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16. Abstract

Full-depth reclamation (FDR) offers a timely, cost-effective solution to restore a pavement's condition. However, FDR represents only one technique in the engineer's toolkit available for addressing deteriorating pavement conditions. The purpose of this project is to provide guidance on determining whether a pavement is a candidate for FDR and, if so, what design, construction, and inspection processes will maximize the performance of the completed reclamation.

This report presents initial recommendations for selecting a candidate FDR project and developing design options (including field sampling and lab design protocols). Along with a literature review, these recommendations are illustrated by application on several projects in TxDOT's Austin and Dallas Districts.

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FIELD AND LABORATORY INVESTIGATIONS FOR FULL DEPTH RECLAMATION PROJECTS

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DISCLAIMER

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EXECUTIVE SUMMARY

Full-depth reclamation (FDR) offers a timely, cost-effective solution to restore a pavement's condition. However, FDR represents only one technique in the engineer's toolkit available for addressing deteriorating pavement conditions. The purpose of this project is to provide guidance on determining whether a pavement is a candidate for FDR and, if so, what design, construction, and inspection processes will maximize the performance of the completed reclamation. This project consists of the following tasks:

- Task 1: Assembling Background Information. This task will assemble information from completed TxDOT projects, TxDOT districts, and industry groups to develop prototype guidelines for design and construction of FDR projects.
- Task 2: Demonstration Project on Up Front Testing of Candidate FDR Projects. This task will perform up-front evaluations on candidate project and provide the evaluation results and FDR recommendations to the TxDOT district.
- Task 3: Developing Design Options and Strength Criteria. This task will recommend an FDR strategy considering FDR objectives, stabilizer selection, and widening considerations. These recommendations will be reported to the district.
- Task 4: Demonstrating Field Sampling and Lab Design Techniques. This task will sample project materials and conduct laboratory tests to select the optimal stabilizer level, with the results reported to the TxDOT district.
- Task 5: Demonstrating Construction Techniques. This task will videotape phases of construction and propose inspection procedures for checking uniformity and quality of construction.
- Task 6: Develop Guidelines for Achieving Adequate Bond of Surface Treatments to FDR Base. This task will develop a new test and criteria for selecting the optimal materials for achieving an adequate bond of the proposed wearing course.
- Task 7: Demonstrate Performance Monitoring. This task will provide case studies on both good and poorly performing sections.
- Task 8: Enhanced Specifications. This task will provide updates to existing specifications and a prototype new draft FDR specification.
- Task 9: Workshop for TxDOT Personnel. This task will provide two FDR workshops for TxDOT covering the results from this project.
- Task 10: Reports, Guidelines, and Online Video. This task will produce the project documentation and a DVD video summarizing the FDR process and recommendations from this project.

This report presents work from Tasks 1−4 and Task 6 for the project's first fiscal year. After the background information, initial findings for evaluating bonding of surface treatments are presented. Next, up-front testing, field sampling, and lab design approaches are illustrated by application on several projects in TxDOT's Austin and Dallas Districts. Finally, based upon the background information and experiences gained on the project evaluations, this report presents a recommended protocol for selecting FDR projects. These FDR selection and design steps include:

- Evaluate project history (current pavement condition, plans, web soil surveys).
- Characterize existing pavement structure with non-destructive testing (NDT) (ground penetrating radar, falling weight deflectometer).
- Verify pavement structure and obtain material samples (focused structure verification and sampling of in-situ materials based upon NDT survey).
- Perform mixture design (selection of stabilization options, laboratory design tests).
- Perform pavement design (traffic data, materials properties, FPS design with triaxial design check).

Ongoing work in this project is investigating construction-related topics, and these findings and recommendations will be presented in a future research project report.

CHAPTER 1

LITERATURE REVIEW

SUMMARY

As a starting point in determining factors for consideration when evaluating, designing, and constructing an FDR project, Texas Transportation Institute (TTI) researchers analyzed the recommendations from industry, TxDOT research, scientific publications, and TxDOT districts.

INDUSTRY RECOMMENDATIONS FOR FDR

Industry sources for FDR guidance include the National Lime Association (NLA), Portland Cement Association (PCA), Asphalt Recycling and Reclaiming Association (ARRA), American Coal Ash Assocaition (ACAA), and Wirtgen.

National Lime Association

In October 2006, the NLA published a Technical Brief titled, "Mixture Design and Testing Procedures for Lime Stabilized Soil" (*1*). The NLA recommends determining the optimum lime content with the pH method in ASTM D 6276, and the recommended accelerated curing environment is 7 days in a sealed, airtight bath at 40°F followed by 24-hour capillary soak. The NLA recommends a 130 psi minimum unconfined compressive strength (UCS) for materials anticipated to be used as a base course. Laboratory test specimens are prepared with Standard Proctor effort.

In FDR construction, the NLA recommends a general sequence of scarification and pulverization, lime spreading, mixing and watering, compaction, and curing (*2*). Additionally, the NLA recommends temperatures be 40°F and rising (*2*). Caution should be exercised if trying to lime stabilize materials with organic contents greater than 2 percent, or sulfate contents greater than 0.3 percent (*1*).

Portland Cement Association

The PCA offers the following scenarios where FDR is appropriate (*3*):

- seriously damaged pavement that cannot be rehabilitated by only resurfacing,
- pavement distress indicates the problem exists in the base or subgrade,
- greater than 15 percent of the existing pavement needs full-depth patching, or
- the existing pavement structure is inadequate for the traffic level.

The PCA recommends a field evaluation to determine the thickness of the existing pavement layers and what materials will be blended for the reclaimed base, noting that a significant difference in materials along a project may require an additional mix design (*3*). If possible, different materials should be kept separate to allow varying proportions during the laboratory mix design (*3*). Additionally the PCA notes the potential need for adding new aggregate if a thicker structure is required for the pavement design, or if the target performance cannot be achieved with the in-situ materials (*3*).

The PCA uses Standard Proctor effort in laboratory sample preparation, and they recommend a UCS between 300 and 400 psi for samples moist cured 7 days followed by a 4-hr submersion period in water. In FDR construction, the PCA recommends a general sequence of pulverizing, grading and shaping, cement placement, mixing, compaction and final grading, curing, then surfacing (*3*). Critical construction controls the PCA identifies include cement content, moisture content, mixing, compaction, and curing; the PCA also recommends air temperatures of at least 40°F (*4*).

Asphalt Recycling and Reclaiming Association

The ARRA notes these types of FDR stabilization: mechanical (addition of granular materials), chemical (addition of lime, cement, fly ash, kiln dust, etc.), bituminous (addition of liquid, emulsified, or foamed asphalt), or combination (for example chemical with bituminous) (*5*). The ARRA notes the following conditions treatable by FDR:

- cracking;
- poor ride;
- rutting, corrugations, and shoving;
- loss of bonding or pavement stripping;
- raveling, potholes, and bleeding;
- shoulder drop off; and
- inadequate structure.

The ARRA recommends starting project evaluations with a pavement condition assessment, structural capacity evaluation, and materials properties assessment (grouped by areas or segments of similar materials). The condition assessment includes type, severity, and frequency of distresses. The capacity assessment includes an evaluation of the capacity required during the design life of the rehabilitation and an evaluation of existing support by using devices such as the dynamic cone penetrometer (DCP) and falling weight deflectometer (FWD). Materials are then gathered from the project and tested for moisture content, gradation, PI, and asphalt binder content (if asphalt emulsion will be used as the stabilizing agent). The ARRA notes that field coring and laboratory crushing produces gradations resembling what is achieved during the FDR process (*5*). They recommend a 6-in. diameter field core.

The ARRA reports the need for stabilizing agents is unique to each project (*5*). Candidate stabilizing agents are screened according to compatibility with the reclaimed material (gradation and PI), then by establishing potential mixture proportions, and finally by evaluating the strength and durability properties of the reclaimed mix (*5*). The ARRA suggests new granular material may be required to add depth, modify gradation, or improve stabilization results. A key difference in the ARRA guidelines between chemical and bituminous stabilization design is that the treatment level with chemical stabilization typically is selected based upon meeting some minimum compressive strength target, whereas with bituminous stabilization methods such as indirect tensile strength, moisture sensitivity value, and maximum soaked strength are used (*5*).

The basic FDR sequence according to the ARRA includes pulverization of the existing asphalt layers, incorporation, and mixing with the underlying material (incorporating a minimum of 1-in. of underlying granular material is recommended), application and mixing of any stabilizing agents, compaction, grading, and curing. When applying stabilizing agents, the ARRA recommends using a calibrated bulk spreader to apply powders and utilizing computerized onboard additive systems to apply slurry or liquid products. Crucial quality issues for successful FDR include treatment depth, gradation, stabilizing agent application rate, moisture content, uniformity, compaction, and smoothness (*5*).

The ARRA notes the most frequent error during mixing in FDR is cutting too deep, resulting in incorporation of subgrade soil into the mixture. However, care should also be taken to overlap passes by at least 4 in., and the gradation of the material should be checked after pulverization to see if it corresponds to the gradation used in design (*5*). The ARRA notes the field gradation depends on the front and rear door openings on the pulverization chamber, the breaker bar setting, the rotating speed of the drum, the travel speed of the reclaimer, the condition of the existing pavement, and the ambient temperature (*5*).

The ARRA divides the curing sequence into initial, intermediate, and final curing (*5*). Initial curing requires as little as 30 minutes to a few hours and is the time needed for the mix to gain surface cohesion and be less susceptible to surface disturbance (*5*). Intermediate curing is the curing needed to take place prior to placing a wearing course. With asphalt stabilization, intermediate curing has been judged by moisture content. For cementitious stabilization, strength gain or time period typically is used to determine when adequate intermediate curing has occurred (*5*). Final curing can take years and is the time until the mixture reaches its ultimate strength (*5*).

American Coal Ash Association

The ACAA recommends FDR with self-cementing fly ash as an option for pavements with granular materials beneath the wearing surface that are too thin, contaminated, or unstable (*6*). Class F ash can also be used in combination with lime or cement (*6*).

In mixture design, the ACAA stresses the importance of the compaction delay time, noting that specifications must state the maximum compaction delay allowed after mixing and the importance of performing lab tests based upon the maximum allowable delay time (*6*). Additionally, the ACAA recommends careful consideration of allowable moisture content ranges, since peak compressive strength generally occurs at moisture contents lower than the optimum moisture content for maximum density (*6*). To perform the lab tests, the ACAA recommends an adaptation based on ASTM C593 and D1633. Specimens are prepared with either Standard or Modified compaction effort, where at least five test specimens are molded over a range of moisture contents for each test series to identify moisture-density and moisture-strength relationships (*6*). The maximum allowable compaction delay time is used when preparing the specimens. Prepared test specimens are then wrapped in plastic wrap and cured for

7 days at 100°F, and then the compressive strength is determined. Due to variations in ash chemistry from different sources, it is also important to use the same fly ash in mix design that will be used in construction.

In construction, the ACAA reports the primary concerns are uniform distribution of ash, proper pulverization and thorough mixing, moisture content control, and achieving compaction within the prescribed time frame (*6*). For pavement recycling construction practices, the ACAA offers the following guidance (*6*):

- The bituminous layer thickness should not exceed 4 in., and the minimum recycling depth should be 6 in.
- Use rotary mixers in the field, noting the asphaltic layer may require initial pulverization.
- The depth of pulverization must be carefully controlled to avoid incorporation of subgrade soils into the mixture.
- Spread ash on a weight per area basis.
- When using add-rock to maintain a minimum section thickness, the new aggregate should be added and pulverized into the existing pavement prior to distribution of ash.
- Soil temperature should be at or above 35°F at the time fly ash is incorporated.
- Moisture contents should be maintained with 2 percent of optimum.
- Moisture content is best controlled by direct injection of water into the drum of the mixer.
- Perform compaction as soon as possible after the final pass of the mixing equipment using a vibratory padfoot roller for initial compaction.
- The stabilized layer should be moist cured for at least 3 days.

Wirtgen

Wirtgen offers a range of products for performing cold recycling of pavements. When formulating rehabilitation options, the Wirtgen Cold Recycling Manual suggests answering these two questions to narrow down options:

1) What is wrong with the pavement, and where is the distress originating from?
2) What does the road authority want?

Getting more detailed, Figure 1.1 illustrates the strategy recommended to develop options for pavement rehabilitation.

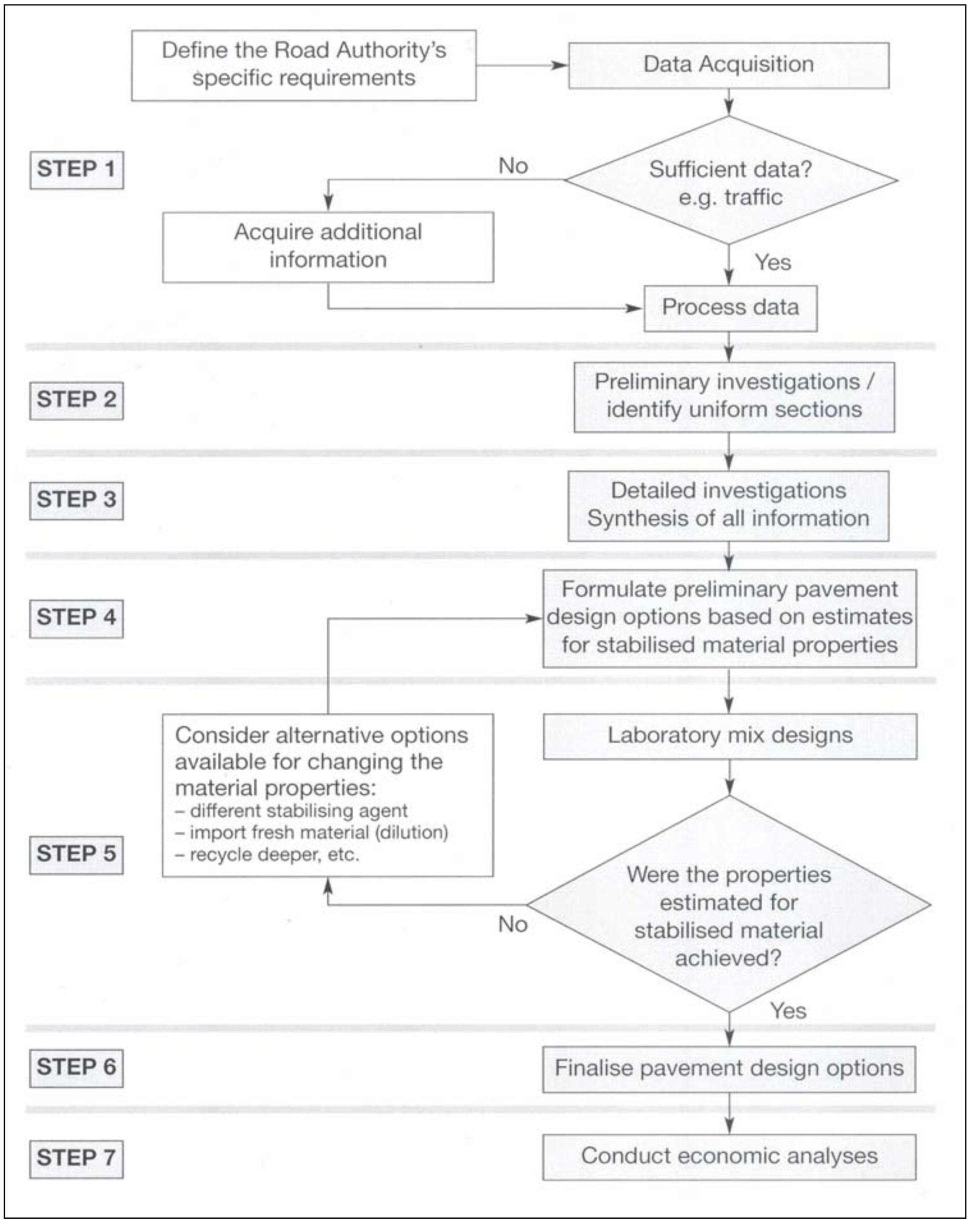


Figure 1.1. Pavement Investigation and Design Process from Wirtgen (*7*).

In Figure 1.1, Step 1 involves collecting historical pavement information. Step 2 identifies section limits based on visual, FWD, or other suitable methods. In Step 3 additional data such as cores, DCP profiles, and material samples are collected and evaluated to better identify the existing properties of each section. Step 4 is where the decision to consider FDR would be made. When the first three steps discover structural problems in the upper pavement layers (to a maximum depth of 12 in.), Wirtgen suggests a one-stage in-place recycling operation can provide a solution. If pavement structure problems exist to a maximum depth of 24 in., a two-stage recycling operation or reconstruction offer solutions (*7*). A pavement design analysis also occurs in Step 4. Then, in Steps 5 and 6, laboratory testing on samples prepared as close as possible to field conditions (with respect to both gradation and curing) are tested to determine which treatment and application rate best meets the pavement design requirements.

Wirtgen suggests selecting stabilizing agents based on cost, availability, material characteristics, and agency policy. Cementitious agents such as cement, lime, ash, and slag primarily produce strength gain, while bituminous agents provide strength gain while retaining some flexibility. A dual-treatment approach combining cement with bituminous stabilization can provide strength gain comparable to chemical stabilization without shrinkage cracking.

When stabilizing with cement, Wirtgen offers several innovations for improving uniformity of application by offering a recycler with integrated spreading device and a slurry injection system (*7*). Wirtgen reports that slurry injection is the most accurate means of distributing cement, and they suggest that water should be added by injection into the recycling machine.

When stabilizing with asphalt emulsion, Wirtgen reports up to 1.5 percent cement may be added to improve strength without reducing fatigue characteristics. Cationic emulsion is generally used for FDR to ensure breaking without compromising mixing and compaction, and design tests are based upon indirect tensile strength and UCS (*7*).

In mixture design, after sampling and reconstituting materials, Wirtgen suggests cementitious stabilization designs employ 7-day strengths (cured at 20 to 25°C in a curing room or in sealed bags). Alternatively, Wirtgen suggests an accelerated curing method of 24 hr curing at 70 to 75°C for cement, or 45 hr at 60 to 62°C for lime.

During field construction, Wirtgen emphasizes the criticality of accurate stabilizer spreading, since most recyclers do not cross-blend material. Additionally, they recommend at least a 6 in. overlap in cuts and stress that the location of longitudinal joints should avoid the wheel paths. When possible, Wirtgen suggests working the full road width to avoid longitudinal joints altogether. Additional construction suggestions from the Wirtgen manual include (*7*):

- Pre-shape bad road profiles prior to stabilization to improve uniformity.
- Avoid pre-pulverizing and, if performed, do not pre-pulverize to as deep as planned for stabilization.
- Mix at travel speeds between 6 and 12 m/min.
- Complete compaction in as short a time as possible.
- Mold and cure field test samples at times and curing conditions representative of the field.

FINDINGS FROM PRIOR TXDOT RESEARCH PROJECTS

Several completed TxDOT research projects include information relevant to FDR. These include projects 7-3903, 0-4182, 0-5223, 0-5797, and 0-5562.

Project 7-3903

In project 7-3903, researchers evaluated performance of 25 base recycling projects in the Bryan District (*8*). This project found that recycling projects constructed over soils with a plasticity index (PI) greater than 35 exhibited longitudinal cracking problems. These cracking problems are also influenced by weather conditions (droughts), presence of trees near the pavement edge, pavement side slopes, and the strength of the stabilized layer.

Project 7-3903 suggested different strategies for FDR as presented in Table 1.1. Additionally, this project suggested a new approach to FDR when working on soils with a PI greater than 35. After performing FDR, this new approach uses a geogrid on top of the stabilized layer with a thin flexible base overlay prior to applying the surface treatment. The geogrid and flexible base overlay approach as illustrated in Figure 1.2 has been documented to significantly reduce problems with longitudinal cracking over plastic soils (*9*).

Table 1.1. Tentative FDR Objectives (*8*).

District Objective	Base Thickening	Upgrade Base to Class 1	Create a Super Flexible Base	Create a Stabilized Base (Class L)
Used When	• Existing base is uniform • No widespread structural damage • Low to medium traffic	• Low – moderate traffic • Subgrade > 10 ksi • Moisture not a concern	• High volume roadways • Moisture a concern • Weak subgrade • Early opening to traffic	• Bridging over poor subgrade • Strengthening required • Low quality variable base/stripped HMA • Higher rainfall • Early opening to traffic
Selection of Stabilizer	No stabilizer added to the existing material. This is a base thickening project, where new untreated granular material is placed on top of existing.	Full Texas Triaxial test (117-E), add low levels of stabilizer Criteria after 10 days capillary rise 1) 45 psi at 0 psi confining 2) 175 psi at 15 psi confining	Full Texas Triaxial test 117-E 1) 60 psi at 0 psi confining 2) 225 psi at 15 psi confining	Test Method (121 E) 7 day moist cure, then 1) Unconfined strength > 300 psi 2) 100% retained unconfined strength after 10 days capillary rise
FPS 19 Moduli	70 ksi	100 ksi	125 ksi	150 ksi
Comments	1) New base should be of higher or equal quality than existing. 2) Blending of existing and new base strongly recommended to avoid trapping moisture in upper layer.		1) No cement used in this option otherwise poor fatigue life.	1) Avoid cutting into high PI subgrade, if existing structure is thin then add new base before milling where needed. 2) To avoid longitudinal cracking consider grids and flex base overlay where the PI subgrade soils > 35. 3) Max RAP 50%. 4) If lab strength > 350 psi then consider pre-cracking. 5) Max cement 4%, other stabilizer can be used.

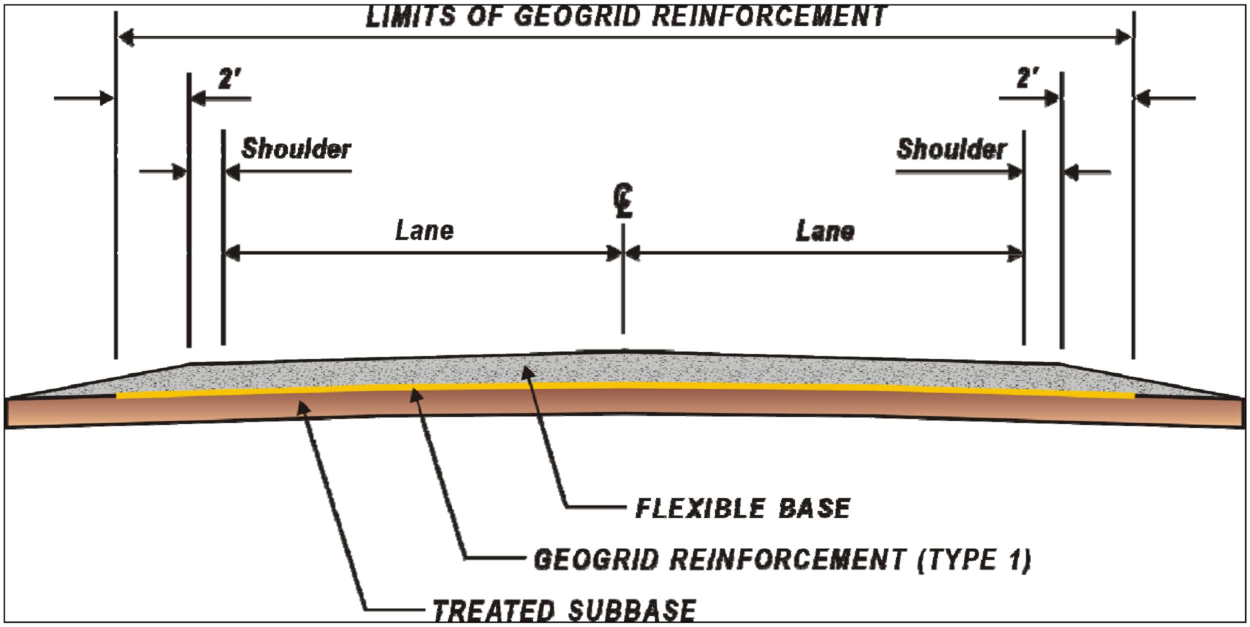


Figure 1.2. FDR with Geogrid and Flexible Base Overlay.
Note: Schematic courtesy of Darlene Goehl, P.E.

Project 0-4182

In project 0-4182, researchers evaluated the performance of full-depth recycling projects around the state of Texas and noted that, although the majority of projects were performing well, the problems encountered included (*10*):

- longitudinal cracking on sections built over clay subgrades,
- bonding problems with fly-ash-treated bases, and
- excessive cracking with some cement treated bases.

From this project, the guidelines shown in Table 1.1 were revised as shown in Table 1.2.

Table 1.2. Revised FDR Guidelines (*10*).

Objective	Base Thickening	Upgrade to Class 1	Super Flexible Base	Stabilized Base
Used When	• Existing base is uniform • No widespread structural damage • Existing subgrade is good (> 15 ksi) • Low traffic	• Low-volume roadway • Good subgrade • Moisture not a concern	• High-volume roadway • Moisture a concern • Reasonable subgrade > 10 ksi • Early opening to traffic	• Bridging over poor subgrade • Strengthening required • Low-quality variable base • High rainfall • Early opening to traffic
Selection of Stabilizer	No stabilizer. Add new flex base only.	Full Texas triaxial evaluation 117-E 1) 45 psi at 0 psi confining 2) 175 psi at 15 psi confining	Full Texas triaxial evaluation 117-E 1) 60 psi at 0 psi confining 2) 225 psi at 15 psi confining 3) < 0.5% gain in moisture over molding moisture after 10 days capillary	7-day moist cure, then 1) UCS > 300 psi 2) Dielectric < 10 after 10 days capillary rise 3) 85% retained strength
FPS 19 Design Recommendations*	Lowest of 70 ksi or 4 times subgrade modulus	100 ksi	150 ksi	200 ksi
Comments	1) New base should be of higher or equal quality than existing. 2) Use Bomag to blend existing and new.			1) Avoid cutting into subgrade, add new base where needed. 2) Consider grids and flex base overlay where high PI soils exist (PI > 35). 3) If lab strength > 350 psi then use microcracking.

*Conservative value: District may wish to change this value based on long-term performance studies.

Project 0-5223

In project 0-5223, researchers evaluated how particle breakup during field pulverization and mixing operations impacts FDR designs. They discovered the majority of breakdown occurs with the first pass of the mixer, and on average 10 percent of the coarse aggregates are crushed to fine sands. The British Aggregate Crushing Value (ACV) was recommended to determine which aggregates were excessively soft. Adhering to target moisture and stabilizer value contents was cited as the key element to success of a FDR project. Adding high-quality virgin aggregate was recommended as a means to preserve the desired final gradation. This project suggested the following for improving FDR processes (*11*):

- Use GPR and FWD to survey the project and aid in selecting sampling locations.
- Consider attempting to optimize gradation, or at least account for particle breakdown during field pulverizing, by the following:
    - Try to obtain approximately 15 percent fine sand (passing the #40 and retained on the #200 sieve).

    - Limit the amount passing the #200 sieve to less than 10 percent.
    - Use the ACV to predict the additional amount of fine sand that will be generated by field mixing operations.
    - Blend materials sampled from different sites along the project to obtain one mix design.
    - Reduce the amount of gravel (retained on the #4 sieve) by 8 percent, and increase the amount of fine sand by 8 percent, if ACV tests are not available.
- Cure lab moisture-density specimens for 24 hr then determine the lab seismic and UCS of those samples. If after 24 hr the UCS is less than 150 psi for cement treatment, or less than 75 psi for fly ash treatment, the compatibility of the additive is in doubt.
- For cement-stabilized project the retained-strength ratio after a 4-hr soak can be used to evaluate moisture susceptibility.
- For projects using fly-ash, an accelerated test program involving only 6 days of bench top curing prior to UCS determination, and targeting 200 psi strength, may provide a method to accelerate the mix design process.
- Hot-mix surfacing should be milled prior to mixing into the existing base.
- Moisture content prior to compaction should be included as a quality control item. Slush rolling should not be permitted.
- Opening to traffic should be dictated by establishment of some minimum strength or stiffness.

Project 0-5797

In project 0-5797, researchers evaluated base stabilization employing dual treatments (an asphalt emulsion combined with a calcium-based stabilizer). This approach typically produces mixes with good strength, moisture susceptibility, and flexibility characteristics. This project presented the following recommendations and observations for dual-base stabilizer projects (*12*):

- Indirect tensile strength (ITS) should be used as the main strength criteria.
- The retained ITS after moisture conditioning should be used as the moisture susceptibility test.
- The new high-shear mixer, proposed for use in mixing emulsion-treated materials resulted in increased strengths as compared to hand mixing.
- Specimens compacted with a gyratory compactor had higher strengths and moduli values than specimens compacted with Tex-113-E.
- The temperature at which the material is mixed does not impact results as long as the temperature is at least 70°F.
- Specimens should be cured for 2 days at 140°F.

To date, all TxDOT dual-base stabilizer projects have been constructed under one-time use special specifications.

Project 0-5562

In project 0-5562 researchers sought to investigate the use of locally-available, low quality base aggregates in place of importing a high quality flexible base. Attaining TxDOT Grade 1 classification was the target (*13*). The researchers found that modifying the marginal materials with lime or with 1 percent cement typically achieved Grade 1 strengths. Additionally, the researchers noted that gradation modification alone did not improve the quality of the materials, and for bases thinner than 12 in. local materials use without modification is not prudent. This project recommended that if the base is thicker than 12 in. the use of marginal local materials as a subbase should be explored.

For pavement design using marginal materials, this project suggested a resilient modulus and permanent deformation analysis should be mandatory, and either the VESYS or TxIntPave programs should be used to validate the design (*13*). Finally, the economics of using low quality base must be evaluated. In some cases importing a high-quality base may be more economical than using local, low-quality materials.

SCIENTIFIC PUBLICATIONS

Syed (*14*) evaluated more than 75 FDR projects ranging in age from 3 to 26 years and noted the following:

- A typical design process involves an investigation of the existing structure followed by a laboratory investigation of stabilized material properties.
- Design procedures used include ASTM D 559 and D 560, the Tube Suction Test, UCS, and/or experience.
- Construction requirements used range from standard to modified Proctor, and some agencies do not allow blending of subgrade soils into the mixture.
- Reducing cement content to reduce shrinkage cracks should be balanced with durability requirements.

In evaluating pavement restoration activities in Nebraska, FDR was noted to provide pavements equivalent to that provided by reconstruction (*15*). The authors noted FDR could be used in lieu of complete reconstruction with much cost savings, and FDR was used primarily where lower layers of pavement had significant distress or insufficient strength.

Recently the Nevada DOT investigated several strategies for rehabilitation of low-volume roads. The FDR strategies used included FDR with lime and asphalt emulsion, FDR with a proprietary liquid stabilizer, FDR with cement, FDR with a proprietary asphalt emulsion, and FDR with foamed asphalt. Of these, only the sections using FDR with cement and FDR with foamed asphalt provided good performance (*16*). The section treated with lime/emulsion raveled before a chip seal could be placed and experienced a rapid decrease in ride quality; the section with the liquid stabilizer raveled immediately and did not cure, and the section with asphalt emulsion produced a spongy material even after attempts at reworking (*16*).

TXDOT EXPERIENCE

Several TxDOT districts actively use FDR. These districts include Lubbock, Bryan, Beaumont, Amarillo, and Dallas. The Lubbock District traditionally used fly ash for treatment of low-volume roads. As the cost of fly ash increased, they now use fly ash or cement since the economic advantage of the fly ash has essentially disappeared. The main problem reported by the Lubbock District is bonding of surface treatments onto the treated base.

The Bryan District has recycled many miles of low-volume roads and pioneered the use of geogrid reinforcement for longitudinal crack mitigation as Figure 1.2 showed. The biggest problem on FDR projects in the Bryan District has been trying to minimize the longitudinal cracking when over expansive clays. Currently the district uses the geogrid when the subgrade PI exceeds 35.

The Beaumont District recently initiated work on several projects where they are using cement in the FDR process. The big initiative in the Beaumont District has been to start using slurry application of cement and microcracking.

The Amarillo District uses plans and cores to identify existing materials and typically uses Type C fly ash and CSS-1H emulsion for stabilization. They report the CSS-1H used in the uppermost layers of base help promote a good bond. The biggest problem reported by the district is priming and bonding asphalt concrete pavement (ACP) layers to materials treated with lime, cement, or fly ash.

The Dallas District faces unique conditions on many of their projects in need of rehabilitation because they often encounter widely varying structures and in some cases have full-depth hot mix directly on subgrade. Combined with the lack of shoulders, plastic soils, steep side slopes, and close proximity to roadside trees, these pavements often exhibit longitudinal cracking and edge failures. The district has tried treatments including geogrids with base overlay, geogrids with emulsion treatment, and cement stabilization with geogrid and base overlay. The geogrid and thick flexible base overlay did not prevent the edge failures from occurring. The geogrid with emulsion-treated base produced mixed results; the longitudinal cracks reappeared and FWD data indicate possible base breakdown, but after three years the ride was still acceptable. Thus far the best performance has been observed with cement stabilization with geogrid and base overlay; however some cracks still reappear and efforts should be made to reduce the amount of longitudinal cracking.

CHAPTER 2

DRAFT LABORATORY PROCEDURE TO EVALUATE BOND OF SURFACE TREATMENT TO BASE COURSE

Given the array of stabilizers, different types of emulsions, restrictions on cutbacks, environmental conditions, and traffic handling needs, one recurring problem that has not been solved statewide is the bonding of the surface treatment to the base course. One of the objectives of this research study is to evaluate a test that can be used in the lab and/or field to measure the bond strength of surface treatments to different base types.

The Direct Tensile Bond Test (ASTM C 1583) shown in Figure 2.1 is being used to assess the adhesion of surface treatments to different types of recycled base materials using different stabilizers cured under different climatic conditions. This test method was originally developed for use as an indicator of the adequacy of concrete surface preparation before applying a repair or overlay material. It is performed on the surface of the overlay material and determines the bond strength to the substrate or the tensile strength of either the overlay or substrate, whichever is weaker. When the test is performed on the surface of the material applied to the substrate, the measured strength is controlled by the failure mechanism requiring the least stress (Figure 2.2). A photo of the test device being used for the laboratory evaluation is shown in Figure 2.3.

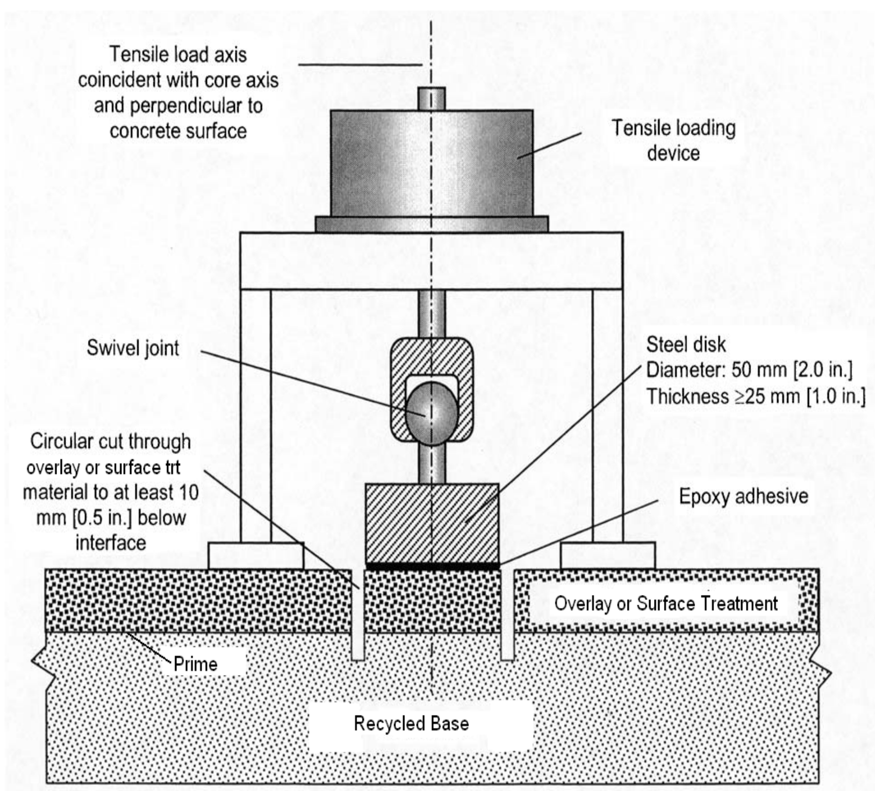


Figure 2.1. Schematic of Direct Tensile Bond Test.

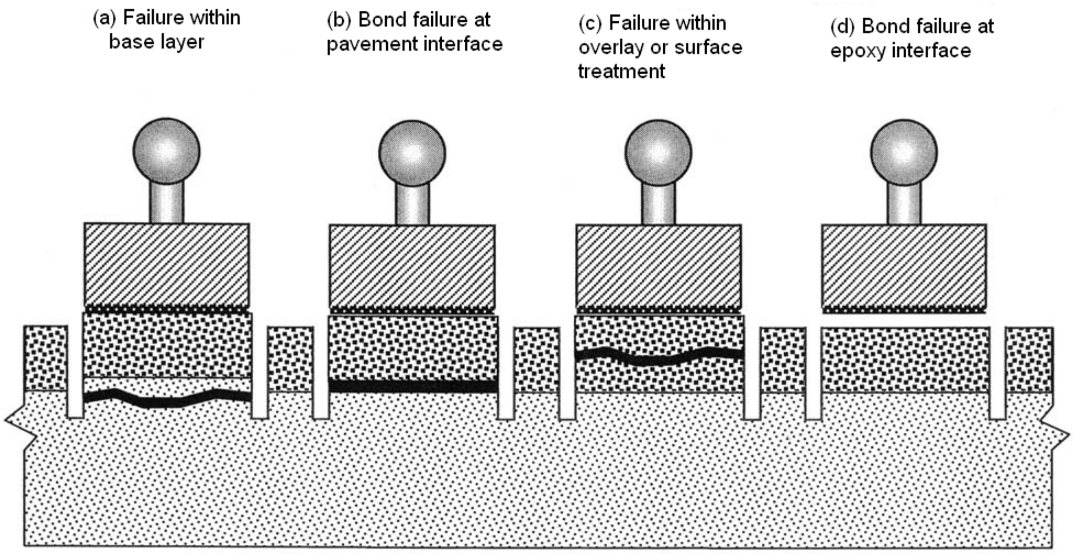


Figure 2.2. Possible Failure Modes.

Figure 2.3. Photo of Direct Tensile Bond Test Apparatus.

This ASTM procedure is well established for testing concrete but required some modification for FDR application, particularly in how to run the test on lab-molded samples. A laboratory procedure has been developed that addresses the following parameters:

- base sample size/configuration,
- base sample preparation,
- curing process,
- application of prime,
- application of surface treatment, and
- coring process.

Direct Tensile Bond Strength Draft Test Procedure

An brief overview of the draft procedure that has been developed for evaluating the bond strength of surface treatments to primed FDR base courses is described below and in more detail in Appendix A.

Step 1. Determine optimum moisture content of the recycled base course according to Tex-113-E for base material.

Step 2. Compact 6 replicate 6-in. diameter by 2-in. high samples in a single lift.

Step 3. Cover entire sample with plastic wrap for 1 hr. After 1 hr remove sample from plastic wrap and re-wrap the sample with plastic leaving only the top surface exposed. Apply prime material at predetermined application rate to the specimen surface (Figure 2.4).

Figure 2.4. Application of Prime to Base Sample.

Step 4. Place sample in 110°F oven to cure for 3 days.

Step 5. Apply surface treatment to samples and place in 110°F oven overnight (Figure 2.5).

Figure 2.5. Application of Surface Treatment to Primed Base Samples.

Step 6. Removed from oven, allow to cool for 1 hr and then core (dry) with a 2-in. diameter core-barrel to a depth just below the asphalt material (approximately ½ in.). See Figure 2.6.

Figure 2.6. Surface Treatment Samples after Coring to a Depth of ½ Inch.

Step 7. After coring, apply epoxy glue to the metal disks and place on to the cored section of the samples. Place sand into the cored ring to prevent epoxy from penetrating into the ring. Allow glue to dry overnight (Figure 2.7).

Figure 2.7. Gluing Metal Disks to Surface Treated Base Samples.

Step 8. Test Sample in Direct Tension Bond Test Apparatus and record the ultimate breaking strength in lbf and identify the plane where failure occurred; i.e., in the surface treatment, interface between prime and surface treatment, within the penetrated portion of the prime, beneath the prime and into the base (Figure 2.8).

Figure 2.8. Sample in Testing Apparatus and after Failure.

Discussion of Test Results

Several testing sequences using the draft procedure in Appendix A were performed to evaluate the direct tension apparatus and some of these results are described below.

- *Testing Sequence 1*. Twelve limestone base samples were stabilized with 3 percent cement and compacted to optimum moisture. Half of the samples were treated with MC-30 and half of the samples were left untreated. The untreated samples were wrapped in plastic and cured for 3 days at 110°F. The sides and the bottom of the primed samples were wrapped in plastic, but the primed surface was left exposed while curing at 110°F for 3 days. This curing period was selected to simulate the specification requirement of Item 275/276 regarding cement treatment: "Cure for at least 3 days by sprinkling in accordance with Item 204 or by applying an asphalt material at the rate of 0.05 to 0.20 gal. per square yard." No surface treatment was applied. The samples were then dry-cored to a depth of ½ in. using a 2-in. diameter core bit (same diameter as the testing disks) to ensure that failure occurred over a defined surface area. The tensile test metal disks were then glued directly to the surface of the specimens using a quick-drying, 30-minute epoxy.

  Test results are presented in Figure 2.9. In this figure, a photograph of the failed surface is shown for each specimen and the breaking strength for that specimen is noted under the photograph. The average tensile strength results for the primed and unprimed specimens are as follows:

  Primed Base: Mean Tensile Strength = 118 lb, Std Dev = 52 lb
  Unprimed Base: Mean Tensile Strength = 62 lb, Std Dev = 41 lb

  While these results indicate a significant amount of variability, the pull-off tensile strength for the primed base is greater than the unprimed base.

- *Testing Sequence 2*. In this experiment, base samples were prepared as previously described and half were treated with MC-30 and the other half with no prime. After the 3-day cure, all 12 specimens were surfaced with a surface treatment consisting of AC-205TR and Grade 4 lightweight as explained in Appendix A. Samples were again placed in the oven overnight and then allowed to cool for an hour. Coring was performed as described previously and the metal disks were glued to the surface of the specimens and tested as before. These results are presented in Figure 2.10 and can be summarized as follows:

  Primed Base: Mean Tensile Strength = 39 lb, Std Dev = 19 lb
  Unprimed Base: Mean Tensile Strength = 30 lb, Std Dev = 13 lb

  As shown in Figure 2.10, several of the specimens failed at the interface between the glue and the surface treatment. In addition, the surface irregularities created by the Grade 4 surface treatment aggregate made it difficult to glue the metal disk such that it was level.

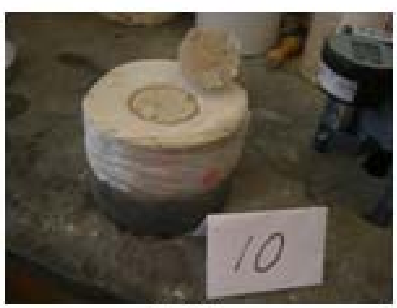
Strength = 198 lb | 64 lb | 111 lb

163 lb | 87 lb | 87 lb

CTB with MC-30 Prime

Mean Pull-Off Strength of all 6 samples: 118 lb
Standard Deviation: 52 lb

Strength = 52 lb | 58 lb | 140 lb



23 lb | 64 lb | 35 lb

CTB with No Prime

Mean Pull-Off Strength of all 6 samples: 62 lb
Standard Deviation: 41 lb

Figure 2.9. Tensile Bond Strength Test Results with Steel Disk Glued on Top of Cement Treated Base for Both Primed and Unprimed Specimens.

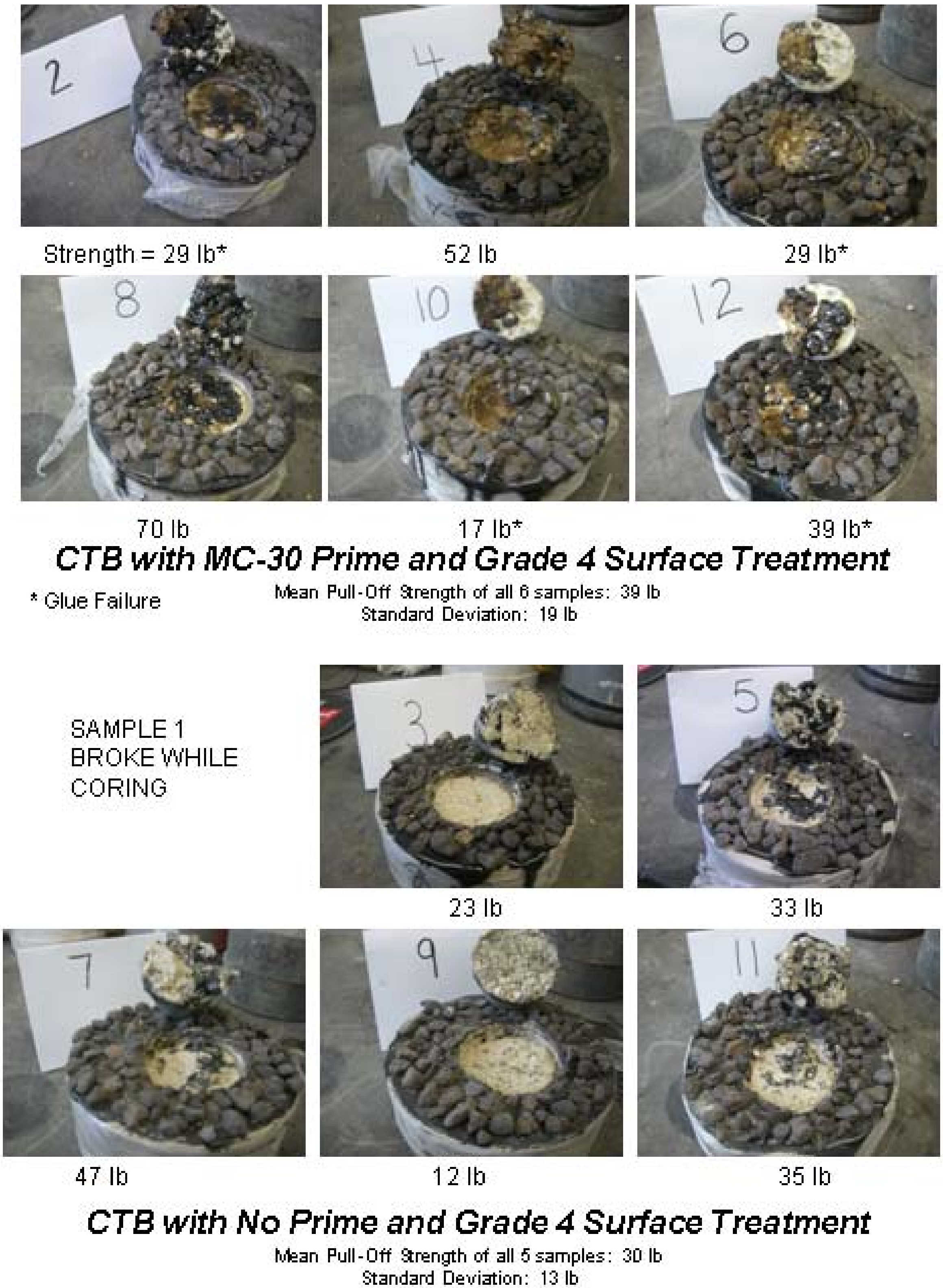


Figure 2.10. Tensile Bond Strength Test Results with Steel Disk Glued on Top of Grade 4 Surface Treatment for Both Primed and Unprimed Specimens.

- *Testing Sequence 3.* To alleviate some of the problems and sources of variability noted in the previous testing sequence, two changes were made to the previous experiment:
  - a different (more fluid) type of epoxy was used (which required drying overnight); and
  - a Grade 5 (instead of Grade 4) aggregate was used to increase the surface area for gluing and minimize the surface irregularities and provide for a more level surface.

  These results are shown in Figure 2.11 and summarized as follows:

  Primed Samples: Mean Tensile Strength = 118 lb, Std Dev = 45 lb
  Unprimed Samples: Mean Tensile Strength = 43 lb, Std Dev = 18 lb

  Eliminating the single outlying value for each set of specimens notably improves the standard deviation as follows:

  Primed Samples: Mean Tensile Strength = 133 lb, Std Dev = 28 lb
  Unprimed Samples: Mean Tensile Strength = 49 lb, Std Dev = 12 lb

These results indicate that the test procedure can measure a difference between primed and unprimed stabilized bases and that the bond provided by a primed base course is significantly greater than without a prime coat. Additional testing is underway to evaluate different prime materials and recycled base courses.

140 lb 128 lb 41 lb

99 lb 175 lb 122 lb

CTB with MC-30 Prime and Grade 5 Surface Treatment

Mean Pull-Off Strength of all 6 samples: 118 lb
Standard Deviation: 45 lb

52 lb 29 lb 12 lb

58 lb 58 lb 47 lb

CTB with No Prime and Grade 5 Surface Treatment

Mean Pull-Off Strength of all 6 samples: 43 lb
Standard Deviation: 18 lb

Figure 2.11. Tensile Bond Strength Test Results with Steel Disk Glued on Top of Grade 5 Surface Treatment for Both Primed and Unprimed Specimens.

CHAPTER 3

SAMPLING AND MIXTURE DESIGN OF FM 487

SUMMARY

In coordination with the Austin District, TTI researchers evaluated FM 487 in Williamson County from Bartlett to the Williamson County line. Based on the primary pavement distress of rutting on the project, and sampling and testing of materials in the lab, FDR could be performed on this project with 3 percent cement.

CURRENT PAVEMENT CONDITION

The primary distress is rutting, which exceeds 2 in. in some locations. The project also has some longitudinal cracking. Figure 3.1 shows the pavement condition.

Figure 3.1. Rutting on FM 487.

EXISTING PAVEMENT STRUCTURE

A GPR survey conducted to quickly investigate the pavement structure indicates the section is quite uniform in structure. The GPR indicates the pavement is probably built on another pavement structure. Figure 3.2 shows typical GPR data from the section. There are some surface patches and a few isolated locations (50 to 75 ft long) of deep patches as Figure 3.3 shows. With the exception of the deep patches, the maximum thickness of bituminous surfacing was approximately 5 in., which occurred at some locations of maintenance surface patches.

Figure 3.2. Typical GPR on FM 487.

Figure 3.3. Surface Patches and Deep Repairs in GPR Data.

CORING AND SAMPLING

Three core locations were selected for validation of the pavement structure and for collecting materials for laboratory testing. These locations were in the eastbound direction and were in sections selected by the maintenance office identified as sections 7, 8, and 10. Figures 3.4 through 3.6 show the locations.

Figure 3.4. FM 487 Sampling Locations in Maintenance Location 7.

Figure 3.5. FM 487 Sampling Locations in Maintenance Location 8.

Figure 3.6. FM 487 Sampling Locations in Maintenance Location 10.

TTI used an auger rig to verify the pavement structure to the subgrade and collect material samples. Figure 3.7 illustrates the structures observed at the three sampled locations.

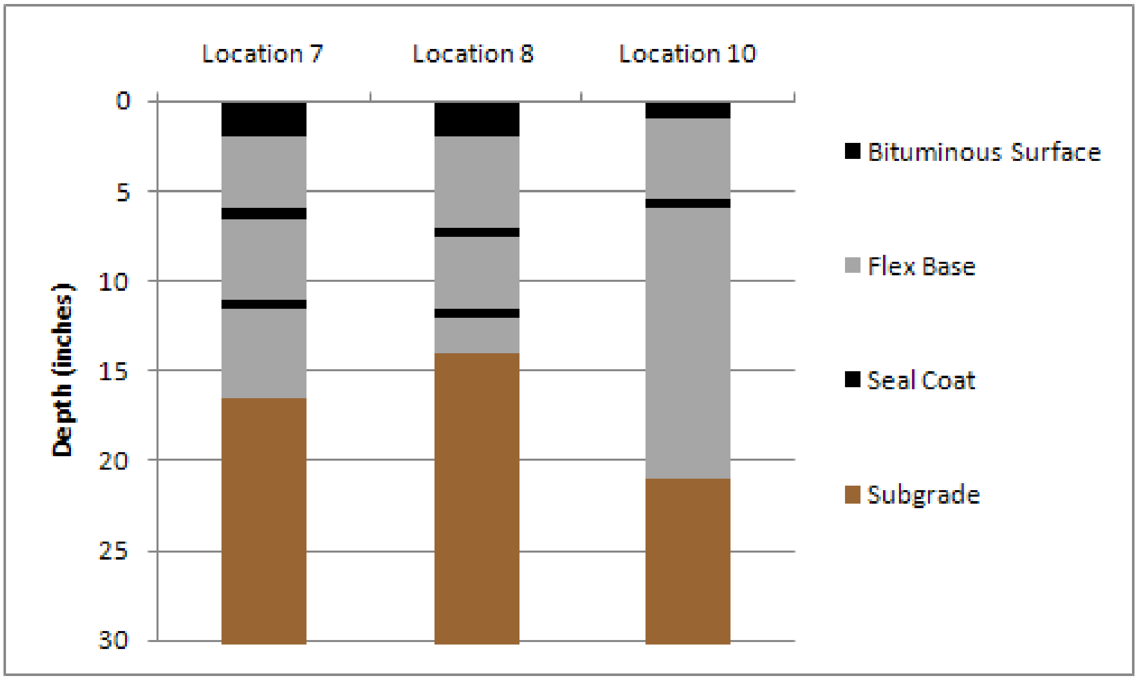


Figure 3.7. Pavement Structures on FM 487 Sample Locations.

TTI also collected subgrade samples from beneath the base at each site. Table 3.1 presents the Atterberg limits and sulfate contents measured on these soils.

Table 3.1. Atterberg Limits and Sulfate Content on FM 487 Soils.

Location	Liquid Limit	Plastic Limit	Plastic Index	Sulfate Content (ppm)
7 (16–23 inches)	39	17	23	120
8 (13–19 inches)	52	18	33	None detected
10 (21–27 inches)	46	17	29	186

DCP profiles were collected at locations 7 and 8 as Figure 4.8 shows. Although the Texas Triaxial Class is currently not generally used for bases, according to correlations by van Til et al. (1972), the base would be a Texas Triaxial Class of approximately 2.3 and the subgrade 5.1.

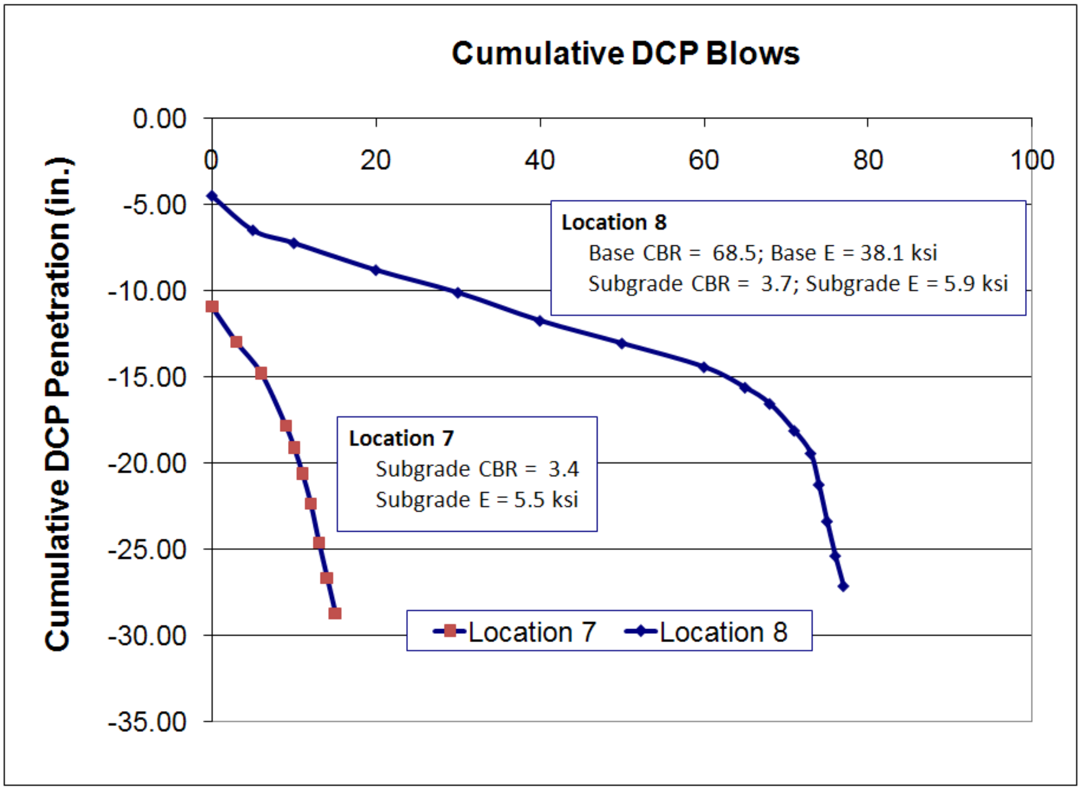


Figure 3.8. DCP on FM 487*.

*CBR is referenced in this figure as an intermediate step to predict elastic modulus from the DCP penetration rate using standard Corps of Engineers and AASHTO methods

LAB TESTING DESIGN RESULTS

The district desired to investigate cement as the treatment option. TTI sampled materials primarily from locations 7 and 8 for laboratory design tests. TTI augured to the anticipated recycling depth of typically 10 in. to collect the materials. This mixture consists of approximately 25 percent RAP and 75 percent flexible base. Table 3.2 presents the gradation of the RAP/base blend, Figure 3.9 presents the moisture-density curve, and Table 3.3 presents the design test results. The performance criteria were met with 3 percent cement, with an optimal moisture content of 7.9 percent.

Table 3.2. Gradation of FM 487 Material.

Sieve Size	% Retained
1 ¾	0
1 ¼	4.0
7/8	9.8
5/8	19.1
3/8	38.1
#4	60.3
#10	76.3
#40	84.8
#100	89.5
#200	91.3

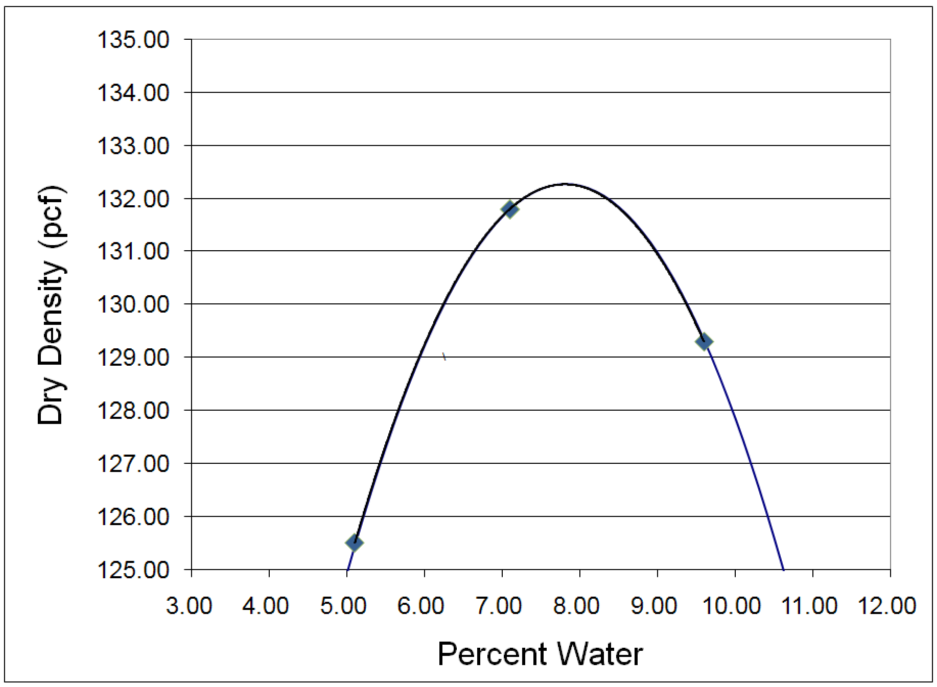


Figure 3.9. Moisture-Density Curve for FM 487.

Table 3.3. Design Test Results for FM 487.

Cement Content	2%	3%	4%	Spec Limits
Unconfined Compressive Strength (psi) @ 77°F (Tex-120-E)	173	260	429	175 psi min
Retained UCS (psi) @ 77°F after Tube Suction Test	220	343	484	80% min
Retained UCS (psi) after 7-day cure and 4-hr submersion	178	290	353	For Information Only
Tube Suction Test Final Dielectric (Er) and moisture content (%) (Tex-144-E)	15.3 7.1%	16.1 7.0%	15.9 6.3%	For Information Only
Unconditioned Seismic Modulus (ksi) (Draft TxDOT Method)	982	788	1858	For Information Only Tested at 7 days

PAVEMENT DESIGN RECOMMENDATIONS

The existing structure should be recycled to a depth of 8 in. with 3 percent cement. Based on discussions with Austin District staff, the project is scheduled for widening. In light of this fact, the existing material recycled with cement should be spread to 12 ft wide and a depth of 7 in. This sequence accomplishes the construction of a cement-treated subbase and pavement widening without a longitudinal construction joint. Figure 3.10 shows the proposed sequence.

The FDR layer can be sealed then additional thickness added based upon the traffic loading requirements of the pavement. Traffic data were not available at the time of this report, so FPS verification is not presented for this pavement. However, the lab design and pavement design must coordinate with each other. For example, with this pavement if 8 in. treatment depth resulted in elevation problems due to the additional thickness required, consideration could be given to increasing the treatment depth (so long as no more than 50 percent RAP is contained in the FDR mixture and the subgrade is not cut into) to reduce the amount of additional thickness.

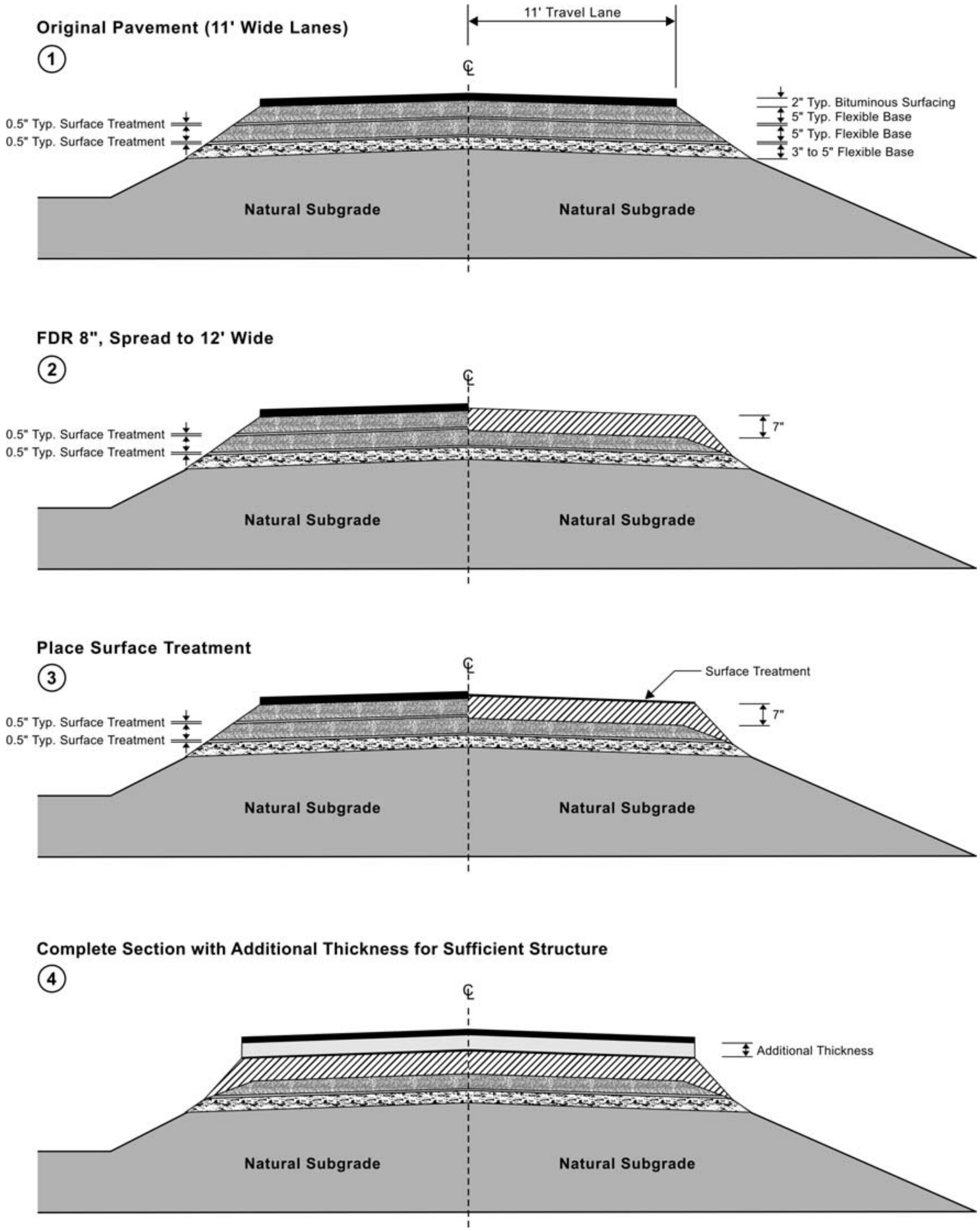


Figure 3.10. Proposed Sequence for FDR on FM 487.

CHAPTER 4

SAMPLING AND MIXTURE DESIGN OF FM 112

SUMMARY

In coordination with the Austin District, TTI researchers evaluated FM 112 in Williamson County from US 79 to FM 486. This section of pavement has extensive longitudinal cracking and some faulting occurring. This project would be a good candidate for FDR with widening. Based on the data collected, lab results obtained, and discussions with the district staff, the recommended strategy for FDR should be to recycle 8 in. with 4 percent cement and widen the pavement by 2–3 ft.

WEB SOIL SURVEY RESULTS

Figure 4.1 shows the section of FM 112 under investigation in the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) Web Soil Survey database. According to NRCS data, the soils in this area are very limited in suitability for roads and streets due to low strength and shrink-swell. Typical surface soil plasticity index values range from 25 to 47, as Figure 4.2 illustrates. The plasticity index tends to increase with depth, as Figure 4.3 illustrates that at depths from 12 to 48 in. the typical plasticity index values range from 38 to 54, with slightly reduced values (26 to 38) at the southeast end of the section. Figure 4.4 shows the higher plasticity soils also exhibit higher organics contents, averaging around 2 percent. Figure 4.5 shows that some pockets of sulfates may also exist, particularly in the middle of the section.

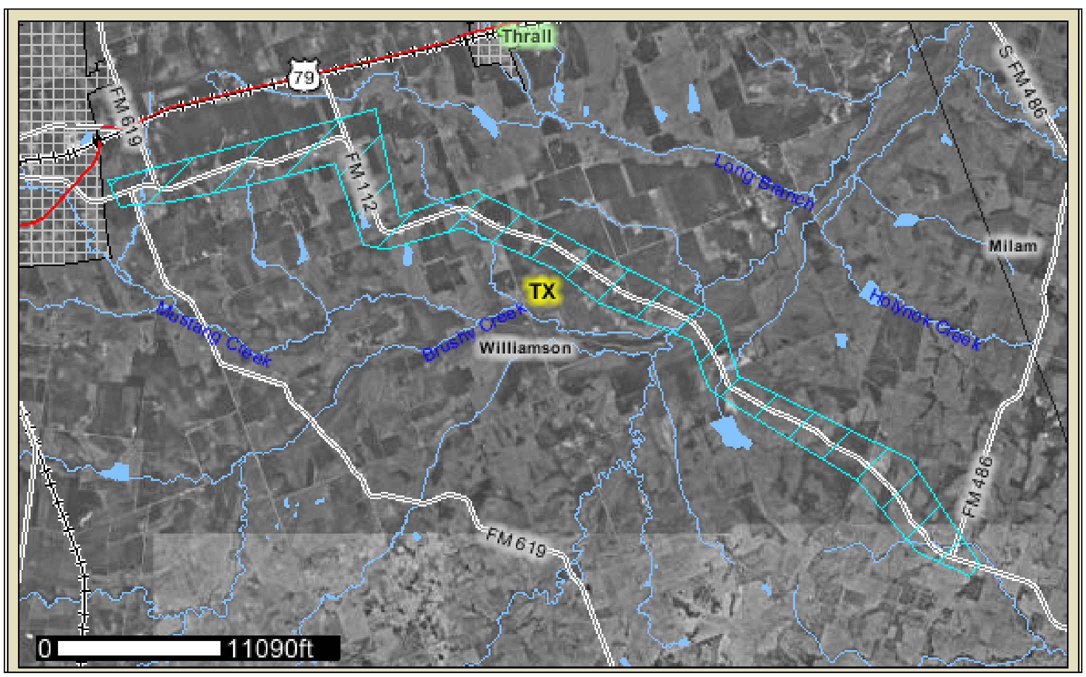


Figure 4.1. Web Soil Survey Area for FM 112.

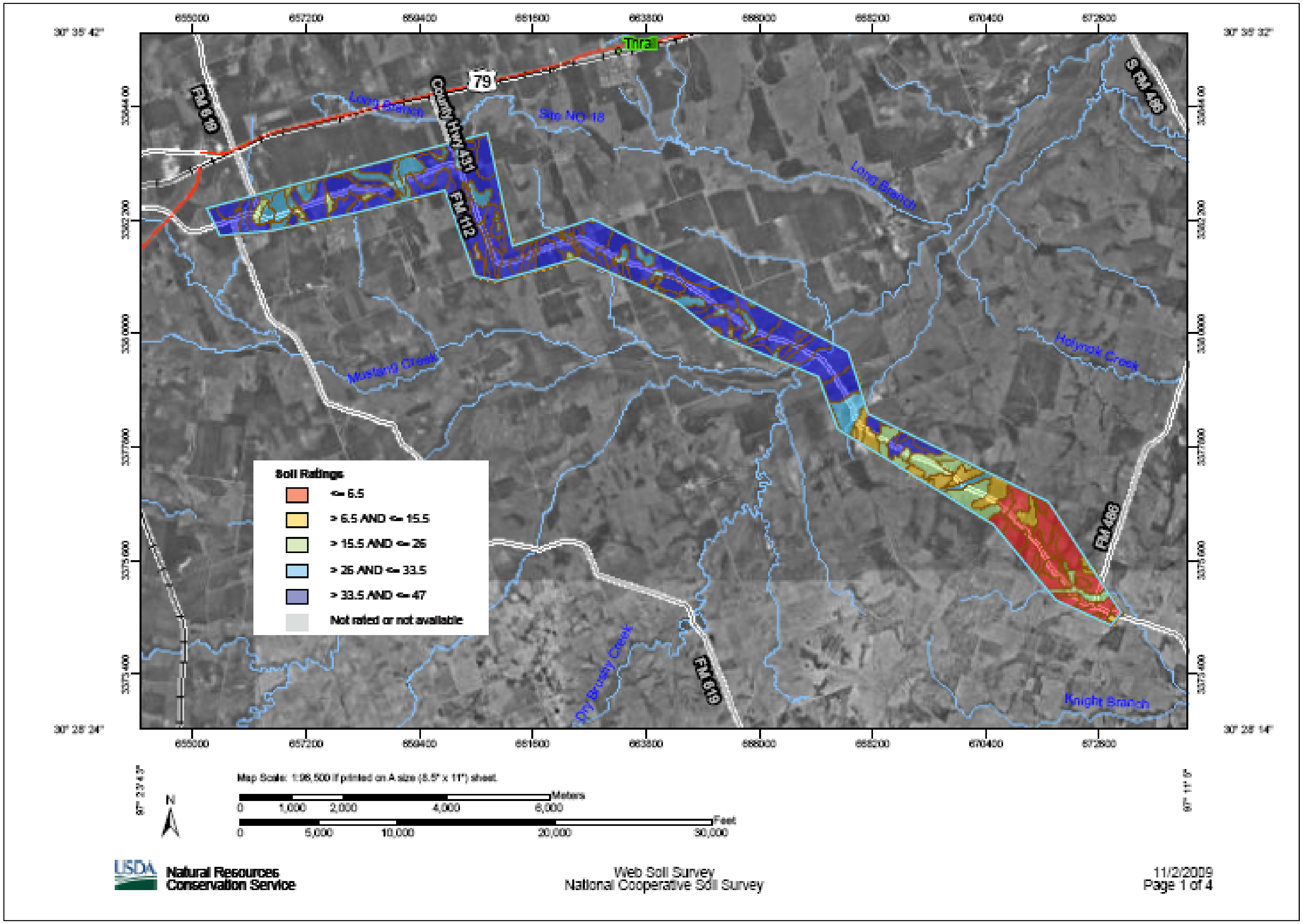


Figure 4.2. Surface Soil Plasticity Index on FM 112.

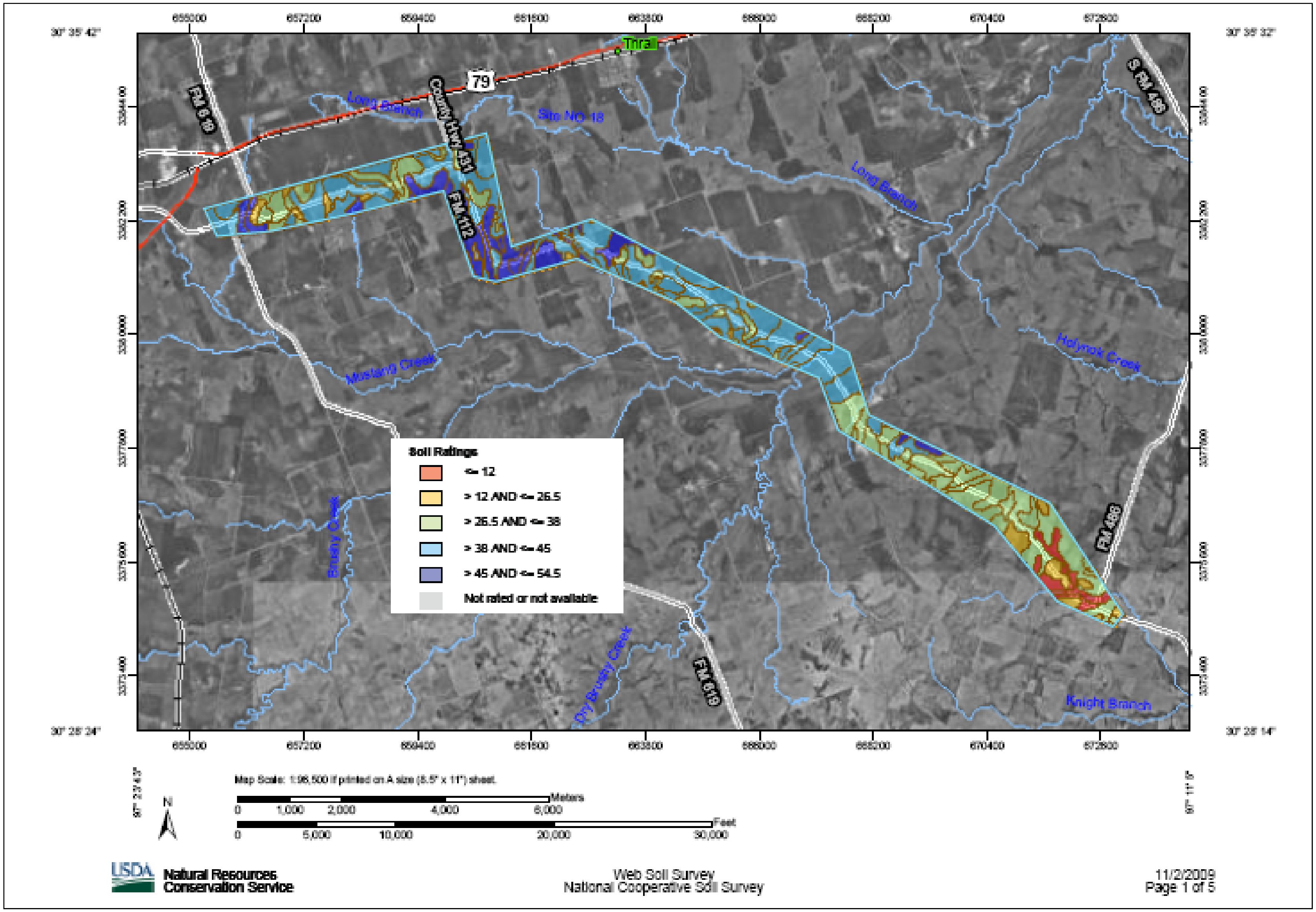


Figure 4.3. Soil Plasticity, 12–48 Inches, for FM 112.

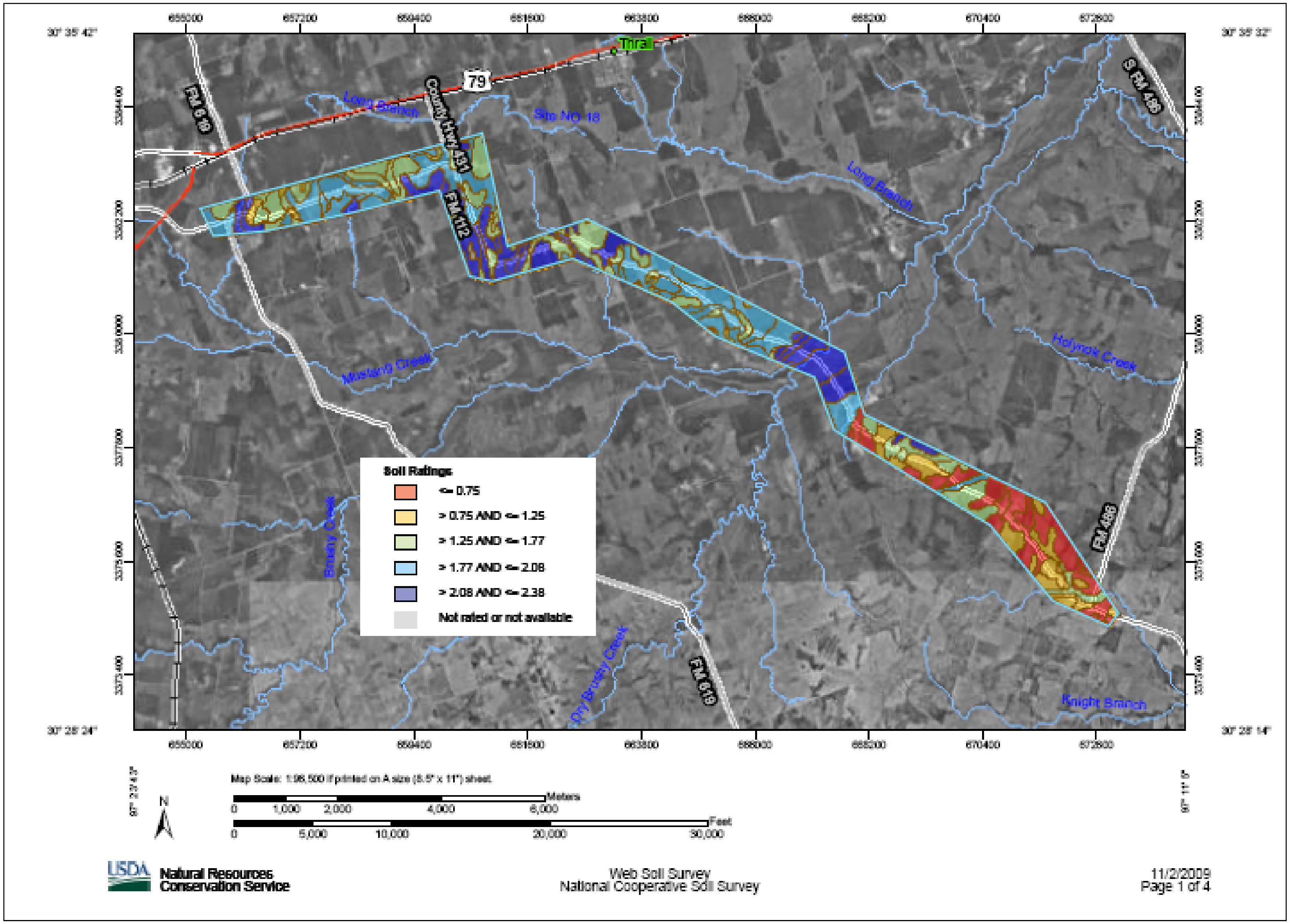


Figure 4.4. Organic Matter (Percent) for Top 12 Inches of FM 112 Soil.

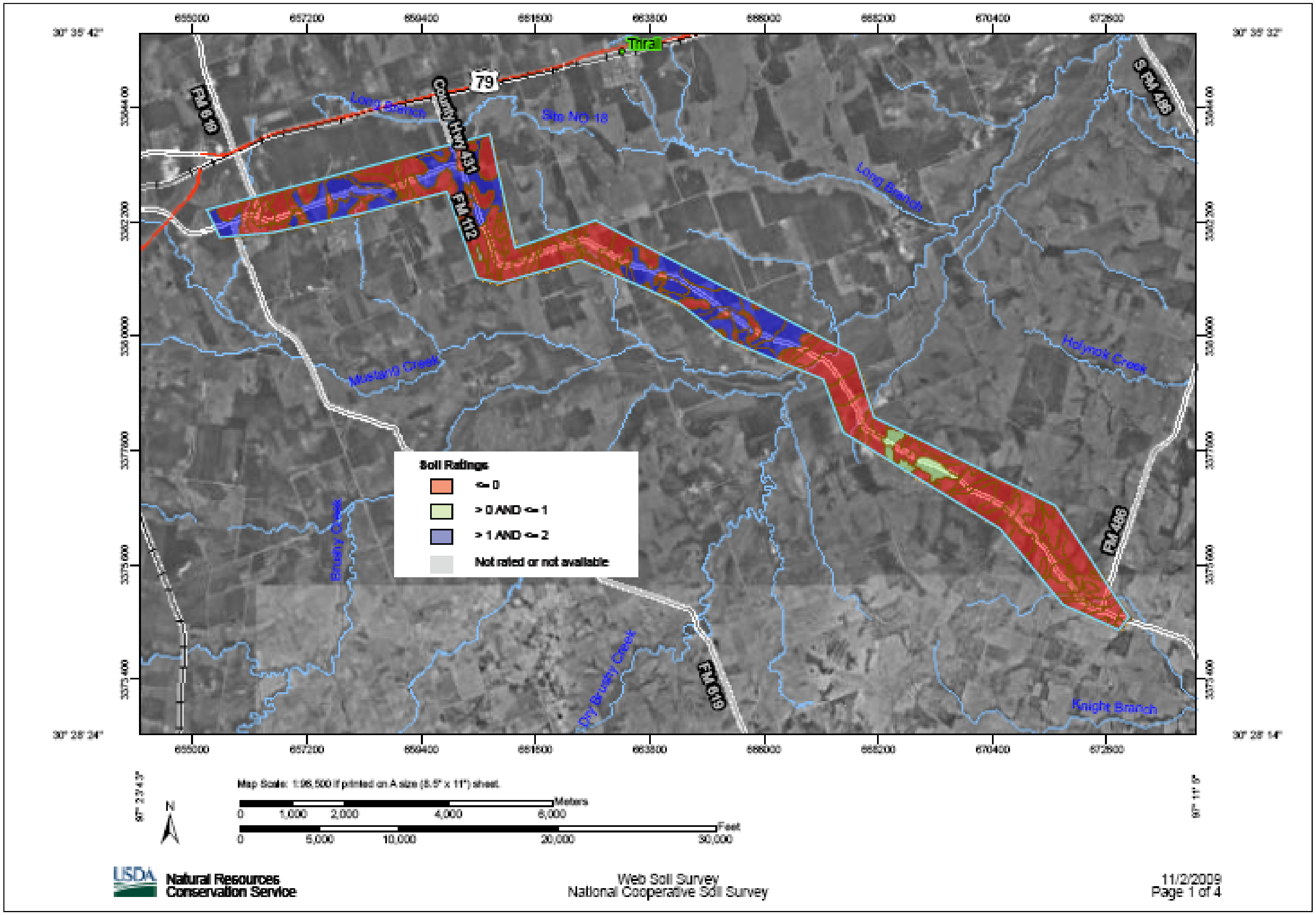


Figure 4.5. Gypsum Content (Percent) for Top 12 Inches of FM 112 Soil.

CURRENT PAVEMENT CONDITION

The primary distress is longitudinal cracking and faulting as Figures 5.6 and 5.7 show.

Figure 4.6. Pavement Distress on FM 112.

Figure 4.7. Longitudinal Cracking on FM 112.

EXISTING PAVEMENT STRUCTURE

A GPR survey conducted to quickly investigate the pavement structure indicates the pavement is probably built on another pavement structure. Numerous locations of maintenance activities also exist. Figures 4.8 through 4.12 show the GPR data from locations selected for coring. Figure 4.13 shows how the pavement condition improves, and the structure is quite uniform, after the location shown in Figure 4.12. The basic pavement structure consists of a thin surfacing with a thin layer of flexible base (typically 4 to 6 in.) on top of an existing roadbed.

Figure 4.8. FM 112 Sampling Location 1.

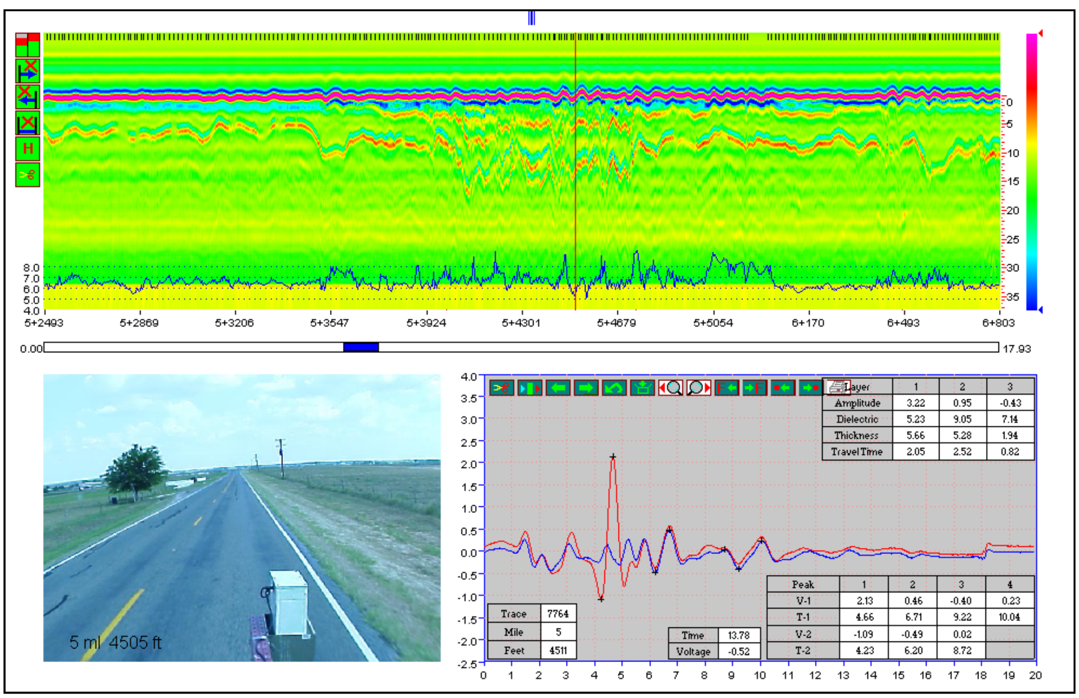


Figure 4.9. FM 112 Sampling Location 2.

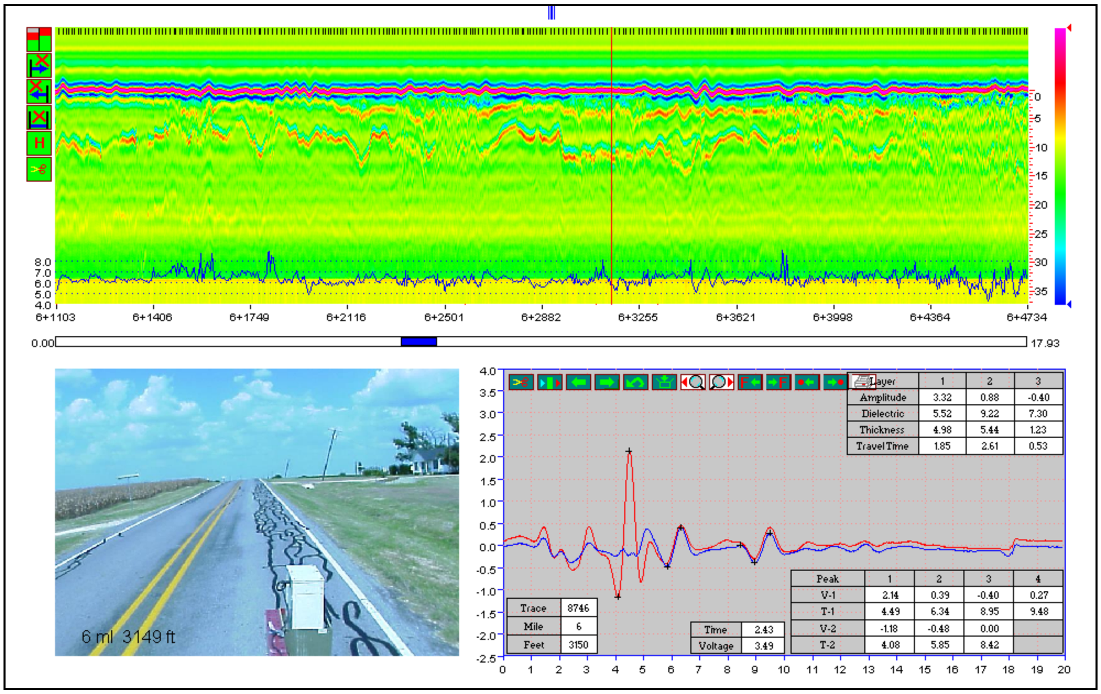


Figure 4.10. FM 112 Sampling Location 3 by Noack Church.

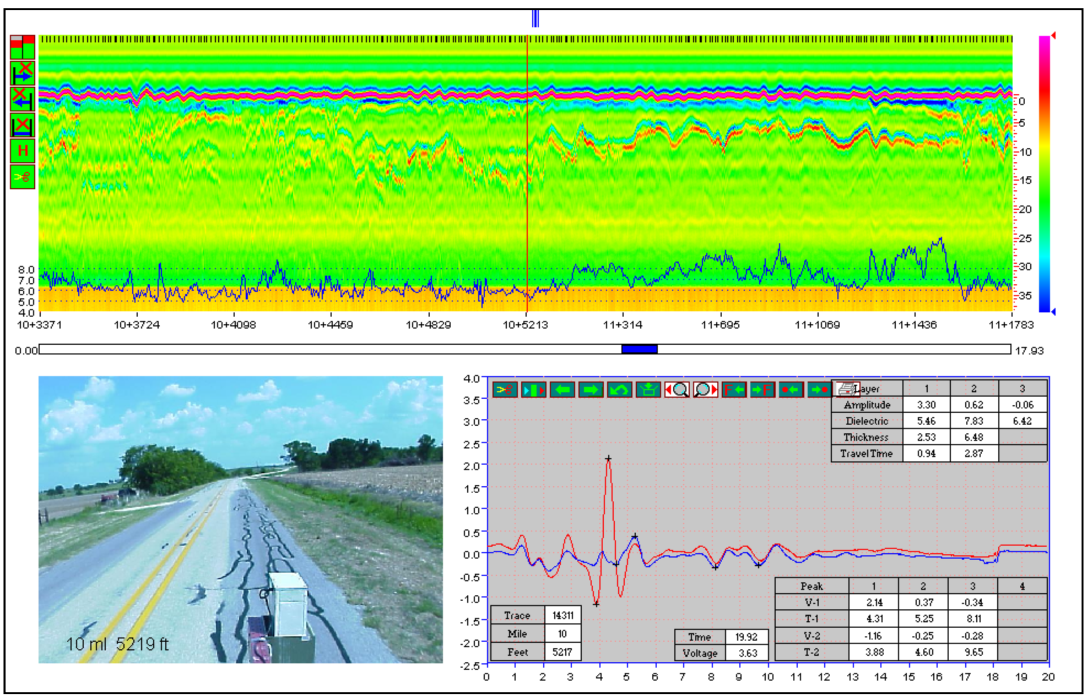


Figure 4.11. FM 112 Sampling Location 4.

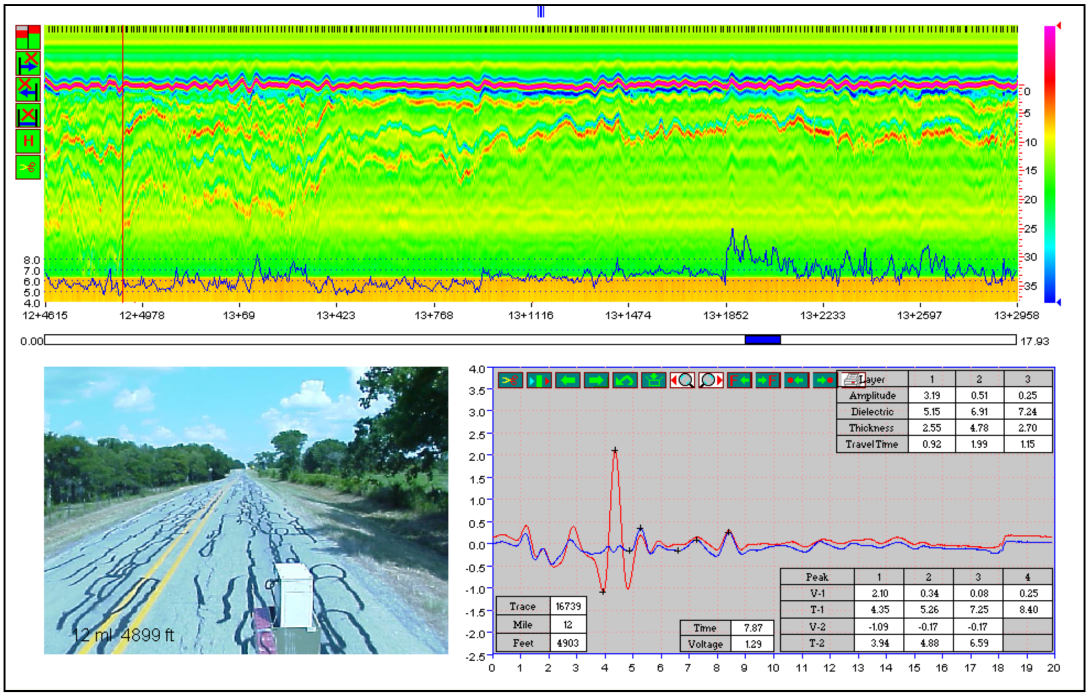


Figure 4.12. FM 112 Sampling Location 5.

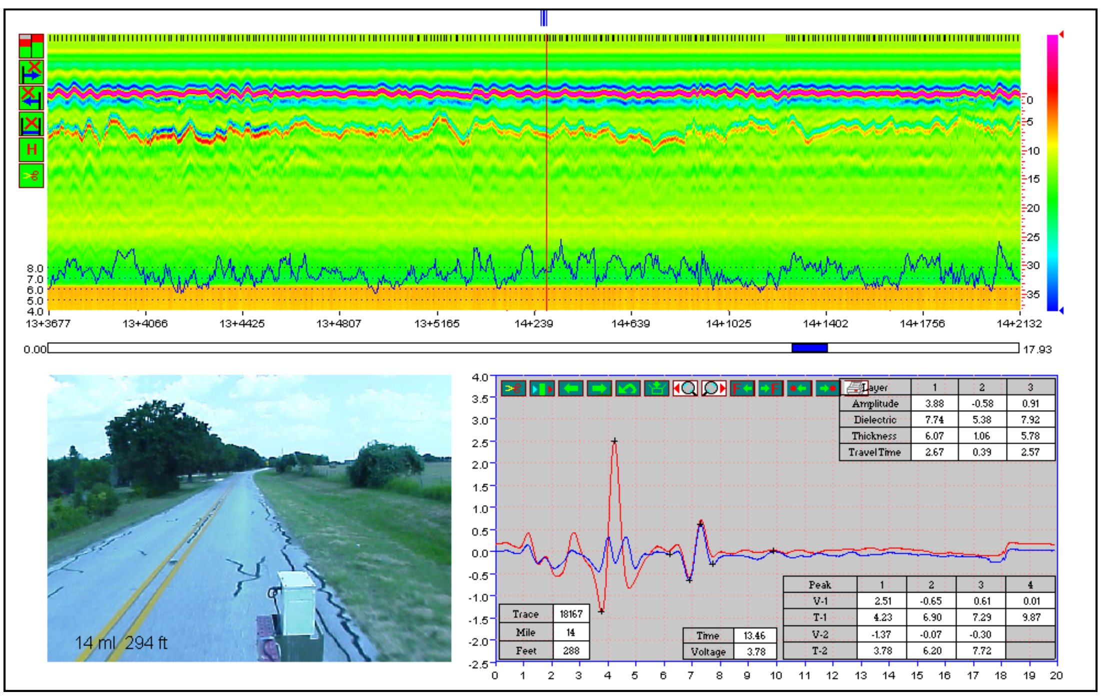


Figure 4.13. Typical FM 112 GPR Profile after Sampling Location 5.

CORING AND SAMPLING

Five core locations were selected for validation of the pavement structure and for collecting materials for laboratory testing. These locations were in the southbound direction and shown previously in Figures 4.8–4.13. TTI used an auger rig to verify the pavement structure and collect material samples. Figure 4.14 illustrates the structures observed at the sampled locations.

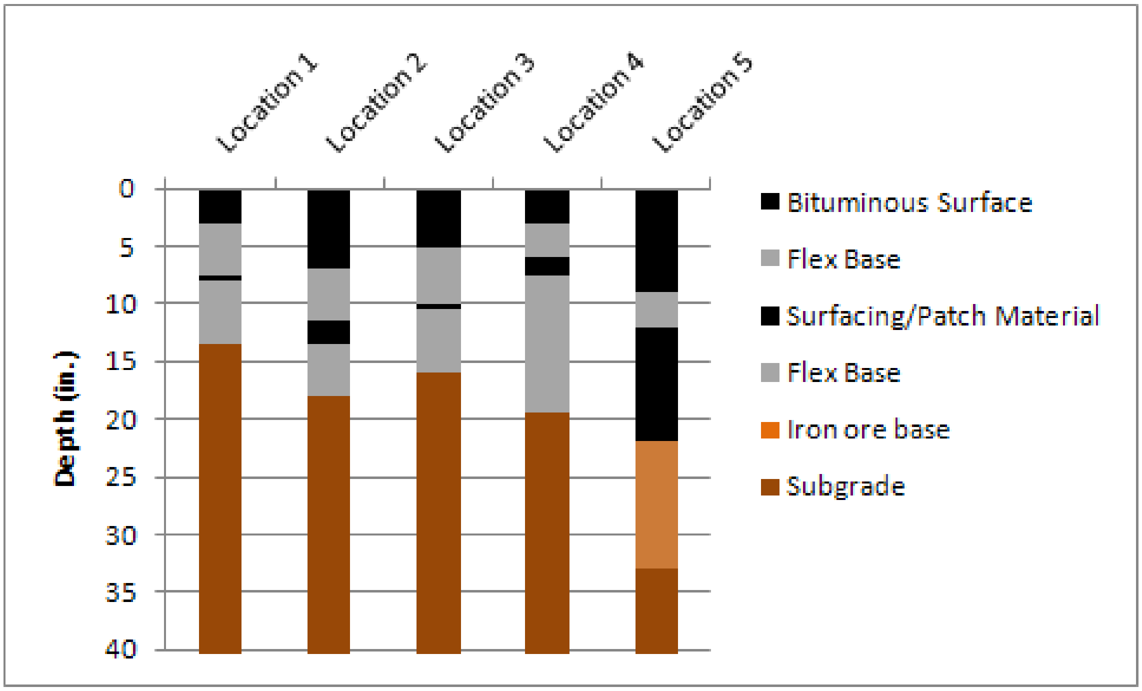


Figure 4.14. Pavement Structures on FM 112 Sample Locations.*

**Note: due to pavement faulting and maintenance level ups, surfacing thickness varies from ~ 1.5 to ~ 8 in. from the pavement centerline to pavement edge at Locations 2–4.*

TTI also collected subgrade samples from beneath the base at each site. Table 4.1 presents the Atterberg limits and sulfate contents measured on these soils.

Table 4.1. Atterberg Limits and Sulfate Content on FM 112 Soils.

Location	Liquid Limit	Plastic Limit	Plastic Index	Sulfate Content (ppm)
1 (16–22 inches)	45	17	29	126
2 (18–26 inches)	47	17	30	180
3 (22–29 inches)	47	17	30	180
4 (19–26 inches)	50	17	32	200
5 (33–39 inches)	47	19	28	160

LAB TESTING DESIGN RESULTS

TTI sampled materials primarily from locations 2, 3, and 4 for laboratory design tests. TTI augured to the anticipated recycling depth of typically 10 in. to collect the materials. This mixture consists of approximately 50 percent RAP and 50 percent flexible base. Table 4.2 presents the gradation of the RAP/base blend, Figure 5.15 presents the moisture-density curve, and Table 4.3 presents the design test results. The performance criteria were met with 4 percent cement, with an optimal moisture content of 9.0 percent.

Table 4.2. Gradation of FM 112 Material.

Sieve Size	% Retained
1 ¾	0
1 ¼	6.4
7/8	12.2
5/8	23.6
3/8	37.3
#4	60.0
#10	74.6
#40	85.7
#100	90.2
#200	91.9

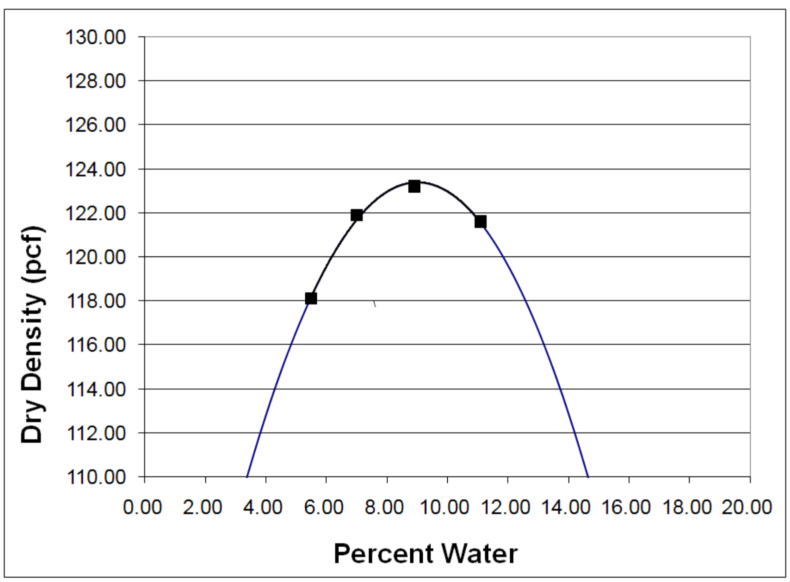


Figure 4.15. Moisture-Density Curve from FM 112 Material.

Table 4.3. Design Test Results for FM 112.

Cement Content	2%	3%	4%	Spec Limits
Unconfined Compressive Strength (psi) @ 77°F (Tex-120-E)	108	136	250	175 psi min
Retained UCS (psi) @ 77°F after Tube Suction Test	70.1	180	271	80% min
Retained UCS (psi) after 7-day cure and 4-hr submersion	74	144	226	For Information Only
Tube Suction Test Final Dielectric (Er) and moisture content (%) (Tex-144-E)	8.9	10.5	12.3	For Information Only
Unconditioned Seismic Modulus (ksi) (ASTM D 4123)	387	764	770	For Information Only Tested at 7 days

PAVEMENT DESIGN RECOMMENDATIONS

Given the current pavement condition and the steep side slopes, the existing structure is a good candidate for FDR with widening. The subgrade plastic index values immediately beneath the pavement oddly were not extremely high; however the soil may become more plastic with depth. The general strategy for FDR should be to recycle 8 in. with 4 percent cement and widen the pavement by 2–3 ft. The locations with the most distress and most maintenance activity will require milling or some additional new base to keep the percentage RAP in the FDR blend from becoming excessive. These locations are evident in the GPR data, which was provided to the district staff. In these locations, the following options are proposed:

- Option 1: Mill 2 in. and FDR 8 in.
- Option 2: Add 4 in. new base and FDR 8 in.

In the heavily distressed area represented by test location 5, 8 in. of material should be removed prior to initiating FDR to a depth of 8 in. After performing the FDR process, a thin overlay with a low-fines base (as defined in draft Item 245 in Product 5-4358-01-P2) should be considered to help control longitudinal cracking. The areas with a history of the worst cracking should also be considered for geogrid reinforcement.

CHAPTER 5

SAMPLING AND MIXTURE DESIGN OF FM 969

SUMMARY

In coordination with the Austin District, TTI researchers evaluated FM 969 in Travis County from Decker Creek Drive to the Travis County line. The primary distress on this pavement is longitudinal cracking, with some edge faulting. Pavement distress on the project appears to be due to a lack of edge support and is compounded in some areas by highly plastic soils. This project would be a good candidate for FDR with widening. For the typical sections, 2 in. of the existing HMA should be milled off. This RAP should be mixed with new base to achieve a 50/50 blend and used for widening the existing base. Next, the existing material should be recycled with 3 percent cement to a depth of 8 in. and spread to extend each half-section by 3 ft.

CURRENT PAVEMENT CONDITION

The primary distress is longitudinal cracking, with some edge faulting. Figure 5.1 illustrates the typical pavement condition.

Figure 5.1. Typical Distress on FM 969.

EXISTING PAVEMENT STRUCTURE

A GPR survey conducted to quickly investigate the pavement structure indicates the pavement appears to be built upon an old roadbed, and there are several locations of full-depth patches. Figure 5.2 shows an example of an area that appears to have deep patches, and Figure 5.3 shows the radar profile that appears typical of most of the project.

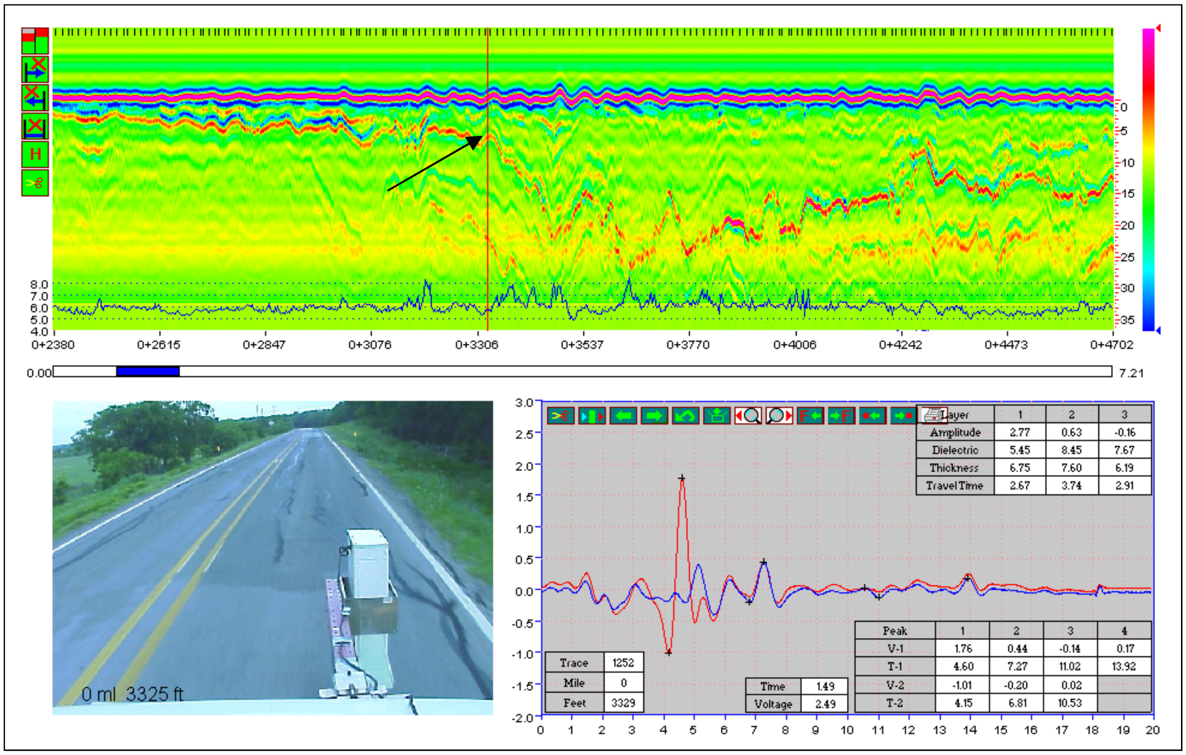


Figure 5.2. GPR on FM 969 with Deep Patching.

Note: Reflection indicated by arrow confirmed to be bottom of HMA by auguring.

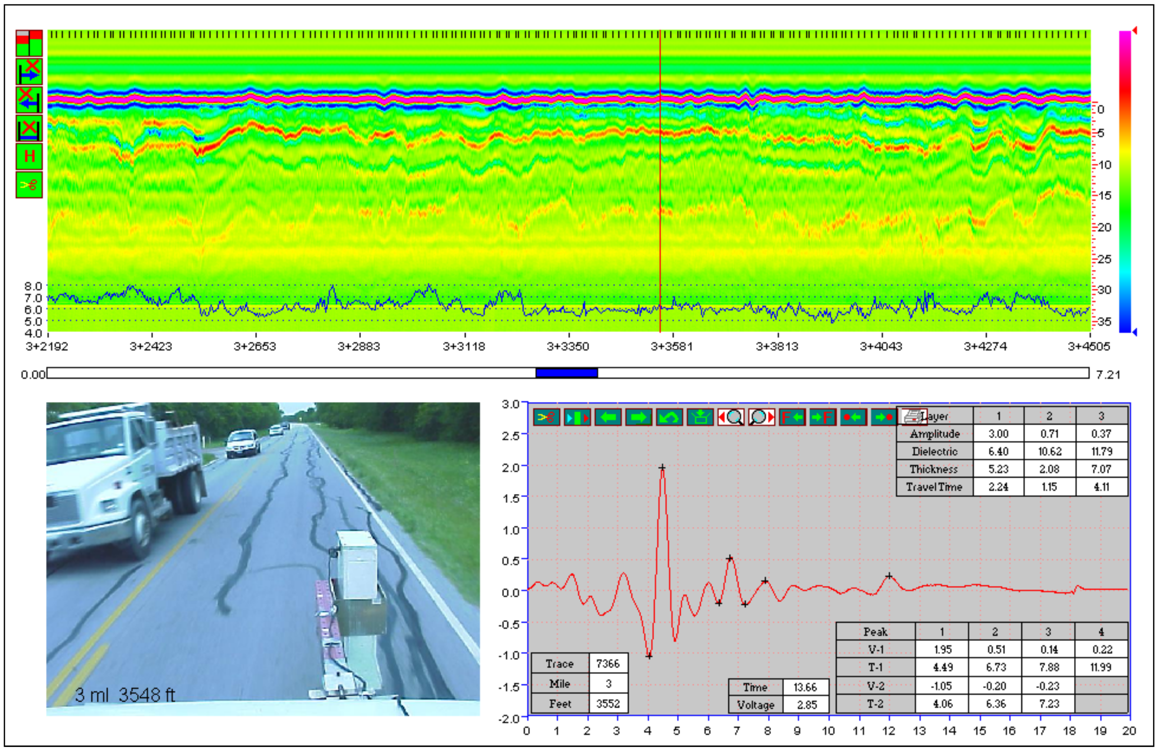


Figure 5.3. GPR Data Representative of Majority of FM 969 Project.

MATERIAL SAMPLING

Two sampling locations were selected for validation of the pavement structure and for collecting materials for laboratory testing. These locations were in the westbound direction at distances of 2667 ft, and 3 miles + 2892 ft, from the county line. Figures 5.2 and 5.3, respectively, showed the GPR data at sampling locations 1 and 2. Figure 5.4 shows the sampling locations, and Figure 5.5 illustrates the steep side slopes present at sampling location 1.

Figure 5.4. FM 969 Sampling Locations 1 (Left) and 2 (Right).

Figure 5.5. Steep Side Slopes at FM 969 Sampling Location 1.

TTI used an auger rig to verify the pavement structure and collect material samples. The majority of materials were collected from Location 2 since the GPR indicated this location was most representative of the typical structure. Figure 5.6 illustrates the structures observed at the two sampled locations.

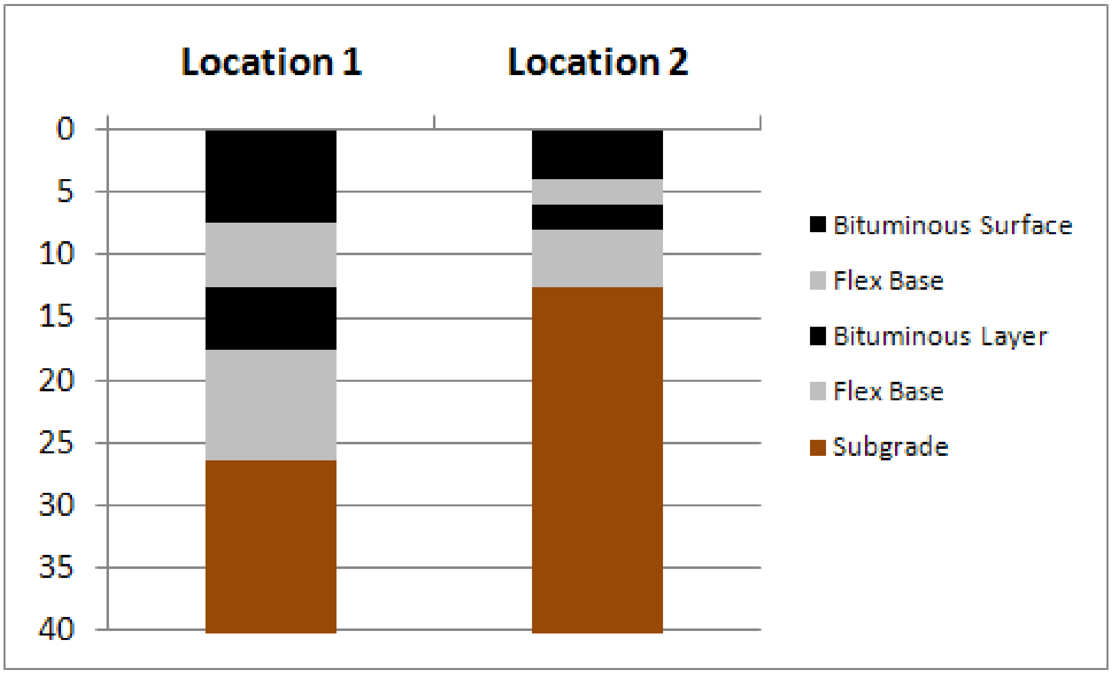


Figure 5.6. Pavement Structures on FM 969 Sample Locations.

TTI also collected subgrade samples from beneath the base at each site. Table 5.1 presents the Atterberg limits and sulfate content measured on these soils. Soluble sulfate tests at both locations resulted in a measured value of approximately 160 ppm.

Table 5.1. Atterberg Limits and Sulfate Content on FM 969 Subrade.

Location	Liquid Limit	Plastic Limit	Plastic Index	Sulfate Content (ppm)
1 (26–33 inches)	22	12	10	126
2 (15–22 inches)	63	19	44	126

DCP profiles were collected at both sampling locations; Figure 5.7 presents the DCP data. At location 1, the DCP encountered refusal in the buried bituminous layer. At location 2, the DCP data indicate good base and subgrade support. According to correlations by Van Till (1972), the base would be a Texas Triaxial Class 1, and the subgrade approximately 4.0. At the time of testing, however, the area had been experiencing drought conditions. Given the plasticity index of the soil at this location, it is suspected during normal weather conditions the DCP results would not have been as favorable for the subgrade.

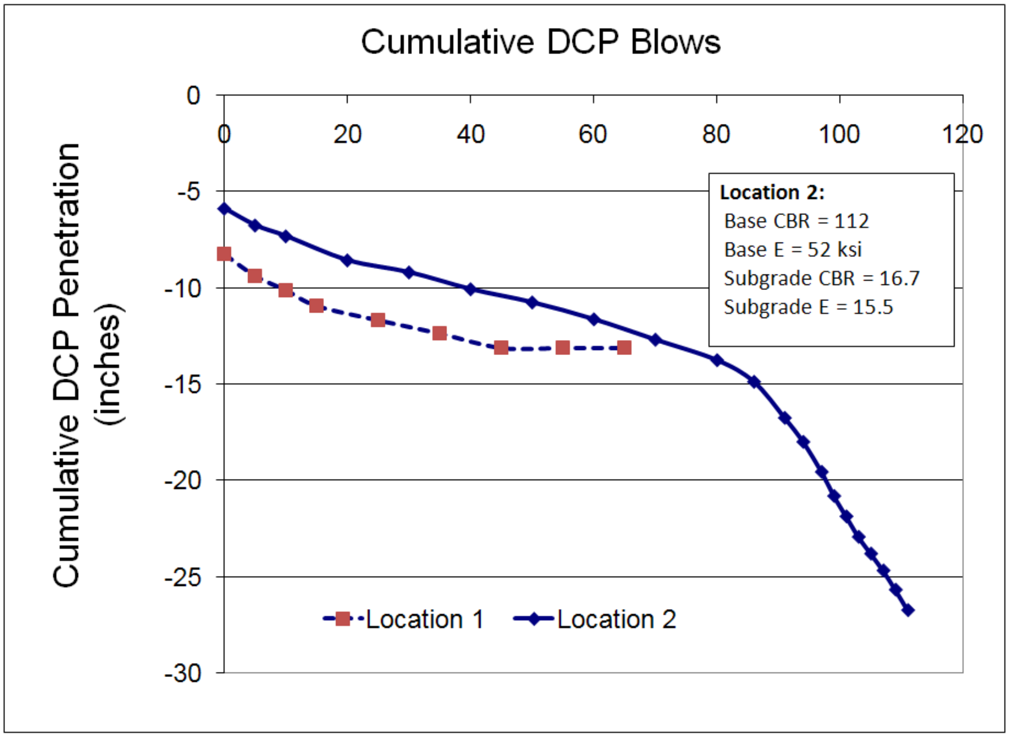


Figure 5.7. DCP on FM 969.

LAB TESTING DESIGN RESULTS

TTI sampled materials primarily from location 2 for laboratory design tests. TTI maintained the augured bituminous surfacing separate, then augured to an additional depth of 8 in. to collect the materials. In the lab, the RAP and base/RAP blend were mixed in proportions to obtain a blend containing approximately 50 percent RAP. Table 5.2 presents the gradation of the blended materials, Figure 5.8 presents the moisture-density curve, and Table 5.3 presents the design test results. The performance criteria were met with 3 percent cement with an optimal moisture content of 6.6 percent.

Table 5.2. Gradation of FM 969 Material.

Sieve Size	% Retained
1 ¾	0
1 ¼	5.7
7/8	11.1
5/8	18.5
3/8	33.5
#4	51.5
#10	64.4
#40	81.1
#100	89.6
#200	91.7

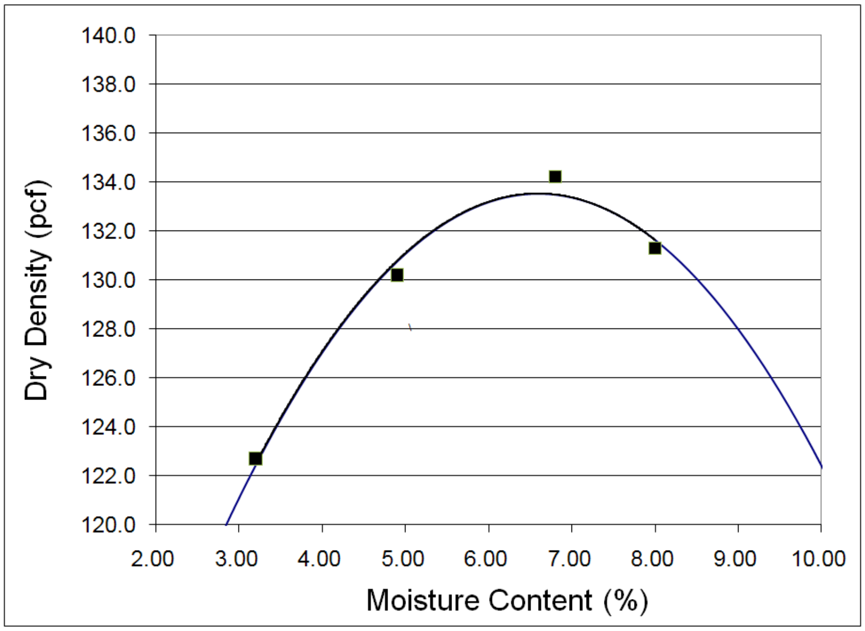


Figure 5.8. Moisture-Density Curve of FM 969 Material.

Table 5.3. Design Test Results for FM 969.

Cement Content	**2%**	**3%**	**4%**	**Spec Limits**
Unconfined Compressive Strength (psi) @ 77°F (Tex-120-E)	166	247	327	175 psi min
Retained UCS (psi) @ 77°F after Tube Suction Test	193	304	359	80% min
Retained UCS (psi) after 7-day cure and 4-hour submersion	162	222	263	For Information Only
Tube Suction Test Final Dielectric (Er) and moisture content (%) (Tex-144-E)	13.5	13.1	11.3	For Information Only
Unconditioned Seismic Modulus (ksi) (ASTM D 4123)	957	1314	1512	For Information Only Tested at 7 days

PAVEMENT DESIGN RECOMMENDATIONS

Based on discussions with Austin District staff, the project is scheduled for widening as part of the FDR process. The majority of this project is built upon an old roadbed. In the majority of the project, on top of the old roadbed is a thin (2–5 in.) flexible base overlay then 4 to 8 in. of HMA surface. Pavement distress on the project appears due to a lack of edge support and is compounded in some areas by highly plastic soils.

For the typical sections, after subgrade widening, 2 in. of the existing HMA should be milled off. This material should be pug-mill mixed with new flex base to achieve a 50/50 blend and used for widening the existing base. Next, the existing material should be recycled with 3 percent cement to a depth of 8 in. and spread to extend the width of each half-section by 3 ft. If no additional thickness is required for the traffic loadings, the FDR layer can then be sealed. If additional thickness is needed, or for added protection against the risk of longitudinal cracking, a flexible base overlay can be employed with geogrid reinforcement at areas with subgrade plasticity index values exceeding 35. Figure 5.9 shows the proposed sequence.

As traveling westbound, two long sections exist with substantial amounts of deep patching. These are at the following distances from the county line:

- 2530 ft to 1 mile + 1590 ft, and
- 5 miles to 6 miles + 135 ft.

In these sections, other options are needed to avoid recycling 100 percent RAP. The best approach would be:

- mill and remove 4 in.
- mill an additional 4 in.
- add 4 in. of new flexible base, and
- cement treat 8 in. with 3 percent cement and spread to the new pavement width.

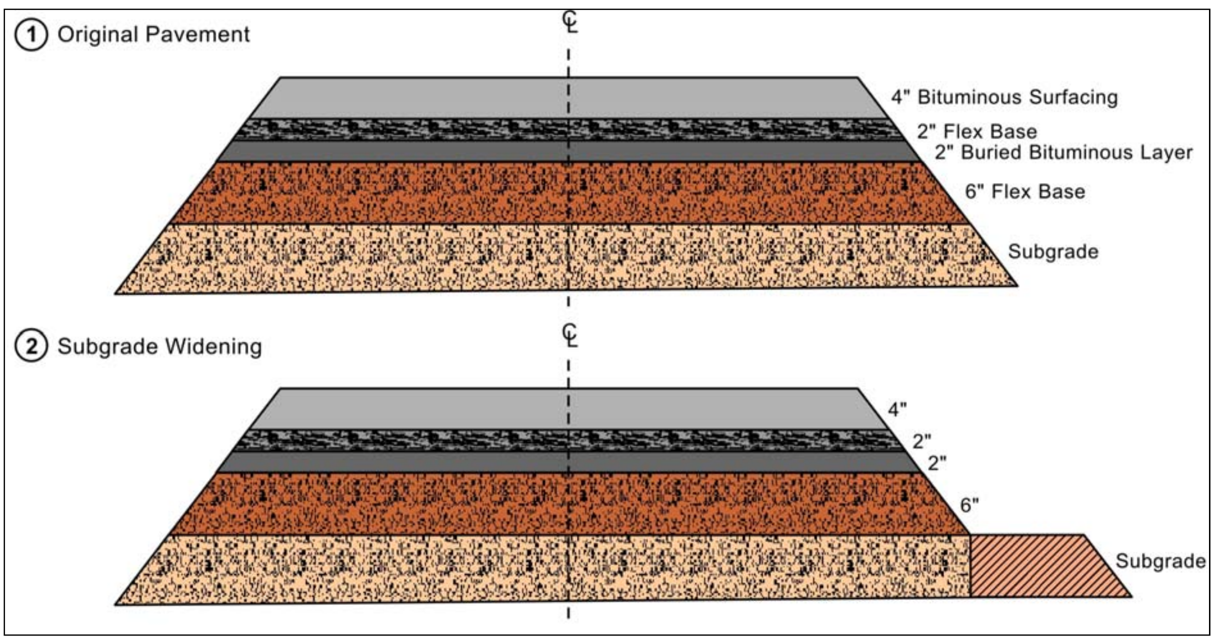


Figure 5.9. Proposed Sequence for FM 969.

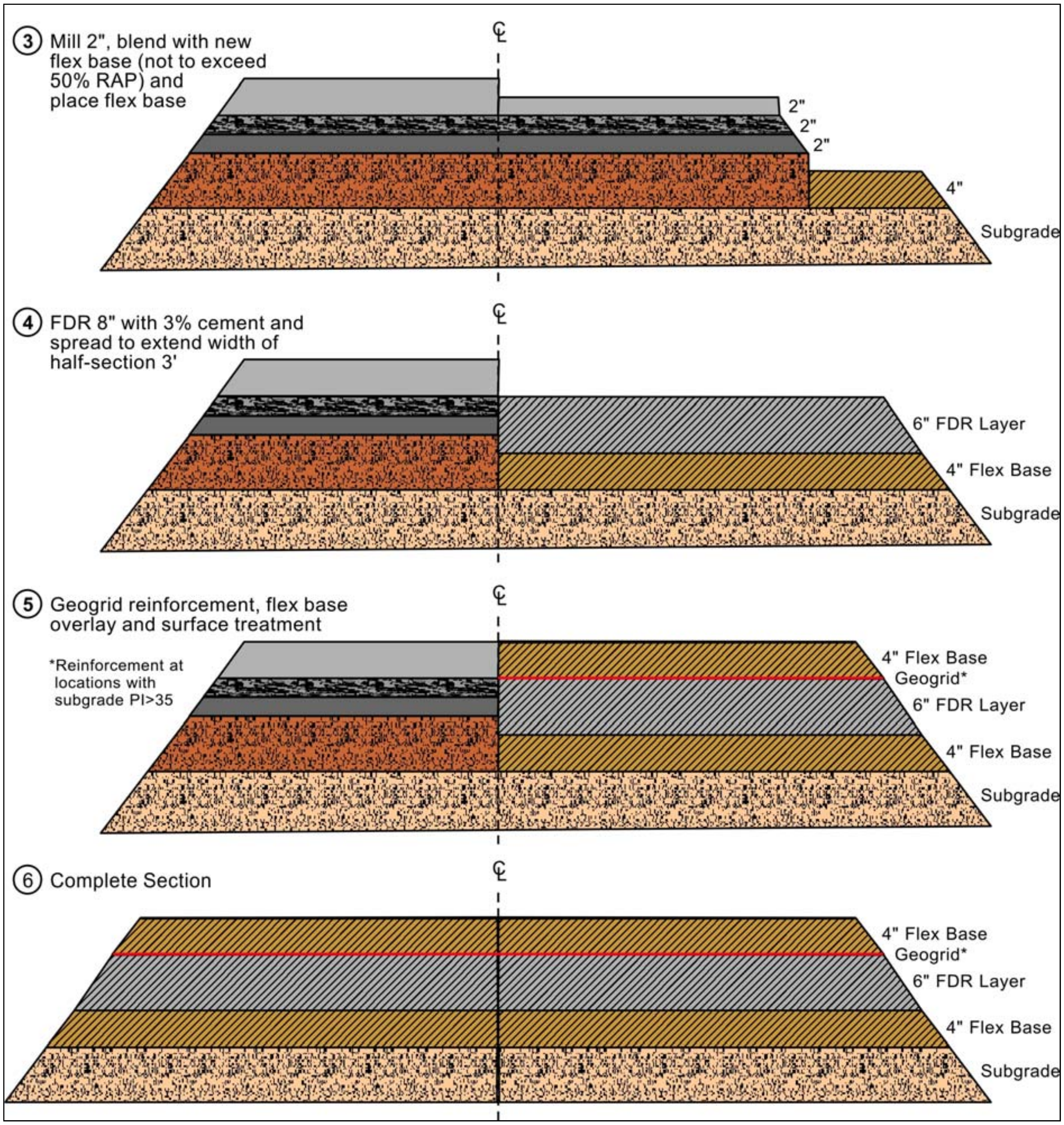


Figure 5.9. Proposed Sequence for FM 969 (Continued).

CHAPTER 6

SAMPLING AND MIXTURE DESIGN OF BUSINESS (US) 289

SUMMARY

In coordination with the Dallas District, TTI researchers evaluated Business (US) 289 in Collin County from FM 255 to SH 289. The primary distress on this pavement is severe longitudinal cracking with faulting. Since the most severely distressed locations were typically between 100 to 750 ft long, this investigation focused on maintenance options that could be applied to the problem locations. Current maintenance practices of milling and overlaying do not provide a long-term solution; often, the problems re-occur in 1 to 2 years. Long-term solutions must address the root cause of the problem, which is a lack of edge support. In some cases a slip plane may also exist; any edge repairs should go beyond the depth of the failure plane. Based on the existing pavement structure, three maintenance options should be considered. One option is a partial full depth repair; the other two options are methods that maintenance forces could employ to improve lateral edge support. On this project, no lab testing was conducted; this project primarily served as a brainstorming session to identify potential options that maintenance forces could perform to get the district's feedback on the ideas.

CURRENT PAVEMENT CONDITION

Figure 6.1 shows the current pavement condition, where the primary distress is longitudinal cracking with edge faulting.

Figure 6.1. Pavement Distress on Business (US) 289.

EXISTING PAVEMENT STRUCTURE

A GPR and coring program revealed a thick pavement structure, with 27 in. of thickness above the subgrade. Figure 6.2 shows the field coring in progress, and Figure 6.3 illustrates the typical existing pavement structure, which consists of:

- 7 in. HMA,
- 7 in. RAP/base blend, and
- 13 in. sandstone base over black clay.

Figure 6.2. Coring on Business (US) 289.

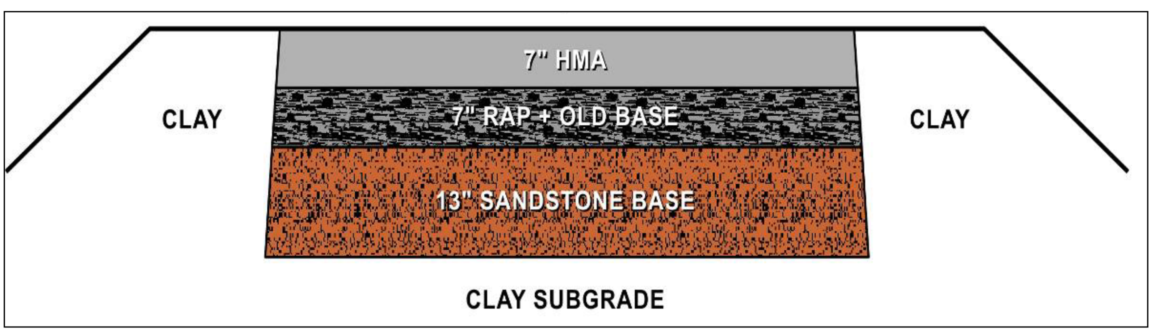


Figure 6.3. Typical Section on Business (US) 289.

PAVEMENT REPAIR RECOMMENDATIONS

Since the most severely distressed locations are confined to locations ranging only from 100 to 750 ft long, the Dallas District desired localized repair options within the scope of maintenance activities. Based on the pavement structure and distress, the following four options are suggested for the district's consideration.

Partial Width Full-Depth Repair

This is the most complicated and extensive repair option. It includes widening the pavement, creating a stiff foundation layer and installing a geogrid and new flexible base to minimize reflection cracking. This option has mostly been used in FDR treatments where the full roadway gets treated, but the approach may also be successful when applied as a partial-width treatment. Figure 6.4 illustrates the construction sequence for the partial-width FDR approach.

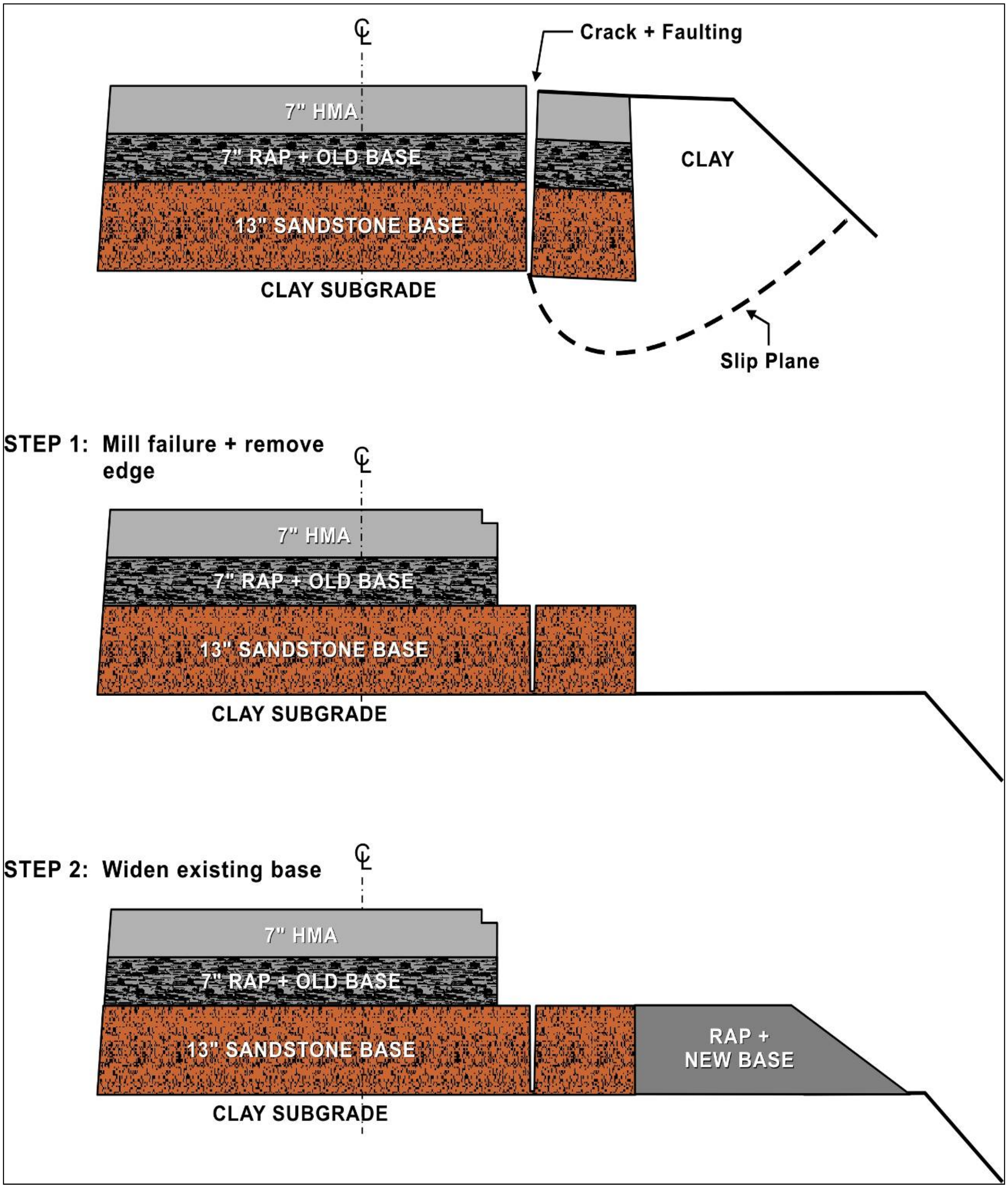


Figure 6.4. Partial-Width FDR Option on Business (US) 289.

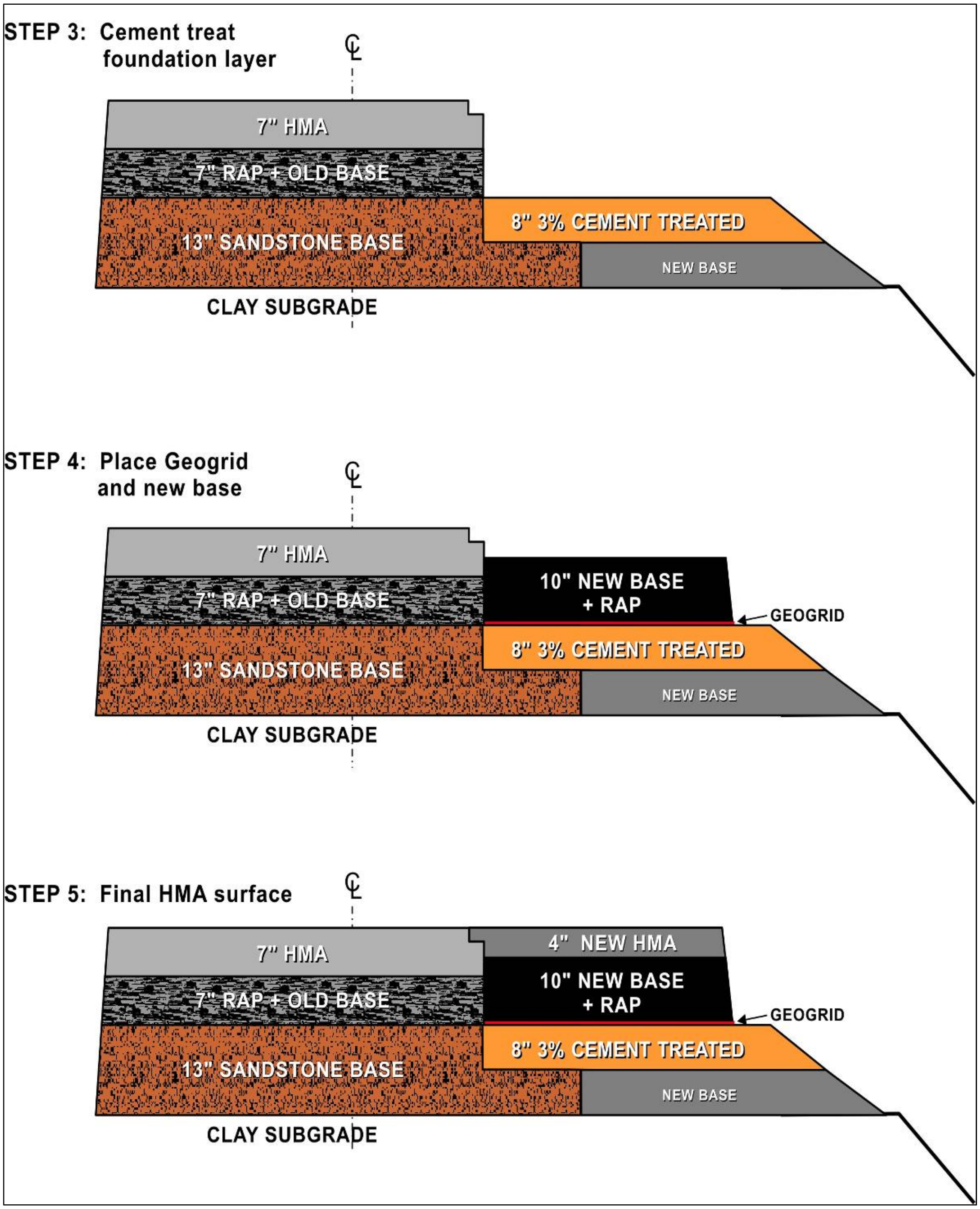


Figure 6.4. Partial-Width FDR Option on Business (US) 289 (Continued).

Adding Edge Support with Cement Treated Base

With this option, the pavement is widened and edge support increased with minimal disruption to the existing structure or traffic. A critical first step is to run the DCP to see how deep the cut needs to be. Next, a pug mill-mixed blend of locally-available low class base and RAP treated with cement could be used for the widening. Compaction of the material could present some challenges due to the narrow width.

Only minimum repairs would be recommended for the riding surface. This would include some filling of the existing cracks; if the cracks are wide they could be filled with Grade 5 rock and perhaps some fine mix near the surface such as the crack attenuating mix (CAM). Crack seal should be avoided because of expansion that can occur when a hot mix surface is applied. For the surface layer it is recommended that a crack resistant HMA layer such as CAM be used. Figure 6.5 illustrates the typical cross section that would exist after applying this maintenance treatment.

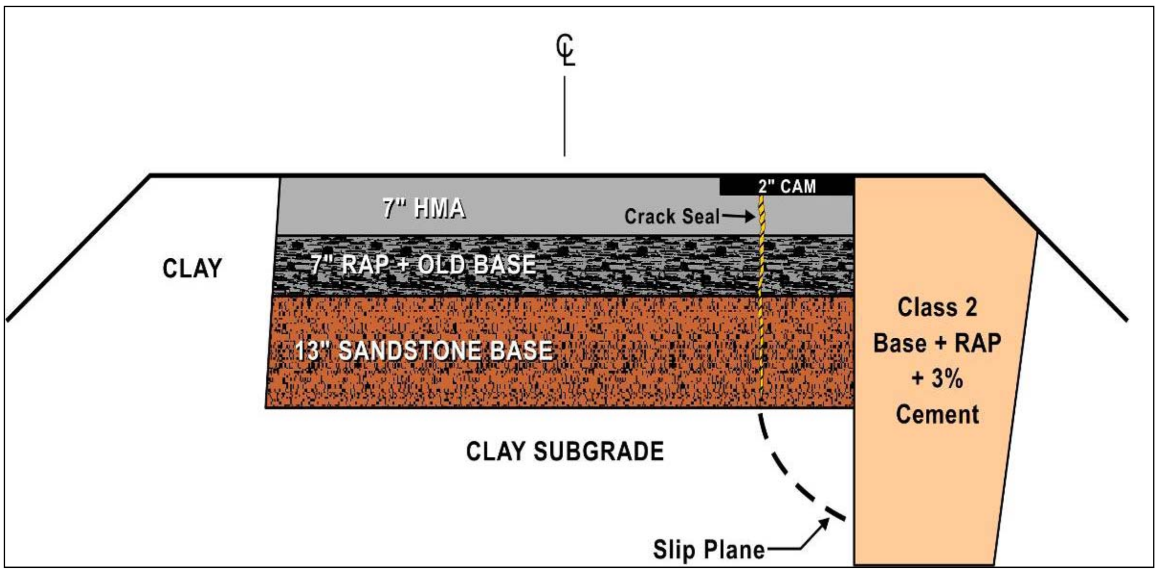


Figure 6.5. Adding Edge Support with Cement-Treated Base.

Adding Edge Support with Guardrail Reinforcement

This is the most exotic and perhaps least practical of the three options. Consideration should be given to the post spacing. The pavement surface would receive minor milling and receive an application of a crack resistant hot mix (either a CAM or a modified Type C mix).

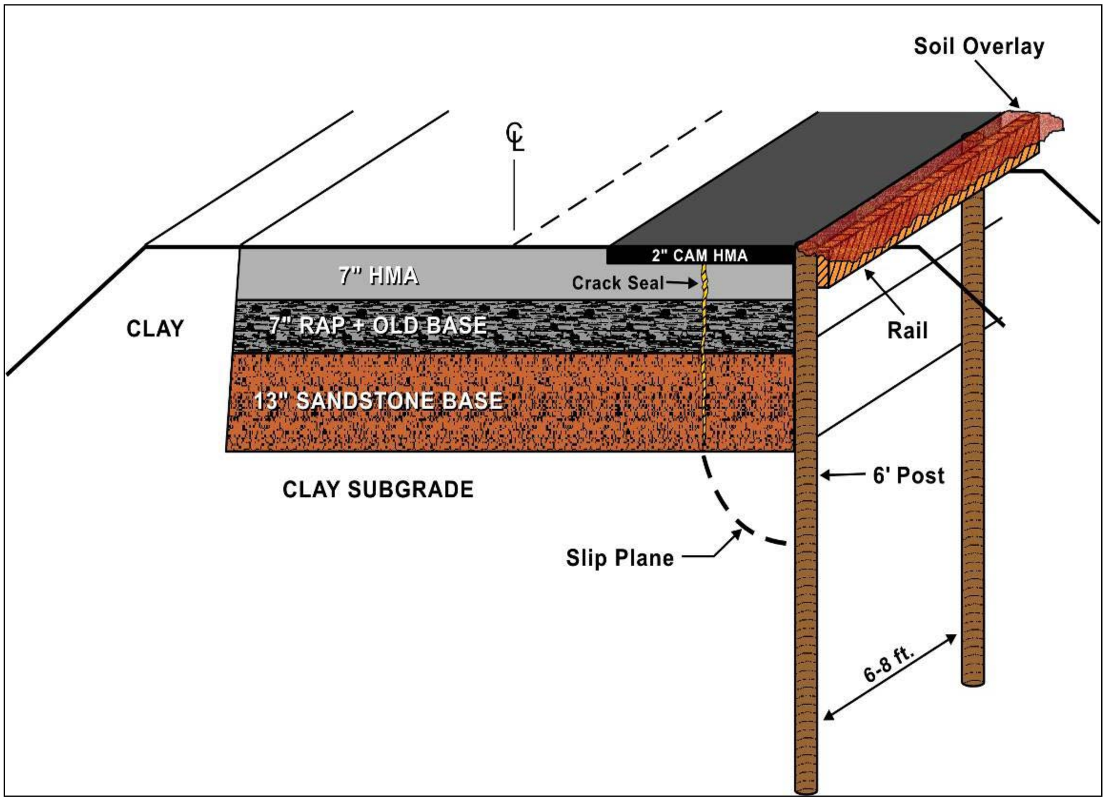


Figure 6.6. Adding Edge Support with Guardrail Reinforcement.

Repairing Non-Faulted Locations

For localized areas of distress that are not faulted, it may be feasible to use the traditional maintenance approach of mill and overlay, except the current low cost Type C or D mixes should be replaced with mixes designed for crack resistance. This could be a modified Type C or D mix design or a CAM. Figure 6.7 illustrates this approach for treating non-faulted locations.

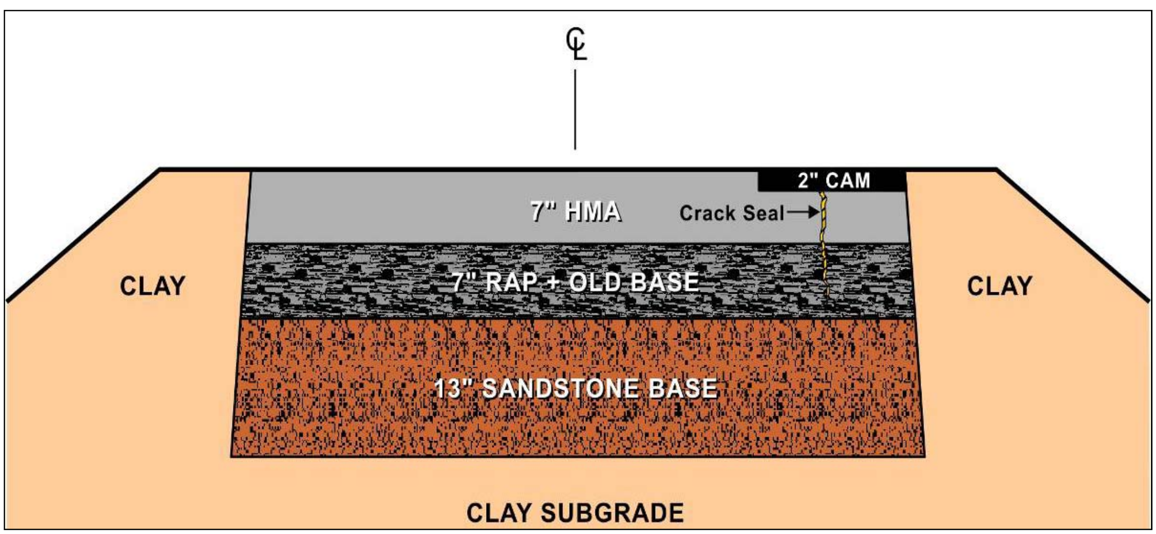


Figure 6.7. CAM for Repairing Non-Faulted Locations of Longitudinal Cracking.

CHAPTER 7

SAMPLING AND MIXTURE DESIGN OF FM 148

SUMMARY

In coordination with the Dallas District, TTI researchers evaluated FM 148 from 0.5 miles south of IH 20 to FM 987 in Kaufman County. The primary distress on this pavement is severe longitudinal cracking with faulting.

CURRENT PAVEMENT CONDITION

As with many other roadways in the Dallas District, the most prevalent distress is edge failure. These are often found as deep ruts (up to 3 in.) as shown in Figure 7.1. Other areas, particularly where trees are close to the side of the roadway, have longitudinal cracks. Many sections of the pavement also have steep side slopes.

Figure 7.1. Typical Edge Failure on FM 148.

EXISTING PAVEMENT STRUCTURE

FM 148 has a variable HMA pavement structure. The original pavement consists of 5 to 6 in. of HMA over a 6 in. lower quality flexible base. However, many areas have received additional HMA overlays, and numerous locations have full-depth patches. A GPR survey was conducted to determine areas with a HMA layer much thicker than the standard sections. Figure 8.2 shows the pavement thickness versus distance. The starting location is the beginning of the chip seal approximately 0.5 miles south of IH 20. The 12 in. thick designation covers all locations greater than or equal to 12 in. thick; at one location a 15 in. core was found.

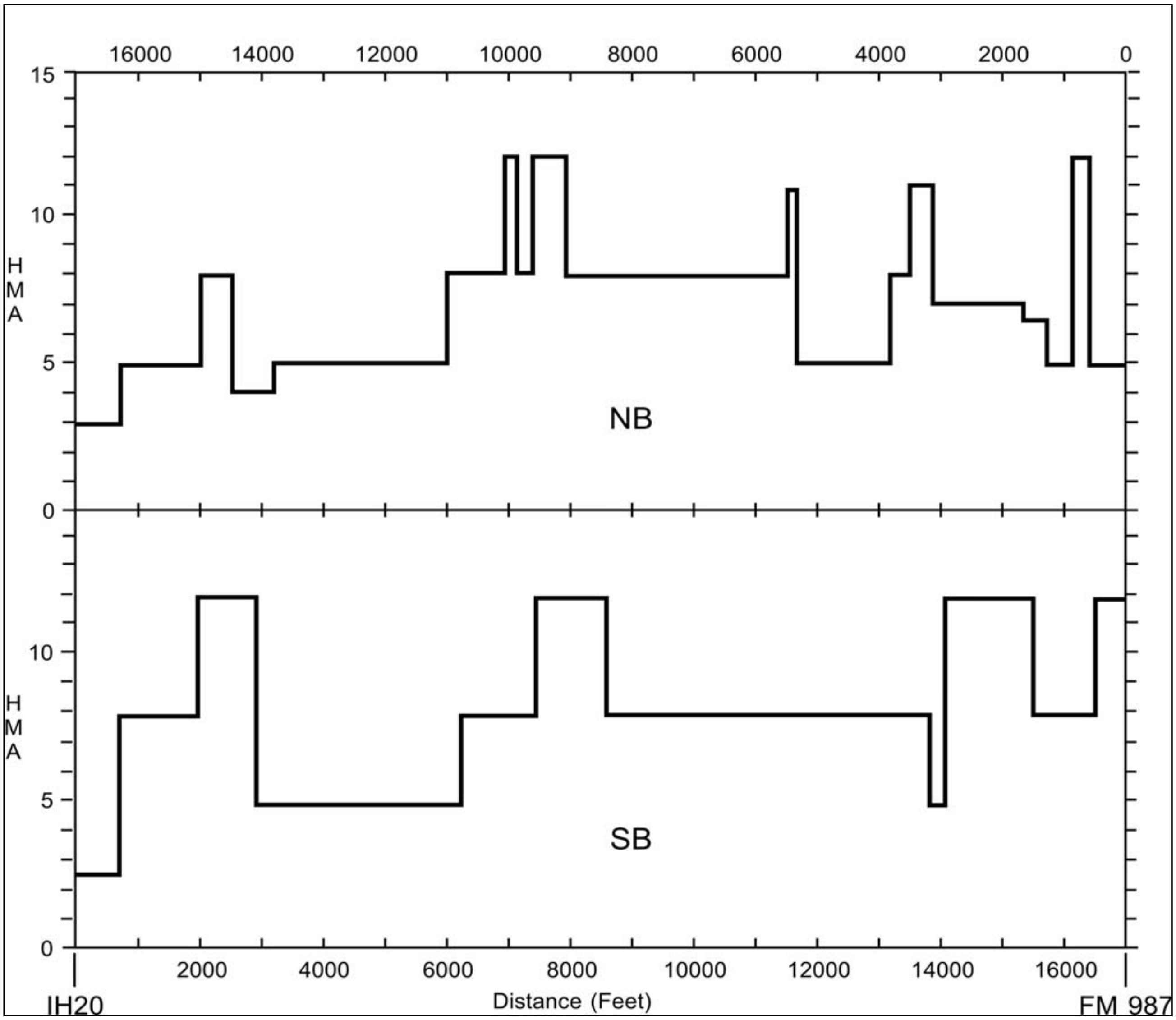


Figure 7.2. Surface HMA Thickness with Distance on FM 148.

The detailed thickness estimates for the northbound direction are shown in Table 7.1. The starting (zero distance position) was the center of the intersection with FM 987 as shown in Figure 7.3.

Table 7.1. Detailed Estimates of HMA Thickness for FM 148 NB.

From	To	HMA Thickness (inch)	Base Thickness (inch)	Comment
0	593	5	10	FM 987
593	695	14		Patch
695	1138	5	9	
1138	1470	6.5	8	
1470	3155	7	variable	
3155	3345	11		Culvert
3345	3694	8	6	
3694	5305	5	10	
5305	5385	13		
5385	9068	8	8	
9068	9460	13		Driveway
9460	9731	8	8	
9731	9861	17		
9861	10963	8	8	
10963	13837	5	10	
13837	14400	4	8	
14400	14940	8	8	
14940	16157	5	10	
16157	17059	3	10	0.5 mile south of IH 20

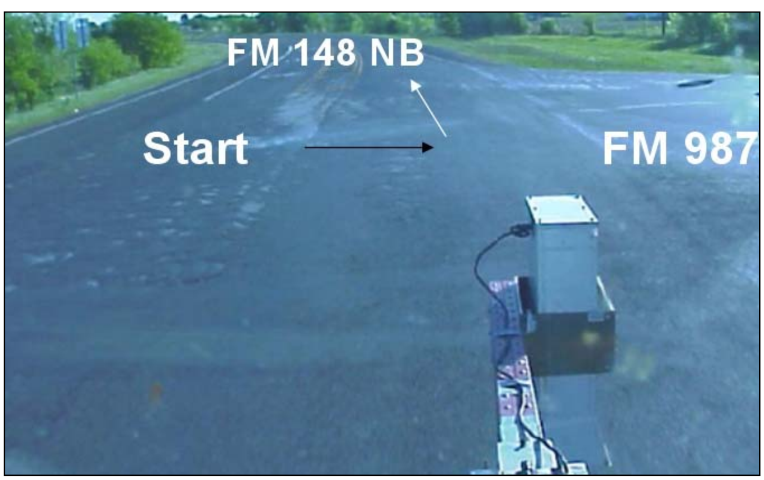


Figure 7.3. Zero Position in NB GPR Collection on FM 148.

Table 7.2 shows the detailed thickness results for the SB. Figure 7.4 shows the start location of the southbound run.

Table 7.2. Detailed Estimates of HMA Thickness for FM 148 SB.

From	To	HMA Thickness (inch)	Base Thickness (inch)	Comment
0	705	3	10	
705	2140	8		
2140	2294	12		
2294	2912	14	8–18 variable	
2912	6259	5	10	
6259	7576	8		
7576	7925	16		
7925	8668	12		
8668	13926	8		
13926	14160	5		
14160	15610	12	variable	
15610	16663	8		
16663	17060	12		Widening

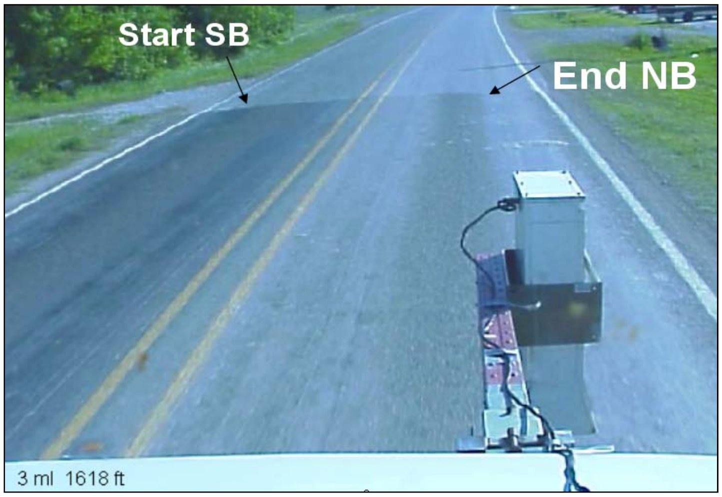


Figure 7.4. Start Location of SB GPR Run on FM 148.

FWD was not available on the section under design, but FWD data were available for a nearby section on the same highway. Figure 7.5 shows the subgrade modulus with distance for the adjacent section of FM 148. The highway support is between fair and poor. The average subgrade modulus value is close to 6.5 ksi with some locations below 6 ksi. For the FPS design 6 ksi was assumed for this highway.

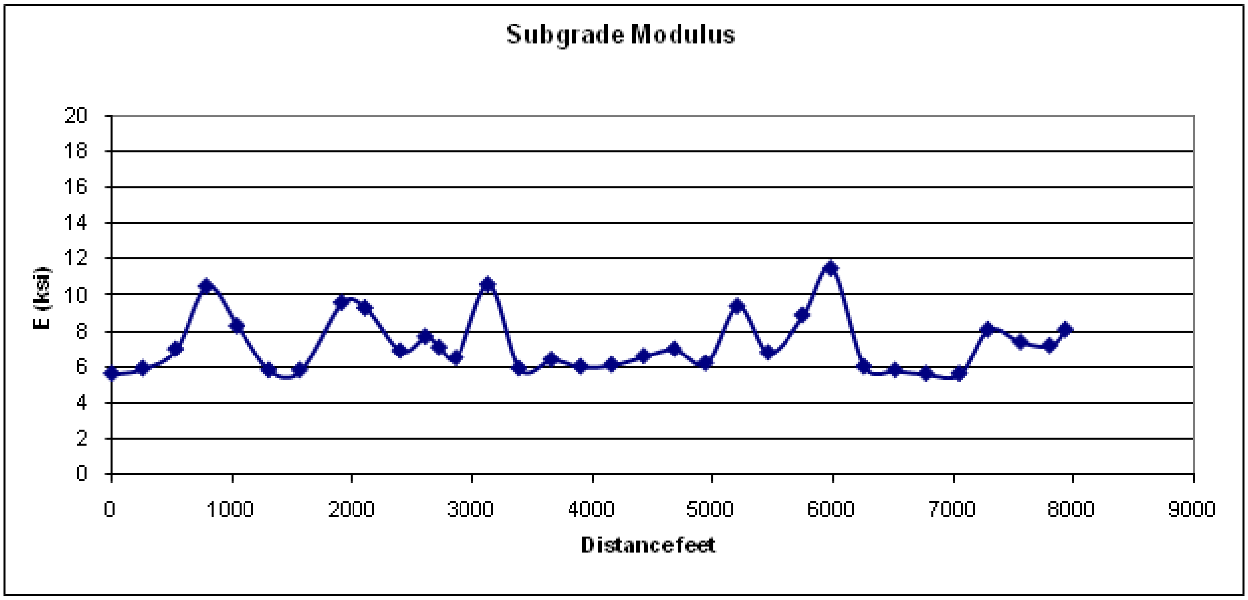


Figure 7.5. FWD Subgrade Modulus from Adjacent Section of FM 148.

CORING AND SAMPLING

Two coring locations were selected for validation of the thicknesses predicted by GPR. Figure 7.6 shows the augur material at a location representing the standard structure. At this location 5 in. of HMA over 9 in. of granular base were found. The base was a good quality limestone. No lime stabilized layer was found, and the soils in the area were found to have high plasticity values (liquid limit of 89 with a plasticity index of 59).

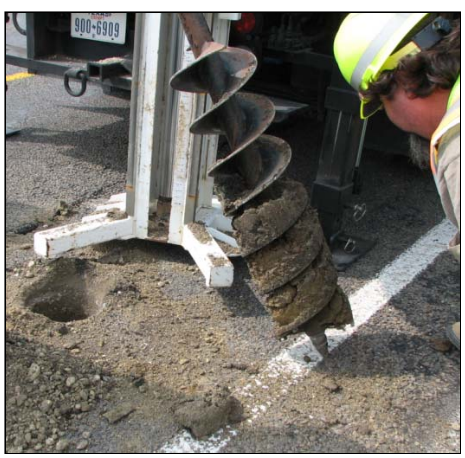


Figure 7.6. Augur Hole from Standard Location on FM 148.

Four validation holes were drilled in FM 148, and samples were taken from Hole 1, which was judged to be representative of the majority of the sections. The results from the four holes are tabulated below.

Table 7.3. Layer Thickness on FM 148 from Sampling.

Hole	Location (ft)	HMA (inches)	Base (inches)	Soil Plasticity Index
1	5153	6	6	20
2	7873	15	6	34
3	10,478	11	9	21
4	15,200	8	7	39

The soil plasticity along FM 148 was lower than found on other highways in Kaufmann County. Localized areas of high plasticity were found. The importance of the soil plasticity index is that criteria established in other TxDOT districts indicate that geogrid reinforcement was only required if the soil plasticity index exceeded 35, or if the section was already exhibiting longitudinal cracking.

LAB TESTING DESIGN RESULTS

The materials from FM 148 were evaluated in the lab as a 50/50 RAP/Base blend and tested in a cement-treatment design series. Table 7.4 shows the gradation, and Table 7.5 shows the test results. The performance criteria were met with 3 percent cement, with an optimal moisture content of 7.1 percent, and a maximum dry density of 122.6 pcf.

Table 7.4. Gradation of FM 148 RAP/Base Blend.

Sieve Size	% Retained
1 ¾″	0
1 ¼″	2.4
⅞″	8.1
¾″	18.1
⅜″	38.4
#4	62.7
#40	82.0
#200	n/a

Table 7.5. Design Test Results for FM 148.

Cement Content	2%	3%	4%	Spec Limits
Unconfined Compressive Strength (psi) @ 77°F (Tex-120-E)	138	198	240	175 psi min
Retained UCS (psi) @ 77°F after Tube Suction Test	148	220	301	80% min
Tube Suction Test Final Dielectric (Er) and moisture content (%) (Tex-144-E)	Not tested	12	Not tested	For Information Only
Unconditioned Seismic Modulus (ksi) (ASTM D 4123)	531	841	1010	For Information Only Tested at 7 days

PAVEMENT DESIGN RECOMMENDATIONS

The design recommended for this section of FM 148 is a 2-in. HMA surfacing with a flexible base overlay over a geogrid and cement treated recycled layer. The main design consideration is the required thickness of the granular base overlay.

The FPS system was used to generate this thickness. FWD data from FM 1827, which has a similar structure but is in Collin County, found high values of backcalculated modulus for both the cement stabilized layer (430 ksi) and the granular base (160 ksi) over the CTB. Very high modulus values for base layers are possible if the layer is dry and placed over a stiff layer. The values from FM 1827 are thought too high for standard design. For the FM 148 analysis the following values were assumed:

- HMA 500 ksi (Standard TxDOT recommendations)
- Flexible Base 70 ksi (Good base over CTB)
- Cement Stabilized FDR layer 100 ksi (Bryan District recommendation for FDR)
- Subgrade 6 ksi (FWD data)

The traffic levels assumed for this highway are Current Year ADT 1590 vehicles per day with a 20 year 18 kip ESAL estimate of 1.433 million.

Pavement Type 4 of the FPS design system was used and the results are shown in the standard design report in Appendix B to this report. The analysis called for the use of 6 in. of flexible base over the stabilized layer to provide a time to first overlay of 15 years. The triaxial check was also performed on the FPS structure and the results are shown in Figure 7.7. Using the modified cohesiometer value of 1000 for cement treated subbase, the total design thickness of 15 in. was found to be adequate.

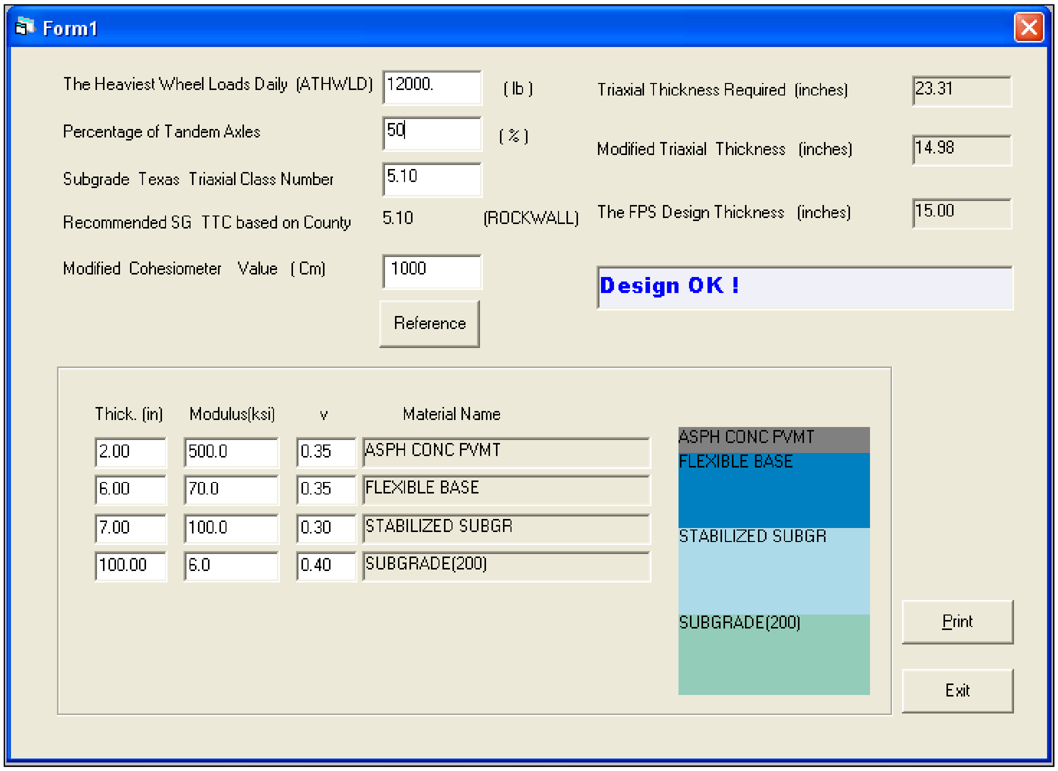


Figure 7.7. Triaxial Check on FM 148 Pavement Design.

The biggest challenge in any FDR project is accommodating the natural variability of the existing pavement structure. This includes variability of HMA thickness as shown earlier in Figure 7.2, together with the variability of soil type. The soils on this section of FM 148 are medium plasticity and variable. The other compounding issue is the presence of trees alongside the roadway, which increases the potential for excessive pavement edge cracking.

Historically it is very difficult to get reasonable engineering properties when the material is 100 percent RAP. For this highway, samples were molded at 3 percent cement with 100 percent RAP, and the resulting strengths were marginal at 120 psi. The current TxDOT design recommendations call for a maximum of 50 percent RAP in the base blend. However, with projects such as FM 148, maintaining this percentage is difficult due to the thick surfacing present. There are two options:

1) Ignore the variations in HMA thickness, and apply the same treatment for the entire highway. This will provide variable support, which may not be critical as a flexible base layer will be placed over this highway.
2) Use the GPR data and plan a milling process where excessive HMA is removed, and in the extreme case use a flexible base overlay prior to FDR.

In the example described below the second approach is used. The thicknesses from Figure 7.2 will be used to plan a milling operation with a goal of obtaining a consistent support layer. The other requirement that must also be enforced is to avoid cutting into the existing subgrade soil layer.

This highway has the further complication of soils with plasticity index values ranging from 20 to 39. Other TxDOT district experience recommends the geogrid treatment at the following locations:

- where the soil PI exceeds 35, since these are the soils where excessive shrinkage caused by summer drying will occur,
- at historically bad areas where very thick HMA is present, and
- at areas with steep side slopes and/or trees close to the pavement edge.

Only a few areas along this section of FM 148 meet these requirements. Based on these requirements, the areas where geogrid is needed are shown in red in Figure 7.8.

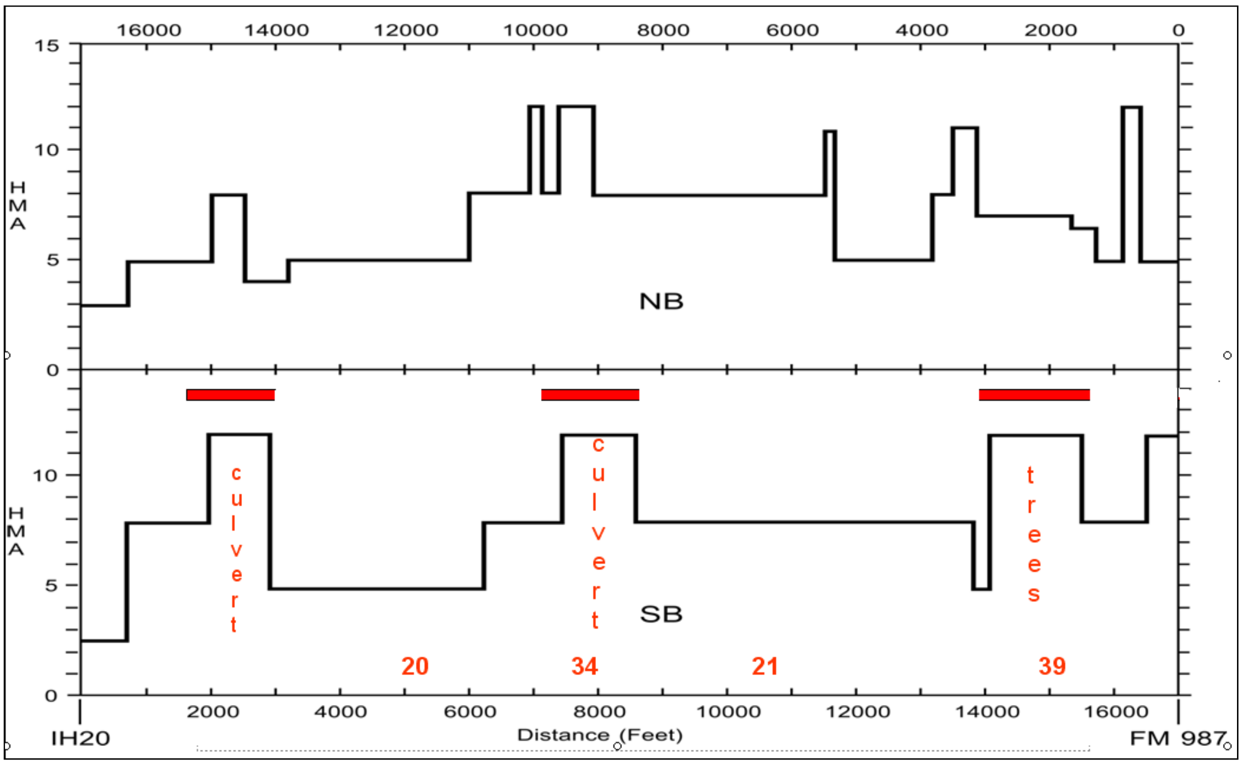


Figure 7.8. HMA Thickness with Locations Requiring Geogrid.
Note: Red bars indicate limits of sections requiring geogrid. Numbers in red are soil PI.

There are a variety of thicknesses along this section of FM 148. The predominant structure is 8 in. of HMA over 6 in. of granular base. Figure 7.9 shows the proposed construction sequence in this structure. This sequence calls for milling 4 in. of HMA and then recycling 8 in. of existing material and treating it with 3 percent cement. If required, geogrid will be placed on top of the cement treated base. This is followed by a 6 in. flexible base overlay and a two-course surface treatment. The first will be CRS 250 with a Grade 4 rock followed by an asphalt seal with Grade 5 rock. Traffic will be allowed to run on this section for as long as possible before placement of the final HMA surface.

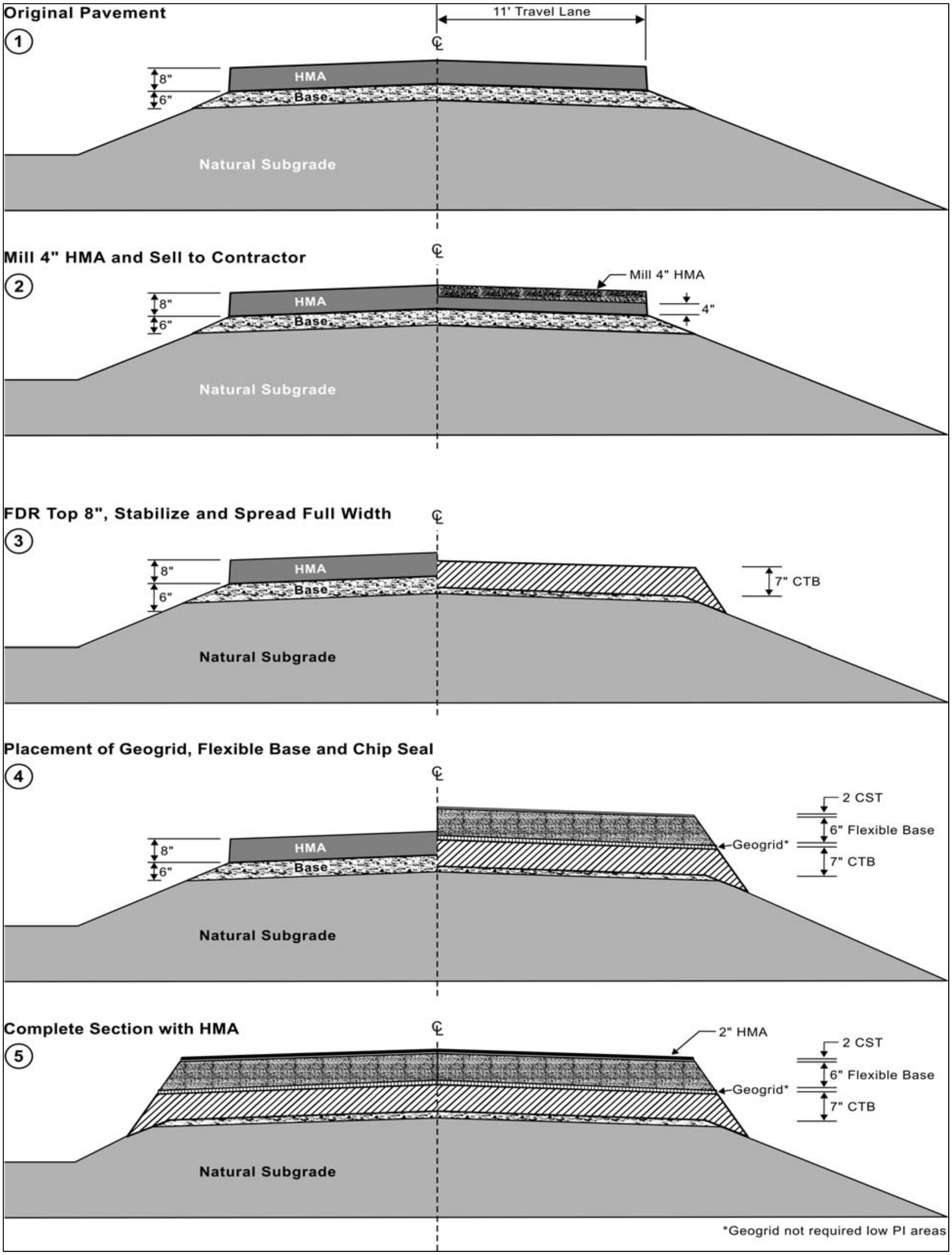


Figure 7.9. Proposed Construction Sequence for FM 148.

Based on the need for a uniform support layer the milling and construction treatments shown in Table 7.6 are recommended for this project. The zero location is the start of the section in the SB direction shown earlier in Figure 7.4. The typical sequence shown in Figure 7.9 will be used in all areas where the HMA is 8 in. thick. Where the HMA is only 5 in. no milling will be performed and a total of 8 in. recycled. For very thick HMA sections a mill followed by a new base overlay is proposed.

The varying of treatment based on existing pavement structural conditions may be difficult to implement in the field. The fall back position could be a single milling depth, such as 3 in., for the entire project, followed by recycling 8 in. This position would result in some areas of 100 percent RAP, which would exhibit less strength than the typical section.

Table 7.6. Proposed Milling and Construction Treatment of FM 148.

From–To (ft)	Treatment
0–700	2-inch overlay only (new construction)
700–1800	Mill 4 inches of HMA the FDR 8 inches + base overlay
1800–3000	Mill 6 inches HMA, add 4 inches new base; FDR 8 inches + Geogrid + base overlay
3000–6000	FDR 8 inches + base overlay
6300–7200	Mill 4 inches of HMA then FDR 8 inches + base overlay
7200–8900	Mill 6 inches HMA, add 4 inches new base; FDR 8 inches + Geogrid + base overlay
8900–14000	Mill 4 inches of HMA then FDR 8 inches + base overlay
14000–15600	Mill 6 inches HMA, add 4 inches new base; FDR 8 inches + Geogrid + base overlay
15600–16700	Mill 4 inches of HMA then FDR 8 inches + base overlay
16700–end	2-inch HMA overlay only (intersection is new construction)

CHAPTER 8

RECOMMENDATIONS

SUMMARY

The protocols used for field and laboratory testing FDR candidate projects work well to provide a detailed analysis of the project's materials and variability and for formulation of FDR treatment options. Based upon industry, TxDOT, and scientific research recommendations, along with the field investigations conducted, this chapter presents recommendations for the FDR design stage (site investigations and laboratory materials testing) and construction stage.

RECOMMENDATIONS FOR FDR DESIGN STAGE

Step 1: Evaluate Project History

- Evaluate visually the current pavement condition including types of distresses and likely causes of distresses.
- Obtain and review plans for preliminary information on the existing pavement structure.
- Use the Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/app/ to review the subgrade soil types likely to be encountered.

Step 2: Characterize Existing Pavement Structure with NDT

- Evaluate the existing pavement structure, and measure the in-situ materials properties, with upfront non-destructive test surveys. Ground-penetrating radar (GPR) should be conducted on all projects; falling weight deflectometer (FWD) should be conducted if structural deficiencies are suspected, or if measurement of the subgrade modulus is needed.
- Note existing drainage problems.
- Analyze the GPR and FWD surveys to identify section breaks in the existing pavement and determine the in-situ modulus values.

Step 3: Verify Pavement Structure and Obtain Material Samples

- Use the NDT survey analysis as guidance to select focused verification and sampling locations.
- Verification locations should be selected at locations of non-typical GPR signature to verify the pavement structure and aid in interpreting the GPR signal. Verification locations are not used to generate materials for laboratory testing. Only one boring takes place at verification locations, and the boring should go into the subgrade.
- Sampling locations should be selected at locations representative of the typical pavement structure as based on GPR. These locations serve to both verify the pavement structure and generate materials for laboratory testing. Multiple borings take place at sampling locations to generate sufficient quantities of materials for use in laboratory testing. At

least one boring at sampling locations should go into the subgrade to fully validate the interpretation of the GPR signal at that location and enable collection of subgrade samples for laboratory testing.

- At each verification location perform the following:
    - Collect a dynamic cone penetrometer profile from within the pavement.
    - Move approximately 2 ft off the pavement edge and collect a dynamic cone penetrometer profile to a depth of interest as determined by the Engineer, which will typically be between 2 and 5 ft.
    - If sufficient hot mix asphalt (HMA) is present, collect a pavement core to verify the condition of the HMA.
    - Collect material samples to verify the pavement structure.
    - Collect subrade soil samples for plasticity index, sulfates, and organic tests.
- At the sampling location(s) perform the following:
    - Collect a dynamic cone penetrometer profile.
    - Move approximately 2 ft off the pavement edge and collect a dynamic cone penetrometer profile to a depth of interest as determined by the Engineer, which will typically be between 2 and 5 ft.
    - If sufficient HMA is present, collect a pavement core to verify the condition of the HMA.
    - Collect material samples to verify the pavement structure down to the subgrade.
    - Collect subrade soil samples for plasticity index, sulfates, and organic tests.
    - Use an auger to excavate existing materials that will be used in the laboratory mixture design and maintain separate samples of recycled asphalt pavement (RAP), flexible base, and subgrade.
        - Based on district preferences and availability of stabilization agents, most lab tests focus on a cement-based stabilization design. For this series of tests, the amount of material collected among all the sampling locations combined should be at least 15 five-gallon buckets of material.
        - An additional 10 five-gallon buckets of material is required to perform a laboratory emulsion-series with two different emulsion levels.
        - If lime or lime-fly ash treatment is being considered, an additional 5 five-gallon buckets of material is required for each level of lime or lime-fly ash (LFA) treatment under consideration.

Step 4: Perform Mixture Design

- Use TxDOT's Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures to determine the appropriate additive for treatment. Availability and cost of additive can be a determining factor but are secondary to performance.
- For laboratory testing, reconstitute RAP and base materials in proportions representative of field conditions. However, limit RAP to no more than approximately 50 percent of the mixture for design purposes.
    - If substantial particle breakdown is suspected beyond that produced in the field sampling program, consider increasing the amount of fine sands (passing the #40 and retained on the #200) in the reconstituted laboratory mixture 10 percent and

decreasing the amount of coarse aggregate in the reconstituted laboratory mixture by 10 percent.

- Perform strength and tube suction test if considering options with no stabilization.
- For stabilization options, use appropriate TxDOT Test Procedures to select the optimum stabilizer contents. Supplement the standard strength tests with determination of the seismic modulus, performance in the tube suction test, and retained strength test after 4-hr submersion in water. The two moisture conditioning tests are used in this project for experimental purposes because the currently recommended tube suction test takes 10 days for conditioning; the experimental 4-hr submersion test potentially could provide moisture susceptibility indication while requiring much less testing time. The following specifications are recommended in this project; some of these methods are not current TxDOT practice as noted in Tables 8.1 through 8.4 below.
- Cement treatment is the most commonly investigated option. Cement content is based on the demonstrated strength and durability characteristics and includes satisfying the following criteria in Table 8.1.

Table 8.1. Laboratory Requirements for Cement Treatment.

Test	Spec Limits
Unconfined Compressive Strength (psi) @ 77°F (Tex-120-E)	175 min
Retained UCS (psi) @ 77°F after Tube Suction Test*	80% min
Retained UCS (psi) after Tex-120-E 7-day cure then 4-hr submersion*	For Information Only
Tube Suction Test Final Dielectric (Er) and moisture content % (Tex-144-E)*	For Information Only
Unconditioned Seismic Modulus (ksi) (Draft TxDOT Method)*	For Information Only Tested at 7 days

*These tests are recommended in this project but currently not in standard TxDOT practice.

- Emulsion treatment, with or without a small percentage of cement, has become a somewhat popular option to provide increased strength while retaining some flexibility. Table 8.2 presents the criteria for emulsion treatment.

Table 8.2. Laboratory Requirements for Emulsion Treatment from SS3066.

Test*	Spec Limits
Unconfined Compressive Strength (psi)	150 min
Indirect Tensile Strength (Tex-226-F)**	> 50 psi
Tube Suction Test Final Dielectric (Er) (Tex-144-E)	Report
Unconfined Compressive Strength after the Tube Suction Test	≥ 80% Dry UCS
Unconfined Compressive Strength after 4-hr submersion in water***	≥ 80% Dry UCS
Seismic Modulus	Report

*All tests are preceeded by 2 days curing at 60°C and 1 day cooling
**Recommended from project 0-5797
*****Experimental test; not currently in TxDOT Specifications or Methods

- Fly ash and lime-fly ash are used in some districts for stabilization. Table 8.3 shows the lab requirements for these mixtures.

Table 8.3. Laboratory Requirements for Fly Ash and Lime-Fly Ash Treatment.

Test	Spec Limits
Unconfined Compressive Strength (psi)* (Tex-127-E)	150 min as subbase; Similar to cement treatment for base course
Unconfined Compressive Strength (psi)**	200 psi

*After conditioning per Tex-127-E over 17 days
**After 6 days benchtop curing per project 0-5223 recommendations; not currently in TxDOT practice

- The least common FDR stabilizing agent is lime. Lime-treated mixtures are tested in accordance with Tex-121-E and should achieve strengths after the 17-day conditioning program as shown in Table 8.4.

Table 8.4. Laboratory Requirements for Lime Treatment.

Test	Spec Limits
Unconfined Compressive Strength (psi) (Tex-121-E Part I)*	50 psi min as subbase; 150 psi for final course of base construction

*After conditioning per Tex-121-E over 17 days

Step 5: Perform Pavement Design

- Using the materials properties measured in the lab and the traffic information, use FPS 19W to perform pavement design and economic evaluations. Perform the Texas Triaxial design check in FPS to make sure the design adequately protects the subgrade.
- Include in the design recommendations any additional considerations such as pavement widening, geogrid reinforcement, or specialized materials (such as low-fines bases or crack-attenuating mixes) or construction practices (such as microcracking or delayed placement of final surfacing) that may be needed to minimize the risk of recurring problems.

RECOMMENDATIONS FOR FDR CONSTRUCTION STAGE

- Use field sieve analysis to check that proper gradation has been obtained.
- Use a non-nuclear insertion probe, such as a Vertek probe, to check field moisture prior to compaction. A calibration must be developed for each project.
- Determine section lengths to be treated with each stabilizer load (based upon the treatment width, depth, required treatment level, and weight of stabilizer load). Use visual inspection as the first quality check for stabilizer application rate.

Ongoing work in this project includes investigating other construction-related topics, including:

- reviewing ambient temperature restrictions,
- checking field moisture contents with non-nuclear insertion probes prior to compaction,

- checking stabilizer application rate and uniformity of application and mixing,
- investigating requirements for curing base, and
- developing guidelines for adequate bond of surface treatments.

These findings and recommendations will be presented in a future research project report. Additionally, future work in the post-construction phase should focus on performance monitoring of constructed FDR sections and revising specifications based upon results or performance problems noted.

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APPENDIX A

DIRECT TENSILE BOND STRENGTH PULL-OFF TEST

DRAFT PROTOCOL

A. Preparation of Base Material

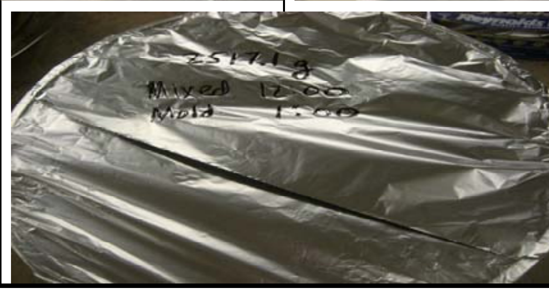
1. Dry the material in an oven (110 ºF) overnight to eliminate excess water within material.

2. Sieve the material over sizes: 1 1/4, 7/8, 5/8, 3/8, #4, Pan. and separate into specific labeled buckets.

• Re-sieve the 5/8 over sizes: 3/4, 3/8, Pan. to separate the 5/8 size rocks. Discard or store all material greater than 3/4 size.

3. Weigh out total mass of material and determine the percentages of the various material sizes for preparation of the sample.

Using these percentages, the cumulative masses of each size can be found to make a specimen.

4. Using predetermined percentages of each aggregate fraction, weigh-up samples to prepare for molding. 5. Optimum moisture is found using the TxDOT weigh-up sheet given for this material. (total weight x opt moisture % = water weight added) 6. In this example, 3% cement will be used as a stabilizer. Using the total sample weight, calculate 3% of total weight to be used as added cement weight. (total weight x 3% = cement weight added)	
7. Place an aggregate sample in mixing pan and mix thoroughly with amount of required water. • Cover with foil and weight pan with sample. • Record the weight and allow the mixture to sit for an hour.	 
8. Upon return: • Re-weigh the sample and replenish lost water due to evaporation • Add allotted amount of cement to mixture • Mix thoroughly.	

B. Compaction of Base Material

1. Prepare the base material according to (A), while mixing in additives according to the additive-specific mixing procedure.
2. Setup lab equipment to compact the base specimens according to the Tex-113-E procedure.
Have a porous stone weighed out to help in the extruding and weighing process.

3. Prepare a 6-inch x 8-inch compaction mold with two 3-inch round blocks on bottom, to allow for 2-inch space left on top for exact sample size.

4. With compactor and compaction mold in place, begin loading the mold with thoroughly mixed sample.
• Place more loose fines on the bottom and avoid having the larger rocks around the outside edge.
• By using a spatula or your hand you can move the bigger rocks and add fines to fill in void spaces.

5. Compact the 6-inch x 2-inch in one layer using the standard compaction effort (Tex-113-E): 10-lb hammer, 18-inch drop, 50 blows/layer.

6. Once compacted, scarify the surface using a spatula.
• Finish off the sample by using 10 blows from a raw-hide hammer and a small level to flatten the surface.





C. Finishing Compaction and Applying Primer

7. Once level, remove the mold from the base plate and apply previously weighed porous stone to top of sample.

8. Extrude the sample and porous stone from the mold.

9. Weigh the porous stone and sample together then calculate the total sample weight.

10. Record the sample weight and height.

11. Proceed to cover the entire sample with saran wrap and label it.

• Leave the samples covered for about an hour to allow them to harden.

12. Once hardened, select samples to put a layer of prime on.

13. Choose the best side (top or bottom) and re-wrap the sample with plastic wrap to expose only the side chosen for prime coat.

• Nine grams of prime should be applied to entire open area of each sample. This amount would be adjusted depending on the prime material and desired application rate.

14. Once prime is applied, place samples in the 110 ºF room for 3 days.

D. Applying Asphalt Surface Treatment and Coring

15. After the 3-day cure, apply surface treatment. For this example, an AC-20-5TR asphalt binder was used with a lightweight aggregate..

- Thirty grams of asphalt is applied to the tops of every sample and a Grade 4 or 5 seal-coat is immediately added.
- A metal pipe is used to roll the stone in place, then all 12 samples are placed back in the 110 ºF room.

- 16. After leaving samples in the oven overnight, the samples are removed and allowed to cool for an hour before being cored.
- Core to a depth of ½-inch or just below the asphalt layer when you can see original base material. Exercise care to not tear up seal-coat layer when coring.

E. Testing samples with asphalt and seal-coat layer

17. After coring, epoxy glue is applied to the metal pullers and stuck onto the cored section of the samples. Sand is placed in the cored ring so when the epoxy flowed it contacted the free sand instead of the outside of the sample.

Small weights may also be applied to the disks to aid in the adhesion process.

18. Once the glue has set, place sample in the testing apparatus and perform tensile test until sample fails.

• Record the breaking force in lb and identify where the failure plane occurred within the specimen.

APPENDIX B

FPS 19W OUTPUT FOR FM 148

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              TEXAS DEPARTMENT OF TRANSPORTATION
FPS19W           FLEXIBLE PAVEMENT SYSTEM                 VS. 1.1.36978

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PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB  DIST.-18  COUNTY-199  CONT.  SECT.  JOB    HIGHWAY      DATE    PAGE

006    Dallas     ROCKWALL    2       2     123   FM 148    6/1/2009    1
--------------------------------------------------------------------------------
                        COMMENTS ABOUT THIS PROBLEM


FDR design for FM 148
Subgrade from FWD
Base and stabilized CTB conservative values based on Bryan Recommendations

--------------------------------------------------------------------------------

BASIC DESIGN CRITERIA
*********************

  LENGTH OF THE ANALYSIS PERIOD (YEARS)                                 20.0
  MINIMUM TIME TO FIRST OVERLAY (YEARS)                                 15.0
  MINIMUM TIME BETWEEN OVERLAYS (YEARS)                                  8.0
  MINIMUM SERVICEABILITY INDEX P2                                        2.5
  DESIGN CONFIDENCE LEVEL ( 95.0%)                                        C
  INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)                         7.0

PROGRAM CONTROLS AND CONSTRAINTS
********************************

  NUMBER OF SUMMARY OUTPUT PAGES DESIRED ( 8 DESIGNS/PAGE)               3
  MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)          99.00
  MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)           69.0
  ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)   6.0

TRAFFIC DATA
************

  ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)                  3700.
  ADT AT END OF TWENTY YEARS (VEHICLES/DAY)                           6700.
  ONE-DIRECTION 20.-YEAR ACCUMULATED NO. OF EQUIVALENT 18-KSA      1433000.
  AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)                       50.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION) (MPH)          30.0
  AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)      50.0
  PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)         6.0
  PERCENT TRUCKS IN ADT                                                  4.0


ENVIRONMENT AND SUBGRADE
************************

  DISTRICT TEMPERATURE CONSTANT                                         31.0
  SWELLING PROBABILITY                                                  0.00
  POTENTIAL VERTICAL RISE (INCHES)                                      0.00
  SWELLING RATE CONSTANT                                                0.00
  SUBGRADE ELASTIC MODULUS                                           6000.00
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PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB	DIST.-18	COUNTY-199	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
006	Dallas	ROCKWALL	2	2	123	FM 148	6/1/2009	2

INPUT DATA CONTINUED

CONSTRUCTION AND MAINTENANCE DATA
****

SERVICEABILITY INDEX OF THE INITIAL STRUCTURE	4.2
SERVICEABILITY INDEX P1 AFTER AN OVERLAY	4.2
MINIMUM OVERLAY THICKNESS (INCHES)	2.0
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	12.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1.90
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	200.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	0.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	0.00

DETOUR DESIGN FOR OVERLAYS
****

TRAFFIC MODEL USED DURING OVERLAYING	3
TOTAL NUMBER OF LANES OF THE FACILITY	4
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	2
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	0.00
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.00
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.00

PAVING MATERIALS INFORMATION
****

LAYER	CODE	MATERIALS NAME	COST PER CY	E MODULUS	POISSON RATIO	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	ASPH CONC PVMT	115.00	500000.	0.35	2.00	2.00	30.00
2	B	FLEXIBLE BASE	37.00	70000.	0.35	6.00	12.00	75.00
3	C	STABILIZED SUBGR	15.00	100000.	0.30	7.00	7.00	90.00
4	D	SUBGRADE(200)	2.00	6000.	0.40	100.00	100.00	90.00

PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB	DIST.-18	COUNTY-199	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
006	Dallas	ROCKWALL	2	2	123	FM 148	6/1/2009	3

C. LEVEL C SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1	2
MATERIAL ARRANGEMENT	ABC	ABC
INIT. CONST. COST	15.47	21.13
OVERLAY CONST. COST	2.71	0.00
USER COST	0.00	0.00
ROUTINE MAINT. COST	0.00	0.00
SALVAGE VALUE	-2.86	-3.46
TOTAL COST	15.31	17.66
NUMBER OF LAYERS	3	3
LAYER DEPTH (INCHES)		
D(1)	2.00	2.00
D(2)	6.00	11.50
D(3)	7.00	7.00
NO.OF PERF.PERIODS	2	1
PERF. TIME (YEARS)		
T(1)	16.	21.
T(2)	38.	
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)		
O(1)	2.5	
SWELLING CLAY LOSS (SERVICEABILITY)		
SC(1)	0.00	0.00
SC(2)	0.00	

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 13