles north-west of Houston, Texas. In 1996, an extensive network of longitudinal cracks was observed in the pavement section over 4 km stretch of the road extending to the west of the Little River Relief Bridge. 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, it was planned to reinforce the pavement with a layer of geogrid at the interface between the base and subgrade. Further, to evaluate the influence of geogrid on the required base course thickness, two geogrid reinforced sections were constructed. The first section (section1) had a base course thickness of 0.20 m underlain by a geogrid, while the second (section 2) had a base course thickness of 0.127 m underlain by the same geogrid. Also, a control section was constructed with a base course thickness of 0.20 m without a geogrid. The details of each test section are summarized in Table 5. A view of the site is as shown in Figure 5.

Table 5 Details of three test sections constructed at FM 1915

Section	Section 1	Control section	Section 2
Material used	Geogrid	No Geogrid	Geogrid
Base course thickness, m	0.20	0.20	0.127
Plasticity index (PI)	49	37	37
Total length of each section, km	1.26	1.34	1.31

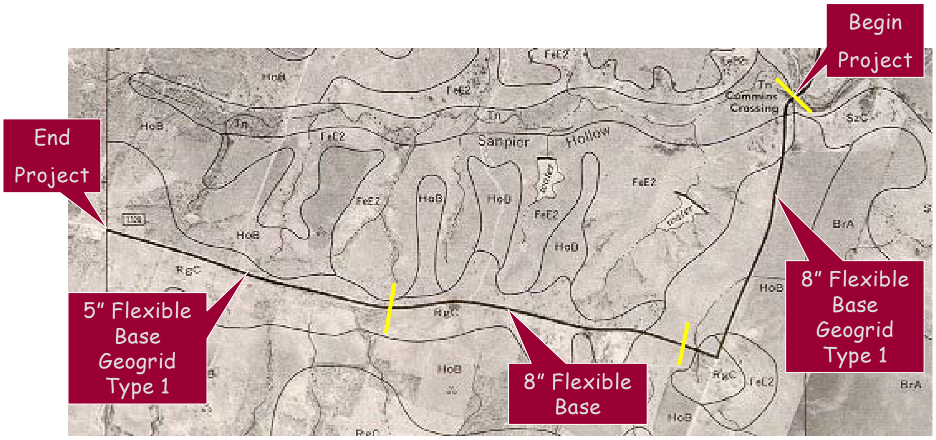


Figure 5. View of the extent of three sections at FM 1915

5.2 Field Testing

In July 2001, TxDOT performed falling weight deflectometer (FWD) tests along the 4 km of the reconstructed pavement section. The tests were conducted at intervals of 30.5 m starting from section 1. The FWD deflection data was analyzed using the Modulus 6.0 software program, which 4was developed by the Texas Transportation Institute (Scullion, 2004) and the elastic modulus for each pavement section layer was then back calculated. The average values of modulus obtained for pavement layers of each section are summarized in Table 6.

Table 6: Mean modulus (M_r) values obtained using Modulus 6.0 for pavement layers on three test sections at FM 1915

Section	SECTION 1	CONTROL	SECTION 2
MODULUS, (MPa)	Mean (MPa)	Mean (MPa)	Mean (MPa)
Seal coat	2068	2063	2020
Base course	1724	1660	1451
Sub base	443	380	302
Sub grade	139	134	132

5.3 Analysis and Results

The results from the FWD test for Section 1 indicate higher moduli for the base course, sub base, and subgrade layer when compared with the values for the control section. However, the FWD results for Section 2 indicate lower base and subbase moduli as compared to the other two sections. These results lead to conclusion that a consistent comparison between a geogrid reinforced section and an unreinforced section is only reasonable when the base course thickness is the same. The benefits of using a geogrid are not apparent in an FWD when a smaller pavement thickness is used.

Despite the difference in FWD results for the three sections, the control section was found to have failed after several months of use. Specifically, longitudinal cracks were observed in the control section. On other hand, the two geogrid reinforced sections were found to be performing well without any evidence of surface cracking. The anomaly between the field observations and FWD testing is mainly due to the current pavement analysis procedures for FWD loading, which do not appropriately consider the effects of the geogrid reinforcement layer in the back-calculation method. Presently the analysis is conducted by neglecting the geogrid layer (as it has a negligible thickness) and directly computing the modulus values for various pavement layers in the given section. These values are then compared to the modulus values for various pavement layers of a control section. The increases in the base course, sub base, and subgrade moduli between sections 1 and the control section are attributed to the presence of the geogrid layer. Although this method of analysis can quantify the benefits for the same base course thickness, it can be misleading if the base course thickness is varied. Therefore, there is a need for an improved method of analysis to quantify the benefits of geogrid reinforcement in pavements.

6. LESSONS LEARNED FROM PROJECT EVALUATION

Forensic investigation conducted at a newly constructed FM 542 was reported. The longitudinal cracks were observed in the geogrid reinforced pavement before it was open to traffic. But when site was excavated near the cracks, no geogrid was found below the pavement section. Further investigation reveled that the contractor had laid 3 m roll of geogrid and the pavement being 4.2 m long, remaining 1.2 m section was unreinforced and thus cracked. This study showed that use of geogrid can prevent cracking in the pavements.

Field performance of two geogrid reinforced pavement consisting of subgrade having clay of high plasticity are reported. The pavement had two different types of geogrid. Both the geogrids meet the project specifications set by TxDOT. Whereas one section reinforced with geogrid type 1 (polypropylene) was found to be performing well, the other section reinforced with geogrid type 2 (polyester) showed longitudinal cracking. The review of the material properties leads to the preliminary conclusion that poor performance in the geogrid type 2 sections is due to inadequate junction efficiency but closer inspection indicated the higher tensile modulus of geogrid in this section. Since tensile modulus is an important property of geogrid, the need for better material characterization is stressed to predict the actual cause of difference in field performance.

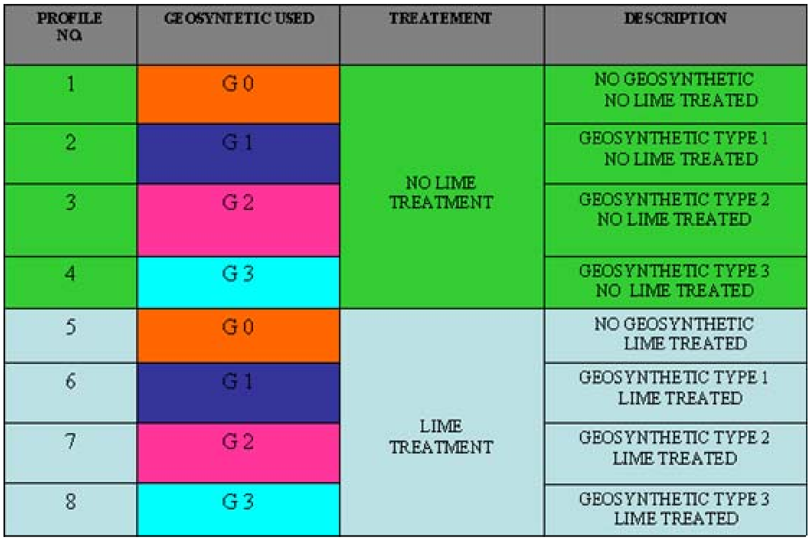
In the third pavement, three sections were constructed. The two geogrid-reinforced pavement sections (i.e., section 1 and 2) had base course thickness of 8 inches (0.20 m) and 5 inches (0.127 m) respectively; whereas control sections (no geogrid reinforcement) had 8 inches (0.20 m) thick base course layer. FWD testing showed higher pavement modulus for the geogrid reinforced section with 8 inches (0.20 m) thick base course layer over the control section whereas lower modulus value were predicted for geogrid reinforced section having 5 inches (0.127 m) thick base course layer . This indicates better performance for the section 1 and poor performance of section 2 when compared with the control section. But field visual assessment showed cracking in the control section and the two geogrid reinforced section were performing well. The geogrid reinforced sections outperform the unreinforced sections though the FWD testing indicates otherwise. This shows the inadequacy in the present analysis technique for non destructive testing to quantify the geogrid benefit in pavements.

Based on the lessons learned by the survey of TxDOT districts and field case histories, it was decided to construct geosynthetic reinforced pavement sections in the field and conduct a full-scale field study to monitor their performance

7. FUTURE WORK

Based on the lessons learned by the TxDOT district survey and the observations from the field case histories, TxDOT proposed to build several geosynthetic-reinforced pavement sections on a road under renovation. Further, this project would involve post-construction monitoring to evaluate the long-term performance of the pavement. The field testing program was proposed to include both geosynthetic-reinforced sections intended to perform well as well as section that are expected to perform poorly. The main goals to be addressed in this study were:

- i) Construction of test sections with different geosynthetic types (i.e., geogrid and geotextiles)
- ii) Construction of test sections with different type of geogrids in order to compare the performance of different products
- iii) Construction of sections to provide a baseline control section for the study
- iv) Construction of sections with and without lime treatment
- v) Construction of repeat sections to account for variations due to environmental, construction, and site factors with location along the road



PROFILE NO.	GEOSYNTETIC USED	TREATEMENT	DESCRIPTION
1	G 0	NO LIME TREATMENT	NO GEOSYNTHETIC NO LIME TREATED
2	G 1		GEOSYNTHETIC TYPE 1 NO LIME TREATED
3	G 2		GEOSYNTHETIC TYPE 2 NO LIME TREATED
4	G 3		GEOSYNTHETIC TYPE 3 NO LIME TREATED
5	G 0	LIME TREATMENT	NO GEOSYNTHETIC LIME TREATED
6	G 1		GEOSYNTHETIC TYPE 1 LIME TREATED
7	G 2		GEOSYNTHETIC TYPE 2 LIME TREATED
8	G 3		GEOSYNTHETIC TYPE 3 LIME TREATED

Figure 6 Schematic layout of test sections constructed at FM 2 site

Based on the above requirements, it was decided to construct four test sections. In addition to a control section (GG0), three geosynthetic reinforced sections were constructed [geogrid type 1 (GG1), geogrid type 2 (GG2), and a woven geotextile (GG3)]. Each of the sections was constructed over a length of road that were both lime-treated and non-lime-treated base course. There are overall 8 sections that were constructed in the field as shown schematically in Figure 6. Further, each of the above 8 sections was repeated four times at the site for redundancy, making 32 pavement sections. Based on the proposed test sections, TxDOT decided to incorporate these sections into a recently renovated road FM-2 near Navasota, Texas.

8. CONCLUSIONS

In summary, there is ample field evidence that geogrid reinforcement provides benefits by stabilizing pavement over weak subgrades and expansive clays with high plasticity. However, there is still a need for new laboratory tests to help provide insight into field performance of geogrid-reinforced pavements. Further, new methods for the analysis of FWD testing need to be developed which can better predict the field performance of geogrid reinforced and unreinforced section. The results obtained from the above full scale test sections are useful to help address issues related to the current lack of understanding on the effects of geosynthetic reinforcements to the pavement structural performance and its resistance to environmental changes.

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