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16. Abstract

The primary objective of this field phase of the research project was to evaluate geosynthetic products placed under or within hot mix asphalt (HMA) overlays to reduce the severity or delay the appearance of reflection cracks. In the laboratory phase of this study, researchers evaluated six geosynthetic products, representing fabrics, grids, and composites, using the large TTI Overlay Tester. Phase I produced comprehensive guidelines for using geosynthetics with HMA overlays to reduce reflection cracking; a design check for considering a geosynthetic product during pavement design using FPS-19; recommended new specifications for fabrics, grids, and composites; summarized results of a statewide questionnaire; and a review of pertinent literature.

Comparative field test pavements were established in three different regions of Texas (Amarillo, Waco, and Pharr Districts) with widely different climates and geological characteristics. Tests in the Amarillo and Pharr Districts utilized flexible pavements; whereas, the test in the Waco District utilized an old, jointed rigid pavement. Performance of these test pavements has been monitored for three to four years, depending on the date of construction. The oldest test pavements (Pharr District) are exhibiting essentially no cracking. The Amarillo District test pavements are exhibiting only a small percentage of reflective cracking. The Waco District test pavements are exhibiting significant reflection of underlying joints and cracks. Construction and preliminary performance of the test pavements are described.

Cost of selected geosynthetic materials for reducing reflection cracking and their installation are discussed. Based on first cost alone, installation of an inexpensive fabric must increase the service life of an overlay by more than 15 percent to be cost effective. On a similar basis and, of course, depending on the actual geosynthetic product and installation cost, a more expensive grid or composite material may need to double the service life of an overlay to be cost effective.

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FIELD TESTS USING GEOSYNTHETICS IN FLEXIBLE AND RIGID PAVEMENTS TO REDUCE REFLECTION CRACKING

by

Joe W. Button
Senior Research Fellow
Texas Transportation Institute

and

Arif Chowdhury
Assistant Research Scientist
Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are 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 FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The engineer in charge of the project was Joe W. Button, P.E. # 40874.

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During the initial stage of this project, Ms. Hua Chen, Engineering Specialist, of the TxDOT Design Division, served as Project Director, and Mr. Kenneth J. Boehme, P.E., served as Project Coordinator. Subsequently, Mr. Greg Cleveland served as Project Director. Since July of 2005, Dr. German Claros has served as Project Director. Mr. Craig Clark now serves as Project Coordinator. These TxDOT leaders have been instrumental in guiding this project to this stage. Their guidance, assistance, and support are gratefully acknowledged.

Three TxDOT districts cooperated in the placement of test pavements to evaluate the long-term performance of a variety of geosynthetic products. The engineers in these districts that were instrumental in securing these agreements and working with the researchers included the following: Amarillo – Joe Chapel, P.E., and Randy Hochstein, P.E.; Pharr – Rosendo Garcia, P.E., and Carlos Peralez, P.E.; and Waco – Jeff Kennedy, P.E., and Larry Stewart, P.E. Their cooperation and assistance is gratefully acknowledged.

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CHAPTER 1:
INTRODUCTION

BACKGROUND

For flexible, rigid, and composite pavements, a common technique used by many highway agencies for preventive maintenance and/or rehabilitation is simply to construct a thin hot mix asphalt (HMA) overlay, normally between 1.5 and 2 inches thick. An HMA overlay is designed to restore smoothness and thus improve ride quality, increase structural capacity, restore skid resistance, and protect the pavement from water intrusion.

When placing an overlay over a pavement containing joints and/or cracks, one of the more serious concerns associated with the use of thin overlays is reflective cracking. This phenomenon is commonly defined as the propagation of cracks from the movement of existing cracks or joints in the underlying pavement or base course into and through the new overlay as a result of load-induced and/or temperature-induced stresses. Increasing traffic loads, inclement weather, and insufficient maintenance/rehabilitation funding compound this problem and reduce the service life of overlays in all areas of the United States.

The paving industry has seen dramatic increases in materials costs in the past two to three years. The U.S. Department of Energy (USDOE, 2000) is projecting a 60 percent increase in world oil consumption from 1997 to 2020. Correspondingly, costs associated with constructing and maintaining pavements will undoubtedly continue to increase. Therefore, methods to extend pavement service life are becoming increasingly important.

Reflection cracking decreases the useful life of HMA overlays and/or increases the need for cost-effective preventive maintenance techniques. Promising techniques include incorporating geosynthetic products, defined herein as fabrics, grids, or composites, into the pavement structure. This procedure is typically accomplished by attaching the geosynthetic product to the existing pavement (flexible or rigid) with an asphalt tack coat and then overlaying with a specified thickness of HMA pavement. Based on findings in Phase I of this project (Cleveland et al., 2002), these materials have exhibited varying degrees of success. The use of geosynthetics within a particular agency has been based primarily on local experience or a willingness to try a product that appears to have merit.

OBJECTIVE AND SCOPE

The overall objective of the research project was to investigate and develop information that will aid in the evaluation of the relative effectiveness of commercially available geosynthetic materials in reducing the severity or delaying the appearance of reflective cracking in HMA overlays. Specific objectives were to monitor the relative performance of geosynthetic test pavements and control pavements that were constructed in the Amarillo, Pharr, and Waco Districts during Phase I (Cleveland et al., 2002) of this project. When information from these construction projects permits, the ultimate project goals include determining the relative effectiveness of each category of geosynthetic product (fabric, grid, and composite) in reducing or delaying reflective cracking and determining which, if any, of these products can provide cost-effective extensions of service life of thin overlays that are typically applied for maintenance and rehabilitation of Texas Department of Transportation (TxDOT) pavements.

CHAPTER 2:
DEVELOPMENT OF FIELD TEST PAVEMENTS

INTRODUCTION

TTI researchers in cooperation with TxDOT and construction contractors installed multiple end-to-end geosynthetic test pavements at three different locations in Texas. These test pavements were designed to evaluate, as a minimum, the same geosynthetic products that were evaluated in the laboratory. The products evaluated in the laboratory were selected to represent the three major categories of geosynthetics (fabrics, grids, and composites) that are often used to address reflection cracking. The three test locations selected in coordination with TxDOT were the Pharr District (McAllen), the Waco District (Marlin), and the Amarillo District (northeast of Amarillo). These regions provide mild, moderate, and cool climates, respectively, for the long-term evaluation. Pharr and Amarillo provided flexible pavements while Waco provided a rigid pavement. Table 1 presents a summary of the three test pavements. Figure 1 shows the locations of the test pavements on the map of Texas divided into different climatic regions.

Table 1. Summary of Test Pavements.

District	Highway Name	Pavement Type	Average Daily Temperature Range (°F)	Annual Rainfall / Precipitation (inch)	Traffic (2005)	
					AADT	ESAL
Amarillo	SH 136	Flexible	23 – 92	18.0	4000	1933
Pharr	FM 1926	Flexible	48 – 96	24.0	27500	1279
Waco	BU 6	Flexible over Jointed concrete	34 - 97	36.0	3100	791

Details of these test pavements are provided below.

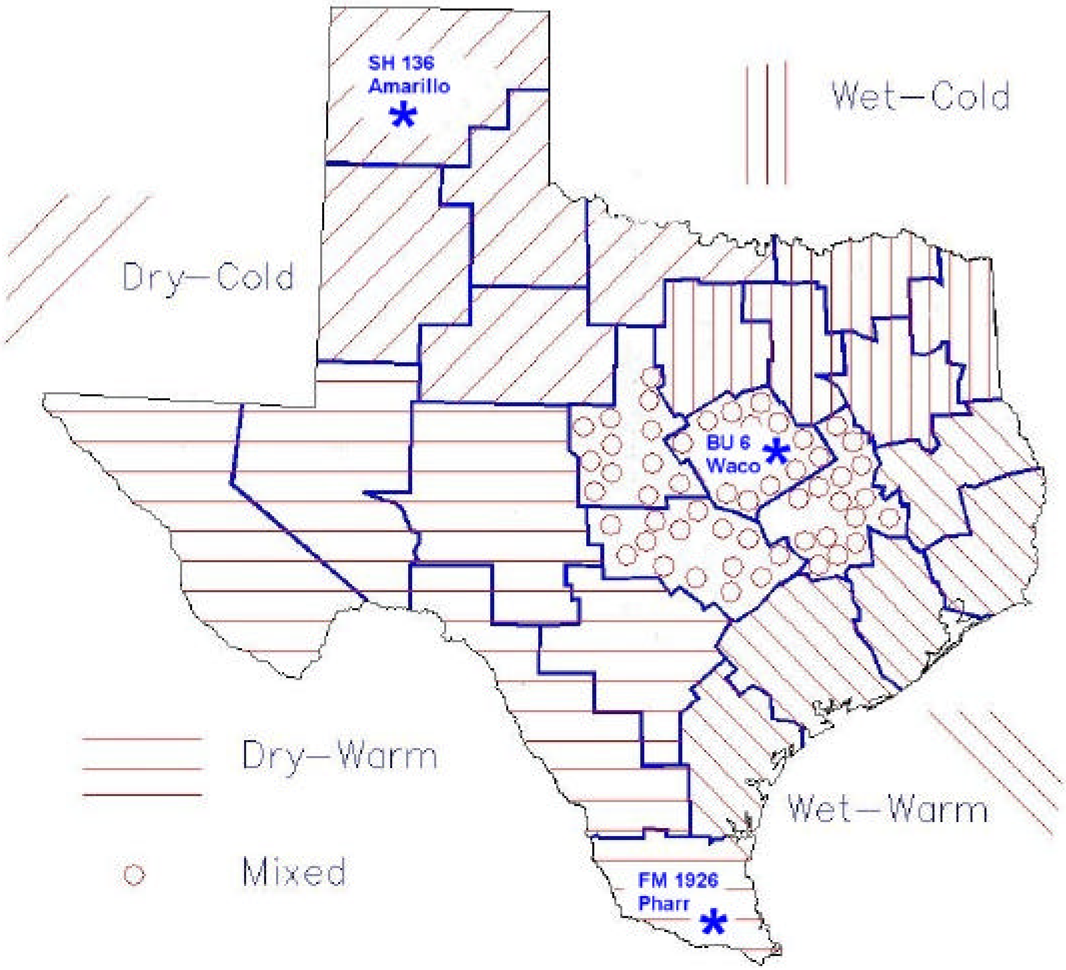

Figure 1. Location of Test Sections in Texas Map.

PHARR DISTRICT TEST PAVEMENTS

A specific segment of FM 1926 in the McAllen, Texas, urban area was selected for construction of six 500-foot geosynthetic test pavements, a 500-foot control pavement, and a similar pavement with a 1-inch thicker (i.e., 2.5-inch) overlay. The terrain is flat with silty-clay soil in a warm, dry climate. Detailed maps showing all cracks visible at the surface of the original pavements before milling were prepared and filed. Assuming reflection cracks will appear with time in the new overlay, these crack maps will be useful in determining the percentage of reflection cracks that appear in the overlay and what types of cracks are most likely to reflect through the overlay control section and test sections. Engineers have evaluated these test pavements on an annual basis to record (map) all cracks or any other forms of distress that may appear.

Test pavements were placed on FM 1926 in McAllen on April 9, 2001, as part of TxDOT construction contract CPM 1804-01-19 by Ballinger Construction. FM 1926 is a four-lane urban facility with concrete curbs and a continuous turn lane in the center (a total of five lanes). The existing roadway consisted of 12 inches of lime-stabilized subgrade, 14 inches of lime-stabilized flexible base, and 2.5 inches of HMA pavement. Plans required milling of the outside lane from near zero depth at the inside of the lane to approximately 1.5-inch depth at the curb edge, placement of reflection cracking treatments, and overlaying with 1.5 inches of Type D HMA. Milling exposed the base in a few small places near the curb. Figure 2 illustrates the plan view of this test pavement.

Construction

Ballinger Construction Company constructed all test pavements on April 9, 2001, as part of TxDOT construction contract CPM 1804-2-19. This portion of FM 1926 is a four-lane urban facility with concrete curbs plus a continuous turn lane in the center (a total of five lanes). The existing roadway consisted of 12 inches of lime-stabilized subgrade, 14 inches of lime-stabilized flexible base, and 2.5 inches of HMA pavement. Industrial Fabrics, Inc. professionally installed all geosynthetic products full within the outermost southbound lane only. To match the curb height with the new overlay, the plans required milling of the outer lane from near zero depth at the inside of the outer lane to approximately 1.5-inch depth at the curb edge. This was followed by placement of the reflection cracking treatments and then overlaying with 1.5 inches of Item 340 Type D HMA. Appendix A provides the mix design for this Type D paving mixture. Milling exposed the base in several small areas (Figure 3) (i.e., removed the entire existing HMA layer down to the surface of the base).

The geosynthetic materials were placed in 500-foot test sections in the outermost southbound lane only (Figure 2). All geosynthetics were placed from south to north. Although probably not ideal, all geosynthetic products were placed directly onto the milled pavement surface. After three to four geosynthetics had been placed, the contractor began placement of the overlay for the test pavements. Following this procedure, the overlay paving operation

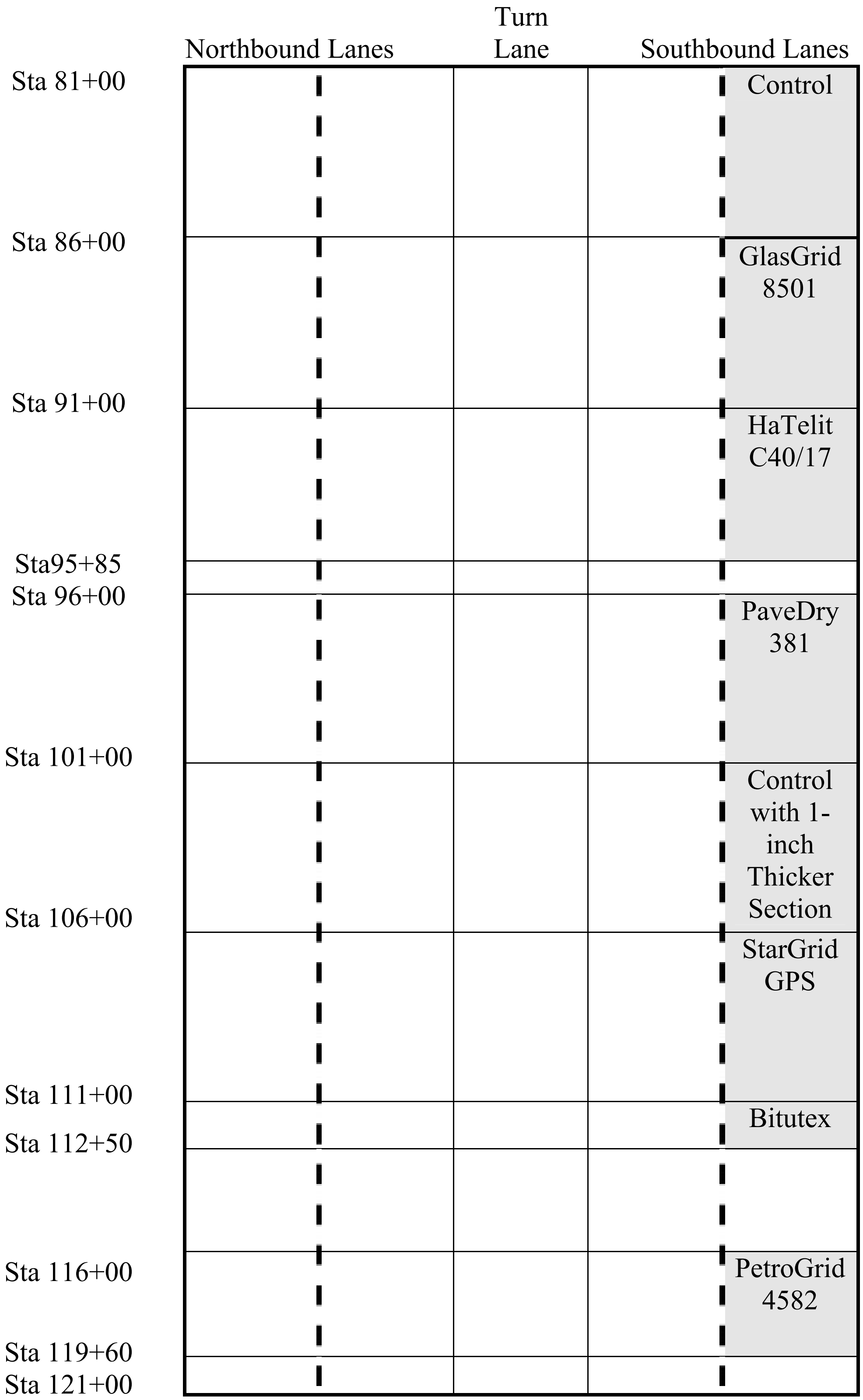

Figure 2. Plan View of Test Pavements Placed in McAllen — Pharr District.

caught up with the geosynthetic installation at the end of the day leaving no geosynthetic products exposed to traffic.

Figure 3. View of Exposed Base due to Milling Operation.

Representatives from only GlasGrid® and HaTelit® C40/17 manufacturer were present during construction of the test sections. The Industrial Fabrics representatives used their small tractor unit to install all six geosynthetic products. Some of the geosynthetic rolls were wider than 12 feet and had to be sawn to 12 feet. This was accomplished with relative ease using a standard chain saw. Others came in widths less than 12 feet and had to be sawn to accommodate sequential placement to accommodate the 12-foot wide lane.

Weather during installation was clear, 80°F to 92°F, and extremely windy with gusts upward of 40 mph (estimated).

A manhole is located adjacent to each storm drain outlet (in the curb/gutter) which prohibited milling between the manhole and the curb. Therefore, there is an unmilled area about 6 feet square near the outer edge of the lane at each storm drain outlet. This should be accounted for during subsequent performance evaluations.

Placement of Geosynthetic Products

The control section received no treatment. It received only a light tack coat and the 1.5-inch overlay that was placed on all of the geosynthetic test pavements.

GlasGrid 8501 (100 kN) was supplied in approximately 5-foot wide rolls. Therefore, it was placed in two approximately 5-foot strips plus one approximately 2-foot strip to cover the 12-foot lane. All strips were overlapped about 2 to 4 inches. In accordance with the manufacturer's recommendations, no tack was used with GlasGrid 8501.

HaTelit C40/17, from Hueskar, is a grid laminated to a thin, paper-like sheet that assists during installation (i.e., adhesion to tack coat) but ostensibly melts when the hot overlay is applied such that it becomes inconsequential during service. Therefore, the manufacturer claims the product should be considered a grid and not a composite. The design tack rate for HaTelit was 0.10 gallons/yd^2 of AC-20. HaTelit was placed using rolls slightly wider than 12 feet and weighing about 500 pounds. HaTelit rolls were 492 feet long, and about 7 feet of damaged geotextile was cut off the front end of the roll, therefore, the test section received only about 485 feet of HaTelit. Pave-Dry® 381 was placed in the northernmost approximately 15 feet of this section.

Pave-Dry 381 fabric was placed using approximately 12.5-foot wide rolls that were 360 feet in length. Therefore, the contractor created a joint at 360 feet from the south end of the test section. Significant asphalt spillage occurred at this joint. Contractor personnel placed soil on the spillage, mixed it with the hot asphalt, and removed most of the mixture from the site. (Note: if flushing, slippage or other problems occur at this location (approximately Station 99+60) later in service, this spillage may be the source of the flushing.) The first 360-foot shot of tack was about 8 inches narrower than the fabric width; therefore, the inside approximately 8 inches of fabric did not receive tack. Although not witnessed by the researcher, the contractor supposedly cut away this untacked fabric before overlaying. Tack coat for Pave-Dry 381was applied using approximately 0.20 gallons/yd^2 of AC-20.

A 1-inch (approximately) level-up was placed before April 9, 2001, to provide a thicker overlay test section upon placement of the 1.5-inch overlay. Since the leveling course was new, no tack was used prior to placement of the overlay. This section will provide a comparison in performance with the geosynthetics. No geosynthetic product was placed in this section. This section may be called as a 'second control' section that includes 1-inch level-up.

StarGrid GPS® composite manufactured by Luckenhaus arrived in 360-foot rolls and, therefore, had to be placed in two segments (360 feet, then 140 feet) with separate shots of tack. Transverse overlaps were typically about 6 inches. StarGrid GPS was placed using a tack rate of 0.10 gallons/yd^2 of AC-20. The first 360 feet went down smoothly. The latter 140 feet went down with several wrinkles due to high wind gusts that pulled it partly up such that it had to be reapplied by hand.

Bitutex® composite, manufactured by Synteen, was placed only on the first 150 feet (from the south) of the test section. The Bitutex, which is impregnated with bituminous material, was firmly adhered to itself on the roll and was thus extremely difficult to peel off the roll. In fact, unrolling the product stalled the tractor unit and the tractor tires were beginning to spin on the composite and cause wrinkles. After unsuccessfully attempting some adjustments to the tractor unit to accommodate this situation, the remainder of the roll was placed by hand with much difficulty in peeling the composite product off the roll. This hand operation caused the Bitutex to have significant wrinkles in the latter half (approximately) of the 150 feet. The Bitutex came in 150-foot rolls and, due to extreme difficulty in getting the Bitutex off the roll, only one roll was installed. (Apparently, the Bitutex had been stored for an extended time in a hot area to cause it to adhere to itself.) The last 350 feet (approximately) of this section contain no geosynthetic product. Tack coat was applied using approximately 0.25 gallons/yd^2 of AC-20.

PetroGrid® 4582, produced by Amoco, arrived in five 81-inch wide and 180-foot long rolls. Therefore, two rolls were cut down to approximately 67 inches wide such that, when the 81-inch and 67-inch rolls were placed side by side, they were designed to cover the 12-foot lane and allow approximately 4 inches for overlap. During installation, however, the actual overlap was probably closer to 2 inches. The 81-inch roll was placed next to the concrete curb; therefore, the longitudinal joint between the two rolls is approximately 81 inches from the curb. Workers placed four of the five rolls starting at the south end to cover approximately 360 feet of the 500-foot section. Tack coat was applied at approximately 0.25 gallons/yd^2 of AC-20. Due to an inadequate amount of PetroGrid, the last 140 feet of this section contains no geotextile.

Test Section Evaluation

Researchers have typically evaluated these test pavements each spring since construction. The researchers believe that, generally, most cracks appear during cooler weather, and further, cracks can sometimes disappear from view during hot weather due to pavement expansion and kneading action of traffic at the HMA surface.

An evaluation of the pavements in May 2002 revealed a single crack less than 1/16 inch wide and about 40 feet long located about 6 inches from the curb in the Pave-Dry 381 section. No other forms of distress were visible in any of the test or control pavements.

In May 2003, no cracks were visible at the surface of any of the pavements. The crack observed in 2002 had disappeared, probably due to lateral movement of the HMA in the warm South Texas climate. There were, however, a few flushed strips transversely across the lane. These flushed areas were expected due to one incident of asphalt spillage and overlaps of the truck when it would start too far back onto the previous shot of asphalt tack. These distress are no fault of the geosynthetic product and likely would not have been produced by a crew experienced with placing geosynthetic products.

In April 2004, no cracking was observed nor were any other significant forms of pavement distress. Isolated shoving or rutting was observed in the outer wheelpath about 10 to 20 feet north of the Buddy Owens intersection (1-inch thicker overlay section). This rutting may be due to a base problem, as similar rutted areas were recorded during the initial evaluation of the pavement before the project began.

In April 2005, no cracking was observed nor were any other significant forms of pavement distress. Generally, the pavement surface exhibited a slight flushed appearance in the wheelpaths, but this is not significant. The transverse strips of flushing and a few isolated spots of shoving in the outer wheelpath at the approach of a couple of intersections were still visible. Figure 4 shows a general view of one of the test pavements in 2005. Figure 5 depicts an example of shoving near an intersection approach.

Figure 4. View of Typical Test Pavement in McAllen in 2005.

Figure 5. Shoving with Flushing at an Intersection Approach in McAllen.

In November 2005, three test sections (GlasGrid, Pave-Dry, and HaTelit) had developed few longitudinal cracks. Their reflective cracking percentages (with respect to before-construction cracking) were only 12, 8, and 4 percent, respectively. About 150 feet of the thicker HMA section had suffered significant rutting in both wheelpaths in the approach to a major intersection with a truck route. Additionally, a few isolated areas showed flushing. The flushing may have resulted from application of excessive tack coat in those areas during construction. More than four years after construction, the overall condition of the test pavements is very good.

Because so few cracks were visible at the writing of this report, no maps showing the progression of cracks were prepared for the Pharr test pavements. This test sections were laid out on a lane with very thin asphalt layer due to the milling operation to match the curb and gutter (Figure 3) which may have contributed to very little amount of reflected cracks.

WACO DISTRICT TEST PAVEMENTS

After several delays for various reasons, Lindsey Contractors of Waco, Texas, constructed the test pavements in 2002/2003 on BUS 6 in Marlin as part of TxDOT construction contract CPM 0049-05-006. The seven 500-foot test sections begin at the junction of BUS 6 with SH 7 in downtown Marlin and proceed south 3500 feet. BUS 6 is a two-lane urban facility, northern part with curb and gutter and southern part without curb and gutter. The terrain is rolling hills with a few large trees in the vicinity of the roadway that shade parts of the pavement in early morning and late afternoon. The existing structure is an old 6-inch jointed concrete pavement with several thin HMA overlays. Construction plans required milling of the HMA down to the existing concrete and repairing any failures in the concrete pavement. Detailed maps showing all cracks and joints visible at the concrete pavement surface after milling were prepared and filed. These crack maps will be useful in determining the relative percentage of reflection cracks that appear in the overlay. Researchers have evaluated these test pavements on an annual basis to record (map) all cracks or any other forms of distress that may appear.

After the old HMA was milled off and before construction began, the Falling Weight Deflectometer (FWD) was used to determine load transfer efficiency of every third joint in the old concrete pavement. These data will be useful in determining the maximum allowable load transfer efficiency that does not cause a crack to reflect through a thin overlay from this concrete pavement.

Construction

All geosynthetic products were placed in 500-foot test sections (Figure 6) in both the northbound and southbound lanes in the following sequence of construction:

- mill off existing HMA down to old concrete,
- repair any concrete pavement failures,
- seal cracks larger than 1.25 inches,
- apply underseal (seal coat of Type PB Grade 4 aggregate and AC-15-5TR),
- spot level pavement using HMA,
- place a 1-inch leveling course of Type D HMA,
- turn over to traffic for a few months,
- apply tack coat over the leveling course
- place geosynthetics (except PavePrep which was placed below the level-up) on the leveling course, and

- place 1.5-inch overlay of Item 340 Type D HMA.

The leveling course was placed in the fall of 2002 and turned over to traffic until the summer of 2003. During this period, some joints and cracks reflected through the thin leveling

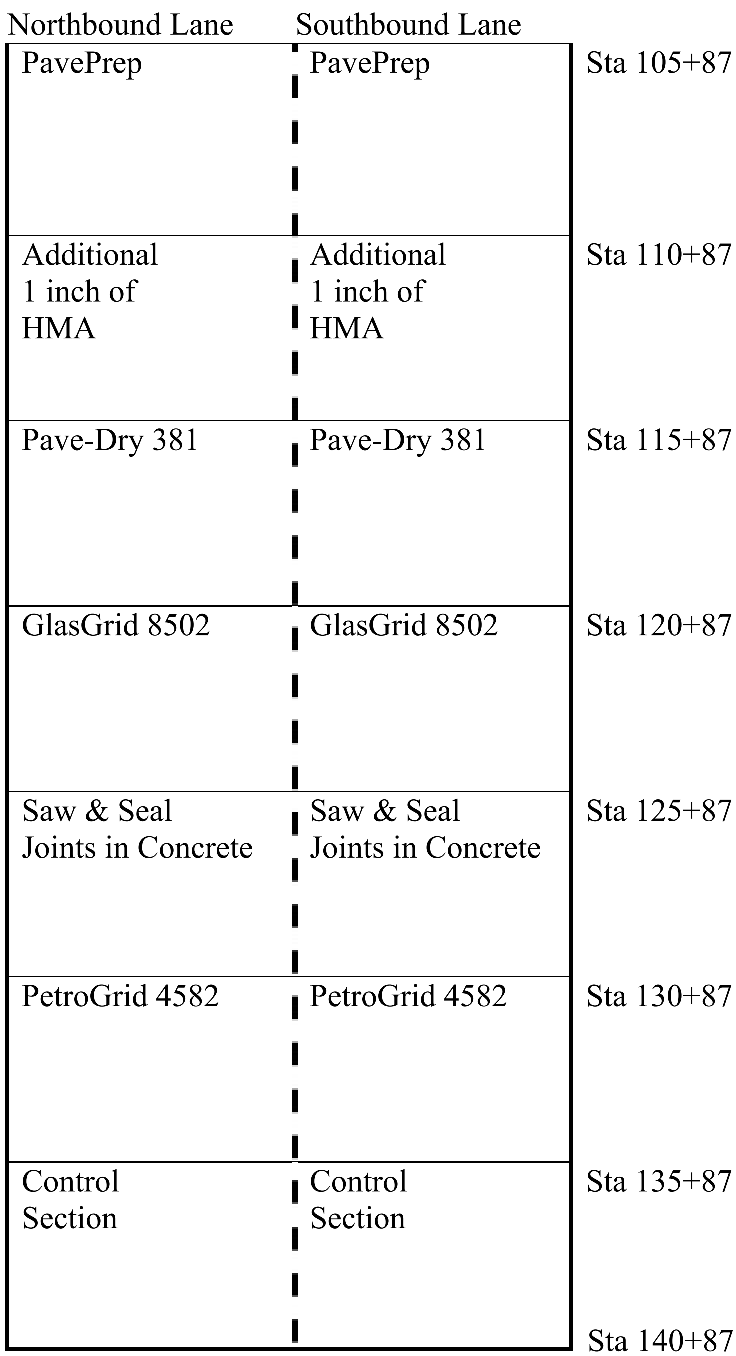

Figure 6. Plan View of Test Pavements Placed in Marlin – Waco District.

course, so, on June 10, 2003, the researchers mapped the cracks that were visible at the surface of the leveling course; more than one-half of the original joints/cracks had reflected through the leveling course. The geosynthetic test sections were constructed on BUS 6 during July 2003. The weather was hot with intermittent rainfall during the first few days of construction.

For overlay placement, the contractor used a Roadtech® material transfer device (MTD) and live-bottom trucks (Figure 7). The haul trucks deposited the HMA into the hopper of the MTD, which, in turn, deposited the remixed HMA into the paving machine. All geosynthetic products were placed in strips over all longitudinal (centerline and both edges) and transverse joints (Figure 8). The level-up surface was tacked using AC-20 prior to application of the geosynthetics by a distributor truck using a 5-foot (approximate) spray bar. Generally, no tack was placed on the pavement surface areas between the strips of geosynthetic products. Quite often, the contractor spread loose HMA on the geosynthetic products to reduce the tendency of construction equipment tires to stick and pull them up. Placement of each geosynthetic product is described in the following paragraphs.

Figure 7. View of Paving Train at Bus 6 in Marlin, Texas.

Figure 8. Marlin Project showing Geosynthetic Strips with No Tack between Them and Application of Loose HMA to Reduce Sticking to Construction Equipment Tires.

The construction project was originally designed to receive PavePrep® strips placed directly onto the milled concrete pavement to cover the joints and selected major cracks. In fact, PavePrep was used on the entire project north of SH 7. Regarding the test pavements, only the PavePrep was placed directly onto the concrete pavement surface (per manufacturer's instructions and TxDOT's desires) and the leveling course was placed on top of the PavePrep. PavePrep was placed in the fall of 2002 just prior to placing the leveling course, almost one year before the other geosynthetic products were placed. Placement of PavePrep was not observed by the researchers. All other geosynthetics were placed onto the surface of the leveling course during July 2003.

The additional 1 inch of HMA overlay was placed over the leveling course. To accomplish the thicker overlay, the screed of the paving machine was simply raised an additional inch in this section. The screed was incrementally raised along the first 25 feet of the test section and similarly lowered over about 25 feet at the end of the test section to return to the standard

1.5-inch overlay. A light tack coat of dilute emulsion was applied ahead of the overlay. This section can be called as ‘thick control’ section.

The contractor placed the Pave-Dry 381 fabric by hand in strips over the joints and major cracks. Tack was placed using a 5-foot (approximately) spray bar on the asphalt distributor truck. The design tack rate was 0.15 gallons/yd^2. However, throughout construction of most of the test pavements, the contractor’s distributor truck operator had little control of tack rate. He would sometimes dribble the asphalt in streams (Figure 9) and other times shoot excessive material. Starting and stopping often produced pools of excess tack. Apparently, his nozzles were too large for shooting low rates of AC-20 as tack. Therefore, there was much variation in tack rate during placement of the Pave-Dry 381, some areas with insufficient tack and some with much excess tack.

Vance Brothers Inc. placed the GlasGrid 8502 using a small tractor modified for this purpose. The researcher suggested the use of a light tack over the GlasGrid after it is placed. In the northbound lane, the construction contractor either dribbled a little AC-20 in streams from the distributor truck over the GlasGrid or shot up to 0.20 gallons/yd^2 (estimated). That is, a light application of tack was not uniformly spread over the GlasGrid strip, as hoped. While overlaying, GlasGrid was lost from the fifth transverse joint from the south end of the northbound lane. In the southbound lane, a new distributor truck driver spread a much more uniform light coat of tack over the GlasGrid. It should be noted that a transverse crack approximately ¾ inch wide and full of mud was visible in the leveling course near the center of this section in the northbound lane. Further, the southern portion of the northbound lane was damp due to rainfall when paving began.

For the saw-and-seal section, the contractor marked the ends of the cracks (over transverse joints) in the leveling course using stakes at each side of the roadway. After overlaying, the contractor stretched a string between the stakes and attempted to mark the location of the transverse joints in the concrete pavement. These marks were sawn about 3/8 inch wide and 1 inch deep and sealed with rubber-asphalt crack sealer. Based on the location of cracks that subsequently reflected through the overlay, it is evident that many of the sawn areas missed the joint locations by about 8 to 12 inches. Therefore, most of the sawn and sealed joints are not functional.

The contractor placed the PetroGrid 4582 composite in strips over the joints and major cracks by hand. Again, there was extreme variability in tack rate, ranging from dribbled streams to obvious excess. Visibly less tack was used in the southbound lane than in the northbound lane. PetroGrid in the northbound lane was exposed to traffic for several hours before overlaying. PetroGrid in the southbound lane was placed several days later and the researchers were unable to observe this operation. On July 28, 2003, TxDOT required the contractor to remove and replace HMA overlay from Station 133+87 to Station 135+87 in the northbound lane because the overlay was disintegrating (apparently slipping and tearing). This activity will significantly reduce the validity of this portion of this test section.

For the control section, the leveling course was lightly tacked and then overlaid with the 1.5 inches of the standard Type D HMA.

Figure 9. Example of Dribbled, Insufficient Asphalt Tack.

Test Section Evaluation

These test pavements have been evaluated each spring since construction. In May 2004, there was not a great deal of cracking in any of the test pavements; however, several of the transverse joints in the underlying concrete had reflected through the overlay. The visible cracks matched quite well with the original joints/cracks mapped at the beginning of the project. There were no other signs of distress.

In May 2005, several more joints/cracks had reflected through the overlay. The most notable ones were located at the transverse joints. Percentage reflection cracking was calculated separately for transverse, longitudinal, and total cracks using the following equation.

$$\text{Reflective cracking (\%)} = \frac{\text{Length of cracks for a given year (ft)}}{\text{Length of cracks before construction (ft)}} \times 100$$

Plots of percentage reflection cracking (transverse, longitudinal, and total) versus time (Figures 10, 11, and 12, respectively) illustrate that most of the reflection cracking is from the transverse joints in the underlying concrete pavement. Recall that the geosynthetic products, except for PavePrep, were placed approximately one year after placement of the leveling course. Therefore, the first points on the graphs represent only the leveling course and the PavePrep. The PavePrep has shown the least reflective cracking from the beginning. Two years after placement of the remaining geosynthetic products, all four geosynthetic products (PavePrep, PetroGrid, Pave-Dry, and GlasGrid) are showing less than about 40 percent reflection of the transverse joints, whereas, those sections without a geosynthetic product (control, thicker section, and saw & seal) are exhibiting approximately 40 percent or more reflection of the transverse cracks.

Regarding reflection of longitudinal cracks (Figure 11) two years after placement of the geosynthetic products, all of the geosynthetic products exhibited less reflection cracking than the control section. All geosynthetic test pavements exhibited less than 10 percent reflection of the longitudinal cracks, whereas, the control section exhibited greater than 15 percent.

Alternately, percent cracking after the overlay were recalculated based on the cracks measured on level-up instead of original cracks measured before construction. Graphs similar to Figure 10, 11, and 12 were redrawn based on new calculation and documented in Appendix B.

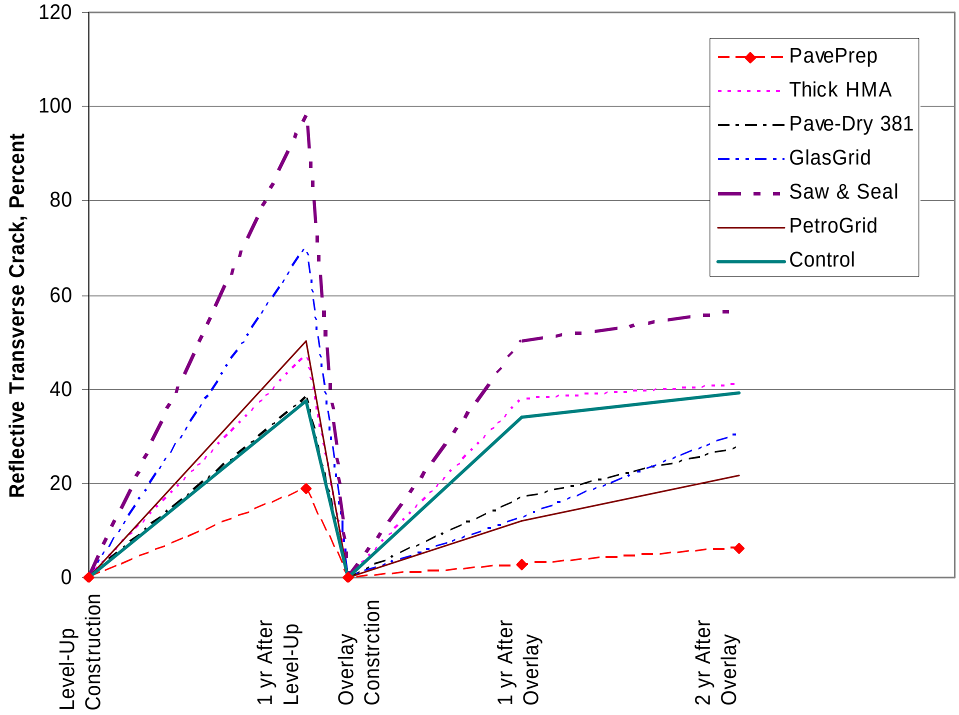

Figure 10. Reflective (Transverse) Cracking vs. Time — Waco District.

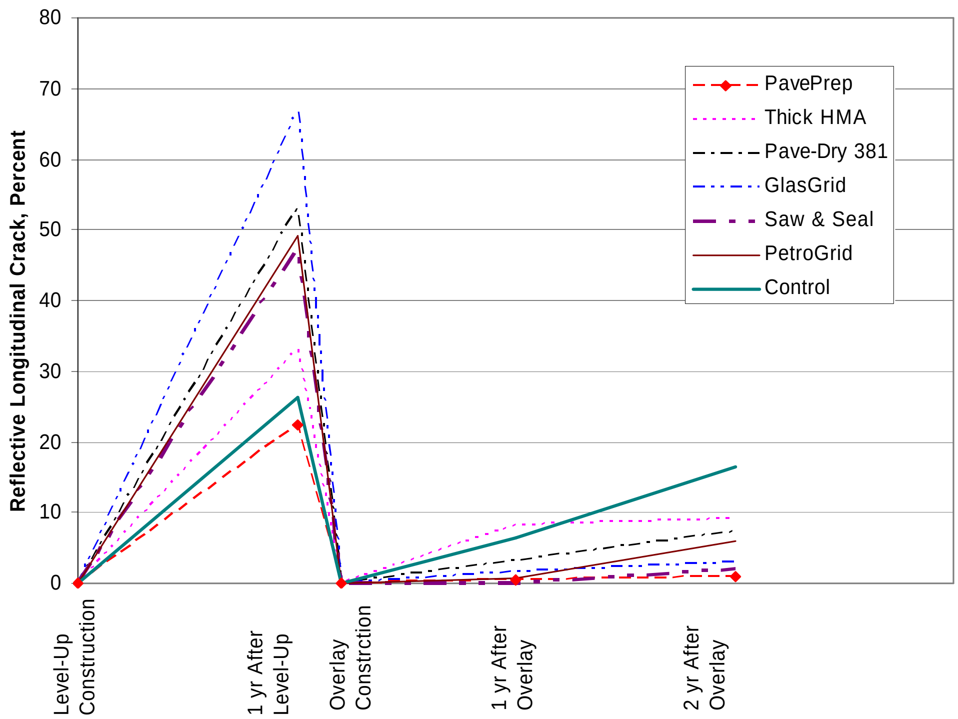

Figure 11. Reflective (Longitudinal) Cracking vs. Time —Waco District.

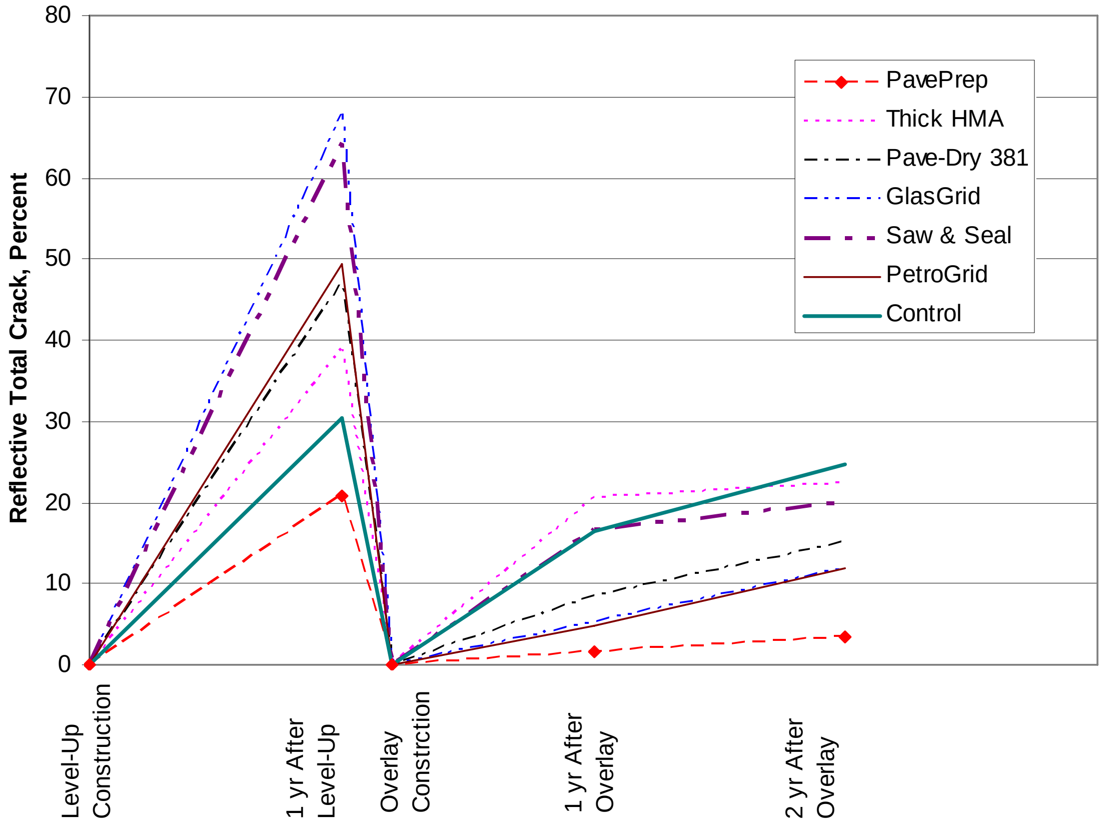

Figure 12. Reflective (Total) Cracking vs. Time —Waco District.

AMARILLO DISTRICT TEST PAVEMENTS

Test pavements were originally planned for construction in the Amarillo District on SH 136 just northeast of Amarillo in the summer of 2001. However, various delays pushed construction into June of 2002. Details of this project are found in the plans for project number CPM 379-3-19. However, the actual locations (Figure 13) of some of the test pavements were modified from those station numbers listed on the TxDOT plans.

This segment of SH 136 is a two-lane, fairly rural facility in a relatively flat plain. The existing structure consists of 12 inches of flexible base, 4 inches of asphalt-stabilized base, and 3 inches of asphalt concrete pavement. Typically, the construction plans require placement of a 1-inch level-up course of Type D containing PG 70-28, reflection cracking treatment, and then a 2-inch HMA overlay of Type D containing PG 70-28. All geosynthetic products were placed on without underlying seal coat, and hot-in-place recycling of HMA. Table 2 shows a summary of these test sections. Figure 13 presents the plan view of all Amarillo test sections.

Detailed maps showing all cracks visible at the surface of the original pavements were prepared and filed. The original pavement had a very large number of both longitudinal and transverse cracks. Before construction, there were approximately 150 feet of longitudinal cracks per 100-foot station per lane. There were also six to seven transverse cracks per 100-foot station.

Table 2. Description of Test Pavements in the Amarillo District.

Test Section No	Material	Limits	Tack Rate (gal/yd^2)	Remarks
1	Control Section	585+00 – 590+00	0.05	Tack rate is estimated.
2	GlasGrid 8501	590+00 – 595+00	0.0 NB 0.10 SB	Tack was used in SB lane only because pavement was wetted by light rainfall.
3	PaveTrac Wire Mesh	595+00 – 600+00	0.10	--
4	HaTelit C40/17	600+00 – 600+80	0.10	Northbound lane only. Not placed in southbound.
5	PetroGrid 4582	600+80 – 605+30	0.20	--
6	Pave-Dry 381	605+30 – 610+18	0.20	--
7	StarGrid G-PS	610+18 – 615+10	0.10	--
8	Additional 1 inch of HMA	615+00 – 621+10	0.10	--
9	Hot In-Place Recycling	640+00 – 700+00	NA	--
10	1.25 inch PFC over 1-inch level-up	706+18 – 711+18	--	--
11	1.25 inch PFC over seal coat	712+18 – 717+18	--	--

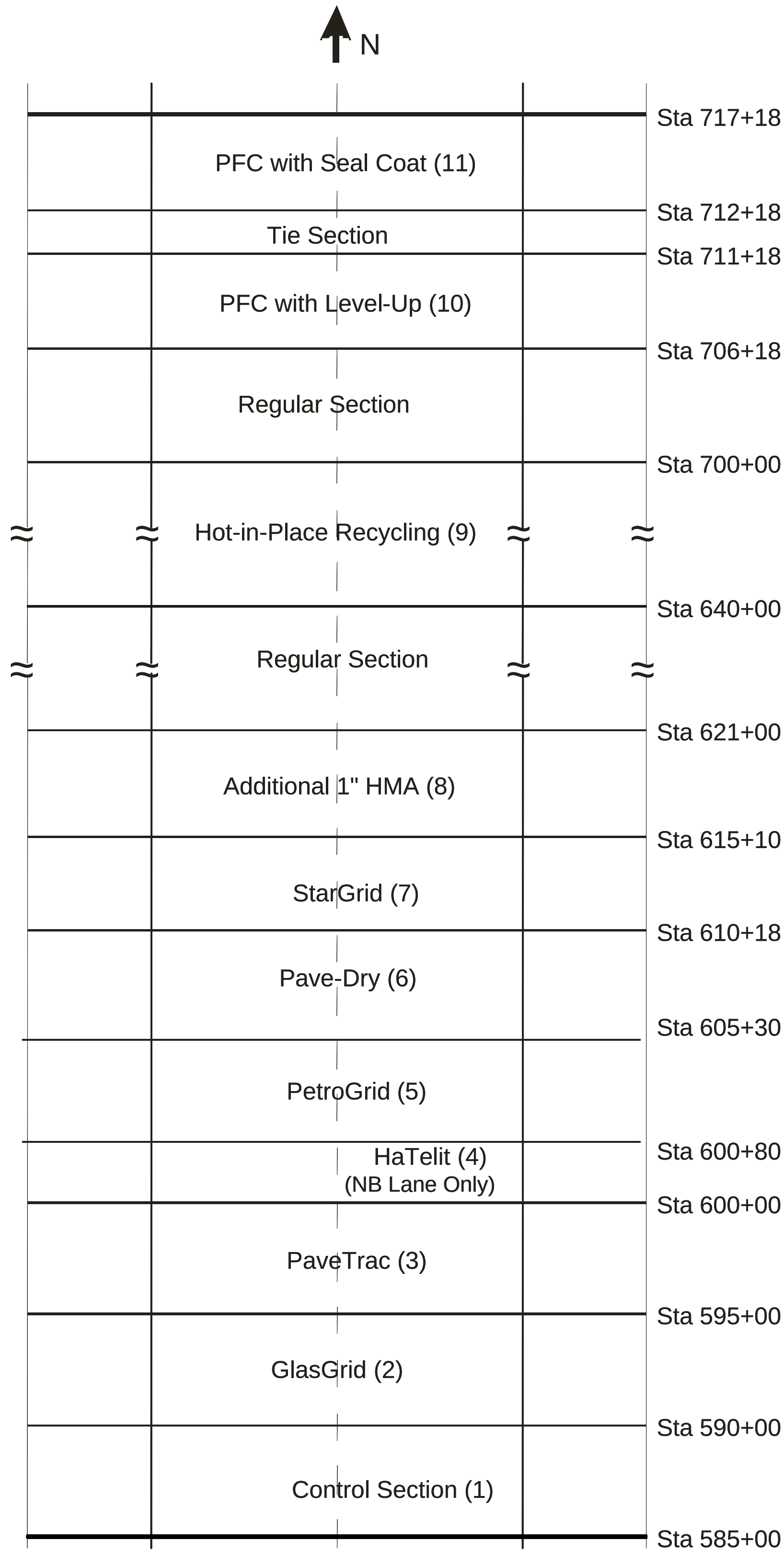

Figure 13. Amarillo Test Pavement Layout.

These crack maps of original pavements will be used to determine the percentage of any reflection cracks that may appear in the overlay. These test pavements have been evaluated on an annual basis to record (map) all cracks or any other forms of distress that may appear.

Construction

The total length of these test pavements is approximately 2.5 miles. Construction of all test pavements required several weeks to complete due to delays caused by rainfall, plant breakdowns, and a change in surface mixture type. The researchers were present during the construction of all sections containing a geosynthetic material. The control section was paved over the level-up course using 0.05 gallons/yd^2 of tack coat followed by 2 inches of Type D HMA. Gillman and Terrel served as the prime contractor on this project. Representatives from the manufacturers of GlasGrid, PetroGrid, and PaveTrac were present during construction. Construction began on June 2, 2002, and construction of the geosynthetic sections was completed only in the northbound lane. At start time, the temperature was approximately 82°F and rising, and as usual, the wind velocity was quite high. All geosynthetic (except northbound GlasGrid) materials were tacked using PG 70-28. All geosynthetic products were placed in approximately 500-foot test sections as shown in Figure 13 (except HaTelit) in both the northbound and southbound lanes in the following sequence of construction:

- apply tack coat on original pavement surface
- place a 1-inch leveling course of Type D HMA,
- apply tack coat overl leveling course (except GlasGrid in northbound lane)
- place geosynthetics on the leveling course, and
- place 2 inch Type D HMA as overlay.

Placement of Fabric and Paving

Industrial Fabrics, Inc placed GlasGrid 8501 on the northbound lane from station 590+00 to 595+00. Each roll was about 5 feet wide and 330 feet long. Three mats were placed in the lateral direction with 2-3-inch overlaps (perpendicular to the direction of traffic). These three mats side by side actually covered the whole northbound lane and extended 2 feet into the southbound (west side of centerline) lane. One and one-half rolls were used to cover the 500-foot length with 6 inches of transverse overlap. Application of the self-adhesive GlasGrid using the small modified tractor was relatively easy and quick. It took 30 to 40 minutes to place this 500-foot section. Figure 14 illustrates placement of the GlasGrid product.

The contractor (in the absence of a representative from HaTelit) tried to place the HaTelit material using a modified front-end loader. They sprayed tack coat at about 375°F and at a rate of 0.10 gallons/yd^2. The contractor experienced notable difficulties during application of the heavy, 13.1-foot rolls. The lifting device attached only to the two ends of the roll. As a result, the roll sagged significantly in the middle, which prevented it from rotating properly during installation. They inserted a steel pipe through the core of the roll. After several unsuccessful attempts, the contractor gave up and decided to use PaveTrac wire mesh instead of HaTelit.

Figure 14. Placement of GlasGrid Product.

PaveTrac was placed between Stations 595+00 to 600+00 in the northbound lane on the first day. PaveTrac representatives supervised the operation. The PaveTrac rolls were 160 feet long. They placed the mesh flush with the outer pavement edge with a 6 to 12-inch overlap near the centerline of the pavement. A pneumatic roller was used to smooth out the mesh to eliminate the bulges. Every 25 feet along the length, they cut the outside thick wire to relieve longitudinal tension and allow the mesh to lie flat on the pavement. Further, the mesh was anchored to the pavement using nails 25 feet apart in the longitudinal direction and 4 feet apart in the lateral direction. The whole procedure required about one hour. Tack coat was applied at a rate of 0.1 gallons/yd^2. Application of tack was not uniform; that is, it was heavy at the center and light on both sides. Figure 15 illustrates anchoring of the wire mesh.

Figure 15. Anchoring PaveTrac Wire Mesh to Leveling Course Using Special Nail Gun.

The contractor made a second attempt to place HaTelit. Tack coat was applied at a rate of 0.1 gallons/yd^2 and at 375°F. Placing the fabric was again very difficult, and there were excessive wrinkles in the mat. The contractor gave up on this material after placing 80 feet (Station 600+00 to Station 600+80) in the northbound lane. The roll width was 13 feet, which resulted in the material extending 1 foot into the southbound lane. About one hour was required to place this segment of fabric. Figure 16 depicts wrinkles in the HaTelit.

From Station 600+80 to 605+30, PetroGrid 4582 fabric was placed in the northbound lane using a tack coat rate of 0.2 gallons/yd^2. A manufacturer's representative was present during the placement operation. Each roll was 81 inches wide and 180 feet long. Transverse and longitudinal overlaps were about 4 inches. PetroGrid extended 1 foot into the southbound lane. This operation proceeded relatively easily with only a few wrinkles in the 450-foot test section.

Figure 16. Wrinkles in 80-foot HaTelit Section.

Pave-Dry fabric was placed from Station 605+30 to 610+18 using a tack coat rate of 0.2 gallons/yd^2. No representative from the manufacturer was present. Placement of fabric was easy and quick. A few wrinkles occurred near Station 605+50. The construction crew cut the fabric to relieve the bulging developed by wrinkles. The 12-foot rolls covered the entire lane. Overlaps at the transverse joints were 6 to 8 inches. Less than one-half hour was required for the placement of Pave-Dry.

StarGrid GPS was placed between Stations 610+18 and 615+10 with tack coat applied at a rate of 0.10 gallons/yd^2. No representative from the manufacturer was present. A single roll covered the entire lane width. Overlap at the transverse joint was 6 to 8 inches. The left center of the first 100 feet of the StarGrid was somewhat wrinkled due to skewed maneuvering. The first part of the second roll experienced slight wrinkling in the first 50 feet in the right side of the lane. Placement of fabric proceeded efficiently, requiring only about 20 minutes.

Placement of the Type D overlay in the northbound lane began at 3:00 pm at the beginning of the GlasGrid section. Two steel-wheel rollers (one vibratory and one static) were used for compaction. No measurement of mat density was observed. Some fine cracks (checking) were noticed on the surface of the overlay between Stations 595+00 and 597+00 (see Figure 17), probably due in part to dry mix. From Station 597+00 to 599+94 (end of wire mesh), only one vibratory roller (i.e., no static roller) was used for compaction. During HMA placement on the wire mesh section, uplift or buckling of the PaveTrac occurred due to action of truck tires. The remaining portion of the section in the northbound lane proceeded smoothly.

Operations resumed on the following morning in the southbound lane starting from south to north. The morning was cloudy with very light intermittent rainfall. Following the suggestion of the manufacturer, the contractor applied GlasGrid using a tack rate of 0.10 gallons/yd^2 in an attempt to offset the dampness of the pavement surface. Two rolls were placed side by side to cover the remaining width of the southbound lane (Station 590+00 to 595+00).

Figure 17. Checking (or Crazing) Observed During Portions of Overlay Paving.

PaveTrac was placed (from Station 595+00 to 599+97) with an overlap with the previous application from the centerline and 1 foot into the southbound lane. Therefore, PaveTrac extended 1 foot onto the southbound shoulder. Again, the manufacturer cut the outside wire on both sides of the mesh at 25-foot intervals. Tack coat was excessive in a few spots. Overlay paving started at 10:00 am. The mix temperature and existing pavement temperature were 300°F and 65°F, respectively. Ambient temperature was approximately 72°F. A pneumatic-tired roller was used as a finish roller on the second day.

Overlay paving over the tacked GlasGrid experienced some minor problems at the beginning. The grid was lifted upward by the truck tires due to the presence of the sticky tack. The smaller wheels on the paver (front) also lifted the GlasGrid, but fortunately, the larger rear wheels pressed it back down.

Paving on the PaveTrac section started at 10:30 am. The paver wheels occasionally lifted the mesh slightly and loose HMA flowed underneath the mesh. As a result, some places exhibited gaps (about 0.25 inch) between the wire mesh and the surface of the leveling course. In the first 100 feet of the PaveTrac section, the sticky tires of the pneumatic roller often pulled rocks/mix from the surface of the mat. From Station 600+00 to 600+80 in the southbound lane (adjacent to HaTelit), overlay paving was completed without any geosynthetic product or tack coat. Rain began at 11:00 am, and paving operations ceased.

On June 6, 2002, operations resumed at 1:30 pm after a chilly morning and an HMA plant breakdown. It was sunny and the temperature was approximately 83°F with a light breeze. Anchoring of the PaveTrac that extended 1 foot onto the southbound shoulder was slightly damaged due to traffic and brooming, and the mesh curled up a small amount.

PetroGrid was placed in the southbound lane from Station 600+80 to 605+30. The contractor established a 6-inch longitudinal overlap with the PetroGrid placed earlier in the northbound lane and used a 4 to 6-inch overlap in the transverse direction.

PaveDry and StarGrid were placed in the southbound lane without any incidents. Due to previous experience of the crew, placement of geosynthetic products proceeded much more smoothly than the first day. Very few wrinkles were observed, and the entire operation proceeded quite rapidly.

Paving began at 2:30 pm and was completed up to the StarGrid section at 3:30 pm. Overlay paving and compaction also proceeded better than the first day of operation. Mixture temperature was periodically recorded as 275, 280, 310, and 315°F. A nuclear density gauge indicated 94 to 95 percent density. The researchers were not present during the construction of the remaining test pavements.

Test Section Evaluations

These test pavements have been evaluated each spring since construction. Detailed crack maps have been prepared for each section. Findings from each evaluation are tabulated in Appendix B. Percentages of reflective cracking were calculated for each year for each section based on the total cracks observed for that particular section before construction.

In June 2003, one year after overlay construction, the surfaces of the test pavements were in excellent condition with no sign of cracking, rutting, flushing, or raveling. Even though a few short transverse cracks had developed in the shoulder (where no geosynthetic products were placed), the researchers did not detect any cracks in the travel lanes. Only one crack was observed at the transverse joint (transition) between the PaveTrac and HaTelit sections.

In April 2004, the surfaces of the test pavements generally appeared to be in excellent condition. Minor transverse and longitudinal cracks were observed in some of the test sections. The PFC with seal coat did not exhibit any cracking, but the PFC with level-up exhibited a few short, narrow longitudinal and transverse cracks. The PFC with seal coat developed a few small potholes.

The hot-in-place recycled section is quite long (almost 6000 feet). Only the first 500-foot segment from the north end was selected for evaluation. The hot-in-place recycled section exhibited very few transverse cracks (Figure 18). Only one transverse crack developed by 2004 in the southbound lane of the StarGrid section. The Pave-Dry section showed only a few very short transverse cracks. No cracks were observed in the travel lane of the PetroGrid section. HaTelit comprised a very short section (80 feet) and only in northbound lane. The researchers have observed the HaTelit section realizing that the findings are not statistically significant. A few short, narrow cracks were noticed in the PaveTrac section, and the longitudinal joint along its centerline was prominent. A few spots in the southbound lane of PaveTrac experienced mild raveling (Figure 19). Several cracks started on the shoulder and barely penetrated the travel lane of the GlasGrid section. Some places on the surface of the GlasGrid and control sections exhibited a few very thin alligator-like cracks probably due to the checking that occurred during construction (mentioned earlier). Otherwise, the GlasGrid and control sections looked good.

Figure 18. Transverse Crack Observed in 2004 in Hot-In-Place Recycled Section.

Figure 19. Raveling Observed in the PaveTrac Section in 2004.

By April 2005, some of the cracks in the overlay had grown longer, and in some cases, wider. Development of some totally new cracks was observed as well. TxDOT had repaired small pot holes that developed in 2004 in the PFC/seal coat section. This section had very few cracks. The PFC/leveling course exhibited a few new transverse cracks, particularly in the northbound lane (Figure 20). The northbound lane of the hot-in-place recycled section had almost no transverse cracks, but a significant number of new cracks had developed in the southbound lane since the 2004 evaluation.

A few new cracks developed in the StarGrid section. Some of the transverse cracks that had developed in the shoulder were beginning to enter the main lane. The northbound lane and shoulder of the Pave-Dry section exhibited no cracks, but the southbound lane had a few transverse cracks that initiated in the shoulder in 2004 and entered the main lane in 2005. The Pave-Dry surface looked good. A few short transverse cracks initiated during the past 12 months. A few short transverse cracks appeared in the southbound lane of the PetroGrid section during the year; whereas, no crack was noticed in the northbound lane or shoulder.

No new cracks developed in the short HaTelit section. The transverse crack that originally developed two years ago grew somewhat longer. A few new short, narrow transverse cracks initiated during the past year in the PaveTrac section. The longitudinal joint along the centerline was quite prominent. A few longitudinal cracks were observed in the southbound shoulder. Raveling was observed in the southbound lane of the PaveTrac section. The PaveTrac section exhibited several short, parallel transverse cracks in a short segment that appeared to have initiated from the centerline (Figure 21). Most likely, these cracks developed due to lateral movement of wire mesh underneath during the construction. The PaveTrac surface was not as good as the other sections.

In 2005, the GlasGrid section exhibited several cracks that initiated in 2004 and grew longer and a few more short transverse cracks that initiated during 2005. Some places on the surface of the northbound GlasGrid section still showed the checking observed during construction. The control section developed a few new transverse cracks in the main lane and shoulder as well, and the cracks that developed in 2004 grew a little longer and wider.

Figure 20. A Transverse Crack in PFC with Leveling Course Test Section.

Figure 21. Short Parallel Transverse Cracks Radiating from the Centerline of the PaveTrac Section.

Measured crack lengths were used to calculate the percentages of reflective cracks for each year of evaluation. Figures 22 through 24 present the growth of transverse, longitudinal, and total reflective cracks, respectively. The highest percentage of reflective cracks was observed in the PFC plus leveling course section. PFC plus seal coat is performing better than PFC without seal coat (with level-up). Generally, the sections with a geosynthetic product are performing slightly better than the control section. The control section experienced approximately 7 percent total reflective cracking three years after overlay construction; whereas, during the same period, total reflection cracking of the geosynthetic sections was less than 4 percent. The hot-in-place recycling section is performing essentially identical to the control section.

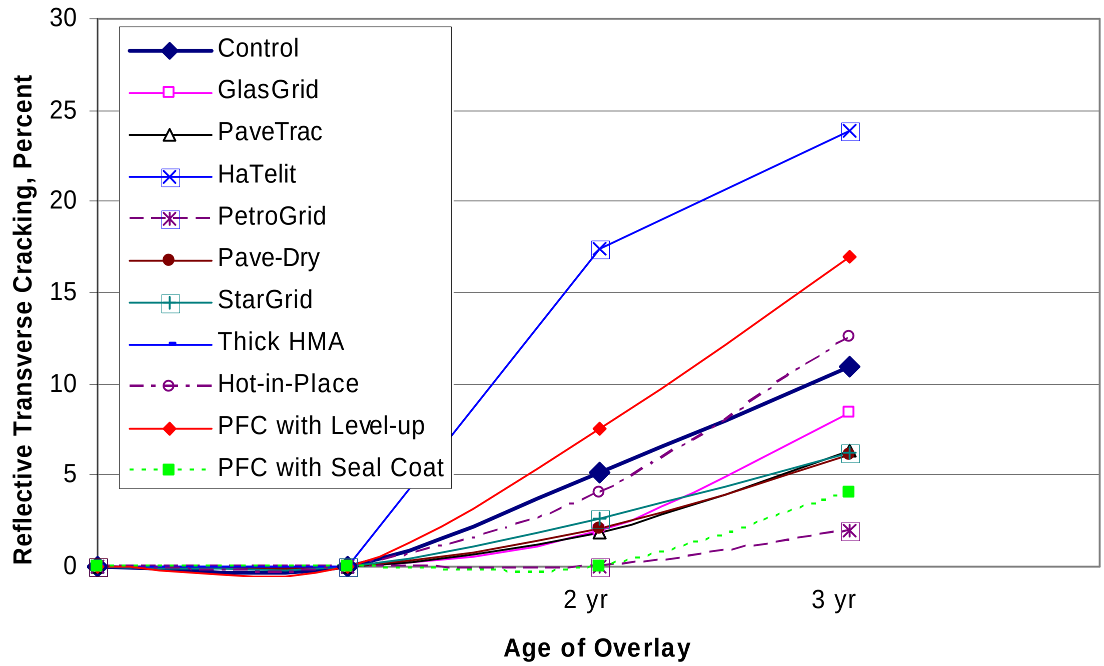

Figure 22. Reflective (Transverse) Cracking vs. Time after Placement of the Overlay.

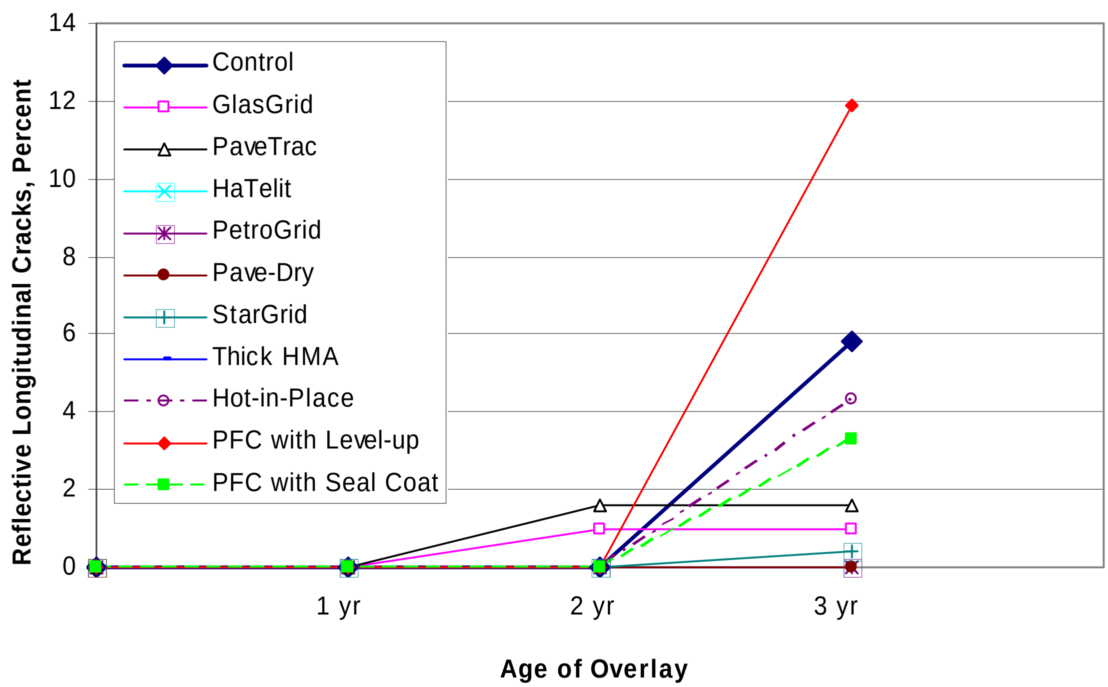

Figure 23. Reflective (Longitudinal) Cracking vs. Time after Placement of the Overlay.

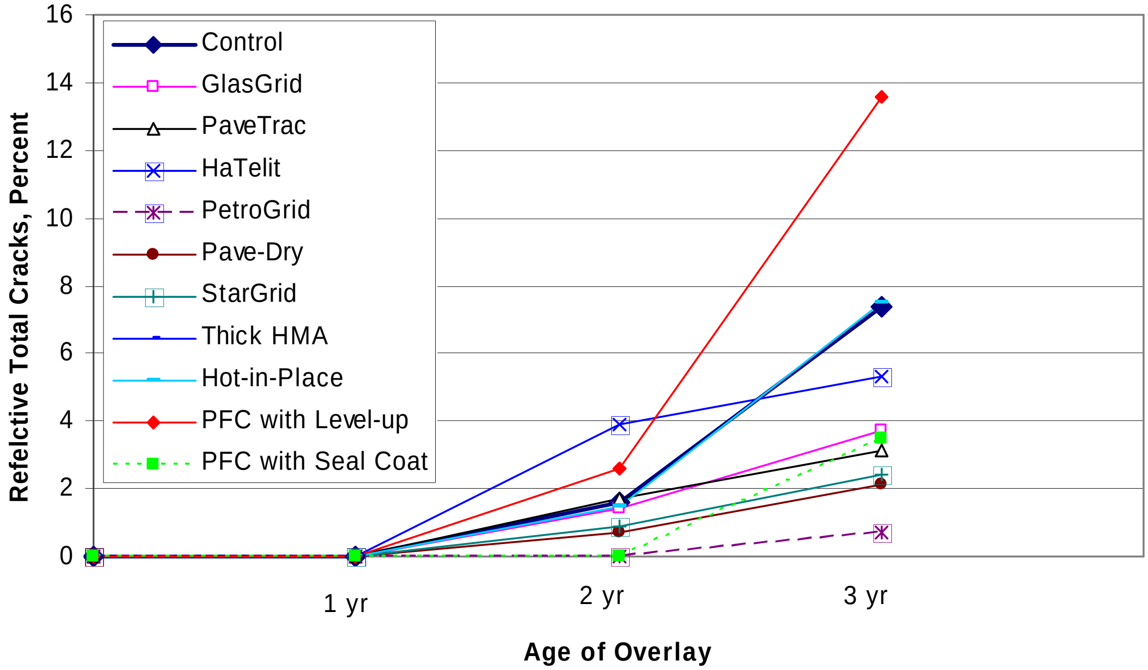

Figure 24. Reflective (Total) Cracking vs. Time after Placement of the Overlay.

The overall percentage of reflective cracking in all the sections for all three districts is great when compared to the number of cracks in the original pavement. At the writing of this report, it is too early to reach comprehensive conclusions about the relative performance of the different treatments used to mitigate reflective cracking in flexible pavements.

CHAPTER 3:
GEOSYNTHETIC COST ESTIMATE

When designing an overlay for a pavement containing significant cracking, an engineer may select from several rehabilitation alternatives that are suitable for reducing the severity and/or delaying the appearance of reflection cracking or reducing the intrusion of surface water after reflection cracking occurs. Some successful products that have been used in overlay systems to address these issues include:

- an interlayer composed of a geosynthetic (fabric, grid, or composite) or an asphalt rubber chip seal;
- heater scarification before overlaying;
- a seal coat or underseal;
- cracking and seating of concrete pavement; or
- simply a thicker overlay.

Cost comparisons of these and other alternatives on both first-cost and life-cycle bases are of interest to the engineer and should be considered when selecting the optimum rehabilitation alternative for a particular segment of pavement. The information in this section is provided to assist the designer when considering a geosynthetic interlayer as an alternative.

The information provided in this section is based on cost estimates provided by geosynthetic product application contractors (usually subcontractors to the paving contractor), geosynthetic product manufacturers, paving contractors, and TxDOT district personnel. The 500-foot test pavements placed as part of this research project did not provide realistic cost information for the following reasons:

(1) the test pavements were very short as compared to a typical highway project;
(2) the geosynthetic products were sometimes provided by the manufacturers at a reduced cost to the construction project;
(3) bid prices for geosynthetic installation may have been unrealistically high because of the short test sections, the number of different geosynthetic products used on the job, and the number of different geosynthetic product application subcontractors; and

(4) it is very difficult to extract accurate cost values for geosynthetic products and their installation from construction contract bids.

The final cost to a state agency for geosynthetic installation evolves in three tiers:

- the manufacturer's cost to the distributor/installer,
- the installer's bid price to the paving contractor, and
- the paving contractor's bid price to the state agency.

Installation costs of the stiffer products, such as grids and composites, may be a little more than that for fabrics because they typically come on smaller rolls and cannot be stretched to accommodate application on curves; however, offsetting this cost, grids usually require less tack than fabrics or composites. Further, prices for geosynthetic products and their installation vary significantly depending upon the location of the construction project (and thus the haul distances involved), the size of the project, and contractor experience (level of confidence or sense of risk). Furthermore, the cost of plastics such as polypropylene (from which many fabrics and some composites are made) and, of course, tack coats, relate closely to the petroleum industry, which has fluctuated drastically during the past several years. Therefore, the cost data provided herein should be used only as a general guide.

As an example of the convolution of geosynthetic product/installation costs from contractor bids, the following was obtained from two bids for construction of the Pharr District test sections. For the HMA plus geosynthetics only, one contractor bid \$194,000 plus \$114,000, respectively, while a competing contractor bid \$303,000 plus \$23,000, respectively. The total for this portion of the two bids (\$308K and \$326K) differed by only \$18,000. But the difference between the bid prices for the geosynthetic materials and installation (\$114 – \$23) differed by \$91,000!

Tables 3 and 4 show cost information assembled during this project for geosynthetic products and non-geosynthetic products, respectively. These data were obtained from geosynthetic installation contractors, construction contractors, and the most recent TxDOT average low-bid unit price database. At the time this information was obtained (summer 2005),

Table 3. Cost Estimates of Various Geosynthetic Products and Installation.[1]

Product Category	Product	Product Cost, dollars/yd^2	Tack Coat Cost, dollars/yd^2	Estimated Total Installed Cost, dollars/yd^2	Actual Bid Price @ Amarillo[3] (2001), \$/yd^2
Fabric	Petromat 4598	0.40	0.25	1.00	
	Propex	--	0.31	0.75	
	Mirapave 400	--	0.31	0.75	
	Pave-Dry 381	--	0.28	2.00	1.30
	Pave-Dry 461	--	0.28	2.00	
	TruPave (fiberglass)	--	0.25	2.00	
Grid	GlasGrid 8501 100 kN	--	--	6.00 – 7.50	2.00
	GlasGrid 8502 200 kN	--	--	10.00 – 14.00[2]	
Composite	PetroGrid 4582 100 kN	3.50–4.00	0.31	5.25	7.50
	Bitutex	--	0.31	5.25	5.50
	HaTelit	--	0.31	5.25	5.50
	StarGrid GPS	--	0.31	5.25	4.00

[1] These prices generally do not include paving or general contractor markup.
[2] Price is based on only one project in Illinois.
[3] From the Amarillo test pavement bid sheet, it is unclear whether this price includes installation.

the cost of asphalt for tack coat was approximately \$1.25 per gallon. Appropriate tack coat application rates depend not only on the geosynthetic product but also on the relative porosity of the old pavement, ambient temperature, solar radiation, and the tack coat material. So, actual tack coat cost for a given geosynthetic product will vary between projects. One geosynthetic product manufacturer estimated in 2005 that installation labor cost alone was about \$0.60 per square yard, again depending on the several factors mentioned above.

At the writing of this report, the 12-month moving average in-place cost of a 2-inch dense-graded surface mix HMA overlay in Texas was about \$60/ton or about \$6.30/yd^2

Table 4. Cost Estimates for Typical Treatments to Renew a Pavement Surface.

TxDOT Item No. Product	Reasonable Average Unit Cost	Installed Cost per Square Yard
Item 340 Dense-Graded HMA	\$60/ton	\$3.15/inch of thickness
Item 340 Additional 1 inch Overlay Thickness	\$52/ton	\$2.73
Item 316 Seal Coat	\$1.50/yd^2	\$1.50
Item 316 Seal Coat With AC-15-5TR	\$1.75/yd^2	\$1.75
One-inch depth of Surface Recycling/ Heater Scarification	\$1.40–2.10/yd^2	\$1.75

(assuming 3800 pounds/yd^3 of HMA). Therefore, in the simplest terms (considering only first cost), if one specifies a fabric costing approximately \$1.00/yd^2 to prolong the performance of a 2-inch overlay, the overlay/fabric system must provide a service life approximately 17 percent (1.00 ÷ 6.30 × 100 percent) longer than the 2-inch overlay alone for the fabric to be cost effective. For a fabric costing \$2.00/yd^2, the overlay/fabric system must last approximately 34 percent longer. If, for example, 100 kN GlasGrid is selected and its installed cost is \$6.75/yd^2, it would need to prolong the service life of the 2-inch overlay by 107 percent, or that is, it must essentially double the service life to be cost effective. These cost data are intended to be illustrative only. This simplified approach assumes no maintenance costs and a zero percent rate of return and is appropriate for general comparisons only.

Assuming a 2-inch overlay is to be placed on a certain roadway and the cost is \$6.30/yd^2, since mobilization cost is already covered, the cost of an additional inch of overlay would be approximately \$2.75/yd^2. Therefore, if one specifies the additional inch of overlay primarily to prolong the cracking performance of the 2-inch overlay, to be cost effective, the thicker overlay system must provide a service life approximately 44 percent longer than the 2-inch overlay alone.

When there is sufficient performance data from the geosynthetic test sections constructed as part of this study, the findings will be used to estimate the cost effectiveness of the various products evaluated based on life-cycle costs. The idea will not be to promote one commercial product over another but to show which categories of products (e.g., fabric or grid, stiff or compliant) demonstrate the best performance in a particular situation (e.g., pavement type, climate, traffic intensity) to the extent possible.

CHAPTER 4:
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

All of the test pavements are in reasonably good condition and have not approached the end of their life cycle. Based on the current status of the project, no conclusions can be reached regarding the life-cycle cost effectiveness of the various products evaluated. Further, it is not possible to show which categories of products (e.g., fabric or grid, stiff or compliant) demonstrate the best performance in a particular situation (e.g., pavement type, climate, traffic intensity) to the extent possible.

Based on first cost alone, installation of an inexpensive fabric must increase the service life of an overlay by more than 15 percent to be cost effective. On a similar basis and, of course, depending on the actual geosynthetic product and installation cost, a more expensive grid or composite material may need to double the service life of an overlay to be cost effective.

RECOMMENDATIONS

The authors recommend continuing annual evaluations of the test pavements until sufficient surface distress (primarily reflective cracking) has occurred such that the life cycle of the overlay can be predicted and, thus, life-cycle cost effectiveness of the various products tested can be estimated.

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APPENDIX A:
OVERLAY MIXTURE DESIGN AND GEOSYNTHETIC DATA

Combined Gradation

District:	21	CSJ #:	1804-02-019	Producer:	B.C.CO. PL. #3
County:	HIDALGO	Design #:	2004-D w/ LIME	Spec.Item	3146
Highway:	F.M. 1926	Contractor:	B.C.CO.	Type Mix:	Type "D"

	Source 1 FORDYCE Grade 4		Source 2 FORDYCE Grade 6		Source 3 FORDYCE W.C. Screenings		Source 4 Fordyce Cyclone Sand		Source 5 Aggr. Num 5 Lime		Source 6 Aggr. Num 6 Lab Num 6		Total % 100.0			
Sieve Size	Bin #1 32.0	Total %	Bin #2 32.0	Total %	Bin #3 20.0	Total %	Bin #4 15.0	Total %	Bin #5 1.0	Total %	Bin #6 0.0	Total %	Cumultive Pass	TxDOT Specs.	Individ. Ret.	Cumul. Ret.
-	100.0	32.0	100.0	32.0	100.0	20.0	100.0	15.0	100.0	1.0	100.0	0.0	100.0	-	0.0	0.0
-	100.0	32.0	100.0	32.0	100.0	20.0	100.0	15.0	100.0	1.0	100.0	0.0	100.0	-	0.0	0.0
1/2"	98.1	31.4	100.0	32.0	100.0	20.0	100.0	15.0	100.0	1.0	100.0	0.0	99.4	98 - 100	0.6	0.6
3/8"	71.6	22.9	100.0	32.0	100.0	20.0	100.0	15.0	100.0	1.0	100.0	0.0	90.9	85 - 100	8.5	9.1
#4	14.0	4.5	74.6	23.9	95.0	19.0	100.0	15.0	100.0	1.0	100.0	0.0	63.4	50 - 70	27.5	36.6
#10	4.9	1.6	21.3	6.8	61.3	12.3	99.6	14.9	100.0	1.0	100.0	0.0	36.6	32 - 42	26.8	63.4
#40	2.3	0.7	3.8	1.2	31.2	6.2	97.6	14.8	100.0	1.0	100.0	0.0	23.7	11 - 26	12.9	76.3
#80	1.2	0.4	2.5	0.8	8.9	1.8	37.4	5.6	100.0	1.0	100.0	0.0	9.6	4 - 14	14.1	90.4
#200	0.8	0.3	2.0	0.6	2.8	0.6	8.1	1.2	100.0	1.0	100.0	0.0	3.7	1 - 6	5.9	96.3
Pan															3.7	100.0

Asphalt Content of RAP in Bin # 1(If Applicable) = %

Asphalt Source & Grade: Coastal PG Grade 64-22

NOTES: This design contains 1.0% lime as a antistripping agent

English	1 1/2"	1 1/4"	1"	7/8"	5/8"	1/2"	3/8"	1/4"	#4	#10	#40	#80	#200
Metric	37.5 mm	31.5 mm	25.0 mm	22.4 mm	16.0 mm	12.5 mm	9.5 mm	6.3 mm	4.75 mm	2.0 mm	0.425 mm	0.180 mm	0.075 mm

Level 2 Technician: D. Nicholas Anders Tx. DOT Certification #: 372

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Figure A1. Pharr Test Pavement Overlay Mixture Design – Aggregate Gradation.

SUMMARY

District:	21	CSJ #:	1804-02-019	Producer:	B.C.CO. PL. #3
County:	HIDALGO	Design #:	2004-D w/ LIME	Spec.Item:	3146
Highway:	F.M. 1926	Contractor:	B.C.CO.	Type Mix:	Type "D"

Asphalt Content %	Sp.Grav. of Specimen Ga	Maximum Sp.Grav. Gr	Effective Gravity Ge	Theoretical Max. Sp. Gr Gt	Density (From Gt) %	VMA %	Hveem Stability %	Static Creep Test: Creep Stiffness (Psi)	Static Creep Test: Permanent Strain x 1,000 (In./In.)	Static Creep Test: Slope of SS Curve x 100,000,000 (In./In./Sec.)
3.0	2.241	2.502	2.618	2.492	89.9	16.6				
4.0	2.292	2.453	2.603	2.456	93.3	15.6				
5.0	2.327	2.429	2.617	2.421	96.1	15.2				
6.0	2.348	2.387	2.607	2.387	98.4	15.3				
7.0	2.341	2.339	2.587	2.354	99.4	16.5				
Interpolated values at optimum density of:					96.0 %	15.2				

Effective Spec. Gr. (Ge)= 2.607

Optimum Asphalt Content = 5.0 %

VMA @ Optimum Asphalt Content = **15.2**

Interpolated Values

Ga @ Optimum Asphalt Content =	2.326
Gr @ Optimum Asphalt Content =	2.430
Gt @ Optimum Asphalt Content =	2.422

Figure A2. Pharr Test Pavement Overlay Mixture Design Summary.

TEXAS DEPARTMENT OF TRANSPORTATION

WACO DISTRICT LABORATORY

HMACP MIXTURE DESIGN : COMBINED GRADATION

Refresh Workbook

File Version: 01/28/04 14:02:38

SAMPLE ID:	HOD09000010302	SAMPLE DATE:	
LOT NUMBER:	0001	LETTING DATE:	
STATUS:	COMP	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	1993
SAMPLED BY:		SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	NONE
MATERIAL:	QCQA1CMD00	MIX TYPE:	Type_D
PRODUCER:	Lindsey Contractors		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

BIN FRACTIONS

	Bin No.1		Bin No.2		Bin No.3		Bin No.4		Bin No.5		Bin No.6		Bin No.7		Combined Gradation
Aggregate Source:	Vulcan-Tehuacana		Vulcan-Tehuacana		Lindsey										
Aggregate Number:	DF Rock		Scrngs		434 F sand		Lime								
Sample ID:															
Rap:(Yes/No), % Asphalt:															Total Bin
Individual Bin (%):	60.0	Percent	30.0	Percent	9.0	Percent	1.0	Percent		Percent		Percent		Percent	100.0%

Sieve Size:	Sieve Size: (mm)	Bin No.1 Cum.% Passing	Bin No.1 *Wtd* Cum. %	Bin No.2 Cum.% Passing	Bin No.2 *Wtd* Cum. %	Bin No.3 Cum.% Passing	Bin No.3 *Wtd* Cum. %	Bin No.4 Cum.% Passing	Bin No.4 *Wtd* Cum. %	Bin No.5 Cum.% Passing	Bin No.5 *Wtd* Cum. %	Bin No.6 Cum.% Passing	Bin No.6 *Wtd* Cum. %	Bin No.7 Cum.% Passing	Bin No.7 *Wtd* Cum. %	Cum. % Passing	Within Spec's	Lower Type_D Specification Limits	Upper Type_D Specification Limits	Individual % Retained	Cumulative % Retained	Sieve Size
1/2"	12.500	100.0	60.0	100.0	30.0	100.0	9.0	100.0	1.0		0.0		0.0		0.0	100.0	Yes	98.0	100.0	0.0	0.0	1/2"
3/8"	9.500	98.8	59.3	99.3	29.8	100.0	9.0	100.0	1.0		0.0		0.0		0.0	99.1	Yes	85.0	100.0	0.9	0.9	3/8"
No. 4	4.750	39.7	23.8	98.2	29.5	100.0	9.0	100.0	1.0		0.0		0.0		0.0	63.3	Yes	50.0	70.0	35.8	36.7	No. 4
No. 10	2.000	3.2	1.9	73.7	22.1	98.6	8.9	100.0	1.0		0.0		0.0		0.0	33.9	Yes	32.0	42.0	29.4	66.1	No. 10
No. 40	0.425	1.6	1.0	46.1	13.8	93.5	8.4	100.0	1.0		0.0		0.0		0.0	24.2	Yes	11.0	26.0	9.7	75.8	No. 40
No. 80	0.180	1.3	0.8	23.3	7.0	53.6	4.8	100.0	1.0		0.0		0.0		0.0	13.6	Yes	4.0	14.0	10.6	86.4	No. 80
No. 200	0.075	1.3	0.8	4.2	1.3	10.5	0.9	100.0	1.0		0.0		0.0		0.0	4.0	Yes	1.0	6.0	9.6	96.0	No. 200

\# Not w ithin specifications # Not cumulative

Asphalt Source & Grade:	Wright PG 70-22 S	Binder Percent, (%):	5.5	Specific Gravity of Asphalt:	1.030

Figure A3. Waco Test Pavement Overlay Mixture Design – Aggregate Gradation.

TEXAS DEPARTMENT OF TRANSPORTATION

WACO DISTRICT LABORATORY

HMACP MIXTURE DESIGN : SUMMARY SHEET

File Version: 01/28/04 14:02:38

SAMPLE ID:	HOD09000010302	SAMPLE DATE:	
LOT NUMBER:	0001	LETTING DATE:	
STATUS:	COMP	CONTROLLING CSJ:	
COUNTY:		SPEC YEAR:	
SAMPLED BY:		SPEC ITEM:	
SAMPLE LOCATION:		SPECIAL PROVISION:	NONE
MATERIAL:	QCQA1CMD00	MIX TYPE:	Type_D
PRODUCER:	Lindsey Contractors		
AREA ENGINEER:		PROJECT MANAGER:	

COURSE\LIFT:		STATION:		DIST. FROM CL:	

Target Density:	**96**	Percent

Asphalt Content (%)	Specific Gravity Of Specimen (Ga)	Maximum Specific Gravity (Gr)	Effective Gravity (Ge)	Theo. Max. Specific Gravity (Gt)	Density from Gt (Percent)	VMA (Percent)	Hveem Stability (%)	Static Creep: Creep Stiffness (psi)	Static Creep: Perm. Strain X1000 (in/in)	Static Creep: Slope of SS Curve X 10^9 (in/in/Sec)
4.50	2.315	2.477	2.653	2.477	93.5	16.7				
5.00	2.328	2.462	2.656	2.459	94.7	16.6				
5.50	2.340	2.438	2.649	2.441	95.9	16.6				
6.00	2.354	2.422	2.651	2.424	97.1	16.6				
6.50	2.362	2.408	2.655	2.406	98.2	16.7				

Effective Specific Gravity:	2.653

Optimum Asphalt Content:	**5.6**
VMA @ Optimum AC:	**16.6**

Interpolated Values	
Specific Gravity (Ga):	**2.342**
Max. Specific Gravity (Gr):	**2.436**
Theo. Max. Specific Gravity (Gt):	**2.439**

Figure A4. Waco Test Pavement Overlay Mixture Design Summary.

PaveTex

Engineering and Testing, Inc.
3991 Highway 290 East, Building C
Dripping Springs, Tx 78620
(512) 858 2993   Fax (512) 858 2921

Mixture Design Summary

PaveTex Design Number: 2237 R   **Date: April 29, 2002**

Projects:	SH 136, Potter County
CSJ:	CPM 379-3-19
Mixture Type:	Type D
Stockpiles:	
Fletcher D-Rock	18%
Fletcher 5/16"-Rock	41%
Fletcher Screenings	31%
G-T Field Sand	9%
Hydrated Lime	1%

Antistripping Additive: 1% Hydrated Lime
Asphalt : Royal Trading Co. PG 70-28
Optimum Asphalt Content is 5.0% based on 4.0 % air voids

Mixture Properties at optimum Asphalt Content are :

VMA:	15.6%
Bulk Specific Gravity:	2.351
Max. Specific Gravity:	2.444

Based on Results summarized here and details documented in following sheets, this proposed mixture design meets requirements of Special Specification Item 3146

STATE OF TEXAS
M. TAHMORESSI
64944
REGISTERED
PROFESSIONAL ENGINEER

Reviewed By:
Maghsoud Tahmoressi, P.E.
PaveTex Engineering & Testing, Inc

Figure A5. Amarillo Test Pavement Overlay Mixture Design Summary.

Combined Gradation

District: Amarillo	CSJ #: CPM379-3-19	Producer: Gilvin-Terril
County: Potter	Design #: 2237 R	Spec.Item: 3146
Highway: SH 136	Contractor: Gilvin-Terril	Type Mix: D

	Fletcher D-Rock Lab # 4143		Fletcher 5/16"-Rock Lab # 4142		Fletcher Screenings Lab# 4145		G-T Field sand Lab# 4144		Hydrated Lime		Source Source		Total % 100.0			
Sieve Size	Bin #1 18.0	Total %	Bin #2 41.0	Total %	Bin #3 31.0	Total %	Bin #4 9.0	Total %	Bin #5 1.0	Total %	Bin #6 0.0	Total %	Cumultive Pass	TxDOT Specs.	Individ. Ret.	Cumul. Ret.
-	100.0	18.0	100.0	41.0	100.0	31.0	100.0	9.0	100.0	1.0	100.0	0.0	100.0	-	0.0	0.0
-	100.0	18.0	100.0	41.0	100.0	31.0	100.0	9.0	100.0	1.0	100.0	0.0	100.0	-	0.0	0.0
1/2"	100.0	18.0	100.0	41.0	100.0	31.0	100.0	9.0	100.0	1.0	100.0	0.0	100.0	98 - 100	0.0	0.0
3/8"	61.2	11.0	100.0	41.0	100.0	31.0	100.0	9.0	100.0	1.0	100.0	0.0	93.0	85 - 100	7.0	7.0
#4	1.2	0.2	50.9	20.9	100.0	31.0	100.0	9.0	100.0	1.0	100.0	0.0	62.1	50 - 70	30.9	37.9
#10	0.8	0.1	0.4	0.2	82.2	25.5	100.0	9.0	100.0	1.0	100.0	0.0	35.8	32 - 42	26.3	64.2
#40	0.6	0.1	0.3	0.1	30.0	9.3	93.7	8.4	100.0	1.0	100.0	0.0	18.9	11 - 26	16.9	81.1
#80	0.4	0.1	0.3	0.1	14.2	4.4	31.0	2.8	100.0	1.0	100.0	0.0	8.4	4 - 14	10.5	91.6
#200	0.1	0.0	0.1	0.0	5.4	1.7	3.7	0.3	100.0	1.0	100.0	0.0	3.0	1 - 6	5.4	97.0
Pan															3.0	100.0

Asphalt Content of RAP in Bin # 1(If Applicable) = %

Asphalt Source & Grade: Royal Trading Co. PG 70-28 Lab # 4179

NOTES:

Mixing Temperature 325 F, Compaction Temperature 300 F

English	1 1/2"	1 1/4"	1"	7/8"	5/8"	1/2"	3/8"	1/4 "	#4	#10	#40	#80	#200
Metric	37.5 mm	31.5 mm	25.0 mm	22.4 mm	16.0 mm	12.5 mm	9.5 mm	6.3 mm	4.75 mm	2.0 mm	0.425 mm	0.180 mm	0.075 mm

Level 2 Technician: Maghsoud Tahmoressi

Tx. DOT Certification #: 169

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Figure A6. Amarillo Test Pavement Overlay Mixture Design – Aggregate Gradations.

SUMMARY

District:	Amarillo	CSJ #:	CPM379-3-19	Producer:	Gilvin-Terril
County:	Potter	Design #:	2237 R	Spec.Item:	3146
Highway:	SH 136	Contractor:	Gilvin-Terril	Type Mix:	D

Asphalt Content %	Sp.Grav. of Specimen Ga	Maximum Sp.Grav. Gr	Effective Gravity Ge	Theoretical Max. Sp. Gr. Gt	Density (From Gt) %	VMA %	Hveem Stability %	Static Creep Test: Creep Stiffness (Psi)	Static Creep Test: Permanent Strain x 1,000 (In./In.)	Static Creep Test: Slope of SS Curve x 100,000,000 (In./In./Sec.)
4.0	2.315			2.488	93.0	16.0				
4.5	2.333	2.483	2.662	2.469	94.5	15.8				
5.0	2.350	2.445	2.638	2.451	95.9	15.6				
5.5	2.368	2.426	2.637	2.433	97.3	15.4				
6.0	2.380			2.416	98.5	15.5				
Interpolated values at optimum density of:				96.0 %		15.6				

Effective Spec. Gr. (Ge)= 2.646

Optimum Asphalt Content = 5.0 %

VMA @ Optimum Asphalt Content = **15.6**

Specific Gravity of Binder = **1.022**

Interpolated Values

Ga @ Optimum Asphalt Content =	2.351
Gr @ Optimum Asphalt Content =	2.444
Gt @ Optimum Asphalt Content =	2.450

Figure A7. Amarillo Test Pavement Overlay Mixture Design Properties.

Table A1. Summary of Geosynthetics Used in Different Test Pavements.

Brand Name	Manufacturer	Type/Description	Recommended Tack Use (gal/yd^2)	Comment
PavePrep®	Crafco, Inc.	Woven Polyester Composite	0.15	
GlasGrid® 8501	Bayex, Inc.	Woven/Coated Fiberglass Grid,	Tack not required except for wet pavement	
GlasGrid® 8502	Bayex, Inc.	Woven/Coated Fiberglass Grid, wider string and double strength compared to 8501	Tack not required except for wet pavement	
PaveDry® 381	Synthetic Industries	Polypropylene Nonwoven Fabric	0.20	
StarGrid® GPS	Luckenhaus, N.A.	Woven/Coated Fiberglass Grid/Nonwoven Composite	0.25	
HaTelit® C40/17	Huesker	Woven/Coated Fiberglass Grid	0.10	
PetroGrid® 4582	Amoco Fabrics	Woven/Coated Polyester Grid/Nonwoven Composite	0.23	
PaveTrac®	Bekaert Corporation	Woven steel mesh with torsioned flat-bar	--	Steel wire mesh (not geosynthetic)
Bitutex® Composite	Synteen USA	Woven/Coated Polyester Grid/Nonwoven Composite	0.25	

-- data not available

APPENDIX B:
CRACKING DATA

Table B1. Crack Length Measurement of Test Pavements in Pharr District.

Test Section	Length of Cracks (ft)					
	Before Construction, 2001			November 2005		
	Transverse	Longitudinal	Total	Transverse	Longitudinal	Total
PetroGrid	26	1097	1123	0	0	0
Bitutex	103	548	651	0	0	0
StarGrid	48	666	674	0	0	0
Thick Control	85	601	686	0	0	0
Pave-Dry	34	578	612	0	71	71
HaTelit	65	786	851	0	36	36
GlasGrid	15	700	715	0	56	56
Control	44	535	579	0	0	0

Table B2. Crack Length Measurement of Test Pavements in Waco District.

Test Section	Length of Cracks (ft)											
	Before Construction			1 yr After Level-Up			1 yr After Overlay			2 yrs After Overlay		
	Trans	Long	Total	Trans	Long	Total	Trans	Long	Total	Trans	Long	Total
PavePrep	696	743	1439	132	166	298	20	4	24	44	6	50
Addn. 1 in. HMA	885	1240	2125	417	410	827	334	102	436	362	113	475
GlasGrid	929	1454	2383	353	771	1124	155	48	203	254	105	359
Pave_Dry	616	1316	1932	433	879	1312	79	22	101	189	40	229
Saw & Seal	507	1024	1531	499	485	984	255	0	255	287	22	309
PetroGrid	828	1358	2186	415	666	1081	99	8	107	179	80	259
Control	906	1578	2484	341	415	756	307	100	407	355	259	614

Table B3. Crack Length Measurement of Test Pavements in Amarillo District.

Test Section	Length of Cracks (ft)											
	Before Construction, May 2003			1 yr after Overlay, June 2003			2 yrs after Overlay, April 2004			3 yrs after Overlay, April 2005		
	Trans	Long	Total	Trans	Long	Total	Trans	Long	Total	Trans	Long	Total
Control	782	1712	2494	0	0	0	40	0	40	85	100	185
GlasGrid	835	1450	2285	0	0	0	16	15	31	70	15	85
PaveTrac	738	1601	2339	0	0	0	14	26	40	47	26	73
HaTelit	46	160	206	0	0	0	8	0	8	11	0	11
PetroGrid	658	1315	1973	0	0	0	0	0	0	13	0	13
PaveDry	654	1284	1938	0	0	0	14	0	14	40	0	40
StarGrid	616	1184	1800	0	0	0	16	0	16	38	5	43
Thick Control	847*	1388*	2235*	0	0	0	--	--	--	--	--	--
Hot-in-Place#	847	1388	2235	0	0	0	34	0	34	107	60	167
PFC With Level-Up	834	1603	2437	0	0	0	63	0	63	142	190	332
PFC with Seal Coat	930	1524	2454	0	0	0	0	0	0	37	50	87

Considered only 500 ft, * Used same original crack as Hot-in-Place Recycle Section

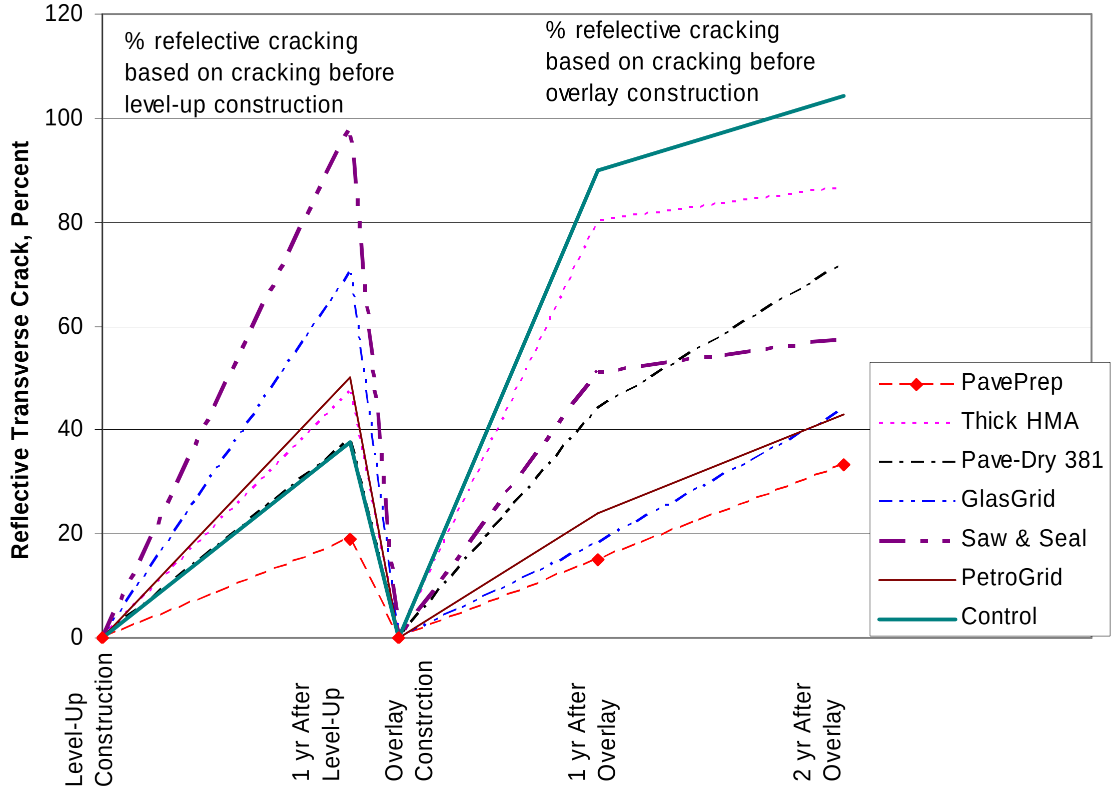

Figure B1. Waco District Reflective (Transverse) Cracking vs. Time — Based on Cracking Measured on Leveling Course Before Overlay.

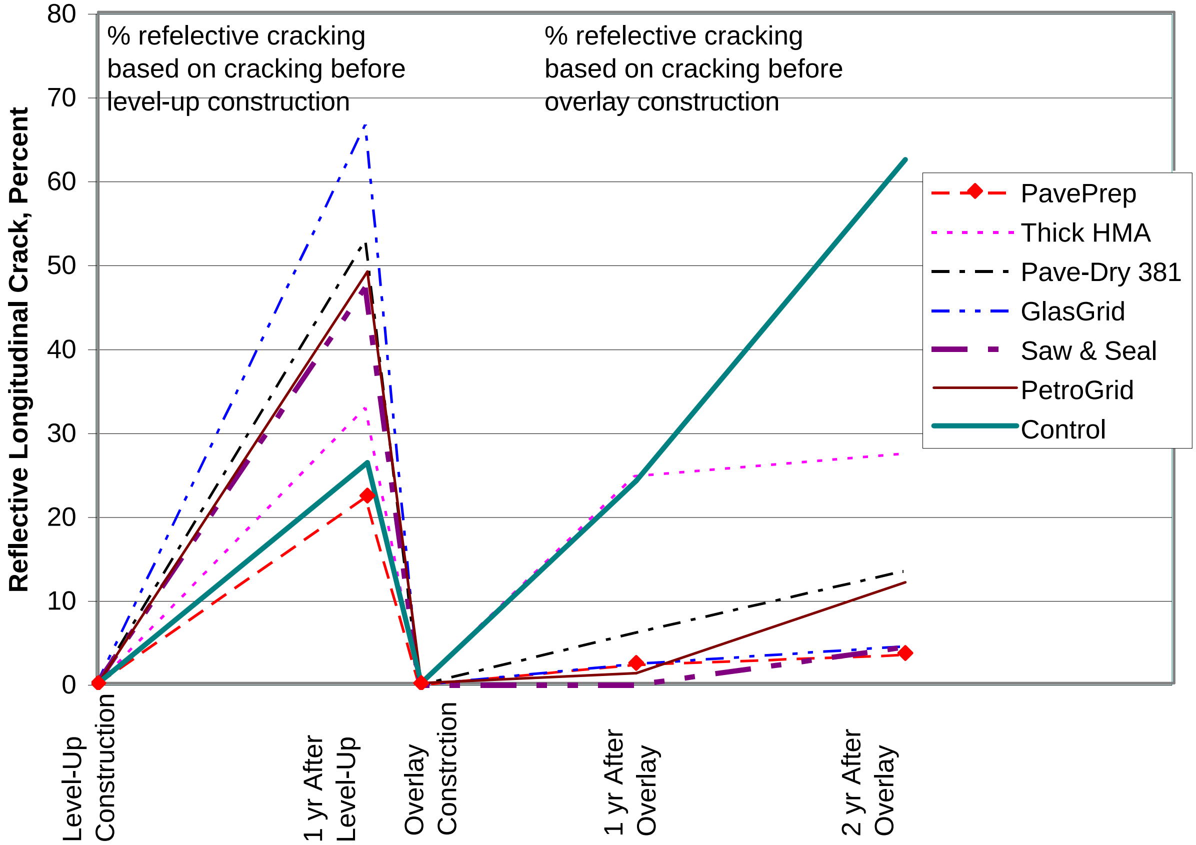

Figure B2. Waco District Reflective (Longitudinal) Cracking vs. Time — Based on Cracking Measured on Leveling Course Before Overlay.

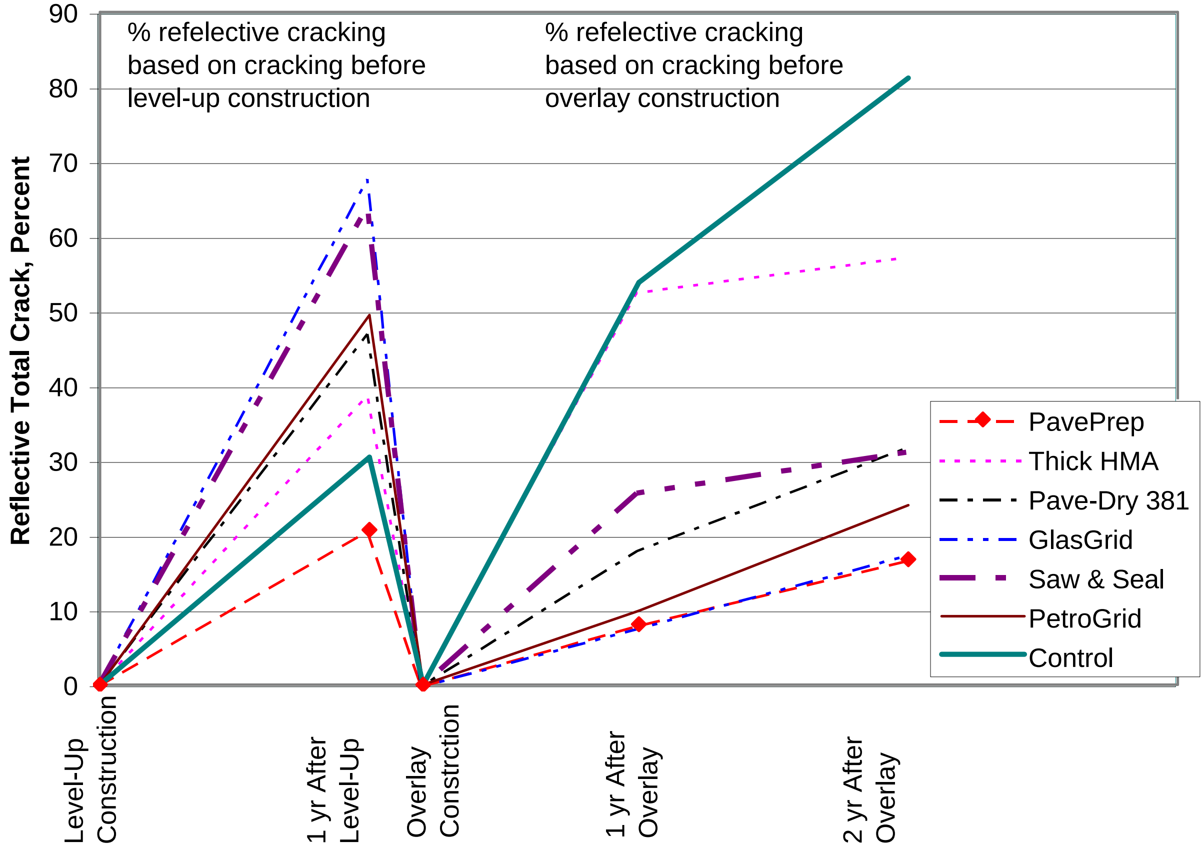

Figure B3. Waco District Reflective (Total) Cracking vs. Time — Based on Cracking Measured on Leveling Course Before Overlay.