Performance of Various Pavement Repairs in Low-Volume Roadways over Expansive Soil

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ABSTRACT

Expansive soil is considered one of the most common causes of pavement distresses. Depending upon the moisture level, expansive soils will experience changes in volume due to moisture fluctuations from seasonal variations. The objective of this research was to evaluate existing repair projects on selected roadways. Those roadways experienced failures in the form of fatigue and rutting in the wheel path, and longitudinal (faulted) cracking including edge cracking. The causes of those failures were mainly linked to high plasticity expansive soil and narrow pavement. The study involved visual survey, field and laboratory testing, surface condition/ride data and structural design calculations for three project sites. The study concluded, from 3-14 years of performance records, that geogrid reinforcement, lime-treated subgrade and cement-treated base were found to be effective treatment options for low-volume roadways where high plasticity expansive soil exists.

Keywords: Geogrid, Expansive soil, cement-treated base, Lime-treated subgrade, GPR, FWD

Word Count: 4,600 + 12 FIGURES AND TABLES (250 each) = 7600
INTRODUCTION

High-plasticity expansive soil is considered one of the most common causes of pavement failures (Puppala et al. 2004). Depending upon the moisture level, high-plasticity soils will experience changes in volume due to moisture fluctuations from seasonal variations. During high moisture seasons expansive soil swells underneath pavement structure. Conversely during dry seasons, soil contracts and depends on severity may result in shrinkage cracking. This shrinkage propagates through the pavement structure causing longitudinal, transverse and block cracking and edge failure distresses. Expansive soils located in regions where cool and wet periods followed by hot dry periods are more prone to such distresses. For narrow roadways this type of distress primarily starts from the pavement edge. In addition to the expansion/shrinkage cycles, the lack of lateral support and accumulation of water near the edge and side slope instability are examples of causes that expedite pavement failures. In Texas, the majority of the roadways network is classified as low-volume narrow roads. Those constructed over expansive subgrade experienced frequent maintenance problems.

Zornberg et al. (2008) grouped the methods used in expansive soils treatments into three categories; Mechanical/chemical stabilization of base and/or soil (e.g., soil lime stabilization and base cement stabilization), geogrid reinforcement and moisture control barriers. The stabilization tends to increase strength and stiffness, reduce swelling, decrease permeability, and moderate suction of the soil (Harris 2008 and Freeman and Little 2002). Geogrid reinforcement tends to increase lateral stiffness of base materials against soil expansion/shrinkage. Vertical barriers are used along the pavement edge to prevent moisture infiltration.

Studies on lime treatment suggested lime stabilization for subgrade/base materials with a plasticity index (PI) greater than 10 (Little 1995). The main concern with lime treatment is the resulting slow strength gain immediately after application. Due to the necessity of reopening to traffic on the same day, lime treatment may be an option for lightly trafficked FM roads, but is not a good candidate for higher trafficked roads (Sebesta 2002). Using Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP) Harris (2008) suggested that lime-treated soil gains strength after few days of applications. Cement-treated base is one of the most used applications for stabilization. However, the major concern is that it causes block/longitudinal cracking when used over expansive soil, due to a brittle layer formed on a weak subgrade. A laboratory evaluation conducted by Sebesta (2004) and Scullion et al. (2000) suggested that 2-3 percent cement provides adequate strength, durability, and economy for base stabilization.

The geogrid can also be combined with lime-treatment resulting in an effective method to prevent longitudinal cracking caused by the shrinkage of expansive soil. Chen (2007) proposed a rehabilitation procedure for existing surface treated pavements at high plasticity subgrade areas (PI > 35). In this study geogrid was used over lime- or cement- treated subgrade before the
placement of flexible base to minimize longitudinal cracking. The existing base and portion of the existing subgrade were mixed with a determined amount of lime or cement. Then the geogrid is placed over the mixed material prior to the flexible base. Sebesta (2004) remarked that the geogrid serves as an initial barrier to upward crack propagation and the flexible base overlay on top of the geogrid serves as a stress relief layer.

Vertical moisture barriers with impermeable geomembranes could reduce the moisture variation in expansive subgrade and restrain pavement roughness (Jayatilaka and Lytton 1997). The vertical moisture barriers isolate the soil from the climatic changes and thus minimize moisture variations. In dry season, the barrier prevents subgrade access to free water. On wet season, the barrier prevents excessive drying of the subgrade soil, especially under pavement shoulders, and thus prevents longitudinal shrinkage cracking (Steinberg, 1992). There are concerns that this procedure was not effective due to the unfavorable results obtained at test sections in Bryan, Texas (Dessouky et al. 2012).

There are numerous studies based on laboratory and field evaluations that addressed treatment methods for pavements constructed over expansive soils. Nowadays with limited financial resources and an extensive road network to maintain there is a press need to find cost-effective long-lasting treatments that rectifies the main cause of these failures. The significant of this study is to provide comprehensive field and laboratory performance of existing low-volume roadways built over expansive. Three existing projects with various treatments that target failures due to expansive soil were evaluated. The performance life of these projects ranged from 3 to 14 years. All projects were built on expansive soils and exposed to traffic volume ranged from 400-11200 Average Daily Traffic (ADT). More details on site characteristics are listed in Table 1.

Table 1. Selected Projects for Field/Laboratory Evaluation

<table>
<thead>
<tr>
<th>Roadway</th>
<th>District</th>
<th>Surface type</th>
<th>Soil type</th>
<th>Treatment</th>
<th>Service life (years)</th>
<th>Failure mode in control section</th>
<th>Traffic (ADT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM 471</td>
<td>San Antonio</td>
<td>Asphalt</td>
<td>Expansive</td>
<td>Cement-treated base and asphalt overlay</td>
<td>3</td>
<td>Base failure</td>
<td>11,200</td>
</tr>
<tr>
<td>FM 1915</td>
<td>Bryan</td>
<td>Seal coat</td>
<td>Expansive clay</td>
<td>Lime-treated subbase and Geogrid</td>
<td>14</td>
<td>Severe Longitudinal cracking</td>
<td>400</td>
</tr>
<tr>
<td>FM 734</td>
<td>Austin</td>
<td>Asphalt</td>
<td>Expansive clay</td>
<td>Lime-treated subgrade and Geogrid</td>
<td>10</td>
<td>Longitudinal and transverse cracking</td>
<td>7,400</td>
</tr>
</tbody>
</table>

ADT: average daily traffic
PROJECT SITES AND VISUAL SURVEY

At each project site, one control section and at least one repaired section were identified. Figure 1 describes the structural design of each section. Letter “C” refers to Control section, “R” refers to Reconstruction and “O” refers to Overlay.

The FM 1915 site is one of the earlier efforts constructed in Bryan District to rehabilitate rural roadways using geogrid reinforcement. All sections in the site have 10 inch lime treated subbase (5 percent lime), granular base layer and a seal coat surface. The FM 471 site consists of three sections, control, reconstruction and overlay. The reconstructed section was built to sustain high ESALs truck loading. Cement treatment was used to stabilize the base layers and two layers of asphalt concrete (AC) were used. The overlay section was constructed to improve ride quality and skid resistance. The base layer was reworked and a new 3 inch AC was applied. The control and overlay sections consist of a two-layer structure while the reconstructed section consists of a three-layer structure including two AC layers (base and surface course layers). FM 734 is a divided two-direction four-lane highway consists of two sections; control (734-C) and geogrid-reinforced (734-R). Both sections have lime-treated subgrade to reduce shrinkage cracking. Severe surface cracking is evident in the control section with poor ride quality while the geogrid section has only minor surface cracking. Complete summary of visual survey is shown in Table 2.

Figure 1. Schematic diagram of the projects structural design
Table 2. Summary of Field visual survey

<table>
<thead>
<tr>
<th>Site</th>
<th>Original (control) condition</th>
<th>Performance of repaired section</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM 1915</td>
<td>Faulted surface cracking due to soil movements and cycles of shrinkage/swelling of high PI expansive clay.</td>
<td>Longitudinal cracks continue to appear in the geogrid sections in lesser degree.</td>
</tr>
<tr>
<td>FM 471</td>
<td>Fatigue cracking and rutting in the wheel path due to insufficient structural capacity (base failure) and expansive soil.</td>
<td>Reconstructed and overlay sections are in good conditions with distress-free surface.</td>
</tr>
<tr>
<td>FM 734</td>
<td>Frequent swells and dips and faulted shrinkage cracking due to heave and seasonal soil swelling.</td>
<td>Section is in good conditions with minor surface cracking in the geogrid section.</td>
</tr>
</tbody>
</table>

FIELD AND LABORATORY TESTING

The field and laboratory testing program in this study was implemented to evaluate the effectiveness of the applied treatment to alleviate the distresses related to expansive soil. Field testing included the following:
Ground Penetrating Radar (GPR): A widely used nondestructive test used to determine pavement layers thicknesses. The GPR system estimates the dielectric constant of the layers from measurement of electromagnetic wave speed of the travel time between the layers systems. Identification of delamination in-between layers can also be detected using the PAVECHECK program developed by Liu and Scullion (2009).

Falling Weight Deflectometer: A non-destructive test used to determine the existing pavement layers moduli. In this process, an impact load is applied from a standard height on the pavement surface. The pavement vertical deformations were measured by a set of seven geophone sensors ($W_1, W_2, \ldots$ and $W_7$). The MODULUS 6 program was used to analyze the measured deflection basin to determine the layer moduli and assess the pavement condition in terms of surface curvature index (SCI) and base curvature index (BCI). These indices were used to establish layer strength classification criteria as suggested by Michalak and Scullion, (1995). The SCI is determined as the difference of $W_1$ and $W_2$ and the BCI is determined as the difference of $W_2$ and $W_3$. The FWD was performed along the travel at data sampling rate of 0.1 mile.

Base and subgrade materials were sampled close to the edge of the pavement from control and repaired areas. Samples was collected following the FWD testing and bagged for the laboratory testing. The laboratory testing was concurrently performed to characterize the material properties from control and repaired sections at each project site. Comparison of testing data from repaired and observed failures areas were used to investigate the cause of failure. The laboratory testing includes Atterberg limits, shrinkage, sulfate concentration, suction and three-dimensional (3-D) swelling. Gradation and proctor compaction testing were also performed as input parameters for the laboratory tests.

The shrinkage test was used to determine the linear shrinkage of soil. Soil materials in liquid limit condition were used to form beam samples in shrinkage molds. The mold length is determined before and after oven drying at 110 ± 5°C. The shrinkage severity was classified based on the criteria developed by Nelson and Miller (1992). Sulfate concentration test was performed to determine the presence and amount of sulfates and they cause a heaving problem in soils (Chen et al. 2009). A colorimeter was used to measure sulfate concentration in parts per million (ppm). Sulfate content over 3000 ppm can negatively affect pavement integrity and quality.

Soil suction is an indicator of moisture susceptibility and/or retention capability. The soil-water characteristic curve is used to represent the relationship between moisture content versus soil suction. Higher suction corresponds to lower moisture content level and vice versa. The tube test was used to determine the suction for subgrade and base materials. Base materials were molded at optimum moisture content to maximum density to form 6 inch diameter and 8 inch height specimen. The mold was oven dried at 140°F for two days. The mold was wrapped with latex.
membrane and kept in container on top of fixed-depth water level for 10 days. The dielectric value (DV) was measured using the *Adek Percometer*™. The final DV determined as the average readings of the last three days were used to classify the moisture susceptibility of the base materials (Barbu and Scullion 2006). DV with more than 16 is classified as high moisture susceptibility and poor quality base materials. For subgrade soil the water characteristic curve was established using pressure plate extractors that are used in determining the permeability of soil cores in accordance with ASTM D 6836-02. Different soil matric suction levels, difference between the pore-air and pore-water pressures, were applied on subgrade soil specimen. The application of matric suction to the specimen causes the pore-water to drain out. The specimen weight was measured after equilibrium at each applied matric suction level to construct the soil water characteristic curve.

The 3-D swelling test was conducted on soils to gauge soil potential volume changes due to moisture variation. Molded soil materials were compacted at optimum moisture content to fabricate cylindrical samples with 4 inch diameter and 4.5 inch height. The samples were exposed to a three-day air dry before wetting. The mold dimensions were measured and the monitoring over a period of 30 days (Harris 2008).

**FIELD TESTING EVALUATION**

**Ground Penetrating Radar**

The GPR images were able to capture the distinct layers structure of each section as shown in Figures 2-4. To verify the quality of the GPR images layers thicknesses were estimated and compared with the coring samples in Figure 1. For example, the AC layers in the FM 471 site were detected with thicknesses of 6-8 and 3-4 inch for the reconstructed and overlay sections, respectively.

Irregularity in the layers profile may be used as signs of substantial movements in the pavement structures. For instance, the FM 471 control section suggested a heave action due to the wavy signals in the subgrade as shown in Figure 2. However, during the field testing, there was no sign of pavement distresses noticed at the surface. This may be attributed to the thickness of the base layer. The figures also showed an evident of moisture entrapped zone between the AC and cement-treated base in the reconstructed section. However, the presence of the moisture has no damage effect in the pavement system which may be attributed to the thickness of the AC layer and base stabilization.
At the FM 1915 site, the GPR images on sections 1915-R1 and 1915-C showed higher variability due to the soil movements compared to section 1915-R2 (Figure 3). These results are in agreement with the visual survey. For instance, the control section (1915-C) had a total of 47 observed distresses with a total longitudinal cracking length of 688ft. The geogrid section, 1915-R1, also revealed severe surface condition with 743 ft total length of longitudinal cracking and 19 observed distresses. Section 1915-R2 was found to perform the best as indicated by the shortest length of longitudinal cracking of 425ft and 21 observed distresses.

At FM 734, numerous repaired areas within the control section were captured by GPR images as shown in Figures 4. The control section experienced severe shrinkage cracking due to the frequent movements of subgrade soils. Nevertheless, there were no signs of moisture entrapped between the layers. On other hand, the geogrid section is showing almost cracking-free surface and uniform GPR signals suggesting improved performance as compared to the control section.
Figure 3. GPR processed images of FM 1915

Figure 4: GPR processed images for reconstruction (above) and control (below) sections of FM 734
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**Falling Weight Deflectometer**

The layers moduli determined for all sections as shown in Table 3, suggested that the reconstructed sections have higher base and subgrade strength compared to their control sections counterparts. The significant increase in base layers strength in each site is due to the geogrid reinforcement in the FM 1915 and FM 734 and the base cement-stabilization in FM 471. These treatments have shown an average base stiffness increase of 48, 36 and 20% for FM 471, 1915 and 734, respectively.

<table>
<thead>
<tr>
<th>Site/section</th>
<th>FM 471</th>
<th>FM 1915</th>
<th>FM 734</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>471-C</td>
<td>471-R</td>
<td>471-O</td>
</tr>
<tr>
<td></td>
<td>1915-R1</td>
<td>1915-C</td>
<td>1915-R2</td>
</tr>
<tr>
<td></td>
<td>734-C</td>
<td>734-R</td>
<td></td>
</tr>
<tr>
<td>Base Modulus (ksi)</td>
<td>128</td>
<td>728</td>
<td>345</td>
</tr>
<tr>
<td>Subgrade Modulus (ksi)</td>
<td>23</td>
<td>28</td>
<td>40</td>
</tr>
</tbody>
</table>

Michalak and Scullion (1995) suggested that pavement layers condition can be classified based on the AC layer thickness and the difference between particular FWD geophone sensors. For instance, pavement with lower BCI values (in mils) represents high strength AC and granular base layers, respectively, and vice versa. They classified the pavement condition in five-rating criteria; very good, good, moderate, poor and very poor.

Figure 5 shows the analysis results of FWD indices and the rating criteria for every section in each site. The rating was adjusted in the reconstruction section, 471-R, to reflect the thickness of the AC layer. At the FM 471 site, the indices can clearly distinguish between the three sections. This agrees with the GPR data that identified the distinct zones layer structure. The SCI values suggest that the reconstruction sections exhibit the highest AC layer strength followed by the overlay. Similar trends were also found in the analysis for the BCI (Figure 5a). It is suggested that the cement-treated base has a significant role to improve the base layer strength. Considering the new AC layer and reworked base layer in the overlay section, the BCI values were slightly decreased compared to the control section. Overall, the control and overall sections fall in zones representing moderate to very good condition.

At the FM 1915 site, analysis of BCI values suggested that all sections were in very good condition. The SCI was discarded in this section due to the nonexistence of AC layer. Another observation was that the geogrid section 1915-R2 showed the least index although it had the lowest base thickness. This could be attributed to the relatively lower plasticity among consecutive sections reflected by the soil PI data in Table 4. As a result of the lower plasticity
the 1915-R2 section may have the least subgrade movements due to moisture changes that affect the stability and strength of the supported base layer.

In the FM 734 site, the layer moduli from the reconstruction section with geogrid were slightly higher than in the control section. The BCI values suggested that the layers conditions correspond to moderate to good condition (Figure 5c). It is evident in this site that the geogrid reinforcement at the base-subgrade interface along with the subgrade lime-treatment mitigated the longitudinal cracking.
LABORATORY TESTING EVALUATION

The test results showed that the sulfate content was not significant (< 3000) for the tested soils. Moisture susceptibility using Barbu and Scullion (2006) criteria indicated that the base materials in all sites are classified as marginal quality. The only exception is the cement treated base, 471-R, which yields a DV below 10 indicating low moisture susceptibility and good quality materials. The subgrade properties in all sections suggested that soil with high plasticity exhibits high shrinkage, swelling potential and sulfate content and vice versa.

The subgrade at the FM 1915 site is classified as highly plastic soils according to Wattanasanticharoen (2000) classification. Particularly, the 1915-R1 exhibited an extreme high value of PI, determined to be the primary cause of soil movement and higher deflection deduced from the SCI and BCE values. This is in agreement with the field visual survey that indicated a significant damage despite the geogrid reinforced treatment. Table 4 indicated that the subgrade of sections 1915-R1 and 1915-C was more prone to shrink/swell than that in section 1915-R2. This is in consistent with GPR data interpretation, FWD deflection data analysis, and field visual survey. Considering the severe shrinkage potential of 1915-R1 soils, geogrid reinforcement alleviates soil movement to some extent, where a relatively lesser extent of damage was observed compared to control section.

The subgrade properties at the FM 471 site seem to support the results of the visual inspection, FWD and GPR. For instance, the control section 471-C has the highest plasticity index,
shrinkage strain, sulfate content and swelling potential. These properties attributed to the severe longitudinal and transverse cracking in the pavement surface as determined by the visual survey. Although the sulfate content is insignificant, it is five times higher in the control section compared to the counterpart sections.

In the FM 734 site, the soils were part of lime stabilized subgrade resulting in low shrinkage, plasticity and sulfate content. The measured shrinkage strain was below 5%, sulfate content was less than 200 ppm and plasticity index was less than 10%. The 3-D Swell Test suggested that soil samples from both sections exhibited a similar volume expansion due to moisture absorption. Compared to the percent swell observed on FM 1915 soil, FM 734 exhibits a lower level of swelling potential due to addition of lime.

Table 4 suggested that the subgrade properties in 471-C (2-4 inch AC) and 1915-C (with 10 inch subbase layer) are slightly comparable. Considering the same weather conditions, the section with AC layer out-performed the one with seal-coat surface treatment and subbase layer suggesting the significance of the AC to improve pavement performance.

Table 4. Summary of Laboratory Testing

<table>
<thead>
<tr>
<th>Testing</th>
<th>Specs/ reference</th>
<th>FM 471</th>
<th>FM 1915</th>
<th>FM 734</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade Plasticity Index (%)</td>
<td>Tex-104E</td>
<td>35</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Subgrade Shrinkage (%)</td>
<td>Tex-107E</td>
<td>25</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Subgrade Sulfate Content (ppm)</td>
<td>Tex-145E</td>
<td>576</td>
<td>&lt;100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Subgrade Swelling (%)</td>
<td>Harris (2008)</td>
<td>19</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Base moisture susceptibility (DV)</td>
<td>Barbu and Scullion (2006)</td>
<td>13.5</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

The soil water characteristic curves in Figure 6 suggested that the 471-C soil yields the greatest change in gravimetric water content against the matric suction. This seems consistent with the highest shrinkage potential that indicates severe volume change occurs with the change in moisture content. In the FM 1915, the variation of moisture content was not sensitive to the change of matric suction. This suggested that the soils tend to have a high capability of retaining water and a higher possibility to yield larger movement in case the soil encounters considerable...
amount of rainfall. In the FM 734, the Pressure Plate Test suggested that the control section soil seems to be more capable of releasing water than the treated section soil. This explains the potential of control section soil to retain water resulting in the heave and dips spots noticed in the visual survey.

![Figure 6. Soil water characteristic curves of a) FM 471, b) FM 1915 and c) FM 734 subgrade soil](image)

**PERFORMANCE AND STRUCTURAL DESIGN EVALUATION**

**Pavement Condition and Ride Quality**

Effectiveness of treatments in pavement surface condition and ride quality was assessed using field performance data. Performance data from the TxDOT pavement management information system (PMIS) database were collected before and after the treatment repair. Pavement evaluation using two rating scores namely; condition score and ride score. The former reflects the pavement distresses types and severity and ranges from zero (completely damaged) to 100 (undamaged). The latter defines the ride quality of the pavement surface and ranges from zero (rough) to 5 (smooth). Figure 7 suggests that the condition and ride scores significantly increased after the repair was conducted at each site (with the exception of FM 734 in which historical data prior to 2006 were not available). The higher score prior to reconstruction (FM 471) is due to application of temporarily surface treatments by TxDOT to preserve the pavement until a major repair is scheduled. According to the TxDOT, the average bid price for cement-treated base, lime-treated subgrade, geogrid-reinforced base and asphalt overlay are 2.3, 2.3, 3.17 and 2.4 $/square yard, respectively. This estimate is determined for base layers of 6-8 inch and asphalt layer of 1-3 inch.

One can notice in Figure 7 the effectiveness of the cement-treated base (e.g., 471-R) through a stable condition score for three years after reconstruction. This treatment showed higher scores against the expansive soil conditions and heavy traffic. Geogrid at base-subgrade interface was
also shown an effective treatment against expansive soil. The Geogrid effectiveness is improved when combined with lime-treated subgrade (e.g., 734-R) or lime treated subbase (e.g., 1915-R2). The combination of geogrid and lime treated, however have not shown reliable treatment in areas where severe soil plasticity exist (e.g., 1915-R1). Considering the combined cost of lime and geogrid, this treatment is better used with low to moderate plasticity soil.

The asphalt overlay repair includes milling an existing asphalt concrete layer and reworking the base layers (if needed) before applying a new asphalt layer. Although this treatment only addressed surface repair, the section showed accepted results within three years after completion (e.g., 471-O). This may be attributed to the structural design of the section that is capable to sustain the traffic loading and movements from the expansive soil. While this treatment is considered one of the less costly repairs particularly if no base rework is needed, it is necessary to continue monitor the performance of this section to have a comprehensive evaluation of the long-term performance.

**Structural Design Evaluation**

Effectiveness of treatment options in pavement structural design was assessed using the LoadGage program. Fernando et al. (2007) developed the LoadGage program to improve the current Texas Triaxial design check procedure. The program considered the moisture correction on subgrade strength based on the soil water characteristic curves (SWCC) of predominant soils. The program determines the allowable wheel loads based on the Mohr-Coulomb yield criterion as given in Eq. 1. If the yield function is less than zero, the pavement structure can sustain the specified wheel load otherwise the pavement structure is required to be thicker or the specified load needs to be reduced.

\[
f = \frac{1}{3} \sin(\phi) + \sqrt{J_2 \sin\left(\theta + \frac{\pi}{3}\right) + \frac{J_2}{3} \cos\left(\theta + \frac{\pi}{3}\right) \sin(\phi) - c \cos(\phi)}
\]

Where, \(I_1\) = first stress invariant, \(J_2\) = second deviatoric stress invariant, \(\phi\) = friction angle, \(\theta\) = Lode angle, and \(c\) = cohesion. Given a SWCC, soil type, FWD backcalculated layer moduli and pavement layer thickness, the LoadGage program was executed. For the moisture correction, the field moisture content that corresponds to a value of 3.5 pF matric suction was used, which is typically considered as an equilibrium condition. A 12 kips of average ten heaviest wheel loads daily (ATHWLD) for dual-tire with 14 inch of tire spacing was used throughout the analysis. Table 5 suggested that the three control sections of FM 471 and FM 1915 and one treated section of FM 1915 failed to sustain the specified wheel load for both of the moisture correction scenarios.
Figure 7. The Condition Scores and Ride Scores Before and After the Reconstruction for a) FM 1915, b) FM 471 and c) FM 734.

An attempt to verify the structural design results was executed using the condition and ride scores of Year 2010 (Table 5). The LoadGage analysis results were in agreement with the PMIS data. Results suggested that sections with insufficient structural capacity also experience relatively lower condition and ride score compared to their counterparts sections in each site.
Table 5. *LoadGage* and PMIS Results

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>LoadGage w/o Moisture correction (f)</th>
<th>w/ Moisture correction (f)</th>
<th>PMIS Condition score (0–100)*</th>
<th>Ride score (0–5)+</th>
</tr>
</thead>
<tbody>
<tr>
<td>471-O</td>
<td>Overlay</td>
<td>Fail (1.22)</td>
<td>Pass (-0.21)</td>
<td>100.0</td>
<td>3.98</td>
</tr>
<tr>
<td>471-R</td>
<td>Cement treated</td>
<td>Pass (-1.31)</td>
<td>Pass (-4.24)</td>
<td>100.0</td>
<td>3.90</td>
</tr>
<tr>
<td>471-C</td>
<td>Control</td>
<td>Fail (1.54)</td>
<td>Fail (1.57)</td>
<td>63.0</td>
<td>2.70</td>
</tr>
<tr>
<td>1915-R1</td>
<td>Geogrid/lime</td>
<td>Fail (0.17)</td>
<td>Fail (0.40)</td>
<td>69.0</td>
<td>2.60</td>
</tr>
<tr>
<td>1915-C</td>
<td>Control</td>
<td>Fail (0.79)</td>
<td>Fail (0.79)</td>
<td>68.0</td>
<td>2.70</td>
</tr>
<tr>
<td>1915-R2</td>
<td>Geogrid/lime</td>
<td>Fail (0.5)</td>
<td>Pass (-1.78)</td>
<td>90.0</td>
<td>3.50</td>
</tr>
<tr>
<td>734-R</td>
<td>Geogrid</td>
<td>Pass (-0.10)</td>
<td>Pass (-0.11)</td>
<td>83.5</td>
<td>3.35</td>
</tr>
<tr>
<td>734-C</td>
<td>Control</td>
<td>Pass (-0.89)</td>
<td>Pass (-0.89)</td>
<td>79.0</td>
<td>3.15</td>
</tr>
</tbody>
</table>

*f*: Mohr-Coulomb yield function

*: Indicated in a scale of 0 (failure) to 100 (no damage)

+: Indicated in a scale of 0 (poor ride) to 5 (excellent ride)

CONCLUSION

Three low-volume roadway sites were investigated to evaluate the effectiveness of existing repair against distresses related to expansive soil. Those roadways experienced failures in the form of fatigue and rutting in the wheel path, and longitudinal (faulted) cracking including edge cracking. The causes of those failures were mainly linked to expansive soil and narrow pavement. Each site was evaluated using visual survey, field and laboratory testing, surface condition/ride data and structural design calculations. At least three years of field performance of each treatment were available and used to investigate each site.

The following can be concluded from the sites evaluation:

- Geogrid has shown to be an effective treatment by increasing the lateral stiffness of base layer and hence its vertical stiffness. In this study, the geogrid has proven beneficial when used in combination with subgrade stabilization in areas with low to moderate plasticity soil. The geogrid sections in FM 2 and FM 734 indicated good pavement performance with combined treatment.
- Cement-treated base showed the best performance as indicated by the condition and ride scores. The performance over expansive soil combined with moderate cost ($2.3/ SY) could lead to higher cost-effective treatment with relatively high ADT conditions. The reconstructed section in FM 471 experienced good performance for 3 years after construction.
- Overlay treatments have also shown adequate performance in FM 471. The treatment was applied over expansive soil with relatively high traffic loading. Depends on its condition, the base layer can be replaced or reworked before applying the overlay.
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The projects examined in this report are examples of how TxDOT might choose to address severe pavement failures on low-volume roadways under certain conditions. These projects do not represent the only options for treatment of these pavement conditions. It is important to mention that this study did not cover all possible treatment options for expansive soil. The effectiveness of the treatments mentioned here was limited to the selected sites including their climatic, soil and traffic conditions.

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