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Pavement Repair Strategies for Selected Distresses in FM Roadways

Technical Report 0-6589-1

Cooperative Research Program

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16. Abstract
Expansive soil is considered one of the most common causes of pavement distresses in FM roadways. 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 FM 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 PI expansive soil and narrow pavement.

This study involved field and laboratory testing on those projects to examine the effectiveness of the applied treatments. The projects presented in this report are examples of how TxDOT districts choose to address severe pavement conditions that lead to failure on FM roads. Some of those examples are innovative, and others are routine. These projects do not represent the only options for treatment, and each project should be designed based on its existing conditions, such as the intended design life cycle, cost effectiveness, local climate, local traffic, and available local materials.

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PAVEMENT REPAIR STRATEGIES FOR SELECTED DISTRESSES IN FM ROADWAYS

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INTRODUCTION

INTRODUCTION

Shrinkage of high plasticity expansive soil due to drying seasons is one of the major causes of pavement failures in low-volume Farm-to-Market (FM) roadways. Shrinkage cracking initiated from the drying soil propagates through the pavement system causing longitudinal, transverse and fatigue cracking and rutting in the pavement surface. For narrow pavements with lack of shoulders, FM roadways also experienced deterioration along the pavement edges due to shrinkage cracking. These deteriorations are referred to edge failures. However, there are many other potential causes of edge failures such as lack of lateral support, accumulation of water near the edge, side slope instability, base failures and aging of bituminous mixes. Edge failures are common major distresses in farm-to-market (FM) narrow roadways in Texas. They appear in the form of longitudinal cracking, alligator cracking, or rutting within 2 ft of the pavement edge and typically occur where unpaved shoulders are not exist.

With finite resources and an extensive road network to maintain, TxDOT maintenance forces must select a cost effective repair strategy that rectifies the main cause of these failures. This research project focuses on evaluating selected rehabilitation projects that target failures due to expansive soil in FM roadways. This study conducted field and laboratory evaluation on four project sites in the San Antonio, Austin, Bryan, and Beaumont Districts with various traffic, soil conditions and repair methods. The projects examined in this report are examples of how TxDOT districts might choose to address severe pavement failures on FM roads for certain conditions. Some of treatments are innovative while others are routine. These projects do not represent the only options for treatment of these pavement conditions.

RESEARCH OBJECTIVES

The main objective of this research is to evaluate the effectiveness of the repair and rehabilitation options used by the district on selected projects with history of expansive soils related distresses. Also pavement widening options for edge failure treatment were also evaluated. To accomplish this objective, the following tasks were performed:

1. Review current literatures in Texas, nationally and internationally. The focus of the literature review was in the common forms of failures in FM roadways, the causes of those failures, and the treatment options implemented by state agencies. District survey was developed to seek information from the experience of districts with these failures.
2. Perform a series of laboratory and field tests on selected projects that incorporate different soil, traffic and failure mechanism. The selected sites were located in four

districts; Beaumont, San Antonio, Austin, and Bryan. The laboratory tests included the Atterberg limit tests, swelling, shrinkage, suction and sulfate concentration. Field testing included Falling weight deflectometer (FWD) and Ground Penetrating Radar (GPR) of both control and repaired sections.

3. Evaluate the performance of those sections through visual inspections and performance records from the Pavement Management Information System (PMIS) database before and after treatment was applied.

OVERVIEW OF FINAL REPORT

This report consists of five chapters. Chapter 1 provides an introduction with a background explaining the significance of the project, research objectives, and report organization. Chapter 2 discusses literature review in the effect of expansive soil in narrow FM roadways including causes of failure and suggested treatments. Chapter 3 presents the district survey responses and analysis. The survey provided information on current experience with edge failure in narrow pavement in TxDOT districts. Chapter 4 presents results of the field and laboratory testing and evaluation of selected projects performance. A comprehensive correlation between field and laboratory findings is covered in this chapter. The causes of edge failure and effective treatment at different sections are compared and summarized. Chapter 5 presents overall summary of the study.

CHAPTER 2
LITERATURE REVIEW

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. During periods of high moisture expansive will "swell" underneath pavement structure. Conversely during periods of falling soil moisture, expansive soil will "shrink" and can result in significant deformation. These cycles of swell and/or shrinkage can also lead to pavement cracking. Puppala et al. (2006) implied that expansive soils encountered in various districts particularly in northern Texas are the primary causes of pavement failures. Expansive soils located in regions where cool and wet periods followed by hot dry periods are more prone to such problems

The majority of the roadways transportation network in Texas is classified as low-volume roads. Of those roads constructed over expansive subgrade is the source of frequent maintenance problems. This chapter summarizes the review on the most common distresses and failures on low-volume roads with narrow cross-section constructed over high plasticity soils. For example, longitudinal cracking results from the volumetric change of the expansive subgrade, is one of the most common distresses form in low volume roads (Figure 2.1). This type of cracking is initiated from the drying highly plastic subgrade (PI>35) through the pavement structure during the summer (Sebesta 2002 and 2005). Other forms include fatigue (alligator) cracking, edge cracking, rutting in the wheel path, shoving, and popouts. Complete forms of distresses with the corresponding causes of distress mechanism are shown in Table 2.1.

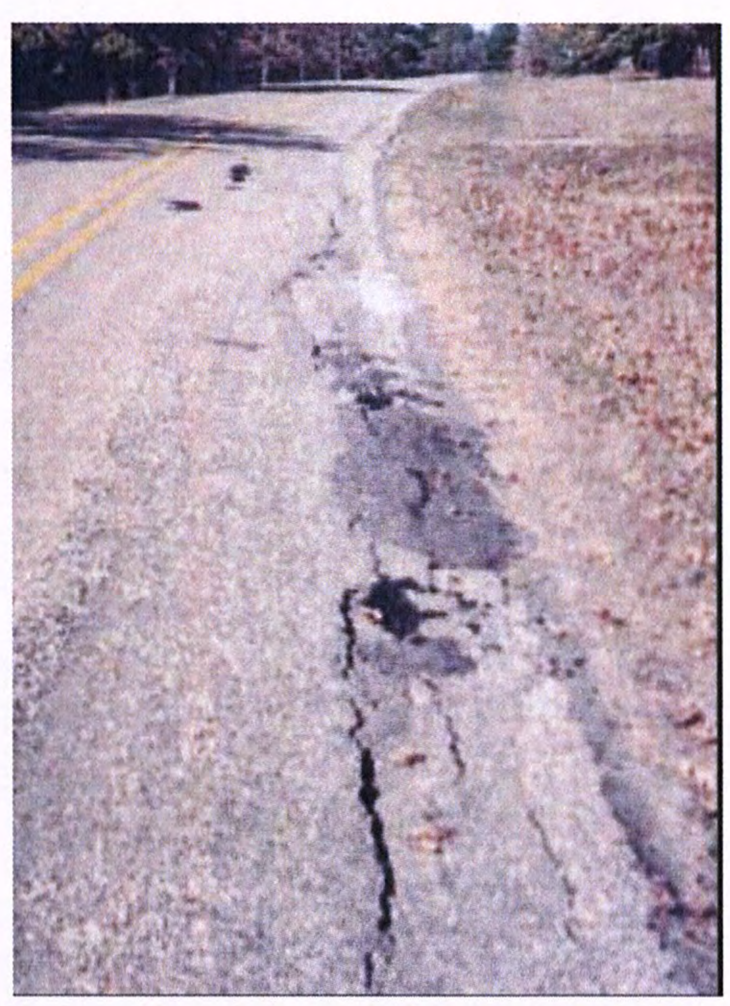


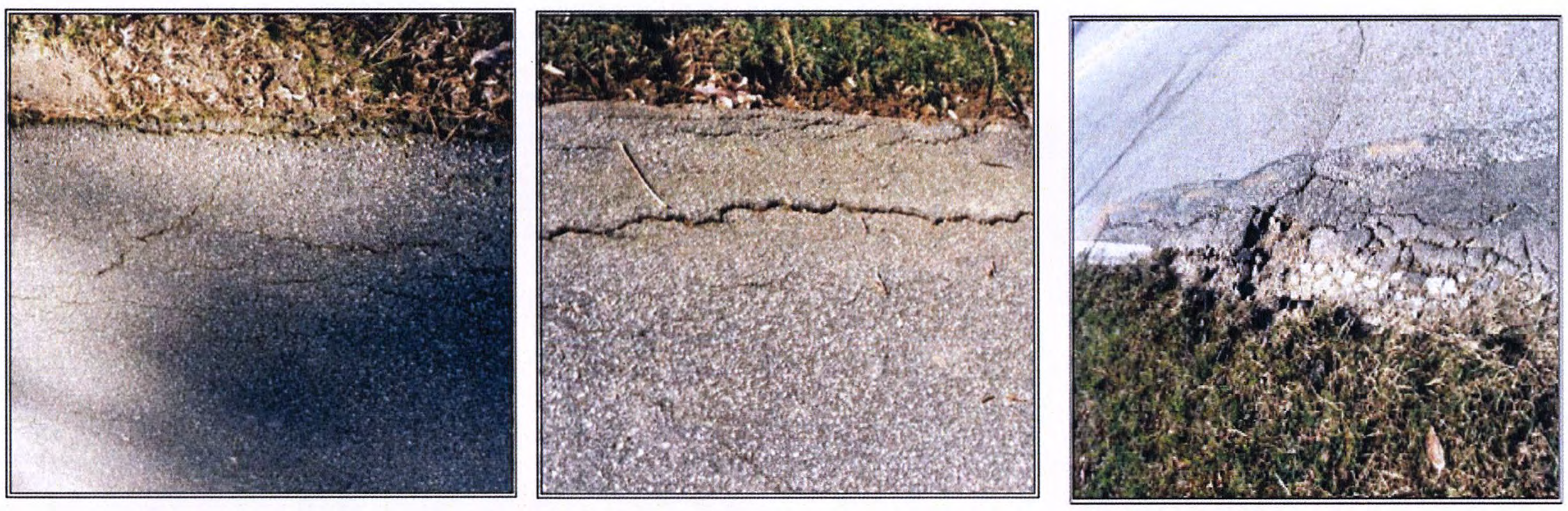
Figure 2.1. Longitudinal cracking and failure (Sebesta 2005).

Table 2.1. Pavement distresses in low volume roads (MS-16 *Asphalt in Pavement Preservation and Maintenance*).

	Excessive loading /Heavy traffic	Base failure or consolidated subgrade	Poor drainage	Lack of lateral support/ shoulder or narrow pavement	Shrinkage/swelling of drying out sulfate soil/ expansive soil	vegetation along edge/ Erosion	Settlement of underlying material	Poorly constructed joint / segregation	Shrinkage of asphalt layer	Cycles of temperature change	Differential movement between asphalt and concrete layers	Insufficient design thickness	moisture infiltration/damage	Lack of good bond between surface layer	Poor quality mixture/ improper aggregates	Tack coat not been used	Poor construcion /lack of compaction	Asphalt binder hardened excessively	Frost heave and freeze/thaw	Vehicular turning or stopping movements
Fatigue (Alligator) Cracking	•	•	•																	
Block Cracking					•												•			
Edge Cracks/drop-off		•	•	•	•	•	•												•	
Long./ Transverse Cracking					•			•	•	•										
Reflection Cracking					•						•									
Rutting		•										•	•		•		•			
Upheaval/Swell					•					•			•						•	
Shoulder drop-off	•			•		•													•	
Popouts/ potholes															•			•		
Raveling													•		•			•		
Stripping													•					•		
Polished Aggregate	•														•					
Corrugation and Shoving															•					•
Bleeding															•		•			

NARROW PAVEMENT

Narrow Low volume roads, that lack lateral shoulder support, are experienced longitudinal cracking combined with rutting along the edge of the pavement. This type of narrow pavement constitute to significant. These types of distresses are referred to edge failure. Edge failures on narrow roads occur within 1–2 ft of the pavement edge in the form of longitudinal, fatigue and alligator cracking, rutting or a combination of these distresses. These failures can propagate toward the travel lane in the form of transverse cracks. Although these cracks are formed within a finite distance from the edge, they often propagate along the wheel paths and allow intrusion of moisture in the subgrade and base materials. Example of edge failures severity is shown in Figure 2.1 (Sebesta 2005).



(a) Light (b) Moderate (c) Severe

Figure 2.2. Edge Failure with Low, Medium, and High Severity (*Distress Survey Manual*).

Other forms of failures in narrow roads are edge break and drop-offs (Figure 2.3). Edge breaks generally occur where the edge of the bituminous surfaces are fretted or broken; while edge drop-offs happen where the elevation of pavement shoulders has eroded and settled several inches lower than the pavement. The possible causes of edge breaks include: insufficient pavement width; alignment that encourages drivers to travel on the pavement edge; lack of lateral support; and loss of adhesion in the base material.

The causes of edge drop-offs include erosion caused by wind, rain or other environmental conditions. Lawson and Hossain (2004) conducted a study to investigate the causes of edge drop-off in Texas. They found that certain types of construction procedures often cause significant edge drop-off problems. They also remarked that edge drop-off occurs mainly in East Texas as a result of buildup of soil along the pavement edges. This problem occurs during the service life of pavement as vegetation adjacent to the pavement starts to encroach onto the pavement and cause a higher edge elevation than the pavement surface. As mentioned (Lawson and Hossain 2004), other factors also affect edge drop-offs, such as traffic type, volume and speed of the traffic, pavement subgrade condition, snowfall and freeze/thaw, shoulder existence, narrow pavement width, and pavement age.

(a) Edge breaks due to loss of adhesion

(b) Edge drop-off due to erosion

Figure 2.3. Several Edge Drop-offs in Texas Roadways (Lawson and Hossain 2004).

Normally, edge cracks are caused by a lack of side or shoulder support. They may also be caused by settlement or yielding of the base material underlying the cracked area. They are the result of poor drainage, frost heave, or shrinkage from the drying out of the surrounding soil. Also, improper compaction, inadequate stabilization, and/or water drain may play a role in loss of foundation support and differential settlement. In the last case trees, brush, or other heavy vegetation close to the pavement edge may be a cause. Other causes include very flexible surface courses; bitumen hardening and inadequate pavement width that forces traffic very close to the pavement edge. Chen (2007) stated that longitudinal cracks result from edge drying while transverse cracks result from an insufficient mellowing period. Other causes include:

- Premature age of asphalt due to high plant production temperature.
- Heavy agricultural related traveling along the pavement edge in Texas.
- Summer rainfall, soil type and the reduced stiffness of the base during the summer.
- Brittleness of the base material.

Hearn et al. (2008) (Figures 2.4) correlates edge failure of roads ground movements at the edge of roads combined with existence higher wet season groundwater and water content in soils. Weathered rock masses at exposed steep roadside cuts also accelerate the ground movements at edges. These conditions are more common in roads at higher elevations. In addition, Heath et al. (1990) summarized the causes of edge slope instability, such as exceptional storms, seismic activity, erosion or the disturbances of materials due to road construction, and weak cohesive soils due to rapid weathering.

Figure 2.4. Edge Failure due to Slope Instability (Hearn et al. 2008).

While the majority of distresses in narrow low volume roads in high plasticity soil areas are due to expansive soil shrinkage/swell movements and base failure, the effective treatment will be to target base and subgrade. For instance, chemical stabilization and reinforcement of soil and base layer to increase the strength capacity are examples of effective treatment that was studied extensively in research studies. The next section targets the rehabilitation treatment in expansive soils.

TREATMENTS OF EXPANSIVE SOILS

Project 0-4829 remarked number of methods used in expansive soils treatments, grouped into three categories:

i) Mechanical, chemical or physical alteration of expansive soil. Lime stabilization is one of the most extensively used alterations in the subgrade. Stabilizers tend to increase the strength and stiffness of the treated soil, reduce the swelling, decrease the permeability, and moderate the suction.

ii) Geogrid reinforcement and sometimes combined with lime treatment is another effective method to prevent longitudinal cracking caused by the shrinkage of expansive subgrade.

iii) Control of subgrade moisture conditions with vertical barriers.

Chemical treatment for base and subgrade

Lime and chemicals such as cement or lime-fly ash can be used to solve the expansive soil problem and stabilize the subgrade soils. Several research projects have been conducted in Texas, (e.g., Harris 2008 and Freeman and Little 2002), in which both FWD and DCP data showed that the subgrade benefited from the addition of stabilizers.

Cement or lime treated base is a popular method used for maintaining bases. The major concern in cement treated base is that it causes block cracking. When used in expansive soil, it may result in longitudinal cracks due to a brittle layer formed on a weak subgrade. A laboratory evaluation between cement treated and black base conducted in study 0-4395 suggested that cement-treated materials with 2 percent cement had roughly double the strength of the black bases. Also Hamburg tests indicated that the limestone performed better than either of the black bases even at 2 percent cement.

Work by Scullion et al. (2000) on cement treated bases for full depth reclamation (FDR) focused on balancing strength with the probability for shrinkage, and led to the development of proposed criteria for cement treated bases, which optimizes cement content for adequate strength, durability, and economy. The design cement content is the minimum amount that meets both strength and moisture susceptibility criteria. Experience has shown 2 to 3 percent Type I cement is usually adequate for reasonable quality limestone and most recycled materials (i.e., where the existing surfacing is mixed into the existing base).

Several studies investigated how shrinkage and cracking in cement-treated bases and subgrade are affected by key factors such as; cement content, material type, density, pre-treatment moisture content, molding moisture content, curing time and compaction method. The following is a summary of the factors affecting the cement-treatment in pavement systems:

- Cement Content: research studies shown controversy to prove the relationship between optimum cement content and shrinkage. Incorporating higher cement content required more moisture content that eventually increases shrinkage but at same time improve tensile strength against cracking. Studies (George 1968, Adaska and Luhr 2004, Scullion et al. 2000) have concluded that optimal cement content exists where shrinkage will be minimized. However, work by (Bofinger et al. 1978, Nakayama and Handy 1965) could not observe any relationship between cement content and shrinkage. Bahar et al. (2004) suggested cement content higher than 8% at the dry state and after 48 h of immersion in water.
- Material Type: studies have shown the contribution of clay type and content with the shrinkage. Particularly, the montmorillonitic clay is one of the most active minerals to boost shrinkage (George 1968). Walker (1995) suggested that soils with a plasticity index above 20-25 are not suited to cement stabilization using manual presses, due to problems with excessive drying shrinkage.
- Density: while compaction density shall be target at its highest value to minimize shrinkage, other studies found greater shrinkage with increasing density. On other hand, Adaska and Luhr suggested maximizing density without increasing moisture content above the optimum level to mitigate shrinkage (Adaska and Luhr 2004). For expansive soils, cement treatment is not effective unless lime agents are included to reduce the PI of the soils.

- Pre-Treatment Moisture Content: soil pre-treated with moisture showed more potential to shrinkage than dry soil. Studies recommend blending cement and water simultaneously to dry soil immediately followed by compaction to minimize shrinkage (Bofinger et al. 1978).
- Curing Time: placement of the pavement layers above the treated layer can be ranged from one day (George 1968, Jonker 1982) or 7-day (Kuhlman 1994).
- Additives: supplementary additives such as lime, fly ash (Kolias et al. 2005) and sulfate salt resulted in reduced shrinkage in cement treated soil (Wang 1973).
- Compaction method: Mechanical stabilization by dynamic compaction seems to give better results as compared to static or vibro-static compaction (Bahar et al. 2004).

Studies on lime treatment suggested lime stabilization for subgrade/base materials with a plasticity index (PI) greater than 10 and more than 25 percent passing the #200 sieve (Little 1995). The main concern with lime treatment is the resulting slow strength gain. TxDOT specifications require 7 days curing for lime-treated bases. 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).

Findings from TxDOT implementation study 5-4240 have suggested high plasticity soil can be treated using lime. Figure 2.8 indicated that untreated raw soil swelled to 19.7 percent, the 1 percent lime plus 4 percent slag soil swelled 12.5 percent, while the 5 percent lime soil had a final swell of only 4.7 percent. DCP data obtained at high plasticity sites in Austin revealed that lime tends to reduce penetration rate over time. This result suggests that lime-treated soil gains strength after treatment. The overall conclusion of this implementation study has remarked that the FWD and DCP data show that the subgrade benefited from the addition of lime stabilizer in the form of higher strengths (Harris 2008) (Figure 2.5).

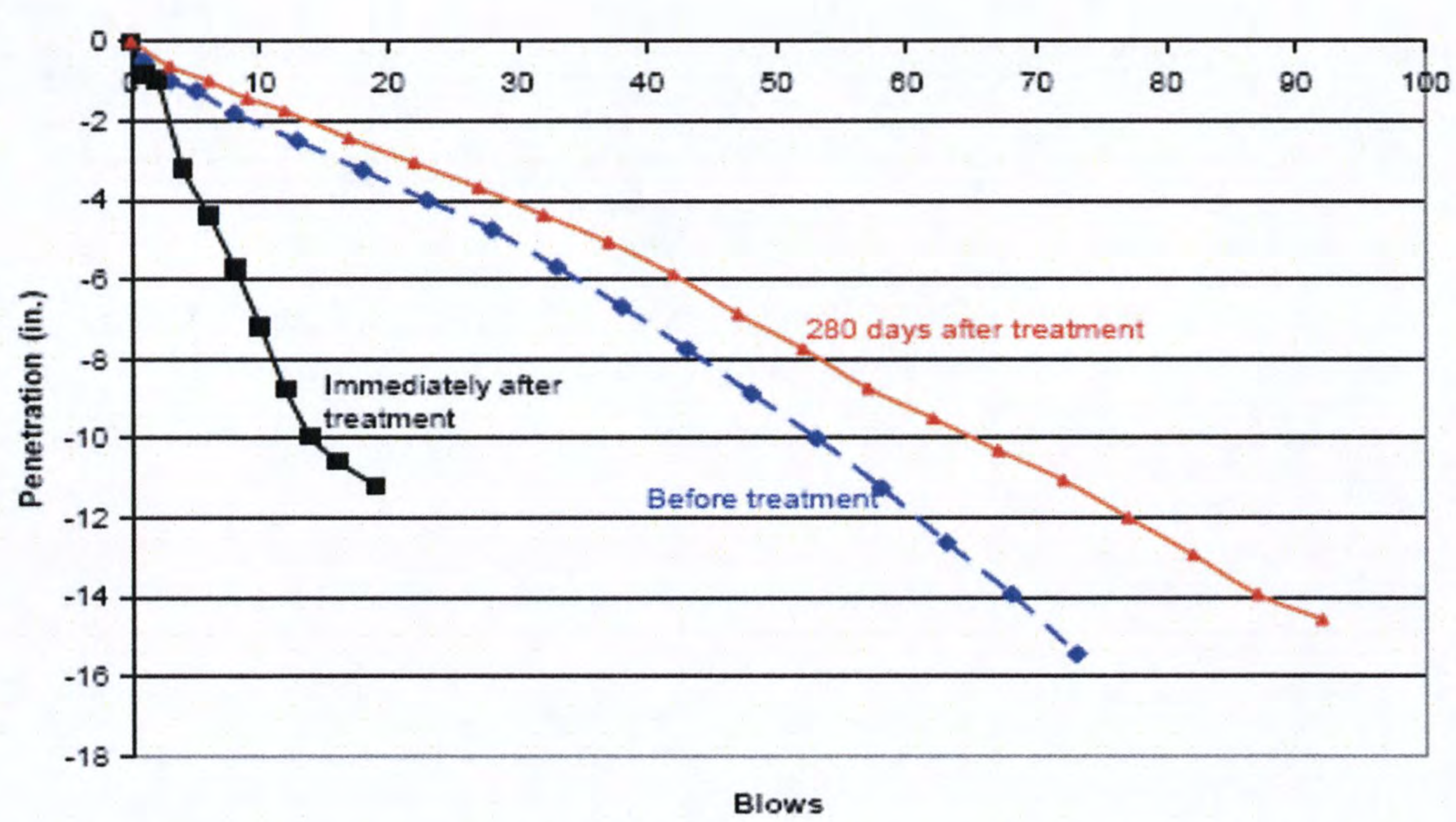


Figure 2.5. DCP measurements showing the strength attained by lime treatment (Harris 2008).

Pavement Reinforcement

Geotextiles and geogrids have been used and promoted for use in numerous pavement reinforcement applications over the years. In an effort to minimize the adverse effect of high plastic subgrade on pavement longitudinal cracks, the Bryan District has been using geogrids beneath a layer of flex base on FM roads. These provide a barrier and keep cracks from affecting upward to the surface (Geo-fibers 1998).

Another geosynthetic product that has potential for minimizing dry cracking in highly plastic clay environments is *fibrillated polypropylene fibers*. These fibers have an approximate length of 1 in. and are mixed into the soil with conventional mixing equipment. When mixed, the fibers open and mechanically reinforce the soil (Hicks et al. 1997). A field study conducted by the U.S. Army Corps of Engineers found that inclusion of fibers into stabilized clay and sand resulted in significant improvements in durability (Grogan et al. 1994). This study also concluded that better post-peak load-carrying ability was exhibited by the treated materials with fibers when subjected to compression testing. This is similar to the findings by Marti et al. (1989) and Hall (2002).

The effective treatment depends on the severity of the distress. Project 0-4395 reported treatments for faulted longitudinal cracking including cement treated bases (CTB), cold-mix surface patch and asphalt base for expansive soils. According to this study, the asphalt base had the longest expected life, while CTB repairs typically had the shortest life. The study suggested a geogrid reinforcement method for the base repair. As reported in the study, the Bryan District used geogrid to mitigate longitudinal cracking in low volume FM roads. Geogrid was placed over the recycled existing roadbed to serve as an initial barrier to upward crack propagation. A thin flexible base overlay on top of the geogrid serves as a stress relief layer.

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 base to minimize longitudinal cracking (Figure 2.6). The existing base and seal coat are mixed with a portion of the existing subgrade, which is then mixed with a determined amount of lime or cement. Then the geogrid is placed over the mixed material. Finally, a layer of untreated flex base is spread over the geogrid and a seal coat is used to seal the surface.

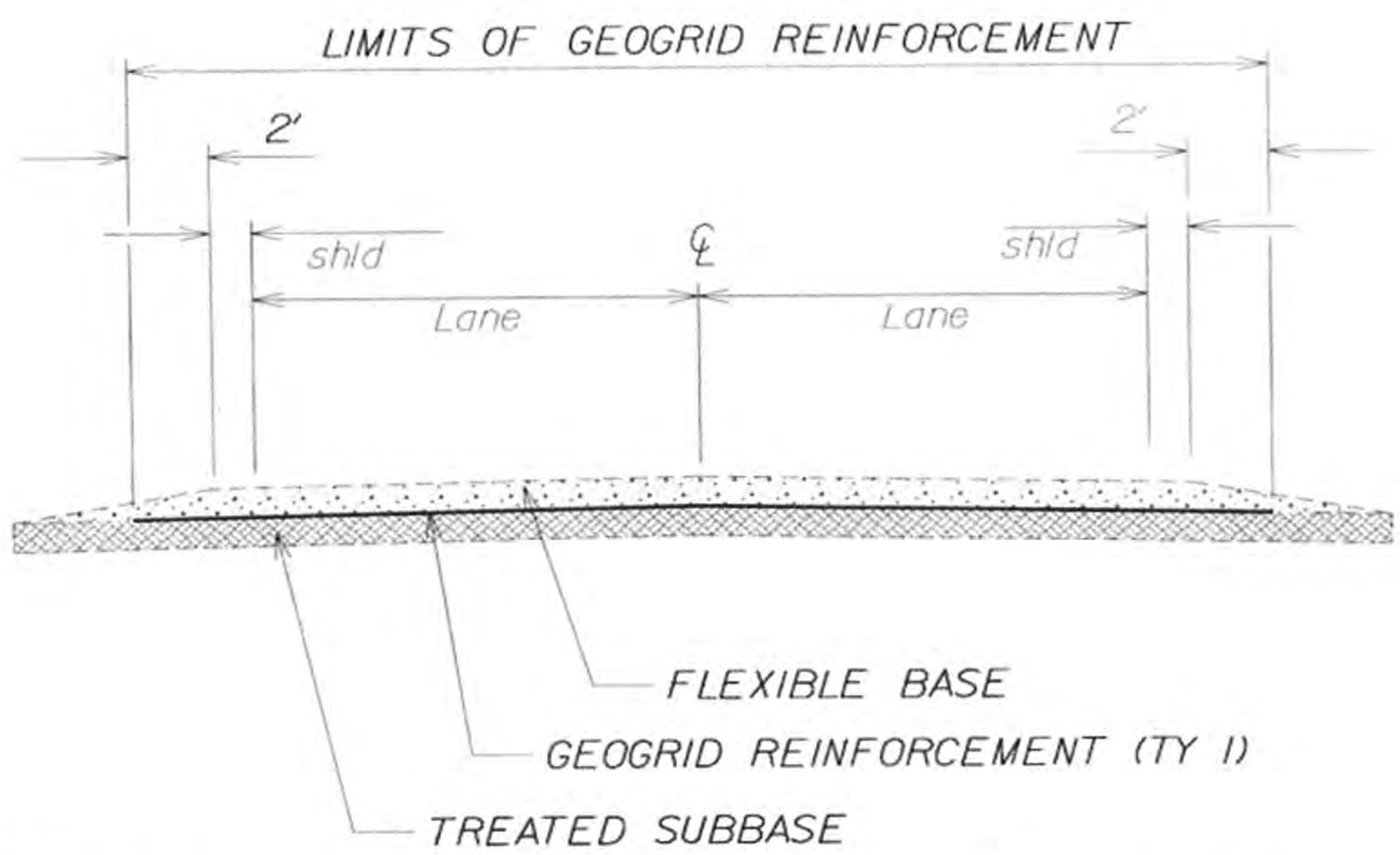


Figure 2.6. Geogrid Reinforcement over Expansive Soil (Schematic courtesy of Darlene Goehl, P.E.).

Moisture Control Methods

Vertical moisture barriers with impermeable geomembranes could reduce the moisture variation in expansive subgrade and then restrain pavement roughness (Jayatilaka et al. 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 in test sections at Bryan district.

Other Treatment Alternatives

Treatments of longitudinal cracking are primarily dependent on severity. For non-faulted cracks, the cracks can simply be sealed. For faulted cracks, a base repair may be necessary. If the problem is limited to the asphalt layer, grinding and milling is used. If the problem is limited to base layer, cement or lime treatment is used. Some TxDOT districts use Type-A hot-mix cold-laid (HMCL) "black base" for base repairs. Black base is an attractive material for use when repairs are needed in inclement weather (Sebesta 2005). If the problem is related to subgrade, treatment such as full depth patching is used.

Lack of adequate surface drainage is one of the critical factors leading to problems with expansive subgrade soils. Drainage systems reduce the time moisture is retained in the pavement system and minimize moisture change in the subgrade (Wanyan et al. 2010). Example of drainage system design for low volume roads can be found at Keller and Sherar (*2003*).

According to the North Carolina Department of Transportation (2010), the alligator cracking near the edge of the pavement can be avoided by strengthening the edge through patching, either partial-depth patching, full-depth patching or by edge widening. For the longitudinal cracks within 1 ft of the edge of the pavement, Walker et al. (2005) proposed that cracks can be repaired by filling or patching. They also pointed out that filling and sealing cracks, overlay or reconstruction can be used to reduce penetration of moisture and increase the strength of the pavement.

In New Zealand, Saleh (2006) mentioned that edge failures can be corrected by using stiff shoulders since they reduce the concentration of deflections, stresses, and strains on the top of the subgrade. Hearn et al. (2008) provided recommendations related to the edge failure of roads due to the slope stability (ground movement) near the edge. These recommendations were based on capacity analysis suggested by the Ministry of Public Works and Transport related to the road sectors. These recommendations were to:

- Improve landslide data collection and monitor the slope/road stability.
- Identify landslide and engineering geology.
- Assess risks of locations based on priority.
- Provide attention in design and construction techniques to improve slope stability and protection.

EXPERIENCE OF EXPANSIVE SOIL TREATMENTS IN TEXAS

The following case studies are examples of maintenance treatments to mitigate the distresses resulting from expansive soil.

Project 0-4573

In this research, an attempt was made to study the potential benefits of compost amendments to mitigate cracking in expansive subgrade. The main objective of this research was to investigate the effectiveness of using two types of composts as shoulder cover material in order to mitigate shoulder cracking. The attempt in this research was limited to soil treatment on paved shoulder only but not under the travel lanes pavement layers.

Two types of inexpensive recycled composts, Biosolids Compost and Dairy Manure Compost (DMC) were used to stabilize shoulder topsoils. Laboratory testing including one-dimensional swell test, linear shrinkage bar test and direct shear test were performed. Also, field monitoring at 17 sites constructed at State Highway 108 near Stephenville, Texas. In the field sites, the compost was mixed with the top soils at different proportions.

The study found that compost provided lesser shrinkage cracking of expansive shoulder than those observed from the control soil. Compost provided low moisture and temperature variations to the expansive soil when compared to control untreated soil. The study developed construction and compaction specifications procedures to blend compost with topsoil.

Project 0-4395

This project focused on examining maintenance techniques for repairs over expansive subgrades to develop a field guide for selecting effective repair treatments. The study indicated that geogrid reinforcement is an effective treatment for this type of distress, although crack filling, sealing and full depth patching can solve longitudinal cracking of the pavement over expansive soils in some cases. The following summarized the conclusion of the study:

- The optimal treatment of roughness distress, in most cases, is a surface patch.
- Use crack sealing for non-faulted longitudinal cracking.
- For faulted longitudinal cracks, a base repair may be necessary. Other effective treatments could be sealing the cracks and applying a surface level-up; or using reconstruction with geogrid reinforcement.
- For fatigue cracking, use of cement-treated provides the best repair life.
- Cracking because of aged HMA can be effectively treated with applying a new surface
- For structural problem, a quality flex base treated with 2 to 3 percent cement was found to have better performance than typical asphalt bases.

The research study clearly stated that that identifying the root cause of the distress is the key to select the most effective repair treatment.

Project 0-4829

Case studies at three pavement sites in SH7, FM 1774 and FM 1915 remarked the effectiveness of geosynthetic in improving pavement performance. However, design parameters and post construction performance evaluation in the field remained unclear to describe the mechanical effect of geosynthetic. Therefore, this research focused on the assessment of the effect of geosynthetic on the pavement structural section through determining the properties that contribute to enhance the performance and developing material specifications that incorporate the geosynthetic and soil properties.

This study summarized the TxDOT experience with the use of geosynthetics (geogrids and geotextiles) in reinforcement of pavement systems through district survey. The survey responses indicated that most of the cracking occurred in pavements when they were constructed over high PI clays. The insertion of geogrids (the mostly used application in TxDOT) in pavement with high PI clays has been evident to mitigate pavement cracking. As remarked by the study, there are two forces applied on the surfaces of the desiccation crack in the geogrid-reinforcement pavement: one is the shrinking stress in the soil, the driving force for the crack propagation; and the other is the geogrid-reinforcement force, which limits the crack growth. If the geogrid can reduce the stress intensity factor of the upper crack tip to a value that is below the fracture toughness of the base, the crack will stop developing upward to the pavement surface.

To investigating the mechanisms of longitudinal cracking in expansive clay subgrades due to volumetric change, the study also summarized moisture monitoring results in the subgrade under an instrumented FM2 section. Field measurements of gravimetric water content indicated that moisture fluctuations occur primarily along the drainage ditch with little moisture migration observed from the shoulder to the center of the pavement. The study conclusion was to use geogrid reinforcement to increase the stiffness of the soil near the edge of the pavement to withstand volume changes in the subgrade during moisture fluctuations.

Project 0-1772

This study offered a maintenance strategy selection plan for distressed chemically-treated bases and subbases using cement, lime and fly ash treatment. The presence of stabilized layers in a pavement greatly reduces the vertical subgrade pressure and improves pavement layer system stability. However, volume and thermal changes are the primary cause of distresses that affect pavements with chemically stabilized layers (George, 1968). These changes caused the load-induced shrinkage cracking at the surface of the stabilized layer and fatigue cracking at the bottom of pavement layers.

The most common distresses identified in this study were selected based on the district questionnaire responses from maintenance engineers including; transverse cracking, longitudinal cracking, rutting, alligator cracking, swell/roughness, and failures. The study used key factors to develop the maintenance strategy selection process based on the questionnaire responses including:

- predominant distress type;
- extent and severity;

- fast or slow (development of distress);
- traffic level or importance; and
- action if only localized, short-term repair, and long-term treatment

A field maintenance guide in the form of a computer program was developed to guide the user through treatment decision criteria to the treatment selection identified by the districts.

Project 0-4502

This project focused on mitigating the shrinkage cracking in cement-treated through the microcracking concept. This concept is based on introducing microcracks to the cement treated base at a short curing stage using vibratory roller. The study demonstrated that microcracking reduced the crack width the total crack length and reduced the risk of reflective cracking through the surface layers

Shrinkage cracking occurs when tensile stress in the base layer exceeds the tensile strength of the material. The study documented the major causes of shrinkage cracks due to cement stabilization in base layers. This included drying, which is the main cause of shrinkage in cement-treated bases. Other causes are due to base expansion restraint by subbase or subgrade friction; tensile strength of the base; contraction of material due to temperatures drop; and traffic loading (George 1968 and Bofinger et al. 1978).

The study recommended for maximum effectiveness a reduced strength mix design system with microcracking. Microcracking in the study field sites resulted in a 60 and a 64 percent decrease in average base modulus at with 4 and 8 percent cement content respectively (Figure 2.7).

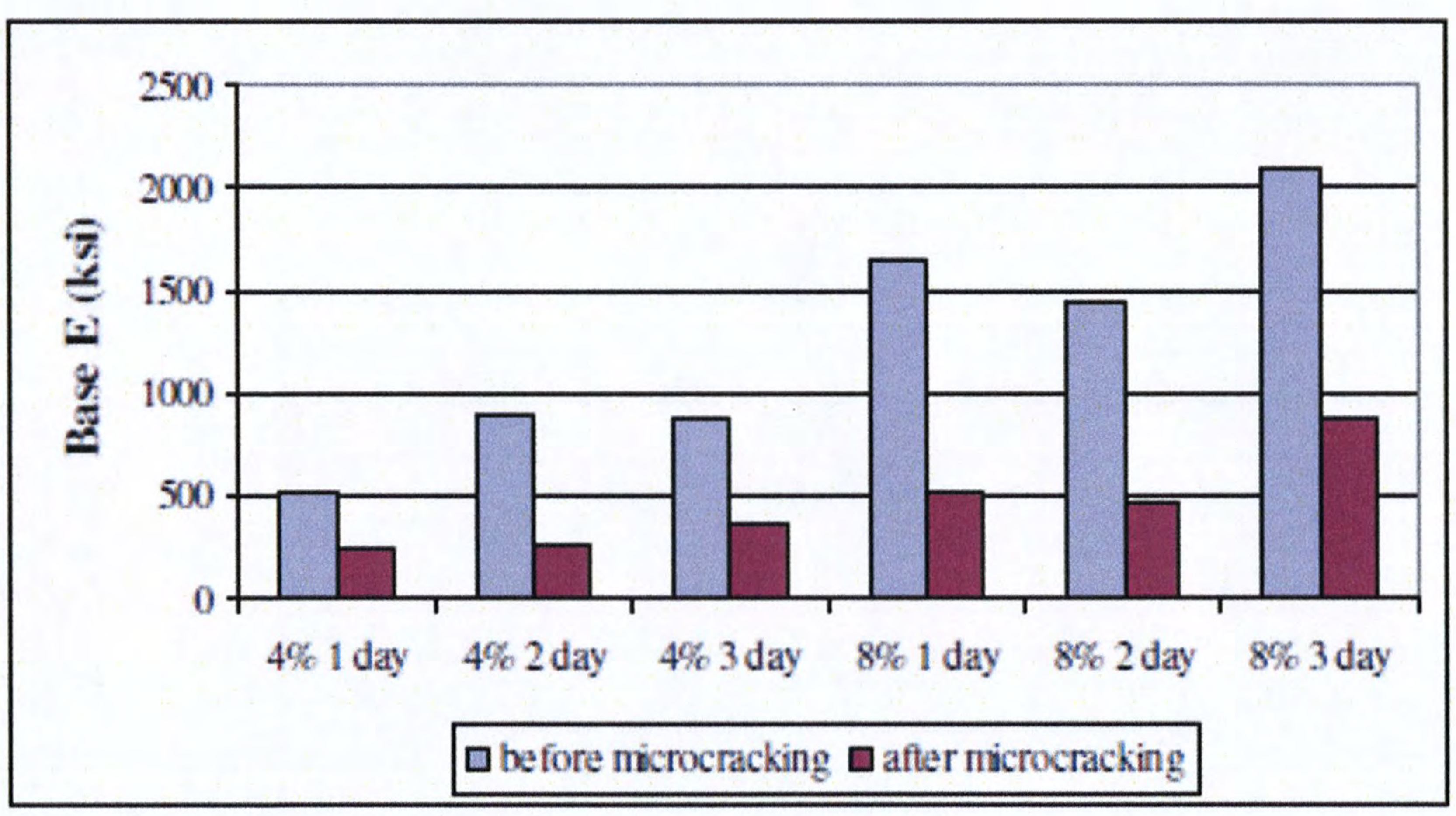


Figure 2.7. Illustrates the average base modulus immediately before and immediately after microcracking for the sections (Sebesta and Scullion 2004).

Monitoring performance of two test sites SH 47 and SH 16 and construction and monitoring controlled test site at the TTI's River Side campus revealed the following remarks from the field study:

- In the long run, higher cement content did not provide a significantly increased base modulus but result in more severe shrinkage cracking.
- Regardless of cement content, microcracking reduces the severity of shrinkage cracks in the base, and also total crack length.
- The portable falling wheel deflectometer (PFWD) was showing a promise for monitoring the microcracking process.
- An asphalt curing membrane was less effective at reducing cracking problems.
- Base moist curing without microcracking resulted in more severe shrinkage cracks that could promote reflective cracking later.
- The study suggested that early opening for traffic would cause no problem. Supported data after only 4 hours curing indicated that the average modulus was 362 ksi which is sufficient for in-service trafficking.

Project 0-4396

The research focused on best practices strategy to define and implement best practices for repair and stabilization of pavement naturally-occurring edge drop-offs on low-volume roads. Edge drop-off as defined in this project is the difference in vertical elevation between the paved surface and unpaved shoulder surface adjacent to it. This type of distresses has maintenance, safety and liability issues for TxDOT. This distress is affected by the narrow road width and absence of shoulders, traffic volume and type, and adverse environmental conditions (Figure 2.8).

Figure 2.8. Pavement edge drop-off.

Examples of the documented treatment of edge drop-offs as suggested by district questionnaire are:

- Raw Edging: Sealing hairline cracks to enliven surfaces at the edge of the pavement. It is a commonly done after "Edge Repair" or "Pulling Shoulders" as a preventive measure,
- Edge Seal/ Strip Seal (seal coat/chip seal) typically done for a one- to two-foot strip at the edge of the pavement instead of full width,
- Promoting growth of desirable vegetation for shoulder maintenance or reshaping operations,
- Conventional delineators to control traffic and help keep vehicles off the pavement edge.
- Reshaping (Pulling) shoulders with on-site material,
- Hand-patching localized broken pavement edges,
- Cutting high edges,
- Replenishing the pavement edge with borrow materials.

Road widening as suggested by the study is a cost-effective edge repair solution. This can target the main causes of drop-off (e.g., narrow roads without shoulders along with abusive traffic and environmental factors). Study reported that the districts experience with rebuilding pavement edges is a more rigorous process than hand patching.

Project 0-5569

The goal of this research project was to develop new accelerated testing methods to minimize the time required for soil specimen preparation, curing, and moisture conditioning to complete the design process.

The study found that the static compacted method suggested in the AASHTO T-307 for preparing fine-grained soil specimens provided specimens with uniform and the moisture conditioning is accomplished more rapidly and uniformly. Simple, low-cost and fast test methods to determine chemical characteristics of the high PI soils were recommended to substitute more costly and time consuming methods. Those tests were; The Cation Exchange Capacity, Specific Surface Area, Total Potassium, Exchangeable Potassium and Reactive Alumina. Finally, back pressure and vacuum saturation tests were also recommended by the study to be employed as a substitution for current TxDOT specifications to complete the moisture conditioning of stabilized specimens.

SUMMARY

Longitudinal (faulted) and fatigue cracking particularly close to the edge of the pavements is one of the main distresses in narrow low volume roads built over high plasticity soils. These distresses are caused by many reasons including lack of lateral support, base failure, expansive soil and moisture infiltration into pavement structure and aging of asphalt surface. The most effective treatment as documented in research are base reinforcement with geogrid, soil chemical stabilization with lime or cement, installation of vertical moisture barrier, edge sealing for asphalt pavement cracking and incorporation or widening shoulders. The key to a successful treatment is to identify the root causes of the failure. For instance, longitudinal cracking due to surface aging should be treated with crack sealing for expansive soils sites involves cement treated base or base reinforcement with geogrid.

The availability and cost of materials can vary widely between TxDOT districts. Furthermore, the traffic control requirements for the repair work can vary significantly. Because of these reasons, the most cost-effective repair method for identical distresses may differ depending on location.

CHAPTER 3
SURVEY OF TXDOT DISTRICTS

INTRODUCTION

The purposes of the survey of TxDOT districts are to identify the causes and effective treatments of edge failures and provide the sections of field testing. The survey instrument, completed surveys, and graphical survey summary report are included in the appendices. The survey of TxDOT districts discussed herein was part of Task 2 of this project. The purpose of the survey was to identify the districts where edge failures had been a persistent maintenance problem of FM roadways, identify innovative treatments for edge failures (short of re-building sections and adding shoulders), and to identify sections of roadway for follow-up field visits and possible inclusion for field and laboratory testing. Lamar University led the survey task.

Although the survey was developed and conducted for the above purposes, the sections for field and lab testing were subsequently selected based on different failure modes, distress types, treatment methods and districts.

The details of the survey results are included in Section 2, Analysis of Survey Results. In general, 19 of the 25 TxDOT districts responded to the 19-question multi-answer survey (see the survey instrument in Appendix A). All districts except Odessa reported that they experience persistent problems with edge failures on FM roadways. Lack of shoulder was the cause reported most often, and the most common treatment was patching. While the focus of the survey was on identifying innovative treatment methods for edge failures, much of the innovative work occurs during section re-building, to include section widening to provide a 2 ft or larger shoulder. The process of developing the survey helped the team to identify and narrow an approach to selecting sections of roadway for further testing. This approach is identifiable in question 19 of the survey. The survey provides a good record of the edge failures experienced by the different districts, the different causes and many treatments. Several sections of roadway are identified with successful and sometimes innovative treatment for edge failures.

DISTRICT CONTACTS

One person from each district was contacted and asked to participate in the survey. The contact list was provided by the project director as shown in Table 3.1. The contact persons and respective districts are listed below. They were both very helpful and knowledgeable, and the project team thanks them for their efforts.

The districts are grouped by zone. Figure 3.1 shows Texas county map showing counties, districts, and zones. The zones are distributed based on the climatic and soil conditions in Texas.

At any rate, the zone information was included along with district information in the graphical survey summary report (included in Appendix B).

Table 3.1. List of contacted engineers to fill in the survey forms.

District	Contact	District	Contact
Abilene (ABL)	Brian Crawford	Lufkin (LFK)	Paul Montgomery
Amarillo (AMA)	Mike Taylor	Odessa (ODA)	Carolyn Dill
Atlanta (ATL)	Miles Garrison	Paris (PAR)	Mykol Woodruff
Beaumont (BMT)	Jackie Anderson	Pharr (PHR)	Pedro Alvarez
Brownwood (BWD)	Gary Humes	San Antonio (SAT)	John Bohuslav
Bryan (BRY)	Terry Paholek	Tyler (TYL)	Michael Schneider
Childress (CHS)	Darwin Lanford	Waco (WAC)	Michael Heise
Corpus Christi (CRP)	Victor Pinon	Wichita Falls (WFS)	Tim Hertel
Laredo (LRD)	Danny Magee	Yoakum (YKM)	Carl O'Neill
Lubbock (LBB)	Ted Moore		

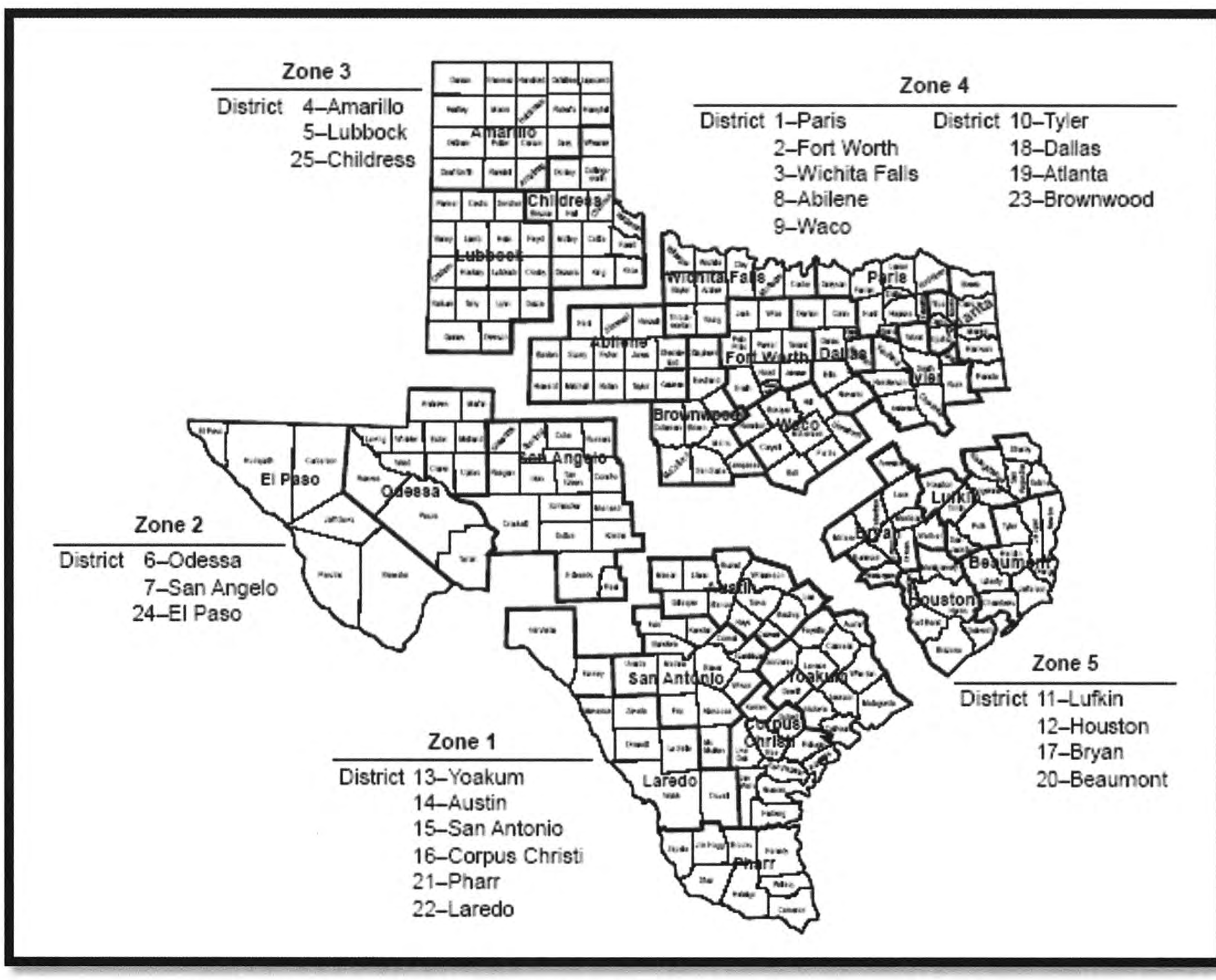


Figure 3.1. TxDOT Districts Grouped by Climatic Zone.

SURVEY INSTRUMENT

The project team collaborated to develop the survey instrument. The intent of the original survey idea was to develop an instrument for data collection by telephone. Rather than attempt to collect data section-by-section from each district, the team tried to organize the survey instrument so that a general picture of the edge failure problems at the districts could be collected. Section-by-section data collection was planned in a later step during site visits. Therefore questions were generalized and suggested multi-part answers were provided along with check boxes.

The finalized survey instrument contained 19 questions and was dated December 22, 2009. The team anticipated making changes to the survey instrument based on feedback during usage. Feedback is included in part in the graphical survey summary report, and on the actual survey instruments, which are included in the appendices. The survey instrument dated December 22, 2009, is included in Appendix A.

ANALYSIS OF SURVEY RESULTS

Question 1 asked, what is your current position at TxDOT? Most participants reported they were director of maintenance and director of operations. Question 2 asked, how long have you worked for TxDOT. The years of experience of the participants ranged from 4 to 38 years, and the average time with TxDOT was 23 years. Question 3 asked the responder to describe his/her role in routine maintenance activities. The role of the participants in the routine maintenance activities includes overseeing maintenance operations, engineering design, budget oversight, and procedure guidance. Fifty-five percent listed their role as overseeing maintenance operations.

Question 4 asked whether the district was experiencing edge failures. Out of the 19 districts, 18 districts experience edge failures. The only district not experiencing edge failures is Odessa.

Question 5 asked, what are the main forms of edge failures in the district? Forty-six different forms of failure were identified. Out of the 18 districts, 14 districts are experiencing edge failure in the form of edge deterioration, which is the most common form of failure (30 percent). The other common forms of edge failure are cracking, shoving and pop outs (17 percent); and, combination of cracking and rutting (17 percent). Sixty-four percent of the edge failures occur in these three forms.

Question 6 asked, overall, how do you evaluate the severity of these distresses? The severity of distresses was distributed 31 percent, 38 percent, and 31 percent, respectively, for high, medium, and low.

Question 7 asked, how far from the pavement edge does the failure generally occur? Most districts (10 districts, 50 percent) have edge failure within a distance of 0 to 1 ft from the pavement edge, followed by 2 to 3 ft (5 districts, 25 percent), and 1 to 2 ft (4 districts, 20 percent) from the pavement edge. From design aspect, this indicates an additional 3 ft shoulder may solve all the edge failure problems and a 2 ft shoulder may solve 70 percent of edge failure problems (Note: This is only from design aspect, not from the consideration of other aspects such as materials and environmental factors).

Question 8 asked, what is the type and width of shoulder in the area of edge failure? The data indicates that most of the FM roads in Texas (83 percent) do not have paved shoulders.

Question 9 asked, what are the possible reasons for edge failures in the district? The most common cause of edge failure of FM roads is insufficient pavement width and lack of lateral support such as shoulder (33 percent). Other common causes for edge failures are aging of asphalt pavement surface (13 percent), moisture entrapped into subgrade and pavement layers (11 percent) and high temperature and dryness of subgrade material (9 percent).

Question 10 asked, what are the soil and base material types in the district. The majority of the soil is clay and expansive clay (51 percent), followed by sandy soil (30 percent), and then silty soils (14 percent). The most common base materials are limestone (50 percent) and sand/gravel (37 percent).

Question 11 asked, does the district have sites with edge failures proximal to poor drainage or flood areas? Fifty-eight percent of the districts have edge failure problems in proximity of poor drainage and flood areas, which suggests that poor drainage and flood areas increase the risk of edge failures.

Question 12 asked, what are the most important causes of edge failures in the district (material, design, environmental causes)? The most common cause of edge failure based on the material criteria is subgrade which consists of 52.9 percent of total observations. The edge failure due to the subgrade is probably primarily caused by expansive clay and soft spots/clay. With regard to design, the most frequent cause is lack of shoulder, which represents 57.6 percent of total observations. Finally, with regard to environmental causes, the most frequent is moisture or rain, 59.1 percent of total observations. In summary, all 18 districts experience edge failures most often due to weak/expansive subgrade material, lack of lateral support, and moisture/rain.

Question 13 asked, does the district have a threshold to decide when the treatment begins on edge failures? Most districts do not have a threshold to decide when treatment begins. Only 11 percent of the districts have a threshold.

Question 14 asked, what are the current rehabilitation methods for edge failures in the district? The most often used methods are partial depth patching, full depth patching, crack sealing/filling and subgrade stabilization using hydrated lime/cement. These are distributed 22.7 percent, 19.7 percent, 18.2 percent and 13.6 percent, respectively. These account for 75 percent of the total methods used by the districts.

Question 15 asked, what other secondary routine maintenance work is applied to edge failures? Secondary maintenance work was reported to consist primarily of shoulder blading and repair, and ditch shaping and cleaning. These consist of 33.33 percent and 29.42 percent of total observations, respectively. Shoulder rebuilding and erosion repair each consists of 13.73 percent of total observations.

Question 16 asked, are there any rehabilitation techniques used not mentioned here? Two techniques used by districts, but not mentioned in the survey were; remove and replace base and backfill low edges.

Question 17 asked, what is the effectiveness of the current treatment? Does the crack reappear? Most cracks reappear after the treatment. Fifty-two percent reported that cracks reappear just after one year from treatment (This includes the 19 percent that reported that cracks reappear after 6 months of treatment.). The responses indicate the need for a more effective treatment method for edge failures.

Question 18 asked, how does the district evaluate the effectiveness of edge failure repairs? The majority of districts evaluate repair effectiveness by visual inspection. About 62.1 percent reported using visual inspection, while pavement condition scores were used by 31.0 percent.

Question 19 asked, with regard to edge failures, does the district have sections with no failures, failures and successful repairs? Of the 18 districts 5 reported having sections for treatment effectiveness comparison. After discussion with the new project director, a suggestion was to contact particular districts for existing projects with control and repaired sections. The projects selected in this study covers, different treatments, pavement conditions (annual daily traffic [ADT], soil, layer structure), geographic zone (districts) and performance life. The following sites have been identified, FM 1915 and FM 2 in Bryan District, FM 471 in San Antonio District, FM 734 in Austin District and FM 1293 and FM 787 in Beaumont District. Details on treatment, locations, traffic, service life, etc. are shown in Chapter 4.

SUMMARY AND DISCUSSIONS OF SURVEY RESULTS

A total of 19 districts responded to the survey. All districts except Odessa reported that they experience persistent problems with edge failures on FM roadways.

Forty-six different forms of failure were identified by key TxDOT maintenance personnel with an average of 23 years of experience. Out of the 18 districts, 14 districts are experiencing edge failure in the form of edge deterioration, which is the most common form of failure (30 percent). The next most common forms of edge failures are cracking, shoving and pop outs (17 percent) and a combination of cracking and rutting (17 percent). They are followed by soft spots (10 percent). Seventy-four percent (74 percent) of the edge failures occur in these four forms of edge failure.

Severity for edge failures in the survey shows an even distribution between low, medium and high in TxDOT. According to the survey, 83 percent of the FM roads do not have paved shoulders, which is believed to be one of the major reasons for edge failure of FM roads. From all the surveys, a total of 52 causes are identified as possible reasons of edge failures. Based on the results, the most common cause of edge failure of FM roads is insufficient pavement width and lack of lateral support such as shoulders. These consist of 33 percent of all causes.

Most districts (10 districts, 50 percent) have edge failure within a distance of 0 to 1 ft from the pavement edge, followed by 2 to 3 ft (5 districts, 25 percent), and then 1 to 2 ft (4 districts, 20 percent) from the pavement edge. From a design point of view, this indicates that an additional 3-ft shoulder may solve all the edge failure problems and a 2 ft shoulder may solve 70 percent of edge failure problems.

In most of the districts surveyed, soils consist of clays (51 percent), some expansive and sandy soils (30 percent). For the base material, fifty percent or responses have limestone, and thirty-seven percent (37 percent) have sand or gravel. Expansive clay covers eight districts including YKM, CRP, LBB, PAR, WAC, BRY, BMT, and ATL. This implies that the major cause of pavement failure in these districts is attributed to expansive clay soil. If sulfate exists in these soils engineers need to use TxDOT specification manual (2004) items 260 and 263 to determine the percent use of lime for soil treatment. The most common cause of edge failure based on the material cause is due to subgrade which consists of 52.94 percent of total observations.

More than half of districts surveyed experienced edge failure due to water intrusion or drainage. Some experienced temperature induced dryness problems as well. The most common cause of edge failure with regard to environmental criteria is moisture or rain consisting of 59.1 percent of total observations. This problem may be solved by better drainage design. In terms of design causes, lack of shoulder is the most common cause of edge failure consisting of 57.6 percent of total observations. As to material, the subgrade layer is identified as the most common cause of edge failures and represents 52.9 percent of total observations, followed by the base layer consisting of 29 percent of total observations.

Currently 89 percent of the districts begin to treat edge failures without any quantitative threshold. BMT and PHR districts use 1.5 in. and 2.0 ft drop-offs, respectively, as thresholds. The most often used rehabilitation methods are partial depth patching, full depth patching, crack sealing/filling and subgrade stabilization using hydrated lime/cement. These make up about 75 percent of total methods reported in all districts.

About 90 percent of cracks will re-appear after repairing, according to the survey results. Fifty-two percent of total survey reveals the fact that cracks reappear just after one year from treatment. Therefore, a more effective and durable treatment method is needed for edge failure repairs. Repair effectiveness measures are primarily (93.1 percent) based on visual inspection and pavement condition scores.

SITE SELECTION

Another objective of the survey was to identify rehabilitation treatment projects applied in the districts to address pavement cracking distresses. Due to district budget constrain, it was not possible to find rehab project to treat primarily edge cracking. Districts choose their projects based on the severity and types of combination of distresses in the pavement. Therefore, projects that have considered longitudinal cracking including those close to the edge were chosen in the study.

Data analysis from the survey was used to identify districts with different edge failure modes, treatment methods, soil types and climatic conditions. Information and locations of sites with different pavement surface types (e.g., asphalt concrete, seal coat) and ADT were obtained through contacting the district offices. As previously mentioned, moisture infiltration has shown the most critical environmental condition that lead to pavement edge failure, therefore, districts with high rain fall (e.g. BMT and BRY) were considered. Also, as subgrade type contributes to the pavement failure, districts located in expansive soil zones (e.g. BRY, AUS and SAT) were considered. Finally, the insufficient lateral support and lack of shoulder has shown to be a major cause of failure, therefore, sites treated with widening the shoulder were also considered (e.g. BMT). After consultation with the project director and project monitoring committee the selection of four sites in Bryan, Beaumont, San Antonio, and Austin have been chosen. It is worth noting that these sites may not represent the whole conditions in the state. They were chosen because they were available for investigation during the course of the study. Details of the sites are described in Table 3.2.

Table 3.2. Selected Projects for Field/Laboratory Evaluation.

Road ID	District	Surface type	Soil type	Perform-ance life (years)	Treatments	Failure mode	Traffic (ADT)
FM 471 (Bexar county)	San Antonio	ACP	Expansive clay	3	Cement-treated base and asphalt overlay	Base failure	11,200 (high ESALs)
FM 1915 (Milam county) & FM 2 (Grimes county)	Bryan	Seal coat	Expansive clay	14	lime-treated subgrade and Geogrid	Severe Longitudinal cracking	400
FM 734 (Travis county)	Austin	ACP	Expansive clay	10 yrs. (lime-treated) and 3yrs. (cement - treated)	Lime-treated subgrade; and cement-treated base	Longitudinal and transverse cracking	7400
FM 1293 & FM 787 (Hardin county)	Beaumont	ACP	Sand	5	Widen the pavement with paved shoulder	Longitudinal edge cracking	1500

ACP: asphalt concrete pavement

ADT: average daily traffic

CHAPTER 4
LABORATORY AND FIELD TESTING PROGRAM

INTRODUCTION

This chapter describes the lab and field testing results for the materials obtained from the project sites. There are six sites in four districts evaluated by the research group. Data for four sites were collected in conjunction with the district office assistance. One of the sites, FM 2, was included in this evaluation since it was monitored by the Bryan District. At each site, one control section and at least one repaired section were identified. Table 4.1 describes the identification of each section. Letter "C" refers to Control section, "W" refers to Widened, "R" refers to Reconstruction, and "O" refers to Overlay.

Table 4.1. Identification for the Field Sites.

District	Road	Description	ID
Bryan	FM1915	Reconstruction with geogrid #1	1915-R1
		Control	1915-C
		Reconstruction. with geogrid #2	1915-R2
	FM2	Reconstruction with geogrid/geotextile and lime stabilization	2-R
San Antonio	FM471	Control #1	471-C1
		Control #2	471-C2
		Reconstruction w/ cement treatment	471-R
		Overlay 1	471-O1
		Overlay 2	471-O2
Austin	FM734	Reconstruction w/geogrid and lime treatment	734-R1
		Control with Lime treatment	734-C
		Reconstruction (cement treatment+ subbase)	734-R2
Beaumont	FM1293	Widened	1293-W
	FM 787	Control	787-C
		Widened	787-W

This chapter will cover the limited testing results of subgrade and base layer materials along with field investigation using falling weight deflectometer, ground penetration radar, and dynamic cone penetrometer. The testing program in this study was implemented to evaluate the effectiveness of the repair in Bryan, San Antonio and Austin districts to alleviate the distresses related to expansive soil and in Beaumont district to diminish the edge failure. The field and laboratory testing in this project were performed in all sites except FM2, in which the testing data were obtained from Bryan district records and research report 0-4829. Moreover, testing at the reconstructed section 734-R2 was limited to non-destructive testing by penetrating radar only due to the historical frequent failures in this section.

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 are measured by a set of seven geophone sensors. Prior to perform asphalt coring and sampling, the FWD was performed along the travel lane in each direction and the data sampling rate was every 0.1 mile.

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. The PAVECHECK program developed by Liu and Scullion (2009) was used in this study.

Dynamic Cone Penetrometer (DCP): Provides indirect measurements of base and subgrade layer stiffness using an empirical correlated equation. The DCP was attempted to obtain layer moduli from the DCP index which is based on the average penetration depth resulting from one blow of the hammer using a given equation:

$$M_r\,(\text{psi}) = 2555(292/DCPI^{1.12})^{0.64} \qquad (4.1)$$

Where DCPI is in mm/blow. This equation is provided as an option in the mechanistic-empirical pavement design guide (M-E PDG) program to estimate layer modulus when DCP data are available. Although DCP data is highly dependent on the testing spot condition, it can be used as a rough indicator of layer moduli.

Laboratory testing was concurrently performed to characterize the material properties from control and repaired sections to correlate with observed failures at the sites and to investigate the cause of failure. Table 4.2 shows a description of the laboratory testing. Laboratory testing was performed by the materials labs at UTSA and TTI.

FM 1915

FM 1915 is located in Milam County of Bryan District. As an initiated effort of the Bryan District to rehabilitate rural FM roadways using geogrid reinforcement, the test sections on FM 1915 were constructed in 1996 from the Little River Relief Bridge to 2.5 miles its west as shown in Figure 4.1. All sections have 10 inches lime treated subbase (5 percent lime) and a seal coat surface.

Table 4.2. Summary of Laboratory Testing Programs.

Test Name	Test Method	Material
Moisture-Density	Tex-113-E	Base / subgrade
Atterberg limit	Tex-104E and 105E	Subgrade
Sieve analysis	Tex-110-E	Base / subgrade
Swelling	3D-Swell*	Subgrade
Shrinkage	Tex-107E	Subgrade
Moisture susceptibility	Tube suction**	Base
Soil-water characteristic curve	Pressure plate ASTM D 6836-02	Subgrade
Unconfined compressive strength	ASTM D 2166-91	Base / subgrade
Sulfate concentration	Tex-145E	Subgrade

*Test was conducted in accordance with the procedure proposed by Harris (2008).

**Test was conducted in accordance with the procedure proposed by (Barbu and Scullion, 2006).

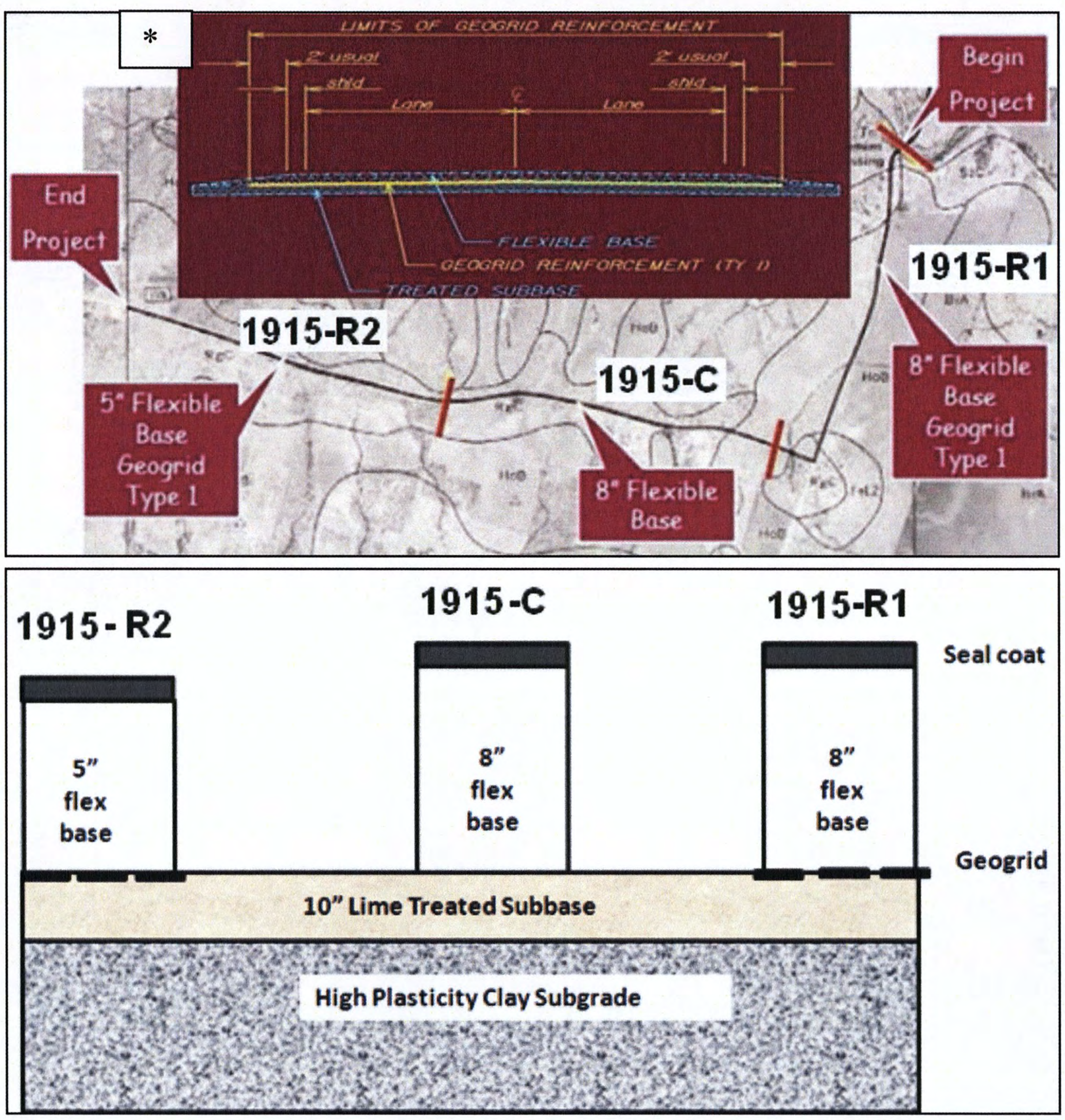


Figure 4.1. FM 1915 Test Sections Layout and Layers Thicknesses. (*Schematic courtesy of Darlene Goehl, P.E.).

Site Condition and Field Testing

The GPR data on sections 1915-R1 and 1915-C (Figure 4.1) showed higher variability in reflections compared to 1915-R2. With respect to layer thickness analysis, researchers estimated 1 in. of surface layer, 7 to 8 in. of base, and 8 to 10 in. of subbase layer from the GPR and the coring measurements. Details of field visual survey (Tables C-1 to C-3) along with captured GPR images (Figures C-1 to C-3) can be found in Appendix C. The results indicated that the control section (1915-C) exhibited more deteriorated areas with a higher number of distresses observed. However, geogrid reinforced section 1915-R1 also revealed severe longitudinal cracking. Section 1915-R2 was found to perform the best, as indicated by the shortest length of longitudinal cracking measured.

The FWD backcalculation was also conducted to gauge the effectiveness of geogrid reinforcement. The results indicated that geogrid reinforced sections generally yielded higher layer moduli compared to the control section as presented in Table 4.3 and 4.4.

Table 4.3. Summary of Layer Stiffness Using DCP on FM 1915.

4. Section	5. Layer	6. Mr (ksi)
1915-R1	7. Base	8. 141.8
	9. Subbase	10. 71.3
	11. Subgrade	12. 11.7
1915-C 13.	14. Base	15. 41
	16. Subbase	17. 32.5
	18. Subgrade	19. 8.5
1915-R2	20. Base	21. 95.4
	22. Subbase	23. 71.3
	24. Subgrade	25. 28.1

Table 4.4. FWD Backcalculation Results of FM 1915.

Section	Average Layer Moduli (ksi)				Absolute Error/Sensor
	Surface	Base	Subbase	Subgrade	
1915-R1	200.0	190.4	88.6	12.6	8.37
1915-C	200.0	147.1	57.0	11.1	4.75
1915-R2	200.0	197.0	127.5	16.6	8.25

Laboratory Testing

Material sampling was performed at each section to obtain base and subgrade materials using mechanical auger as illustrated in Figure 4.2. Sufficient samples were collected to perform the laboratory testing in Table 4.2. The sampled soils from FM 1915 were all clay, classified as highly plastic soils. Particularly, the 1915-R1 exhibited high value of PI of 55.8, considered to be the primary cause of soil movement and higher FWD deflections. The field visual survey concurred with the above observation and indicated a significant damage despite the geogrid reinforced treatment. Table C-4 summarizes the laboratory test results in Appendix C.

Figure 4.2. Material Sampling using Auger.

Figures 4.3 and 4.4 indicated that the subgrade of sections 1915-R1 and 1915-C was more prone to shrink in higher extent than that in section 1915-R2. This seems to be consistent with GPR data interpretation, FWD and DCP 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. Swelling test protocol states that the lime treatment should reduce 3-D swell to 7 percent or less. From this perspective, the soils in sections 1915-R1 and 1915-C are required to be stabilized to prevent further damage.

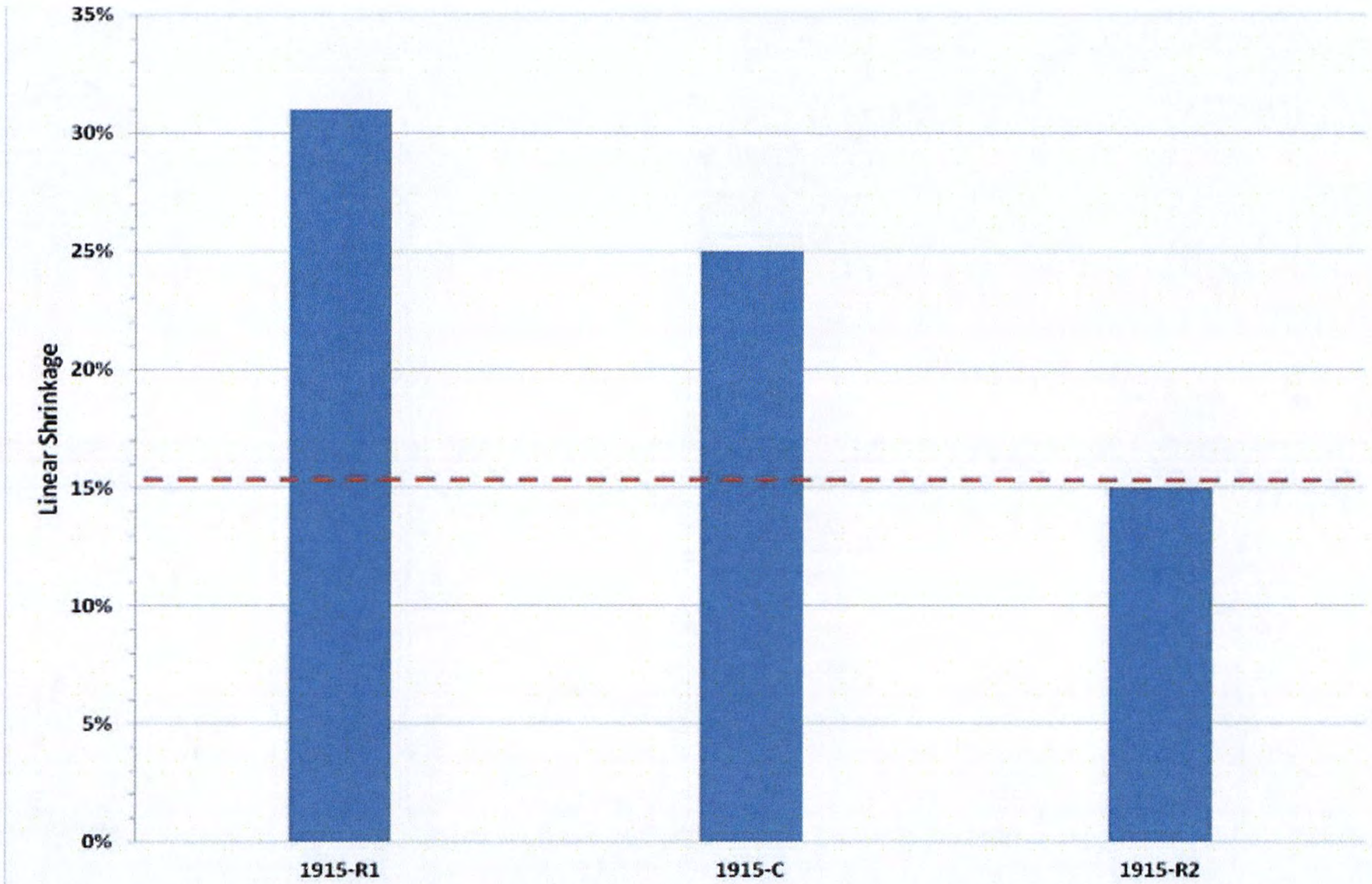


Figure 4.3. Shrinkage Test Results of FM 1915 Subgrade.

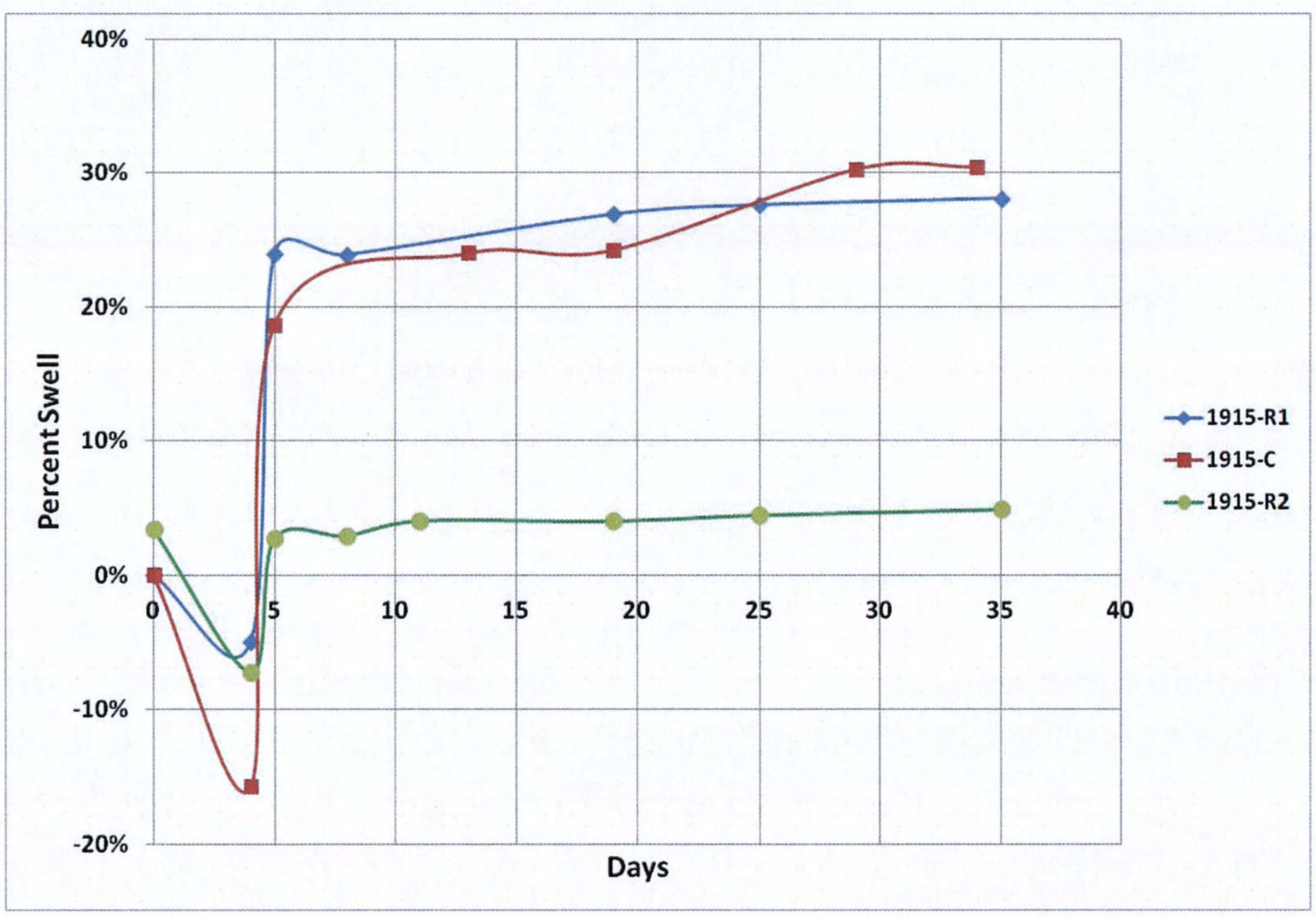


Figure 4.4. Variation of Percent Swell versus Time of FM 1915 Subgrade.

The sulfate content was measured through a colorimeter following the Tex-145-E procedure. Chen et al. (2009) employed this test to identify cause of soil heaving. The test results showed that the sulfate content was not significant for all the tested soils. The pressure plate test (Figure 4.5) revealed that the variation of moisture content was not sensitive to the change of matric suction. This suggests 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.

The tube suction test on the base material revealed a dielectric value (DV) slightly over 16 after 72 hrs. of soaking as shown in Figure 4.6. This figure indicated that the base material can be classified as high moisture susceptible material according to the tentative guideline provided by Barbu and Scullion (2006).

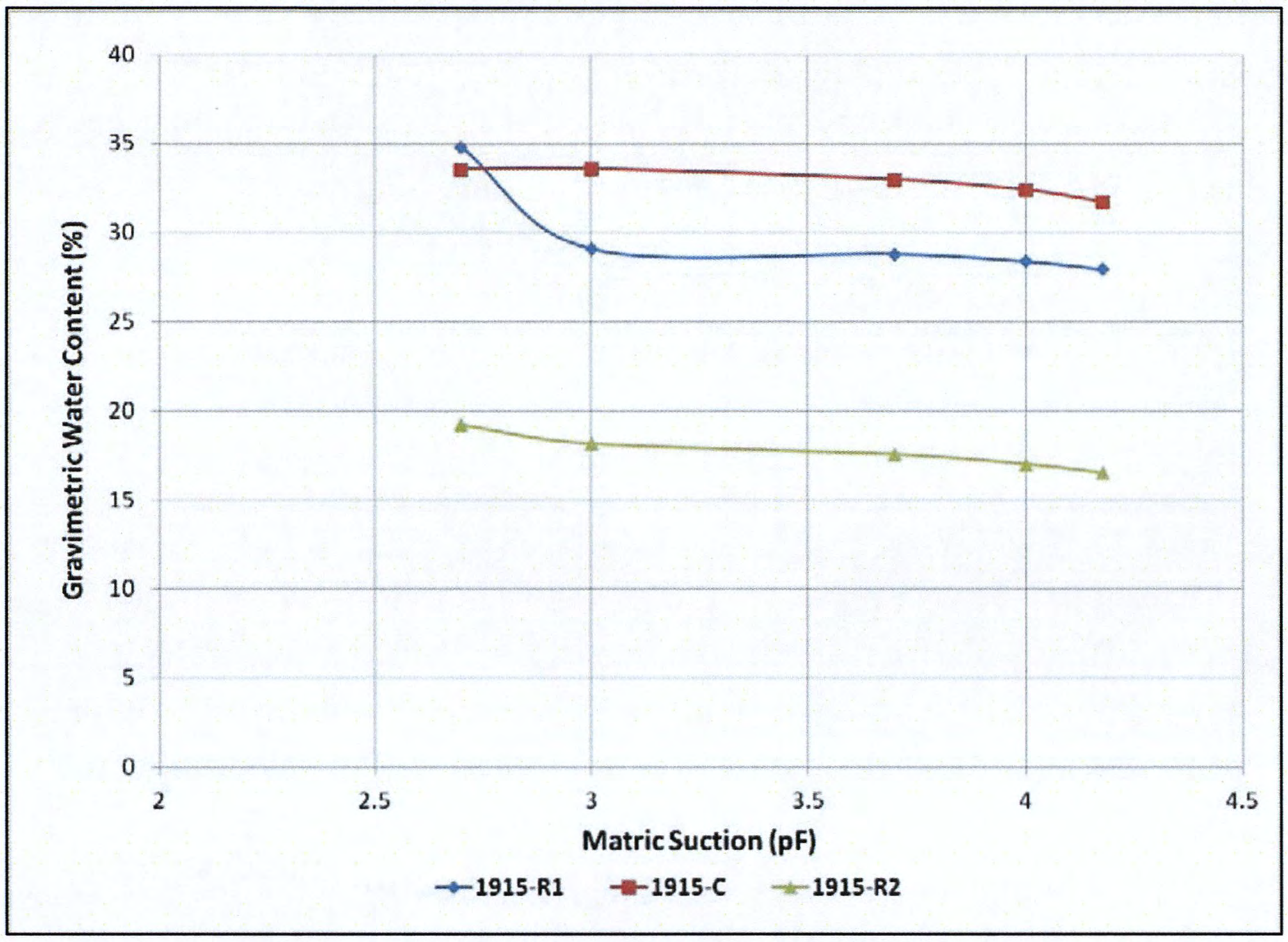


Figure 4.5. Soil Water Characteristic Curves of FM 1915 Subgrade.

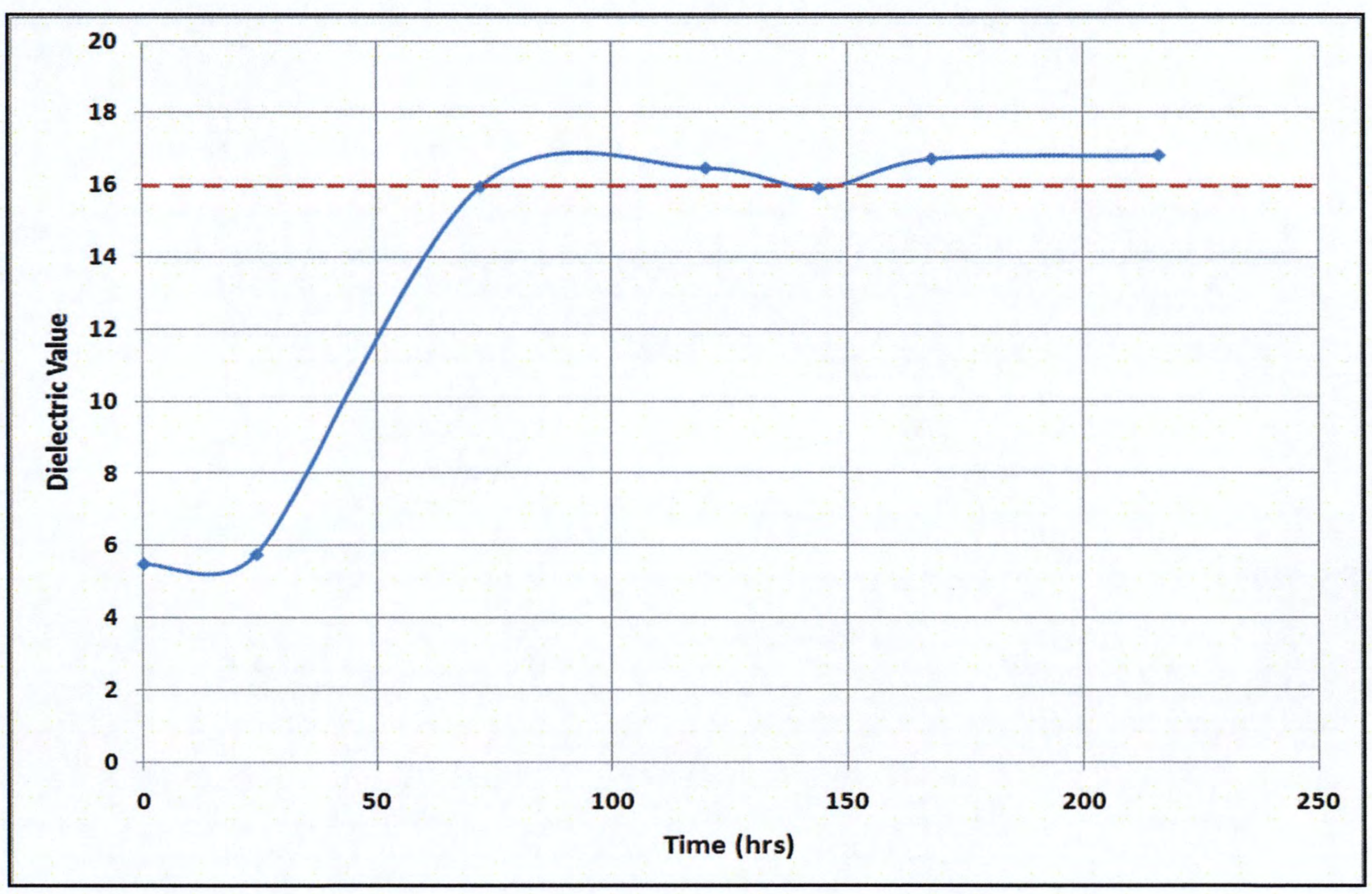


Figure 4.6. Tube Suction Test Results of FM 1915 Base.

Summary of FM 1915

The geogrid reinforcement along with lime stabilization of the subbase layer seems to be limitedly effective in controlling the longitudinal cracking. The soil properties such as plasticity index, shrinkage, and swelling potential are considered crucial in evaluating geogrid-reinforced pavement performance. The DCP and FWD data interpretation generally indicated higher base and subbase layer moduli of geogrid reinforced sections (1915-R1 and 1915-R2) compared to the control section. However it should be also noted that the better subgrade condition of 1915-R2 in terms of shrinkage, swelling, and PI appears to be mainly contributed to the best performance among three segments evaluated. Researchers are of the option that further investigations are needed to gauge the effectiveness of geogrid reinforcement on poor subgrade soil having extremely high PI.

FM 2

The TxDOT research project 0-4829 established a field monitoring program for FM 2 located at Grimes County in Bryan District to investigate the effect of geosynthetics on mitigating longitudinal edge cracking as shown in Figure 4.7. Analysis involved a comparison of the performance of reconstructed pavement which is composed of 8 different rehabilitation schemes as illustrated in Figure 4.8. TxDOT is still monitoring this site to evaluate the effectiveness of the geosynthetics as a maintenance option. The research team obtained the FWD data from the Bryan district office in August of 2009 prior to the beginning of this study. In addition, DCP and GPR tests were conducted during this study. Table C-5 summarizes the laboratory test results characterized from project 0-4829. As presented, this route is mainly composed of high plasticity clay soils.

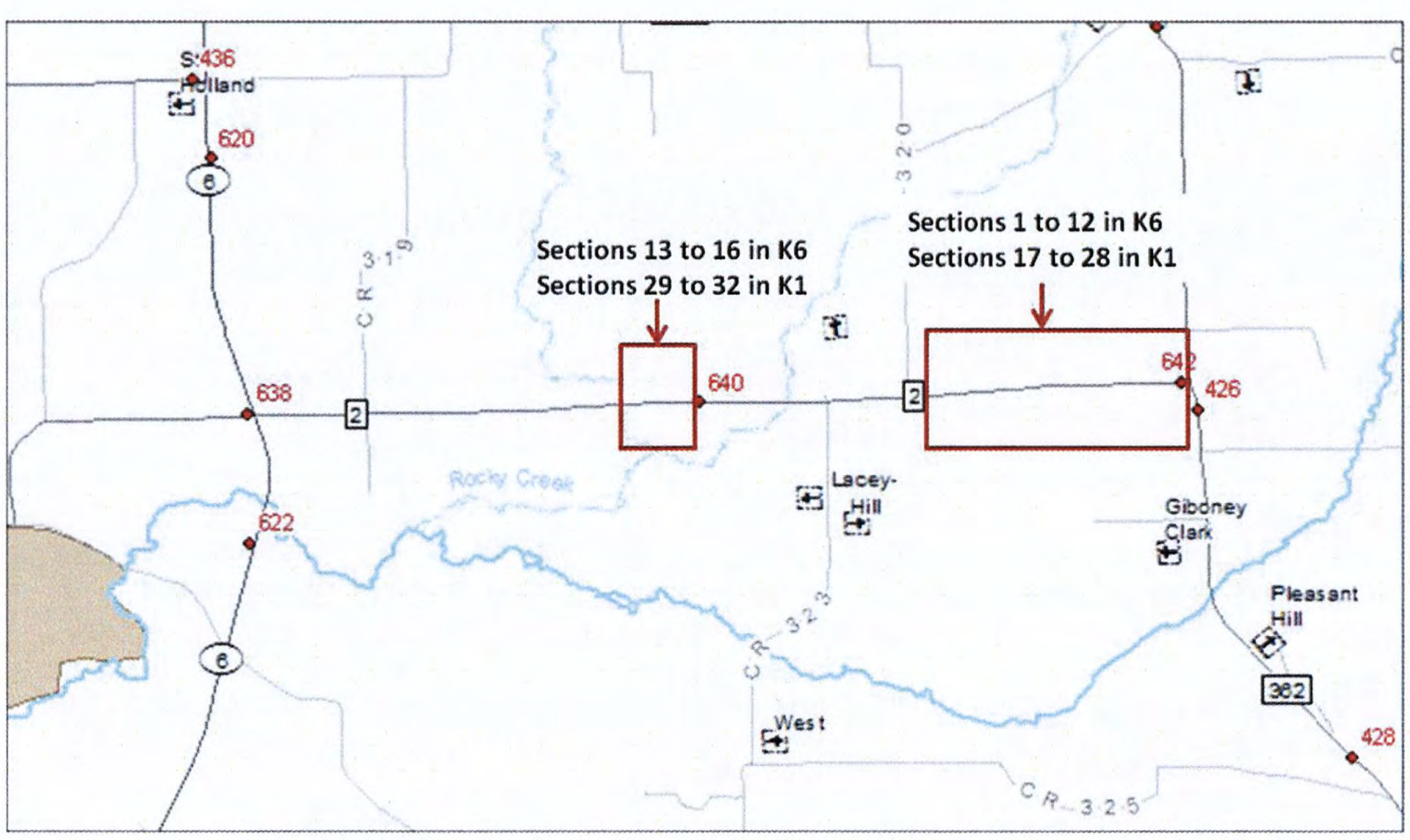
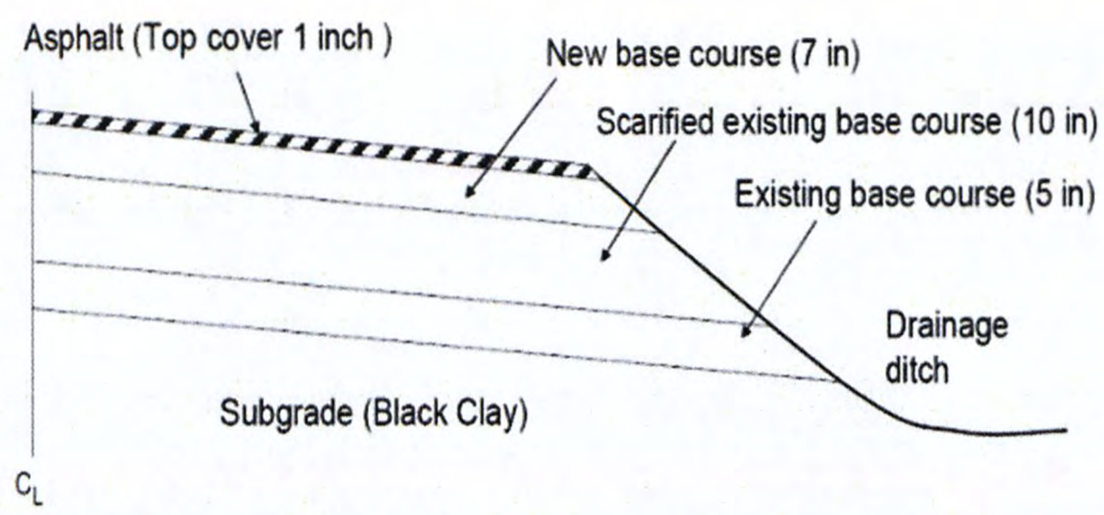
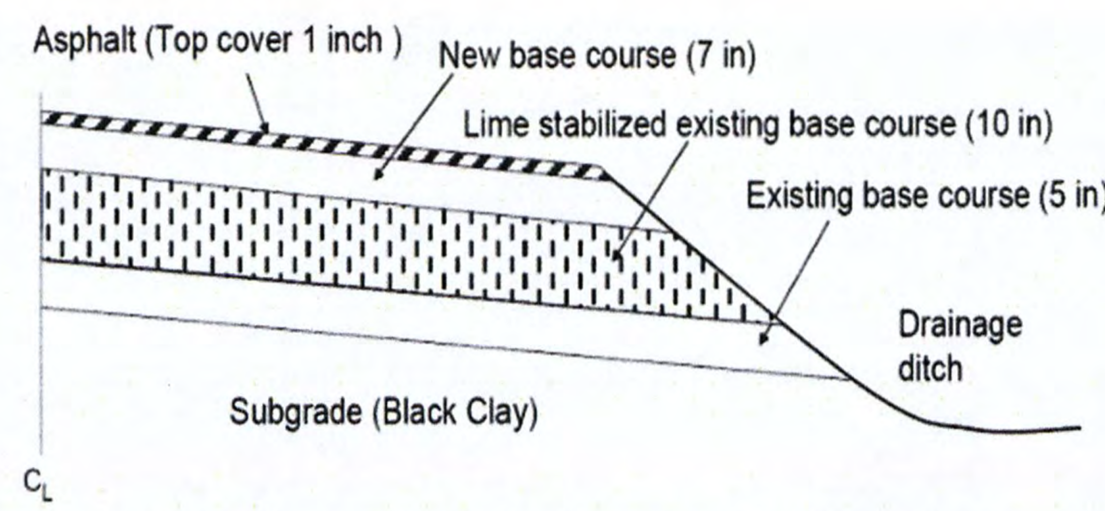


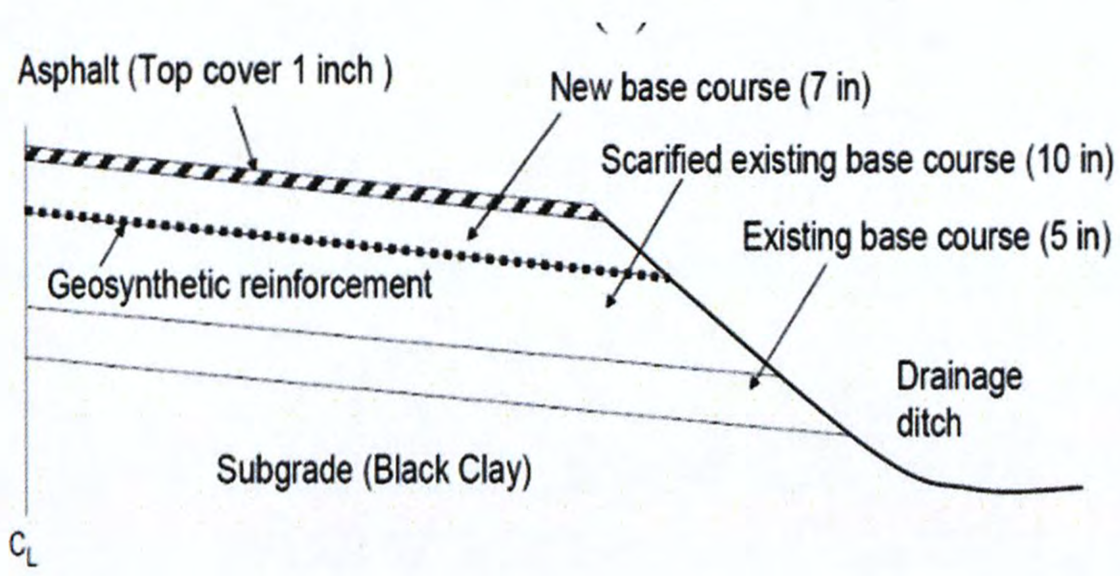
Figure 4.7. Location of FM 2 Test Section.



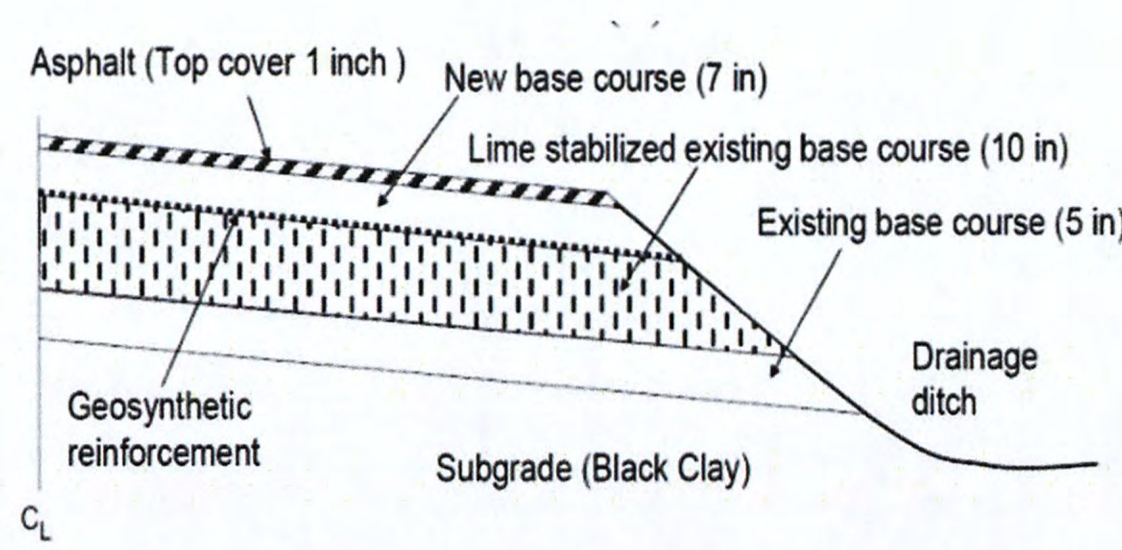
(a) Unreinforced without lime stabilization (control section)



(b) Unreinforced with lime stabilization



(c) Reinforced without lime stabilization



(d) Reinforced with lime stabilization

Station	Section #	K6 (westbound) ↓	K1 (eastbound) ↑	Section #
221+00	1	1Wa	2Ea	17
	2	2Wa	3Ea	18
	3	3Wa	4Ea	19
	4	4Wa	1Ea	20
	5	5Wa	6Ea	21
	6	6Wa	7Ea	22
	7	7Wa	8Ea	23
	8	8Wa	5Ea	24
	9	1Wb	3Eb	25
	10	2Wb	4Eb	26
	11	3Wb	1Eb	27
	12	4Wb	2Eb	28
167+00		1.1 miles No test section		
98+00	13	5Wb	7Eb	29
	14	6Wb	8Eb	30
	15	7Wb	5Eb	31
	16	8Wb	6Eb	32
80+00				

Sections 1–12 / 17–28: 5400 ft. (450 ft.×12)

Sections 13–16 / 29–32: 1800 ft. (450 ft.×4)

No lime treatment
1: No geosynthetic
2: Geogrid 1
3: Geogrid 2
4: Geotextile

Lime treatment
5: No geosynthetic
6: Geogrid 1
7: Geogrid 2
8: Geotextile

Figure 4.8. FM 2 Reconstruction Layout (after Zornberg et al., 2008).

Site Condition and Field Testing

A limited field survey was conducted to check the performance of the section and assess the layer composition after 4.5 years of reconstruction. Although minor signs of longitudinal cracks were detected at several locations (Figure 4.9), the section in both directions has performed well based on the review of video log files taken during the GPR survey and several visual surveys. Detail of the survey can be found in Appendix C. Researchers also reviewed PMIS data of corresponding segment and found that the test segment has exhibited excellent performance history since 2005 (Table 4.5).

Figure 4.9. Longitudinal Cracks Detected in FM 2.

Table 4.5. PMIS Data of FM 2 Test Segment.

Year	0 ~ 0.5 mile		0.5 ~ 1.0 mile		1.0 ~ 1.5 mile		1.5 ~ 2.0 mile	
	Distress Score	Longitud-inal crack	Distress Score	Longitud-inal crack	Distress Score	Longitud-inal crack	Distress Score	Longitud-inal crack
2006	100	0	100	0	100	0	100	0
2007	100	0	100	0	100	0	100	0
2008	100	0	100	0	100	0	100	0
2009	100	3	100	0	100	0	100	0
2010	100	2	94	0	100	0	100	6
2011	100	0	94	0	100	0	100	0

Based on the GPR survey, four locations were selected for further investigations. The locations were located adjacently in the same direction (west bound) and represented all different combinations of pavement structures (control, geogrid without lime stabilization, lime stabilization without geogrid, and lime stabilization with geogrid). Table 4.6 presents the layer thickness estimated from GPR analysis.

Table 4.6. GPR Test Results of FM 2.

Section ID	Description	Layer
1Wa	Control (No lime + No geogrid)	1.5" surface 8.0" base 11.6" subbase & subgrade
2Wa	No lime + geogrid	0.6" surface 10.6" base 9.5" subbase & subgrade
5Wa	Lime + No geogrid	0.9" surface 5.0" base 10.2" subbase & subgrade
7Wa	Lime + geogrid	1.0" surface 5.5" base 9.5" subbase & subgrade

The DCP test was performed on the above locations to evaluate the load bearing capacity of underlying layers. Table 4.7 shows the estimated layer moduli from the DCP index. It was observed that higher layer moduli were obtained in the 2Wa "geogrid section" compared to the 1Wa "control section." For the 5Wa and 7Wa sections, it was difficult to perform the DCP due to the presence of a lime-treated base layer. Thus, DCP was limited to testing subbase and subgrade layers. An access hole was drilled thorough the upper lime treated base layer. Highest resilient modulus of subbase was found from section 7Wa, where reinforced with geogrid along with lime-treated base layer. The FWD back calculation was also performed to compare with DCP test results as presented in Table 4.8. Results indicated that higher moduli of base and subbase layers were obtained from the 5Wa and 7Wa, compared to 1Wa and 2Wa. Such substantial increased base layer modulus is attributed to the lime treated base. However it is interesting to note that the geogrid reinforcement somewhat appears to enhance the load bearing capacity in case of comparing 1Wa versus 2Wa, and 5Wa versus 7Wa, each pair of section has identical base condition.

Table 4.7. Resilient Modulus Estimation from DCP Tests for FM 2.

	1Wa	2Wa	5Wa	7Wa
Layer	Mr (ksi)	Mr (ksi)	Mr (ksi)	Mr (ksi)
Base	21.7	51.7	n/a	n/a
Subbase	11.1	28.1	24.5	46.5
Subgrade	6.2	10.8	12.7	11.5

Table 4.8. FWD Back Calculation Results of FM 2.

Section	Average Layer Moduli (ksi)				Absolute
	Surface	Base	Subbase	Subgrade	Error/Sensor
1Wa	200	62.1	14.1	10.4	6.89
2Wa	200	89.3	44.4	10.3	4.81
5Wa	200	343.0	114.0	9.5	1.94
7Wa	200	569.9	139.5	11.6	4.07

Summary of FM 2

Most sections perform well with very few distresses observed through GPR and visual surveys. PMIS performance history also indicated no significant damage in these sections. From the limited DCP data interpretation along with FWD back calculation of layer moduli seems to indicate an increase of base and subbase layer moduli due to lime-treated base layer combined with geogrid reinforcement. Researchers strongly recommend that this route be further monitored to gauge the effectiveness of the treatment over long-term.

FM 471

The FM 471 site is a 5-mile long project bounded by FM 1560 and SH 211 in San Antonio District. The segment consists of three pavement sections (Figure 4.10). The control section starts at FM 211 (Station 866+92.54) and ends at Culebra rd. (Station 917+18.30). The reconstruction section starts from Culebra rd. and stretches up to Galm rd. (station 1078+98). The overlay section covers the remaining segment from Galm rd. until FM 1560. The reconstructed section was built to sustain the high ESALs loading incurred from the high percentage of hauling trucks going east toward the city. The overlay section was constructed to improve ride quality and skid resistance (see Figure 4.10).

Researchers selected five sample locations based on the design sheet obtained from the district office. Two in control section, one in reconstruction section, and two in overlay section. Field testing and sampling was conducted on April 8, 2010.

Site Condition and Field Testing

Limited field survey was conducted to check the performance of the section after 3 years of construction. There was no sign of longitudinal cracks at the reconstructed and overlay section (shown in Figure 4.11) while cracks (sealed) and rutting was noticed in the control section particularly along the wheel paths.

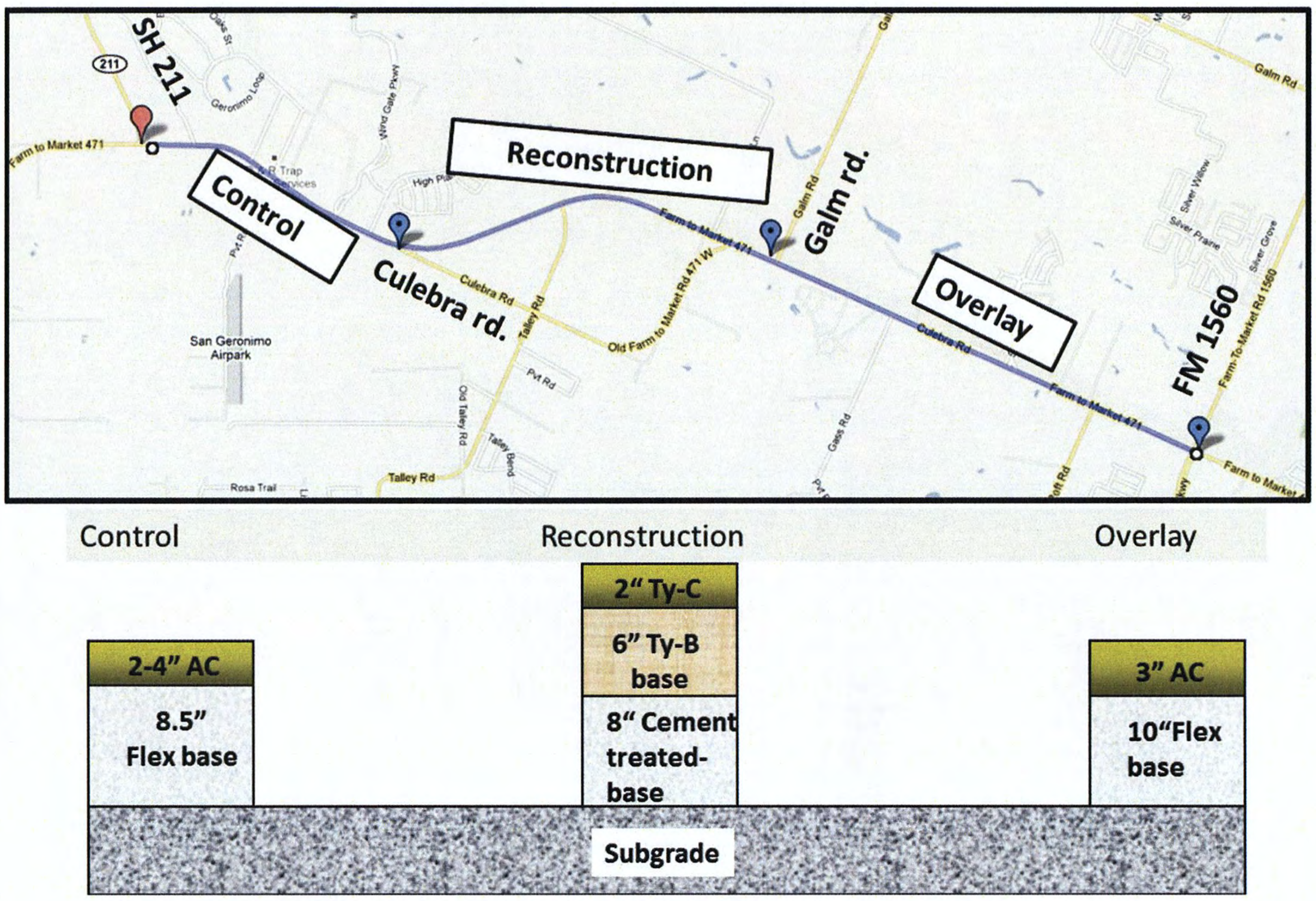


Figure 4.10. Selected Sections of FM 471.

Figure 4.11. Surface Condition Showing Rutting and Cracking in the Wheel Path at the Control (left) and Distress-Free at the Reconstructed (right) Sections.

The GPR successfully captured the transition from the reconstructed to overlay section as shown in Figure 4.12. The Type B and C asphalt surface layers of 6-8 in thickness and the overlay layer of 3-4 in were clearly detected and comparable to the information obtained from TxDOT design sheets. The figure also showed the moisture trapped zone between asphalt concrete and cement treated base layers that may result in moisture induced damage of the asphalt pavement. There was no evidence that this damage was reflected on the surface during the field evaluation.

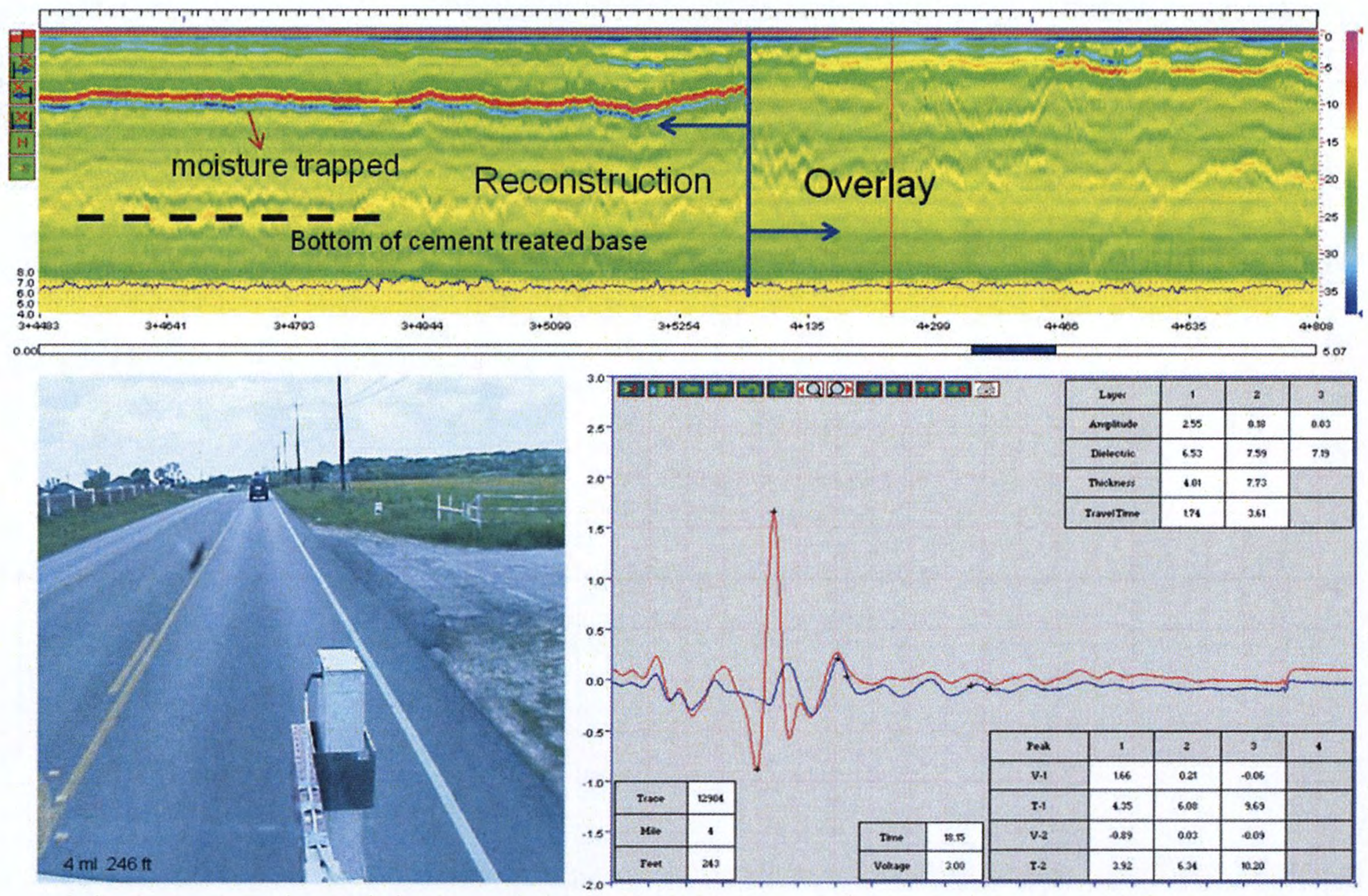


Figure 4.12. GPR Data between Reconstruction and Overlay Section.

The DCP was performed in all sections with the exception of the reconstructed section due to the rigidity of the base layer as shown in Table 4.9. It is noticed that the overlay section was on average two times stiffer than the control section due to the grading and overlay construction dated back to 2007. This was also clarified by the FWD layer moduli in Table 4.10. The base moduli in the cement-treated reconstructed section is twice than that of the overlay section which is roughly twice than that of the control section. DCP and FWD data suggested no significant change in the subgrade moduli throughout the sections. It was confirmed by the district office that no soil stabilization was applied at this site.

Table 4.9. Estimated Layers Moduli (ksi) and Thicknesses Using DCP.

	471-C1	471-C2	471-R	471-O1	471-O2
Base Layer Thickness (in)	8.5	6	x	10	8.5
Base Modulus (ksi)	75	58	x	161	144
Subgrade Modulus (ksi)	27	16	x	18	14.5

Table 4.10. FWD Backcalculated Modulus (ksi) on FM 471.

	Surface	Base	Subgrade	Error (%)
Control	682.0	128.3	22.6	4.82
Reconstruction	702.0	728.2	27.6	5.28
Overlay	912.9	345.3	40.3	6.26

Laboratory Testing

Table 4.11 shows the summary of the laboratory test results. It indicates that the control section 471-C2 subgrade exhibited the highest plasticity index, linear shrinkage strain, and sulfate content. However, sulfate content is still considered insignificant at all sections.

Table 4.11. Summary of Laboratory Test Results on FM 471.

	471-C1	471-C2	471-R	471-O1	471-O2
Plasticity Index (%)	17	35	14	20	5
Shrinkage (%)	9	25	4	10	5
Sulfate Content (ppm)	<100	576	<100	<100	<100

The 3-D Swell Test revealed that the 471-C2 experienced the highest swell among all sections (Figure C-8). The ranking of the % swell for all sections seems to be consistent with the linear shrinkage testing. The soil water characteristic curves (Figure C-9) revealed that the soil sample from 471-C2 yields the greatest change in gravimetric water content against the matric suction. This seems consistent with the highest shrinkage potential that indicates drastic volume change occurs with the change in moisture content.

Summary of FM 471

The performance of the reconstructed and overlay sections at FM 471 seems to be affected by the layer thickness, base stiffness and subgrade expansive characteristics. The layer moduli estimated from DCP and FWD indicated that the control section generally yields lower values compared to the reconstruction and overlay sections. Control section also revealed the highest plasticity, shrinkage strain and swell potential. These factors collectively can be attributed to the poor performance of the control sections. On contrary, the reconstructed and overlay sections seems to hold well due to the higher base moduli and insignificant shrinkage and plasticity characteristics.

Researchers are of the opinion that the treatment of using cement-treated base and overlay seem to be effective particularly in the route sustaining high level of traffic volume. However further monitoring of this route is necessary to warrant the effectiveness of the applied treatments.

FM 734

FM 734, also called Parmer lane, is a 3 mile segment in Austin District with divided two-direction four-lane highway located from Samsung Blvd. to Toll Road 130. The site consists of three sections; control with lime treatment (734-C), reconstructed with geogrid and lime treatment (734-R1) and reconstructed with cement-treated base (734-R2). Layer thickness and layout is shown in Figure 4.13. The reconstructed section (734-R2) was built in 2007 to correct for frequent swells and dips due to sulfate heave and seasonal expansive soil swelling. In addition, the pavement was experiencing longitudinal shrinkage cracking with cracks as wide as one inch and as deep as five feet caused by shrinkage of expansive soil during the drought in 2006. Due to the historical problems prior to the reconstruction, the area office did not grant approval for FWD, DCP, coring laboratory testing and in this section.

The 734-R1 section was constructed as a test section to evaluate the geogrid effectiveness on expansive soil. The performance life of the geogrid and control sections is more than 10 years old. Both sections have lime treatment subgrade to reduce shrinkage cracking.

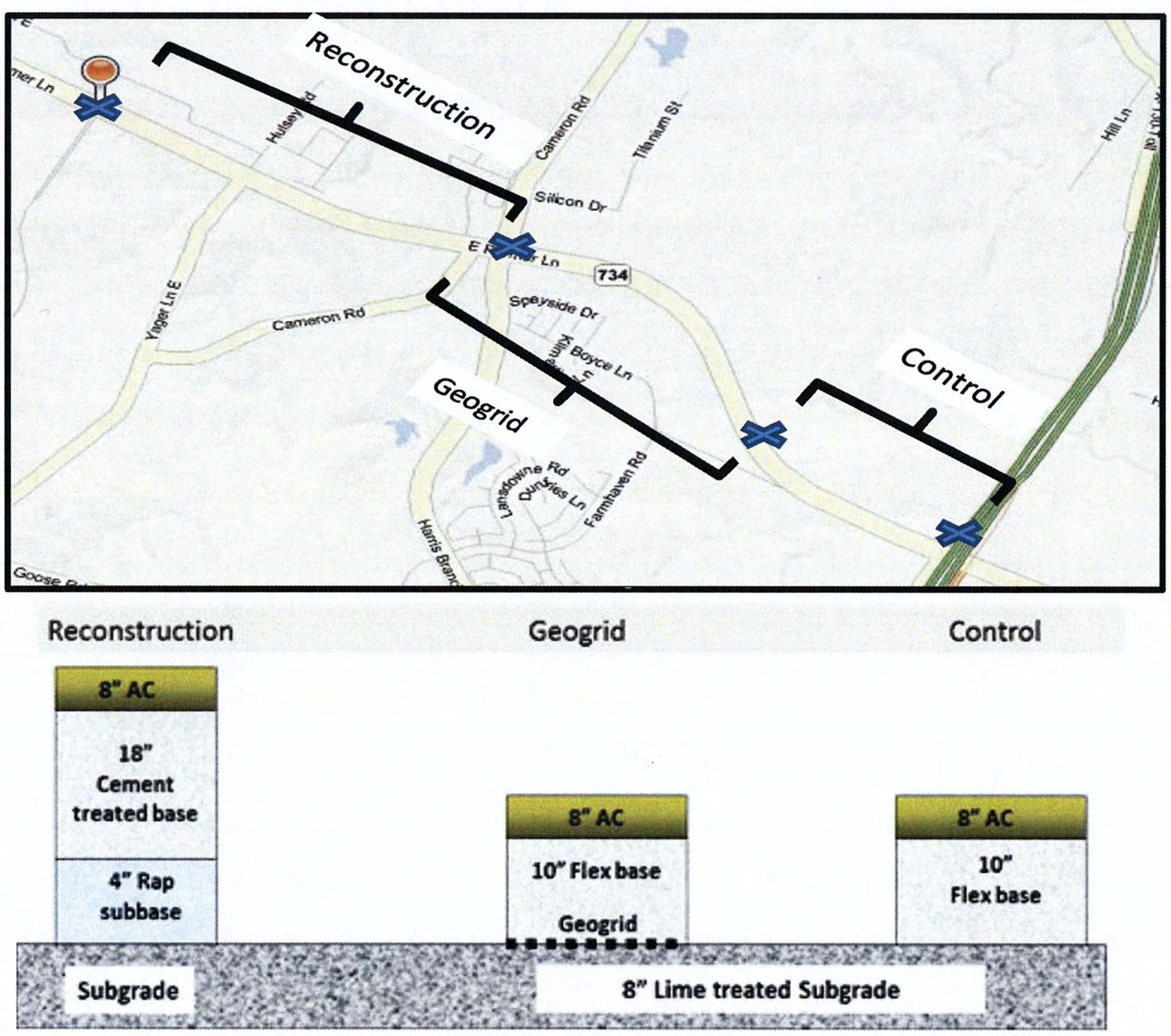


Figure 4.13. FM 734 Test Sections Layout.

Site Condition and Field Testing

Severe surface cracking is evident in the control section with poor ride quality while the geogrid section has only minor surface cracking. There was no sign of distresses at the cement treated reconstructed section as shown in Figure 4.14.

Control (734-C) Geogrid/lime (734-R1) Cement-treated (734-R2)

Figure 4.14. FM 734 Test Sections Surface Conditions.

The GPR revealed that the surface layer thickness was approximately 8 to 8.5 in. and the base layer thickness ranges from 15 to 18 in. The surface layer thickness was consistent with the height of extracting cores from the asphalt layer in the 734-C and 734-R1. Numerous repaired areas within the control section were captured by GPR images (Figures C-10 to C-12). The DCP was attempted on two locations (one from the control section and the other from the geogrid section) to compare the load bearing capacity of underlying layers. The DCP layer thickness was comparable to the GPR assessment. The results of DCP and FWD backcalculation suggested that the layer moduli from the geogrid section were slightly higher than in the control section as shown in Tables 4.12 and 4.13.

Table 4.12. Resilient Modulus from DCP Tests.

	734-R1		734-C	
Layer	DCPI (in./blow)	Mr (ksi)	DCPI (in./blow)	Mr (ksi)
Base	0.05	80.8	0.06	71.1
Subgrade	0.45	16.8	0.62	13.4

Table 4.13. FWD Backcalculated Modulus (ksi) Results on FM 743.

	Surface	Base	Subgrade	Error (%)
734-C	419	110	15	3.75
734-R1	327	145	19	4.65

Laboratory Testing

Table C-7 indicated that the geogrid/lime and control sections have the same plasticity. The tested samples were part of lime stabilized subgrade resulting in low shrinkage and sulfate content. The measured shrinkage strain was below 5 percent, the sulfate content was less than 200 ppm and the plasticity index was less than 10. The 3-D Swell Test suggested that soil samples 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. Pressure plate test revealed that soil samples from the geogrid section seem to be more capable of releasing water than the soil samples from the control section.

Summary of FM 734

The geogrid/lime combination in 734-R1 showed a relatively better performance compared to the control section (734-C) by exhibiting less longitudinal and shrinkage cracking after 10 years in service. Unlike the FM 1915 geogrid reinforced sections, the subgrade soil of both sections has a lower potential in terms of swelling and shrinkage along with lower PI due to the lime-treatment effect. More important, the 8" asphalt layer played a significant role in the performance of this section compared to the FM 1915.

Based on visual inspection only, the cement-treated section (734-R2) suggested very good performance. Although no testing evaluation performed in this section the performance is mainly attributed to the structural design and cement-treated layer stiffness. Moreover, as documented by the construction documents and design sheets, the microcracking process was implemented during the construction of this section. This technique attempts to induce microcracks to relieve internal tensile stresses that cause shrinkage cracking during curing and continuing hydration of the cement. It is strongly recommended to continue monitoring the long-term performance of the cement-treatment process.

FM 1293 & FM 787

This site is located at Kountze County in Beaumont District (Figure 4.15). The sites consists of three sections; the repaired section 1 is located on FM 1293 between reference marker (RM) 729 and 730, the control section 2 is located on FM 787 East between FM 1293 and Kervin Rd., and the repaired section 3 is on FM 787 West between FM 1293 and RM 726. This is an example of a widening job conducted by the district office to alleviate edge failures. A 3-ft shoulder was added to provide lateral support. About 10 in. of material was excavated and replaced with flexible base. The base was compacted, and then a prime coat was applied. Finally, the entire roadway was overlaid with 1.5 in asphalt surface.

Site Condition and Field Testing

Visual survey indicated that the control section (787-C) experienced shallow rutting and fatigue cracking at the wheel path. The widened section (1283-W) experienced surface cracking that is attributed to segregation of the 1.5" overlay (Figure 4.16). No evidence of cracking in the 787-W section.

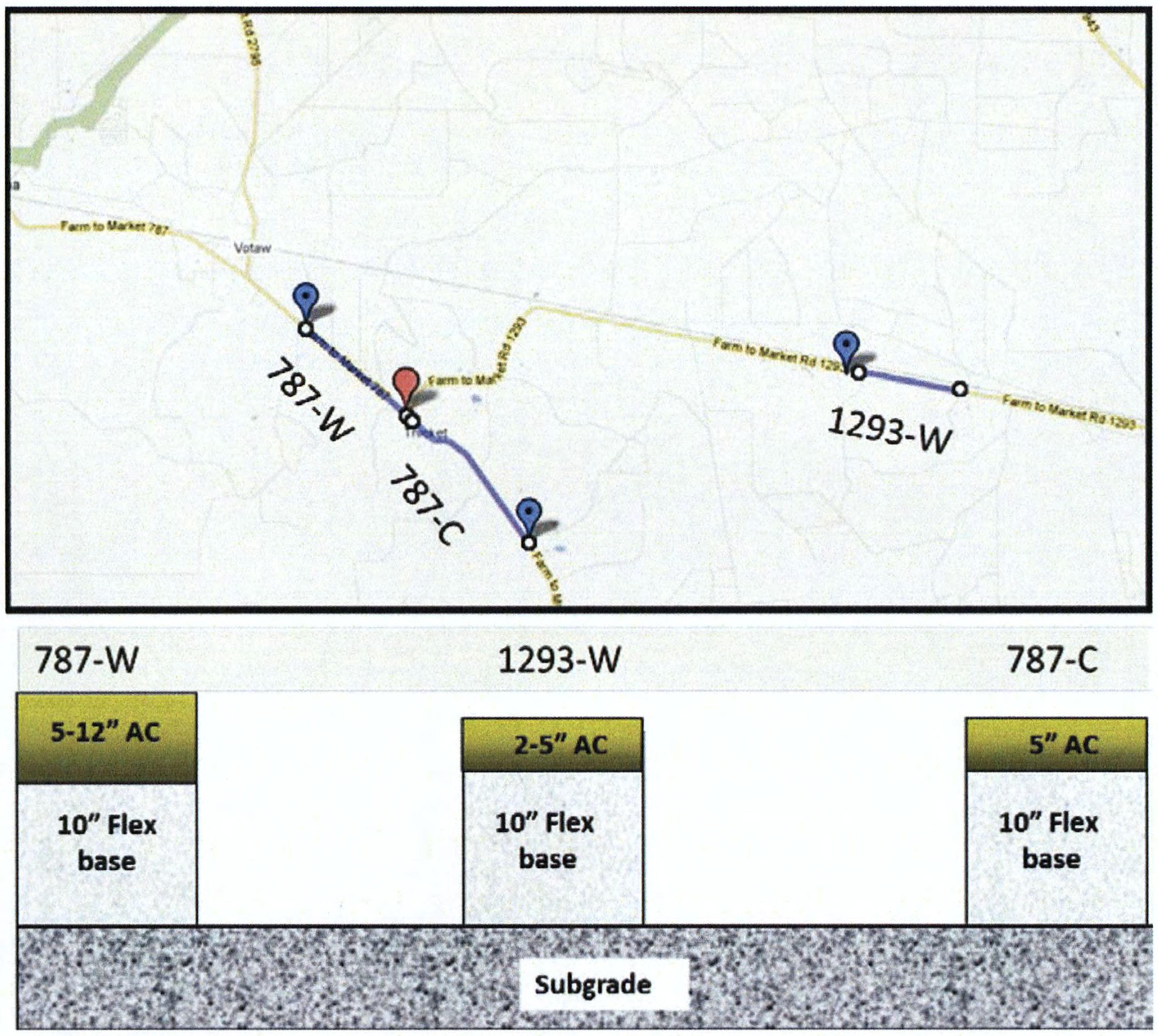


Figure 4.15. Test Sites Layout in Beaumont District.

From the GPR survey, it was recognized that the widened section in FM 1293 exhibited better ride quality than the control FM 787. However, the GPR images suggested that the pavement could become rougher in the near future due to a possible moisture infiltration in the asphalt layer, as denoted by the GPR signals (Figures C-17 to C-18). The DCP was not performed in this site due to the granular nature of the base and subgrade materials. Table 4.14 shows the FWD backcalculation results. It was found that the layer moduli of 1293-W was higher than the 787-W sections. This could explain the structural-related damage in the form of rutting and fatigue cracking in the wheel path of the widened section 787-W.

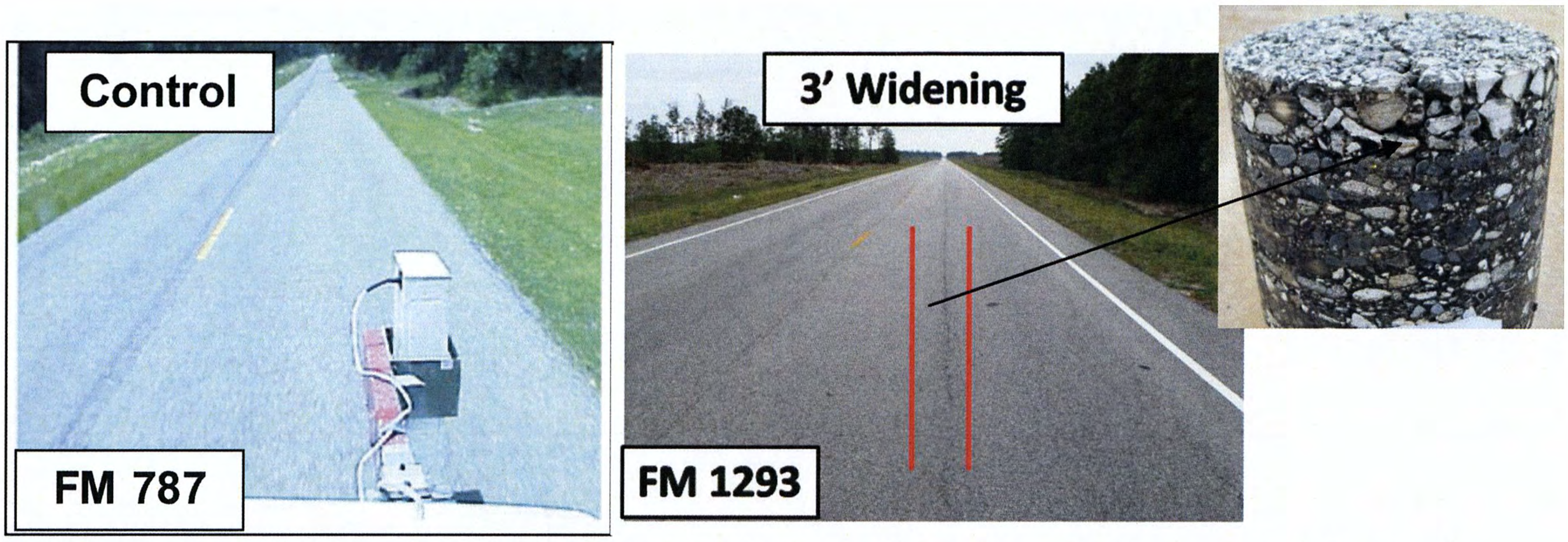


Figure 4.16. Surface Condition Indicated Distress-Free Narrow Pavement at Control Section and Longitudinal Cracking at Widened Section.

Table 4.14. FWD Backcalculated Modulus (ksi) Results on FM 787 & 1293.

	Surface	Base	Subgrade	Error (%)
1293-W	678	101.3	31.1	3.25
787-C	364	30.5	18.6	6.11
787-W	291	26	16	9.35

Laboratory Testing

The Atterberg limits suggested that the subgrade soil in this site has low plasticity. Measurement of shrinkage and sulfate content indicated that the tested soils yielded insignificant shrinkage strain and sulfate content. The measured shrinkage strain was below 3 percent and the sulfate content was less than 100 ppm. This reflects non-plastic characteristics of the soil in this site. The 3-D Swell Test revealed that soil from the control section had higher swelling potential than the widened section. However, the percent swelling is not significant in either case. A complete analysis of subgrade and base materials is shown in Figures C-19 to C-21.

Summary of FM 787 & 1293

It is suggested that the edge failure experienced in this site is due to the narrow pavement and lack of lateral support. Therefore, Beaumont district elected to widen the pavement by incorporating two 3-ft shoulders along each direction. During the site visit, there was no evidence of edge failure at the control section primarily due to the application of seal coat surface treatment. Laboratory investigation implied no evidence that soil condition is related to any form of edge failure in this site. In this particular project where expansive soil does not exist, it is suggested that widening the pavement with lateral shoulder is a viable option to mitigate edge failure.

PMIS PERFORMANCE DATA

An attempt to verify the sites performance with PMIS data of year 2010 is shown in Figures 4.17 to 4.20. The plots showed condition score and longitudinal crack data against the test segment. PMIS data was extracted based on the reference marker taken from the TxDOT statewide map system. The longitudinal crack here was shown in the average length in feet. The correlation between condition score and longitudinal crack seems reasonable. Also, the condition scores are in agreement with the visual inspection of the surface conditions. Figure 4.17 indicated the significant drop in condition score and increase in the longitudinal cracking in the control section (station 20-25). The effectiveness of the cement-treated base and overlay can also be noted (station 0-17). Figure 4.18 indicated the performance of the geogrid section (station zero) compared to the control (station 7-12). Figures 4.19-4.20 indicated the best performance among all sites in this study. Figure 4.21 indicated the effectiveness of the cement-treated base reconstruction section (station 0-6) versus the control lime-treated section (station 12-16).

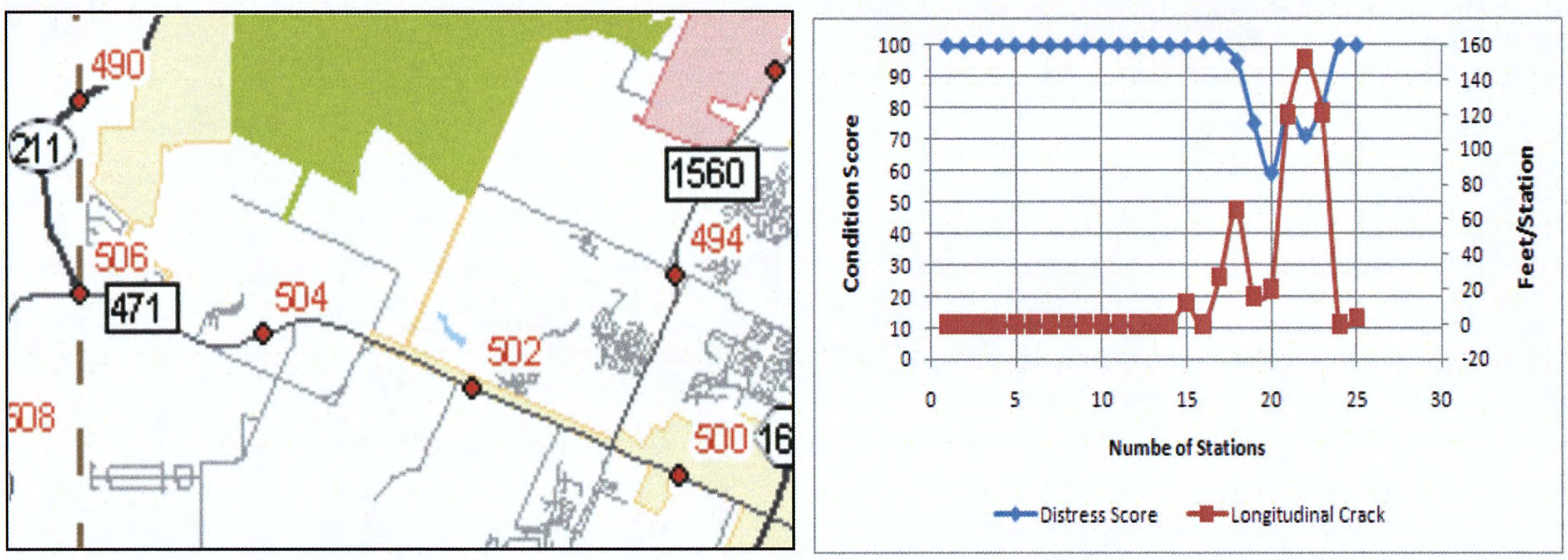


Figure 4.17. Plot of PMIS Data of FM 471.

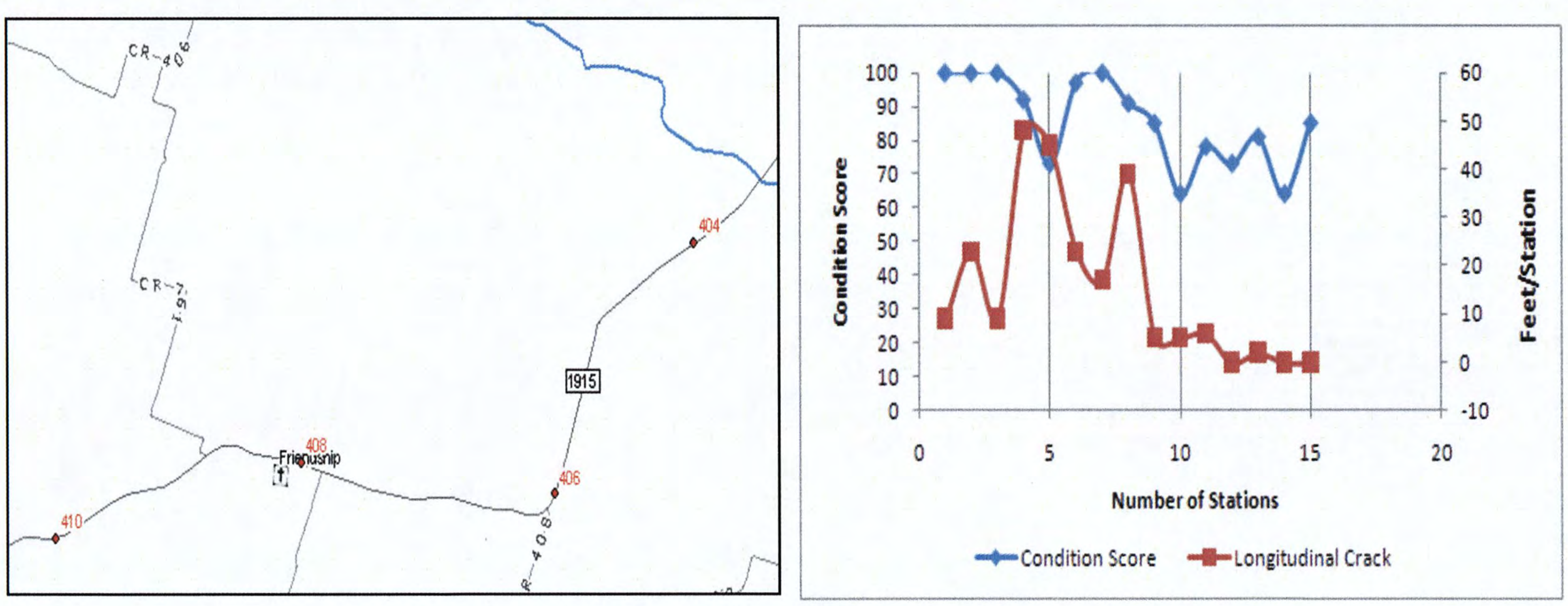


Figure 4.18. Plot of PMIS Data of FM 1915.

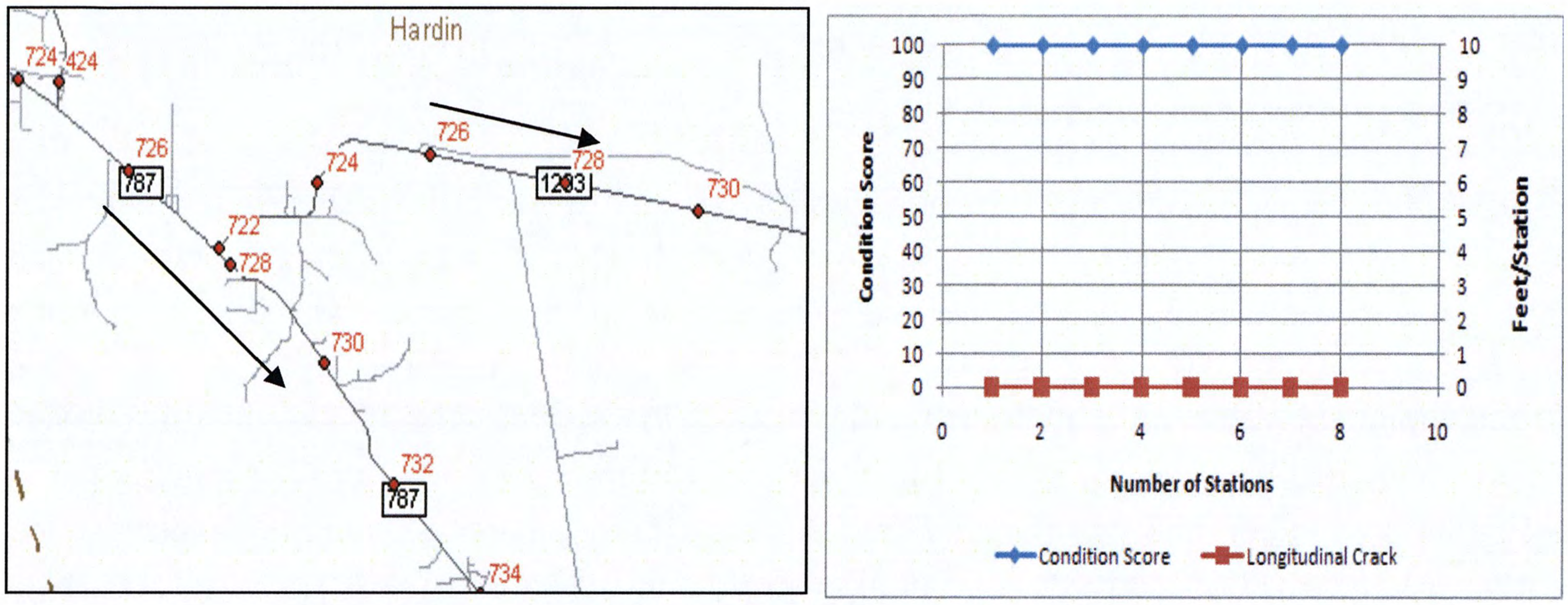


Figure 4.19. Plot of PMIS Data of FM 1293.

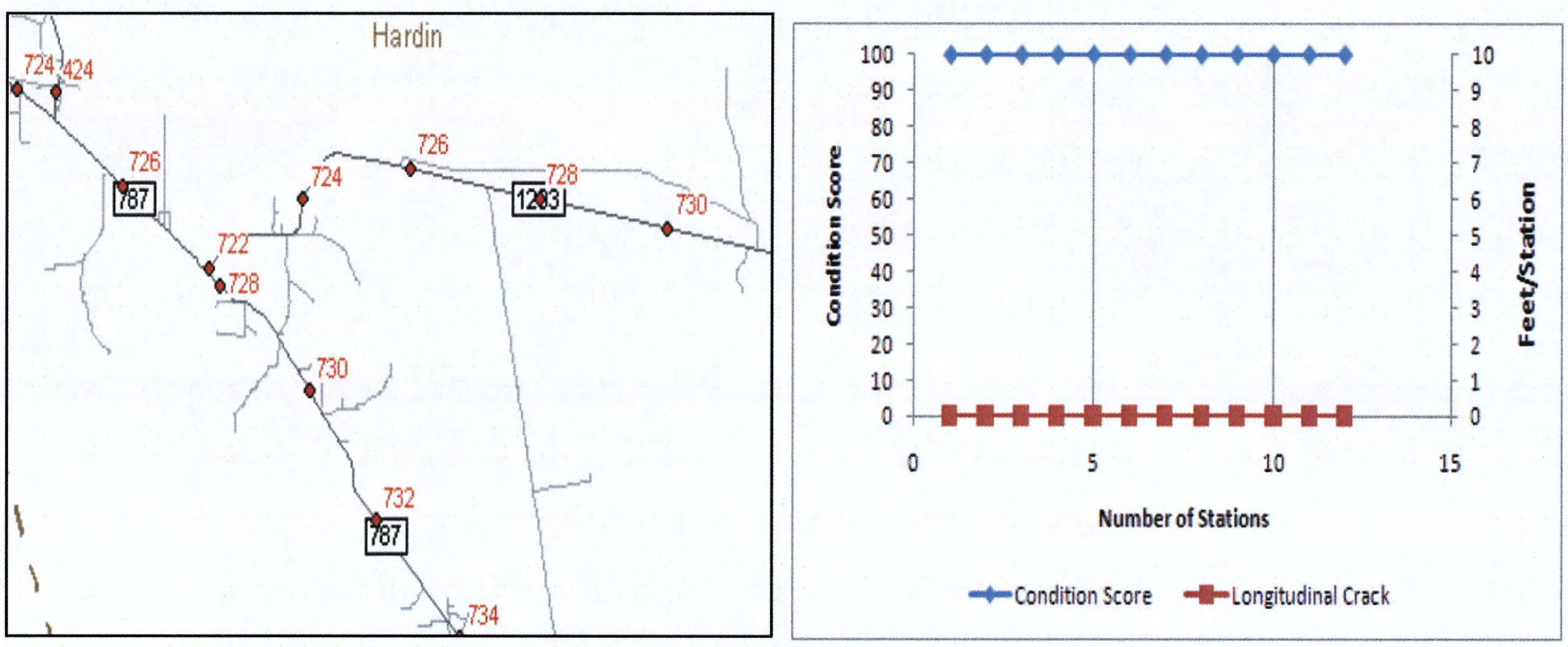


Figure 4.20. Plot of PMIS Data of FM 787.

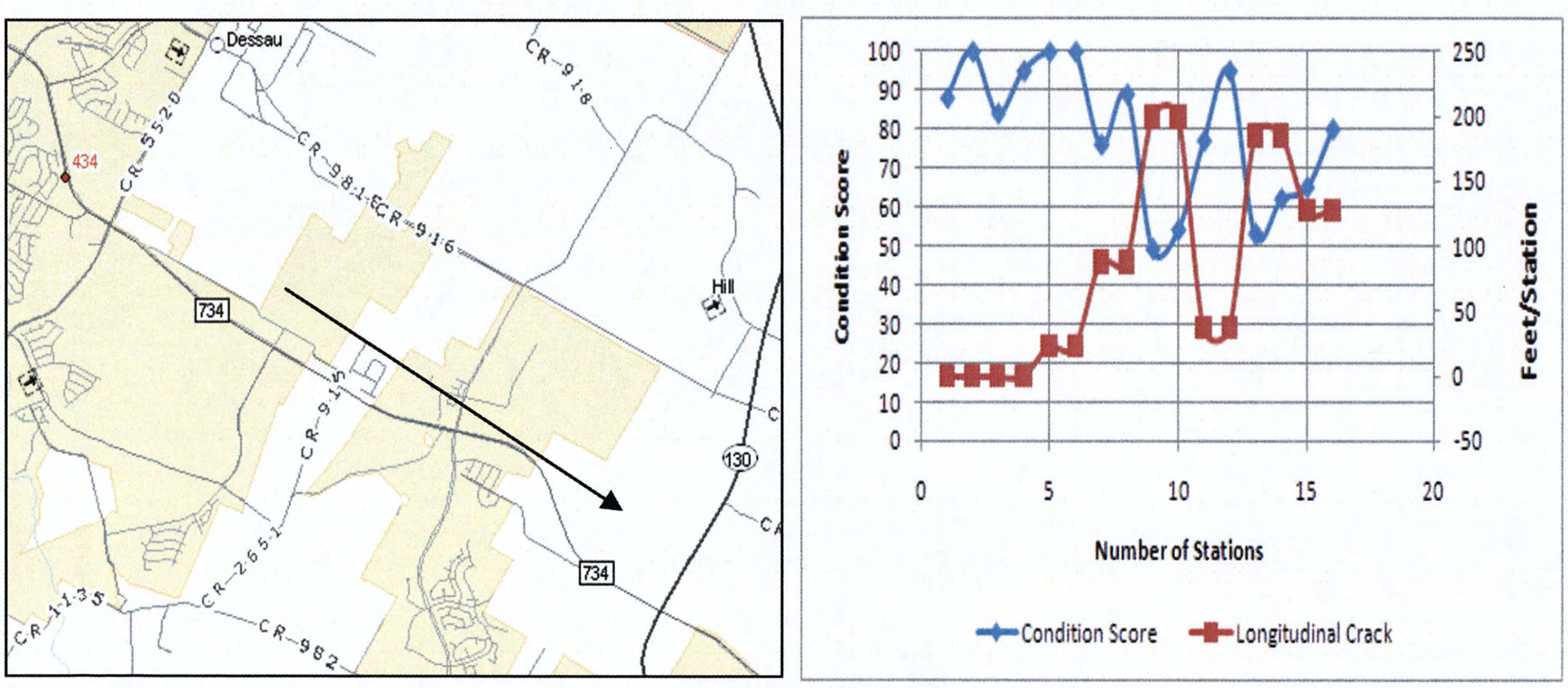
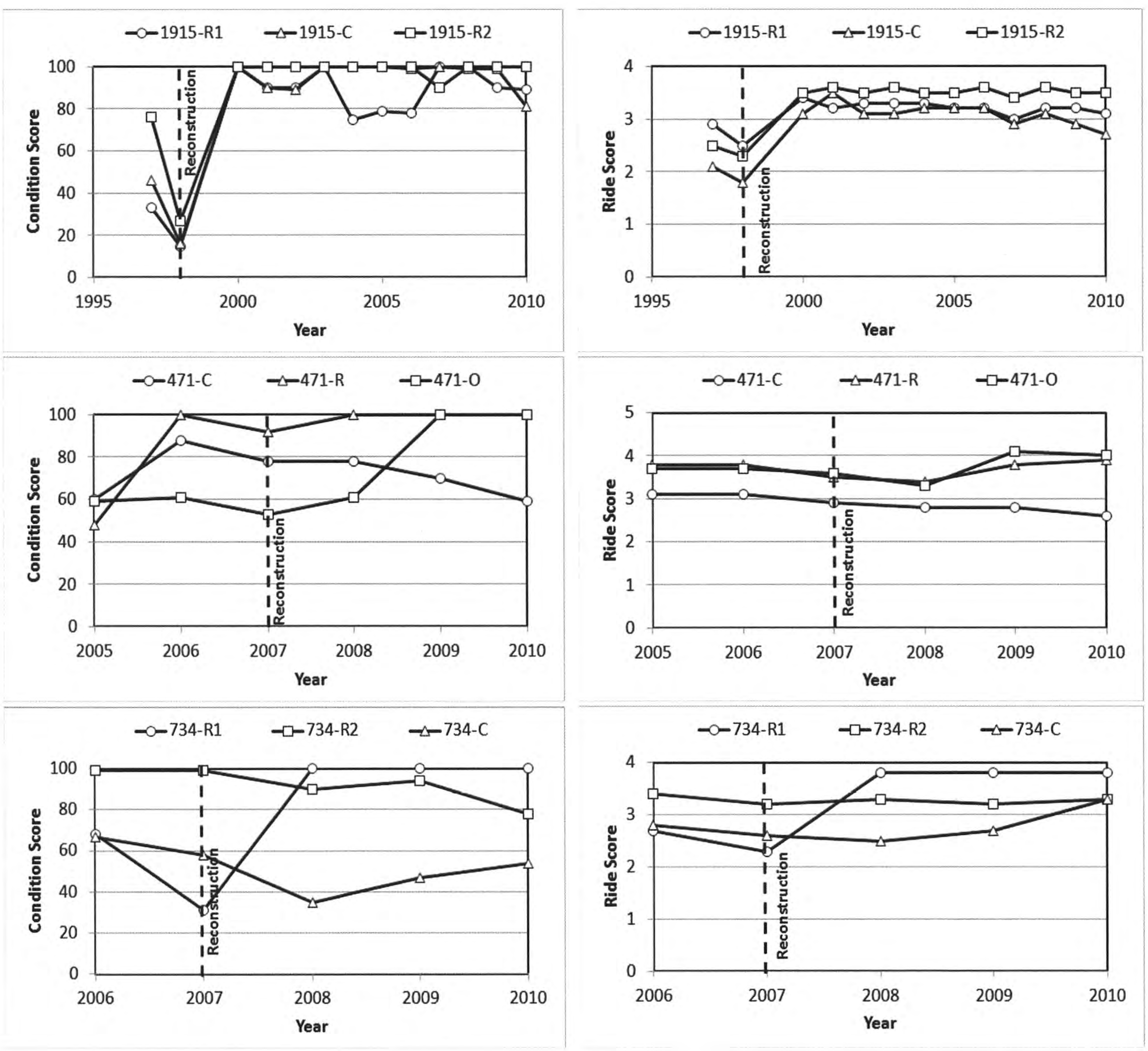


Figure 4.21. Plot of PMIS Data of FM 734.

Figure 4.22 suggest that the condition score and ride scores have significantly increased after the repair was taken place at each site. With regard to the expansive soil sites the treatment of cement-treated base, lime treated subgrade with geogrid and overlay were considered in this study. One can notice the effectiveness of the cement-treated base (471-R and FM 734-R2). Although this treatment was showing higher scores against the expansive soil conditions and the heavy traffic, it is a very costly repair. Geogrid at base-subgrade interface was also an effective treatment against expansive soil. Geogrid effectiveness is increased when combined with lime treated subgrade (734-R1). This repair is also costly but with less degree than in cement treatment base. On other hand, the overlay has also shown acceptable performance (471-O) and could be considered one of less costly treatments. With regard to the edge failure, only one site was investigated. It seems that incorporating the lateral support with overlay increases the performance scores of the pavement (787-W and 1293-W).



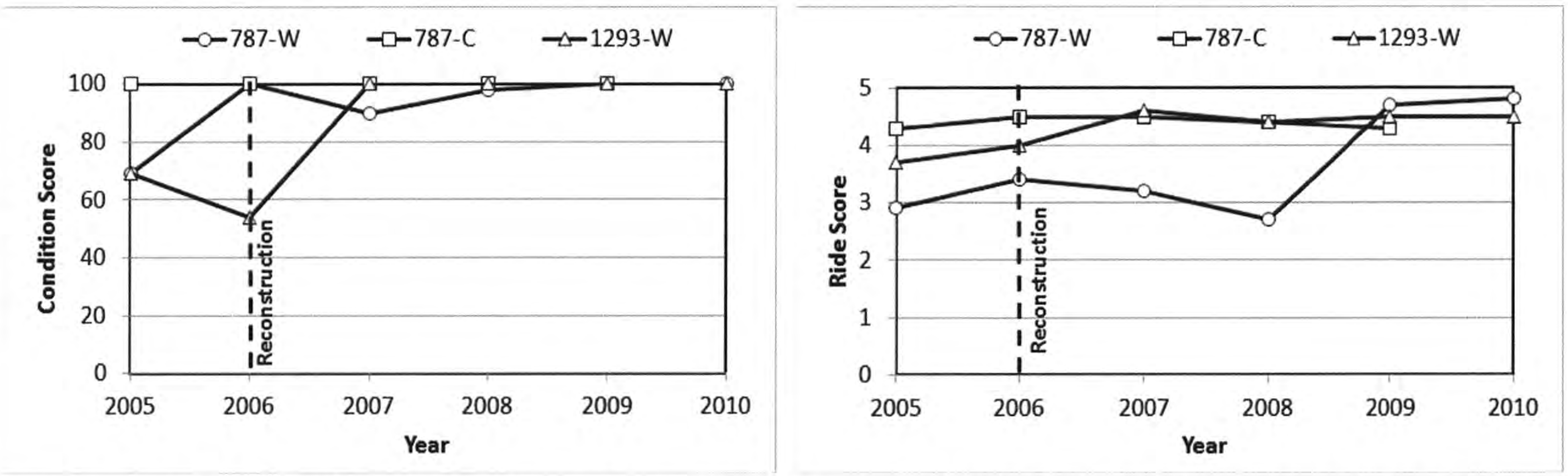


Figure 4.22. The Condition Scores and Ride Scores Before and After the Reconstruction.

CONCLUSION

Six pavement sites in four districts were investigated in this chapter to evaluate the effectiveness of treatment repair against distresses related to expansive soil and edge failure. These sites are FM 1915 and FM 2 in Bryan district, FM 471 (San Antonio district), FM 734 (Austin district), FM787 and FM 1293 in Beaumont district.

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. FM 2 and FM 734 have indicated good pavement performance with combined treatment.
- Cement treated bases have shown the best performance as indicated by the condition and ride scores. Their performance over expansive soil could lead to higher cost-effectiveness treatment with high ADT areas. The FM 734 and FM 471 experienced good performance for 3 years after construction.
- Overlay treatments have also shown adequate performance in FM 471. The treatment was applied on expansive soil and high traffic loading. Depends on its condition, the base layer can be replaced or reworked before applying the overlay.
- Pavement widening has also shown a great potential to improve pavement performance by providing lateral support.

The projects examined in this report are examples of how TxDOT districts might choose to address severe pavement failures on FM roads under certain conditions. Some of treatments are innovative while others are routine. 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 treatments for expansive soil due to the time constraint of this research study. The effectiveness of the treatments mentioned here is only limited to the selected sites including their climatic, soil and traffic conditions.

CHAPTER 6
SUMMARY AND CONCLUSIONS

Pavement distresses in narrow FM roadways are caused by a combination of factors including; lack of lateral support, base failure, expansive soil, moisture infiltration and aging of asphalt surface in addition to other factors. Distresses are shown in the form of longitudinal cracking primarily close to the edge causing edge failure, fatigue cracking and rutting.

The objective of this research was to evaluate existing repair projects on selected FM 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 PI expansive soil and narrow pavement.

The projects examined in this report offered examples of how TxDOT districts choose to address severe pavement failures on FM roads for certain conditions. Some of those examples are innovative, and others are routine. These projects do not represent the only options for treatment of these pavement conditions and each project should be designed based on its pavement condition, the intended design life cycle, cost effectiveness, local climate, local traffic, and available local materials.

This one-year study involved field and laboratory testing on selected projects and examined the effectiveness of the applied treatments. The selected projects may not represent the whole conditions in the state. They were chosen because they were available for investigation during the course of this study.

SUMMARY OF THE EXPERIMENTAL PROGRAM

The following steps were used in the study for investigating the causes of pavement distresses:

1. **Collecting information about the pavement site**: design plan (longitudinal profile, cross section), construction details, traffic and performance records using PMIS (e.g., condition score, distress score, failures, ride quality).
2. **Visual inspection of pavement condition:** Pavement surface conditions, traffic volume, lane and shoulder width, drainage conditions were examined to preliminary identify the cause of pavement distresses. This step was crucial to decide if further field investigations were needed. For instance, for structural-related distresses forensic analysis may be necessary to evaluate the root causes of failure.

3. **Non-destructive testing with GPR and FWD**. These tools provided information of the pavement system stiffness, layers thicknesses, moisture infiltration, delamination, etc. It was implemented to examine if failure was due to insufficient structural capacity, base layer failure or moisture damage in lower layers.
4. **Laboratory testing on base and subgrade materials.** This testing was implemented to examine the granular materials shrinkage and swelling potential, sulfate content, suction and plasticity level. These tests provided insight into the cause of failure that is linked to high PI expansive soil.

It is worth to mention that the experimental tools in steps 2 and 3 were considered because of the nature of the distresses that were analyzed in this study. These tools do not represent the only tools for a comprehensive evaluation. Experimental and measuring tools should be selected based on the pavement conditions and the nature of the distresses.

SUMMARY OF SITES REPAIR AND PERFORMANCE

Four projects represent different treatments were analyzed in this study. The summary of the conditions, treatment and performance are shown in Table 6.1.

Table 6.1. Summary of Field Sites Investigation.

Site (control section)	Original Condition	Treatment	Performance
FM 1915: Low ADT site with seal coat over 8" granular base and clay expansive soil.	Significant movement due to cycles of shrinkage /swelling of high PI expansive clay soil.	Lime-treated granular base and geogrid reinforcement at the base-subgrade interface.	Geogrid reinforcement alleviates soil movement to some extent. Longitudinal cracks continue to appear in the surface due to soil movements.
FM 471: High ADT site with 2" ACP over 10" flex base and expansive clay soil.	Fatigue cracking and rutting in the wheel path due to combination of excessive truck loading, insufficient structural capacity (base failure) and expansive soil.	1- Reconstruction with 2" ACP, 6" type B base and 8" cement-treated base. 2- Overlay section with 3" ACP over 10" flex base.	Sections are performing well and in good conditions.
FM 734: Moderate ADT with 10" ACP, 12" flex base, and 8" lime treated subgrade.	Frequent swells and dips due to sulfate heave and seasonal expansive soil swelling. In addition, longitudinal (faulted) shrinkage cracking caused by shrinkage of expansive soil.	1- 8" ACP over 18' cement-treated base, geogrid and 4" subbase RAP. 2- 8" ACP over 10" flex base and geogrid at base-subgrade interface.	Sections are performing well and in good conditions. Slight surface cracking in the geogrid section.
FM 1293 and FM 787: low ADT narrow pavement with 5" ACP over 10" flex base.	Edge failures due to lack of shoulder.	Widening with 3ft asphalt shoulder.	Sections are performing well and in good conditions. No signs of edge failure.
FM 2: Low ADT site with 1" seal coat over 15" base course and black clay soil.	Severe longitudinal cracking and edge failures detected.	Lime treated existing base 10" with geosyntehtic reinforcement within base layers.	Sections are performing well and in good conditions. Some signs of longitudinal cracking at the vicinity of control section.

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APPENDIX A
SURVEY FORMS

Survey on Pavement Repair Strategies for 2R and Routine Maintenance (RM) Projects

District:________________

Responder:_____________

Date:__________________

Definition:
Edge failures are one of the major distresses in FM roadways. They appear in the form of longitudinal cracking, alligator cracking, or rutting. Major forms of this failure are longitudinal cracks, which appear parallel to and within a few feet of the edge of the pavement.

Questions about the Engineer's Experience and Familiarity on 2R and RM:

1. What is your current position at TxDOT? ____________________________________
____

2. How long have you been working for TxDOT?______________________________
____

3. Describe your role in routine maintenance activities. ___________________________
____

Questions about the forms of edge failure in the district:

4. Is your district experience edge failure? No _____ Yes _______

If No, end questionnaire and answer the following only:
Has the district experienced this failure in the past? Please list any treatment techniques the district has used, if applicable.

____
____
____

If Yes, answer the following:

5. What are the main forms of edge failure in the district?
   - ☐ Longitudinal cracks only
   - ☐ Rutting only
   - ☐ Longitudinal and transverse cracks
   - ☐ Combination of cracking and rutting
   - ☐ Cracking with popouts
   - ☐ Cracking, shoving, and popouts
   - ☐ Soft spots
   - ☐ Edge deterioration
   - ☐ Other_______________

6. Overall, how do you evaluate the severity of these distresses?
   - ☐ High (describe the length and crack opening)_______________________
   - ☐ Medium (describe the length and crack opening)_____________________
   - ☐ Low (describe the length and crack opening)_______________________

7. How far from the pavement edge does the failure generally occur?
   - ☐ 0-1 ft
   - ☐ 1-2 ft
   - ☐ 2-3 ft
   - ☐ 3-4 ft
   - ☐ 5-7 ft
   - ☐ Other___________________

8. What is the type and width of shoulder in the areas of edge failure?
   - ☐ paved width_______________
   - ☐ unpaved width_______________
   - ☐ no shoulder

<u>Questions about the causes of edge failure in the district:</u>

9. What are the possible reasons for edge failure in the district?
   - ☐ Moisture entrapped into subgrade and pavement layers
   - ☐ High temperature and dryness of subgrade materials
   - ☐ Aging of asphalt pavement surface
   - ☐ Insufficient pavement width and lack of lateral support, such as shoulder
   - ☐ Wash away due to large rain drain
   - ☐ Loss of adhesion between asphalt layer and base materials
   - ☐ Alignment that encourages drivers to travel on the pavement edge
   - ☐ Edge drop-off due to different settlement caused by subgrade
   - ☐ Other ____

10. What are the main soil and base materials types in the district?

Soil
- ☐ Expansive
- ☐ Clay
- ☐ Sandy
- ☐ Silty
- ☐ Other__________________

Base
- ☐ Limestone
- ☐ Sand/gravel
- ☐ Granite
- ☐ Other__________________

11. Does the district have sites with edge failure in the proximity of poor drainage or flood areas?
Yes________ No____________

12. In general, what you would say about the most important main cause for edge failure in the district?

Materials
- ☐ Subgrade
- ☐ Base
- ☐ Asphalt layer
- ☐ Other__________

Design/Construction
- ☐ Compaction
- ☐ Drainage
- ☐ Structure capacity
- ☐ Lack of shoulder
- ☐ Traffic
- ☐ Other____________

Environmental
- ☐ Temperature
- ☐ Moisture/Rain
- ☐ Grass on pavement sides
- ☐ Other___________

Questions about the treatment of edge failure in the district:

13. Does the district have a threshold to decide when the treatment begins on these distresses? Explain.

____

____

14. What are the current rehabilitation methods for the edge failure in the district?
- ☐ Crack sealing or filling (slurry seal or crack seal)
- ☐ Partial-depth patching
- ☐ Full-depth patching
- ☐ Mill and overlay
- ☐ Slope stabilization
- ☐ Mulch to preserve moisture content on the shoulder
- ☐ Side barrier to prevent moisture
- ☐ Subgrade stabilization using hydrated lime or cement
- ☐ Geotextile/geomembrane separation at subgrade/base
- ☐ Geogrid reinforcement
- ☐ Other________________

15. What other secondary routine maintenance work is applied on the affected areas?

- ☐ Shoulder blading and repair
- ☐ Shoulder rebuilding
- ☐ Sweeping/flushing
- ☐ Ditch shaping and cleaning
- ☐ Erosion repair
- ☐ Other____________________________

16. Any techniques used that haven't been mentioned in routine maintenance? If yes, explain.____

____

17. What is the effectiveness of the current treatment? Does the crack reappear?

- ☐ No
- ☐ Yes, after
  - o 6 months
  - o 1 year
  - o 2 years
  - o 3 years or more

18. How does the district evaluate the effectiveness of the repair?

- ☐ Not applicable
- ☐ Pavement condition score
- ☐ Structural testing using FWD, DCP or GPR
- ☐ Visual inspection
- ☐ Other______________________________

19. For comparison analysis, does the district have sections with no failure (control), edge failure (damaged), and with applied effective repair in a single site? Yes______ No_________

If Yes, can you list them (e.g., county, intersection, mile marker)?

1) ____

2) ____

3) ____

4) ____

APPENDIX B
SUMMARY RESULTS OF DISTRICT SURVEYS

Graphical Results of Surveys

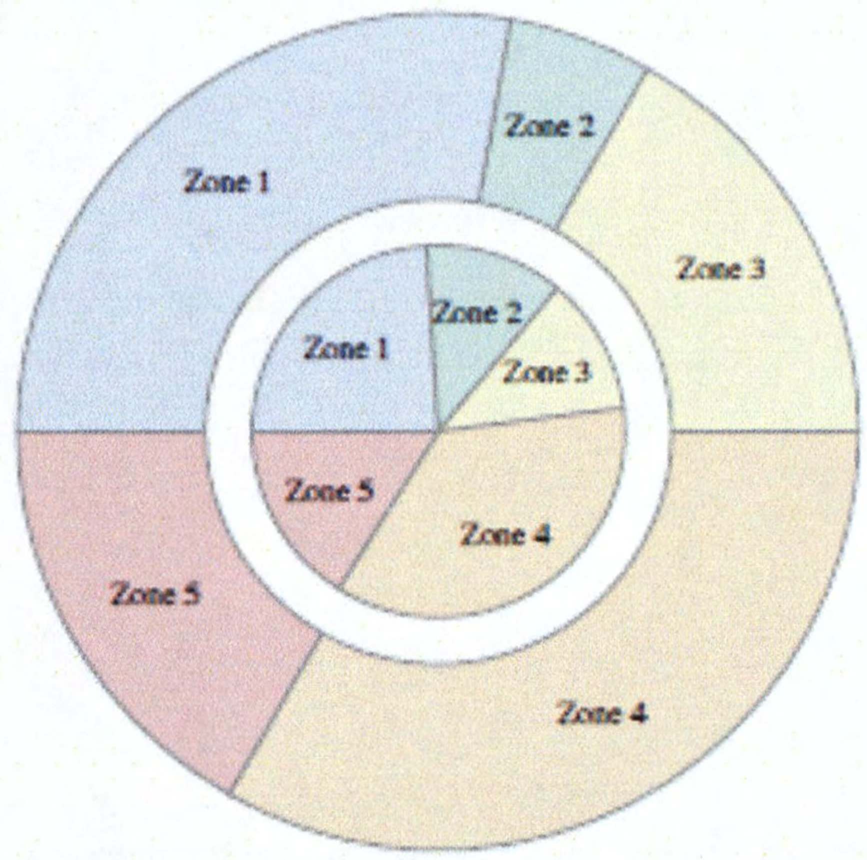


Figure 1. Seventy-Six Percent of TxDOT Districts Responded to Survey
Inside: Twenty-Five Districts, District Population by Zone
Outside: Nineteen Responses from Districts, Sample Population by Zone

Table 1. Districts reponding to survey

	"Zone"	"District"
"YKM"	1	"Yoakum"
"SAT"	1	"San Antonio"
"CRP"	1	"Corpus Christi"
"PHR"	1	"Pharr"
"LRD"	1	"Laredo"
"ODA"	2	"Odessa"
"AMA"	3	"Amarillo"
"LBB"	3	"Lubbock"
"CHS"	3	"Childress"
"PAR"	4	"Paris"
"WFS"	4	"Wichita Falls"
"ABL"	4	"Abilene"
"WAC"	4	"Waco"
"TYL"	4	"Tyler"
"BWD"	4	"Brownwood"
"ATL"	4	"Atlanta"
"LFK"	5	"Lufkin"
"BRY"	5	"Bryan"
"BMT"	5	"Beaumont"

Responses to Question 1

What is your current position with TxDOT?

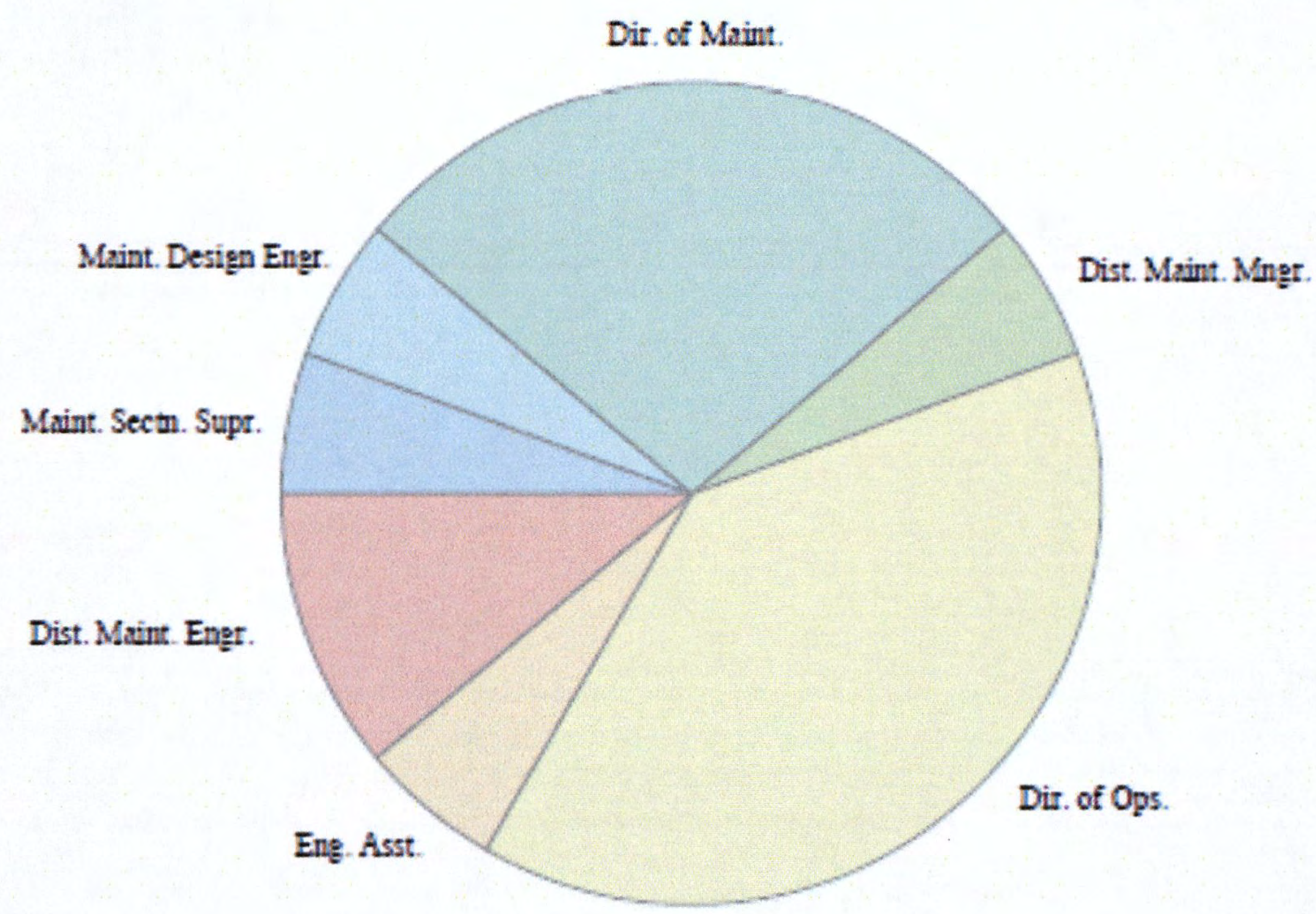


Figure 2. Responses to Question 1

n = 18 (Number of Districts Responding)
R = 18 (Total Number of Responses)

Responses to Question 2

How long have you worked for TxDOT?

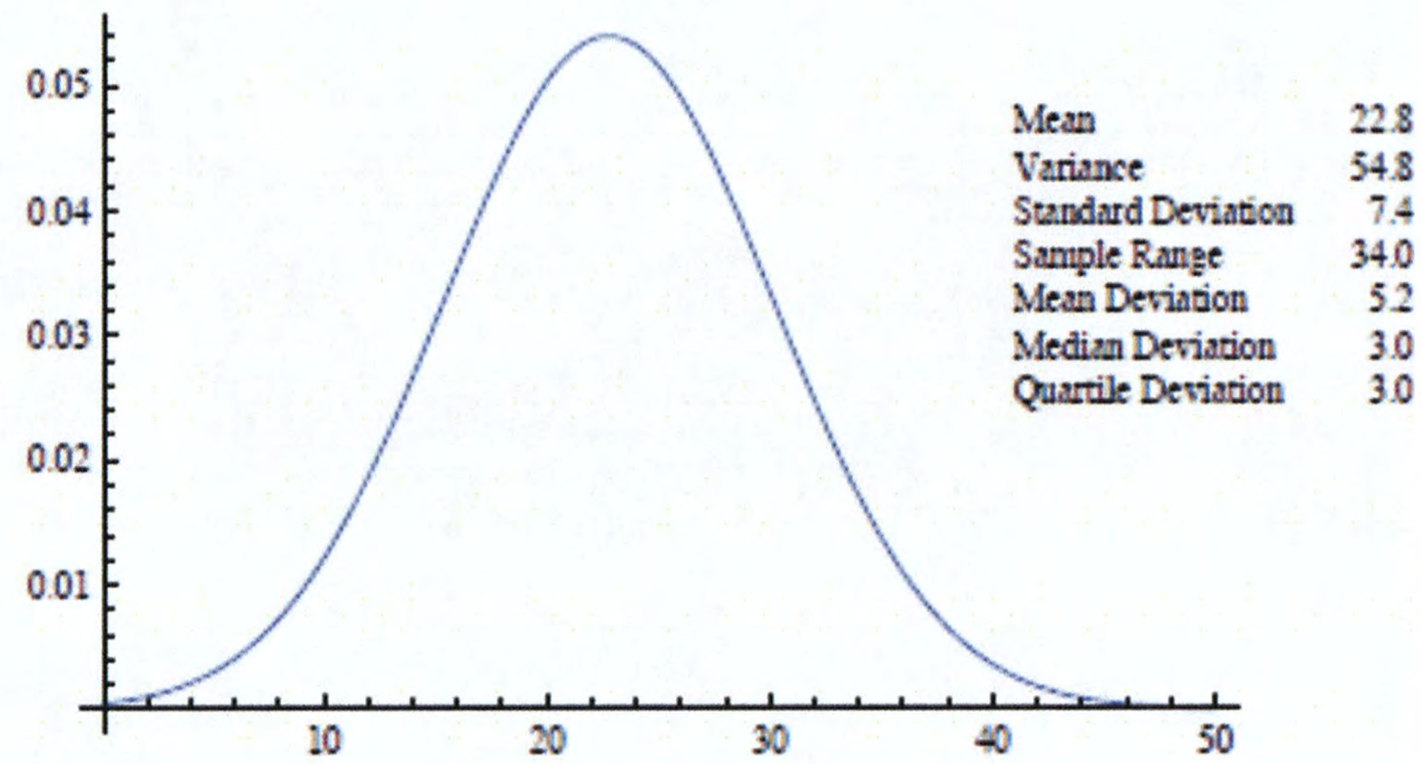


Figure 3. Normal Distribution for Years Experience

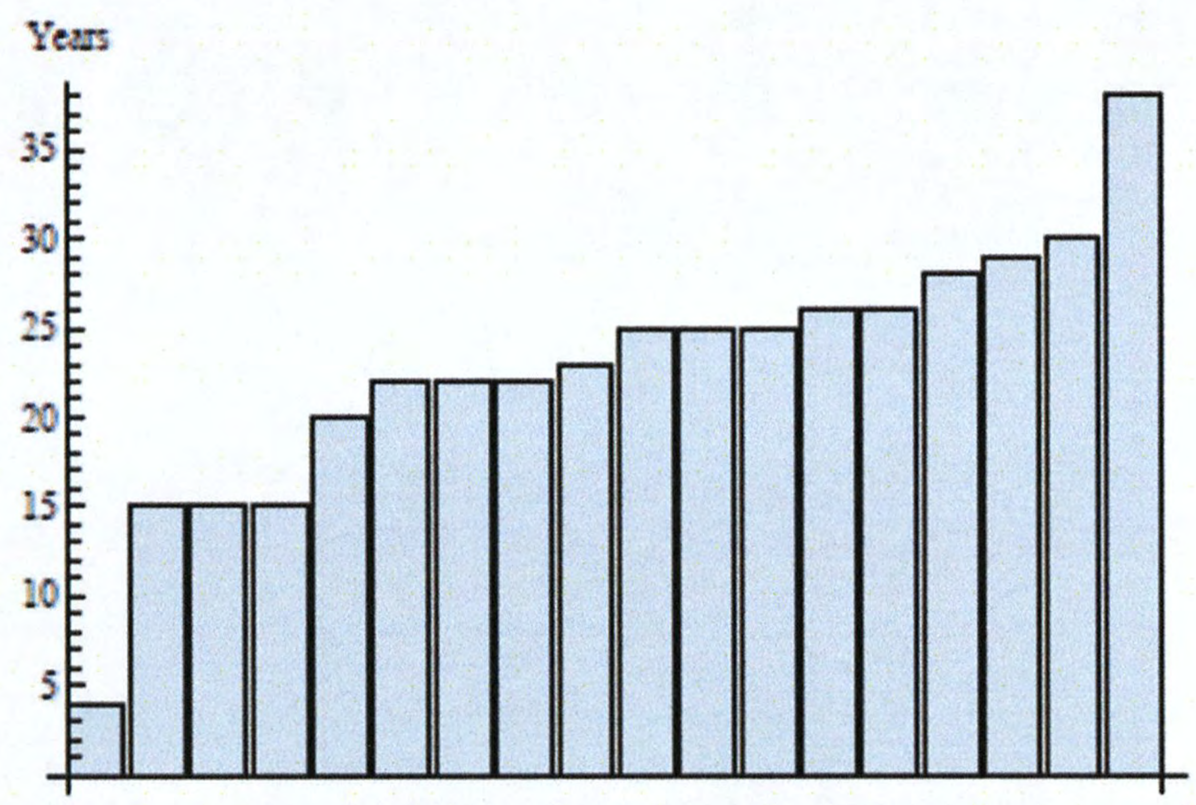


Figure 4. Responses to Question 2

n = 18 (Number of Districts Responding)
R = 18 (Total Number of Responses)

Responses to Question 3

Describe your role in routine maintenance activities?

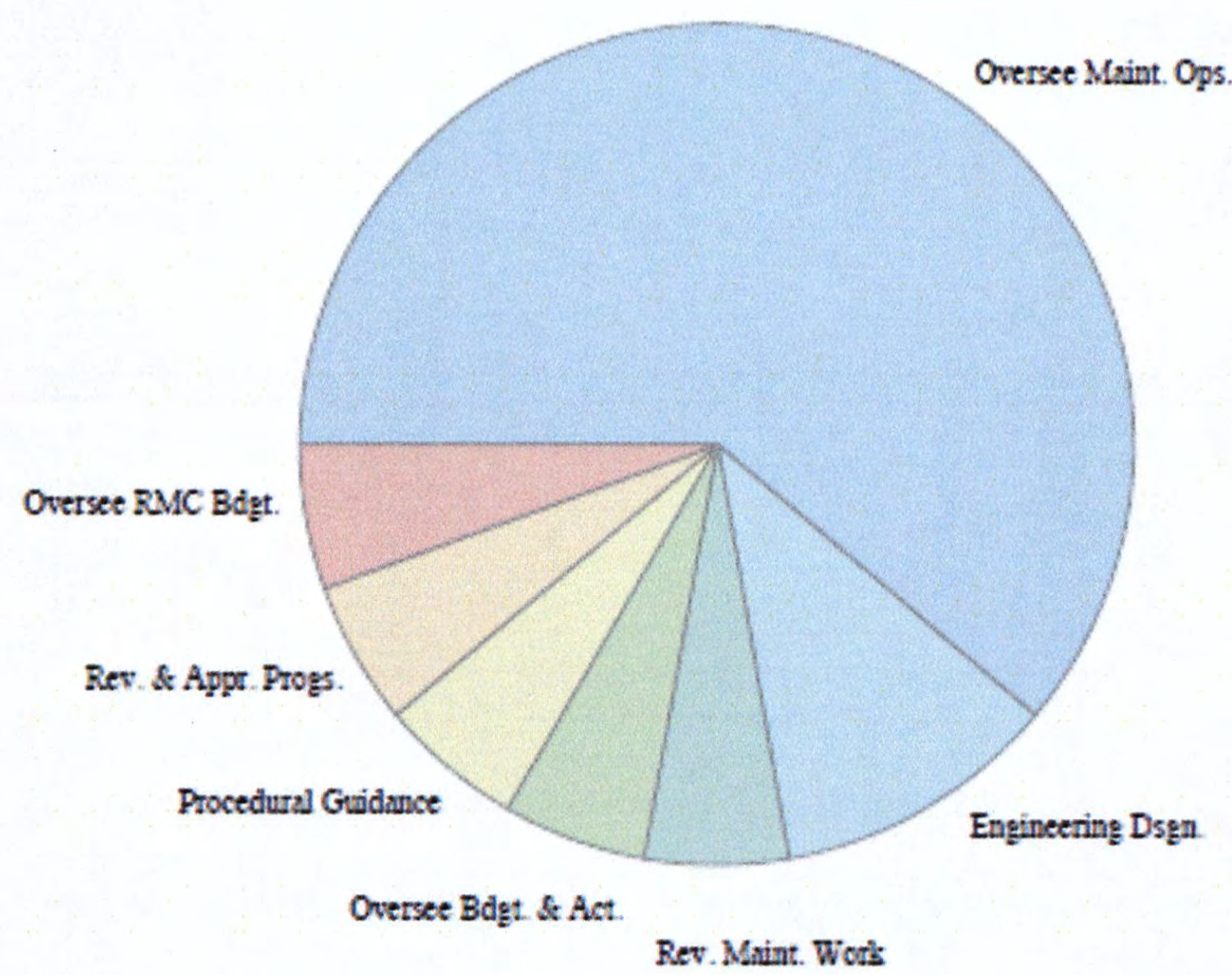


Figure 5. Responses to Question 3

n = 18 (Number of Districts Responding)
R = 18 (Total Number of Responses)

Responses to Question 4

Is your district experiencing edge failures?

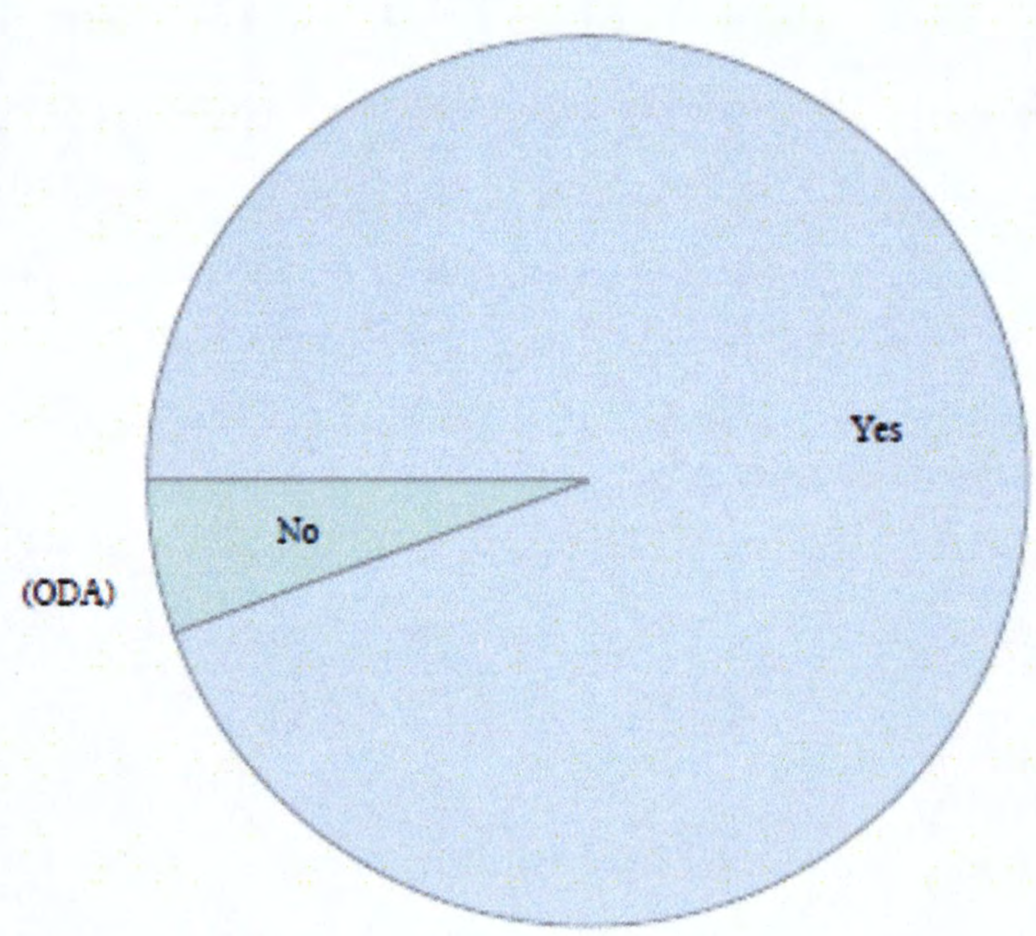


Figure 6. Responses to Question 4

n = 18 (Number of Districts Responding)
R = 18 (Total Number of Responses)

Responses to Question 5

What are the main forms of edge failures in the district?

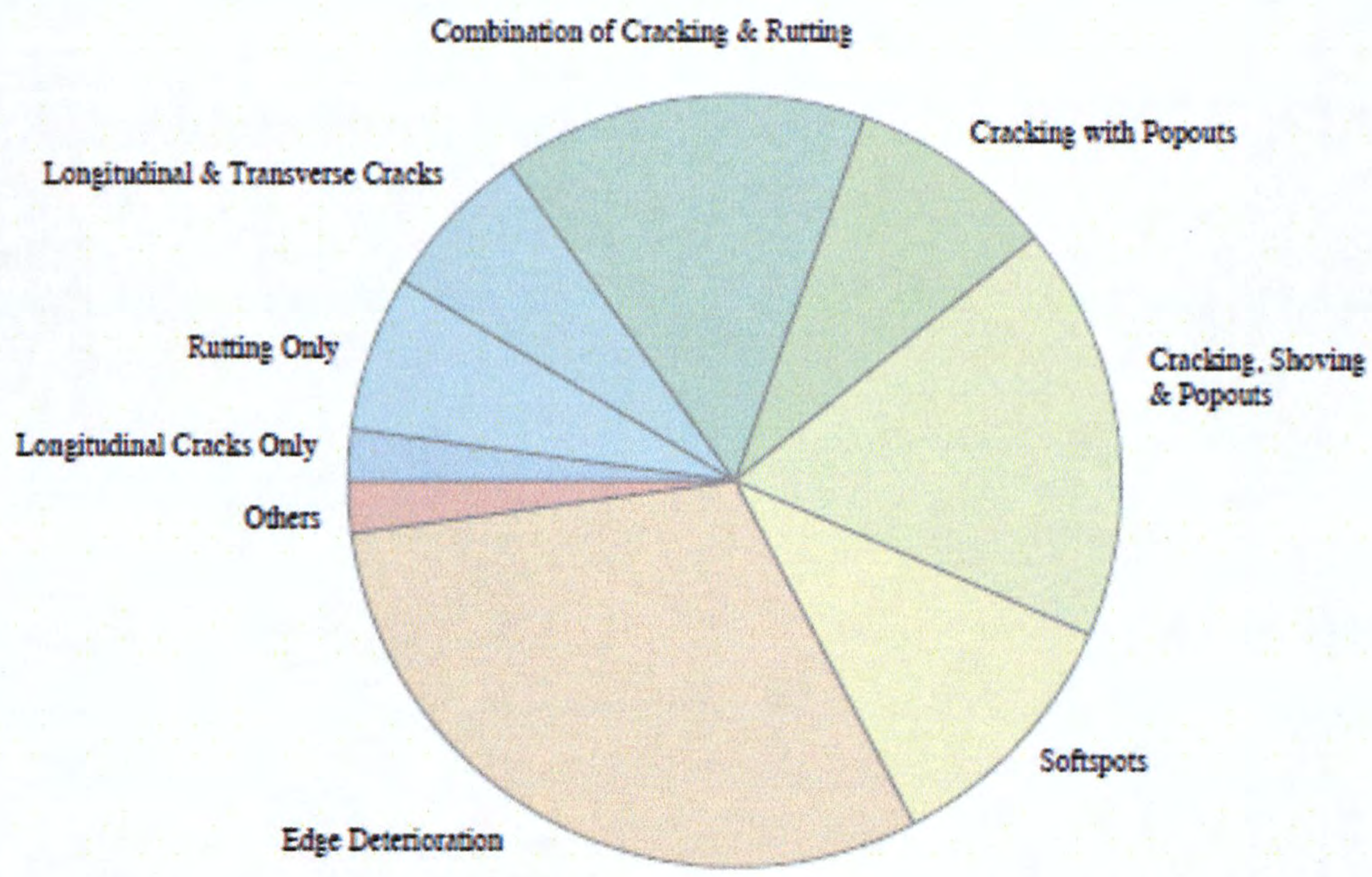


Figure 7. Responses to Question 5

n = 17 (Number of Districts Responding)
R = 46 (Total Number of Responses)

Responses to Question 6

Overall, how do you evaluate the severity of these distresses?

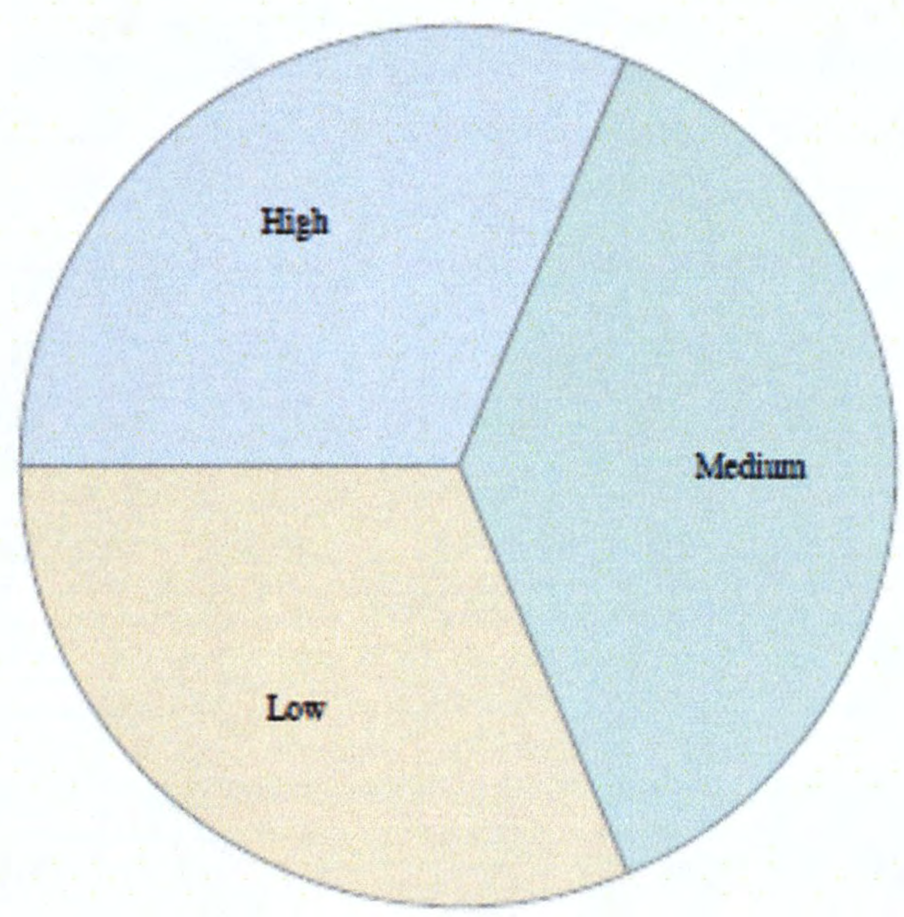


Figure 8. Responses to Question 6

Notes: Only one set of dimensions were available: Low: 50 x 2 ft area, no crack dimensions.

n = 16 (Number of Districts Responding)
R = 16 (Total Number of Responses)

Responses to Question 7

How far from the pavement edge does the failure generally occur?

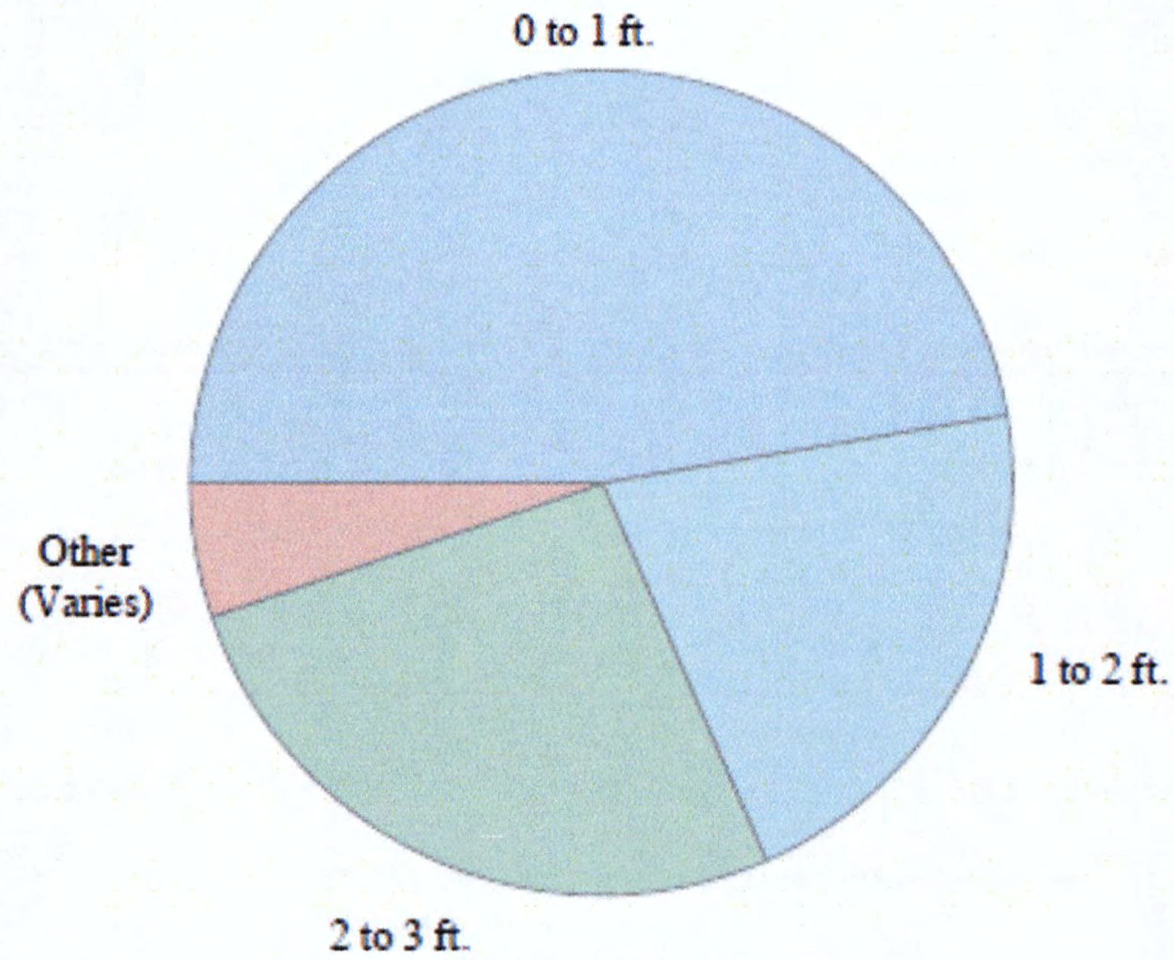


Figure 9. Responses to Question 7

n = 17 (Number of Districts Responding)
R = 19 (Total Number of Responses)

Responses to Question 8

What is the type and width of shoulder in the areas of edge failure?

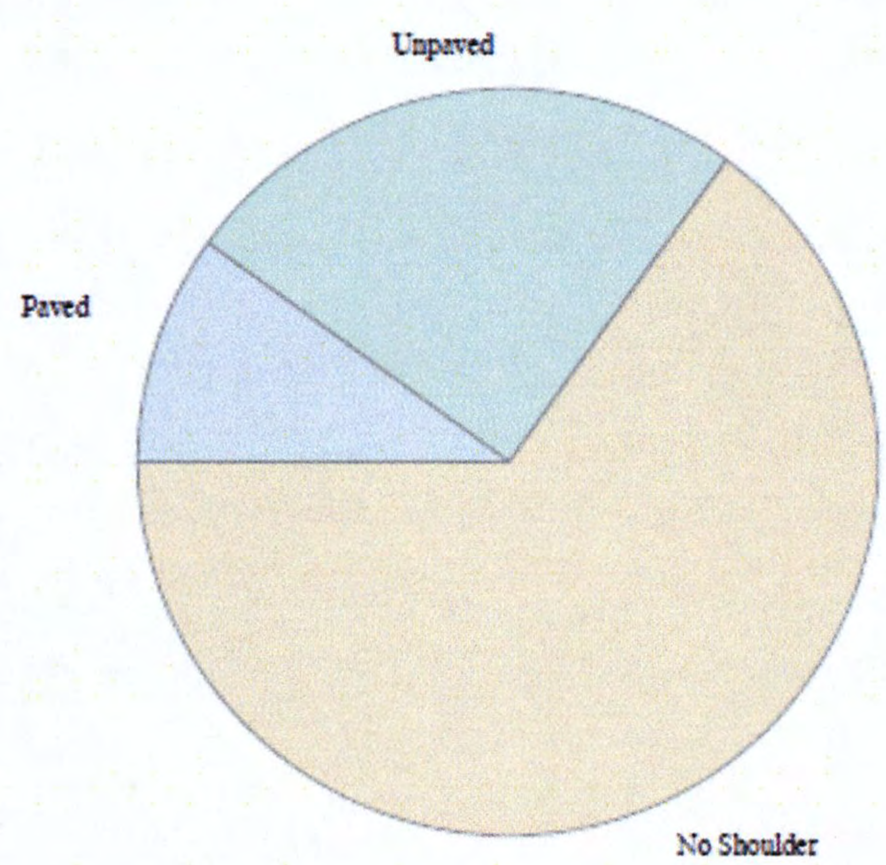


Figure 10. Responses to Question 8

n = 17 (Number of Districts Responding)
R = 20 (Total Number of Responses)

Width (5 Responses)	
Paved	Less than 4 ft Varies
Unpaved	1 to 2 ft Varies Less than 4 ft

Responses to Question 9

What are the possible reasons for edge failures in the district?

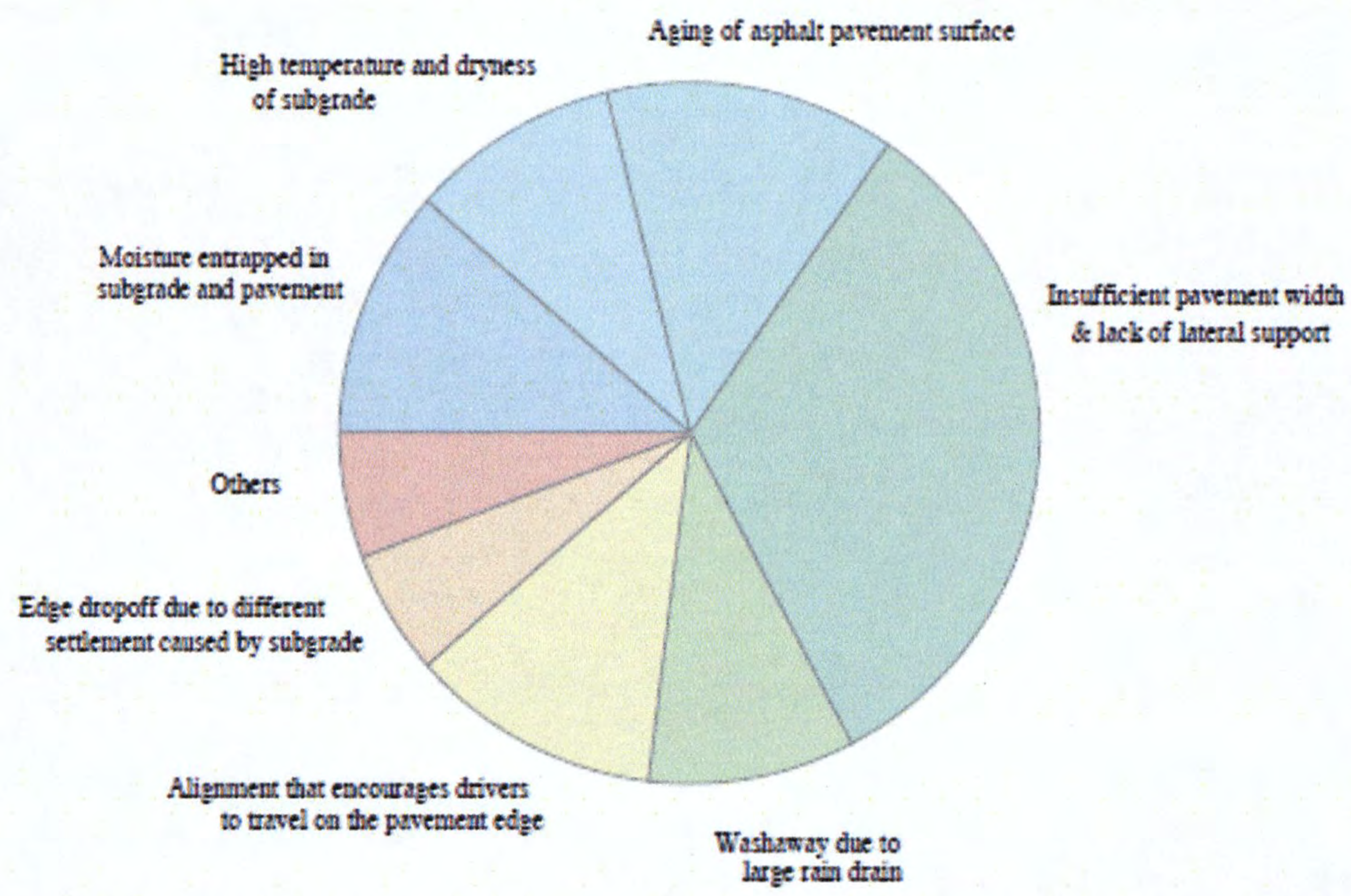


Figure 11. Responses to Question 9

n = 17 (Number of Districts Responding)
R = 52 (Total Number of Responses)

Other:
1. Large vehicle turning at driveways & intersections.
2. Insufficient strength.
3. Not proper cross slope.

Table 2. Responses to Question 9
What are the possible reasons for edge failure in the district?

	Zone	Entraped Moisture	Dry Subgrade	Aged Asphalt	Lack of Shoulder	Washaway	Asphalt-Base Adhesion	Alignment	Subgrade Settlement	Other
"YKM"	1	0	0	1	1	1	0	1	0	0
"SAT"	1	0	0	1	1	1	0	0	0	1
"CRP"	1	0	0	0	1	0	0	0	0	0
"PHR"	1	0	0	1	1	0	0	0	0	0
"LRD"	1	0	0	1	1	0	0	0	0	0
"ODA"	2	0	0	0	0	0	0	0	0	0
"AMA"	3	0	0	1	1	0	0	0	1	1
"LBB"	3	1	0	1	1	0	0	1	0	0
"CHS"	3	0	0	0	1	1	0	1	0	0
"PAR"	4	1	1	0	1	0	0	0	0	0
"WFS"	4	1	1	0	1	1	0	1	1	0
"ABL"	4	1	1	1	1	0	0	0	0	0
"WAC"	4	0	1	0	1	0	0	0	0	1
"TYL"	4	1	0	0	1	0	0	0	0	0
"BWD"	4	0	0	0	1	0	0	0	0	0
"LFK"	5	1	0	0	1	1	0	1	1	0
"BRY"	5	0	1	0	1	0	0	0	0	0
"BMT"	5	0	0	0	1	0	0	1	0	0
"ATL"	4	0	0	0	1	0	0	1	0	1

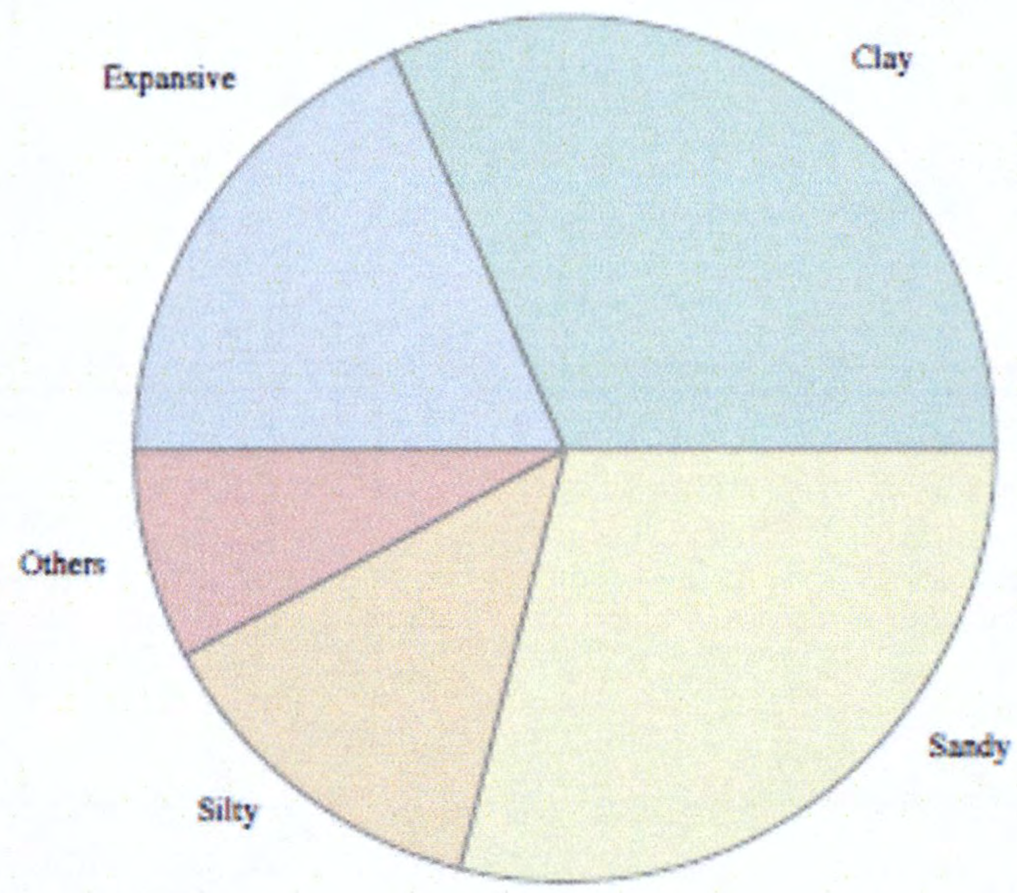
n = 18 (Number of Districts Responding)*
R = 55 (Total Number of Responses)

Other:
1. Large vehicle turning at driveways & intersections.
2. Insufficient strength.
3. Not proper cross slope.
4. Shrinkage cracking due to soil; poor drainage.

*The Atlanta District responses were added to Table 2.

Responses to Question 10

What are the main soil types in the district?



What are the base material types in the district?

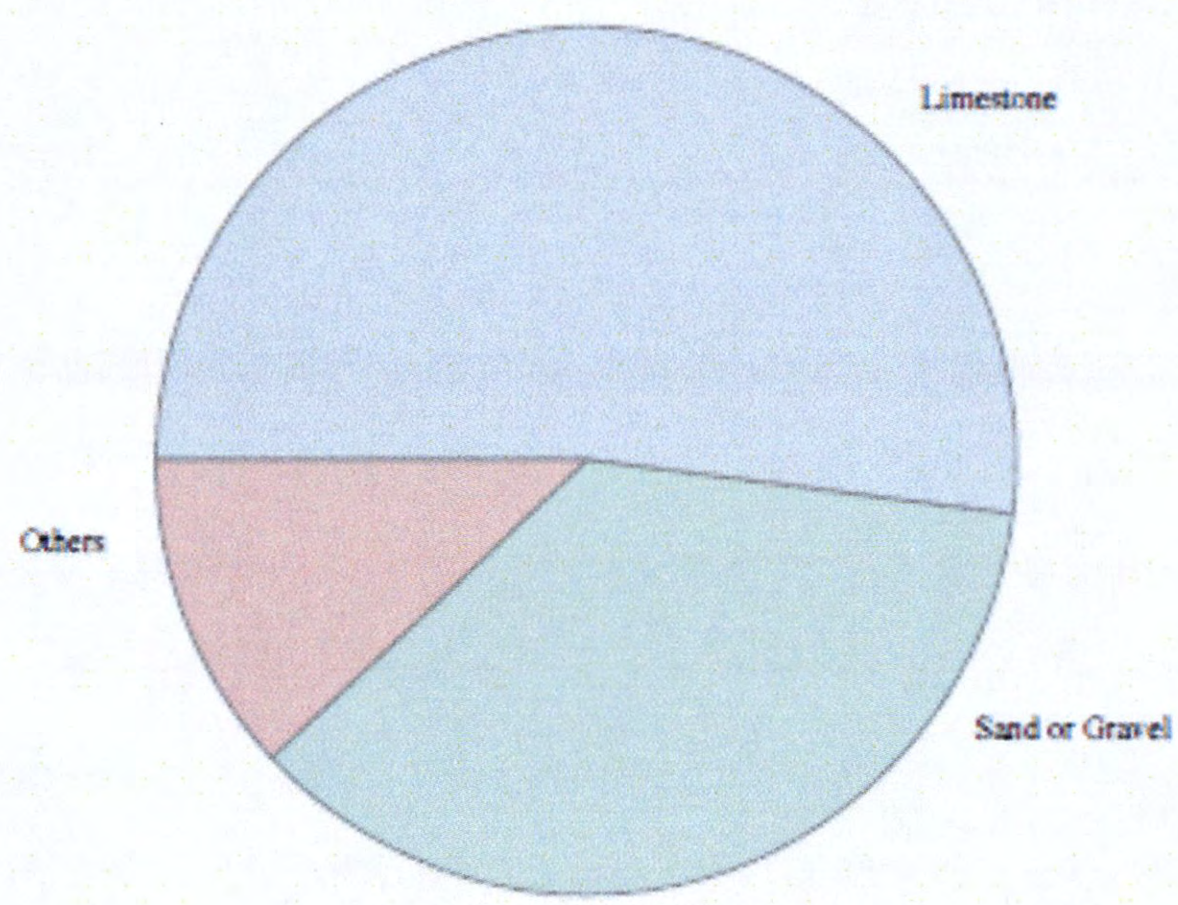


Figure 12. Responses to Question 10

n = 17 (Number of Districts Responding)
R = 63 (Total Number of Responses)

Table 3. Responses to Question 10
What are the main soil and base material types?

	Soils						Bases			
	"Zone"	"Expnsv"	"Clay"	"Sandy"	"Silty"	"Othr"	"Limstn"	"Sand\Grvl"	"Granit"	"Othr"
"YKM"	1	1	1	1	0	0	1	1	0	0
"SAT"	1	0	1	1	0	0	1	0	0	0
"CRP"	1	1	1	1	0	0	1	0	0	1
"PHR"	1	0	1	1	0	0	0	0	0	1
"LRD"	1	0	0	1	0	0	1	0	0	0
"ODA"	2	0	0	0	0	0	0	0	0	0
"AMA"	3	0	1	1	0	0	0	1	0	0
"LBB"	3	1	1	0	0	1	1	1	0	1
"CHS"	3	0	0	1	1	0	0	1	0	0
"PAR"	4	1	1	0	0	0	1	0	0	0
"WFS"	4	0	1	1	1	0	1	1	0	0
"ABL"	4	0	1	1	0	0	1	1	0	0
"WAC"	4	1	1	0	0	0	1	1	0	0
"TYL"	4	0	1	0	0	0	1	1	0	0
"BWD"	4	0	0	1	1	1	1	0	0	0
"LFK"	5	0	0	1	1	0	1	1	0	0
"BRY"	5	1	1	0	1	1	1	0	0	0
"BMT"	5	1	0	0	0	0	0	0	0	0
"ATL"	4	1	1	1	1	0	1	1	0	1

n = 18 (Number of Districts Responding)*
R = 63 (Total Number of Responses)

Other Soils :
1. Rocky.
2. Caliche.
3. Caliche.

Other Bases :
1. Caliche
2. Caliche.
3. Caliche.
4. Iron ore.
5. Sandstone.

*The Atlanta District responses were added to Table 3.

Responses to Question 11

Does the district have sites with edge failures proximal to poor drainage or flood areas?

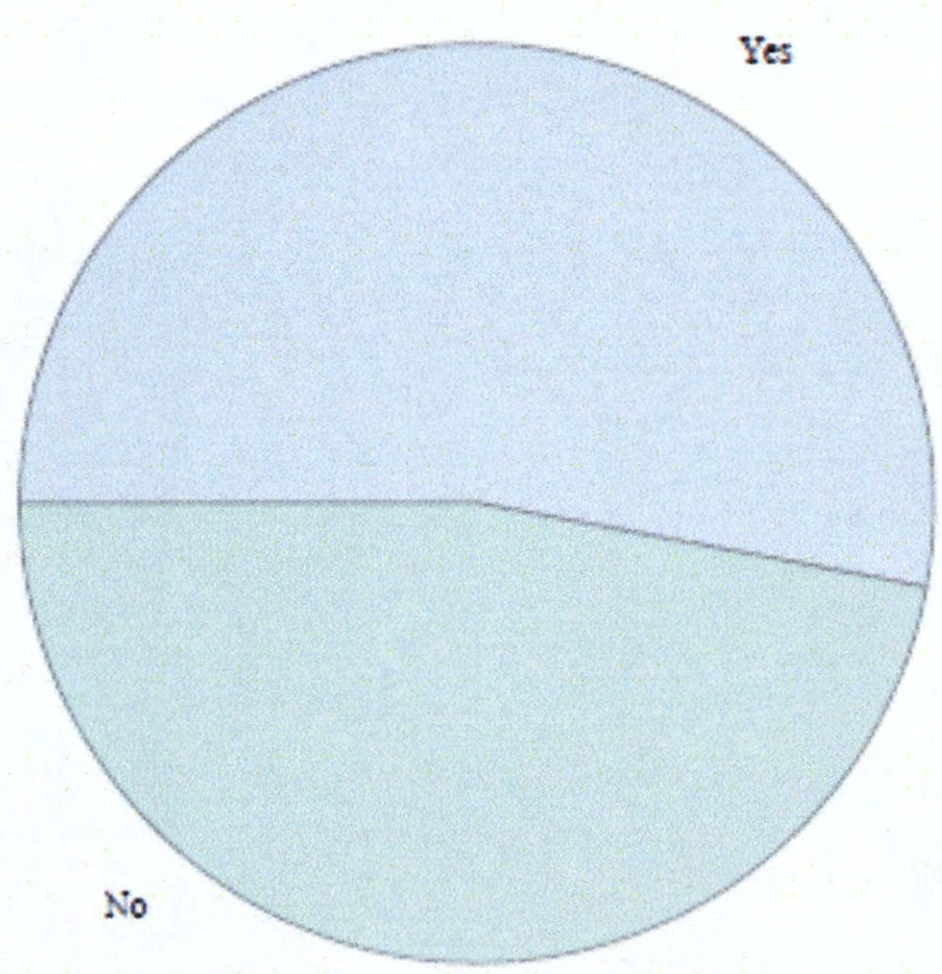


Figure 13. Responses to Question 11

n = 17 (Number of Districts Responding)
R = 17 (Total Number of Responses)

Responses to Question 12

In general, what would you say are the most important causes of edge failures in the district?
(Material, Design, Environmental Causes)

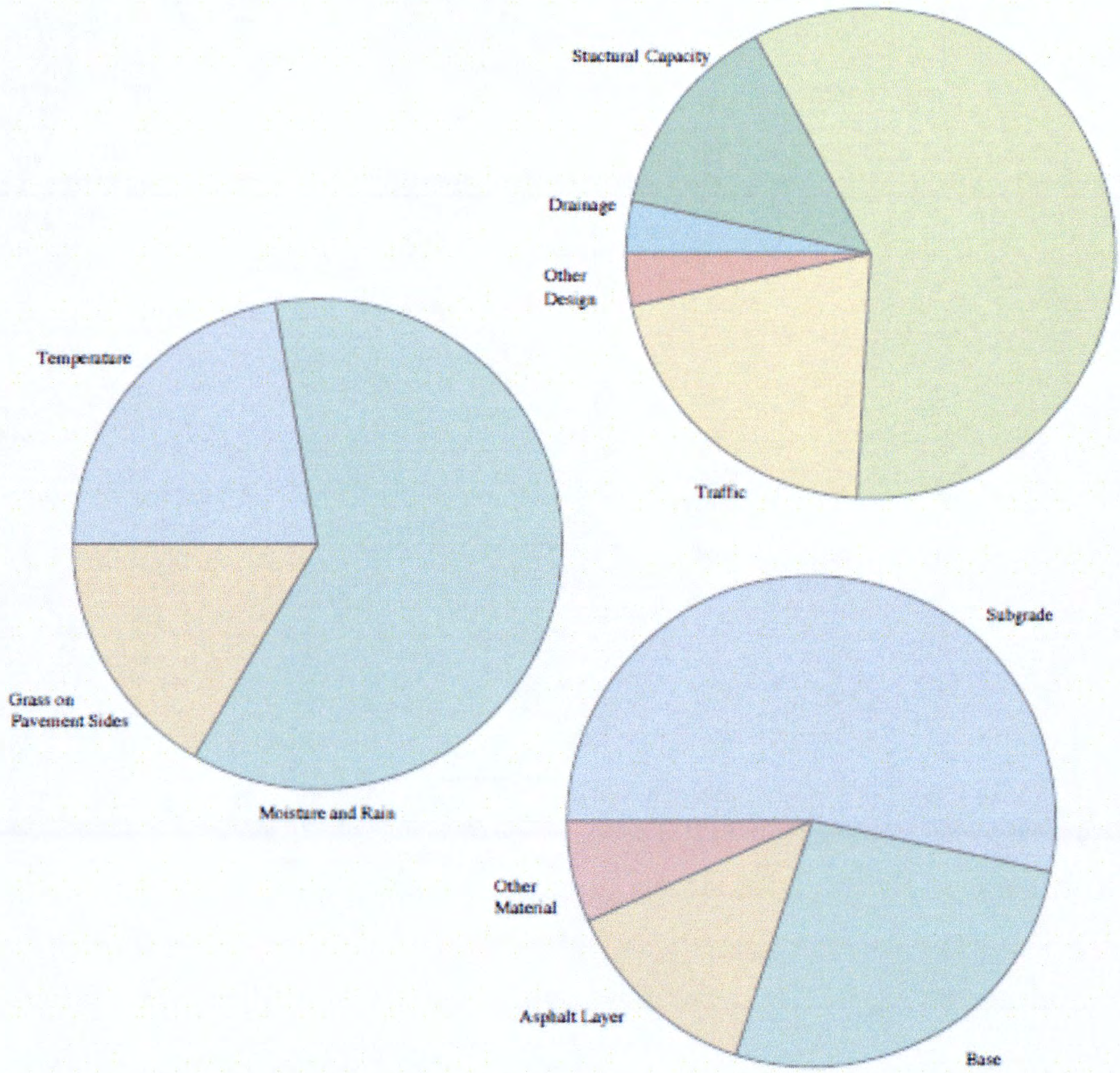


Figure 14. Responses to Question 12

n = 17 (Number of Districts Responding)
R = 62 (Total Number of Responses)

Responses to Question 13

Does the district have a threshold to decide when the treatment begins on edge failures?

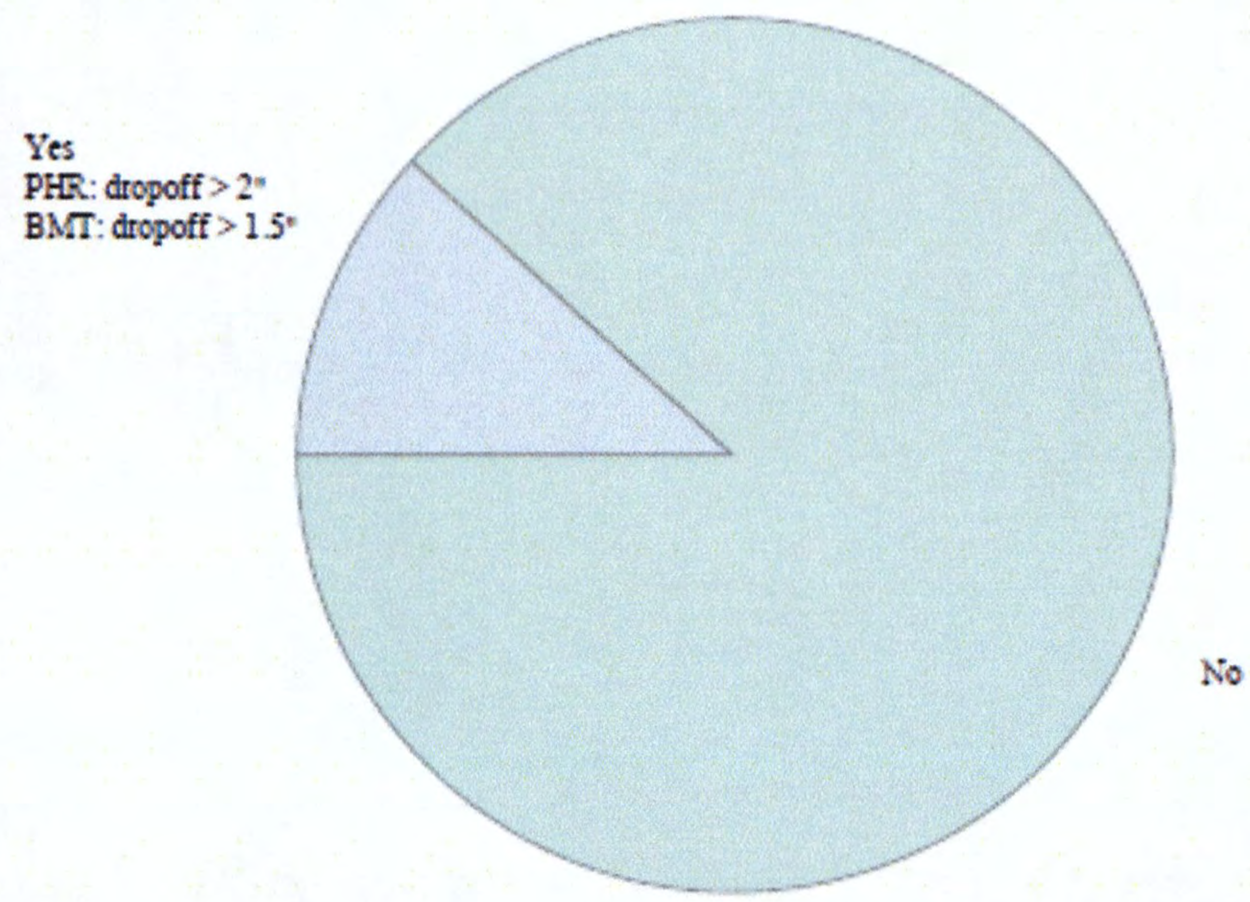


Figure 15. Responses to Question 13

n = 17 (Number of Districts Responding)
R = 17 (Total Number of Responses)

Responses to Question 14

What are the current rehabilitation methods for edge failures in the district?

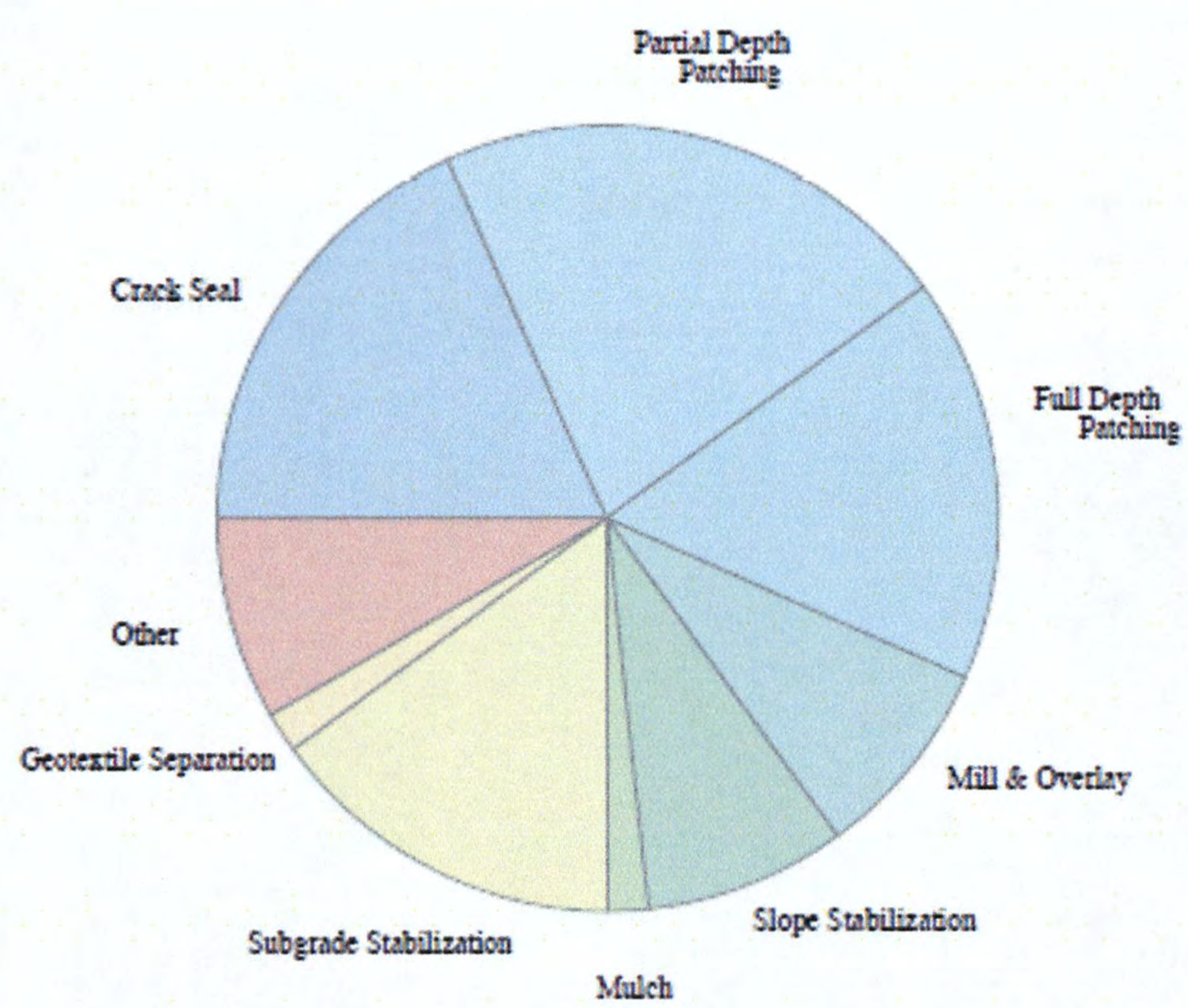


Figure 16. Responses to Question 14

n = 17 (Number of Districts Responding)
R = 60 (Total Number of Responses)

Other:
1. Edge widening.
2. Adding base.
3. Blading material next to pavement.

Responses to Question 15

What other secondary routine maintenance work
is applied to edge failures?

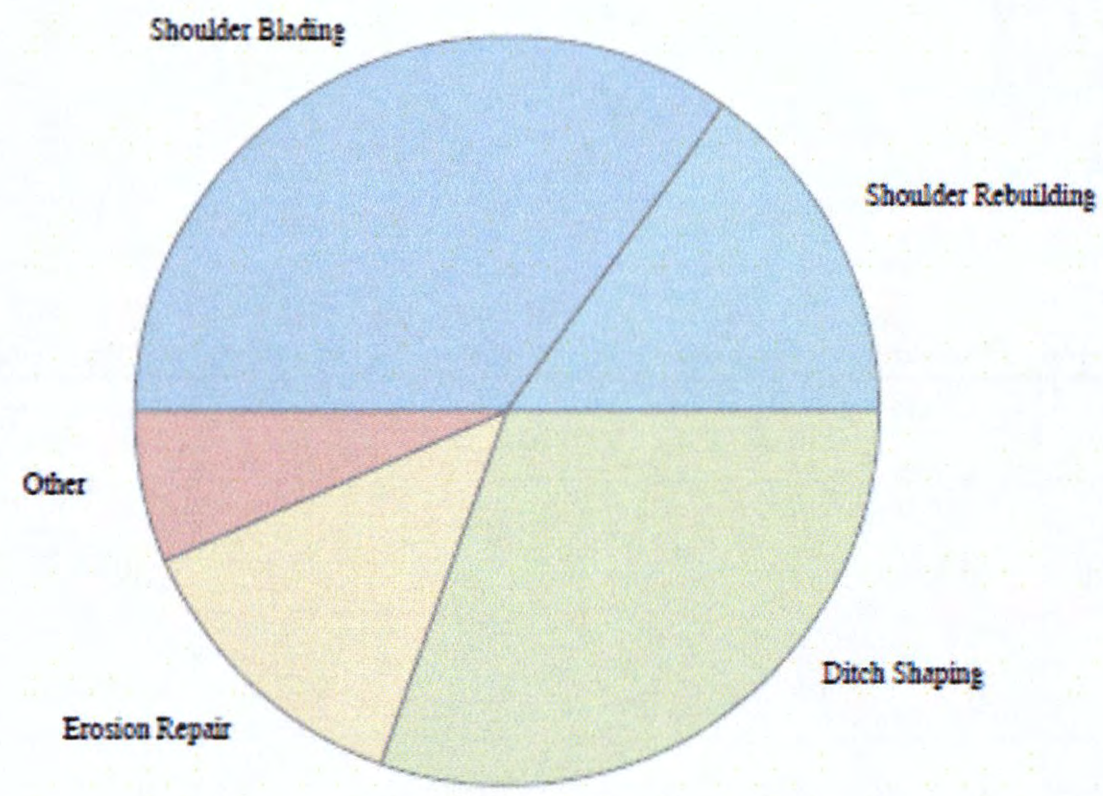


Figure 17. Responses to Question 15

n = 17 (Number of Districts Responding)
R = 46 (Total Number of Responses)

Other: 1. Backfill pavement edges.
2. Strip seal.

Responses to Question 16

Are there rehabilitation techniques used not mentioned here?

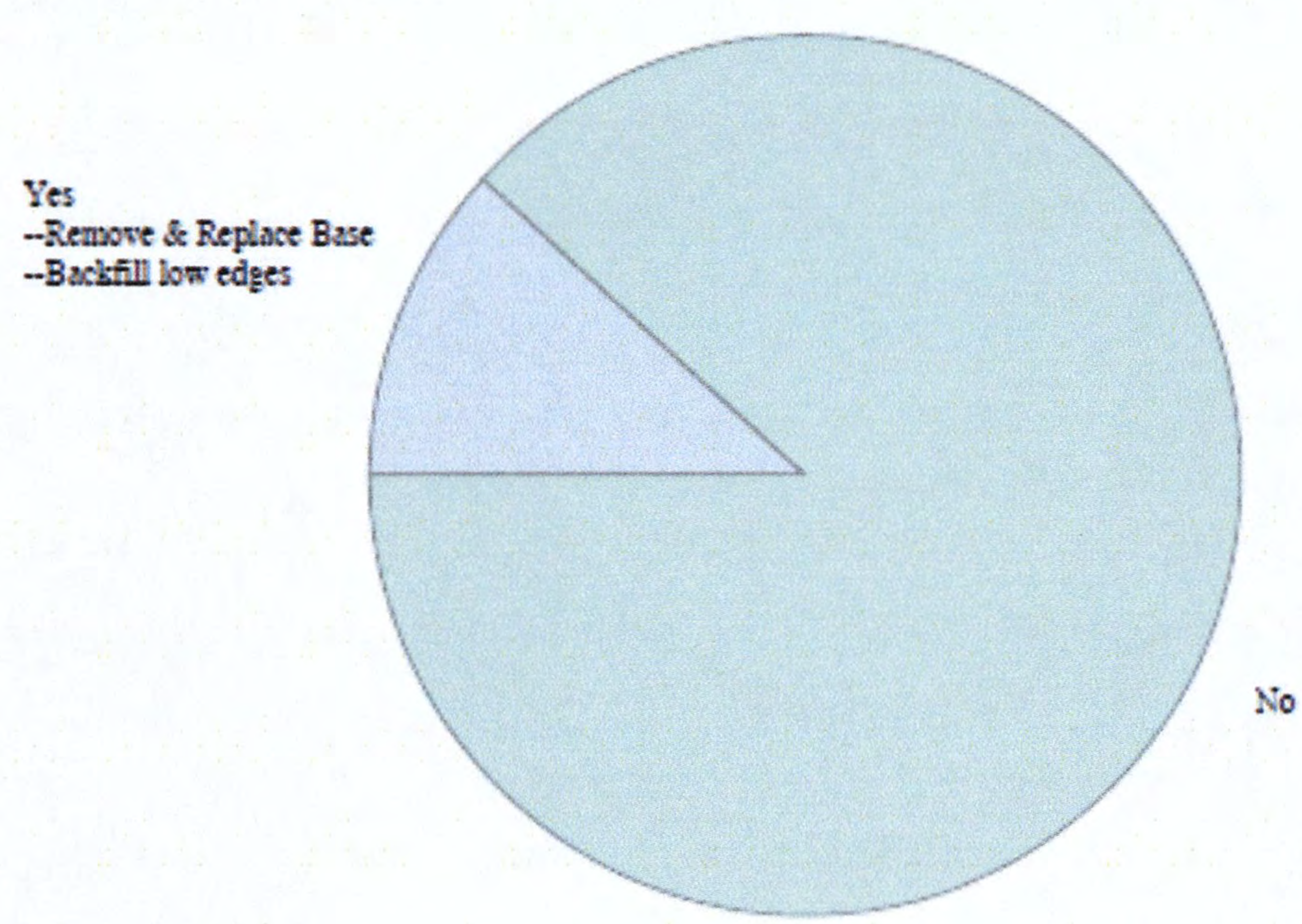


Figure 18. Responses to Question 16

n = 17 (Number of Districts Responding)
R = 17 (Total Number of Responses)

Responses to Question 17

What is the effectiveness of the current treatment?
Does the crack re-appear?

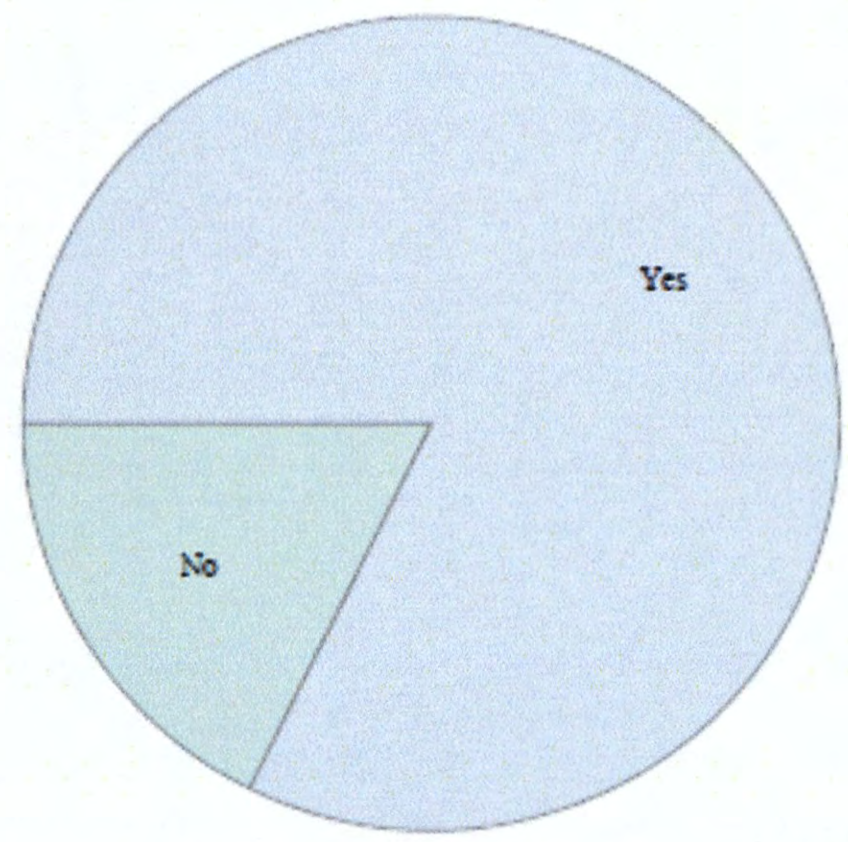


Figure 19. Responses to Question 17

n = 17 (Number of Districts Responding)
R = 17 (Total Number of Responses)

Note: This question is under the subsection of "Questions about the treatment of edge failures in the district." The crack it refers to is unclear.

Responses to Question 18

How does the district evaluate the effectiveness
of edge failure repairs?

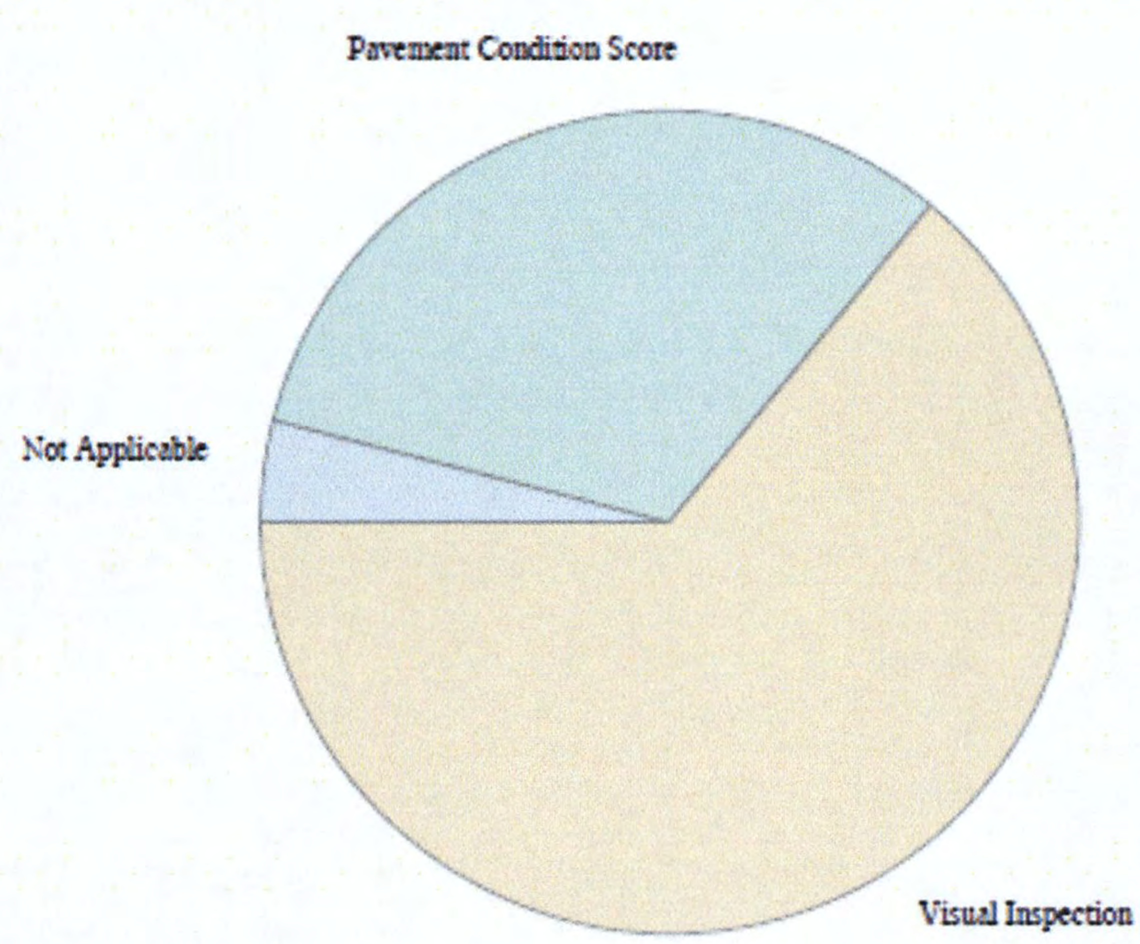


Figure 20. Responses to Question 18

n = 17 (Number of Districts Responding)
R = 25 (Total Number of Responses)

Responses to Question 19

With regard to edge failures, does the district have sections with no failures, failures and successful repairs?

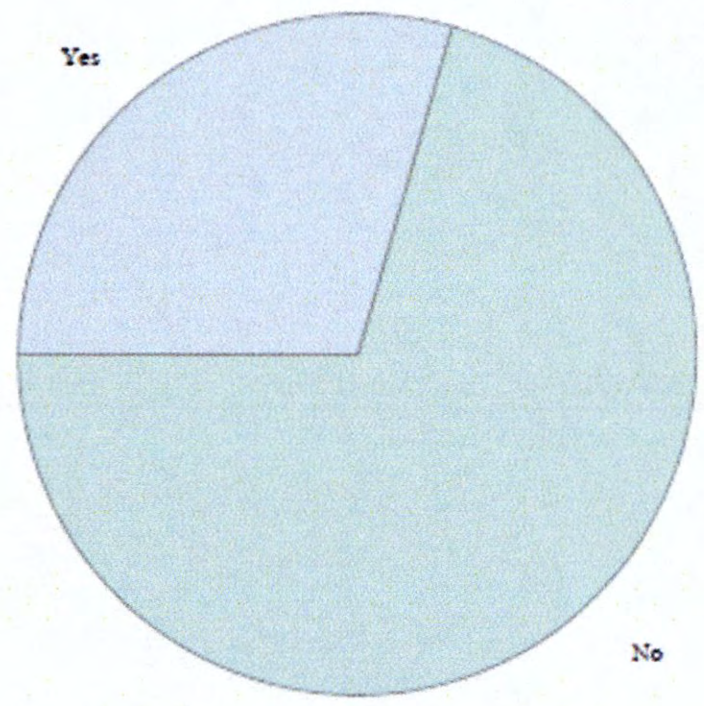


Figure 21. Responses to Question 19

n = 17 (Number of Districts Responding)
R = 17 (Total Number of Responses)

Sections

District	Location
CHS	Wheeler Co., FM 1046 from US83 east.
LBB	FM 1424, RM 170-174 (repaired)
LBB	FM 2528, RM 192-196 (damaged)
LBB	FM 179, RM 196-200 (damaged)
LBB	FM 6025, RM 188-196 (control)
LBB	FM 54, RM 316-318 (control)
BRY	Robertson Co., FM 1940 (so. half of roadway)
LFK	Nacogdoches Co., SH 21
LFK	Sabine Co., FM 2784
LFK	Sabine Co., FM 3229
BMT	(Contact Maint. Div.) FM1293, FM787

APPENDIX C
FIELD AND LABORATORY TEST DATA

Table C-1. Field Visual Survey on FM 1915-R1.

Distance (ft.)	Distress Type	Distress Length (ft)	Location	Description
489	LC*	42	Wheel Path	Patched
1050			Sampling Position	
1120	LC	32	Wheel Path	Patched
1295	TC*			
	LC	10	Wheel Path	Patched
1369	EC*			
1477	LC	25	Wheel Path	
	TC			
1520	LC	16	Wheel Path	
1536	LC	134	Wheel Path	
1685	LC	30	Center of Lane	
1781	LC	78	Center of Lane	
1977	TC			
2354	TC			
2471	LC	40	Center of Lane	
2571	TC			
2852	TC			
	LC	318	Center of Lane	
2928	LC	18	Center of Lane	Severe condition
4039	EC			
4115			End of Section 1	

*LC = Longitudinal crack, TC = Transverse crack, and EC = Edge crack.

Total length of longitudinal cracking: **743 ft

***Total number of distress observed: **19**

Table C-2. Field Visual Survey on FM 1915-C.

Distance (ft.)	Distress Type	Distress Length (ft)	Location	Description
0	LC	23	Center of Lane	
26	LC	38	Wheel Path	
95	LC	14	Center of Lane	
111	EC			
144	LC	19	Center of Lane	
200	LC	18	Center of Lane	
242	LC	103	Center of Lane	Severe condition
297	EC			
300			Sampling Position	
581	TC			
650	TC			
663	TC			
715	EC			
864	EC			
874	EC			
1026	EC			
1128	EC			
1210	EC			
1348	TC			
	LC	42	Center of Lane	
1391	LC	41	Wheel Path	
1432	LC	83		Heaving
1596	TC			
1633	EC			
1654	TC			
1688	TC			
1739	TC			
1759	EC			
1787	EC			
1806	TC			

Table C-2. Field Visual Survey on FM 1915-C (continued).

Distance (ft.)	Distress Type	Distress Length (ft)	Location	Description
1847	TC			
1912	EC			
2085	LC	5	Wheel Path	
2228	TC			
2245	TC			
2274	TC			
2324	TC			
2367	TC			
2413	TC			
2575	LC	203	Wheel Path	
3184	TC			
3545	LC	20	Edge	
3556	TC			
3580	TC			
3615	LC	44	Edge	
3900	LC	55	Wheel Path	
3986	EC			Severe condition
4032	LC	30	Wheel Path	Severe condition
4359			End of Section 2	

*Total length of longitudinal cracking: **688 ft**

Total number of distress observed: **47

Table C-3. Field Visual Survey on FM 1915-R2.

Distance (ft.)	Distress Type	Distress Length (ft)	Location	Description
780	TC			
783	EC			
1049	TC			
1240	LC	8	Wheel Path	
1286	TC			
2002	EC			
2034	TC			
2293	LC	53	Wheel Path	
2428	TC			
2519	TC			
2738	TC			
2953	LC	24	Wheel Path	
3173	TC			
3298	LC	66	Wheel Path	
3434	LC	43	Wheel Path	
3679	LC	41	Wheel Path	
3916			Sampling Position	
4003	LC	87	Wheel Path	
4044	TC			
4088	LC	44	Wheel Path	
4238	LC	57	Wheel Path	
4299	LC	2	Edge	
4488			End of Section 3	

*Total length of longitudinal cracking: **425 ft**

Total number of distress observed: **21

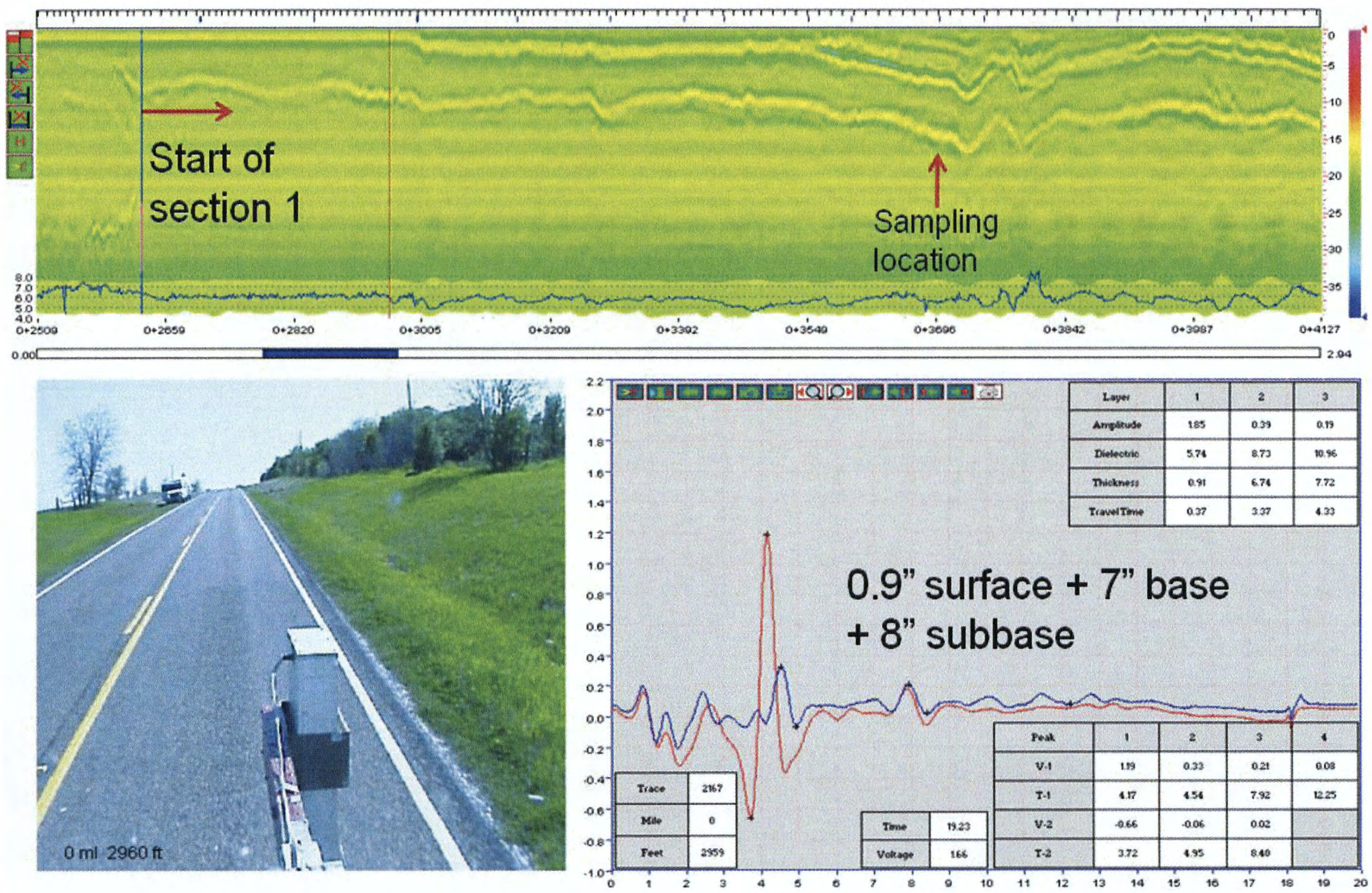


Figure C-1. GPR Data on Section 1 (Geogrid) of FM 1915.

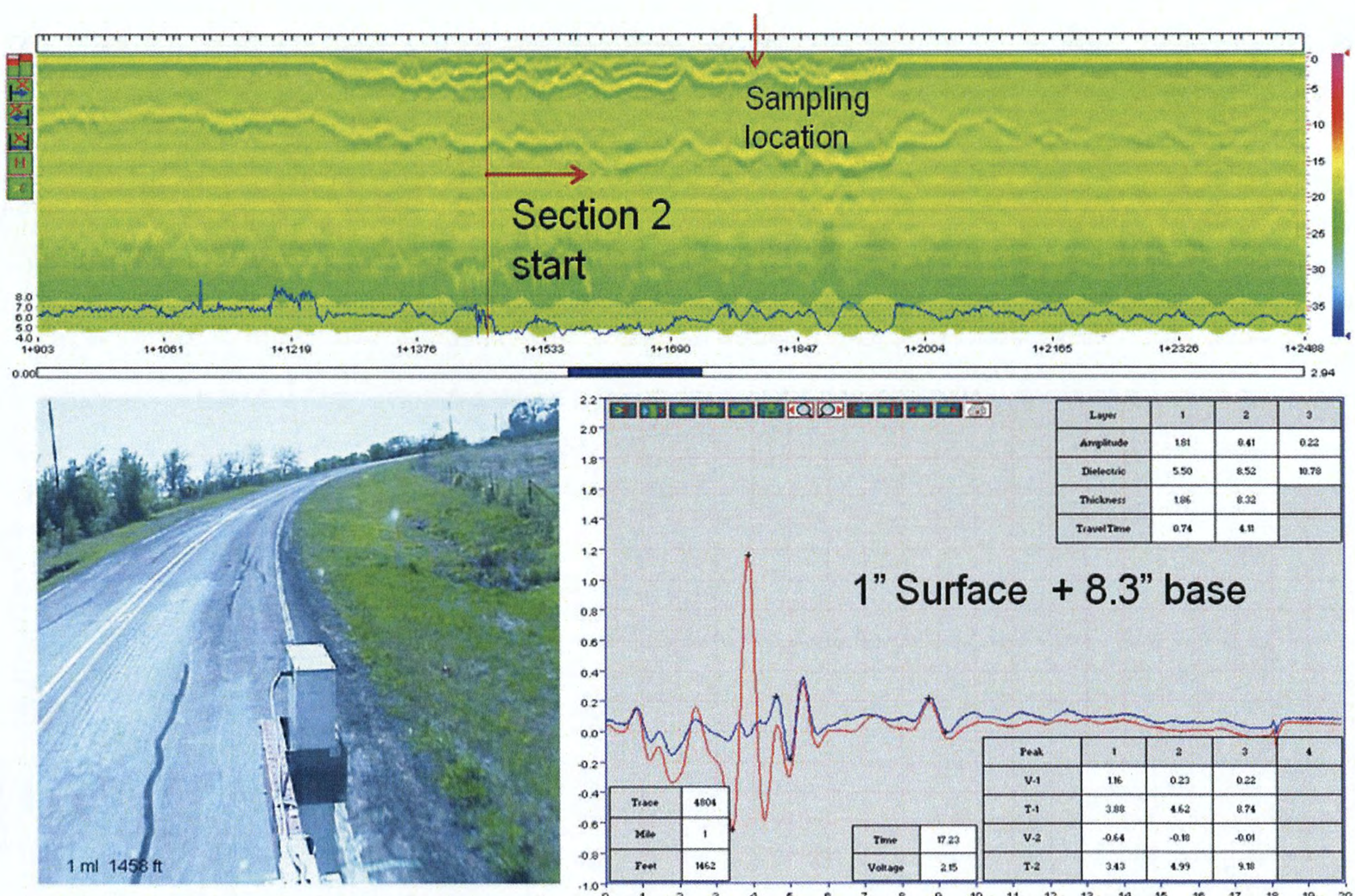


Figure C-2. GPR Data on Section 2 (Control) of FM 1915.

Figure C-3. GPR Data on Section 3 (Geogrid) of FM 1915.

Table C-4. Summary of Laboratory Testing Results of FM 1915 Sections.

	1915-R1	1915-C	1915-R2
Optimum Moisture Content (OMC) (%)*	7.4*		
Maximum Dry Density (pcf)*	114.2*		
Optimum Moisture Content (OMC) (%)	26.0	28.0	18.0
Maximum Dry Density (pcf)	86.0	87.5	109.0
# 200 passing (%)	63.4	76.8	47.3
Liquid Limit (%)	82.8	73.2	48.5
Plastic Limit (%)	27.0	34.0	19.0
Plasticity Index (%)	55.8	39.2	29.5

*The results are for base materials combined from three sections. Other numbers are for subgrade soils.

Table C-5. Soil Properties of FM 2 (after Zornberg et al., 2008).

Test	Index Parameter	Value		
		Base Course	FM2 Clay	Fire Clay
Soil Classification		GM-ML	CH	CH fat clay
Specific Gravity	Specific Gravity, Gs	2.68	2.7	2.7
Particle size analysis	D10, mm	0.6	0.1	
	D30, mm	6.0	0.3	
	D60, mm	10.8	0.7	
	Uniformity coefficient, C_0	18.0	7.0	
	Coefficient of gradation, C_c	5.6	1.3	
Atterberg limits	Liquid Limit, LL (%)		72	59
	Plastic Limit, PL (%)		33	23
	Plasticity Index, PI (%)		39	36
Standard Proctor compaction	Optimum water content (%)	7.5	32	19
	Maximum dry unit weight, g_d (kN/m^3)	22	15.5	18
Modified Proctor compaction	Optimum water content (%)			11
	Maximum dry unit weight, g_d (kN/m^3)			20

Table C-6. Summary of Field Survey on FM 2.

Station *	Description	Pictorial Description
80+00 ~ 89+00	Area surveyed: 5Eb: No geosynthetic w/lime treatment 6Eb: Geogrid 1 w/lime treatment 7Wb: Geogrid 2 w/lime treatment 8Wb: Geotextile w/lime treatment No cracks or ruts – good performance. Some extent of flushing detected from chip seal application.	
89+00 ~ 98+00	Area surveyed: 5Wb: No geosynthetic w/lime treatment 6Wb: Geogrid 1 w/lime treatment 7Eb: Geogrid 2 w/lime treatment 8Eb: Geotextile w/lime treatment There were some longitudinal (edge) cracks which were repaired on eastbound lane, no cracks are on westbound lane.	
203+00 ~ 221+00	Area surveyed: 1Wa/1Ea: No geosynthetic w/o lime treatment 2Wa/2Ea: Geogrid 1 w/o lime treatment 3Wa/3Ea: Geogrid 2 w/o lime treatment 4Wa/4Ea: Geotextile w/o lime treatment There are no edge cracks on both lanes; however, longitudinal cracks were found on a joint of both east and west bound lanes. The cracks length was about 27-ft with medium severity, initiated from 1Wa.	 

*All stations in Table C-6 and Figures C-4 to C7 refer to Figure 5.8.

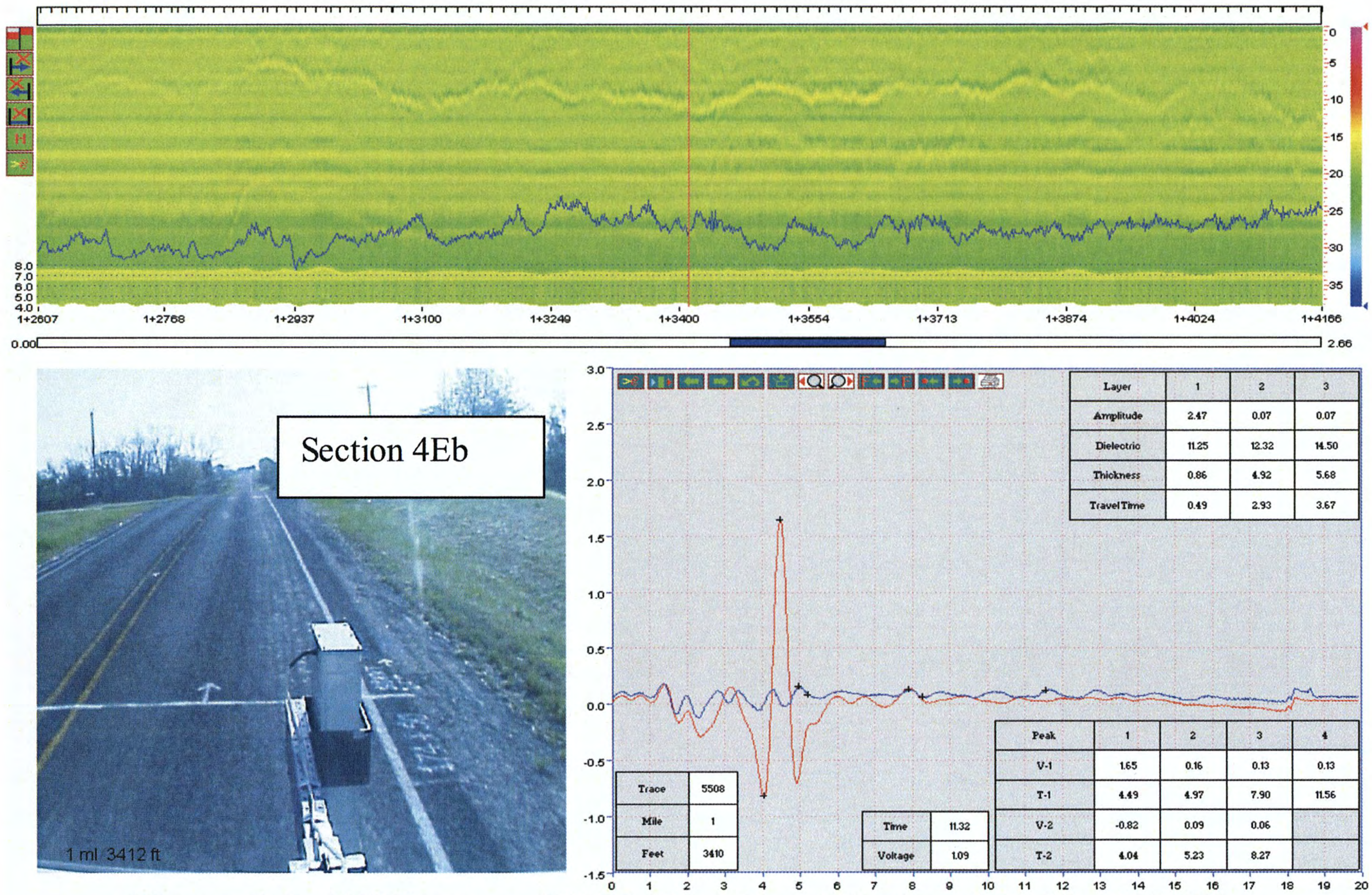


Figure C-4. GPR Survey of FM 2 (East Bound Stations 167+00 ~ 185+00).

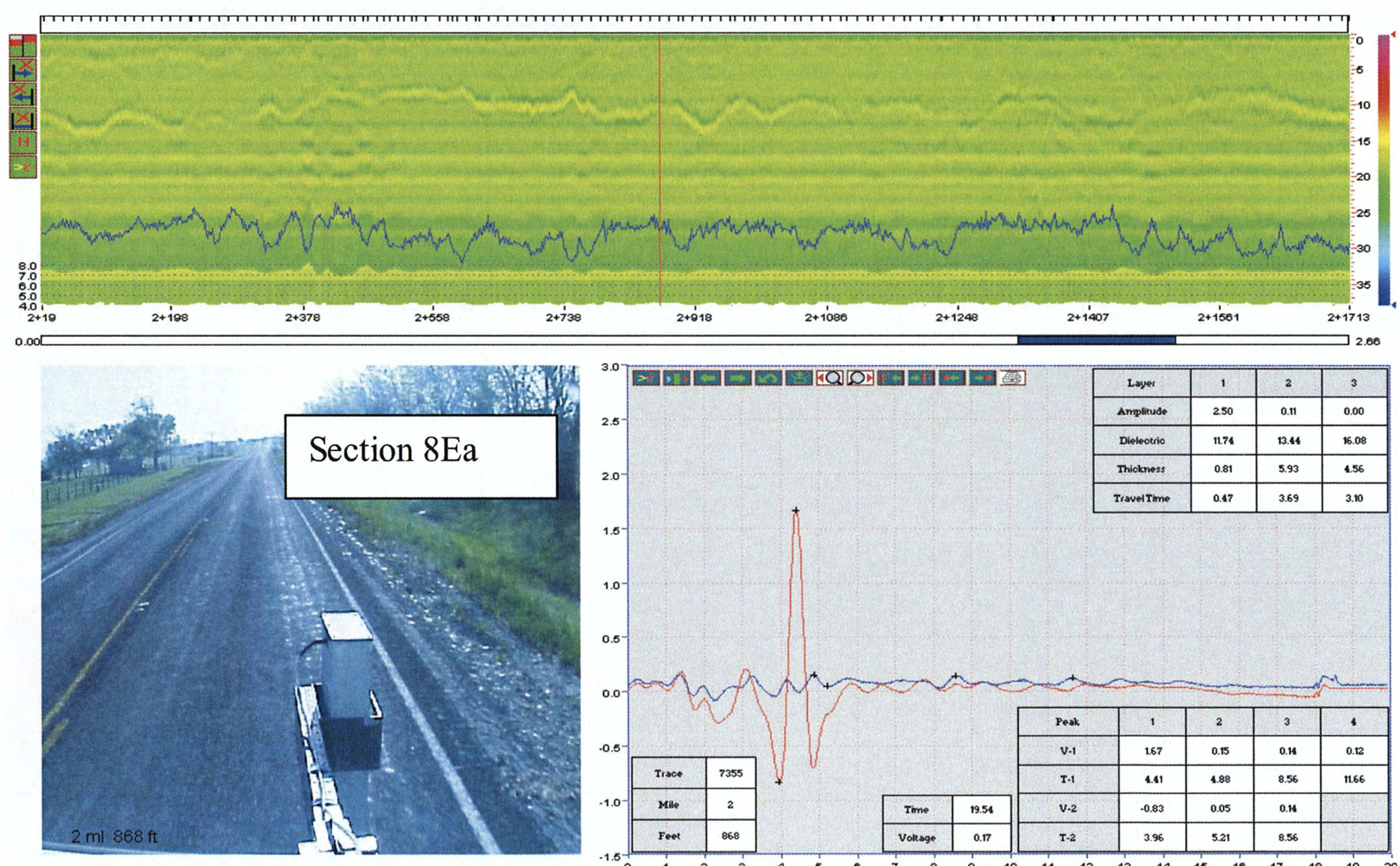


Figure C-5. GPR Survey of FM 2 (East Bound Stations 185+00 ~ 203+00).

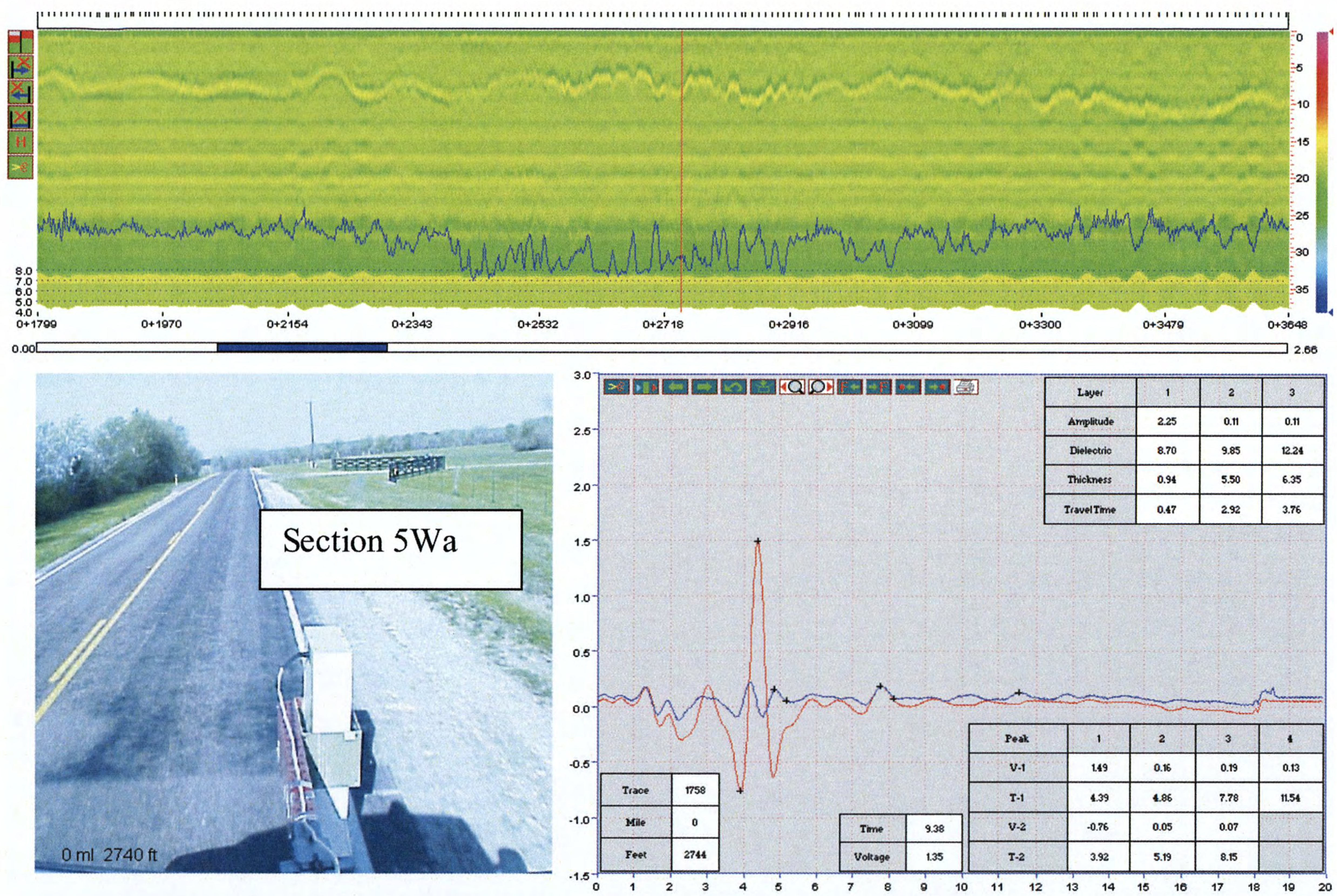


Figure C-6. GPR Survey of FM 2 (West Bound Stations 203+00 ~ 185+00).

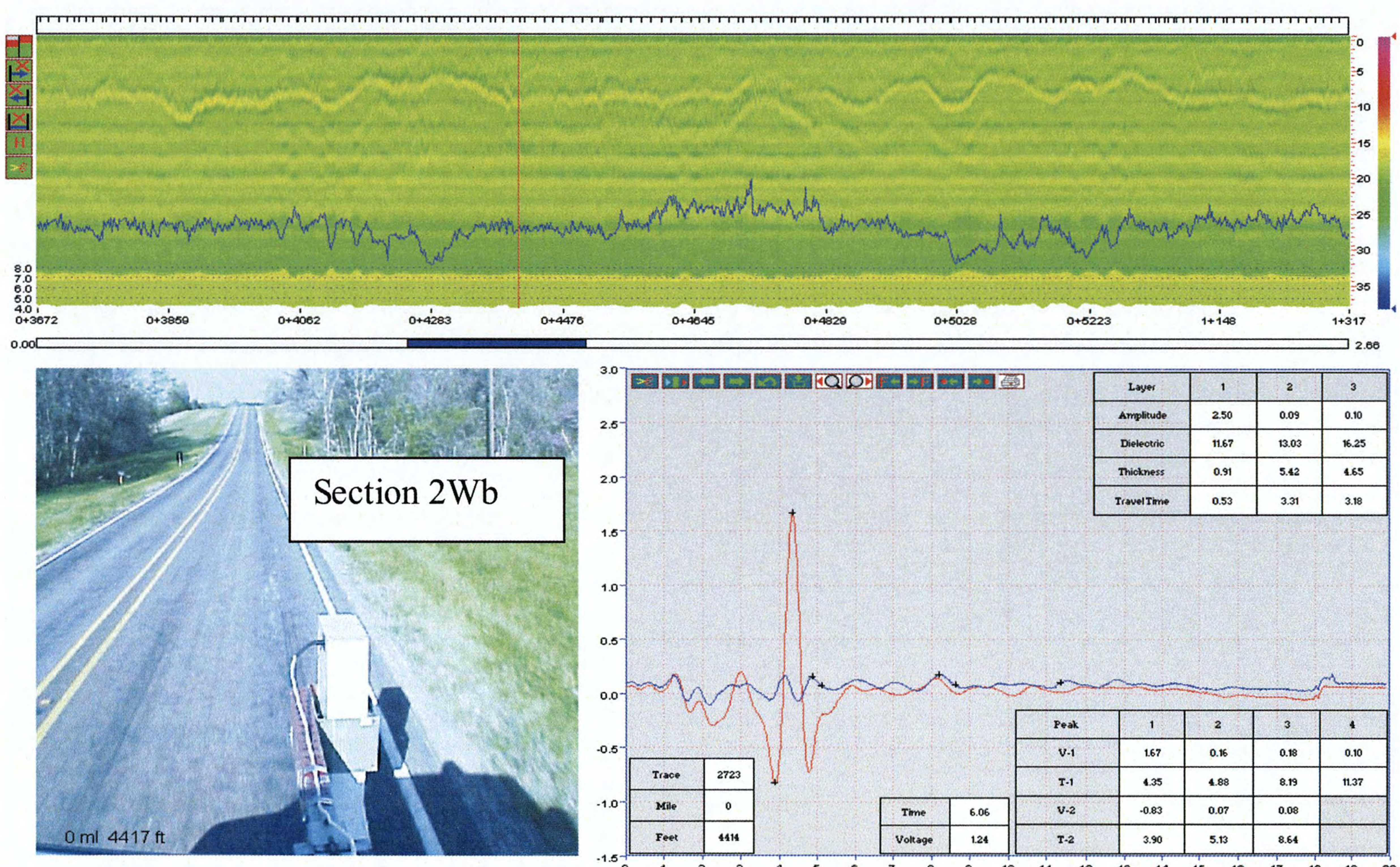


Figure C-7. GPR Survey of FM 2 (West Bound Stations 185+00 ~ 167+00).

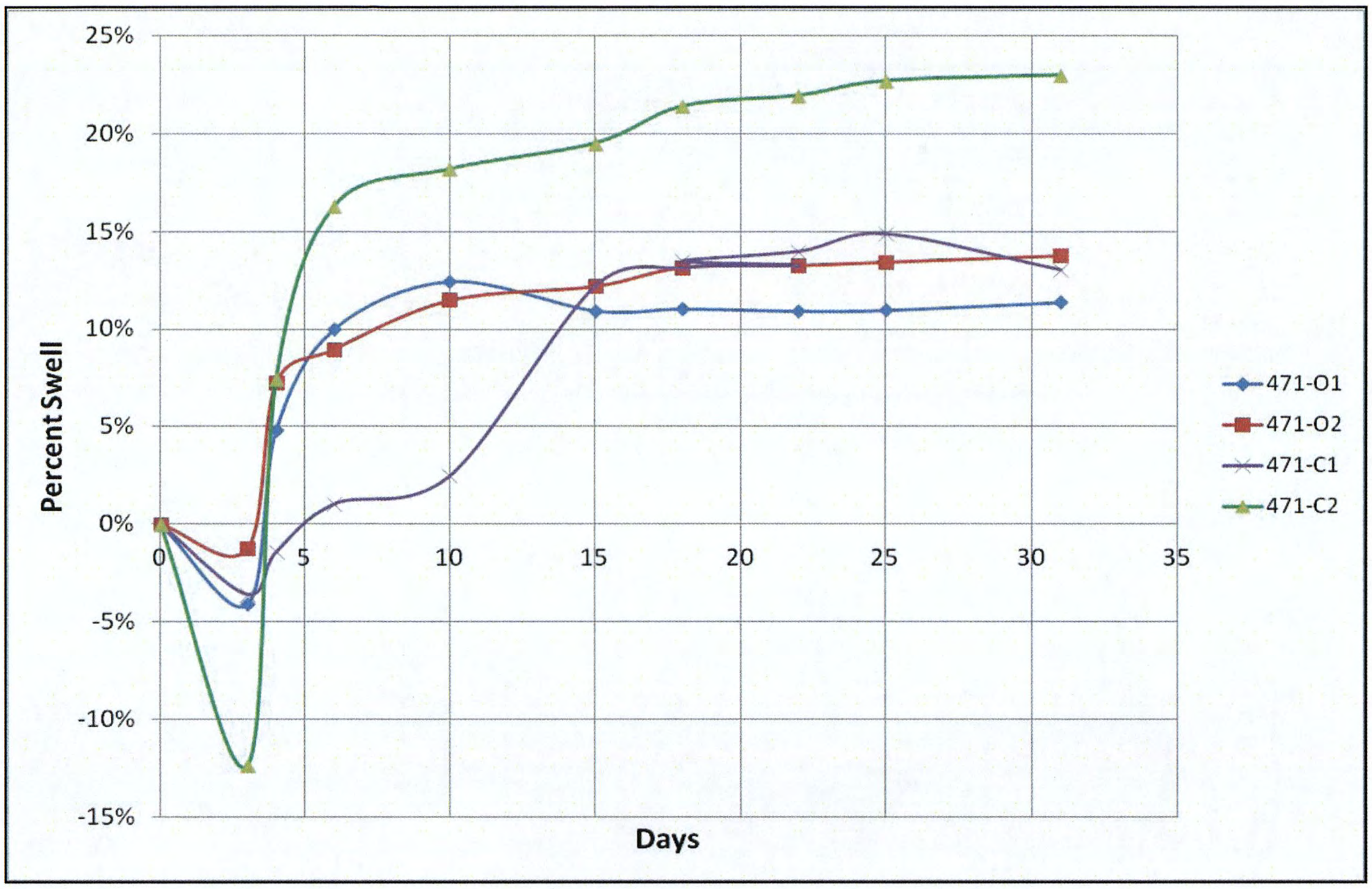


Figure C-8. 3-D Swell Test Results on FM 471.

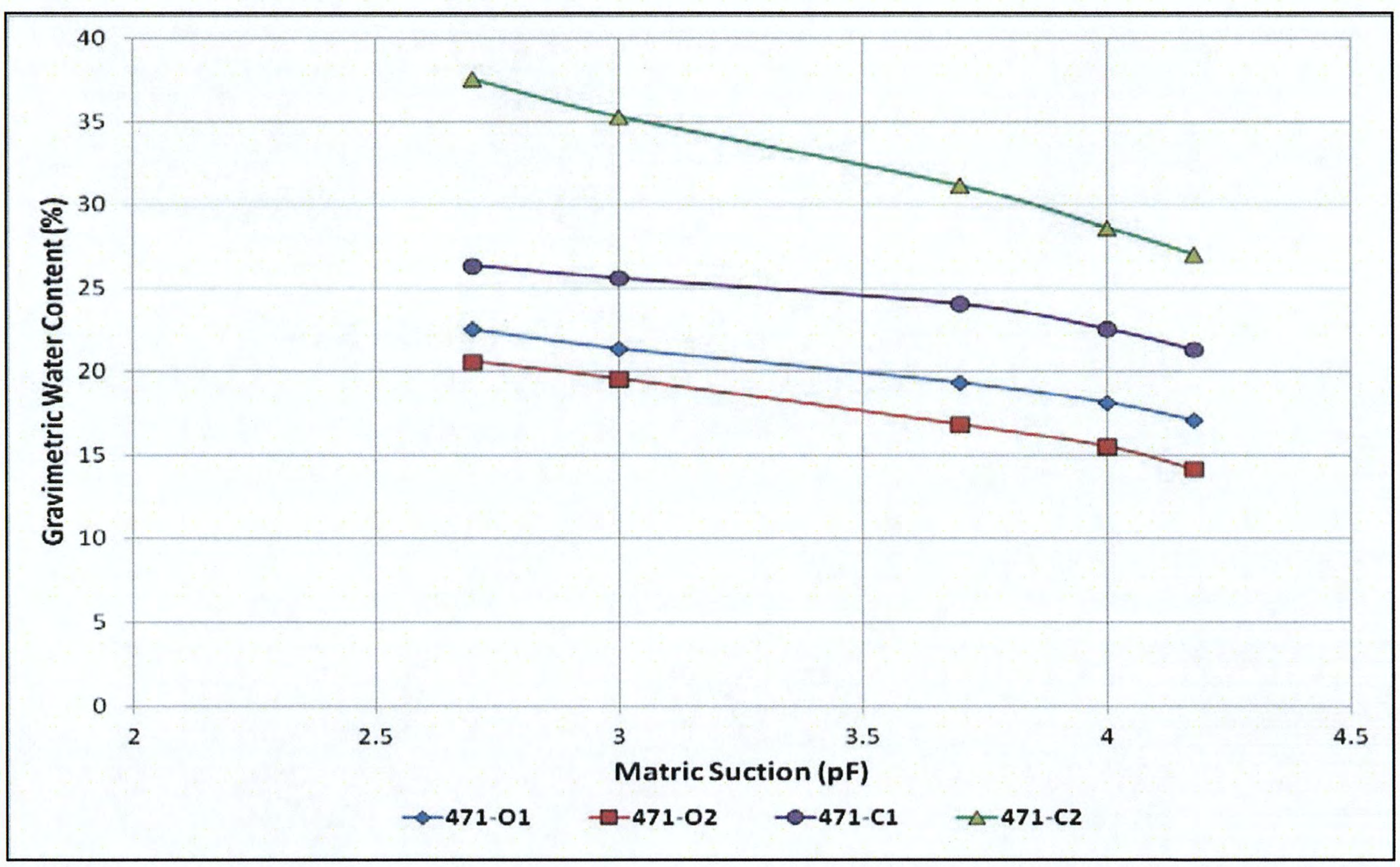


Figure C-9. Soil-Water Characteristic Curves of Subgrade Soils on FM 471.

* Results of 471-R soil are not available for swell and suction tests due to lack of materials.

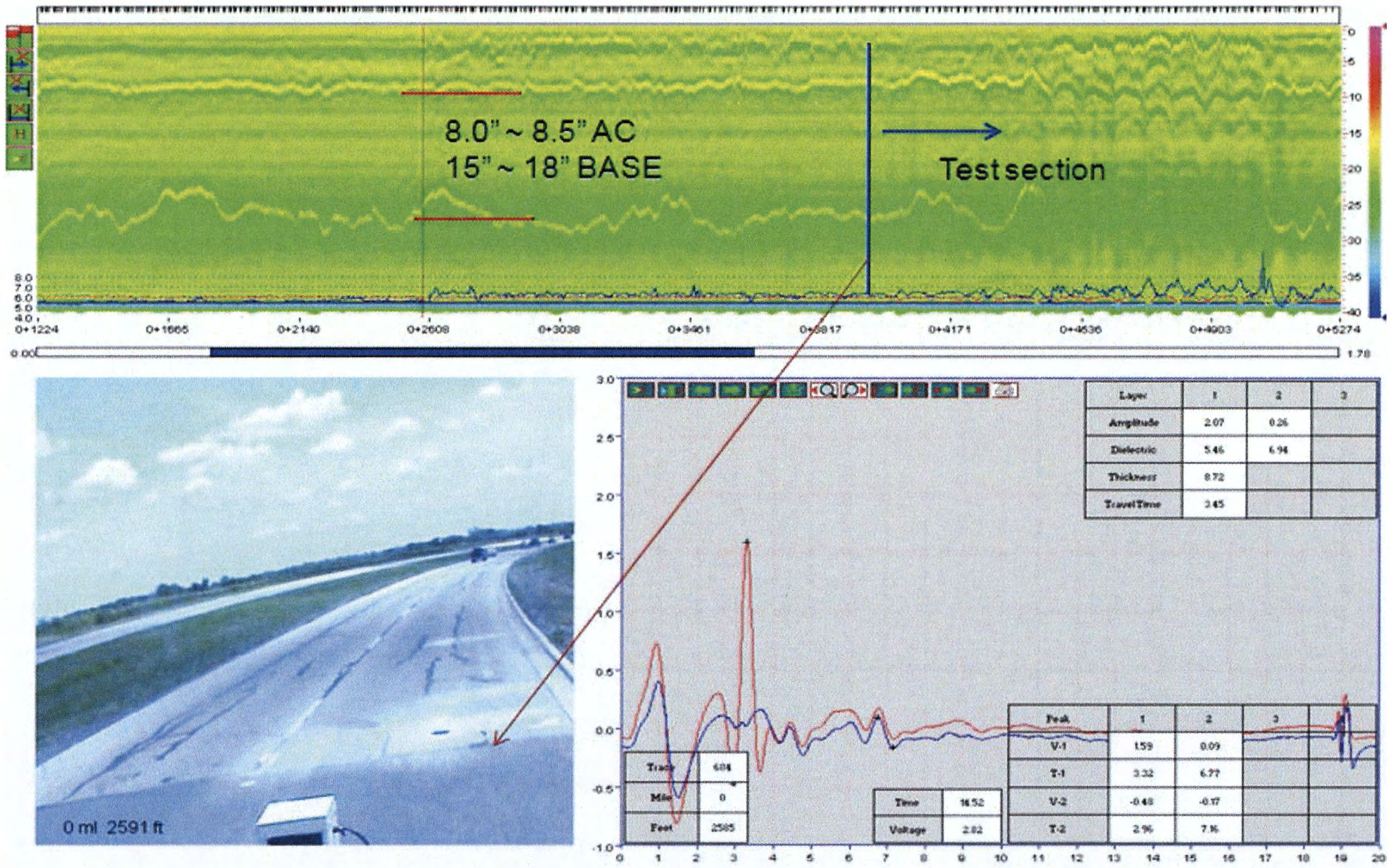


Figure C-10. GPR Data at the Beginning of Test Section of FM 734.

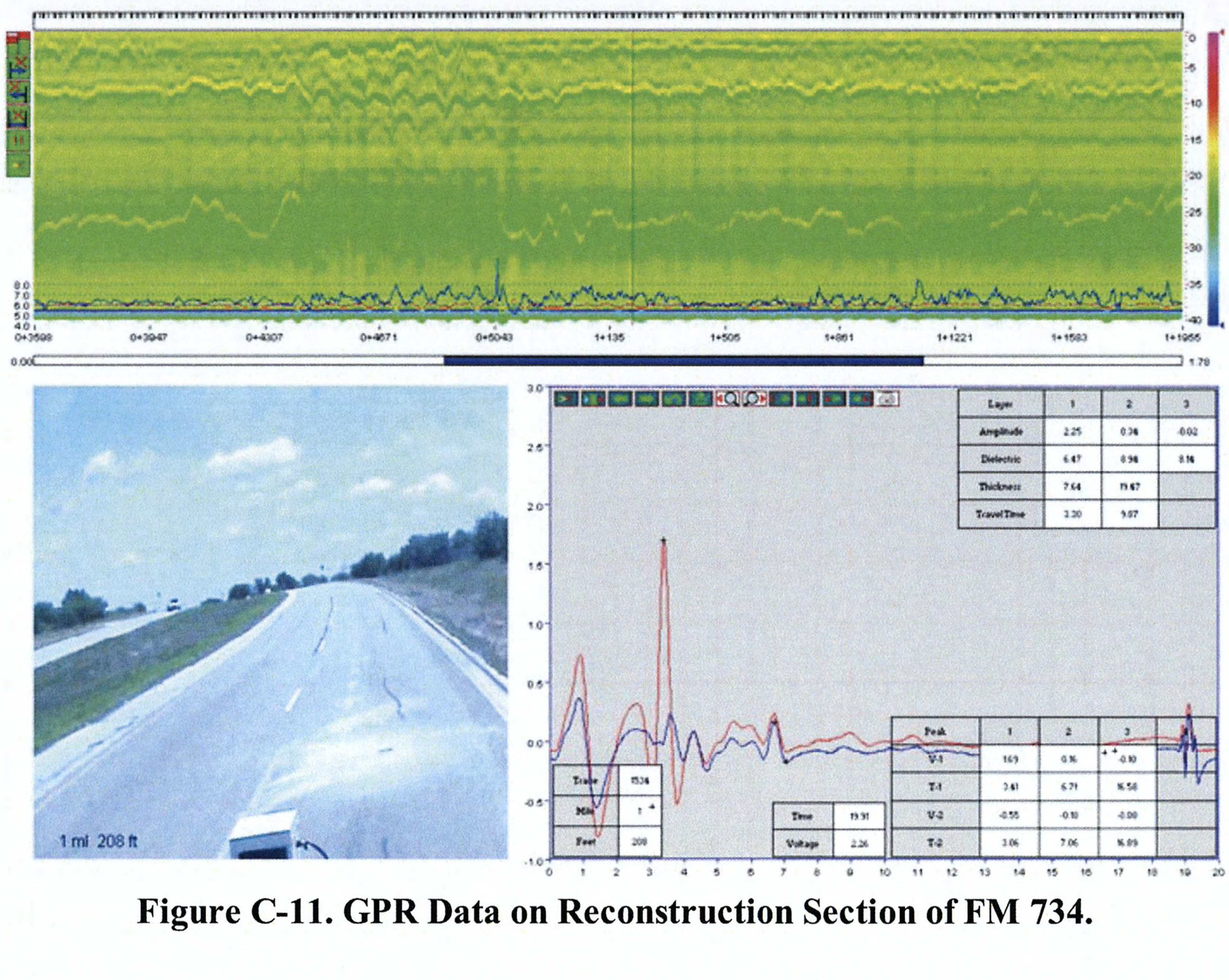


Figure C-11. GPR Data on Reconstruction Section of FM 734.

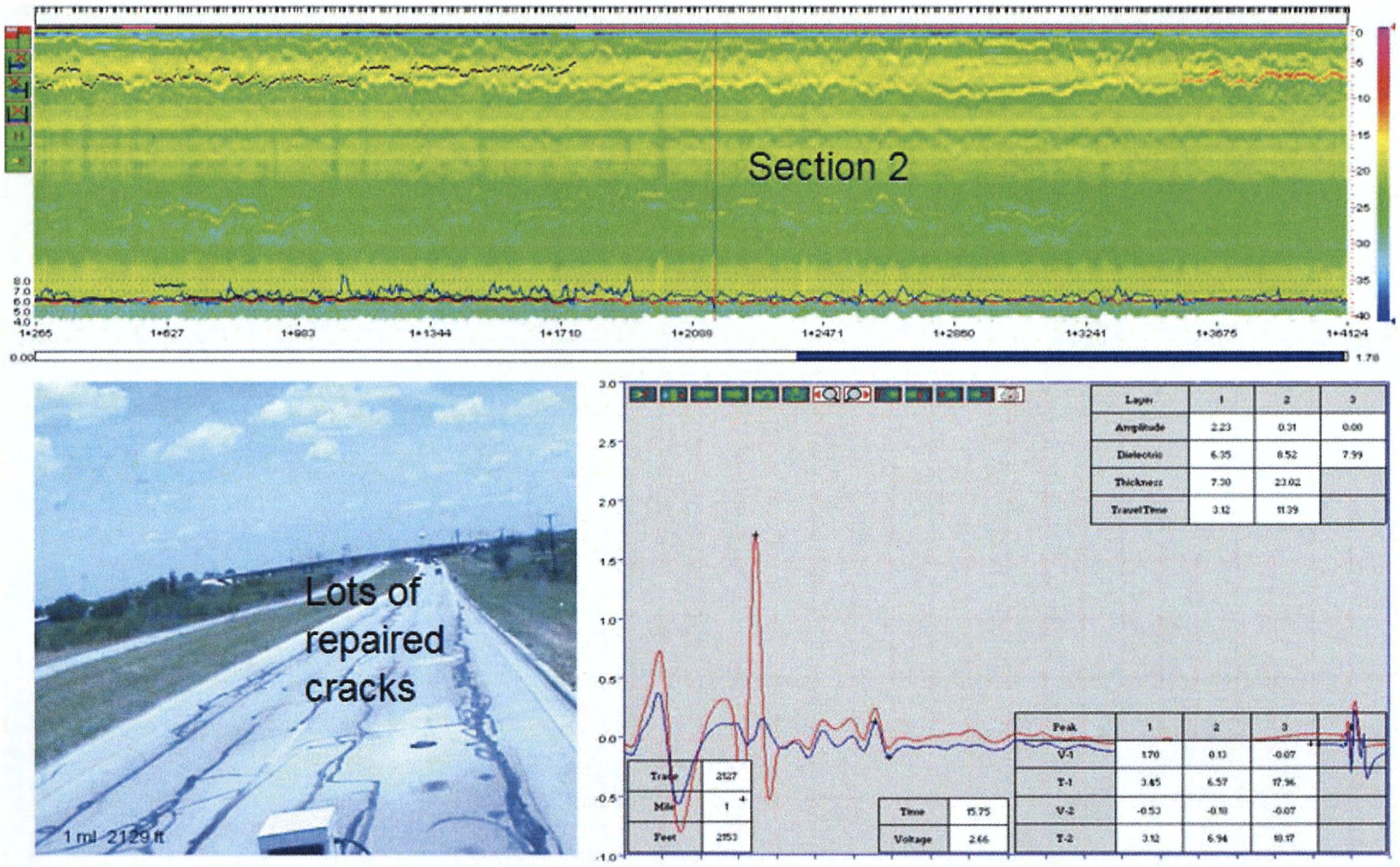


Figure C-12. GPR Data on Control Section of FM 734.

Table C-7. Summary of Laboratory Testing Results of FM 734 Sections.

Section	734-R1	734-C
Base-Optimum Moisture Content (OMC) (%)	8	8.7
Base-Maximum dry Density (pcf)	135	131.2
# 200 passing (%)	63.7	66.9
Plasticity Index (PI)	9.3	8.7
Shrinkage (%)	3	2
Sulfate Content (ppm)	190	<100
AC Indirect Tensile Strength (psi)	103.3	102.5

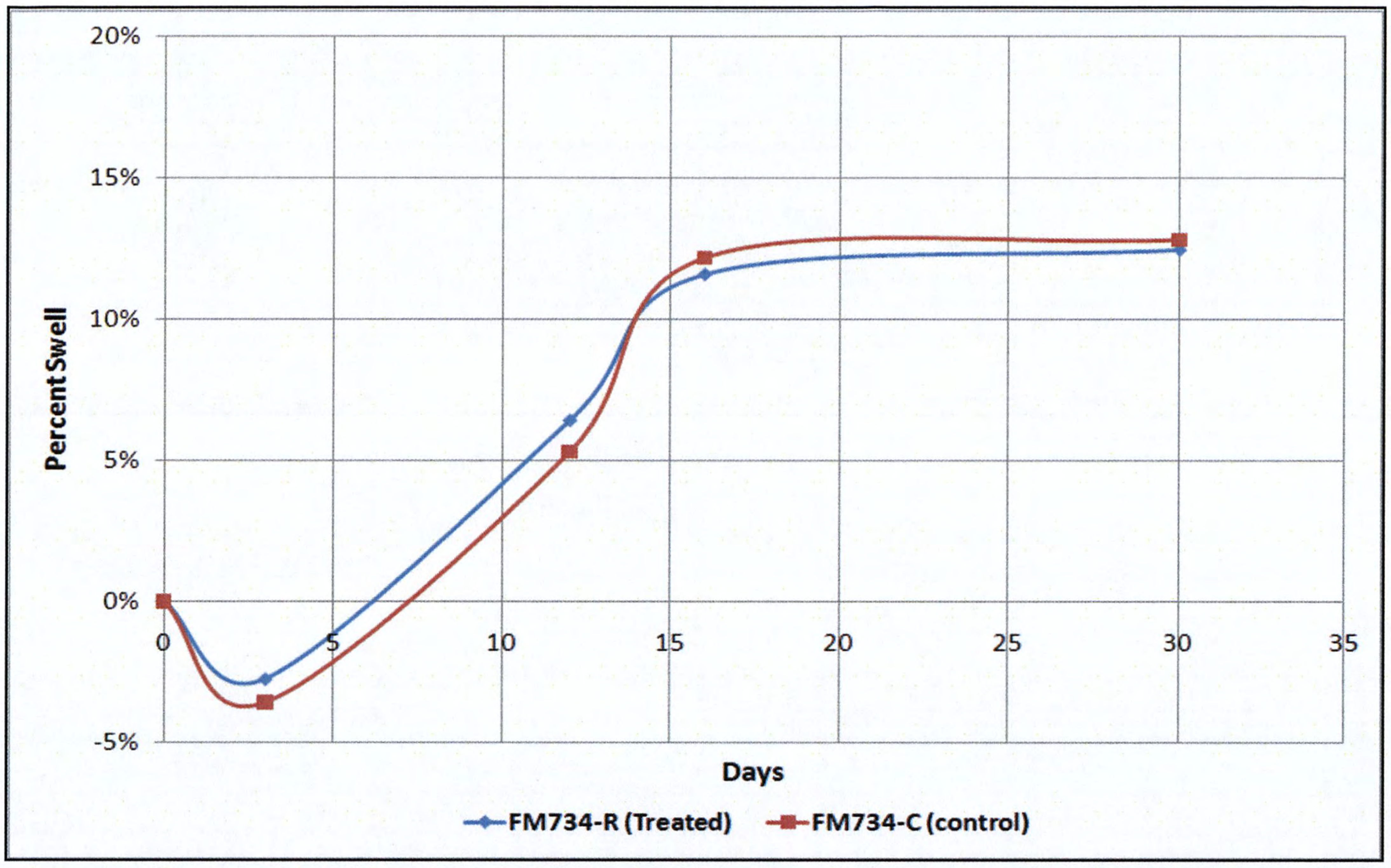


Figure C-13. Variation of Percent Swell versus Time of FM 734 Soils.

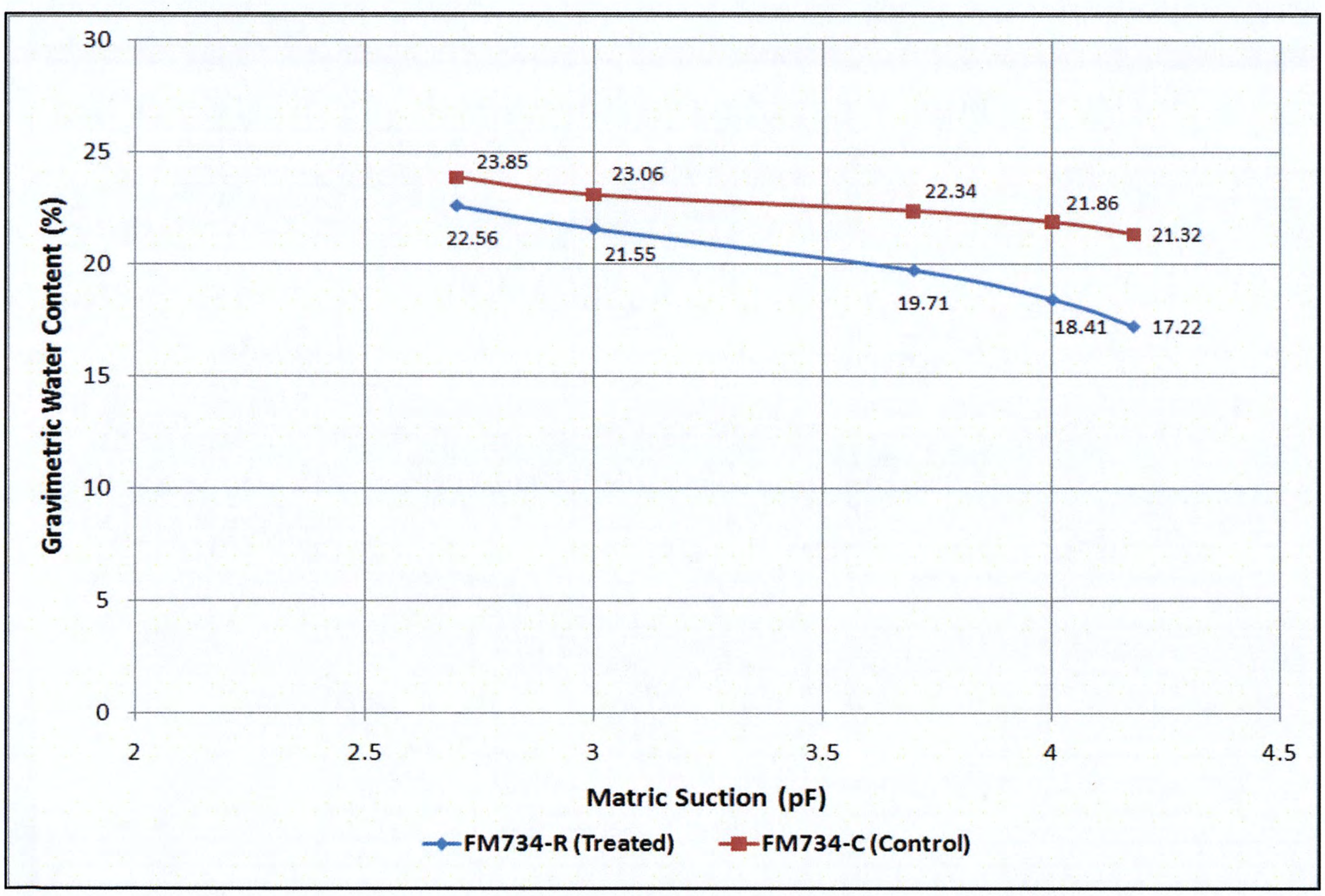


Figure C-14. Soil Water Characteristic Curves of FM 734 Soils.

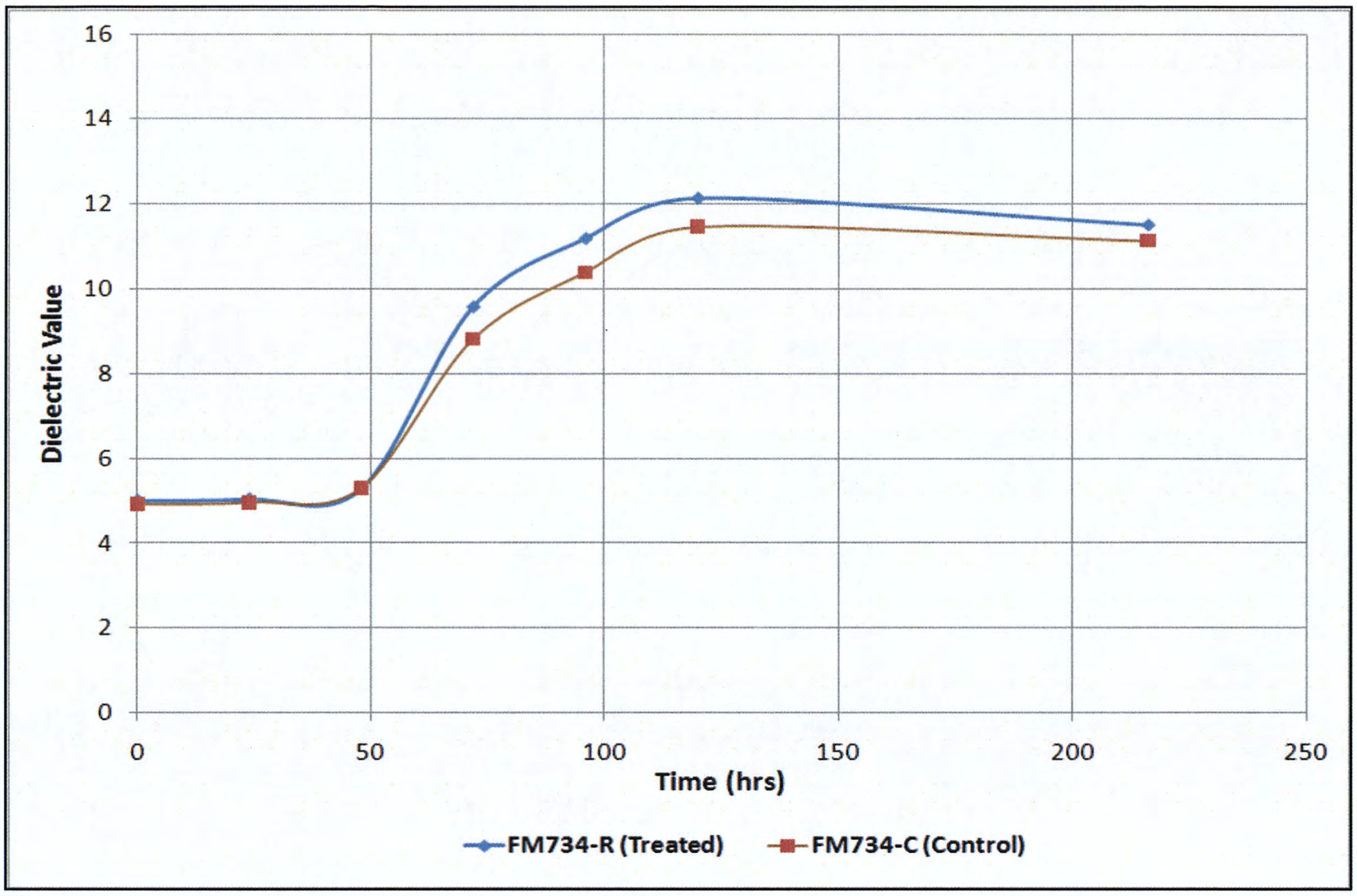


Figure C-15. Tube Suction Test Results of FM 734.

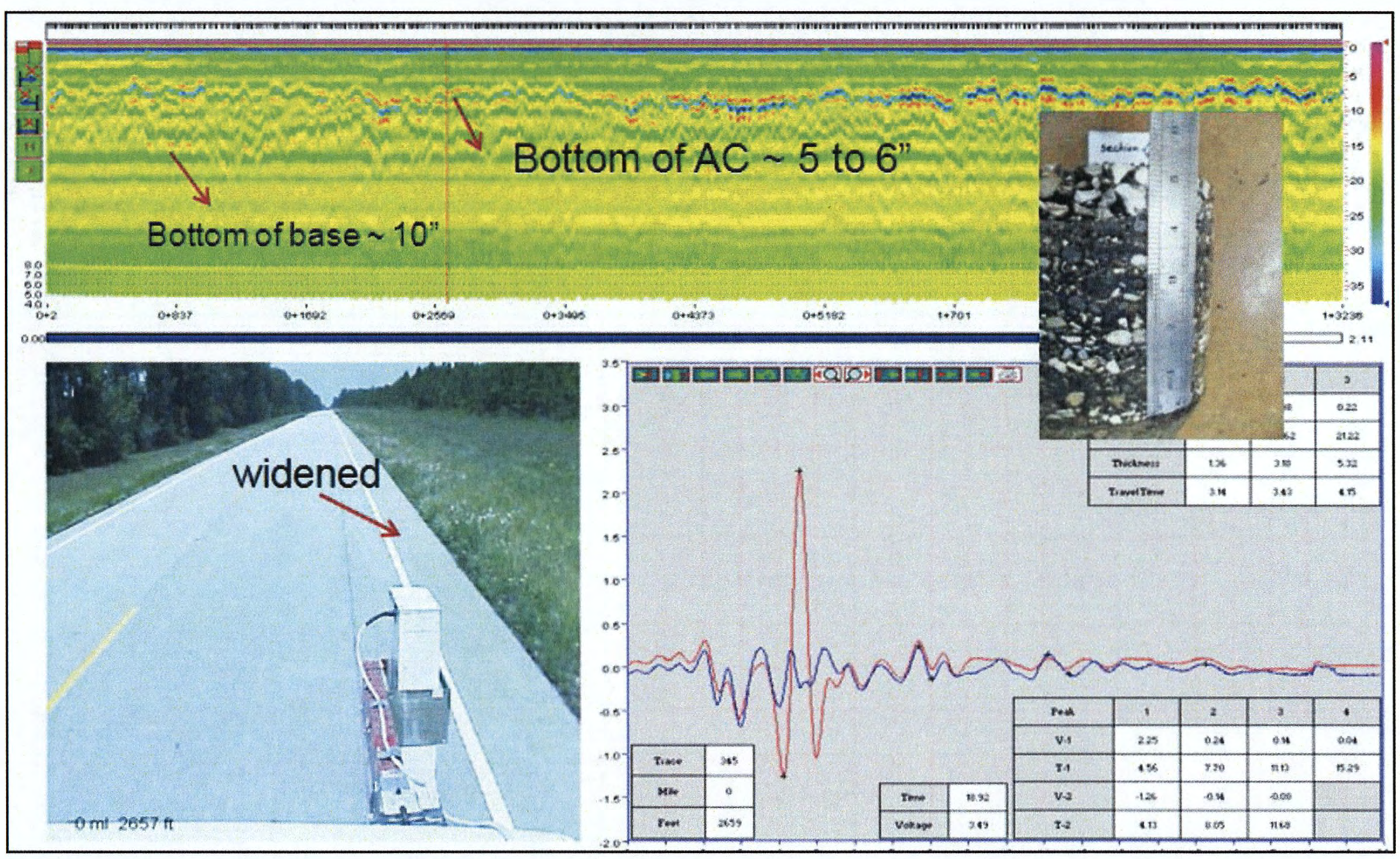


Figure C-16. GPR Data on FM 1293-R1.

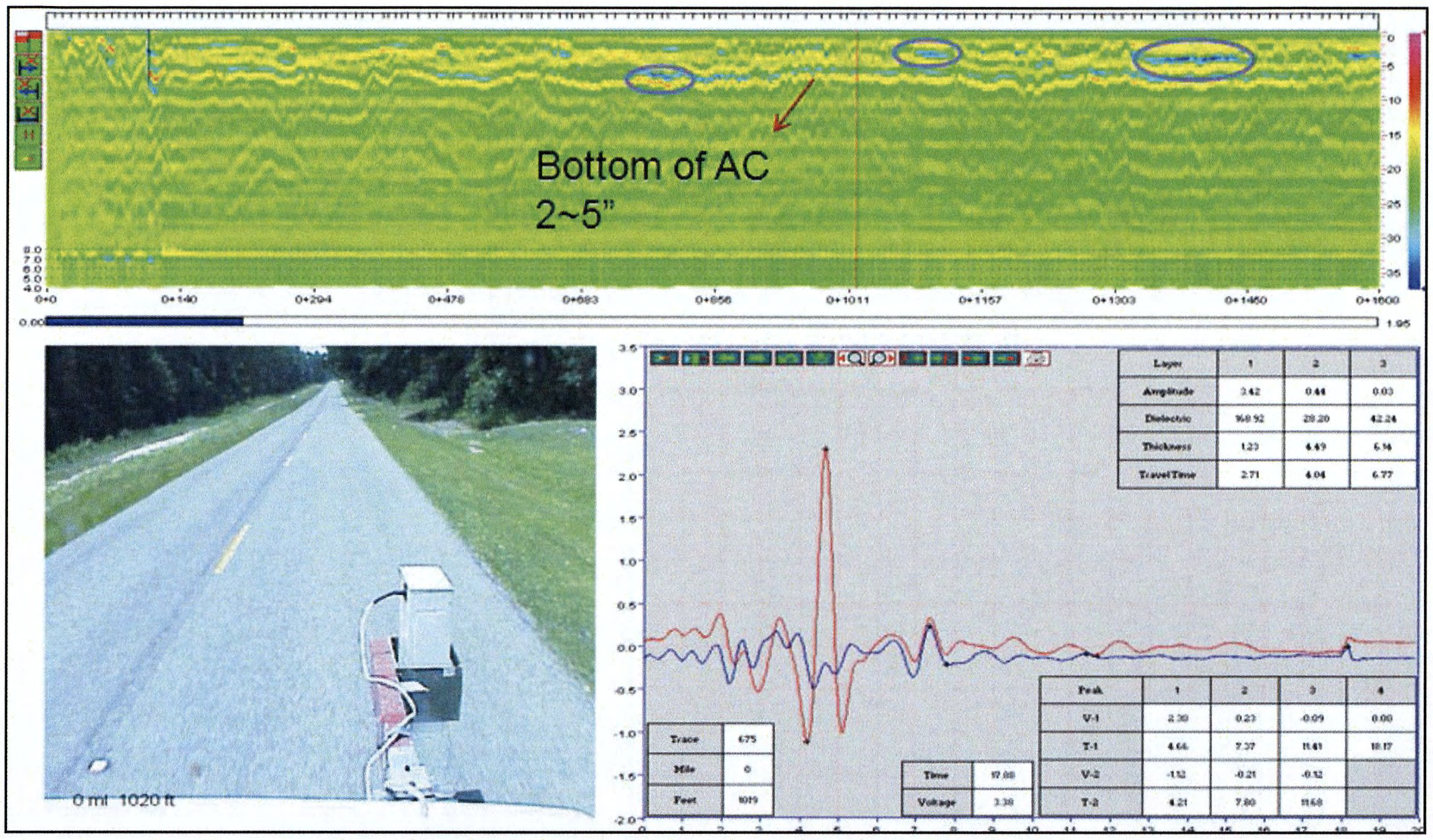


Figure C-17. GPR Data on FM 787-C.

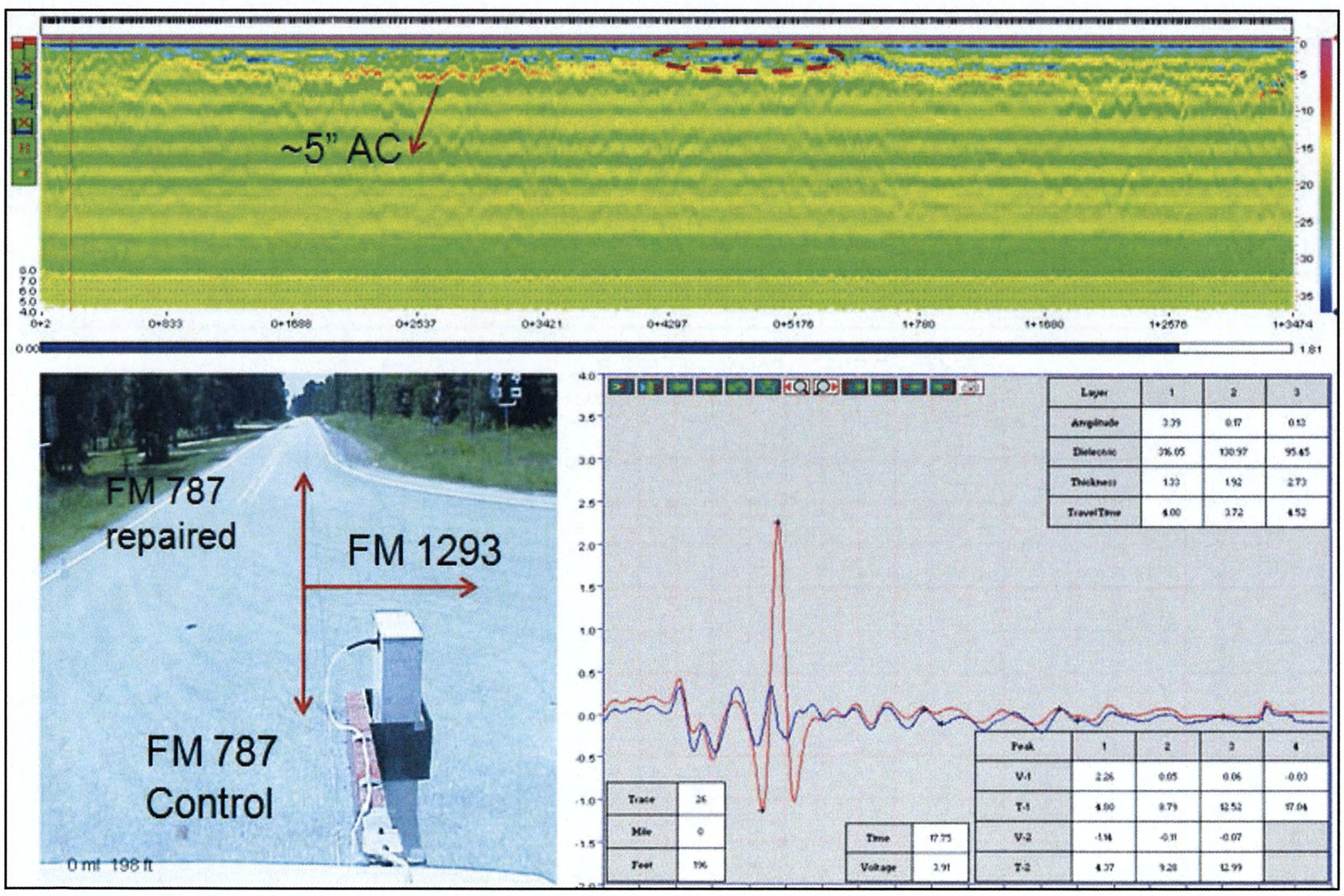


Figure C-18. GPR Data on FM 787-R2.

Table C-8. Summary of Laboratory Testing Results of FM 1293 & 787 Sections.

Section	787-W	787-C	1293-W
Base-Optimum Moisture Content (OMC) (%)	N/A	8.2	10
Base-Maximum dry Density (pcf)	N/A	122.5	118.2
# 200 passing (%)	N/A	5.2	5.7
Plasticity Index (PI)	N/A	7	9
Shrinkage (%)	N/A	3	3
Sulfate Content (ppm)	N/A	<100	<100
AC Indirect Tensile Strength (psi)	71.765	124.954	66.209*

*** Asphalt core was taken from cracked area.**

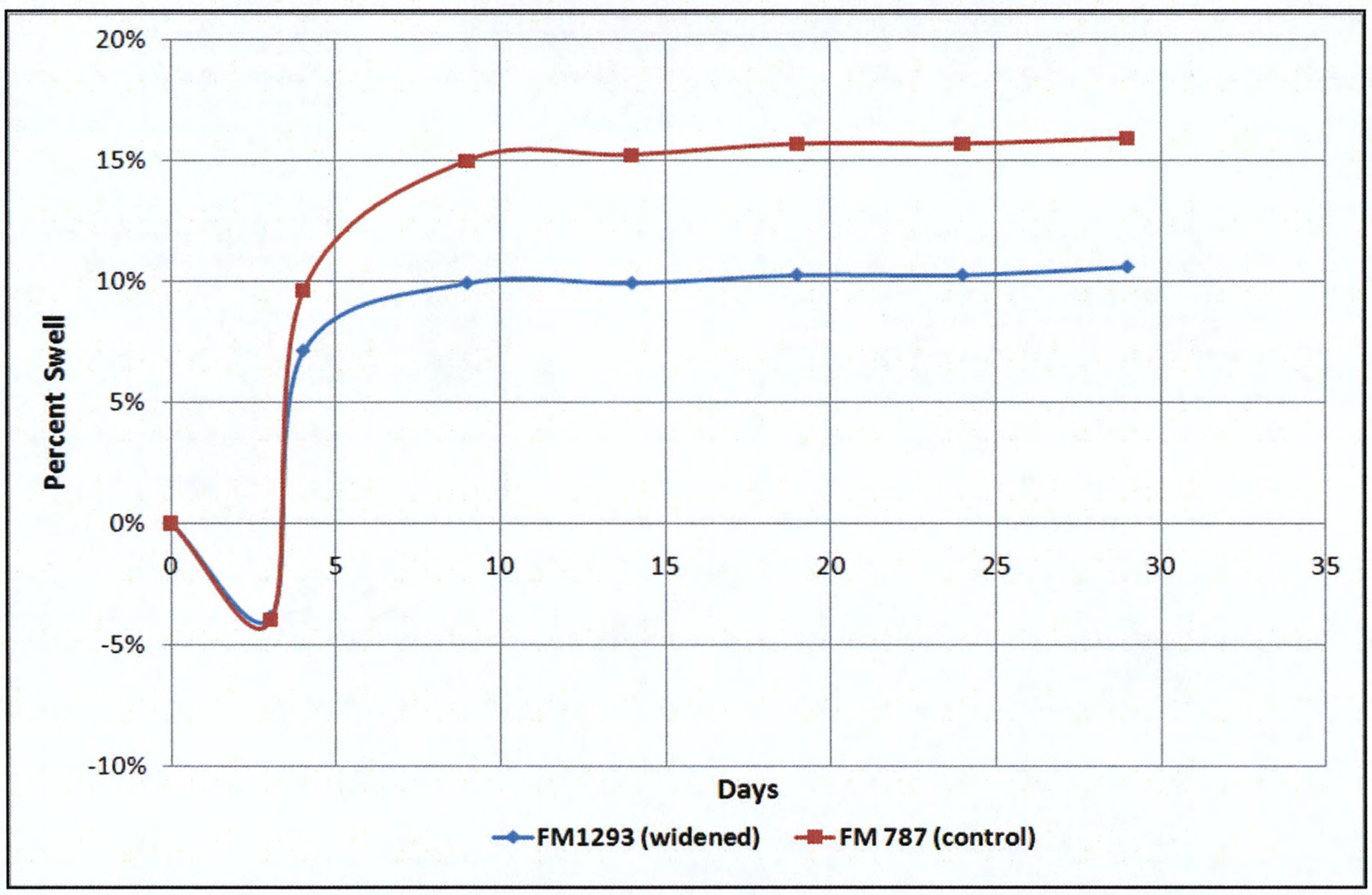


Figure C-19. Variation of Percent Swell versus Time of FM 1293 & FM 787 Soils.

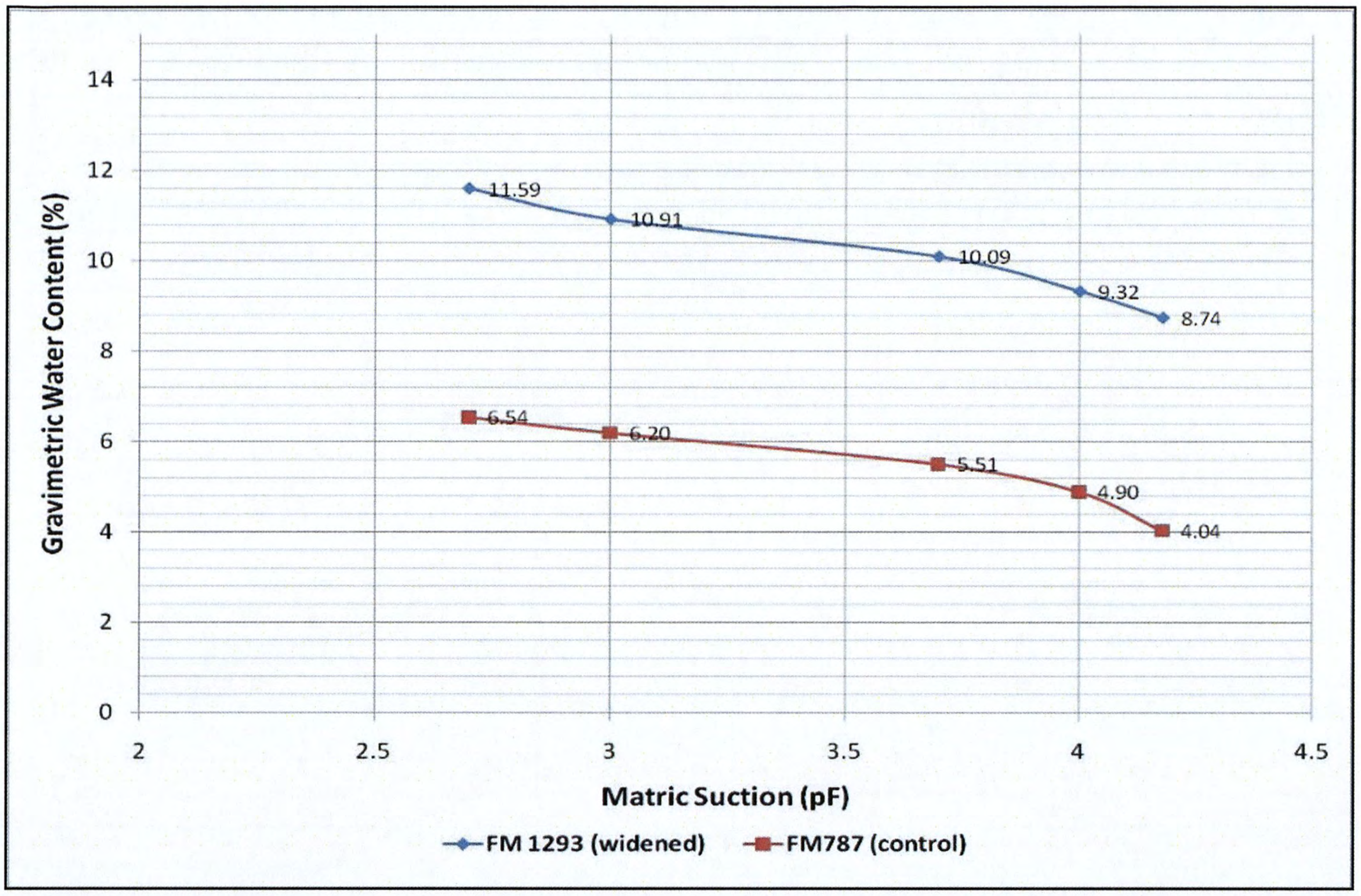


Figure C-20. Soil Water Characteristic Curves of FM 1293 & 787 Subgrade Soils.

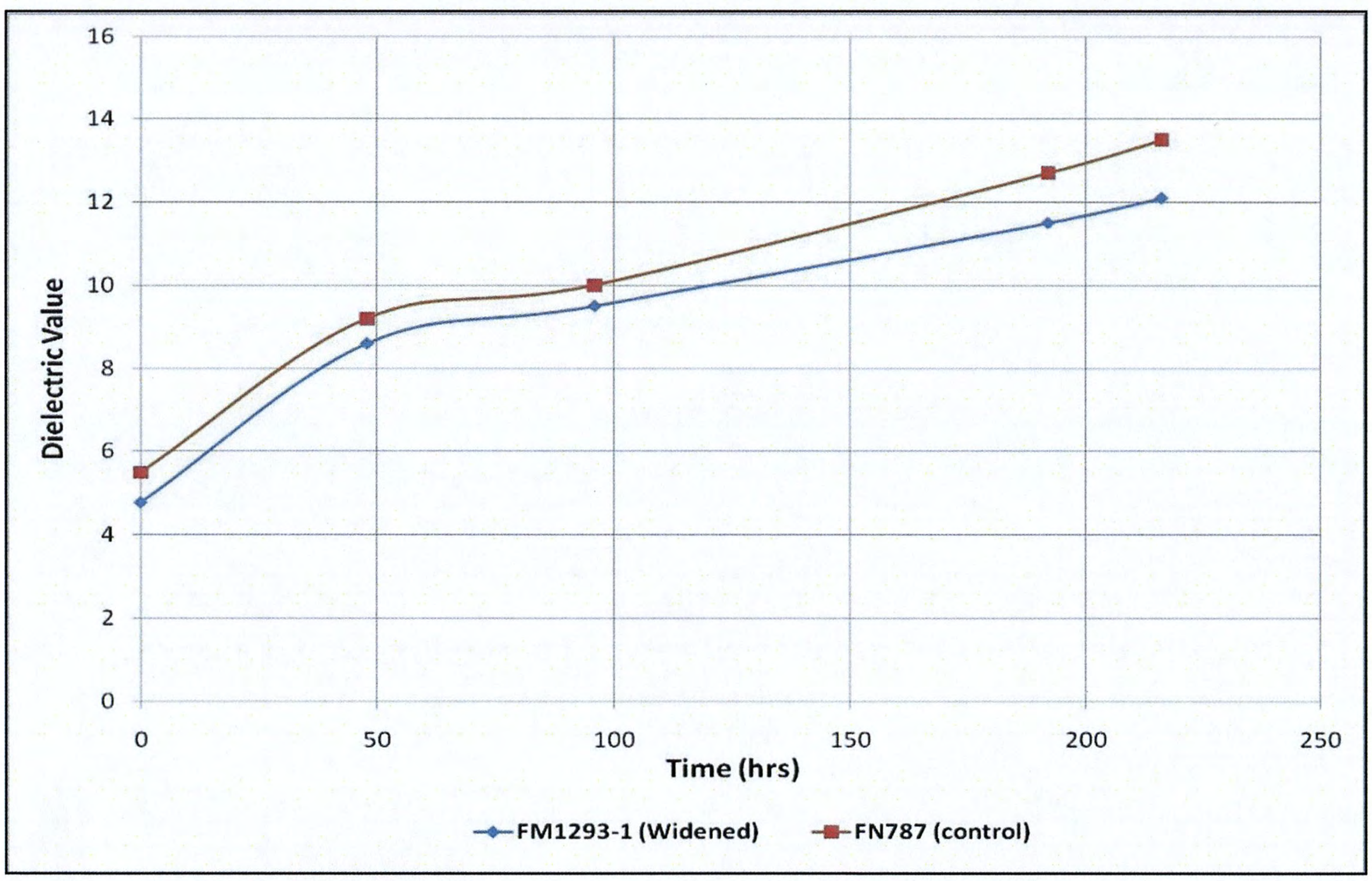


Figure C-21. Tube Suction Test Results of FM 1293 & 787 Base Materials.

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