# *The mitigation of longitudinal cracks on low-volume road pavements built over expansive soils*

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***Abstract*— The design and construction of road pavements over expansive soils is a very challenging task because of their shrink/swell behavior associated with fluctuation in moisture content. The most common distresses found on pavements built over expansive soils are longitudinal cracks that result from shrinkage of expansive soils during dry seasons and appear close to pavement shoulders. A research was conducted to gather the available information, to identify gaps in knowledge and to provide the recommendations for the best practices in mitigating longitudinal cracks on pavements built over expansive soils. It was found that various methods such as lime/cement treatment and geogrids were used to control longitudinal cracks but the latter has shown prominence. Despite the fact that geogrid-reinforcement has shown promise in mitigating longitudinal cracks, it was not sufficiently investigated in this regard and there are still various inconsistencies and disagreements in literature. This area of research is still at its infancy and most of the research published thereof date from year 2000. This study has proven that doubling geogrid stiffness may be more cost effective than combining it with lime-treatment. It was found that when combination with lime is of concern, geogrid location should be below lime-treated layer so as to exploit their combined effect maximally. The research has identified various gaps in knowledge and it has also discussed different inconsistencies and contradictions found in literature, and finally it provided the recommendations for future work and best practices.**

***Keywords*— *longitudinal cracks, expansive soils, geogrids, low volume roads, fracture toughness***

## 1. INTRODUCTION

The expansive soils also known as “shrink/swell soils” exhibit shrink/swell behavior in case of fluctuation in moisture content. Upon wetting, they expand and when dry, they shrink. This change in volume associated with moisture variation of expansive soils is responsible for the damages to the light structures built over them. The cost of damages is estimated to reach billions of dollars per year. Jones and Jefferson (2012) indicated that the estimated cost of damages to infrastructures in the United States alone is beyond 15 billion US dollars annually. It was reported that expansive soils cause more damages to civil engineering structures (particularly low rise buildings and road pavements) than any other geohazards including floods and earthquakes (Mokhtari and Dehghani, 2012).

The expansive soils can be found in many places worldwide especially in arid and semi-arid zones (Tripathy et al., 2002). A lot was done to address problem of expansive soils; for example from mid 1960s to early 1990s, seven international conferences on expansive soils took place and several researches thereof were conducted (Petry and Little, 2002). The researches comprised mainly chemical stabilization (lime and cement), removal of expansive soils and replacing them with inert soils, prewetting, mechanical compaction, use of geosynthetics notably geomembranes and various moisture control measures such as drainage for instance (Jeyapalan et al., 1981). Each of the treatment methods investigated has shown both successes and failures in a number of projects and the research on design of pavements over expansive soils is still ongoing. The wetting and drying of the subgrade underlying road pavements are responsible for two major distresses: roughness and longitudinal cracking (Picornell and Lytton, 1987). It was reported in literature that the most common distress that occur on pavements over expansive soils is longitudinal cracking (Luo and Prozzi, 2010; Wanyan et al., 2010).

These longitudinal cracks are due to tensile stresses developed from shrinking of expansive soils during dry seasons (Dessouky, 2015). Because of the fact that the subgrade is covered by the pavement, there is no evapotranspiration beneath the centerline of the pavement and the water content remains approximately constant. However, the area close to pavement shoulders experiences moisture loss during dry periods and develops longitudinal shrinkage cracks. On the other hand, during wet seasons, there is development of heaves (roughness) in the vicinity of shoulders but not close to the centerline because of moisture increase near pavement edges (Nelson and Miller, 1992; Zornberg and Gupta, 2009). Shrubs and trees close to pavement shoulders can aggravate the problem of longitudinal cracks (Sebesta, 2002; Scullion et al., 2003; Puppala et al., 2011). This is due to the fact that roots can absorb water from beneath pavement edges when they are planted in their close proximity. The example of typical longitudinal cracking is shown in Figure 1.

a) Sebesta (2002)

b)Scullion et al. (2003)

Figure 1 Typical longitudinal cracks found on road pavements built over expansive soils

The experience has shown that building thicker and stronger pavement layers over expansive soil subgrades does not guarantee better performance especially for high plasticity clays (Wanyan et al., 2010). However, the use of geogrids in design does (Luo and Prozzi 2009, Zornberg and Gupta, 2009). The performance of geogrid-reinforced low volume road sections in terms of mitigating longitudinal cracking was found to be promising but the mechanism governing their performance has not been clearly understood (Zornberg et al., 2012). The review of literature showed that geogrids was not sufficiently investigated in this regard. It was found that most of the research incorporating geogrids in design of expansive soils took place after year 2000. These include for instance Luo and Prozzi (2009) and Zornberg and Gupta (2009). This research has put together a number of researchers who worked on the mitigation of longitudinal cracking on pavements built over expansive soils and their various views are discussed in the subsequent sections.

## 2. METHODOLOGY

A comprehensive study was conducted to evaluate the practices used to mitigate longitudinal cracking which is the most predominant distress found on pavements built over expansive soils. This was accomplished through putting together data from various opinions and experiences of different researchers and practitioners who are leaders in this field. Through analyzing their contradictions, agreements, gaps, consistencies and inconsistencies, this research suggests what should be the best practices to control longitudinal cracking on pavements built over expansive soils. The research compares and contrast the opinions, perceptions, findings and experiences of researchers divided in 4 categories as shown in Table 1. These researchers are from the state of Texas in the United States of America and they worked with various institutions such as University of Texas, Texas A&M University, Texas A&M Transportation Institute and the Texas Department of Transportation (TxDOT). The state of Texas has extensive road network built over expansive soils and it is a leader on the research thereof. The research studies both finite element modelling and real-field experiences in the same framework to allow a wide range of engineering analysis and to enhance the research reliability. Figure 2 shows the typical cross sections for the studies considered.

Table 1 Researches on mitigation of longitudinal cracking on pavements built over expansive soils

| **Luo and Prozzi** | **Zornberg and Gupta** | **Dessouky et al.** | **Sebesta, Scullion et al.** |
|---|---|---|---|
| Luo, 2007 | Zornberg and Gupta, 2008 | Dessouky et al., 2013 | Sebesta, 2002 |
| Prozzi and Luo, 2007 | Zornberg and Gupta, 2009 | Dessouky et al. $2015_a$ | Sebesta, 2004 |
| Luo and Prozzi, $2008_a$ | Gupta, 2009 | Dessouky et al. $2015_b$ | Scullion et al., 2003 |
| Luo and Prozzi, $2008_b$ | Zornberg et al., 2010 | | |
| Luo and Prozzi, 2009 | Zornberg et al., 2012 | | |

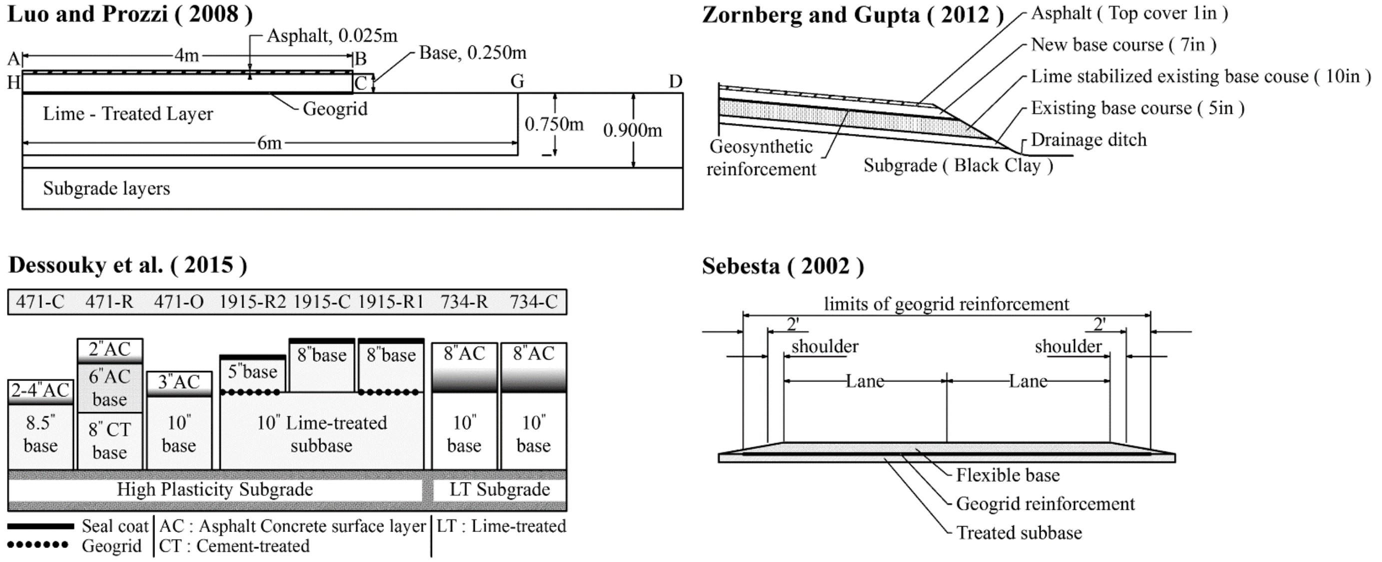

Figure 2. Typical cross sections for the studies considered.

## 3. DISCUSSION AND RESULTS

### 3.1 Analysis regarding Finite Element Modelling in Mitigation of Longitudinal cracks

Using their finite element model, Luo and Prozzi (2009) reported that the combination of lime and geogrid is cost effective in mitigating longitudinal cracking. The longitudinal cracking develops when stress intensity factor at upper crack tip exceeds the fracture toughness of pavement materials. The stress intensity factor at upper crack tip increases as the crack propagates upwards; this is illustrated using various crack propagation stages (See Figure 3). The Figure 4 compares the fracture toughness of pavement materials ($K_c$) and the values of stress intensity factor at upper crack tip ($K_I$) without both lime-treatment and geogrid reinforcement. The fact that $K_I$ values are bigger than $K_c$ values is a sign of a potential development of longitudinal cracking along pavement surface. It is to be noted that the fracture toughness of pavement materials has not been well documented; the values used in analysis were only estimated from the data available in a very limited number of researches found in literature. In addition, the literature did not provide at all the fracture toughness values of lime-treated soils; the value used here was estimated from the one of cement-treated soil documented in one of the earlier researches. The values for fracture toughness used are presented in Table 2.

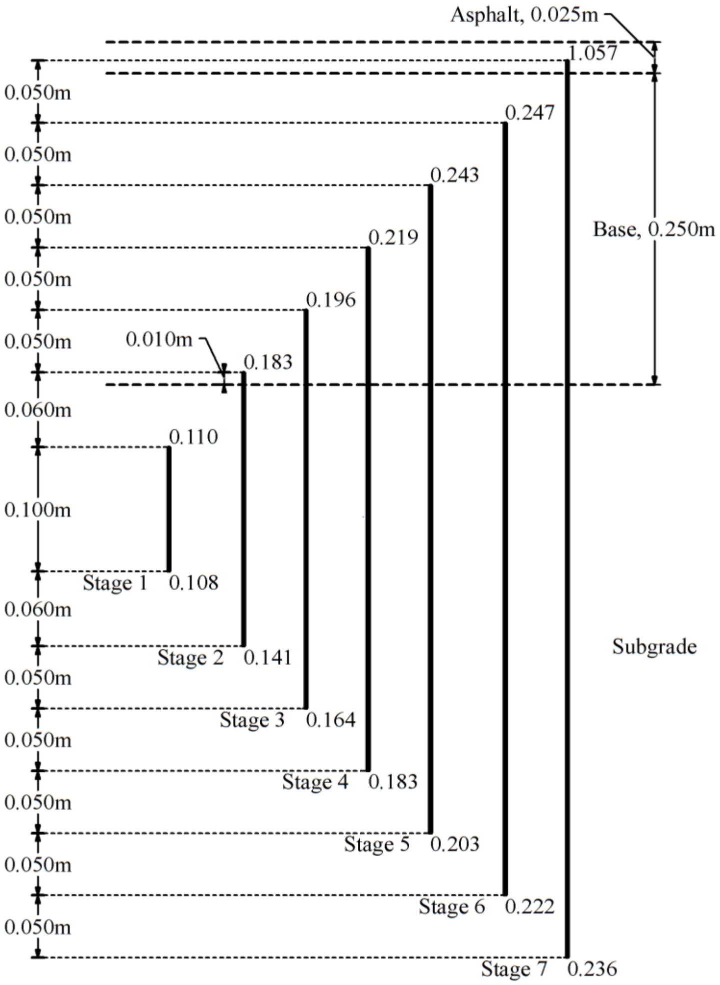

Figure 3. Stress intensity factor values at upper and lower crack tips without both lime treatment and geogrid reinforcement (Luo and Prozzi, 2008)

Table 2 Fracture toughness of subgrade and pavement materials

| Stage number | $K_c$ in MPa.√m |
|---|---|
| 1 | 0.04 |
| 2 | 0.05 |
| 3 | 0.05 |
| 4 | 0.05 |
| 5 | 0.05 |
| 6 | 0.05 |
| 7 | 0.7 |

It is of utmost importance to examine the opinion of Luo and Prozzi (2009) that the combination of lime and geogrid is cost effective in mitigating longitudinal cracks on pavements built over expansive soils. Dessouky et al. (2015) documented the costs of various treatments of roads built over expansive soils as found in Table 3. It is essential to investigate whether the combined cost of lime and geogrid can be justified both economically and technically. It is a good idea to combine all the researches of Luo and Prozzi (as found in Table 1) in one go and investigate their linkage.

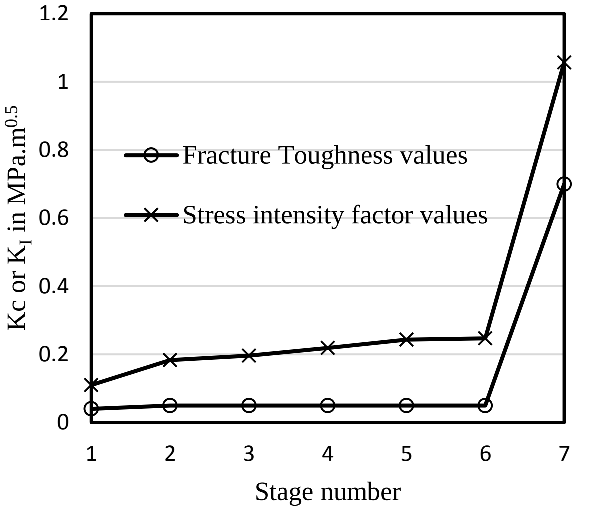

Figure 4. Comparison of Kc and $K_I$ in case of untreated/unreinforced subgrade

Table 3. Pavement treatment costs (Dessouky et al., 2015)

| Pavement treatment | Treatment cost in dollars/m$^2$ |
|---|---|
| Cement-treated base | 2.7 |
| Lime-treated subgrade | 2.7 |
| Geogrid reinforced base | 3.8 |

Figure 5 shows four different scenarios studied; it assumed that a crack is initiated from the subgrade and manages to propagate upwards: a) 10 mm above the top of untreated subgrade (into base layer), b) 10mm above geogrid layer (into base layer), c) 10 mm above untreated subgrade (into lime-treated subgrade) and d) 10mm above geogrid layer (into lime-treated layer). Figure 6 shows the variation of stress intensity factor values at upper crack tip in all of the four scenarios considered. The point A on the graph shows the stress intensity factor ($K_I$) developed in unreinforced/untreated subgrade, which is 0.183. The point B shows that $K_I$ drops from 0.183 to 0.177 at the upper shrinkage crack tip when the subgrade is treated with lime. This shows that the addition of lime (8% by weight) without geogrid reinforcement provides only a slight improvement in terms of reducing $K_I$. In addition to this, the Figure 6 shows that geogrid reinforcement outperforms lime-treatment and that there is only an added minor benefit when lime treatment is combined with geogrid reinforcement. Unlike the view of Luo and Prozzi (2009), this observation suggests that combination of lime and geogrid in treatment of expansive soils may not be cost effective. Mindful that lime-treatment cost can be closely comparable to the one of geogrid as suggested by Table 3, the extra cost of lime-treatment that makes the total cost nearly twice as much may not be economically justified because of its reduced effect in mitigating longitudinal cracking.

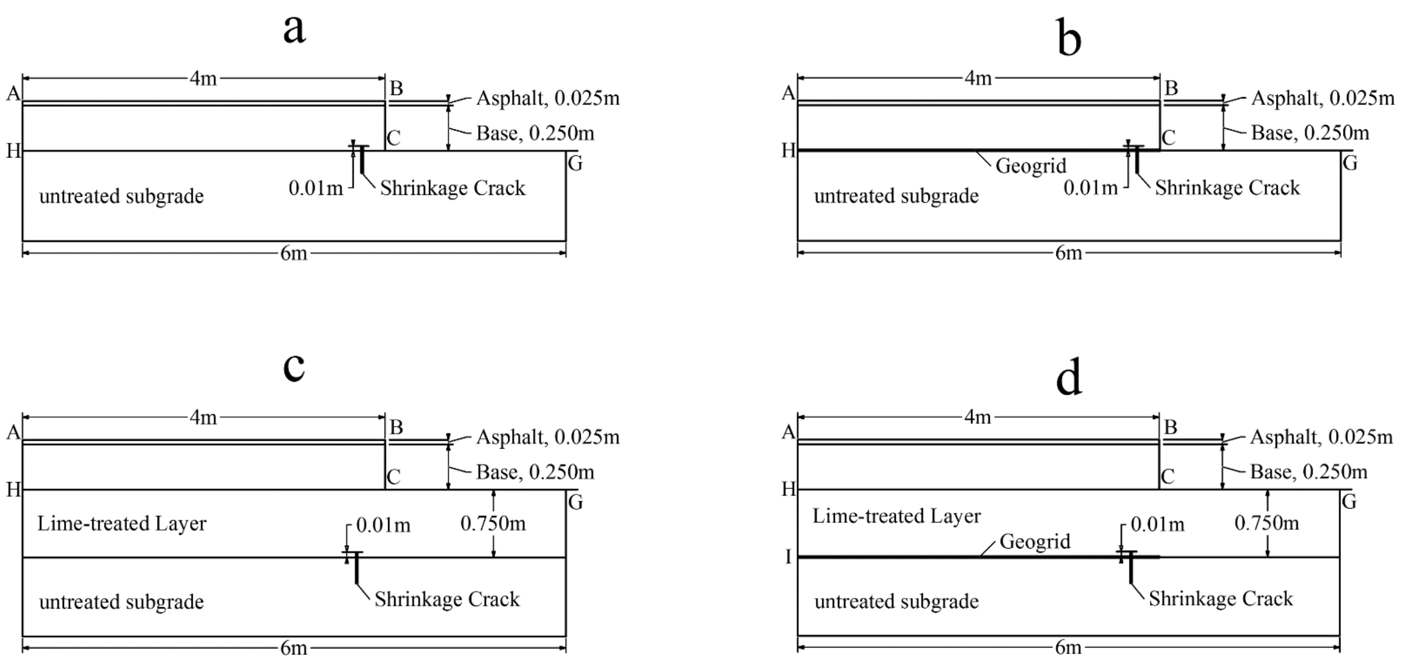

Figure 5 Scenarios where a crack is assumed to initiate in the subgrade and propagates to reach 10mm above the considered pavement layer (presented based on data from Prozzi and Luo (2007), Luo and Prozzi (2008)$_{a}$, Luo and Prozzi (2008)$_{b}$ and Luo and Prozzi (2009))

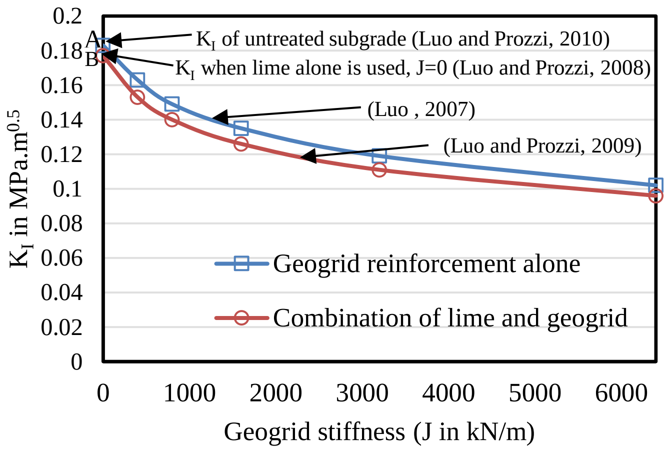

Figure 6 Variation of stress intensity factors at upper crack tip for scenarios considered

It is true that geogrid has shown prominence in mitigating longitudinal cracking but it is equally important to study and quantify the effect of its stiffness in both technical and economical perspective. Mindful of the higher cost and less benefit associated with lime treatment in mitigating longitudinal cracking (as depicted by Figure 6), one would prefer to consider doubling geogrid stiffness instead of combining both options. Figure 7 shows clearly that geogrid of 400 kN/m stiffness (G400) outperforms the lime-treatment (LT) in terms of reducing the stress intensity factor at the upper crack tip. The geogrid of 800 kN/m (G800) outperforms the geogrid of 400kN/m combined with lime treatment (G400+LT), also G1600 outperforms G800+LT and so forth. The Figure 7 openly shows that doubling geogrid stiffness can provide more benefit than combining it with lime treatment but it is also essential to keep in mind that these findings are based on the analysis of the data acquired based on the finite element analysis rather than real-field experience.

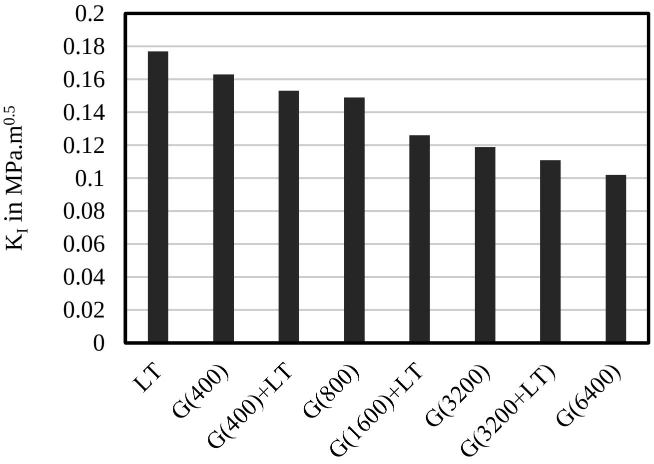

Figure 7 Comparison of performances of geogrid, lime and geogrid combined with lime treatments [presented based on data from Prozzi and Luo (2007), Luo and Prozzi (2008)b and Luo and Prozzi (2009)]

The finite element analysis model of Luo and Prozzi has many assumptions that can have some effect on the results. For example, Luo (2007) assumed a trial crack of 100mm initiating in the subgrade when studying the effect of geogrid in mitigating longitudinal cracking for pavements built over expansive soils. In the other research paper, Prozzi and Luo (2007) did the same study but with a different initial assumption of a trial crack of 25mm length. As the Figure 8 shows it, using such different initial assumptions has affected the results of $K_I$ for geogrid stiffness values below 3200 kN/m; the discrepancy is larger for smaller geogrid stiffness values and it reduces with increasing geogrid stiffness. This can justify possible inconsistencies associated with the model. Despite some important points raised by the model such as best geogrid embedment depth and the mechanism of development of longitudinal cracking for instance, it is of utmost importance to note that a number of assumptions associated with the model can cause various inconsistencies. These assumptions include trial crack depth, length of crack propagation, initial crack position, length of initial crack, linear elastic fracture mechanics theory, values of fracture toughness of pavement materials, etc. Prior to validating the finite element model findings, the evaluation of real-field case studies needs to be considered.

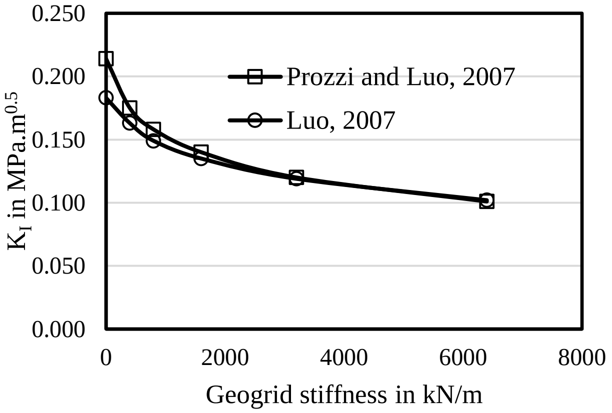

Figure 8 Comparison of $K_I$ values at upper crack tip for different initial crack length assumptions

### 3.2 Analysis of real-field observations A

The findings of Zornberg et al. (2012) presented in Figure 9 result from the study of 32 sections studied for a period of six years. The treatment measures considered include geogrids of type 1 (GG1), geogrids of type 2 (GG2), geotextile (GT) and lime-treatment (LT). The results suggest that lime once combined with geogrid reinforcement does not show any extra-benefit in reducing the longitudinal cracking on pavements over expansive soils. Contrarily, lime seems to make things worse. Even though results look poorer with lime addition to geogrid reinforcement, Zornberg et al. (2012) reported that lime does not seem beneficial in mitigating longitudinal cracking but they were reluctant to say that things got worse probably because of its wide acceptance as a commonly used stabilizer in geotechnical engineering practice. Despite poor performance when combined with geogrid reinforcement, lime outperformed the control section when used alone though only a slight improvement was observed as shown in Figure 9.

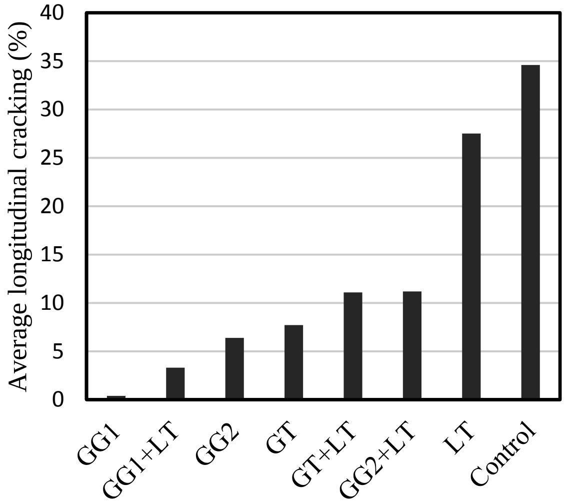

Figure 9 Longitudinal cracking percentage for 32 road sections built on expensive soils; presented based on data from Zornberg et al. (2012)

The seemingly unresponsiveness of lime when combined with geogrid may be attributed to the geogrid location which is above lime-treated layer instead of being placed below it. As proven by Luo and Prozzi (2009), the geogrid location is very important when combining it with lime treatment in order to exploit their combined effect maximally. The geogrid should be positioned below lime-treated layer and as close as possible to the subgrade to reduce the stress intensity factor at the upper crack tip immediately after it is initiated from the subgrade and before it gets increased as the crack lengthens. If by misfortune, the crack progresses upward through geogrid, lime-treated layer may be able to stop its propagation due to the weakened stress intensity factor at the crack tip. It is true that some researchers such as Sebesta (2002) and Scullion et al. (2003) reported success when geogrid was placed above lime treated layer but unfortunately they did not investigate what would have happened if things had been done other way around. Their principle is based on the idea that placing geogrid above a treated layer and below base layer is to create a slippage plane preventing any movement from lower layers to reflect in the upper layers (Scullion et al. 2003). By all means geogrids play a vital role in controlling longitudinal cracking but its position may well determine the extent of the overall performance either combined with lime treatment or when used alone. In addition, the poor performance of lime depicted in Figure 9 may result from the fact that lime was used to stabilize subbase (existing base) which was probably granular rather than cohesive in nature. As it is well known, lime is ideal stabilizer for most cohesive soils and the level of its reactivity is determined by the type and quantity of clay minerals available in the soil (Little and Nair, 2009). If lime-treatment is to be used, the best location may be to stabilize the expansive soil subgrade (to initiate modification reaction to clay structure) as done by Luo and Prozzi (2009) since it is where shrinking cracks initiate. If stabilizing the granular subbase/base is of concern, it may be recommended to use cement due to the fact that it may initiate higher fracture toughness to the treated layer but it is of utmost important to use the minimum amount possible that would not induce block cracking. It is also suggested to allow some time before opening the road to traffic since the fracture toughness of cement-treated base improves with curing time (see section 3.2 B). Further research is needed to clarify the effect of suspending road opening to traffic until the needed fracture toughness is reached and to quantify its implication in terms of mitigating cracking on pavement.

Figure 9 also shows that both geogrid types outperformed geotextile. Even though both geogrids and geotextiles have been used in various road projects for a long time, the engineering community seems to be persuaded that for the reinforcement application specifically, geogrids outclass geotextiles (Flutcher and Wu, 2013). Another thing to note is that the geogrid of type 1 outperformed the one of type 2. It is a good idea to compare and contrast the performance of these two types of geogrids with respect to their engineering parameters such as stiffness, tensile strength and junction efficiency. During earlier monitoring of the 32 road sections under scrutiny, Gupta (2009) used a small borehole to inspect geogrids status and he found that geogrid 2 has been compromised at junctions and therefore causing a slip of transverse and longitudinal ribs. The geogrid 2 had a greater unconfined stiffness (at 2% strain) and tensile strength than geogrid 1 but it had lower junction strength (and thus lower junction efficiency). This shows that the consideration of only geogrid stiffness and tensile strength without taking account of junction strength can be misleading. This also agrees with lessons learnt from the case studies done by Zornberg and Gupta (2008) and Zornberg et al. (2010), which serve as subject of concern because of the fact that junction strength of geogrid seems to be overlooked by various researchers and engineers. The Texas Department of Transportation (TxDot) recommended a minimum value of junction efficiency to be 90% (Zornberg and Gupta, 2008).

The other potential reason of geogrid 1 performing better than geogrid 2 can also be due to the reason of having higher confined stiffness than geogrid 2; interestingly, even though geogrid 2 presented higher unconfined stiffness than geogrid 1, its confined stiffness was found to be far less than that of geogrid 1. The confined stiffness of both geogrid types are documented in Gupta (2009). The instrumentation results of Zornberg and Gupta (2010) showed that the area that experiences moisture fluctuation under pavement is 2 m horizontally from pavement edge and 0.3 m vertically. This is in line with real-field observations of Zornberg et al. (2012) and the findings of Luo and Prozzi (2008) model that the longitudinal cracks develop close to the pavement edges.

### 3.2 Analysis of real-field observations B

It was reported by Dessouky et al. (2015) that cement-treated base is effective in mitigating longitudinal cracking for pavements built over highly expansive soils. This was reported after a long time monitoring of the performance of road section 471-R with cement-treated base shown in Figure 2. This observation can make sense if one considers the theory of Luo and Gupta (2008) that one of the methods of controlling longitudinal cracking is to increase the fracture toughness of pavement materials. The research revealed that the fracture toughness of cement-treated aggregates increases with curing period and decreases with cement content (Hou et al. 2011), and thus a smaller quantity of cement necessary to meet the demand of compressive strength of base layer without overlooking cracking susceptibility should be used (Zhang et al., 2012, Scullion et al. 2000). Experience has shown that 2 to 3% of cement can be adequate in some instances (Sebesta, 2002). Prior to supporting the view of Dessouky et al. (2015), it is essential to first analyze Figure 10. Both sections 471-R and 471-O performed well but section 471-C performed poorly and it has had base failure. The fact of experiencing base failure shows a structural defect rather than shrinkage cracking. Apart from that, the untreated section 471-O which has only had asphalt overlay to strengthen its structural capacity, has performed very well without showing any longitudinal cracking. This suggests that the sections 471 (471-R, 471-O and 471-C) were built on the subgrade without appreciable shrink/swell susceptibility. The subgrade may have reached the equilibrium moisture content and/or the drainage may have been sufficient to prevent the moisture fluctuation close to pavement edges. Based on this, Dessouky et al. (2015) has only less evidence to suggest that cement-treated base is an effective method to mitigate longitudinal cracking. Sebesta (2002) worked on various road pavement projects built over expansive soils in Texas. He reported that rehabilitation using cement-treated base was not effective; later observations indicated the instances of development of block cracking and longitudinal cracking along pavements some of which were occurring within a period between 6 months to 1 year after rehabilitation. He made it clear that in addition to the concern of block cracking formation on pavement which is often associated with cement treatment, a brittle cement-treated layer over a weak expansive subgrade can lead to severe longitudinal cracking that frequently fault. He indicated that the most effective method to mitigate longitudinal cracking for pavement rehabilitation project is the full-depth recycling with geogrid reinforcement and this was also confirmed by Scullion et al. (2003). The latter suggested that the full depth reclamation where the existing road materials were recycled with lime or cement, the performance of the reconstructed pavement depends mainly on the type plasticity of the subgrade. They indicated that the pavements on subgrades of low plasticity (PI<15), and medium plasticity (PI between 15 and 35) performed well but the pavements built on high plasticity subgrade (PI>35) did not perform well and that they are candidates for geogrid reinforcement. Based on the above arguments, it can be concluded that Dessouky et al. (2015) view vis à vis the effectiveness of cement-treated base in controlling longitudinal cracking over highly expansive soils does not seem to be valid. However, it may be applicable for expansive soils of low plasticity even though there is no full guarantee of performance, and the cement quantity to be used needs to be carefully selected in order to avoid block cracking. This can also be strengthened by the fact that the section 471-R inspected by Dessouky et al., 2015 had a plasticity index of 14% which suggests a low plasticity clay rather than a highly expansive clay.

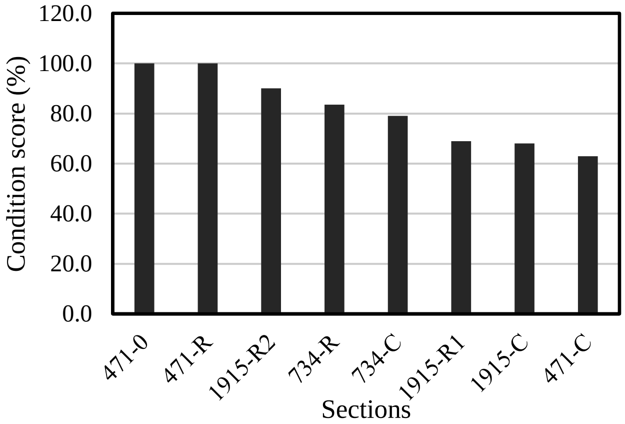

Figure 10. Condition score for various road projects (based on data from Dessouky et al. (2015)

In terms of combination of lime and geogrid, Dessouky et al. (2015) reported that their combination is effective in low to medium plastic clays. This opinion can be supported based on the performance of a low plasticity section 734-R and a medium plasticity section 1915-R2 which yielded relatively good results. However, the opinion can also be deemed subjective since there were no different sections made to study the performance of geogrid reinforcement and lime-treated sections each used alone and then to compare the results with the combined effect of the two. In addition, the poor performance of the highly expansive section 1915-R1 despite the combined effect of geogrid and lime does not necessarily mean that the combination is not effective in highly expansive soils; the location of both lime and geogrid may have not been adequate enough to exploit the combined effect maximally. If the geogrid was laid below lime-treated layer (preferably subgrade instead of subbase), things would have probably got better.

### 3.3 Comparison of the opinions of the researchers

The Table 4 presents briefly the opinions of the researchers as far as mitigation of longitudinal cracking on pavements built over expansive soils is concerned. The detailed discussion on these opinions is presented in the earlier sections.

Table 4 Comparison of the researchers' findings considered in this study

| **Studies**<br>**Parameters under scrutiny** | **Luo and Prozzi (2007, 2008$_a$, 2008$_b$, 2009)** | **Zornberg and Gupta (2008, 2009, 2010, 2012)** | **Dessouky et al. (2013, 2015$_a$, 2015$_b$)** | **Sebesta (2002, 2004) Scullion et al. (2003)** |
|---|---|---|---|---|
| Study type | Modelling | Field and lab study | Field and lab study | Field and lab study |
| Geogrid position | Geogrid should be positioned below lime-treated subgrade | Geogrid above lime-treated layer | Geogrid above lime-treated layer | Geogrid above lime treated layer |
| Geogrid performance | Effective | Effective | Effective | Effective |
| Facts about geogrid performance | Effect of geogrid stiffness follows the rule of diminishing return | Geogrid of lower junction efficiency can fail despite higher stiffness | - | - |
| Combination of lime and geogrid | Combination of lime and geogrid is cost-effective. | Their combination is not cost-effective. Geogrid alone can be effective | The combination is effective in low to medium plastic clays | Geogrid reinforcement was reported to be promising though it was usually combined with lime/cement treatment |
| Effectiveness of lime in mitigation of longitudinal cracks | longitudinal cracks have lower probability of developing in lime-treated layer | Lime was less effective and it was proven to be almost useless | - | - |
| Relocation of longitudinal cracks | Lime relocates longitudinal cracks beyond pavement area | Geogrid relocates cracks beyond pavement area | - | - |
| Efficiency of cement in mitigation of longitudinal cracks | - | - | cement-treated base can be effective in high plasticity soils | cement treated base is not effective but it can work for low plasticity soils |
| Stress concentration at interface between treated and untreated layer | More stress concentration at interface of lime treated layer and subgrade | Most of cracks were found at intersection of unreinforced and reinforced section (evidence of more stress concentration) | - | - |
| Road layers treated with lime or cement in case of combination with geogrid | Lime was used to treat the subgrade | base/subbase were treated with lime | Lime-treated subgrade or lime/cement treated-base were considered | Subbase was treated with lime/cement |
| Limit of geogrid/lime treatment | Lime-treated layer should be extended beyond pavement area to avoid crack initiation close to pavement shoulders | Geogrid layer should be extended a bit beyond pavement surface to prevent crack initiation close to pavement shoulders | - | Geogrid layer should be extended a bit beyond pavement surface to prevent crack initiation close to pavement shoulders |
| Monitoring period | - | 6 years monitoring | Up to 14 years | More than 3 years |

## 4. CONCLUSIONS AND RECOMMENDATIONS

The research has put together the opinions, experiences and perceptions of various researchers who worked on the mitigation of longitudinal cracking along pavements built over expansive soils. The findings from Finite Element Modelling and real-field experiences were studied and analyzed together in the same framework and below are conclusions and recommendations:

1. There is an ample evidence that geogrid-reinforcement plays a significant role in controlling longitudinal cracks on pavements built over expansive soils. However, applying it with or without lime/cement stabilization seems to remain a subject of debate because of disagreements between researchers. This research suggests that the geogrid should be used in designing flexible road pavements over expansive soils (inevitably where highly expansive soils exist). Whenever there is a need to combine it with lime stabilization, the latter should be used to treat the subgrade instead of the subbase. On the other hand, if there is a need to combine geogrid with cement treatment, the latter should be used to treat the base sufficient caution is needed to utilize a minimum amount of cement that will not induce brittleness and block cracking. In addition, more research is required to study the cost effectiveness of the combination of geogrid and lime/cement; from the findings of this research, there is a feeling that the combination of the geogrid and lime-treatment is not cost effective.

2. The fracture toughness of subgrade soils and road pavement materials have not been well documented, there is need to study them in depth in order to be able to predict accurately their cracking susceptibility

3. Through analysis of the finite element model findings, it can be suggested that doubling geogrid stiffness may be more beneficial in mitigation of longitudinal cracking than combining geogrid with lime treatment. A real-field study is recommended to authenticate this finding

4. As far as cement-treated base is concerned, it was found that allowing some time before a road is open to traffic may improve the fracture toughness of the road base, and thus reducing the susceptibility for cracking. However, more research is needed to quantify the effect of delaying the opening of road to traffic as far as mitigation of pavement cracking is concerned.

5. The review of literature has shown that in road repair projects, there is a common practice of laying geogrids above a stabilized existing base (taken as a subbase). Though some successes with this practice were reported, this research suggests that more benefits may be expected when geogrids is placed below lime treated layer. A real-field research based on built road sections is recommended to validate this view.

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