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16. Abstract

Some of the most prevalent cases of distress pavement maintenance forces will encounter in expansive soil environments are roughness, longitudinal cracking, and structural deterioration. This report describes the findings from an extensive literature search, a multi-district survey, numerous field site investigations, and a laboratory testing sequence, all geared toward identifying what types of maintenance treatments and materials give good performance when used on the above distresses. For moderate cases of roughness, a blade-on patch to smooth the section is quick and is the most typically used treatment. Data collected indicate crack filling and sealing is just as effective as conventional full-depth patching for longitudinal cracking. For full-depth repairs due to longitudinal cracking, methods currently being used in the Bryan District of the Texas Department of Transportation (TxDOT) using geogrid reinforcement to prevent cracks from propagating through the pavement surface show promise. In general, all data collected indicate cement treatment is preferred to asphalt cold mixes for base repairs.

TxDOT should consider constructing test sections utilizing the field guide developed as part of this project to verify its usefulness. TxDOT should also consider test sections reworking areas with longitudinal cracking utilizing different geosynthetics to determine if similar performance can be obtained with less costly geotextiles and grids.

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INVESTIGATION OF MAINTENANCE BASE REPAIRS OVER EXPANSIVE SOILS: YEAR 1 REPORT

by

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Report 0-4395-1
Project Number 0-4395
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The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The engineer in charge was Tom Scullion, P.E. (Texas, # 62683).

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- Ronald Cook
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EXECUTIVE SUMMARY

This report describes the activities conducted during the first year of Texas Department of Transportation (TxDOT) research Project 0-4395, "Optimum Spot Base/Subgrade Repair Techniques for Moderate to High Traffic Highways over Highly Expansive Subgrade Soils." During the first year, researchers at the Texas Transportation Institute (TTI) conducted an extensive literature search and a multi-district survey within TxDOT regarding maintenance repairs. The research team also investigated the performance of several existing maintenance repairs in the San Antonio, Lufkin, and Bryan Districts. The materials laboratory at TTI conducted a testing sequence on materials commonly used for maintenance base repairs. Based upon the year 1 activities, the research team developed a field guide to assist maintenance personnel in determining the cause of pavement distress and selecting an appropriate treatment strategy.

Some of the most prevalant cases of pavement distress maintenance forces will encounter in expansive soil environments are roughness, longitudinal cracking, and structural deterioration (fatigue cracking). As such, the research efforts focused on these distresses. For moderate cases of roughness, simply smoothing the section with a blade-on patch was by far the most frequently used treatment method. In general, roughness will reoccur unless action is taken to prevent moisture fluctuations in the expansive clay subgrade. For this reason, roughness often reoccurs shortly after a full-depth maintenance patch because the source of the roughness (the subgrade) is rarely addressed. Research activities indicate crack filling and sealing is just as effective as conventional full-depth patching for sections with longitudinal cracking. As with roughness, the cracking generally reoccurs within a short time frame (6 months to 2 years) after patching because the subgrade is not addressed with the patching activity. However, methods currently being used in the Bryan District using geogrid reinforcement as a method to prevent dry-land cracks from propagating through the pavement surface show promise. If a full-depth patch is to be performed on a section with longitudinal cracking and highly plastic soils, this method of performing the repair should be considered.

For structural repairs, the research activities indicate cement treatment of either the existing or replacement base with nominal levels of cement (2 to 4 percent) results in good performance. In general, the district survey, field observations, and laboratory testing all indicate that cement-treated base is preferred to using black bases for repairs. In fact, TxDOT area offices visited reported they specifically try to avoid using black base if possible. Regardless of the base used, if the repair is on expansive soils, the section will still be subject to environment-related distresses such as swelling of the soil resulting in roughness and longitudinal cracking from dry spells.

TxDOT should consider constructing test sections utilizing the field guide developed in this project as part of the treatment selection process. This activity would provide feedback on the usefulness of the guide and identify ways in which it could be improved. Field performance of the test sections could be monitored to verify the effectiveness of the repair methods. TxDOT should also conduct test sections on locations of dry land cracking using geogrid or geotextile reinforcement. Results in the Bryan District with the Tenax grid are promising; however,

geosynthetics exist that are less costly than the Tenax grid. Sections should be constructed to test whether similar performance can be obtained with the less costly textiles and grids.

CHAPTER 1

LITERATURE REVIEW

I. SUMMARY

Historically, maintenance expenditures account for approximately 25 percent of the monies the Texas Department of Transportation spends on construction and maintenance, and maintenance costs are approximately 20 percent of the department's total expenditures (*1, 2*). Thus, improving the performance of maintenance treatments could have a significant impact on the cost-effectiveness of the department's disbursements. Ideally, a preventive maintenance program will be in place and minimize the occurrences of base failures, as the reactive approach to maintenance typically will be more costly in the long run and jeopardizes the structural capacity of the pavement (*3*). In fact, studies have suggested that preventive maintenance at the right time can be several times more cost-effective than repairing a deteriorated pavement or reconstruction (*4, 5*). However, corrective maintenance action will certainly always account for a portion of maintenance force activities. This chapter will discuss processes for determining appropriate repair methods and materials commonly used for repairs and will present some existing guidelines to aid in selection of an appropriate repair technique. Researchers used information from this literature search, in conjunction with survey results from within TxDOT (discussed in Chapter 2), observations of field performance of various repair methods (discussed in Chapters 3 and 4), and the results from the laboratory-testing phase of this project (discussed in Chapter 6) to create a field guide for use by TxDOT Maintenance Section Supervisors. This report includes the field guide as Appendix D.

II. PAVEMENT INFORMATION USEFUL FOR SELECTING REPAIR METHODS

Understanding the causes of pavement distress is a large factor in deciding upon a repair treatment. The cause of distress needs to be determined to select an optimal treatment strategy, and rehabilitation is often fairly straightforward once the primary cause of the pavement distress has been identified (*6*). Some other pertinent information is:

- an understanding of the project's design history (layer thicknesses, surface type, etc.) (*7-9*),
- a traffic level assessment (equivalent single axle loads [ESAL]) (*7-9*),
- an evaluation of materials used and any problems associated with them (*7*),
- availability of materials (*9*),
- time of year of repair (*9*),
- a general feel of past construction practices (*7*),
- general knowledge of climate history (*7, 9*), and
- an understanding of subgrade characteristics (*7*).

Scullion compiled a summary of TxDOT recorded pavement distresses, along with their potential causes and rehabilitation options, for the use of district pavement engineers as an aid in the rehabilitation process. Although this compilation is geared toward an extensive field evaluation, a brief overview of the specific distresses, their common causes, and treatment options as they relate to base repair is given below (*6*).

Rutting

Possible Causes: hot mix asphalt (HMA) mix design (too much asphalt or rounded aggregates), asphalt cement properties (hot weather characteristics), defects in the HMA layer such as stripping, structural deficiencies, or compaction (density) problems.

Treatment Options:
Rutting is in the upper HMA layer: cold milling.
Rutting is in lower HMA layer: remove and replace or structural overlay.
Rutting in base or subgrade: full-depth reclamation with stabilization (thin-surfaced pavements), surface removal and base stabilization, or structural overlay.

Alligator Cracking

Possible Causes: structural deficiency (weak or wet base and/or subgrade), excessive voids in HMA, asphalt cement properties (burnt binder), stripping in lower HMA layers, layer debonding, construction deficiencies such as poor joints, and segregation.

Treatment Options: seal coat, remove and replace, overlay, recycle HMA, full-depth reclamation with stabilization, or reconstruction.

Failures

Possible Causes: poor pavement edge support, structural deficiencies, or trapped moisture.

Treatment Options: full-depth patching.

Longitudinal Cracking

Possible Causes: structural deficiencies, excessive voids in HMA, asphalt cement properties, stripping of HMA layers, construction problems, edge drying, steep side slopes, and buried stabilized layers.

Treatment Options: crack seal, seal coat, replacement, thin overlay with treatments to seal cracks and minimize reflective cracking, or asphalt rubber membrane with seal coat or thin overlay.

Roughness

Possible Causes: presence of other physical distresses, volume change in lower layers, non-uniform construction, and lack of bonding between pavement layers.

Treatment Options: overlay, cold milling, in-place recycling, or full-depth reclamation.

III. REPAIR MATERIALS

Conventional Materials

Asphaltic Products

Cold mix asphalt is likely one of the most widely used materials for maintenance activities. Despite the temptation to use the cheapest available products, a research study concluded that the best quality of cold mix available should be used because, in most instances, poorer performance from the cheaper mixes leads to more frequent repatching, and thus using better quality material is more cost effective (*10*). Similarly, the Arizona Department of Transportation (ADOT) initiated an effort to ensure maintenance forces were receiving quality cold mix asphalt. ADOT started testing products for percent asphalt and gradation and initiated training of maintenance personnel in materials quality in attempts to verify material quality (*11*).

For repairs with cold mix, literature suggests that a tack coat be used, and if the hole is more than 3 inches deep, cold premix should be placed in lifts that are no more than 1.5 inches thick each after compaction (*12*). In a TxDOT-sponsored research project, hot-mix cold-laid (HMCL) mixes for use as blade-on patches and level-ups compacted to 92 percent density were found to have stabilities and strengths just as high as when compacted to 95 percent density (*13*). Researchers conducting this study thus recommended HMCL mixes designed or produced from November 1 through March 1 be designed for 92 percent density (*13*).

Some TxDOT districts use Type A HMCL "black base" for base repairs. Black base is an attractive material for use when repairs are needed in inclement weather. Due to its coarseness, care should be taken to minimize segregation of the mix. TxDOT's Floresville Area Office has reported problems with raveling of Type A HMCL, but has achieved reasonable performance when sealing the HMCL with Grade V then Grade IV rock. Moisture susceptibility likely caused the raveling since the problem only occurred when the black base was not sealed. According to Special Jobs personnel in the Bryan District, strip seals are placed over repairs as standard practice in order to keep out water (pers. Comm., 2002).

When using hot-mix asphalt for pavement repairs, the product needs to be mixed, delivered, and compacted at appropriate temperatures. Mixing temperatures should generally be between 275 ^{o}F and 325 ^{o}F, and the mix should be delivered and compacted as soon as possible. Preferably, compaction should take place with the mix temperature above 220 ^{o}F (*12*). HMA is preferred to cold mix for certain applications, such as level-ups (*12*). A light tack coat should be applied before the HMA.

Cement Treated Base

According to the district pavement engineer for the Fort Worth District, cement treated base is by far the most widely used material for maintenance base repairs (pers. comm., 2002). The major concern with cement treatment is the block cracking that can result. Also of concern in expansive soils is having a brittle slab over a weak, shifting subgrade, resulting in severe longitudinal cracks that often fault. Some research work has attributed the good cracking performance of pavements recycled with cement to the early application of loads, hypothesizing that a network of small "microcracks" were formed rather than larger block cracks (*14*). More formal research work is currently being conducted on the microcracking concept.

The Portland Cement Association (PCA) has published some general guidelines on reworking pavements with cement. Besides recommending a site investigation to determine the cause of pavement distress, layer thicknesses, and material composition, the following guidelines are given (*15*):

- If the asphalt surface is still "alive" it should not be incorporated into the base.
- The amount of old surfacing in the soil mixture should be less than 50 percent.
- The material must be pulverized to have 100 percent passing the 2-inch sieve and at least 55 percent passing the #4 sieve.

In addition, the PCA suggests a 7-day unconfined compressive strength (UCS) of 300 to 400 psi (*16*). For AASHTO soil classifications that are typical of Texas base aggregates, the PCA suggests 3 to 9 percent cement may be required to make soil-cement (*17*).

Recent efforts at TTI with cement treatment have focused on balancing strength with the propensity for shrinkage. Work performed in 2000 led to the development of proposed criteria for cement-treated base utilizing a testing protocol to optimize cement content for adequate strength, durability, and economy. The design cement content is the minimum amount that meets both strength and moisture susceptibility criteria. Experience has shown 2 to 3 percent Type I cement is usually adequate for reasonable-quality limestone and most recycled materials (where the existing surfacing is mixed into the existing base). Recommended design criteria developed were (*18*):

- unconfined compressive strength: ≥ 300 psi after seven days curing,
- moisture susceptibility: final dielectric in the Tube Suction Test (TST) ≤ 10 for specimens cured seven days,
- retained strength: UCS of TST sample/7-day UCS ≥ 100 percent, and
- shrinkage (optional): 20-day beam shrinkage ≤ 0.000300 in/in for coarse-grained materials.

Lime-Treated Base

Literature suggests that lime treatment may be a good candidate for materials with a plastic index (PI) greater than 10 and more than 25 percent passing the #200 sieve (*19*). The main concern with lime treatment is slow strength gain. TxDOT specifications require 7 days curing for lime-treated base. The Lufkin District reported that when using lime treatment of base for maintenance repairs, the treated base is excavated and recompacted after approximately 10 days of curing (pers. comm., 2002). Due to the necessity of reopening to traffic on the same day, lime treatment may be an option for lightly trafficked farm to market (FM) roads, but is likely not a good candidate for higher trafficked, more important roads (*20*).

Other Treatments

Geosynthetic Products

Geotextiles and geogrids have been used and promoted for use in numerous pavement applications over the years. One major issue with pavements over expansive soils is dealing with the longitudinal cracks, or "dry-land" cracks, that typically develop. An example of this type of cracking is shown in Figure 1. Cracking in the highly plastic subgrade reflects through the pavement structure, creating an inlet for water into the pavement and a headache for maintenance forces. Typical treatments are filling and sealing the cracks or reworking the base, and possibly raising up the side slopes to reduce edge drying in the section. Neither of the first two treatments deals with the source of the problem, the subgrade. In efforts to minimize the longitudinal cracking from highly plastic subgrades, the Bryan District has been using geogrids beneath a layer of flex base on FM roads to provide a barrier to keep cracks from coming through the surface. Results have been promising. Figure 2 shows the geogrid being placed, and Figure 3 shows a representative reworked section utilizing the geogrid after approximately 2 years of service. Chapter 4 of this report contains a complete summary of the design and construction process used in the Bryan District.

Figure 1. Example of Longitudinal Cracking.

Figure 2. Geogrid Being Placed on Rehabilitation of OSR.

Figure 3. OSR with Geogrid after 2 Years of Service.

Fibrillated Polypropylene Fibers

Another geosynthetic product that has potential for minimizing dry-land cracking in highly plastic clay environments is fibrillated polypropylene fibers. These fibers (shown in Figure 4) are strands approximately 1 inch long and are mixed into the soil with conventional mixing equipment. When mixed in, the fibers open and mechanically reinforce the soil (*21*). A field study conducted by the U.S. Army Corps of Engineers (USACE) found that inclusion of fibers into stabilized clay and sand resulted in significant improvements in durability when compared to chemical treatment alone (*22*). The USACE researchers also observed that materials treated with fibers exhibited better post-peak load-carrying ability when subjected to compression testing; similar observations were made when materials treated with fibers were tested at TTI (*22, 23*). The TTI researchers also conducted fracture tests and concluded that the addition of fibers to chemically treated material resulted in improved cracking performance (*23*). Essentially the fibers provide mechanical resistance to crack propagation. This mechanical resistance to crack propagation is the mechanism by which fibers could help minimize problems with dry-land cracking. However, all of the literature reviewed suggested that the fibers were most effective when combined with chemical treatments (either cement or lime) (*22, 23*). Thus, for optimal performance, some type of chemical subgrade treatment would likely be necessary, resulting in increased time requirements for conducting repairs.

Figure 4. Fibrillated Polypropylene Fibers.

IV. EXISTING GUIDELINES FOR MAINTENANCE TREATMENTS

Several sources of guidelines for repairs of pavements exist. This section presents a summary of numerous recent works on methods of maintenance repairs and decision processes to aid in repair technique selection. Regarding methods of repairs, current literature indicates the following guidelines are accepted as methods to obtain good performing, cost-effective repairs:

- use high quality materials (*10*, *24-26*);
- make excavations rectangular with two edges perpendicular to traffic low (*25, 26*);
- excavate at least 1 foot beyond the distressed area to ensure all problematic material is removed (*27*);
- if mixing in the existing surfacing with the base, the amount of old surfacing in the recycled mixture should be less than 50 percent (*15*);

- wet and/or weak base and wet subgrade should be dealt with to prevent a recurrence of problems (cracks, settlements, or heaves are cases where subgrade repairs could be essential) (*12*);
- place the patch material to minimize segregation (*25, 26*);
- wet aggregate base as close as possible to optimal moisture content for compaction; if available, use laboratory-determined moisture-density data (*12*);
- when using black bases, apply a tack coat to the vertical faces and place the material in lifts that when compacted are approximately 1.5 inches thick (*12, 27*); and
- obtain adequate compaction, preferably >95 percent of maximum density, to avoid settlement problems (*12, 25, 26)*.

National Cooperative Highway Research Program (NCHRP) Project 20-50, "LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options," was initiated in October of 1999 to identify pretreatment pavement conditions that affect the performance of maintenance and rehabilitation strategies and to determine the relative performance of maintenance and rehabilitation options (*28*). Currently, a draft final report has been submitted but is not yet publicly available.

Several sources of information exist regarding choosing repair methods. Treatment options compiled by Scullion (*6*) were presented previously. Hicks et. al. have outlined situations in which certain preventive maintenance techniques are generally effective, shown in Table 1. Although not focused on corrective treatments, their work on outlining a framework for selecting preventive treatments provides some relevant guidelines, such as (*29*):

- Selection of maintenance treatments should consider at least the type and extent of distress, traffic level, climate, and existing pavement type.
- Roughness from subsurface layers cannot be treated with preventive maintenance techniques. Milling or bringing up to grade are suggested as corrective maintenance options.
- Load associated longitudinal cracking may be effectively treated by crack filling or chip seal.
- Chip seals should not be used to treat fatigue cracking, rutting, or other structural deficiencies.
- Microsurfacings are generally not effective in reducing reflection or fatigue cracking.
- If the structural condition is not adequate, preventive maintenance treatments are not an option.

Table 1. Guidelines for Maintenance Treatments (*29*).

Pavement Conditions		Parameters	Treatments: Thin Overlay	Slurry Seal	Crack Seal*	Route & Seal*	Route & Fill*	Chip Seal (Fine)**	Chip Seal (Coarse)**	Micro Surface	Fog Seal
Traffic (ADT/lane)***		<1000	E	E	E	E	E	E	E	E	E
		1000<ADT<4000	E	E	E	E	E	E-Q	E-Q	E	E-Q
		>4000	E	E	E	E	E	E-N-Q	E-N-Q	E	E-Q
	Ruts	<3/8 in.	E	E	E	E	E	E	E	E	E
		3/8 in.<R<1 in.	E	M-N	E	E	E	M-N-Q	M-N-Q	E	T
		>1 in.	E	T	E	E	E	T	T	M-C	T
Cracking	Fatigue	Low	E	E	E	E	E	E	E	E	M
		Moderate	E	M	M	M	M	E	E	M	T
		High	M	T	T	T	T	E	E	T	T
	Longitudinal	Low	E	E	E	E	E	E	E	E	M
		Moderate	E	E	E	E	E	E	E	M	T
		High	M	M	M	E	E	M	M	T	T

*Requires routine treatment at 2 year intervals, typically
**For ADT in excess of 50000 (total) and/or truck volumes in excess of 20 percent this treatment can be effective but is not recommended
***Higher percentages of trucks have a significant effect on performance

E - Effective
M - Marginally Effective
N - Not Recommended
Q - Requires a higher degree of expertise and quality control
T - Not effective

The Minnesota Local Road Research Board assembled a set of photos of flexible pavement distresses, along with treatment options, for use as an aid in selecting pavement rehabilitation strategies. Table 2 summarizes their treatment recommendations for the distresses relevant to this study.

Table 2. Recommended Treatments for Flexible Pavement Distresses (*30*).

Distress	Severity	Treatment
Swells	Low	None
	Medium	Full depth patch
	High	Full depth patch
Longitudinal Cracking	Low	Do nothing, crack seal or fill, or rout and seal
	Medium	Crack seal or rout and seal, partial-depth patch or full-depth patch, and slope stabilization
	High	Partial-depth or full-depth patch, and slope stabilization
Edge Cracking*	Low	None or crack seal
	Medium	Crack seal if localized, partial-depth or full-depth patch
	High	Partial-depth or full-depth patch
Fatigue Cracking	Low	Seal coat or rejuvenator
	Medium	Partial-depth or full-depth patch
	High	Partial-depth or full-depth patch

*Improvements to shoulder drainage or sealing the shoulders and reconstruction of the pavement edge and extension of the pavement width may be necessary.

A statewide survey conducted within TxDOT as part of TxDOT research Project 0-1722 led to the compilation of decision trees for maintenance treatment selection based upon distress as a starting point. This work focused on pavements with chemically stabilized layers. District personnel filled in the blanks to what actions they would take under specific cases of pavement distress; the researchers then compiled the results and made decision trees for each district. Figure 5 summarizes the most frequently cited treatments for the various cases of pavement distress.

Most Frequent Treatment for the Given Distresses			
Distress	Severity	Traffic Level	Treatment
Swell/Roughness	Some	Low	Monitor
		Medium	Level up and overlay
		High	Level up and overlay
	Rough	Low	Level up
		Medium	Mill, level up and overlay
		High	Mill, level up and overlay
Alligator Cracking	Minor	Low	Seal coat
		Medium	Seal coat
		High	Seal coat
	Major	Low	Seal coat
		Medium	Plan rehab
		High	Plan rehab and reconstruct
Longitudinal Cracks	Mostly Tight	Low	Monitor
		Medium	Monitor or seal coat
		High	Crack seal
	Open < 0.5"	Low	Crack seal
		Medium	Crack seal
		High	Crack seal
	> 0.5"	Low	Crack seal
		Medium	Crack seal and overlay
		High	Crack seal and overlay
Rutting	0.5" - 1.0"	Low	Fill ruts and seal coat
		Medium	Mill and overlay
		High	Mill and overlay
	> 1.0"	Low	Blade patch and overlay
		Medium	Mill and overlay
		High	Mill and overlay

Figure 5. Summary of Most-Cited Treatments for Pavements with Stabilized Layers (*31*).

Numerous decision tree methods and basic guidelines for selection of repair strategies already exist. Some advantages of decision trees are their capability to generate consistent recommendations and their ease of use (*32*). In general, researchers' review of the decision trees, matrices, and other documented guidelines on pavement treatments indicate:

- Surface treatments or crack sealing may offer reasonable performance on low-severity fatigue cracking. Surface treatments do not perform well on more extensive cracking; thus, higher severity fatigue cracking requires some type of full-depth repair (*33-37*).
- Chip seals should not be used for highly trafficked roadways. For higher-volume roads, microsurfacing or HMA overlays would be more appropriate surface treatments (*33, 36, 38, 39*).
- Conflicting guidelines exist on crack treatments. Sources agree that crack sealing is generally adequate for low- to medium-severity cracks; however, some sources indicate minor to medium-severity cracks can be sealed adequately with surface treatments, while other sources report marginal or poor performance when surface treatments are applied to longitudinal cracks (*33, 34, 38, 39*). The apparent conflicting recommendations may be due to differences in definitions of severity levels and what constitutes a good-performing repair.
- Microsurfacing, recycling, or overlays are good candidates for treatment of rutting not caused by insufficient pavement structure (*33, 35-40*).

CHAPTER 2

TXDOT DISTRICT SURVEY

I. SUMMARY

As part of this project, TTI researchers developed a survey for distribution to TxDOT maintenance personnel in order to determine which strategies are working and which are not when maintenance repairs are made on sections with excessive roughness, longitudinal cracks and faulting, and fatigue cracking. Specifically, the survey sought information regarding:

- how repair strategies are selected,
- materials used for repairs,
- ease of construction of the repair,
- performance of the repair, and
- cost effectiveness of the repair.

Mr. John Saldana, P.E., the project director, distributed the survey to 18 directors of maintenance or directors of operations in the San Antonio, Austin, Waco, Dallas, Fort Worth, Bryan, Beaumont, Houston, and Yoakum Districts. From these points of contact the survey was then forwarded on to Maintenance Section supervisors and assistant Maintenance Section supervisors. TTI received 52 responses to the survey.

The survey results can be summarized with the following observations:

- Only 31 percent of respondents indicated that field testing or lab work is performed as an aid in repair technique selection.
- If no testing is performed, distress type, experience of personnel, and traffic level of the road were indicated to be the major guiding factors in selection of repair methods.
- Cement-treated base was the most recommended base treatment, followed by asphalt base.
- For repairs of roughness, cold-mix asphalt was by far the most frequently used material. The most utilized repair method was to smooth the section with cold mix.
- The most frequently reported treatment methods used for longitudinal cracking and faulting distresses involve use of cement treated base material and smoothing the surface with cold mix.
- For fatigue cracking, many respondents indicated spot seal coats are widely used. The most widely reported base treatment was cement treatment.

II. DISCUSSION OF SURVEY RESULTS

This section discusses the results from each portion of the survey. Respondents were first asked to answer questions related to what processes they use to decide upon a repair method. Next, in context of cases of roughness, longitudinal cracking, and fatigue cracking, respondents answered questions regarding what materials they used in repairs, what methods they used for repairs, and how their repairs performed. Thus, the following sections discuss responses regarding:

- decision processes for repair technique selection,
- roughness,
- longitudinal cracking and faulting, and
- fatigue cracking.

For sections on the three pavement distresses, respondents were asked how often they use particular materials and treatments. From the survey responses, TTI researchers developed a frequency index to indicate how often a particular material or treatment is used. A frequency index of zero means the treatment is never used, and a frequency index of 6 means the treatment is always used. These frequency indices are presented in Appendix A.

Decision Processes for Repair Technique Selection

The majority of respondents (69 percent) indicated that they perform no field or lab testing prior to repairs. By far, visual inspection is the most frequently used analysis method prior to selecting a repair technique, with 98 percent of respondents indicating visual inspection is used to help aid in selecting a repair method. Approximately one-half of the respondents recommended coring, and approximately one-third recommend sampling the existing base and performing laboratory tests on potential repair materials. In the absence of any field or laboratory testing, most respondents (90 percent) indicate the distress type and the experience of personnel guides the decision process for selecting repair methods. Slightly fewer (86 percent) indicate that traffic level is also a consideration.

Roughness

Respondents answered questions regarding a typical case of roughness in which some driver discomfort is experienced, but the distress is not severe enough to require reduced speed. Cold-mix asphalt and cement-treated base were the first and second most frequently cited materials used, respectively, for repairs of roughness. Overall, respondents believed the best treatment for roughness would include:

- lime treatment of the subgrade,
- cement treatment of the base, and
- covering the surface with cold mix asphalt.

Respondents indicated the most often-used surface treatment was simply smoothing the section with cold-mix asphalt. Both smoothing with hot mix and milling were reported to be used roughly one-half as often as smoothing with cold mix. Respondents indicated that some form of cement-treated base (such as treatment in place, replacement with cement-treated base, or milling the base with the surface and adding cement) was by far the most frequently used base treatment. Asphalt base was reported to be used with a frequency of approximately one-third that of cement-treated base. The survey data indicate subgrade treatments are seldom performed on sections with roughness. Treatment with cement or replacement with additional base were the most cited treatments for subgrades. For severe cases of roughness where reduced speed is required, the majority of respondents (74 percent) said they would perform a full-depth repair.

Although the survey responses indicate cold-mix level-ups are the most widely used treatments for roughness, nearly 10 percent of respondents specifically noted surface level-ups when asked if there were any treatments they would *not* recommend. The general consensus from these comments was that the roughness generally reoccurs after a short time period and that overlays are only an expensive temporary solution.

The majority of respondents indicated repairs of roughness take 1 to 6 hours per station and are of average difficulty to construct. Virtually all respondents indicated traffic is allowed back on the road the same day the repair is made. More than half of the respondents reported repairs of roughness to last longer than 3 years, and 41 percent of respondents indicated lives of roughness repairs between 1 and 3 years.

Longitudinal Cracking and Faulting

A typical case of longitudinal cracking, where a moderately wide crack (0.5–1 inch) with approximately a 2-inch fault existed, was presented in the survey as the context for questions regarding longitudinal cracking. Cold-mix asphalt and cement-treated base were the first and second most frequently cited materials used, respectively, for repairs of the example cracking distress. Overall, respondents believed the best treatment for roughness would include:

- excavating into the subgrade and adding additional base depth,
- cement treatment of the base, and
- covering the surface with cold mix asphalt.

The most often-cited surface treatment used when treating longitudinal cracking and faulting distresses was smoothing with cold mix. Filling and sealing cracks was also reported with some regularity. Respondents indicated the most often used base treatment was cement-treated base, with asphalt base used roughly one-third as often as cement-treated base. Subgrade treatments used were equally divided between doing nothing, treating with cement, excavating and adding additional base depth, and excavating and replacing with asphalt material. For longitudinal cracks that are not faulted, the majority of respondents (81 percent) suggested filling and sealing the crack. For severely faulted cracks that would be classified as failures, all responses suggested excavating the section and performing a full-depth repair. Many respondents also suggested drainage improvements.

Respondents that suggested treatments to avoid reported that surface treatments typically do not last very long. The survey data indicate most repairs used for longitudinal cracking take 2 to 6 hours per station to construct, are of average difficulty to perform, and are opened to traffic the same day as the repair. Nearly half of the respondents indicated their repairs typically last 1 to 3 years, and 45 percent of respondents indicated their repairs last longer than 3 years.

Fatigue Cracking

Respondents answered questions regarding fatigue cracking in context of a substantially cracked section with rutting but without popouts. The survey data indicate cold-mix asphalt, hot-mix asphalt, and cement-treated base are all used with approximately the same frequency for repairs of fatigue cracking. The survey responses indicate the most common treatment for fatigue cracking is a seal coat. Some respondents indicated they would mill or blade off the existing surfacing and inlay the sections with fresh asphalt mix. Cement treatment was the most preferred, and most frequently used, base treatment on sections with fatigue cracking. Excavation into the subgrade and replacement with additional depth of base was the preferred subgrade treatment option selected by respondents. In practice, the survey responses indicate the frequency of subgrade treatments performed are approximately equally divided between doing nothing, treating with cement, and replacing with additional depth of base. For early stages of fatigue cracking, the majority (80 percent) of respondents suggested spot seal coats.

Respondents that indicated repair techniques to avoid indicated problems are typically encountered with cracks coming through surface treatments (crack seals, thin overlays). The survey data indicate treatments of sections with fatigue cracking typically take less than 4 hours per station and are opened to traffic the same day the repair is made. Nearly half of the respondents indicated their repairs typically last 1 to 3 years, and almost 40 percent reported repair lives of 3 to 5 years.

III. CONCLUSIONS FROM SURVEY RESPONSES

The survey responses clearly show that testing is seldom conducted in maintenance repairs, and distress type and the experience of personnel are the major factors in how repair methods are chosen. Since the cause of distress is one of the most important factors to consider when choosing an appropriate repair method, and most repair methods are selected without any testing, it is important that maintenance personnel are trained in identifying likely causes for various pavement distresses. Thus, the field guidebook developed in this study (contained in Appendix D), contains sections on identifying the causes of the pavement distress.

The current practice of TxDOT maintenance repairs was one consideration in developing the field guide in this study. Based upon the survey responses, TxDOT maintenance personnel most often use the following treatments:

- roughness: level-up for average-severity cases; full-depth repairs for severe cases where reduced speed is required;
- longitudinal cracking: crack fill and seal for cracks that are not faulted; repair into base and subgrade with cement treatment for faulted cracks; and
- fatigue cracking: seal coat for low-severity cracking; rework base/subgrade with cement for more severe cases.

CHAPTER 3

INVESTIGATION OF TREATMENTS FOR LONGITUDINAL ("DRY-LAND") CRACKING

I. SUMMARY

Longitudinal cracking is one of the most prevalent distresses on pavements over expansive subgrade soils. These cracks often result from edge drying during hot, dry time periods in environments of highly plastic (PI > 35) soils. Steep side slopes and shrubs and trees near the pavement edge can also aggravate problems with longitudinal cracks. TTI researchers examined field sites where longitudinal cracking had been treated with the following methods:

- filling and sealing the cracks,
- surface patching with cold-laid and hot-mix asphalt,
- recycling the existing base with cement then adding a surface treatment,
- placing a thin HMA overlay over the section, and
- recycling the in-place material with cement and using geogrid reinforcement.

The field observations indicate:

- Crack filling and sealing has proved as effective as full-depth patching utilizing conventional methods. The life of treatments where cracks are filled and sealed is typically around 2 years. Investigations have shown that longitudinal cracks generally reoccur within a short time frame (6 months to 2 years) after conventional full-depth repairs.
- Cracks typically reflect through surface treatments within a short time frame, although thin HMA overlays may give slightly better performance as compared to blade-on patches or seal coats.
- Neither surface treatments nor conventional full-depth patching adequately treat dry-land cracking. Cracking typically reoccurs within a short time frame.
- Given the similar time frame to reoccurence of cracking between conventional full-depth rehabilitation and surface treatments, little incentive exists to use the more time-consuming and costly full-depth repair unless pavement deterioration is substantial.
- The most effective treatment for dry-land cracking is the full-depth recycling method utilizing geogrid reinforcement (used in the Bryan District). Section III of this chapter describes the process used by the Bryan District for planning treatments with the geogrid reinforcement.

II. DISCUSSION OF FIELD SITES

The following sections discuss the field sites examined. Appendix B presents the complete core results, and Appendix C contains falling weight deflectometer (FWD) results.

FM 226

Location: Nacogdoches County, Lufkin District, from reference marker (RM) 356 south to approximately 1 mile, 3760 feet south of RM 358.

Primary Distress(es) before Treatment: Longitudinal cracking and faulted cracks.

Treatment(s) Applied: Rehabilitation with cement began in July 1995. District personnel report that cracking occurred within approximately 6 months to 1 year after completion of the rehab. In 2000, maintenance personnel filled the cracks with Grade V rock then sealed the cracks. Some surface patches have been applied over faulted cracks.

Field Observations: Approximately 50 percent of the sealed cracks have failed. The road has extensive block cracking, likely from the cement-treated base, along with several instances of longitudinal cracks in proximity to the pavement edge. Some of these cracks are very wide and/or faulted. Several surface patches are also present. Reportedly, these blade-on patches were applied over faulted cracks that reoccured after the rehabilitation. In most cases, the cracks have reflected through the surface treatments. Steep side slopes are prevalent throughout the section. Figure 6 shows representative views of the section, illustrating the block cracking, blade-on patches, wide longitudinal cracking, and faulting present.

Testing Results: Plastic index values ranged from 4 to 53 on samples taken from FM 226. From FWD data, the base modulus ranged from 211 to 793 ksi.

Overall Road Summary: The combination of stiff bases, steep side slopes, and highly plastic soils appears to have resulted in less than desirable performance from the rehabilitation. Extensive block cracking, longitudinal cracking, and substantial maintenance requirements on the section all seem to indicate a better repair process must exist.

Figure 6. Views of FM 226 in July 2002.

<u>FM 1818</u>

Location: Angelina County, Lufkin District, from FM 58 to Shawnee Prairie.

Primary Distress(es) before Treatment: Longitudinal cracking and faulting (Figure 7). Some localized base failures from logging traffic have also occurred.

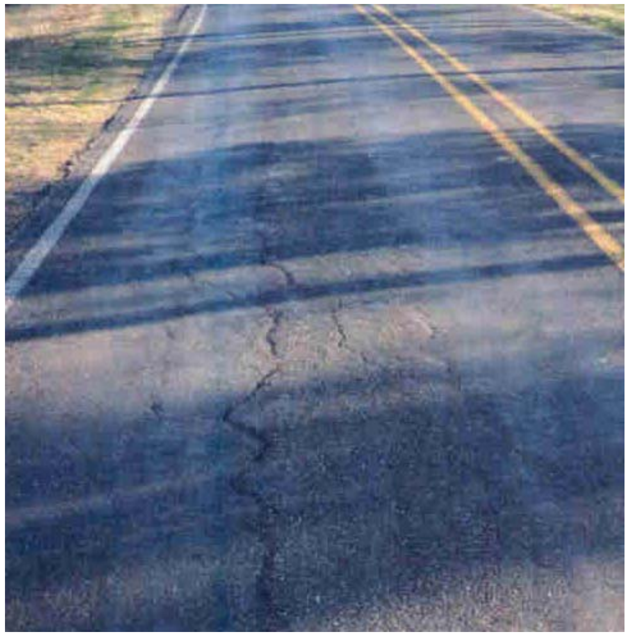

Figure 7. Cracking Distress on FM 1818.

Treatment(s) Applied: A combination of blade-on patches, hot-mix cold-laid, and HMA have been used to maintain FM 1818. As of July 2002, the oldest patches were approximately 2 years old; some patches were only a few months old.

Field Observations: Frequent maintenance appears to be ongoing on this road. The combination of truck traffic and flooding is reported to keep maintenance crews busy. According to the United States Department of Agriculture (USDA) Soil Survey for Angelina County (*41*), the majority of FM 1818 between FM 58 and Shawnee Prairie is on relatively low-plasticity material, with plastic indices typically below 20. Isolated sections of the road are on soils that may have a plastic index as high as 65. The major limitations on the section are low-strength soils, wetness, and flooding (*41*).

Testing Results: Researchers sampled material down to depths of 24 inches on FM 1818. All the cores revealed low-plasticity sandy material, with plastic indices in the range of 6 to 11. These findings are consistent with the USDA soils maps.

Overall Road Summary: It is evident substantial maintenance work takes place on FM 1818; however, based upon both the coring results and the USDA soils maps, it appears reasonable to conclude the problems are due more to low-strength soils, the wetness of the environment, and logging truck traffic.

FM 2076

Location: Houston County, Lufkin District, from RM 664 to Loop 304.

Primary Distress(es) before Treatment: Edge Cracking, faults, and rutting (Figure 8). According to Area Maintenance personnel, some of the longitudinal cracks were up to 2 inches wide before the rehab.

Figure 8. Edge Cracking and Faulting Distresses on FM 2076 before Treatment.

Treatment(s) Applied: A 2100-foot section was rehabilitated with cement by maintenance forces in 1999. TxDOT personnel estimate 5 percent Type I cement was mixed in with the existing material to a depth of 8 to 12 inches. The rehab section starts approximately 1 mile, 630 feet east of RM 664. A seal coat was applied to the entire road in July 2002.

Field Observations: According to the USDA General Soil Map for Houston County *(42)*, the section of FM 2076 examined is on mostly Kirvin and Cuthbert soils. These soils typically have a sandy loam surface and a red clay subsoil *(42)*. Kirvin soils typically have a plastic index in the range of 16 to 43 in subsurface soil horizons *(41)*. Cuthbert soils typically have a plastic index in the range of 11 to 40 in subsuface horizons *(41)*. The USDA soils map indicates low strength as the major limitation for the suitability of these soils for roadways *(42)*.

Three severe longitudinal cracks exist in the rehabilitated section under examination. Figure 9 shows a wide, faulted crack in the westbound direction in June 2002. Area Maintenance personnel indicate cracking reoccured shortly after completion of the rehabilitation. Although the road does not yet exhibit the breakup shown in Figure 8, the wide cracking that exists will certainly allow water into the pavement and result in accelerated pavement deterioration.

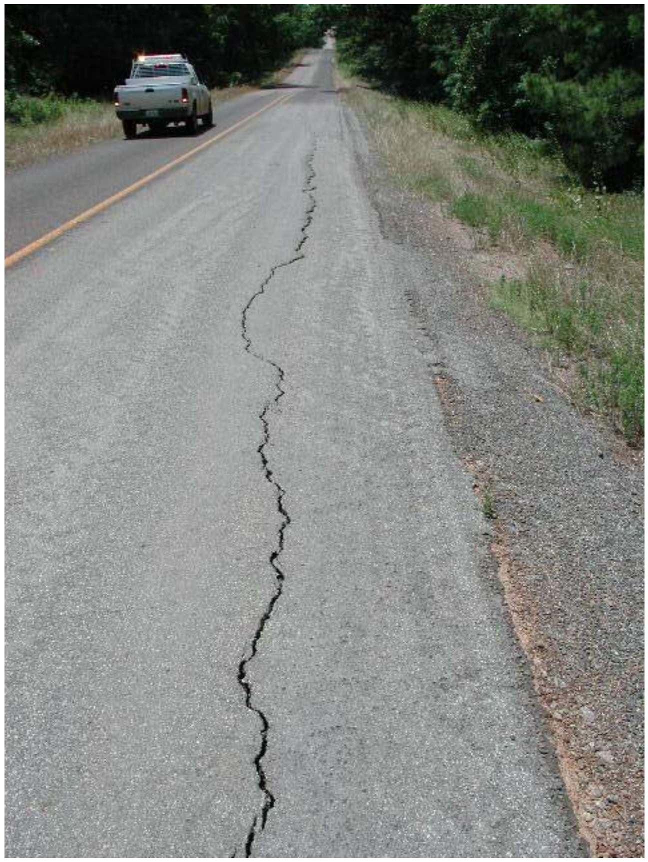

Figure 9. Severe Longitudinal Crack in FM 2076 WB Rehab Section.

Testing Results: The plastic index of the soil from 17 inches and deeper ranged from 29 to 48. Figure 10 shows one of the locations where researchers cored and sampled the subgrade. The plastic index at this location was 29 (from 17 to 22 inches) and 40 (from 22 to 27 inches).

FWD data collected on FM 2076 reveal very stiff base layers exist both in the rehab section investigated, and in the existing section. This is consistent with the cores, which revealed a cement-treated base layer existed even several hundred feet outside the limits of the maintenance rehabilitation. Base moduli ranged from 828 to 1175 ksi.

Figure 10. Core Location by Severe Crack on FM 2076 EB in Rehab Section.

Overall Road Summary: The repair on FM 2076, although exhibiting some severe longitudinal cracks, does not exhibit the edge breakup shown in Figure 8. However, faulting is still occurring, and the wide cracks provide an entry for water into the pavement, which will increase the rate of deterioration. Compared to FM 226, the repair on FM 2076 is performing better with respect to cracking. An interesting observation is the lack of block cracking on FM 2076, despite having base moduli significantly higher than the observed base moduli on FM 226. FM 226 was a contracted job and was likely not opened to traffic immediately. In contrast, FM 2076 was reworked by maintenance forces and would have been reopened to traffic each day. The difference in time to traffic loading could explain the lack of block cracking on FM 2076 and the presence of block cracking on FM 226.

<u>FM 2022</u>

Location: Houston County, Lufkin District, heading north/northeast from Loop 304.

Primary Distress(es) before Treatment: Longitudinal cracking and faulting.

Treatment(s) Applied: Thin HMA overlay applied in 2000.

Field Observations: This road is on the same general soils types as FM 2076. The soils typically have a layer of sandy loam on top of red clay with plastic indices of 16 to 43 (*41,42*). In several locations longitudinal cracking and some faulting has reoccurred.

Testing Results: No testing was conducted on this section.

Overall Road Summary: The thin overlay on FM 2022 resulted in typical performance from surface treatments on dry-land cracking. Maintenance personnel reported cracking reappeared within 6 months after the overlay. Given the resurgence of cracks and faults, it is evident the hot-mix overlay does not really fix the problem, but instead is really an expensive "band-aid" that temporarily improves the pavement condition.

<u>FM 1915</u>

Location: Milam County, Bryan District, from Little River relief bridge to County Road 407.

Primary Distress(es) before Treatment: Longitudinal cracking.

Treatment(s) Applied: Rehabilitated in 1997 using geogrid reinforcement in two sections of the project.

Field Observations: A control section exists between two sections utilizing the geogrid reinforcement on FM 1915. The first geogrid section, shown in Figure 11, starts at the Little River relief bridge and is 0.8 miles long. The section had one blade-on patch, a longitudinal crack approximately 4 feet long, and a short section with severe rutting (Figures 12 and 13). Numerous longitudinal cracks exist in the control section, which is also 0.8 miles long. Figure 14 shows these distresses. The second section with the grid reinforcement, which is 0.6 miles long, had no visible defects. Figure 15 shows this geogrid section on FM 1915.

Figure 11. First Geogrid Section on FM 1915.

Figure 12. Blade-on Patch on First Geogrid Section on FM 1915.

Figure 13. Longitudinal Crack and Rutting on First Geogrid Section on FM 1915.

Figure 14. Longitudinal Cracking on Control Section on FM 1915.

Figure 15. Second Geogrid Section on FM 1915.

Testing Results: A summary of the Bryan District's core data when planning the rehabilitation work is shown in Table 3. The plastic index of the clay subgrade ranged from 30 to 49.

Table 3. Coring Results for FM 1915 (*43*).

Location	Depth	Plastic Index
0.5 miles W of Little River bridge	0 – 6 ft	37
	6 – 8 ft	36
1. 6 miles W of Little River bridge	0 – 1 ft	26
	1 – 2 ft	19
	2 – 6 ft	37
	6 – 8 ft	31
2.5 miles W of Little River bridge	0 – 8 ft	49
3.6 miles W of Little River bridge	0 – 4 ft	33
	4 – 8 ft	30

Overall Road Summary: The second grid section has no signs of distress and is performing better than the first grid section. Both grid sections are performing better than the section without any grid reinforcement. The control section without the grid has numerous longitudinal cracks. The grid reinforcement has shown to be quite effective at reducing longitudinal cracking.

OSR

Location: Madison County, Bryan District, from FM 39 to 3.6 miles west of FM 39.

Primary Distress(es) before Treatment: Longitudinal cracking (Figure 16).

Figure 16. Representative Distresses on OSR.

Treatment(s) Applied: Rehabilitation in 2000 with geogrid reinforcement on sections with highly plastic clays.

Field Observations: The section shows no signs of distress in the sections with geogrid reinforcement. Figure 17 shows a representative section.

Figure 17. Representative Section of OSR with Geogrid Reinforcement.

Testing Results: Table 4 shows the results from cores taken by the Bryan District. Material with a plastic index as high as 55 exists in sections utilizing the geogrid.

Table 4. Coring Results for Plastic Index from OSR (*43*).

	0-1'	1-2'	2-3'	3-4'	4-5'	5-6'	6-7'	7-8'
0.5 mi. W of FM 39	37	37	37	31	39	26	26	26
0.9 mi. W of FM 39	21	21	8	8	37	37	37	55
1.5 mi. W of FM 39	5	5	8	8	37	37	37	55
1.7 mi. W of FM 39	21	21	23	23	38	38	38	38
2 mi. W of FM 39	22	18	29	29	29	29	16	16
2.5 mi. W of FM 39	20	20	20	20	44	44	44	44
3 mi. W of FM 39	14	14	9	9	19	19	19	19
3.5 mi. W of FM 39	32	32	32	54	54	54	32	48

Overall Road Summary: The geogrid reinforcment resulted in substantial improvement in cracking performance on OSR. No signs of distress were evident. The grid reinforcement appears to be a promising candidate for use when reworking sections with longitudinal cracking and highly plastic clays.

III. SUMMARY OF BRYAN DISTRICT'S GEOGRID REHABILITATION

A. Determination of Geogrid Limits

1. From USDA County soils maps, potentially problematic areas in the section are identified. Each county map contains tables with typical plastic index ranges for each soil and lists the limiting factors, if any (such as shrink swell), for use of the soils in roadways.
2. Coring is performed every 0.5 miles to a depth of 10 feet, and the Atterberg limits are determined with depth (typically at each change in soil type).
    i. Additional coring may be performed to verify the geographic limits of potentially problematic soils. In sections of sandy materials, coring is only performed every mile.
    ii. Locations with plastic indices greater than 35 at depths above 7 feet are tentatively considered candidates for geogrid reinforcement.
3. The District Engineer drives the section to make the final determination of the geogrid limits.

i. The road is examined for visual signs of distress (cracking, quantity of maintenance treatments, etc.).
ii. In the summer months the soil in the shoulders can be examined for cracking.
iii. The proximity of vegetation to the roadway and the steepness of side slopes are considered.

B. Performing the Rehabilitation

1. Typically the existing road is widened out. The existing base and seal coat is mixed with a portion of the existing subgrade to achieve the laboratory-determined needed thickness. The recycled material is chemically treated with a laboratory-determined amount of cement or lime.
2. The geogrid reinforcement is placed on top of the treated base layer and extended at least 2 feet outside the crown, as shown in Figure 18. Figure 2 showed the grid used in the Bryan District.

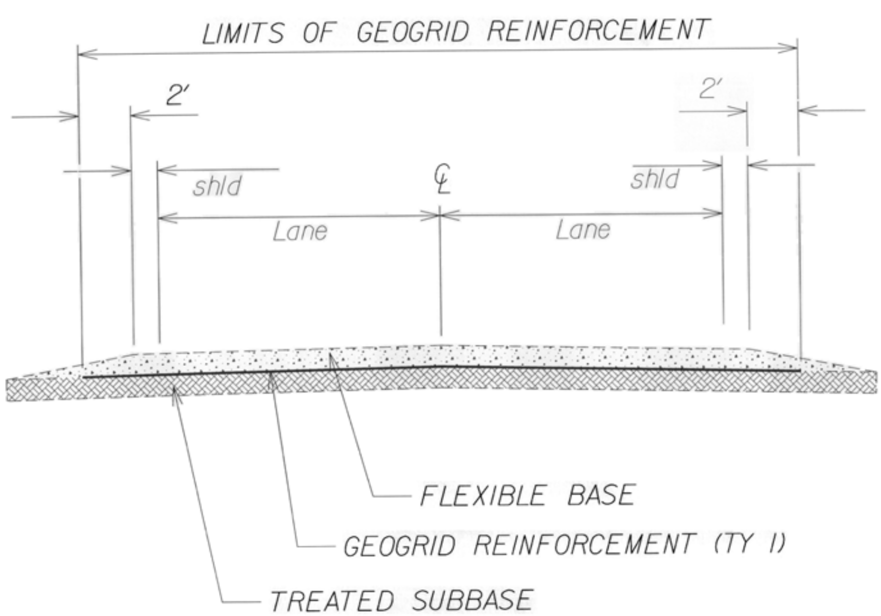

Figure 18. Geogrid Reinforcement on Expansive Soils.
Schematic courtesy of Darlene Goehl, P.E.

3. A 3- to 4- inch layer of untreated flex base is placed on top of the grid.
4. A seal coat is used to seal the surface.

CHAPTER 4

EVALUATION OF STRUCTURAL REPAIRS

I. SUMMARY

The TTI research team visited several sites in the San Antonio District where maintenance forces performed base repairs due to structural deterioration (fatigue cracking and rutting). The team also visited a section in the Lufkin District where maintenance was performing a repair; this section should be considered for monitoring during the second year of the research project.

Two sections in the San Antonio District were visited where repairs were made with cement-treated base. One section where cement was used is on plastic clay and does not show signs of structural problems, but the section is showing signs of cracking distress from the plastic subgrade. The second site where cement was used shows no signs of distress, but coring revealed the section was over soil with low plasticity. Essentially the cement-treated base appears to yield good performance structurally, but when over expansive soils, problems such as longitudinal cracking are still likely.

Two sections where black base was used were identified; however, traffic control was inadequate for conducting any testing at one of the black base sites (FM 78). At the other black base site, maintenance has performed several patches within the original patch. As such, it appears the black base section did not perform very well. Maintenance personnel in the Area Offices indicated they avoid using the black base if possible.

II. DISCUSSION OF FIELD SITES

The following sections discuss the field sites visited by the research team. Appendix B contains core results, and Appendix C shows the results of FWD testing.

<u>FM 2967</u>

Location: Houston County, Lufkin District.

Primary Distress(es) before Treatment: Rutting.

Treatment(s) Applied: Maintenance forces recycled the existing base/seal coat with cement in June 2002. Figure 19 shows the treated base being placed.

Figure 19. Placement of Recycled Base on FM 2967.

Field Observations: This project was constructed at the time researchers were visiting the Lufkin District in June 2002; thus, no performance history is available yet. Maintenance personnel indicated that an increase in truck traffic resulted in the rutting. USDA soils maps indicate this road is on Woodtell and Lacerda soils, with low strength and shrink-swell being the main limitations for suitability for roadways (*42*).

Testing Results: Not applicable.

Overall Road Summary: Testing on FM 2967 should be considered in the second year of the research work.

<u>FM 20</u>

Location: Guadalupe County, San Antonio District, just northeast of Laubuck Road past RM 526.

Primary Distress(es) before Treatment: Fatigue cracking and rutting.

Treatment(s) Applied: FM 20 was rehabilitated in 1999, and maintenance personnel reported some base failures occurred shortly after the rehab. Maintenance forces removed 8 to 10 inches of base and placed new base treated with cement in January 2001. Maintenance forces report that approximately 3 percent cement was added to the new base. Figure 20 shows the site.

Figure 20. Base Repair Site on FM 20.

Field Observations: There is some dry-land cracking evident both on the existing structure and in the patch area. In the existing structure some of the cracks are slightly faulted, as shown in Figure 21. In general, the cracks in the patch are minor longitudinal cracks. The location of the patch is near the interface of Crockett fine sandy loam and Houston black clay soils. The main limitation of both these soils for roadways is their low strength and shrink-swell (*44*). There are no signs of load-induced distress in the patched section.

Figure 21. Cracking on FM 20 Section.

Testing Results: The plastic index in the existing pavement ranged from 12 to 26. In the patch, the plastic index of the subgrade ranged from 20 to 30. From cores, the base in the patch appears quite similar to the base in the existing section. FWD data likewise reveal similar base modulus values between the existing structure and the patch. The average base modulus in the existing section was 73 ksi; the average base modulus in the patch was 88 ksi.

Overall Road Summary: The patched section is not exhibiting structural distresses but is showing signs of distress from the plastic subgrade (longitudinal cracking).

FM 2505

Location: Wilson County, San Antonio District, between County Road 106 and County Road 110.

Primary Distress(es) before Treatment: Potholes/failures.

Treatment(s) Applied: In early 2002, maintenance forces excavated the distressed section and added replacement flex base. Cement was then mixed in place with the new material.

Field Observations: No distresses evident. Figure 22 shows the repaired section.

Figure 22. Patch on FM 2505.

Testing Results: Coring and subsequent laboratory testing revealed that the plastic index of the soil on FM 2505 ranged from 7 to 17 at depths above 35 inches. FWD data were collected, but errors in backcalculation were very high (20 to more than 30 percent). As such, the FWD for this site were disregarded. Instead, the base core from the patch was tested in the seismic modulus equipment at TTI. When tested dry, the modulus was 1350 ksi; when tested saturated, the modulus was 911 ksi.

Overall Road Summary: There are no signs of distress on the section on FM 2505. The base is stiff and the soil has low plasticity, so the likelihood of a reoccurrence of problems on the patch is low.

FM 541

Location: Atascosa County, San Antonio District, just northeast of McCoy.

Primary Distress(es) before Treatment: Base problems.

Treatment(s) Applied: A thin layer of Type A black base was applied on top of the existing base.

Field Observations: Several patches exist within the patch. Maintenance personnel indicated that in several spots failures reoccurred and were patched with cement-treated base.

Testing Results: The Atterberg limits were determined down to a depth of 31 inches on the section of FM 541. In all cases, the plastic index was below 20. FWD testing indicated the modulus of the underlying base was 15 ksi, and the thin layer of black base had a modulus of 125 ksi. The subgrade modulus was 10 ksi.

Overall Road Summary: Unfortunately, this site was not what would be considered a full-depth black base patch. However, the reported reoccurrence of failures in the section indicates the original treatment was not very effective.

CHAPTER 5

LABORATORY TEST PLAN

I. SUMMARY

Since maintenance personnel indicated cement-treated base or black base were the most commonly used materials in base repairs, researchers conducted a laboratory testing sequence on two limestone aggregates and two black bases from the Seguin and Floresville Area Maintenance offices. The Seguin office provided limestone aggregate and a black base, both from Vulcan Materials. The Floresville office provided limestone aggregate from Colorado Materials and black base material supplied by Vulcan Materials. Although laboratory testing will generally not be a routine part of maintenance repairs, the laboratory test phase of this research project was performed to characterize the performance of some commonly used materials for maintenance repairs and to compare the anticipated performance of cement-treated base versus black base. The laboratory sequence was performed to answer two questions:

- How does the performance of the limestone aggregates from the different suppliers compare to each other?
- How does the performance of the cement treated limestone materials compare to the black base?

With these two objectives in mind, researchers developed a laboratory testing sequence to characterize the performance of the materials and allow for a direct comparison between the limestone and the black base. This chapter presents a brief discussion of each test method used in the laboratory testing sequence.

II. TESTS PERFORMED ON UNTREATED LIMESTONE AGGREGATES

A short testing sequence performed on the untreated aggregates provides a general characterization of each aggregate. All test specimens were recombined according to fractionations over the 1¾, 1¼, ¾, $^3/_8$, and #4 sieves. Tests performed include:

- *Moisture-Density Relationship (Tex-113-E)*. This test is used to determine the optimal molding moisture for achieving maximum dry density during compaction.
- *Liquid Limit and Plastic Limit (Tex-104-E and Tex-105-E)*. These tests are used to determine the plastic index of the material.
- *Triaxial Classification (Tex-117-E)*. Test specimens are subjected to a 10-day capillary soak then tested in compression at various confining pressures. The results are used to determine the Texas Triaxial Classification. The lower the triaxial class number, the better the material.
- *Tube Suction Test for Moisture Susceptibility*. Standard TxDOT 6-inch × 8-inch test specimens undergo a 48-hour dryback then are subjected to a 10-day capillary soak in this test. This test simulates conditions in which a base aggregate could absorb water from a wet subgrade or high water table. The surface dielectric value is monitored

during the soaking period, as shown in Figure 23. The final dielectric value at the end of the test is used to estimate the moisture susceptibility of the materials. Materials with a final dielectric value less than 10 are expected to give good performance even when water is readily available. Materials with a final dielectric value between 10 and 16 are expected to give marginal performance when moisture is readily available, and materials with a final dielectric value greater than 16 are expected to be poor performers in the presence of available water.

Figure 23. Surface Dielectric Measurements during Tube Suction Test.

III. TESTS PERFORMED ON CEMENT-TREATED BASES

Discussions with maintenance personnel indicated that 5 to 9 percent cement is typically added when cement treatment is used in maintenance repairs. However, as discussed in the literature review, excessive cement can lead to block cracking and, when over expansive soils, can result in a stiff slab on top of a moving subgrade, resulting in severe longitudinal cracking. Therefore, laboratory testing was performed with cement treatment at lower levels (2 and 4 percent), along with cement treatment at a higher level (7 percent), to investigate the performance of the materials with varying cement content. Specifically, tests conducted include:

- *Unconfined Compressive Strength at 24 hr, 48 hr, and 7 days curing (Tex-120-E procedures except for curing time variations)*. Since maintenance repairs must be opened to traffic quickly, the short-term strength as well as the eventual strength after the majority of curing has taken place was investigated.
- *Tube Suction Test*. Similar to the test method described previously, the Tube Suction Test on the cement-treated materials subjects specimens to a 48-hour dryback then a 10-day capillary soak. The major differences are that the cement treated specimens are allowed to cure for 7 days before the testing is begun, and the cement-treated specimens are the 4-inch × 4.58-inch AASHTO size. The small sample size is used with the treated materials because previous work has shown the results from the Tube Suction Test on the smaller samples is much more indicative of the performance of

the materials in the traditional wet-dry (ASTM D559) and freeze-thaw (ASTM D560) durability tests (*18*).

- *Seismic Modulus at 7 days curing*. The modulus is a measurement of the stiffness of the material. Using a free-free resonant column method developed at the University of Texas at El Paso (UTEP), researchers tested specimens with the seismic equipment before testing samples in the resilient modulus test. The seismic equipment uses a hammer equipped with a load cell to apply energy into the test specimen. Upon impact, a timing circuit is started and an accelerometer at the opposite end of the sample measures the time of arrival of the P-waves. Based upon the P-wave velocity and the density of the sample, the seismic (Young's) modulus can be calculated by (*45*):

  $$E = \rho \cdot V_p^2$$

  where
  E = seismic modulus,
  ρ = density of material, and
  V_p = P-wave velocity.

  Figure 24 shows the seismic modulus test in progress, and Figure 25 illustrates a typical waveform generated in the test.

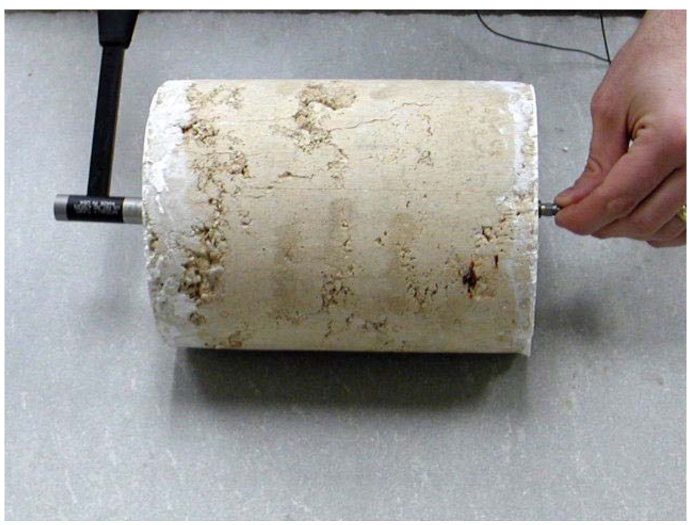

Figure 24. Seismic Modulus Test in Progress.

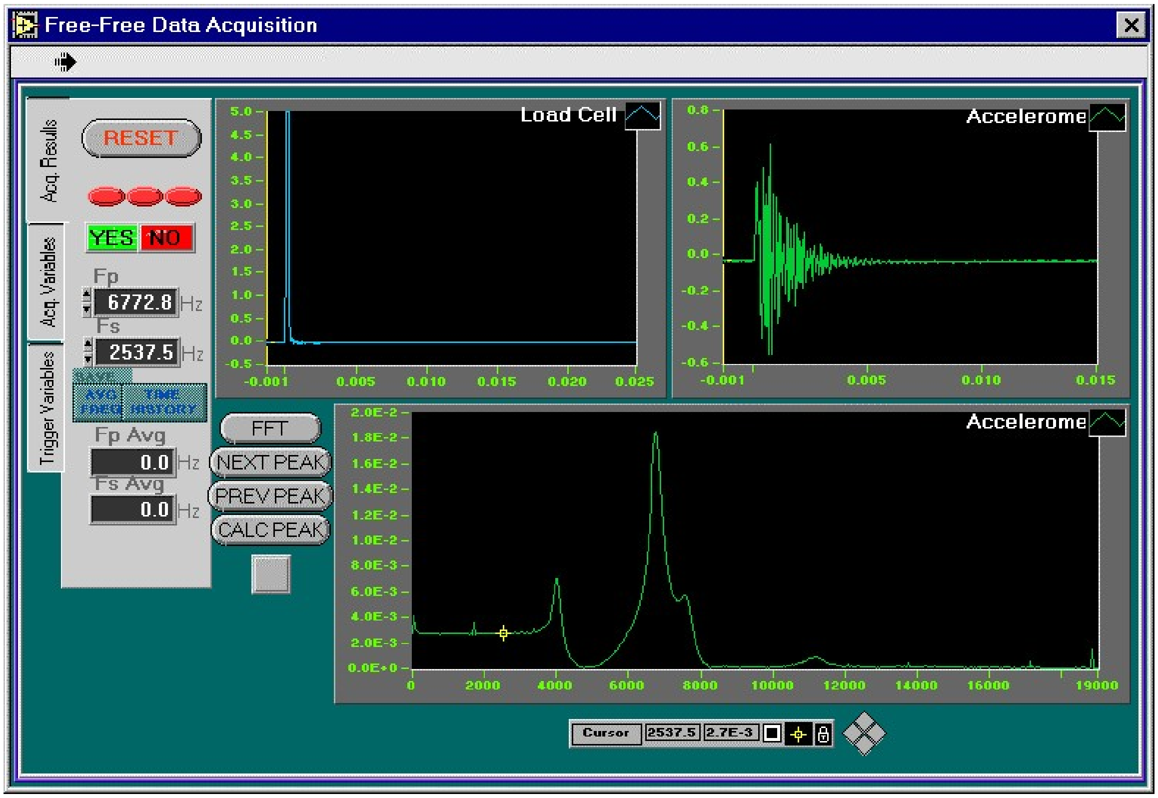

Figure 25. Typical Response of Accelerometer in Seismic Modulus Test.

Cement-treated specimens (4-inch × 8-inch) tested for modulus were made by recombining the materials according to gradation, except only material passing the ¾-inch sieve was used in order to keep a reasonable ratio between the maximum aggregate size and sample diameter. To construct the smaller diameter samples with the same percentage of coarse material as the original fractionation results, the percentage of material greater than the ¾-inch sieve was instead added as additional material retained on the $^{3}/_{8}$-inch sieve.

- *Resilient Modulus at 7 days and 28 days curing (AASHTO T292)*. Researchers used the same specimens tested with the seismic device to measure the resilient modulus. The test for resilient modulus uses servo-hydraulic equipment, shown in Figure 26, to apply a loading wave of 0.1-second duration followed by a 0.9-second rest period. Linear variable differential transformers (LVDTs) attached to the test specimen measure the recoverable deformation following the loading wave. The resilient modulus is defined by *(46)*:

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

where
M_R = resilient modulus,
σ_d = deviator stress, and
ε_r = recoverable strain.

Figure 26. Resilient Modulus Test Setup.

- *Linear Beam Shrinkage*. Shrinkage cracking is one concern with cement treated materials. Following testing procedures from DeBeer (*47*), recent work at TTI proposed a 300 microstrain limit on shrinkage after 20 days curing to reduce the risk of shrinkage cracking distresses (*18*). Researchers prepared 3-inch × 3-inch × 17.7-inch beams with the limestone aggregates at each cement content. Following procedures developed by DeBeer, they cured the beams for 24 hours then measured linear movement over a 20-day period while the specimens remained in a 100 percent relative humidity environment. Figure 27 shows a representative beam and the measurement device used. Figure 28 shows how the measurement device fits over the beam and onto gauge studs attached to each end of the beam to take readings.

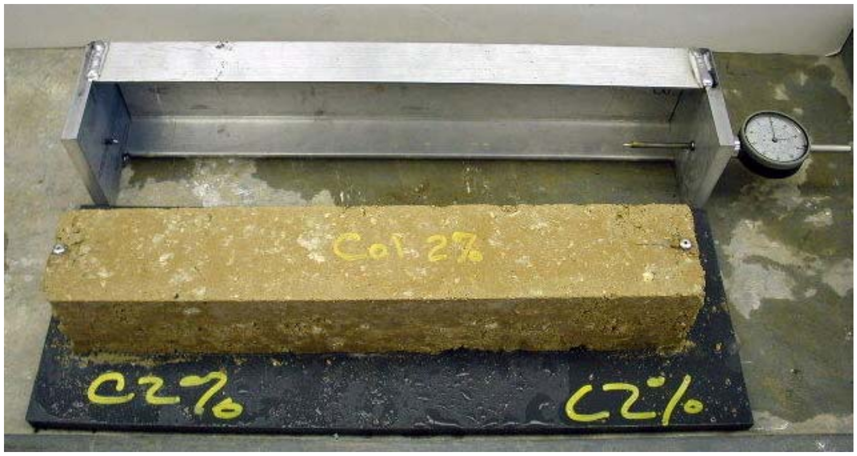

Figure 27. Beam and Measurement Device for Shrinkage Measurements.

Figure 28. Shrinkage Measurement in Progress.

- *Hamburg Wheel Tracking (Tex-242-F)*. The Hamburg test is designed to assess the susceptibility of asphalt mixes to moisture damage (*48*). An 8-inch diameter, 1.58-inch wide steel wheel applies a 158 ± 5 pound load over a test specimen. A water bath maintained at 122 ± 2 ^{o}F keeps the test specimens submerged and at a constant temperature. LVDTs measure the rut depth with the number of passes of the wheel. The test runs for 20,000 load cycles or until a rut depth of 0.5 inch is reached, whichever occurs first. Figure 29 shows the Hamburg test setup. Although traditionally used for bituminous mixes, cement-treated base specimens were subjected to this test to provide data directly comparable to test results from the black bases.

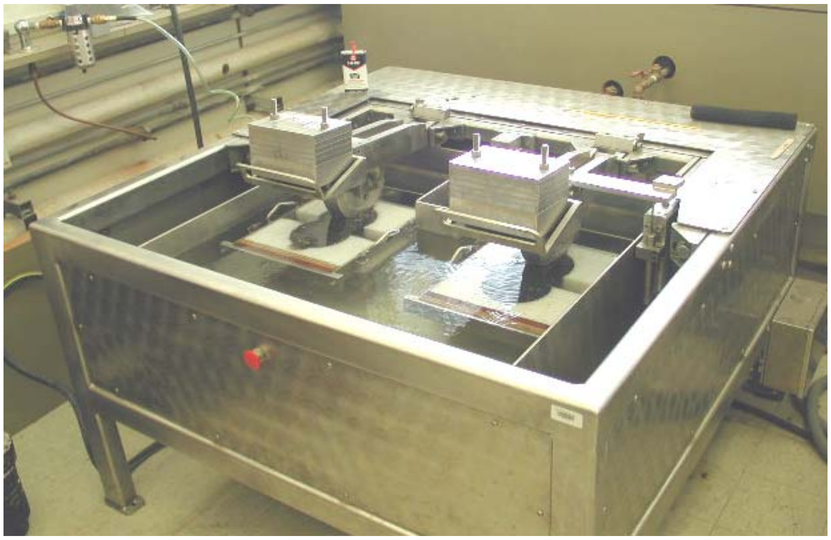

Figure 29. Hamburg Wheel Tracking Test Setup.

IV. TESTS PERFORMED ON BLACK BASES

Given the higher cost of black bases as opposed to chemically treated granular materials, research work sought to evaluate how the performance of the black bases compared to the cement-treated aggregates. The following tests were performed on the black bases:

- *Theoretical Maximum Specific Gravity (Tex-227-F)*.
- *Extent of Field Compaction*. Test specimens in the lab need to be compacted as close as possible to typical void contents obtained in the field. To determine typical field void contents, black base samples from field sites in the San Antonio District were tested for air void content. Tex-207-F is used to determine the density, and Tex-227-F is used to determine the theoretical maximum density.
- *Unconfined Compressive Strength (Tex-126-E)*. Test specimens at 140 ^{o}F are subjected to compressive loading at two deformation rates (0.15 in/min and 10 in/min). At the slow loading rate, TxDOT specifications require a compressive strength of at least 50 psi for Grade 1 material. Figure 30 shows a representative black base specimen in the compression test.

Figure 30. Black Base Specimen in Compression Test.

- *Unconfined Compressive Strength (at 77 °F).* To allow for a direct comparison to the cement-treated materials, black base specimens were also tested in compression at 77 °F with a loading rate of 0.135 in/min.
- *Seismic Modulus at 77 °F and 104 °F.* Testing both the cement-treated bases and the black base for seismic modulus yields data that can be directly compared between materials. However, since temperature affects the stiffness of bituminous mixes, the black bases were tested at standard temperature (77 °F) and at an elevated temperature (104 °F). Figure 31 shows a representative black base specimen being tested with the seismic equipment. Black base specimens for modulus testing were constructed with dimensions of 4 inches × 6 inches to be consistent with recent methodology used for such testing. Material greater than $^7/_8$ inch was removed to maintain a reasonable ratio between maximum aggregate size and sample diameter.

Figure 31. Black Base Specimen Tested for Seismic Modulus.

- *Resilient Modulus (AASHTO T292)*. Following seismic modulus testing, TTI's laboratory tested the black base specimens for resilient modulus with the servo-hydraulic setup previously described. TTI's laboratory tested specimens with deviator stresses of 15 and 30 psi at 77 ^{o}F and 15 psi at 104 ^{o}F.
- *Hamburg Wheel Tracking (Tex-242-F)*. Some offices have reported problems with the performance of black base, especially if not seal coated. The Hamburg test (described previously) provides information used to assess the moisture susceptibility of bituminous mixes. Cement-treated specimens were also subjected to this test for comparison purposes.

CHAPTER 6

LABORATORY TEST RESULTS

I. SUMMARY

Researchers conducted a laboratory testing sequence to characterize the performance of some materials commonly used in maintenance base repairs. Two limestone aggregates, one originally from Vulcan Materials and one originally from Colorado Materials, were sampled from TxDOT stockpiles. Black base was sampled from stockpiles in the Seguin Area Office and the Floresville Area Office. Vulcan Materials produced both black bases. The laboratory sequence was performed to answer two questions:

- How does the performance of the limestone aggregates from the different suppliers compare to each other?
- How does the performance of the cement treated limestone materials compare to the black base?

With these two questions in mind, TTI conducted a series of lab tests (described in Chapter 5) to characterize the performance of the materials and allow for a direct comparison between the limestone and the black base.

II. RESULTS FROM LIMESTONE AGGREGATES

Results from Untreated Materials

Table 5 shows the proportions for recombining material for sample preparation, based upon fractionation as described in Chapter 5. Table 6 presents the results for the characterization tests performed on the untreated limestone materials. The Colorado Materials aggregate has a slightly higher affinity for water, as compared to the Vulcan. This observation is evidenced by the Colorado Materials' slightly higher plasticity, higher final dielectric in the TST, and higher retained moisture content after drying in the TST.

Table 5. Fractionation Results for Recombining Limestone Aggregates.

Sieve Size	Percent Passing (Vulcan)	Percent Passing (Colorado Materials)
1 ¾ inch	100	100
1 ¼ inch	93.0	89.3
¾ inch	71.5	69.7
$^3/_8$ inch	47.0	48.0
#4	32.3	32.0

Table 6. Results from Characterization Tests on Untreated Limestone Aggregates.

Test Procedure	Vulcan Materials	Colorado Materials
Optimal molding moisture (%)	5.4	7.7
Max dry density (lb/cf)	137.1	132.4
Liquid limit	16	20
Plastic limit	12	14
Plastic index	4	6
Triaxial classification	2.5	2.5
Final dielectric after TST	12.8	14.6
Retained moisture after drying in TST (percent of initial moisture)	51.2	59.7

Results from Cement Treated Materials

Unconfined Compressive Strength

Maintenance repairs typically must be opened to traffic shortly after completion, so rapid strength gain is necessary. However, the level of cement treatment needs to be sufficient to provide adequate short-term strength without being so high as to result in an excessively stiff, brittle slab after full hydration.

Figure 32 presents the strength results with age for the Vulcan and Colorado aggregates. From the testing, the following observations are apparent:

- As expected, compressive strength increased with curing time, and higher strengths resulted from higher cement contents.
- At the same cement content, the Vulcan material always yielded higher strengths when tested after the same amount of curing time.
- Even at the lowest cement level (2 percent), both materials had strengths around 200 psi after only 24 hours curing. The Vulcan was 207 psi, and the Colorado was 164 psi.
- With 4 percent cement, both materials had strengths above 500 psi after 7 days. As discussed in the literature review, current practices are moving toward designing cement-treated base for 200 to 300 psi at 7 days cure. With 7 percent cement, strengths were in the 900 to 1400 psi range after 7 days.

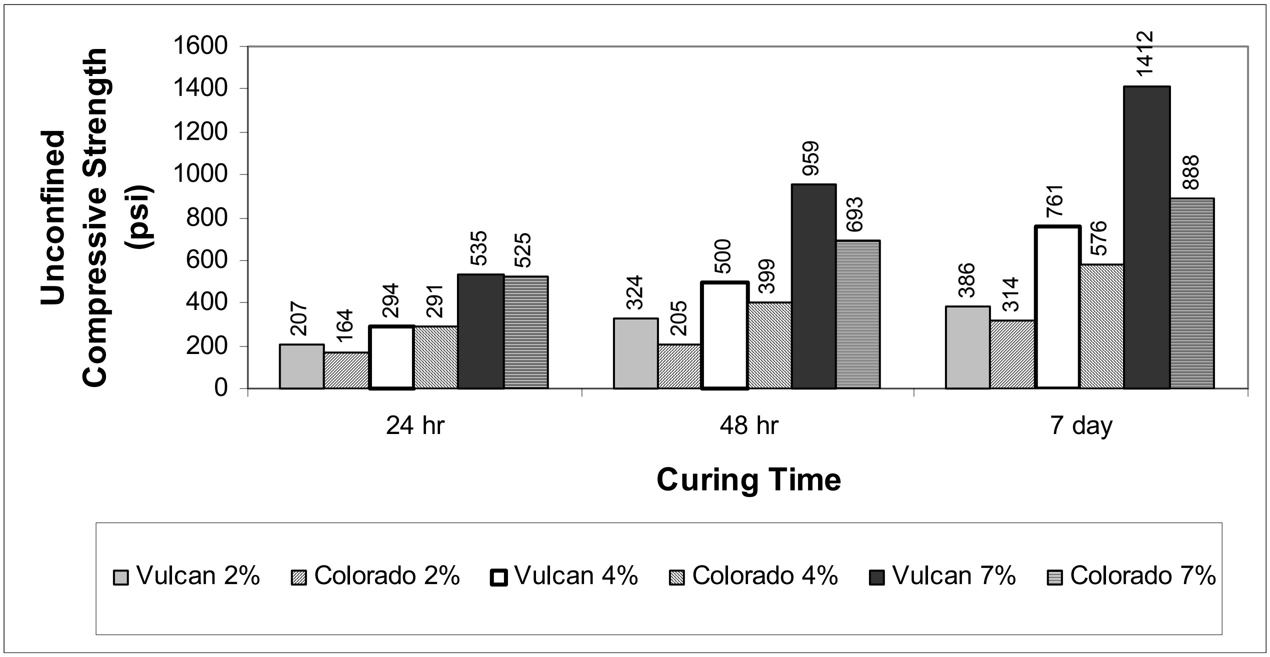

Figure 32. Strength Results for Cement Treated Bases.

Tube Suction Test

A test for moisture susceptibility, the TST has been shown to be a good indicator of how cement treated materials will perform in the traditional soil-cement durability tests, ASTM D559 and ASTM D560 (*18*). The advantage of the TST is that significantly less time and labor is required to perform the test. If the final surface dielectric of the material after the TST is less than 10, the material is expected to give superior performance in the presence of available moisture. Marginal performance is expected from materials with a final dielectric between 10 and 16, and poor performance in the presence of available water is expected when materials have a final dielectric value greater than 16 after the TST.

As shown previously in Table 6, neither of the untreated materials had a final dielectric value below 10 after the TST, meaning personnel should consider some type of treatment to improve base performance if moisture is available in field conditions. Thus, TTI tested the cement-treated materials in the TST. Figure 33 presents the results from the TST on the cement-treated specimens. The Colorado Materials aggregate required 4 percent cement before a final dielectric value less than 10 was achieved, whereas the Vulcan aggregate with only 2 percent cement had a final dielectric below 10. The greater degree of moisture susceptibility of the Colorado Materials aggregate is visually evident when contrasting Figures 34 and 35. Figure 34 shows how the height of water rise progressed all the way through the Colorado aggregate with 2 percent cement. Figure 35 illustrates that the height of water rise is only about one-half that of the sample in the Vulcan aggregate with 2 percent cement.

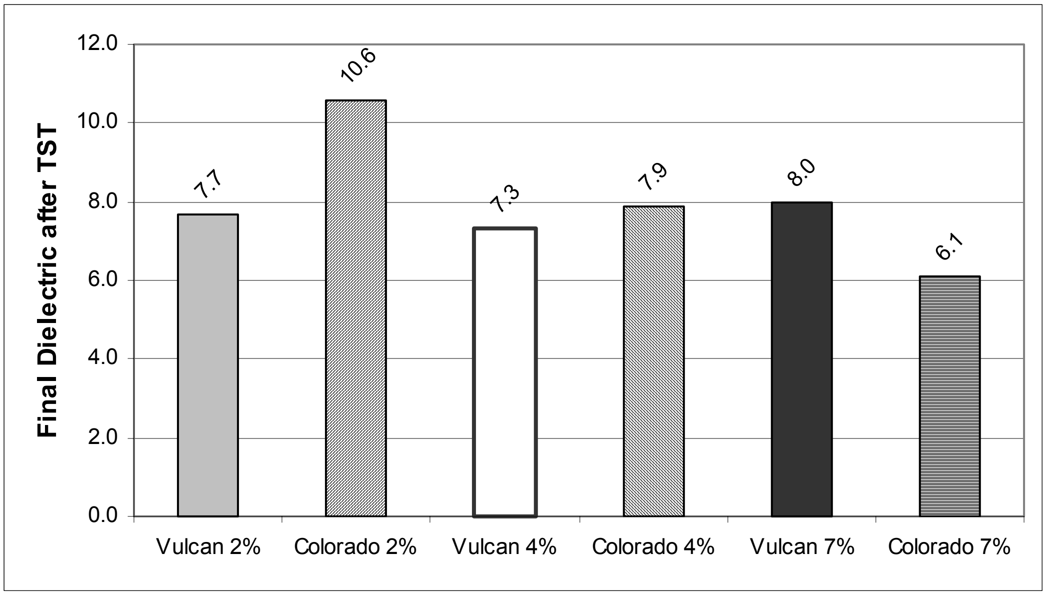

Figure 33. TST Results for Cement-Treated Materials.
Note: Each outcome is the average of two replicate specimens.

Figure 34. Representative Colorado Cement-Treated Base after the TST.
L to R: 2 percent, 4 percent, and 7 percent Type 1 Cement.

Figure 35. Representative Vulcan Cement-Treated Base after the TST.
L to R: 2 percent, 4 percent, and 7 percent Type 1 Cement.

Seismic and Resilient Modulus

A cyclic stress of 30 psi was used for the resilient modulus testing. Table 7 and Figure 36 present the results from the modulus testing. The laboratory-measured moduli for all the specimens were quite high, even at low cement contents. Typical in-service moduli values for untreated granular bases may range from around 30 to 150 ksi. Observed in-service moduli ranges of cement-treated bases may range from around 75 to 2000 ksi. Laboratory-measured resilient moduli on the cement-treated specimens ranged from 619 to 2074 ksi after 7 days cure.

As anticipated, the higher cement contents resulted in a stiffer material. In general, the modulus results were similar between the two materials. The seismic data have been found to be quite repeatable between replicate specimens; thus, the seismic results appear to indicate the Vulcan material is slightly stiffer. In contrast, results from resilient modulus typically have more spread between replicate samples; thus, the resilient data seem to indicate that after full hydration (28 days) the stiffness of the two materials is virtually identical.

The extremely high (3144 ksi) test result at 28 days on the Colorado aggregate with 4 percent cement is likely an erroneous measurement due to problems with the test setup. In the resilient modulus test a slight misalignment in how flat and true a specimen is inserted into the loading frame can result in very little movement of the sample where the LVDTs are mounted, artificially inflating the resilient modulus test result. The test result on this specimen is clearly not consistent with the general trend of the modulus results.

Table 7. Results from Modulus Testing on Cement-Treated Bases.

Specimen	7 Day Seismic (ksi)	7 Day Resilient (ksi)	28 day Resilient (ksi)
Vulcan 2%	1402	945	1044
Vulcan 4%	1830	1521	1770
Vulcan 7%	2546	1691	2098
Colorado 2%	1179	619	1134
Colorado 4%	1777	1594	3144*
Colorado 7%	2237	2074	2070

**Test setup problem suspected*

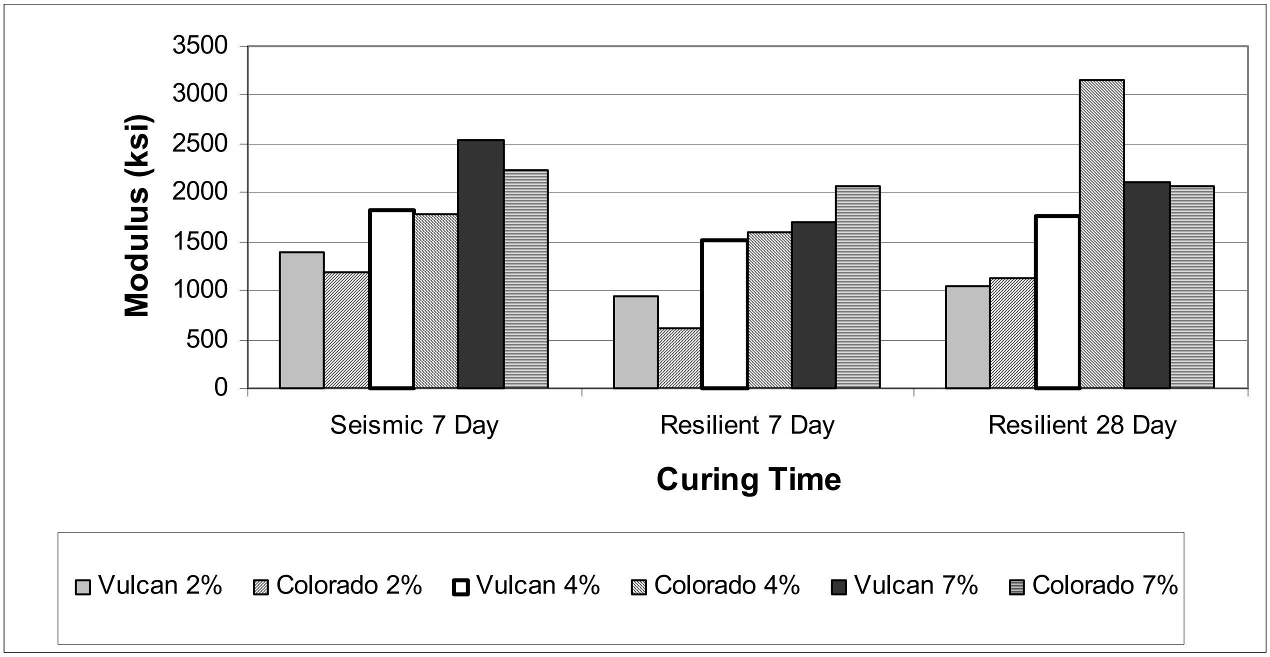

Figure 36. Comparison of Modulus Test Results for Cement-Treated Bases.

Linear Beam Shrinkage

Table 8 presents the results from the shrinkage testing. In the test, the specimens remain in a 100 percent relative humidity environment. Rather than shrinking, all the samples exhibited expansion. TTI researchers have observed similar results in previous studies. Consideration should be given to leaving the specimens in an open room, or just in a sealed bag, if similar future testing is conducted. The mechanism that may be causing the expansion is not understood.

Table 8. Beam Shrinkage Results for Cement-Treated Limestones.

Specimen	Vulcan 2%	Vulcan 4%	Vulcan 7%	Colorado 2%	Colorado 4%	Colorado 7%
Expansion (microstrain)	189	578	378	433	189	200

Hamburg Wheel Tracking

Researchers subjected cement-treated specimens to the Hamburg test in order have more data directly comparable to tests conducted on the black bases. The results, given in Table 9, indicate the Colorado aggregate is more susceptible to moisture than the Vulcan. With 4 and 7 percent cement, the Vulcan material lasted through the entire 20,000-cycle test. Only the Colorado with 7 percent cement reached the end of the test without rutting more than 0.5 inch. These results are consistent with the Tube Suction Test results on the cement-treated materials.

Table 9. Hamburg Results on Cement-Treated Limestones.

	Passes to Failure	
Percent Cement	Vulcan	Colorado
2	7301	1900
4	Did not reach failure limit	2700
7	Did not reach failure limit	Did not reach failure limit

III. RESULTS FROM BLACK BASES

Theoretical Maximum Specific Gravity

The theoretical maximum specific gravity, determined according to Tex-227-F, was measured to be:

- Seguin: 158.6 lb/cf.
- Floresville: 158.6 lb/cf.

Extent of Field Compaction

The TTI laboratory measured the air void content of cores from field sites that utilized black base in order to determine what void content laboratory specimens should be compacted to. The void content of field cores ranged from 8 to 10 percent; thus, all laboratory-prepared black base specimens were compacted to 9 percent air voids with a gyratory compactor.

Unconfined Compressive Strength

Figure 37 presents the compressive strength results from the black base testing. The elevated temperature clearly had an effect on the failure strength of the materials, resulting in a reduction in strength of 70 to 90 percent at the slow loading rates.

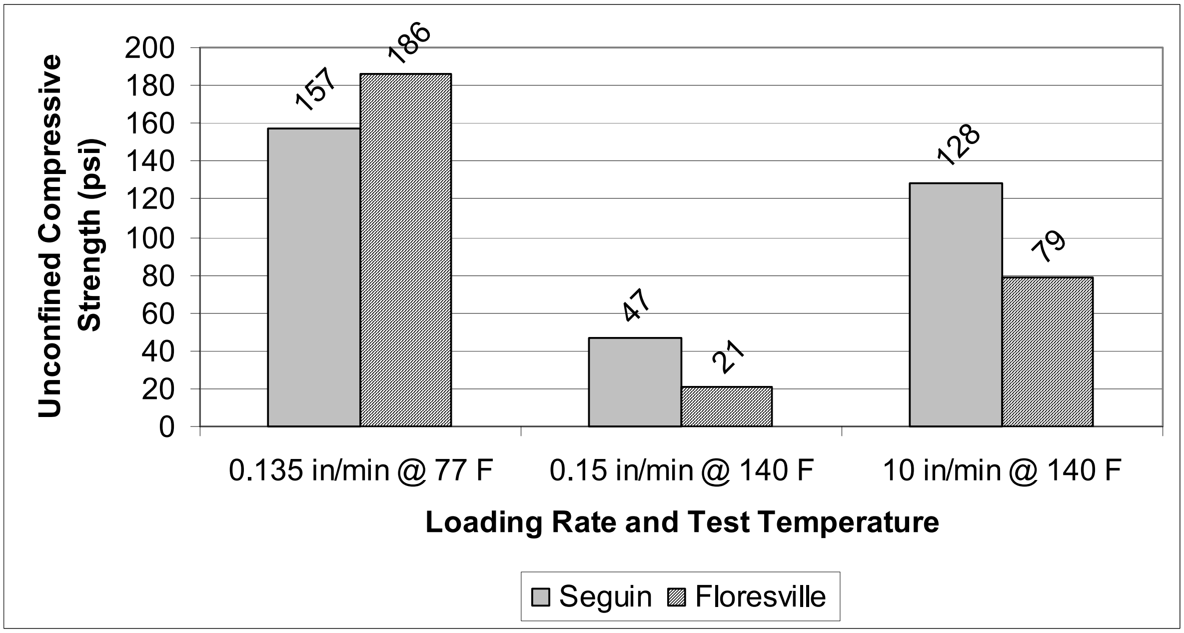

Figure 37. Strength Test Results from Black Bases.

Seismic and Resilient Modulus

Figure 38 presents the results from the modulus testing on the black bases. At 77 °F, the Floresville material was slightly stiffer than the Seguin. At 104 °F, the Floresville material had slightly lower moduli values than the Seguin. The effects of the elevated temperature are apparent, as the Seguin modulus values dropped approximately 70 percent, and the Floresville moduli dropped approximately 80 percent.

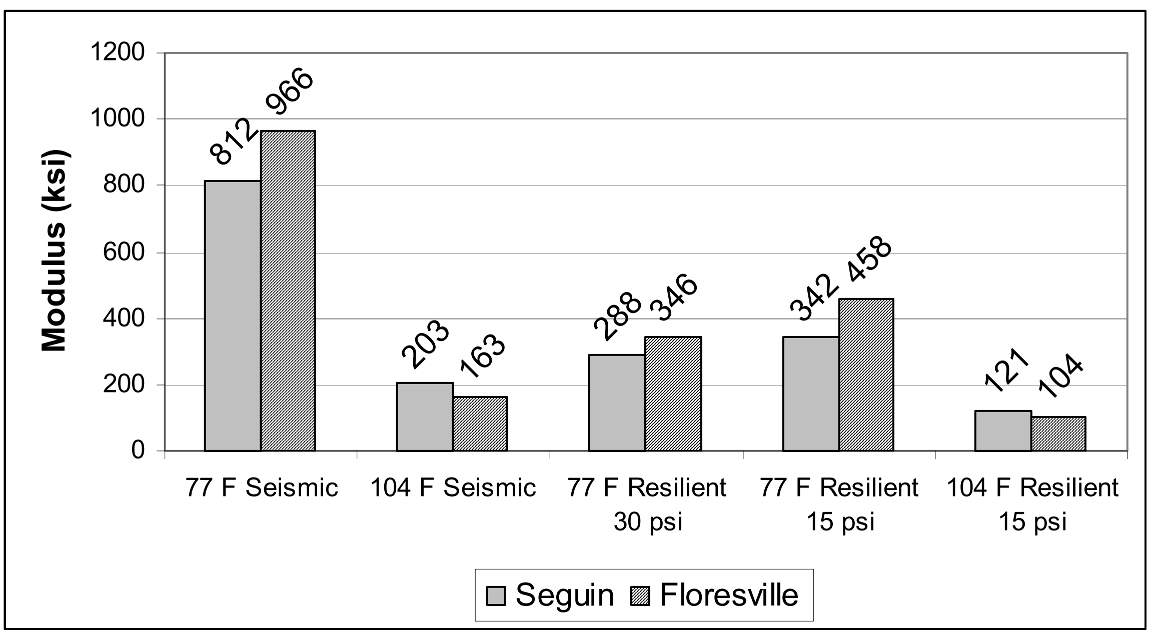

Figure 38. Modulus Results from Black Bases.

Hamburg Wheel Tracking

Table 10 presents the results from the Hamburg test on the black bases. Both the materials reached the failure limit before one-fourth of the test had been completed. Figure 39 shows a representative black base sample after the Hamburg test.

Table 10. Hamburg Results on Black Bases*.

Material	Passes to Failure
Seguin	1270
Floresville	4101

**Each result the average of two tests.*

Figure 39. Black Base after Hamburg Test.

IV. COMPARISON OF CEMENT-TREATED LIMESTONE AND BLACK BASE

Of particular interest in this project was to compare the performance of black base and cement-treated bases. Therefore, this section will contrast the results from these materials for the following tests:

- Unconfined Compressive Strength,
- Hamburg Wheel Tracking, and
- Modulus.

Unconfined Compressive Strength

Although not a traditional test for asphalt materials, the black bases were tested in an unconfined compression test at 77 ^{o}F with a loading rate of 0.135 in/min to provide results directly comparable to traditional strength testing of granular materials. Even with 2 percent cement, strengths after 24 hours curing were comparable to strengths of the black bases, and after 7 days curing the strengths of the cement-treated materials with 2 percent cement were roughly double the strengths of the black bases. Figure 40 illustrates the difference in the unconfined strength results between the materials.

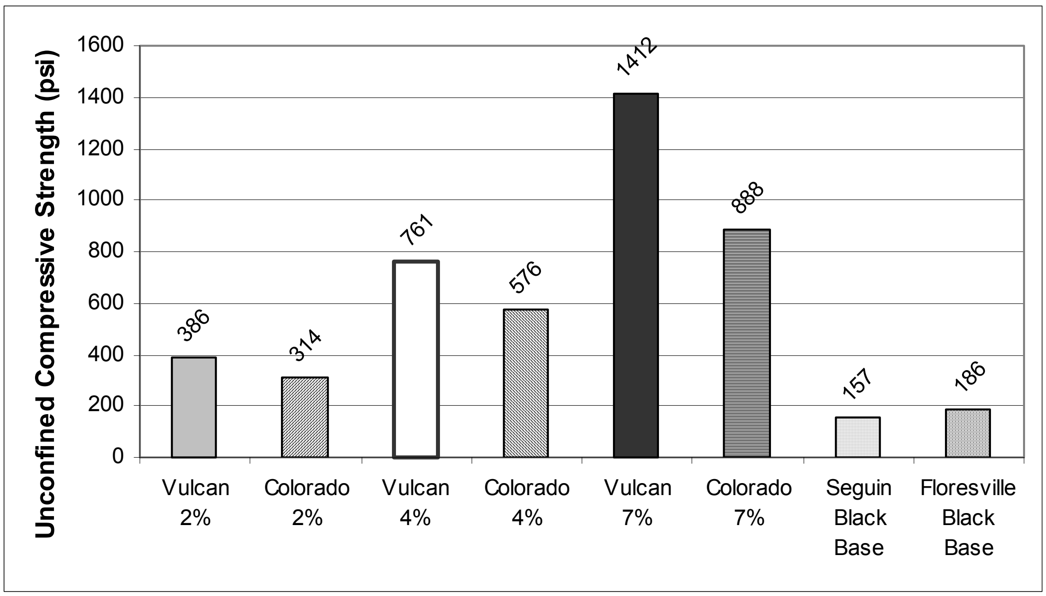

Figure 40. Comparison of Strength Results between Limestones and Black Bases.
Note: All cement-treated limestone results are after 7 days curing.

Hamburg Wheel Tracking

As evidenced from the results shown previously in Tables 9 and 10 (shown graphically in Figure 41), the Vulcan limestone performed better than either of the black bases even at 2 percent cement. The Colorado limestone performed better than the Seguin black base, but only the Colorado limestone with 7 percent cement performed better than the Floresville black base.

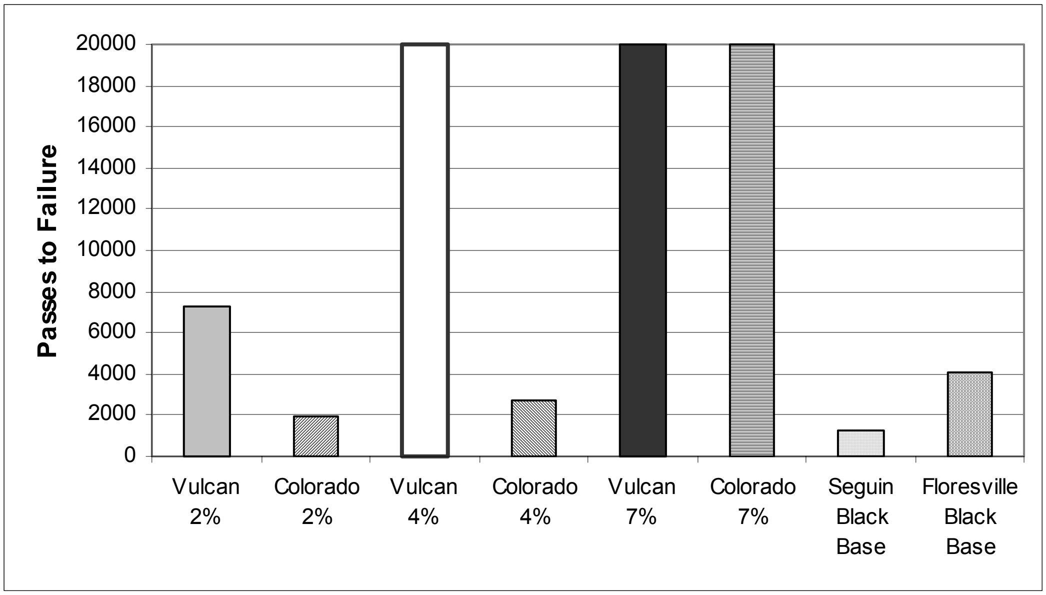

Figure 41. Comparison of Hamburg Results between Limestones and Black Bases.

Modulus

Figure 42 contrasts the modulus testing results between the cement-treated aggregates and the black bases. The cement-treated materials are of substantially higher modulus than the black bases. At room temperature and comparable deviator stresses (30 psi), the resilient modulus of the cement-treated bases with 2 percent cement were approximately 2 to 3 times greater than the modulus of the black bases. The seismic values from the cement-treated bases with 2 percent cement were 20 to 70 percent higher than the black bases. Clearly, a small amount of cement mixed in with the limestone aggregates resulted in much stiffer material than the asphalt bases.

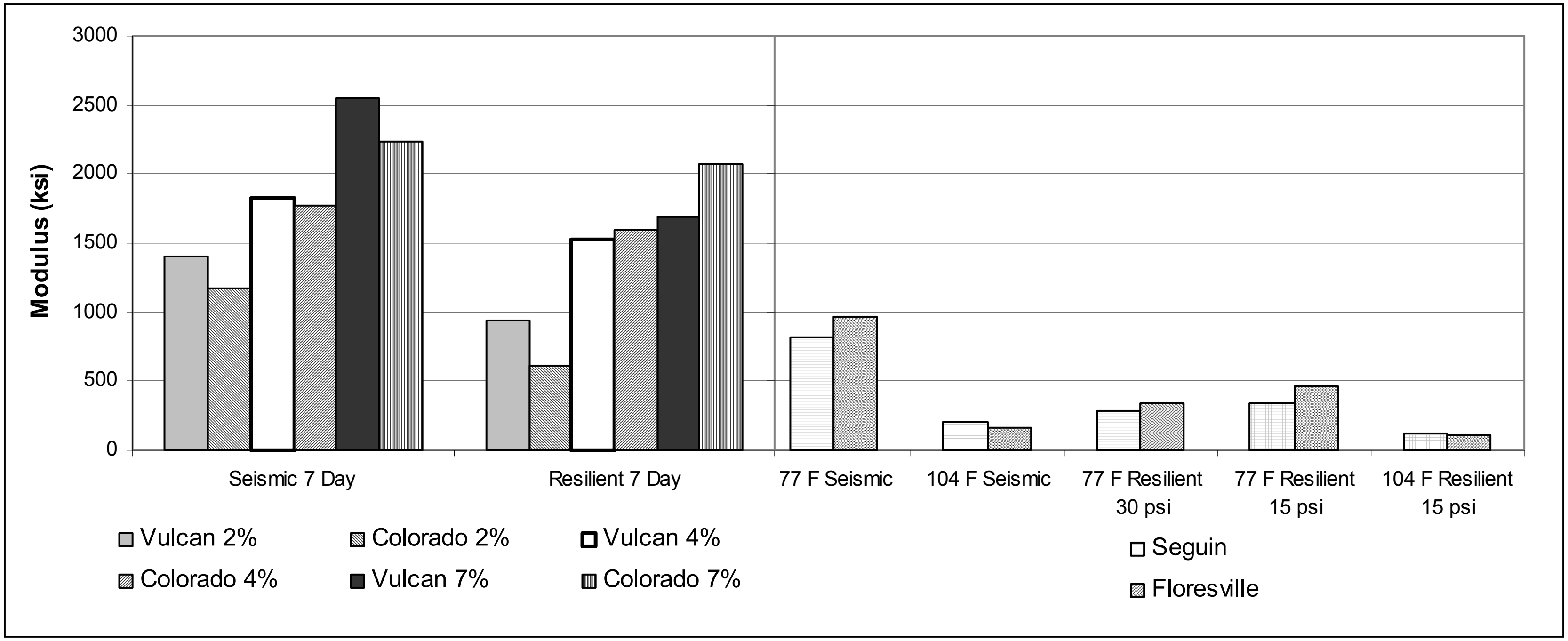

Figure 42. Comparison of Modulus between Limestones and Black Bases.

CHAPTER 7

RECOMMENDATIONS

The work conducted in the first year of this project focused on documenting the performance of existing maintenance repairs. An extensive literature search, and a survey within TxDOT, was also conducted to identify what types of maintenance treatments give good performance for various cases of pavement distress. TTI's laboratory performed a testing sequence to characterize and compare several potential base repair materials. Based upon this work, recommendations in the following areas are offered for consideration by TxDOT:

- The field guide developed in the project should be distributed.
- Regarding maintenance treatment methods, unless pavement deterioration is severe, maintenance forces should consider crack filling and sealing, rather than full-depth patches, for cases of dry-land cracking. Cement treatment of base should be considered for cases of structural problems.
- Regarding materials for base repairs, reasonable-quality aggregates treated with nominal levels of cement (2 to 4 percent) yielded good performance and in general exhibited better characteristics than the black bases tested.
- The Vulcan limestone performed slightly better than the Colorado Materials limestone.
- Field sections should be constructed utilizing the field guide to get feedback on the usefulness of the guide and to verify the effectiveness of the repair methods. In addition, trial sections with several competing geogrids/geotextiles should be constructed on sections with dry-land cracking to determine if acceptable performance can be obtained with less costly grids/textiles.

I. DISTRIBUTE FIELD GUIDE FOR MAINTENANCE TREATMENTS

From the literature review and TxDOT district survey, TTI researchers assembled a field guide to assist maintenance personnel in determining the cause of pavement distress and selecting a treatment. This guide, also included in this report as Appendix D, should be distributed among Maintenance Section supervisors for use. Based upon their feedback, the guide should be revised as deemed appropriate at the end of the second year of this research project.

II. MAINTENANCE TREATMENT METHODS

Regarding maintenance treatment methods, the field observations conducted during the first year of this project indicate crack filling and sealing is generally as effective as conventional full-depth repairs in sections exhibiting longitudinal cracking. The longitudinal cracks generally reoccur through full-depth patches within a short time frame. Similarly, surface treatments, such as blade-on patches and overlays, do not address the cause of the cracking. Cracking generally reflects through these surface treatments rather quickly (6 months to 2 years). Thus, given the similar time frame to reoccurance of cracking between conventional full-depth rehabilitation and surface treatments, little incentive exists to use the more time-consuming and costly full-depth repair unless pavement deterioration is substantial (such as significant edge breakup). The best observed performance of treatments for longitudinal cracking was from sections in the Bryan District. These sections used geogrid reinforcement to provide a barrier to stop the cracking from propagating all the way through the pavement surface.

For structural repairs, sections repaired with cement-treated materials appear to have yielded the best performance. The sites examined indicate good performance can be obtained with small amounts of cement added to the existing or replacement base. At the section examined where asphalt base was used, maintenance personnel reported problems continued, and numerous patches have been placed within the patched section. However, the section was not what would be considered a full-depth patch with black base. Rather, cold-laid asphalt was placed on top of the existing base. Regardless, maintenance personnel interviewed indicated they often have problems with asphalt base and try to avoid its use if possible.

III. MATERIALS FOR MAINTENANCE REPAIRS

A laboratory-testing phase of this project characterized two cement-treated limestone aggregates and two black bases, both provided by the San Antonio District. The Vulcan limestone performed well in all tests with only 2 percent Type 1 cement. The Colorado Materials limestone was slightly more susceptible to moisture but still performed acceptably with only 2 percent cement. Compared to the black bases, the cement-treated aggregates are substantially stronger and stiffer, even at low levels of cement. In the Hamburg test (traditionally for asphalt materials), the Vulcan limestone with 2 percent cement fared better than either of the black bases. In contrast, the Colorado limestone with 2 percent cement performed better than the Seguin black base, but required 7 percent cement before surpassing the performance of the black base from the Floresville office.

Overall, the laboratory test results indicate that approximately 2 percent cement should be an adequate level of treatment for reasonable quality limestone aggregates. No gravels were tested in this project, but previous testing performed at TTI indicates slightly higher levels of treatment may be required with the gravel materials to obtain target strength levels.

IV. CONDUCT TEST SECTIONS

Test sections should be constructed utilizing the field guide in the treatment selection process. This activity would provide feedback on the usefulness of the guide and help identify ways in which the guide could be improved before the final printing. Field performance of the test sections could be monitored to verify the effectiveness of the repair methods. TxDOT should also conduct test sections on locations of dry-land cracking using geogrid or geotextile reinforcement. Longitudinal cracking is one of the most likely distresses over highly plastic soils. Work in the Bryan District indicates using the geogrid reinforcement results in much improved performance when compared to traditional full-depth reclamation. However, geosynthetics exist that are less costly than the Tenax grid used in the Bryan District. Sections should be constructed to test whether similar performance can be obtained with the less costly textiles and grids.

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APPENDIX A

FREQUENCY INDICES FROM DISTRICT SURVEY

Excessive Roughness

	Frequency Index	Replies	"Other" Responses
Material			
Cold mix (placed cold)	3.2	47	
Cold mix (placed hot)	0.2	43	
Hot mix asphalt	1.7	46	
Asphalt impregnated base	0.8	45	
Cement treated base	2.0	43	
Lime treated base	0.5	44	
Existing base milled with existing surface	1.3	44	
Geogrids or fabrics under the base	0.1	42	
Vertical moisture barriers	0.1	43	Similar to others
Other	2.5	6	methods.
Surfacing			
Do nothing, smooth with cold mix	2.7	45	
Do nothing, smooth with hot mix	1.4	43	
Mill off irregularities	1.4	44	
Bomag with base, place as base course, cover with cold mix	0.7	44	Several Bomag with base and cover with seal
Bomag with base, place as base course, cover with hot mix	0.9	43	coat or course treatment. One cement treat
Other	2.0	15	flexbase.
Base Treatment			
Do nothing	0.6	36	
Treat with lime	0.5	40	
Treat with cement	1.8	43	
Excavate, replace with untreated granular base	0.7	37	
Excavate, replace with lime treated base	0.2	37	
Excavate, replace with cement treated base	1.7	43	
Excavate, replace with cold mix	0.8	39	
Excavate, replace with hot mix	0.6	38	
Excavate, replace with asphalt impregnated base	1.4	38	
Mill together with surfacing then compact	0.6	39	
Mill together with surfacing, treat with lime, compact	0.4	37	
Mill together with surfacing, treat with cement, compact	1.2	40	Similar to other
Other	1.5	4	methods.
Subgrade Treatment			
Do nothing	1.5	38	
Treat with lime	0.6	38	
Treat with cement	1.6	38	
Excavate do certain depth, replace with granular base	1.5	42	
Excavate do certain depth, replace with asphalt	1.1	40	Replace with asphalt or cement impregnated
Other	1.7	6	base.
Other Treatment			
Install geogrid or fabric between subgrade and base	0.1	37	
Install vertical moisture barrier	0.1	36	
Other	1.0	3	All install french drains.

Longitudinal Cracking

	Frequency Index	Replies	"Other" Responses
Material			
Cold mix (placed cold)	2.7	36	
Cold mix (placed hot)	0.3	33	
Hot mix asphalt	1.2	34	
Asphalt impregnated base	1.2	33	
Cement treated base	1.8	35	
Lime treated base	0.4	34	Full depth pavement
Existing base milled with existing surface	1.1	37	repair.
Geogrids or fabrics under the base	0.0	33	Stablize shoulder to
Vertical moisture barriers	0.1	33	prevent pushing of edge.
Other	3.0	5	Crack seal.
Surfacing			
Do nothing, smooth with cold mix	2.1	36	
Do nothing, smooth with hot mix	1.0	35	
Mill off irregularities	0.8	31	
Bomag with base, place as base course, cover with cold mix	0.4	34	Fill cracks and cover
Bomag with base, place as base course, cover with hot mix	0.9	34	with mix. Crack seal.
Other	3.6	12	Cement treat flexbase.
Base Treatment			
Do nothing	1.0	30	
Treat with lime	0.4	31	
Treat with cement	1.7	33	
Excavate, replace with untreated granular base	0.9	30	
Excavate, replace with lime treated base	0.1	29	
Excavate, replace with cement treated base	1.9	35	
Excavate, replace with cold mix	0.7	30	
Excavate, replace with hot mix	0.7	29	
Excavate, replace with asphalt impregnated base	1.4	30	
Mill together with surfacing then compact	0.2	29	
Mill together with surfacing, treat with lime, compact	0.2	30	
Mill together with surfacing, treat with cement, compact	1.1	33	Similar to other
Other	2.0	2	methods.
Subgrade Treatment			
Do nothing	1.6	32	
Treat with lime	0.5	28	
Treat with cement	1.4	31	
Excavate do certain depth, replace with granular base	1.5	33	
Excavate do certain depth, replace with asphalt	1.6	31	Similar to other
Other	2.7	3	methods.
Other Treatment			
Install geogrid or fabric between subgrade and base	0.0	30	French drains and ditch
Install vertical moisture barrier	0.1	28	repair. Crack
Other	2.8	5	seal.

Fatigue Cracking

	Frequency Index	Replies	"Other" Responses
Material			
Cold mix (placed cold)	1.8	45	
Cold mix (placed hot)	0.1	41	
Hot mix asphalt	1.7	45	
Asphalt impregnated base	0.6	40	
Cement treated base	1.7	41	
Lime treated base	0.3	40	
Existing base milled with existing surface	1.1	43	
Geogrids or fabrics under the base	0.0	40	
Vertical moisture barriers	0.1	39	Many spot seal or seal
Other	3.0	17	coat.
Surfacing			
Do nothing, smooth with cold mix	1.8	40	Several spot seal or seal
Do nothing, smooth with hot mix	1.0	37	coat. Several
Mill off irregularities	0.5	34	mill and inlay with HMCL or HMHL.
Bomag with base, place as base course, cover with cold mix	0.4	39	Blade out cracks and replace with mix.
Bomag with base, place as base course, cover with hot mix	0.7	38	Fix soft spots in base
Other	3.3	28	with HM.
Base Treatment			
Do nothing	1.0	40	
Treat with lime	0.3	38	
Treat with cement	1.5	40	
Excavate, replace with untreated granular base	0.8	39	
Excavate, replace with lime treated base	0.3	39	
Excavate, replace with cement treated base	1.7	42	
Excavate, replace with cold mix	0.5	39	
Excavate, replace with hot mix	0.9	39	
Excavate, replace with asphalt impregnated base	1.5	40	
Mill together with surfacing then compact	0.4	38	
Mill together with surfacing, treat with lime, compact	0.4	39	
Mill together with surfacing, treat with cement, compact	0.9	41	Similar to other
Other	5.0	1	methods.
Subgrade Treatment			
Do nothing	1.7	43	
Treat with lime	0.7	39	
Treat with cement	1.4	39	
Excavate do certain depth, replace with granular base	1.3	42	
Excavate do certain depth, replace with asphalt	1.2	42	Replace with black base
Other	3.8	5	or cement treated base.
Other Treatment			
Install geogrid or fabric between subgrade and base	0.0	37	Seveal spot seal. Mill and inlay.
Install vertical moisture barrier	0.1	36	Address drainage
Other	2.3	10	problems.

APPENDIX B

CORE RESULTS FROM FIELD SITES

FM 1818 Hole #1

Depth (in.)	PI	General description
0-7	---	Surface
8.5-13	10	gray sandy clay
13-16	9	tan clayey sand
16-20.5	10	tan clayey sand

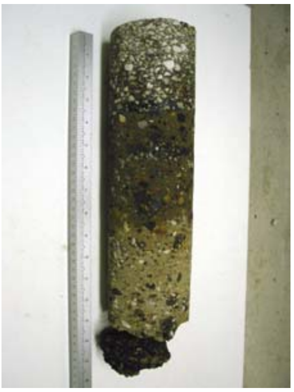
FM 1818 Hole #2

Depth (in.)	PI	General description
0-2	---	Surface
2-10	--	Base
10-15	6	tan and gray clayey sand
15-18.5	11	gray sandy clay
18.5-22	6	tan and gray clayey sand
22-26.5	9	tan clayey sand

FM 1818 Hole #3

Depth (in.)	PI	General description
0-2	---	Surface
2-5	---	black base
5-11.5	---	Subgrade
11.5-16	8	tan clayey sand
16-20	8	tan clayey sand

FM 226 Hole #1

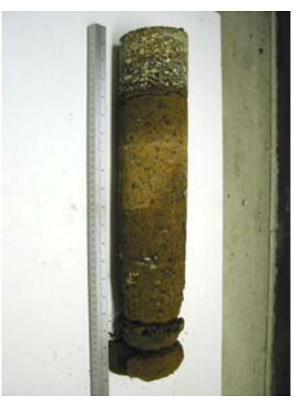


Depth (in.)	PI	General description
0-3.5	---	Surface
3.5-14	---	CTB
14-16	---	old road surface
16-21	6	reddish tan and gray clayey sand
21-29	19	sand at top and reddish clay at bottom
29-34	53	reddish tan and gray fat clay
34-38	32	reddish tan and gray clay

FM 226 Hole #2

Depth (in.)	PI	General description
0-2.5	---	Surface
2.5-12.5	---	CTB
12.5-18	4	brown clayey sand
18-22	4	brown clayey sand

FM 226 Hole #3



Depth (in.)	PI	General description
0-2	---	new surface
2-4	---	old surface
4-17	---	CTB
17-21	---	old road surface
21-29	13	reddish sandy clay with gravel
29-33	18	reddish sandy clay
33-36	15	reddish sandy clay

FM 2076 Hole #1

Depth (in.)	PI	General description
0-1	---	Surface
1-11	---	CTB
11-18	---	Subgrade
18-24	48	tan clay

FM 2076 Hole #2

Depth (in.)	PI	General description
0-1	---	Surface
1-12	---	CTB
12-17	9	reddish tan clayey sand with gravel
17-22	29	reddish tan sandy clay
22-27	40	tan and gray clay

FM 20 Hole #1

Depth (in.)	PI	General description
0-1	---	Surface
1-11	---	Base
11-17	26	brown and gray clay
17-22	24	dark gray clay
22-24	13	tan sandy clay with limestone rocks
24-26	12	tan sandy clay with limestone rocks
26-29	14	tan sandy clay with limestone rocks
29-32	21	tan and brown sandy clay

FM 20 Hole #4

Depth (in.)	PI	General description
0-1	---	Surface
1-16	---	Base
16-20.5	25	brown clay
20.5-24	30	brown clay
24-27	20	brown sandy clay with small limestone rocks

FM 541 Hole #1

Depth (in.)	PI	General description
0-1	---	Surface
1-13.5	---	Base
13.5-15	---	old road surface
15-19	15	brown clayey sand
19-23	12	brown sandy clay
23-27.5	10	brown clayey sand

FM 541 Hole #4

Depth (in.)	PI	General description
0-2	---	Surface
2-14	---	Base
14-19	13	brown sandy clay
19-25	15	brown sandy clay
25-31	28	dark greay clay

FM 2505 SB Hole #1

Depth (in.)	PI	General description
0-2	---	Surface
2-7	---	CTB
7-14.5	---	Subgrade
14.5-20	7	reddish tan clayey sand
20-25	12	tan clayey sand
25-30	16	brown and tan sandy clay
30-35	14	dark gray and tan sandy clay

FM 2505 SB Patch

Depth (in.)	PI	General description
0-0.5	---	surface
0.5-14	---	CTB
14-19.5	12	reddish tan clayey sand with small gravel
19.5-24	17	reddish tan clayey sand
24-29	10	reddish tan clayey sand

APPENDIX C

FWD BACKCALCULATIONS

Road	Location	Surface Modulus (ksi)	Base Modulus (ksi)	Subgrade Modulus (ksi)	Absolute Error per Sensor (%)
FM 226	Blade-on patch (hole 1)	240	212	11	6.2
FM 226	Existing by long. crack (hole 2)	200	793	9.4	0.8
FM 226	Blade-on patch (hole 3)	250	211	13	5.3
FM 2076	Existing (hole 1)	200	1175	11	1.57
FM 2076	Patch near hole 2	200	946	8	4.3
FM 2076	Patch near hole 2	200	834	8	2.2
FM 2076	Patch near hole 3	200	1043	8	1.4
FM 2076	Patch near hole 3	200	828	9	2.2
FM 20	Existing (hole 1)	200	57	12	4.4
FM 20	Existing	200	114	15	5.7
FM 20	Existing	200	41	14	2.8
FM 20	Patch (hole 4)	200	103	12	1.5
FM 20	Patch	200	74	14	2.7
FM 20	Existing	200	47	9	2.0
FM 541	Existing near hole 1	200	38	6	8.5
FM 541	Patch near hole 4	103	9	10	1.4
FM 541	Patch (hole 4)	174	14	9	2.3
FM 541	Patch near hole 4	99	22	10	3.6

APPENDIX D

FIELD GUIDE FOR MAINTENANCE REPAIRS

SELECTION OF MAINTENANCE REPAIR METHODS ON EXPANSIVE SUBGRADES

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- Gary Charlton, P.E.
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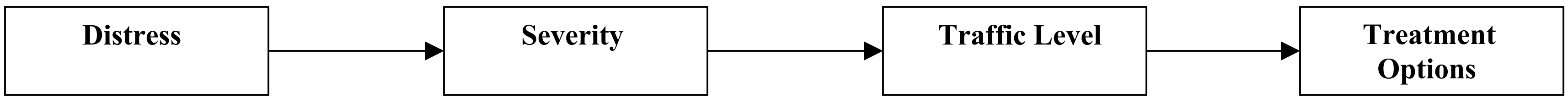
- Harry Thompson, P.E.

Preface

This manual is designed to assist TxDOT Maintenance Section Supervisors in the selection of an appropriate maintenance treatment for pavement distresses over expansive subgrade soils. In expansive soil environments, distresses such as roughness, longitudinal cracking, and fatigue cracking may frequently be encountered; therefore, this manual will focus on these distresses. A section on rutting also is included. This manual was compiled based upon the responses of a multi-district survey within TxDOT, interviews with district personnel, observations of field performance of various repair methods, and review of existing published guidelines and manuals relevant to pavement rehabilitation.

How to Use This Manual

The sections of this manual use the observed primary distress as the starting point for guidance regarding maintenance treatment selection. Thus, if fatigue cracking is the primary distress at the site, the fatigue cracking section of the manual should be referenced. Within each section, a brief definition of the distress is given, along with some possible causes of the distress and simple techniques to investigate the cause of the distress. A decision matrix is then presented to assist personnel in choosing an appropriate repair technique. The following flowchart illustrates the basic steps used in each matrix:



The matrices are designed to flow from left to right, where the first row contains prompts relevant to the pavement condition to respond to, and the columns contain responses to choose from. A brief discussion on issues specific to the distress wraps up each section. The last section of this manual provides some tips on constructing successful full-depth repairs.

When using this guidebook, keep in mind consideration must be given to factors other than what is the "best" treatment. For example, a temporary treatment may be needed to minimize safety hazards until time and/or funding allows for a more appropriate repair. In some circumstances, such as low-severity or medium-severity cracking on a low-volume road, personnel may elect to not apply any treatment at all until the pavement condition worsens, even though a seal coat or crack seal would eliminate moisture flow into the pavement and slow the rate of deterioration. Thus, care must be taken to use the decision charts only as general guides to assist in decision-making, not cookbook formulas applicable to every situation encountered.

Definitions

Most terms are specific to each distress and are self-explanatory or are explained in each section. However, the traffic level/importance of the road is a factor considered in all sections, and thus an example of each category considered is given here:

- Low: A low-volume FM road
- Medium: A high-volume FM road, a state highway, or a US highway
- High: A high-volume US highway or interstate

ROUGHNESS

Definition: Roughness is the lack of smoothness in the longitudinal or transverse profile, resulting in poor vehicle ride quality.

Roughness

Likely Causes: Volume changes in underlying layers (such as subgrade), physical distresses (rutting, corrugations, slippage of HMA, failures, etc.)

Investigative Methods: If roughness is present and physical distresses are absent or minimal, a volume change in materials is likely responsible. Sampling and testing the subgrade for plasticity will validate whether the subgrade is the probable cause. Highly plastic clay subgrades (plastic index >35) often cause roughness due to swelling and shrinking. If the subgrade is found to not be highly plastic, poor construction or consolidation of material due to construction (density) problems could be responsible for the observed roughness. If roughness is due to physical distress, refer to the relevant section on the observed physical distress. If excessive roughness is present in sections with lime treated subgrade soils, testing should be conducted for lime-induced sulfate heave. Simple tests are available from the District Pavement Engineer.

General Maintenance Treatment Options: Blade-on patch to smooth the ride, milling (if sufficient surfacing is present), thin HMA overlay, full depth patch.

Decision Matrix: The decision guidelines for roughness assume movement of subsurface material is causing the distress. If the roughness is from physical distresses, the sections on that distress should be referenced.

Roughness

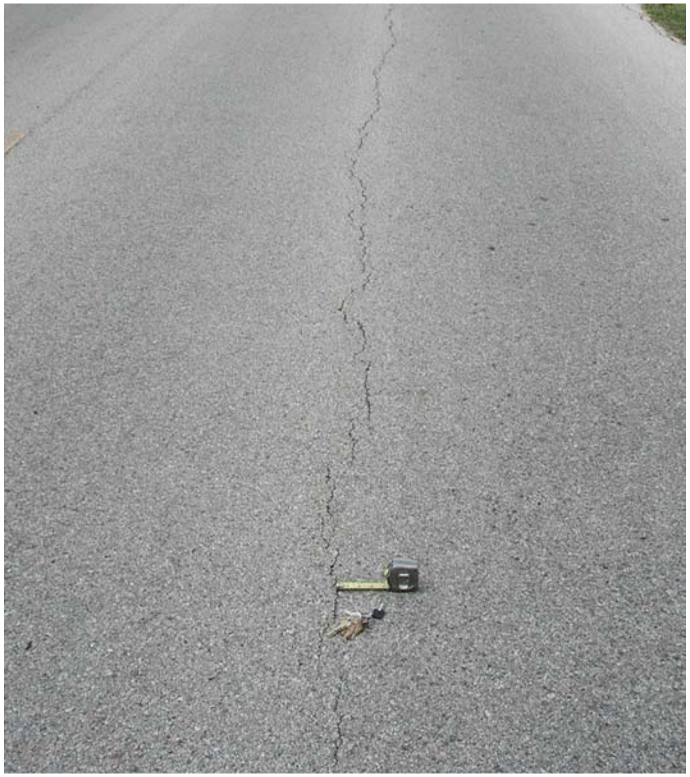
Caused by Physical Distress	Severity	Traffic Level	Treatment Options
Yes			see section on physical distress present
No	Low (wavy but no driver discomfort and no hazard present)	Low	do nothing and monitor
		Medium	do nothing and monitor
		High	do nothing and monitor
	Medium (some driver discomfort when driving speed limit)	Low	blade on patch
		Medium	blade on patch; mill to profile; HMA level-up
		High	mill to profile; HMA level-up; full-depth reconstruction
	High (driver discomfort and difficult to drive; requires reduced speed)	Low	blade on patch or reconstruction
		Medium	reconstruction with subgrade treatment; contact Area or District Engineer *
		High	reconstruction with subgrade treatment; contact Area or District Engineer *

* Perform sulfate test and test for organic matter before lime treatment

Additional Information: Roughness due to environmental factors, such as subgrade shrinkage and swelling, will generally reappear unless action is taken to minimize volume changes in the soil. For example, lime treatment of highly plastic subgrade, vertical moisture barriers, or sealing of shoulders can reduce the risk of a reoccurrence of roughness. Action may be necessary to improve drainage conditions, such as installation of French drains. In some cases isolated roughness could be the result of heaving of the subgrade soil. This heaving can occur when lime or cement treatment is applied to sulfate rich material. Such heaves typically occur shortly after construction, but in some cases heaving may occur after a heavy rain several years after construction. Personnel should contact their District Pavement Engineer if sulfate-related heave is suspected. Prior to any lime stabilization, the material should be tested for sulfates and organic matter.

LONGITUDINAL CRACKING

Definition: Longitudinal cracks are breaks in the pavement surface that generally follow a course approximately parallel to the pavement centerline.



Low Severity Longitudinal Cracking

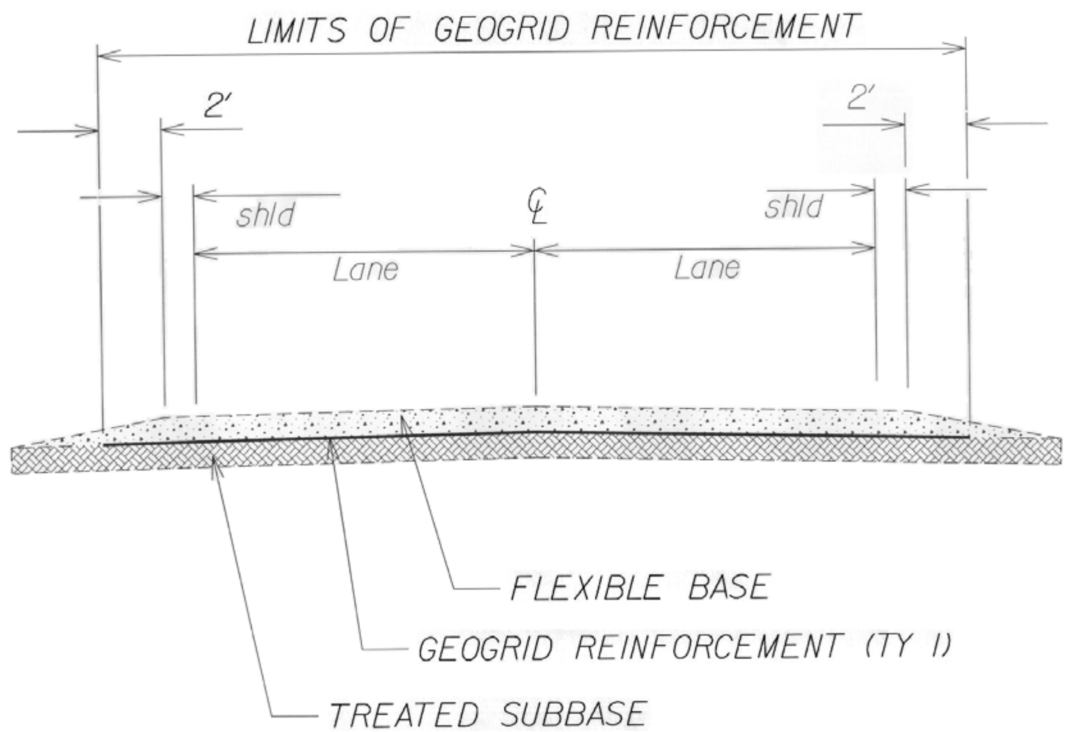
Medium Severity Longitudinal Cracking

High Severity Longitudinal Cracking

Likely Causes: Longitudinal cracks can be load or non-load related. Load-related cracks are in the wheel paths and are early signs of fatigue cracking. Non-load related cracks typically result from highly plastic subgrade material. These cracks meander and often occur near the pavement edge in expansive soil environments. In some cases a lack of edge support and/or weak and wet subgrades result in faulting of these cracks.

Investigative Methods: Observe the location of the cracking. Cracks confined to the wheel paths are likely early stages of fatigue cracking, and thus refer to the section on low-severity fatigue cracking. If the cracking is not confined to the wheel paths, sampling and testing the subgrade for plasticity will validate whether the subgrade is a probable cause. Longitudinal cracks often result from edge drying during drought conditions in highly plastic (plastic index > 35) soils. Steep side slopes and shrubs and trees near the pavement edge can also aggravate problems with longitudinal cracks.

General Maintenance Treatment Options: Crack seal, crack fill and seal, blade-on patch (when faulting is present), seal coat or overlay, reconstruct or recycle utilizing geogrid reinforcement. The geogrid reinforcement method utilizes a synthetic grid placed between a layer of stabilized base and a thin layer of flexible base as shown in the figure on the next page. A thin surfacing placed on top of the flex base seals the pavement. The geogrid has shown promising results for effectively stopping dry land cracks from reflecting through the pavement surface.



Geogrid Reinforcement for Reducing Longitudinal Cracking through the Pavement Surface
Schematic courtesy of Darlene Goehl, P.E.

Decision Matrix: The matrix for longitudinal cracking automatically puts faulted cracks into the high-severity category to be consistent with the TxDOT Pavement Management Information System (PMIS) severity definition. However, some faulted locations will be more distressed than others; thus the listed surface treatments for faulted cracks should only be considered for less severe faulted cracks (elevation drops of 0.5 inch or less).

Longitudinal Cracking

Load Related	Faulted	Severity	Traffic Level	Treatment Options
Yes				See Fatigue Cracking Section
No	Yes	High	Low	crack fill/seal with blade level-up; reconstruct/recycle with geosynthetic reinforcement
			Medium	crack fill/seal with blade level-up; reconstruct/recycle with geosynthetic reinforcement
			High	crack fill/seal with HMA level-up and contact Area or District Engineer
	No	Low (mostly tight; difficult to see except after rain or on careful inspection)	Low	do nothing and monitor
			Medium	crack seal; seal coat
			High	crack seal; thin HMA overlay
		Medium (Open, < 1/2" opening; if edge cracking some disintegration occurring)	Low	crack fill/seal; reconstruct/recycle with geosynthetic reinforcement; if edge cracking reconstruct edge
			Medium	crack fill/seal; reconstruct/recycle with geosynthetic reinforcement; if edge cracking reconstruct edge
			High	crack fill/seal; reconstruct/recycle with geosynthetic reinforcement; if edge cracking reconstruct edge
		High (> 1/2" opening; if edge cracking considerable breakup occurring)	Low	crack fill/seal; reconstruct/recycle with geosynthetic reinforcement; if edge cracking reconstruct edge
			Medium	crack fill/seal; reconstruct/recycle with geosynthetic reinforcement; if edge cracking reconstruct edge; contact Area or District Engineer
			High	crack fill/seal; if edge cracking reconstruct edge; contact Area or District Engineer

Additional Information: In general, field observations reveal that crack filling and sealing has proved as effective as full-depth patching utilizing conventional methods. The life of treatments where cracks are filled and sealed is typically around 2 years. Investigations have shown that longitudinal cracks generally reoccur within a short time frame (6 months to 2 years) after conventional full-depth repairs. Likewise, cracks typically reoccur through surface treatments within a short time frame, although thin HMA overlays generally give better performance as compared to blade-on patches or seal coats. The short life of the full-depth repairs and surface treatments occurs because such repairs do not address key factors such as the subgrade and edge support. If a full-depth repair is performed, methods currently being used in the Bryan District utilizing geogrid reinforcement to prevent cracking from reflecting through the surface should be used. For more severe cases of distress, drainage improvements may need to be made, such as the installation of French drains. Extending the width of the roadway, raising up steep side slopes, and sealing shoulders should also help minimize the risk of reoccurrence of longitudinal and edge cracks.

FATIGUE CRACKING

Definition: Fatigue cracking ("alligator cracking") is a series of interconnected cracks caused by failure under repeated traffic loading.

Low Severity Fatigue Cracking

Medium Severity Fatigue Cracking

High Severity Fatigue Cracking

Likely Causes: Typically fatigue cracking is load related and results from structural problems such as a weak base or subgrade or inadequate surface structure. Occasionally situations are encountered where fatigue cracking is not load related but caused by problems with the HMA surfacing, such as asphalt cement properties, segregation of the HMA, or debonding of layers.

Investigative Methods: Fatigue cracking observed along with rutting generally indicates a structural problem. A simple and quick way to investigate if a structural problem exists is with the dynamic cone penetrometer (DCP). The results of a few tests on the distressed wheel paths should be compared with test results from an area of the pavement wheel path that is not distressed. If the rate of penetration is significantly greater in the distressed area, structural problems exist. If test results are the same between distressed and non-distressed locations, the problem is likely in the HMA surfacing and not structural. Fatigue cracking observed without any rutting typically requires further investigation and could be caused by HMA properties, segregation of the HMA, or layer debonding. Distresses caused by segregation of HMA will typically occur at regular intervals along the road and often are accompanied by a noticeable dip when riding the section. Coring can be used to examine the condition of the base and the state of bonding between the surfacing and base. The District Pavement Engineer can be contacted to assist in identifying the problem if extensive cracking is observed but no rutting is present.

If in doubt, conduct repairs assuming the problem is structural. Fatigue cracking on roads that are only seal coated should be considered structural.

General Maintenance Treatment Options: A wide assortment of treatments can be used on fatigue cracking, ranging from seal coats to reconstruction, depending on the severity of the distress and whether the cracking is a structural problem. A full-depth repair is needed for fatigue cracking when structural deterioration exists, possibly with an increase of the base thickness.

Decision Matrix: No options are given in the non-structural category for low-volume roads, since these lower importance roadways will typically only have seal coat surfaces and thus fatigue cracking on low-volume roads should be considered structural.

Fatigue Cracking

Structural	**Severity**	**Traffic Level**	**Treatment Options**
Yes	Low (early stages; appears similar to longitudinal cracks with very few interconnected cracks)	Low	monitor
		Medium	seal coat or full-depth patch
		High	full-depth patch to solid material
	Medium (a network of cracks with a fair amount of connected cracks)	Low	full-depth patch to solid material
		Medium	full-depth patch to solid material
		High	full-depth patch to solid material
	High (extensive interconnected cracking; popouts or failures likely)	Low	full-depth patch to solid material
		Medium	full-depth patch to solid material
		High	full-depth patch to solid material
No	Low (early stages; appears similar to longitudinal cracks with very few interconnected cracks)	Medium	crack seal and monitor
		High	crack seal and monitor
	Medium (a network of cracks with a fair amount of connected cracks)	Medium	replace surface with new HMA or thin HMA overlay
		High	replace surface with new HMA or thin HMA overlay
	High (extensive interconnected cracking; popouts likely)	Medium	replace surface with new HMA
		High	replace surface with new HMA

Additional Information: The optimal treatment for fatigue cracking distress is partially dependent on what, if any, upcoming rehabilitation work is planned for the road. For example, if reconstruction or full-depth recycling of the pavement is planned for the near future (6 months to 1 year), a seal coat or thin HMA overlay may adequately serve as a temporary fix. However, if an overlay is planned for the near future, a full-depth patch is warranted. If cracking is due to debonding of the HMA surface, the debonded layer should be removed and replaced. Similarly, distress due to segregation of HMA will require replacing the distressed area with new HMA. Structural problems (look for cracking accompanied by rutting) warrant full-depth repairs. If problems are structural but cracking is at the low to medium severity level and no rutting is present, a seal coat or thin HMA overlay may hold until rehabilitation is possible, but a full-depth repair is the only way to be confident that the repair will last.

RUTTING

Definition: Rutting is a longitudinal surface depression in the wheel path. Rutting is load related.

Low Severity Rutting

Medium Severity Rutting

High Severity Rutting

Likely Causes: Rutting can result from densification of pavement layers; rutting may be caused by problems with the surfacing and thus limited only to the HMA layer, or rutting may be the result of a structural deficiency.

Investigative Methods: Observe if the rutting is progressing rapidly or if rutting is occurring slowly over time. If rutting suddenly appears and progresses rapidly, the road may have become overloaded from a change in traffic makeup (like increased truck traffic), and problems are likely structural. Observe the width of the ruts. In general, wide ruts are indicative of problems from deeper down in the pavement, while narrow ruts generally indicate problems in the upper HMA. If fatigue cracking is evident along with rutting, a structural repair is warranted. Likewise, rutting on roads that are only seal coated can be considered structural.

With the dynamic cone penetrometer (DCP), test results from rutted and non-rutted wheel paths can be compared. A significantly higher rate of penetration of the DCP in the rutted areas indicates structural deterioration. Comparison of cores from the rutted wheel path and the lane centerline can be used to investigate if rutting is confined to the HMA surfacing. For example, if a 0.5-inch rut exists and cores reveal an HMA layer thickness of 2.5 inches in the rutted wheel path and a HMA layer thickness of 3.0 inches in the centerline, the rutting is occurring in the surface layer.

General Maintenance Treatment Options: Milling (if sufficient surfacing is present), blade level-up, microsurfacing (shallower ruts), remove and replace rutted surfacing, structural overlay, full-depth patch, full-depth recycling.

Decision Matrix: In general the decision tree for rutting gives treatment options assuming a treatment is going to be applied. However, oftentimes when rutting is minor (< 0.5 inch) no treatments will be applied until the rutting worsens. Since rutting in seal coated roads will be considered structural, no treatments for low-volume roads are listed in the non-structural category.

Rutting

Structural	Severity	Traffic Level	Treatment Options
Yes	Low (< 1/2")	Low	do nothing and monitor
		Medium	microsurfacing and monitor; full-depth repair
		High	microsurfacing and monitor; full-depth repair
	Medium (1/2" - 1")	Low	blade level up and monitor; full-depth recycling/reconstruction
		Medium	full-depth repair
		High	full-depth repair; mill and structural overlay
	High (>1")	Low	full-depth recycling/reconstruction
		Medium	full-depth repair; mill and structural overlay
		High	full-depth repair; contact Area or District Engineer
No	Low (< 1/2")	Medium	mill; microsurfacing or blade patch; remove and replace with HMA
		High	mill; microsurfacing; remove and replace with HMA
	Medium (1/2" - 1")	Medium	mill to profile; blade patch or overlay; remove and replace with HMA
		High	mill to profile; overlay; remove and replace with HMA
	High (>1")	Medium	mill and overlay with HMA; remove and replace with HMA
		High	mill and overlay with HMA; remove and replace with HMA; contact Area or District Engineer

Additional Information: It is necessary to determine what layer is causing the rutting before selecting a repair method. If rutting is confined to the surfacing, only a surface treatment is necessary. Any planned rehabilitation activities may also influence the chosen treatment. For example, if rehabilitation activities are already planned, using surface treatments to maintain a reasonable level of safety may be used until the rehabilitation work is performed. In cases of a structural deficiency, additional base depth may be needed.

TIPS FOR SUCCESSFUL FULL-DEPTH REPAIRS

Listed below are some tips for constructing base repairs, sorted according to the sequence of the construction process.

Replacement Material: Options for the base are to recycle the existing base or replace the base with either a granular material or black base. When recycling existing material or using a new granular base, treatment with cement is often used to achieve a strong material in a short time frame. Some considerations for selecting a base are:

- Existing base can often be treated and recycled. If the material is not contaminated with clays, this option may be quite attractive.
- On thin surfaced roads, the existing surfacing can usually be mixed into the existing base as part of the reconstruction process. However, the amount of old surfacing in the recycled mixture should be kept below 50 percent.
- If possible, have the laboratory determine the Texas Triaxial Class of available new materials to see how materials from various suppliers compare. Materials with a lower triaxial class number are better.
- When using cement, 2 to 3 percent of Type 1 cement is usually adequate, especially with limestone bases of reasonable quality. Too much cement typically results in block cracks that reflect through the surface and allow water into the pavement. If possible, utilize the laboratory to test the performance of candidate replacement materials at two or three levels of stabilization.
- Despite its ease of use, black base is more expensive and may not perform as well as a treated granular base. Black base is most appropriate for use when a full-depth repair is needed but weather conditions are unfavorable for placement of treated granular materials.

Excavation:

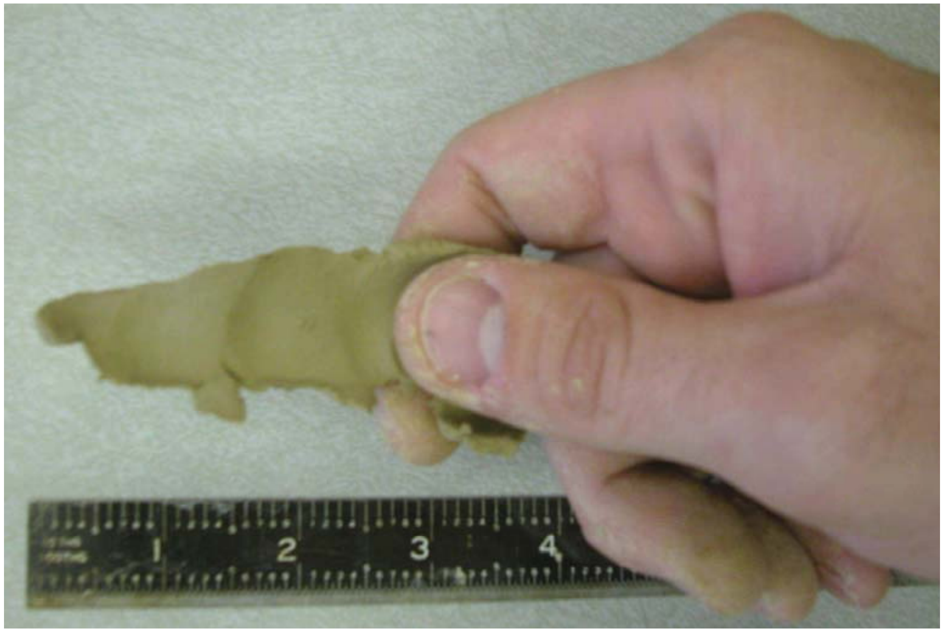
- If the old base will be recycled, avoid contaminating the base with clay from the subgrade during the excavation process.
- Excavate at least 1 foot beyond the distressed area to ensure all problematic material is removed.
- Make excavations rectangular with two edges perpendicular to the direction of traffic flow.
- Two sides of the excavation should be close to vertical to aid in compaction.

After the Excavation:

- Check the condition of the subgrade. A very wet/weak subgrade may need treatment with lime and/or improvements to drainage. Another option would be to excavate deeper and search for a more stable material deeper down. If treating subgrade, it is necessary to determine if the material is suitable for treatment, the treatment must be selected, and the level of treatment must be chosen.

Determining the Suitability of Subgrade Soil for Chemical Treatment

- Most frequently cement or lime will be used for subgrade treatment.
- For lime treatment, the soil must be somewhat plastic or "clayey" for the lime to react. Test in the field by taking a wet soil and squeezing it into a ribbon between the thumb and pointer finger, as shown in the photo below. If the wet soil will not form any ribbon, the soil is likely not suitable for treatment with lime. If any laboratory test data is available, the plastic index of the soil should be greater than 10 to treat the soil with lime.
- The soil should have a soluble sulfate content below 3000 parts per million. Sometimes sulfates can be visually identified in soils in the form of gypsum crystals, which typically are shiny, glass-like crystals as shown in the photo on page 107. These crystals can vary greatly in size, as evidenced by contrasting the crystals shown on page 107 to the crystals on page 108.
- The organics content of the soil should be below 1.0 percent.
- The District Pavement Engineer can provide assistance with estimating organic and sulfate contents.



"Ribboning" of soil Illustrating High Plasticity (scale in inches)

Gypsum Crystals

Gypsum Crystals in Soil (scale in inches)

Large Gypsum Crystals (scale in inches)

Considerations in Selecting a Subgrade Treatment

- For highly plastic soils that are suitable for treatment, lime typically reacts better with the soil; however, the lime reaction is slower than the cement reaction and thus maintenance forces oftentimes use cement even in plastic soils.
- Although soils with sulfate contents above 3000 parts per million can be treated with lime or cement, unique construction procedures are necessary which require allowing the soil to "mellow" for 1 day or longer prior to final compaction. Such practices are not suitable for maintenance activities because of the time requirements.

Selecting a Treatment Level

- Test Method Tex-121-E provides a graph for determining the lime content to use in soils. This graph is based upon the percent binder in the soil and the plastic index of the soil.
- In the absence of laboratory test data, 6 percent hydrated lime by dry weight is a typical treatment level for clay soils. This treatment level is also a typical "optimal" lime content for plastic soils as determined with test method ASTM D 6276, "Standard Test Method for using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization."
- Treatment levels used with cement in highly plastic soils are typically comparable to treatment levels with lime (3 to 6 percent).

Placing the Base:

- Mix in thoroughly any treatments (cement or lime) applied to the base.
- Wet the base to as close to optimal moisture content for compaction as possible. If available, use laboratory-determined moisture-density data. When near optimal moisture content, granular bases typically will hold together when squeezed into a ball with the fist, but will bust apart when dropped onto a firm surface from a few feet.
- When the repair size is sufficiently large, place aggregate base material in lifts of no more than 6 inches. Alternatively, if placing the base in one thick lift, check specifications of the rollers to make sure compaction equipment can sufficiently compact the deep layer.
- Compact the base with several passes of a steel wheel or pneumatic roller to obtain adequate density.
- When using blackbases, apply a tack coat to the vertical faces and place the material in lifts that when compacted are approximately 1.5 inches thick.

Sealing the Surface:

- Always seal the surface to keep water out of the pavement. A chip seal or HMA will protect the base from moisture damage. Seal blackbases to minimize the risk of moisture damage (stripping).

REFERENCE MATERIAL

AASHTO Maintenance Manual: The Maintenance and Management of Roadways and Bridges, American Association of State Highway and Transportation Officials, Washington, D.C., 1999.

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Scullion, T. Selecting Rehabilitation Options for Flexible Pavements: Guidelines for Field Investigations, Report 1712-4, Texas Transportation Institute, 2001.