Monitoring Performance of Geosynthetic-Reinforced and Lime-Treated Low-Volume Roads under Traffic Loading and Environmental Conditions

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ABSTRACT

Geosynthetic reinforcements have shown effective performances in basal reinforcement of low volume roads under traffic loads. In recent years, these reinforcements have also been used to improve roads against environmental loading. This study evaluates the performance of geosynthetic-reinforced and lime-treated low volume roads under both traffic loads and environmental conditions. Thirty two test sections were constructed in 2006 over expansive clay subgrade in Grimes County, TX. The sections involved eight different cross sections, including control (unreinforced) sections, subbase lime-treated sections, base geosynthetic-reinforced sections with three geosynthetics types, and combinations of subbase lime-treated with base geosynthetic-reinforced systems. An index of pavement performance was used to compare and rank the overall performance of the road sections. The geogrid reinforced sections were found to significantly enhance the performance of the road sections by preventing the development of longitudinal cracks in paved area. On the other hand, lime treatment showed only limited improvements to the performance of the reinforced sections.

INTRODUCTION

For decades, geosynthetics have been used in pavement system layers to perform different functions including separation, filtration, drainage, reinforcement and containment. However, reinforcement function of geosynthetic has been proven to be most effective in the basal reinforcement of the low-volume flexible pavements with thin asphalt surface. Benefits of using geosynthetic reinforcement in pavement system layers are typically addressed as reduction in the thickness of the base layer or extension in the service life of the pavements.

A variety of methods have been used to address the contribution of geosynthetic reinforcement in pavement systems (Barksdale et al. 1989, Perkins and Edens 2003a,b, Kwon et al. 2005a, Kwon et al. 2005b, Perkins et al. 2009, Douglas 1997, Tingle and Jersey 2005). However, there is still a lack of detailed understanding about the actual properties govern the behavior of geosynthetic reinforcement in pavements (Christopher et al. 2001, Zornberg and Gupta 2009). Moreover, a nationally recognized design procedure has not been established yet, and cost-benefit ratio of the reinforced sections has not been clearly identified.

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Recently, the Texas Department of Transportation (TxDOT) has used geosynthetic basal reinforcement technique to improve the performance of the low volume roads over expansive subgrade soils. The major problem involved with construction of pavements over expansive clays is the environmental longitudinal cracks. These cracks are mainly developed by cyclic shrinkage and swelling of the subgrade due to the seasonal moisture fluctuation in the area. The performance of the geosynthetic reinforced sections to mitigate the development of the longitudinal cracks has not been clearly identified. Specifically, the effectiveness of the combination of lime treatment, as a conventional stabilization method for subgrades, with the geosynthetic reinforcement has not been adequately studied.

The purpose of the current study is to investigate the performance of actual geosynthetic reinforced and lime treated road sections under traffic loading and environmental conditions. Moreover, the efficiency of combining geosynthetic reinforcement with lime treatment has been studied.

DESCRIPTION OF THE PROJECT

The present experimental study focuses on the performance of 32 low-volume road test sections located on FM2 road in Grimes County, Texas. The road was founded on a black clay subgrade with plasticity index of 35 to 50%. Each test section was 12 feet wide and almost 450 feet long. The sections fall into eight groups:

- Control (unreinforced) test section (CONTROL)
- Subbase lime treated test sections (LT)
- Test sections reinforced with three different types of geosynthetics including two geogrids (GG1 and GG2), and one geotextile (GT)
- Combination of the geosynthetic reinforced sections with lime treatment (GG1+LT, GG2+LT, GT+LT)

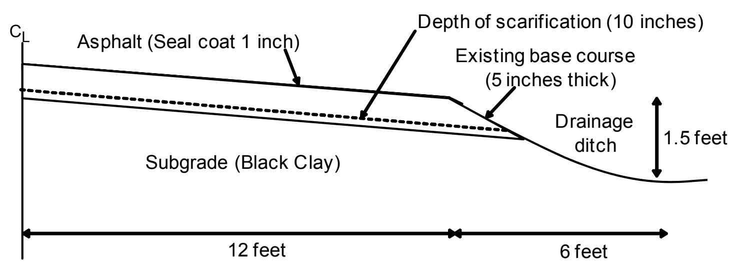


Fig. 1. Cross section of the FM2 pavement before reconstruction (Gupta 2009)

For the purpose of this project, the existing road was reconstructed by removing the top 10 inches of the existing base course layer and installing geosynthetics. Then the removed base material was re-compacted and placed over the geosynthetic reinforcement. On top of this layer, a new 5-inch base course material was constructed which was overlain by 1 inch asphalt cover. In lime treated sections, the 10-inch base course layer was stabilized with lime to act as a subbase layer for the new 5-inch base course layer. Figures 1 and 2 demonstrate the cross sections of the road before and after reconstruction.

Reconstruction of the test sections was completed in January 2006 and the road reopened to traffic in the same month. According to TxDOT estimation, the average daily traffic (ADT) of the road was 800 vehicles in 2002 and is expected to increase to 1300 vehicles in 2022. Of this traffic, trucks account for 6.6 %.

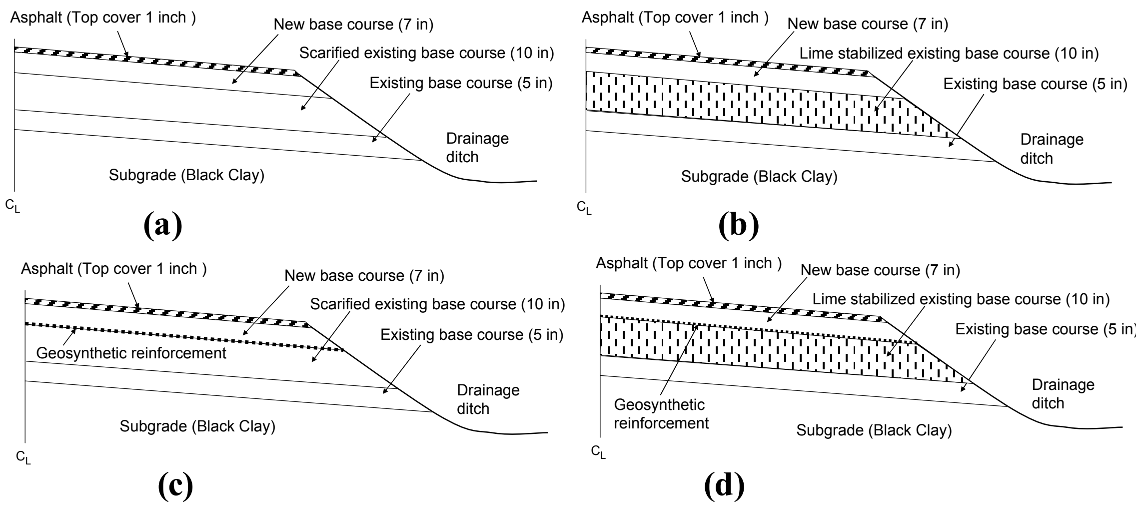


Fig. 2. Pavement test sections at FM 2: (a) Control (unreinforced) Sections; (b) Lime Treated Sections; (c) Geosynthetic Reinforced without lime stabilization; (d) Geosynthetic Reinforced with lime stabilization (Gupta 2009)

MONITORING PROGRAM

A comprehensive monitoring program was planned to evaluate the performance of the test sections under traffic loads and environmental conditions. This program included:

- Performing nondestructive tests including Rolling Dynamic Deflectometer (RDD) and Falling Weight Deflectometer (FWD) to evaluate changing in the mechanical properties of pavement layers (Joshi and Zornberg 2011, Joshi 2010, Gupta 2009)
- Installing moisture sensors in horizontal and vertical arrays to study the moisture migration pattern under the pavement (Gupta 2010)
- 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
- Periodic conditions surveys to identify and quantify the distresses involved in each section and determine the condition of the pavement surface

The focus of this paper is on the results of the visual conditions surveys. Although different types of complex instruments are typically used to evaluate the condition of roads, these instruments do not provide all of the required information. The information provided by this type of surveys can be used to develop a numerical rating which determines the condition of each test section.

QUANTIFICATION OF DISTRESSES

A total of sixteen visual conditions surveys have been conducted from the reconstruction of the road sections in January 2006 to the date of preparing this paper. The surveys are conducted mainly based on the instructions recommended in the TxDOT Pavement

Management Information System, Rater's Manual. According to this manual, flexible pavement distress types may be categorized in ten groups described below:

Fig. 3. Measurements of rutting in FM2 road test sections

Shallow Rutting and Deep Rutting: Rutting is measured as the percentage of the section's total wheel paths area in different severity levels. While Shallow Rutting is defined as 0.25 to 0.49 inch (6 to 13 mm), Deep Rutting is determined as 0.5 to 0.99 inch (13 to 25 mm). Severe Rutting is referred to rutting as large as 1.0 to 1.99 inches (25 to 51 mm), and Failure Rutting is called to rutting equal to or greater than 2.0 inches (51mm). In this study, rutting of test sections is measured using a 6-foot straight edge and a steel ruler (Fig. 3).

Alligator Cracking and Block Cracking: Alligator (or Fatigue) cracks are irregularly shaped interconnected cracks mainly developed under the wheel paths by the traffic load. Block Cracks are much larger in dimensions and divide the pavement surface into almost rectangular shaped blocks. Unlike Alligator Cracking, Block Cracking is mainly caused by non-traffic associated reasons such as shrinkage of the asphalt layer or swelling and shrinkage of the base course layer. According to TxDOT PMIS Rater's Manual, Alligator Cracking should be measured as "the percentage of the rated lane's total wheel path area that is covered by alligator cracking" regardless of the cracks width. This manual does not define any severity level for Alligator Cracking. Similar to Alligator Cracking, no severity level has been defined for Block Cracking in the Rater's Manual. Block Cracking should be measured in terms of the percentage of block cracking area out of the total lane's area.

Longitudinal and Transverse Cracking: Since TxDOT PMIS Rater's Manual ignores longitudinal and transverse cracks with width less than 3mm, results presented in this paper refer to cracks wider than 3mm. However, during the conditions surveys all cracks, even those cracks less than 3mm wide, have been recorded. This allowed us to better differentiate the performance of the sections and enabled tracking initiation and progress of cracks over time. The cracks are measured in terms of the linear foot of cracking per 100-ft stations, for longitudinal cracking, and the number of cracks per 100-ft stations, for transverse cracking.

Patching: Repairs made to cover distresses appeared on the pavement surfaces are called patches. According to TxDOT PMIS Rater's Manual patching should be measured in terms of the percentage of the patches area with respect to the total area of the lane.

Raveling and Flushing: Disintegration of the material of the asphalt mix causes the aggregate particles to be exposed on the surface of the pavement. This distress is called Raveling and is measured as the percentage of the rated lane's total surface area that is covered by the raveling. On the other hand, exposure of the bituminous material on the surface of the pavement is referred to as Flushing. This distress is measured as the percentage of flushing area out of the total surface area of the pavement.

Failures: Areas that are severely distressed are counted as failures. Failures may be caused by extreme rutting or widely opened cracks or even high severity alligator cracking.

RESULTS AND DISCUSSION

In this section, the results of the last conditions survey on FM2, which is performed on April 30, 2011, are described and discussed. Since the main purpose of the current study is the evaluation of the role of geosynthetic reinforcements, the primary focus of the discussion is on the distresses that the reinforcement can prevent them. As a result, flushing and raveling, which are more relevant to problems in asphalt mixture, are not considered in the analysis. TxDOT commonly uses geosynthetics to mitigate the longitudinal cracking mainly caused by the differential movement beneath the surface of the road due to environmental loading such as swelling and shrinkage. However, geosynthetic reinforcement can be attributed to an inhibited initiation and propagation of other types of cracks and deformation on the road surface.

In the following sections, the results of the conditions surveys are presented for all relevant types of distresses. However, the level of some types of distresses has been relatively low (almost zero) in many sections. For simplicity, all distress levels are presented in the equivalent percentage numbers. It should be noted that TxDOT PMIS Rater's Manual considers edge cracking as a kind of longitudinal cracking. As a result, in the presented tables, Longitudinal Cracks column covers all kind of longitudinal cracks recorded inside the pavement regardless of proximity of the cracks to the edge of the road.

Control Sections and Lime Treated Sections

Table 1 shows the results of the survey for control (unreinforced) sections and lime treated sections. As indicated in the table, all control sections have experienced significant amount of cracking. Of the five control sections, four of them had more than 30% of Longitudinal cracking and two of them, Sections #1 and #27, showed more than 50% of Longitudinal cracking. In the only section with small amount of longitudinal cracking, i.e. Section #26, significant amount of rutting and alligator cracking was observed. In this section, 61% of the wheel paths length had experienced rutting, of which 18% was severe rutting.

Table 1. Results of the conditions survey for CONTROL and Lime Treated (LT) sections

Layout	Section Number	Rutting			Patching	Cracking				
		Shallow	Deep	Severe		Block	Alligator	Transverse	Longitudinal	Shoulder
		% AREA			% AREA	% AREA	% AREA	No. / 100' STA. (%)	Linear ft/100' STA. (%)	Linear ft/100' STA. (%)
CONTROL (Unreinforced)	1	11%	0%	0%	0.0%	0.0%	0%	0.2%	52%	0%
	10	38%	25%	0%	0.0%	0.0%	28%	0.0%	31%	0%
	20	0%	0%	0%	0.1%	0.0%	0%	0.0%	30%	16%
	26	21%	22%	18%	0.0%	0.0%	31%	0.0%	6%	6%
	27	15%	0%	0%	0.0%	0.0%	0%	0.0%	54%	0%
	Average	17.1%	9.3%	3.6%	0.0%	0.0%	11.7%	0.0%	34.6%	4.4%
	Max	37.9%	24.5%	18.1%	0.1%	0.0%	30.7%	0.2%	53.8%	15.8%
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.8%	0.0%
LT (Lime Treated)	5	16%	0%	0%	0.0%	0.0%	14%	0.0%	39%	0%
	6	0%	0%	0%	0.0%	0.0%	0%	0.4%	51%	0%
	7	0%	0%	0%	0.0%	0.0%	0%	0.4%	15%	0%
	8	39%	0%	0%	0.0%	0.0%	11%	0.4%	9%	0%
	13	0%	0%	0%	0.0%	0.0%	0%	0.0%	0%	0%
	21	0%	0%	0%	0.0%	0.0%	0%	0.0%	22%	16%
	22	0%	0%	0%	0.0%	0.0%	0%	0.0%	38%	17%
	23	5%	4%	3%	0.0%	0.0%	4%	0.0%	86%	7%
	24	0%	0%	0%	0.0%	0.0%	51%	0.1%	12%	0%
	31	4%	0%	0%	0.1%	0.0%	30%	0.0%	4%	0%
	Average	6.5%	0.4%	0.3%	0.0%	0.0%	11.1%	0.1%	27.5%	3.9%
	Max	39.5%	4.3%	3.0%	0.1%	0.0%	51.1%	0.4%	86.0%	16.7%
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

On the other hand, the Lime Treated Sections performed relatively well in terms of rutting, but they still present considerable amount of cracking. While out of 10 lime treated sections one performed pretty well without any distress, i.e. Section #13, the rest showed notable amount of either longitudinal cracking or alligator cracking. In the worst case, the percentage of longitudinal cracking was as high as 86% in Section #23. Comparing the average numbers between the Control Sections and the Lime treated Sections, it can be concluded that lime treatment significantly reduced the percentage of rutting area in the sections, but it seems not to improve the cracking percentage considerably.

Geogrid Reinforced Sections with and without Lime treatment

The results of the survey for Geogrid reinforced sections with and without lime treatment are summarized in Table 2. By studying this table, it becomes clear that both Geogrid Reinforced Sections without lime, i.e. GG1 and GG2, perform pretty well in terms of longitudinal cracking. The maximum percentage of longitudinal cracking was 2% in GG1 sections, and 13% in GG2 sections. However, the data do not suggest significant improvement in longitudinal cracking when geosynthetic reinforcement was combined with lime treatment. Comparing to the maximum of 2% in GG1 sections, the maximum value of longitudinal cracking in GG1+LT sections was 7%. Similarly, while the maximum longitudinal cracking percentage in GG2 sections was 13%, GG2+LT sections showed as high as 22% of longitudinal cracking. In terms of rutting, GG1+LT sections perform slightly better than GG1, but GG2+LT sections did not show significant improvement compared to GG2 sections.

Table 2. Results of the conditions survey for Reinforced Sections with and without lime

Layout	Section Number	Rutting			Patching	Cracking				
		Shallow	Deep	Severe		Block	Alligator	Transverse	Longitudinal	Shoulder
			% AREA		% AREA	% AREA	% AREA	No. / 100' STA. (%)	Linear ft/100' STA. (%)	Linear ft/100' STA. (%)
GG1	2	0%	0%	0%	0.0%	0.0%	16%	0.0%	0%	7%
	9	72%	0%	0%	0.0%	0.0%	23%	0.2%	0%	0%
	17	0%	0%	0%	0.0%	0.0%	0%	0.0%	2%	0%
	28	28%	0%	0%	0.0%	0.0%	0%	0.0%	0%	4%
	Average	25.0%	0.0%	0.0%	0.0%	0.0%	9.8%	0.1%	0.4%	2.7%
	Max	72.5%	0.0%	0.0%	0.0%	0.0%	23.3%	0.2%	1.8%	6.7%
	Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GG1 + LT	14	0%	0%	0%	0.0%	0.0%	0%	0.0%	7%	0%
	32	17%	0%	0%	0.0%	0.0%	0%	0.0%	0%	0%
	Average	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	0.0%
GG2	3	13%	0%	0%	0.0%	0.0%	6%	0.0%	6%	0%
	11	32%	0%	0%	0.0%	0.0%	3%	0.0%	13%	0%
	18	0%	0%	0%	0.0%	0.0%	3%	0.0%	0%	10%
	Average	15.0%	0.0%	0.0%	0.0%	0.0%	3.7%	0.0%	6.4%	3.2%
GG2 + LT	15	11%	0%	0%	0.0%	0.0%	5%	0.0%	22%	0%
	29	25%	0%	0%	0.0%	1.7%	39%	0.0%	0%	7%
	Average	18.1%	0.0%	0.0%	0.0%	0.9%	21.9%	0.0%	11.2%	3.3%

Investigation of the numbers for longitudinal cracks and shoulder cracks provide an evidence for one of the reinforcement mechanism in geogrids: geogrid causes the longitudinal cracks to be relocated from the pavement area to the outside of the pavement (Zornberg and Gupta 2009). Refer to the two last columns of Table 2, four geogrid reinforced sections, including Sections #2, #28, #18 and #29, were observed to have shoulder cracks. However, no longitudinal crack was recorded in these four sections.

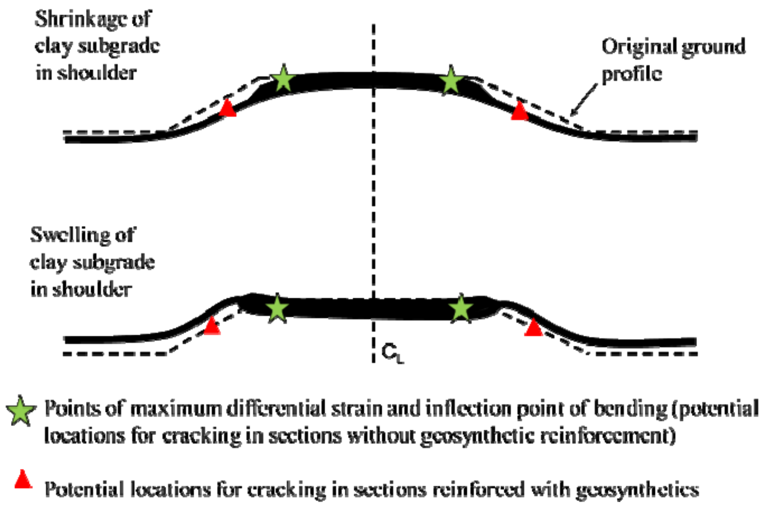


Fig. 4. Mechanisms involved in relocation of cracks from paved area to shoulder area

Surprisingly, the opposite was observed in the unreinforced sections. As seen in Table 1, shoulder cracks in unreinforced sections have been always accompanied by longitudinal cracks in the paved surface of the road. It can be concluded that the inclusion of geogrid reinforcement can lead to relocation of the cracks from the paved surface to the shoulder area. This mechanism is especially important in road sections constructed over expansive clays. As described in Fig. 4, shrinkage and swelling of an expansive subgrade result in formation of inflection points within the paved area of the road. The inclusion of geogrids leads to an increased stiffness of the pavement layers and causes the pavement to deform more rigidly. Consequently, the locations of inflection points are transferred to the outside of the paved area. Fig. 5 shows a sample of relocated crack observed in FM2.

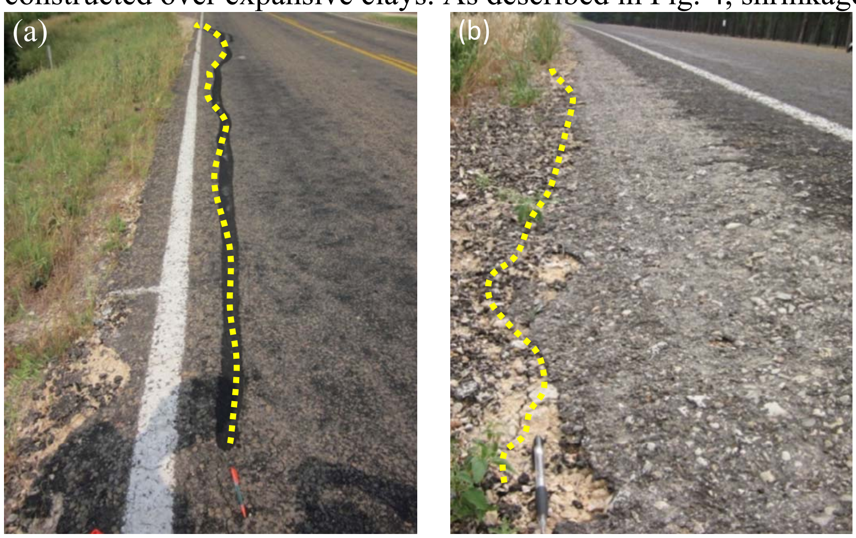


Fig. 5. a) A crack developed in the paved area in an unreinforced section (Section #20), b) A crack developed in the shoulder area in a geogrid reinforced section (Section #29)

Geotextile Reinforced Sections with and without Lime treatment

The results of the survey for Geotextile reinforced sections with and without lime treatment are presented in Table 3. Almost all GT sections demonstrated considerable amount of alligator cracking and rutting. Compared to GT sections, GT+LT sections had significantly lower alligator cracking but almost the same amount of rutting. On the other hand, in terms of longitudinal cracking performance of GT+LT sections is reasonably comparable with GT sections. While the maximum percentage of longitudinal cracking in GT sections was as high as 26%, this number in GT+LT sections was observed as 22%.

Table 3. Results of the conditions survey for Reinforced Sections with and without lime

Layout	Section Number	Rutting: Shallow	Rutting: Deep	Rutting: Severe	Patching	Cracking: Block	Cracking: Alligator	Cracking: Transverse	Cracking: Longitudinal	Cracking: Shoulder
		% AREA	% AREA	% AREA	% AREA	% AREA	% AREA	No. / 100' STA. (%)	Linear ft/100' STA. (%)	Linear ft/100' STA. (%)
GT	4	6%	0%	0%	0.2%	0.0%	29%	0.0%	26%	0%
	12	46%	2%	0%	0.0%	0.0%	3%	0.0%	0%	0%
	19	18%	7%	0%	0.0%	0.0%	20%	0.0%	5%	0%
	25	28%	2%	0%	0.0%	0.0%	28%	0.0%	0%	8%
	Average	24.3%	2.9%	0.0%	0.0%	0.0%	19.9%	0.0%	7.7%	2.1%
	Max	45.6%	6.8%	0.0%	0.2%	0.0%	29.3%	0.0%	25.8%	8.2%
	Min	5.6%	0.0%	0.0%	0.0%	0.0%	3.0%	0.0%	0.0%	0.0%
GT + LT	16	37%	0%	0%	0.0%	0.0%	0%	0.0%	22%	81%
	30	11%	0%	0%	0.0%	0.0%	2%	0.0%	0%	0%
	Average	24.1%	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	11.1%	40.6%

Table 4. Comparison of longitudinal cracking percentage

Layout	Section Number	Longitudinal Cracking Linear ft/100' STA. (%)	Layout	Section Number	Longitudinal Cracking Linear ft/100' STA. (%)
CONTROL	1	51.6%	GG1	2	0.0%
	10	31.4%		9	0.0%
	20	30.2%		17	1.8%
	26	5.8%		28	0.0%
	27	53.8%		Average	0.4%
	Average	34.6%		Max	1.8%
	Max	53.8%		Min	0.0%
	Min	5.8%	GG1 + LT	14	6.7%
LT (Lime Treated)	5	38.7%		32	0.0%
	6	51.1%		Average	3.3%
	7	14.9%	GG2	3	5.8%
	8	8.6%		11	13.3%
	13	0.0%		18	0.0%
	21	22.0%		Average	6.4%
	22	38.4%	GG2 + LT	15	22.4%
	23	86.0%		29	0.0%
	24	12.0%		Average	11.2%
	31	3.8%	GT	4	25.8%
	Average	27.5%		12	0.0%
	Max	86.0%		19	4.9%
	Min	0.0%		25	0.0%
GT + LT	16	22.2%		Average	7.7%
	30	0.0%		Max	25.8%
	Average	11.1%		Min	0.0%

Discussion

Table 4 compares the performance of all 32 sections in terms of longitudinal cracking. The most revealing finding of this table is that the percentage of cracking in the reinforced sections is by far less than the cracking in the control sections and the lime treated sections. In addition, this table suggests that lime treatment may have very limited contribution to the improvement of the performance of the sections in longitudinal cracking. Based on the average values for each group, while the cracking percentage in the control sections (CONTROL) and the lime treated sections (LT) sections is on the order of 28 to 35%, this number is on the order of 1% to 6% in Geogrid1 (GG1), Geogrid1+Lime treatment (GG1+LT) and Geogrid2 (GG2) sections, and it is on the order of 8% to 11% for Geogrid2+Lime (GG2+LT), Geotextile (GT) and Geotextile + Lime (GT+LT) sections. Therefore, it seems reasonable to conclude that in terms of longitudinal cracks both geogrid reinforcements present the best performance, following by the geotextile reinforced sections.

A single index, referred to as the Index of Pavement Performance (IPP), was used to compare the overall performance of the road sections under traffic loads and environmental conditions. This index is defined as the summation of all weighted distress percentages:

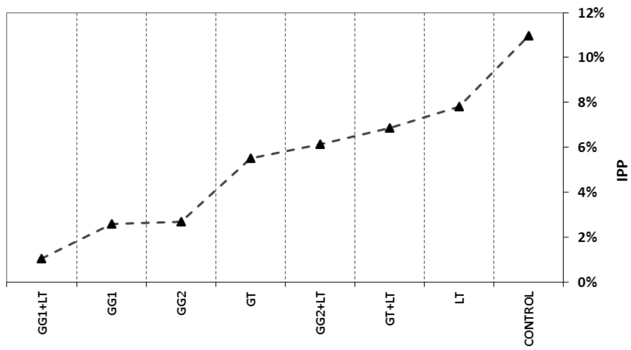
$$IPP = \sum_{i=1}^{n} W_i D_i$$

where D_i is the percentage of each distress and W_i is the corresponding weighing factor. Table 5 shows the assigned weighing factors for different distress types. Since the focus of this study has been on the performance of the geosynthetic reinforcement and lime treatment under the environmental condition, the highest weighing factor was chosen for longitudinal cracks, following by alligator cracking and severe rutting which are mainly caused by traffic loading.

Table 5. Assigned weighing factors for different types of distresses

Distress Type	Rutting			Patching	Cracking				
	Shallow	Deep	Severe		Block	Alligator	Transverse	Longitudinal	Shoulder
Weighing Factors	**1**	**2**	**3**	**1**	**1**	**3**	**1**	**5**	**2**

The IPP index allowed us to correlate the overall performance of each section with a single number. Fig. 6 summarizes the calculated values of IPP averaged in each group and the corresponding ranking for the overall performance of the sections. Note that higher value of IPP is an indication of higher distress level in the section.



Section	IPP
GG1+LT	1.0%
GG1	2.6%
GG2	2.7%
GT	5.5%
GG2+LT	6.1%
GT+LT	6.9%
LT	7.8%
CONTROL	11.0%

Fig. 6. Ranking of the overall performance of the test sections based on IPP value

SUMMARY AND CONCLUSIONS

An experimental field study was conducted at the University of Texas at Austin to evaluate the performance of 32 road test sections located on FM2 road in Grimes County, Texas. The road composed of eight different types of sections: Control (unreinforced) Sections with and without lime treatment, Geosynthetic Reinforced Sections (including two types of Geogrids and one type of Geotextile) with and without lime treatment. In this paper, the performance of the sections was studied based on the results of the last conditions survey performed 5 years after the construction of the sections. The major findings of this study can be summarized as follows:

- Geogrid reinforced sections demonstrated the best performance in mitigating the longitudinal cracks, which mainly are developed by seasonal shrinkage and swelling of the expansive subgrade soils.
- Geogrids not only reduced the percentage of longitudinal cracking, but also they relocated the cracks from the paved area to a zone beyond the paved surface.
- The performance of the Geotextile reinforced sections was not as good as geogrid reinforcement, but still notably better than unreinforced sections.
- Compared to unreinforced sections, lime treatment could reasonably mitigate rutting

in the pavement. However, lime treated sections seems not to mitigate the longitudinal cracking in the unreinforced pavement sections.

- Combining lime treatment with geosynthetic reinforcement seems not to significantly improve the performance of the road sections, compared to geosynthetic reinforcement without lime treatment.

The results of this filed study provided valuable information for the performance of geosynthetic reinforcement in pavement layer systems. It remains to be seen how this information can be used in the design procedure of reinforced pavements.

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