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# Comparative Analysis of Tack Coats, Spray Paver Membranes, and Underseals: Technical Report

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COLLEGE STATION, TEXAS

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16. Abstract
Tack coats, trackless tack coats, spray paver underseal membranes, and underseals provide varying levels of bonding and sealing performance, but these benefits have not been sufficiently quantified, and neither has the overall impact on the asphalt overlay service life. This study 1) evaluated the performance of bonding and sealing treatments for bond strength, resistance to reflection cracking, and permeability, 2) estimated the life-cycle cost for each treatment, and 3) provided a reference guide for bonding and sealing treatments.

Laboratory samples and field samples from 42 test sections on five overlay projects were tested for bond strength (Texas shear bond strength test), cracking resistance (modified Texas overlay test and compact tension test), and permeability (Florida falling head permeability test). All tests were sensitive to treatment type. Hot-applied trackless tack had the highest bond strength and spray paver membranes and underseals were the weakest, though all treatments demonstrated acceptable performance. Bond strengths varied significantly among the projects. Bonding was very sensitive to sample age with older samples having higher strength. Most of the bond strength is likely gained in the first month. The highest cracking resistance and also the lowest permeability was from high-residual treatments (underseal, spray paver membrane, and hot-applied trackless tack).

The performance of an overlay over aged transversely cracked pavement was modeled. Higher bonding increased fatigue and rutting life. For reflection cracking, a partial bond resulted in longer service life. The spray paver membrane and underseal treatments had the longest service life and the spray paver membrane had the lowest life-cycle cost. For other scenarios, constrained by rutting or fatigue, a different treatment is likely to prove more cost-effective.

A bonding and sealing treatment guide was developed with scenario recommendations for applying each treatment.


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# COMPARATIVE ANALYSIS OF TACK COATS, SPRAY PAVER MEMBRANES, AND UNDERSEALS: TECHNICAL REPORT

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Field evaluations were assisted by James (TxDOT-Bryan), Joe Seago (TxDOT-Bryan), Jace Lee (TxDOT-Bryan), Arif Chowdhury (TTI), Tony Barbosa (TTI), Jason Huddleston (TTI), Big Creek Construction, APAC-Wheeler, and Foremost Paving, Inc. Bill Crockford (TTI) was instrumental in developing the tack spray system. Sheng Hu (TTI) advised us on pavement modeling. Test materials and technical advice were provided by the following asphalt emulsion vendors: Blacklidge Emulsions (Grover Allen) and Ergon Asphalt & Emulsions (Tom Flowers). Dr. Mariam Sakhaeifar (Texas A&M) served as an advisor for Amin Banihashemrad. Several Texas A&M students was invaluable in completing laboratory and field testing, namely Aswin Easwaran, Utsav Goyal, Jianxin Huang, and Yash Menaria.

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# CHAPTER 1
# INTRODUCTION

## PROBLEM STATEMENT

The bond quality between pavement layers significantly impacts pavement life. Poor overlay bonding may lead to delamination, slippage cracking, and premature fatigue cracking, reflection cracking, and rutting. Different treatments can be used to ensure proper bonding of a new asphalt overlay, including:

- Traditional tack coats.
- Trackless tack coats.
- Spray paver underseal membranes.
- Traditional underseals.

The treatments provide varying levels of bonding and sealing performance, but these benefits have not been sufficiently quantified, and neither has the overall impact on the asphalt overlay service life. Consequently, for a given overlay scenario, there is confusion about which treatment would provide the best long-term performance for the lowest possible cost.

## SCOPE AND OBJECTIVE

This study:

1. Evaluated the performance of different bonding and sealing treatments for:
    - Shear bond strength.
    - Resistance to reflection cracking.
    - Permeability.
2. Estimated the life-cycle cost for each treatment.
3. Provided a reference guide for bonding and sealing treatments.

The scope of this study was to:

1. Review the literature for bonding and sealing treatments and associated performance.
2. Survey Texas Department of Transportation (TxDOT) districts about their experience with each treatment.
3. Develop a laboratory tack spray system for sample fabrication.
4. Test bond strength, reflection cracking, and permeability performance of laboratory samples.
5. Test the performance of several test sections from five field projects.
6. Predict the long-term performance of test sections on one project and perform a life-cycle cost analysis.
7. Develop a bonding and sealing treatment reference guide.

## OUTLINE

This report contains seven chapters:

- Chapter 1 describes the problem statement, objectives, and scope.
- Chapter 2 gives background information for bonding and sealing treatments.
- Chapter 3 presents the results of a survey to TxDOT districts.
- Chapter 4 presents an evaluation of bonded pavement layer performance in the laboratory.
- Chapter 5 discusses the construction and testing of field sections.
- Chapter 6 presents the Life Cycle Cost Analysis (LCCA) for the comprehensive test section.
- Chapter 7 summarizes the research, findings, and offers recommendations.

# CHAPTER 2
# BACKGROUND

This chapter gives background information on the following topics:

- Bonding and sealing treatments.
- Effect of bonding on overlay performance.
- Effect of interlayer stress relief on reflection cracking.
- Effect of bonding and sealing treatments as moisture barriers.

## BONDING AND SEALING TREATMENTS

### Traditional Tack Coat

Tack coat is a light application of bituminous material to an existing surface to provide a bond between existing and new pavement layers (ASTMD8-02) (Figure 2-1). The most common tack materials are asphalt emulsions, CSS-1H and SS-1H. Other possible tack materials are polymer-modified (pm)-emulsion, neat asphalt (asphalt cement (AC) 5, AC 10), pm-asphalt, and cutbacks.

**Figure 2-1. Traditional Tack Coat.**

Proper application rate is important to a quality tack coat. Each project has an optimal tack rate based on surface texture, existing surface age, and overlay type. If the rate is too low, there is insufficient surface binder to interact with the overlay mixture. Too high and the interface can become unstable and act as a slip plane. The rate will normally be between 0.04 and 0.10 gal/sy (about 0.02 to 0.05 gal/sy residual). Coarse surfaces (milling, surface treatment, etc.) require higher tack rates to cover greater surface area. Similarly, coarse and open-graded overlays require more tack. Aged surfaces, with little to no surface binder also require a higher rate than on a new pavement. Bleeding surfaces should not be tacked.

Tack coat applications should also be uniform (Figure 2-2). This is especially important at lower rates. Poor uniformity is caused by clogged nozzles, nozzle misalignment, slow pump speed (usually related to slow vehicle speed), and low tack temperature. Asphalt emulsions and cutbacks can be sprayed at lower temperatures around 150°F while neat and modified asphalt must be applied at 275°F or higher.

**Figure 2-2. Proper and Improper Application Rate/Distribution.**

Even when tack is applied correctly, the material may be picked up and contaminated by construction traffic ahead of the paver. This is especially a problem on aged roads where a good tack coat is critical. The issue can be mitigated by using a trackless tack that resists tracking, using a spray paver, or loading hot mix asphalt (HMA) from the adjacent lane with a material transfer vehicle.

### Trackless Tack Coat

Trackless tacks have gained popularity in Texas in the past 5–10 years. They use a hard-pen base asphalt or heavily pm-asphalt that hardens shortly after application and loses its tackiness. Consequently, the tack resists pick up under traffic (Figure 2-3). When HMA is applied and compacted over the material, the tack is reactivated and bonds to the new overlay. There are stiff emulsion types, softer emulsion types, and hot-applied types of trackless tack. The best performing tacks for tracking resistance are the hot-applied types. Stiff residual emulsions types also performed well except at the hottest temperatures (~160°F). The soft-residual emulsions performed well at low and moderate temperatures but still exhibited tracking characteristics at typical summer-paving temperatures (*1*). Both emulsion materials may pick up under slow, heavy paver or material transfer vehicle traffic.

**Figure 2-3. Trackless Tack.**

Application temperatures are about 170°F for emulsions and 325°F for hot-applied. Suggested rates for emulsion are comparable to regular tack and are between 0.10 and 0.20 gal/sy for hot-applied tack. The main construction issue is keeping the temperature within the distributor lines hot enough to keep the material at low viscosity.

Many studies have shown that trackless tacks yield higher bond strengths than traditional tacks (*1*, *2*, *3*). The high strength also suggests the material is more brittle. It may be more prone to allowing reflection cracks to propagate through the new overlay.

**Spray Paver Underseal Membrane**

A spray paver underseal membrane is a thick (0.13–0.30 gal/sy) pm-emulsion applied with a spray paver immediately in front of the overlay mixture. The high application rate can help seal existing distress and may provide stress relief against reflection cracking. When used with a gap- or open-graded mix, there are enough voids to accommodate the extra emulsion.

A spray paver is a specialty paver that incorporates a heated tank and spray bar on a standard asphalt paver. The spray bar is located immediately in front of the asphalt augers and screed. Using a spray paver eliminates the possibility of tack coat contamination. Because the speed of a spray paver is limited to the paving speed, the spray system cannot apply tack rates as low as a regular distributor. The tack tank also has a much smaller capacity than a distributor (500 gal versus 1,000–4,000 gal).

**Figure 2-4. Underseal Membrane Applied with a Spray Paver.**

**Underseal**

An underseal is a surface treatment with a light single-application of aggregate applied ahead of an overlay (Figure 2-5). The binder is any seal coat asphalt like pm-asphalt, rubber-asphalt, pm-emulsion, or rubber-emulsion. The rock is a uniform Grade 3 or Grade 4 and may be pre-coated. Binder application rates are 0.25 to 0.40 gal/sy and the rock rate is typically 1 cy/sy.

An underseal provides several benefits, such as waterproofing the surface, sealing cracks, and relieving stress from propagating cracks. During construction, the loose rock provides a temporary riding surface for construction traffic.


**Figure 2-5. Traditional Underseal.**

## EFFECT OF TREATMENTS ON SHEAR BOND STRENGTH

The strength of a layered pavement is largely dependent on the bond quality at the layer interfaces. A perfect bond will cause the two layers to act as one, dispersing traffic loads from one layer into the next (Figure 2-6). On the other hand, a poor bond will concentrate compressive, tensile, and lateral shear stresses within the upper layer, expediting fatigue cracking, slippage cracking, and delamination. All these problems are then exacerbated by moisture accumulating at the de-bonded interface.

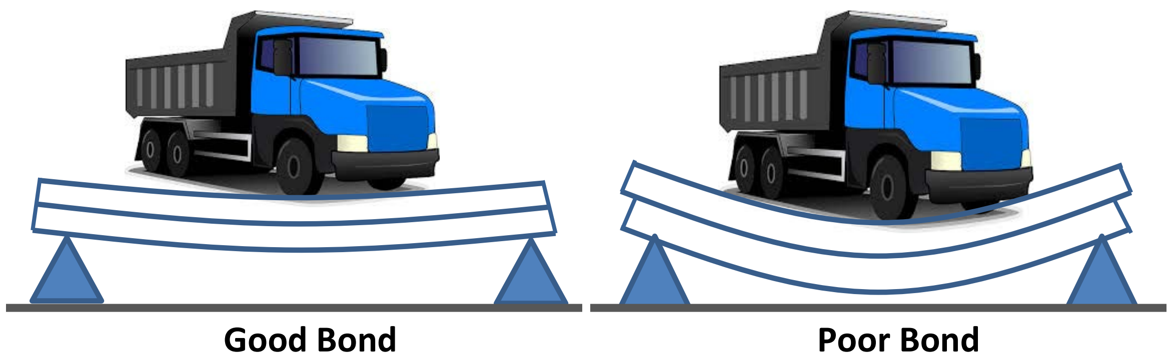
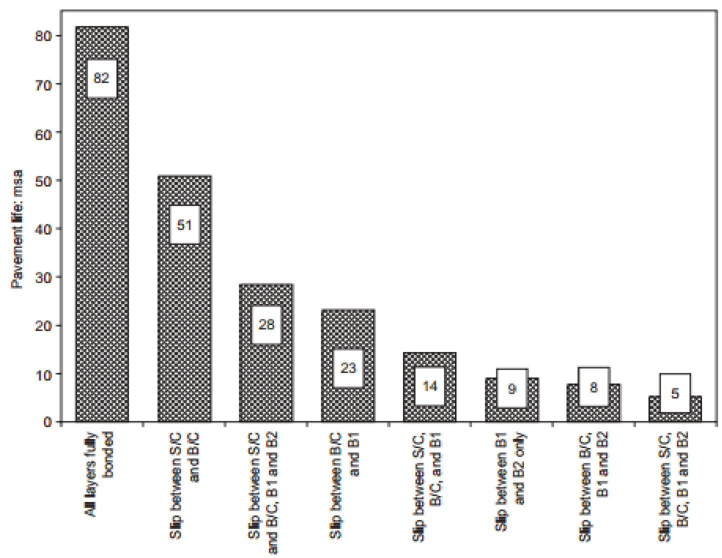



**Figure 2-6. Simplified Physics of Bonding.**

Figure 2-7 presents a few examples that highlight the importance of bonding to pavement life. Khweir and Fordyce modeled several bonding scenarios by varying slip conditions between base and subgrade layers and estimating millions of standard axles (*4*). They found that the most rapid failures occurred when slip occurred between multiple layers, decreasing the potential service life by about 20 to 80 percent. Brown and Brunton concluded that a full-slip condition at the second interface would reduce the pavement life as much as 75 percent and an intermediate slip as much as 30 percent (*5*). Al Hakim quantified slippage by a shear reaction modulus and found that full slip conditions can reduce pavement life by 50 percent (*6*).

Mohammad et al. used a two-dimensional finite element (FE) model to evaluate the effect of interface bond strength on fatigue life for thick and thin pavement designs (*7*). Bond strength was more impactful on performance on the thin pavements than thick ones. The minimum laboratory-measured interface shear bond strength for acceptable fatigue performance was 28 psi (190 kPa) for thin pavements and 19 psi (128 kPa) for thick pavement (tested at 0.5 mm/min.).

Wilson et. al modeled the performance of a composite pavement with variable bond condition for reflection cracking and rutting (Figure 2-8) (*3*). They found that under a no bond condition, reflection cracking over milled HMA was fully developed after 2 years and for a perfect bond, reflection cracking surfaced after around 10 years. The best performance occurred with a partially bonded interface. Rutting decreased with improved bonding.

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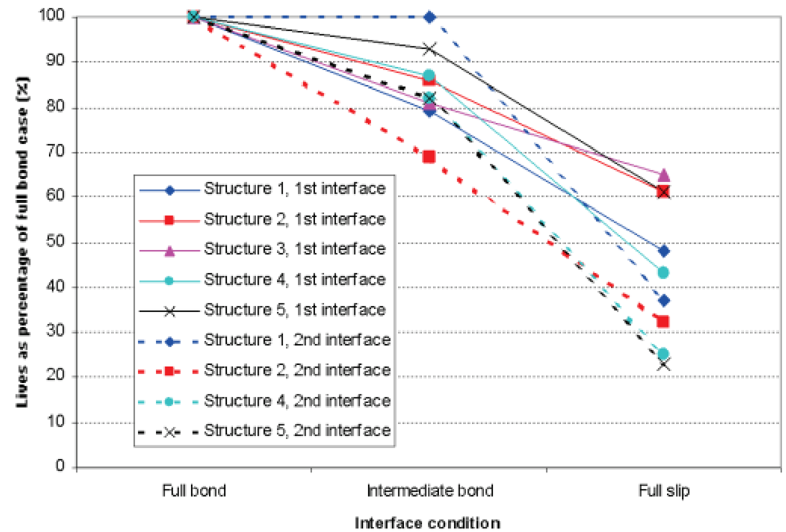


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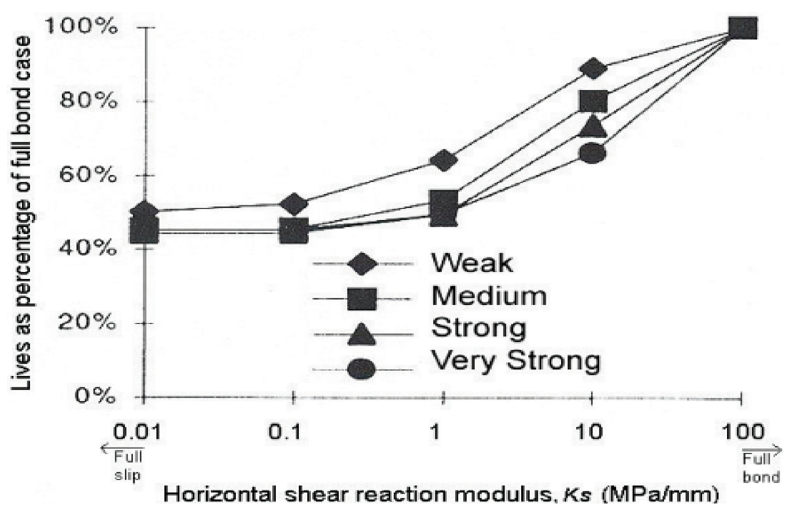
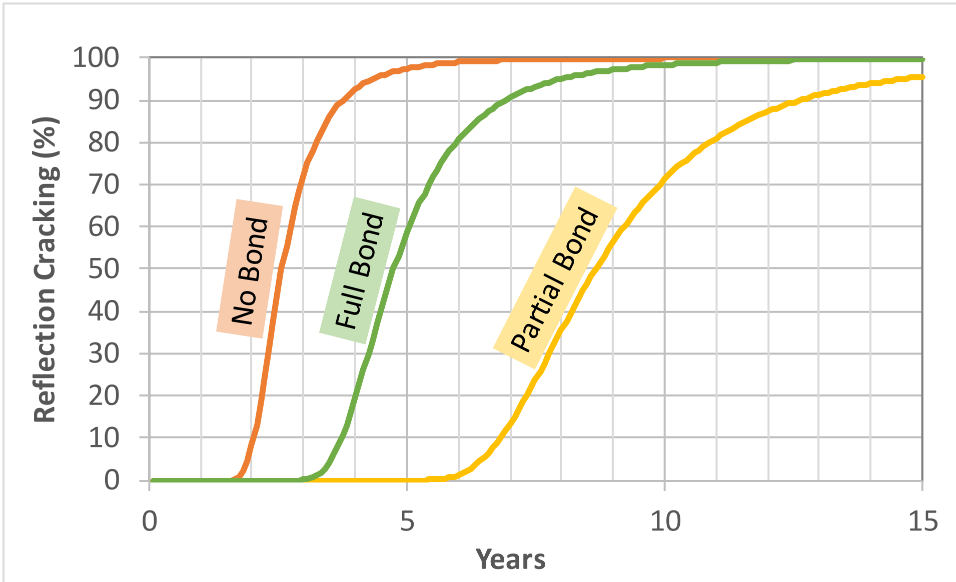
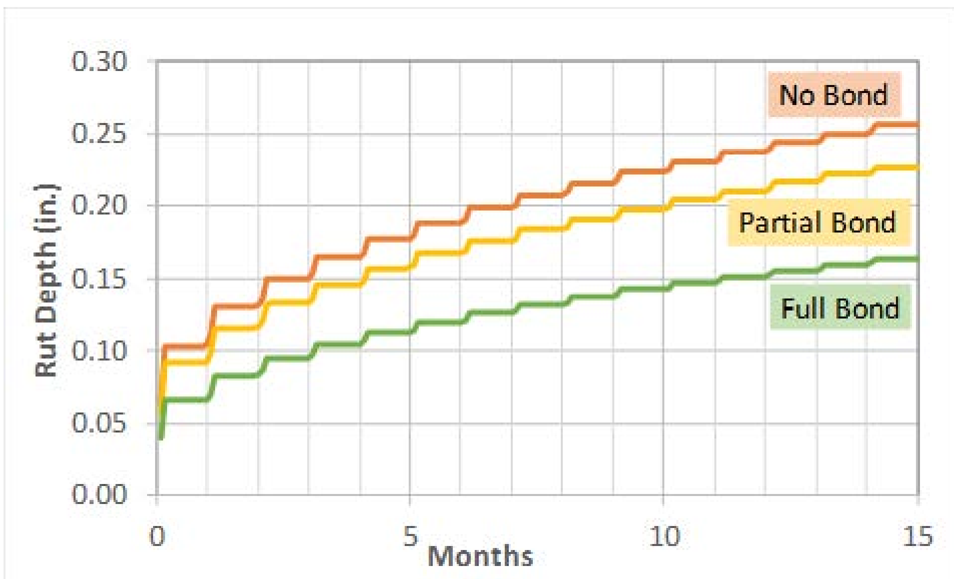



(c)

**Figure 2-7. Influence of Layer Bonding on Pavement Life: (a) Khweir and Fordyce, (b) Brown and Brunton, and (c) Al Hakim.**




**(a)**




**(b)**

**Figure 2-8. Predicted Performance with Different Bond Conditions: (a) Reflection Cracking and (b) Rut Depth.**

## STRESS RELIEF AND RESISTANCE TO REFLECTION CRACKING

Much research has focused on the effect of interlayer stress relief to reduce reflection cracking. Treatments that claim to provide this stress relief are underseals, stress absorbing membrane interlayers (SAMIs), and asphalt-rubber modified interlays (ARMIs). All of these consist of heavy asphalt applications followed by aggregate embedment. The performance of these interlayers is mixed in the literature.

Elseif and Dhaka compared reflective cracking control treatments for constructability, performance, and cost-effectiveness (*8*). The results show that chip seal and open-graded interlayer (underseal) perform well and have relatively lower cost than other treatments.

Shatnawi et al. studied the reflection cracking performance of SAMIs with field projects, laboratory tests, and FE analysis (*9*). The field studies showed that treatments using rubber-asphalt could sustain five times the level of strain than treatments with traditional asphalt binder. This was attributed to the aging characteristics and elastic properties of the interlayer. In the FE analysis, the rubber-asphalt treatment reduces strain and stress levels from 92 to 98 percent, and softer binders were more effective in reducing strain than stiffer binders.

Greene et al. evaluated ARMI performance through accelerated pavement testing (APT), laboratory testing, and FE modeling (*10*). They found that ARMI has potential to rut in hot seasons and is not effective in mitigating reflection cracking. The results show that the number of loading cycles to failure for samples without ARMI is greater than the samples with ARMI.

Ogundipe et al. examined the performance of SAMI in APT facility (*11*). The performance of the SAMI depends on interface bond quality, layer stiffness, and thickness. A thin SAMI layer (5 mm) performed better than the thick one (10 mm).

Yu et al. evaluated the effectiveness of different stress absorbing interlayers on their reflection cracking resistance (*12*). The Hamburg wheel tracking tester was used to simulate reflection cracking under a dynamic load in the laboratory. The results showed that SAMI does not have an acceptable performance; however, SAMI showed improved field performance due to the limitation of laboratory test set-up.

Another stress relieve technology is a thick application of asphalt prior to the overlay. One such treatment is ultra-thin bonded wearing course or Novachip. These maintenance treatments are a thin HMA layer with gap-graded design applied over a thick polymer-modified emulsion layer. The thick emulsion layer acts as the interlayer just like underseal membrane. The first project in the United States was constructed in 1992 in Alabama by National Center for Asphalt Technology (NCAT) (*13*). It is observed that the surface texture of Novachip is very similar to the typical open-graded friction course. They concluded that Novachip is suitable for high traffic roads based on the performance and it could be a potential alternative for permeable friction course (PFC), micro surfacing, and chip seal.

In 1992, TxDOT used the Novachip process on two surface rehabilitation projects in Comal County (*14*). This project was monitored and documented for 3 years. Novachip significantly increased the skid resistance of the surface. The ride quality was improved from one project but not the other. The Novachip mixture had poor workability and was sensitive to change in mixture proportions.

There is little research on Novachip's performance on reduction of reflective and fatigue cracking. Washington State Department of Transportation monitored the performance of a project for six years. They reported that Novachip was effective in reducing the severity and frequency of cracking (*15*). Similar projects in Louisiana and Minnesota show the same trend (*16*, *17*). The projects performed satisfactorily in transverse and longitudinal cracking.

In Kansas, 69 one-mile segments of Novachip have been constructed and rehabilitated in 10 different projects during 2002 to 2012. Service life was six years on average but had high variability. Transverse cracking, fatigue cracking, and roughness have been reduced one year after treatment; however, a sharp drop-off in effectiveness of treatment in fatigue and transverse cracking was observed after a couple of years (*18*).

## MOISTURE BARRIER PERFORMANCE

Researchers found little literature on the performance of bonding and sealing treatments as moisture barriers. Estakhri and Ramakrishnan surveyed TxDOT districts about their motivations for using underseals (Figure 2-9) (*19*). All districts indicated they use underseals specifically to seal the existing surface to keep water from infiltrating. Some districts thought underseals could prevent subsurface moisture from rising, and to improve the bond. Very few districts expected underseals to reduce reflective cracking. One problem that could arise is trapping moisture in the pavement at the time of construction.

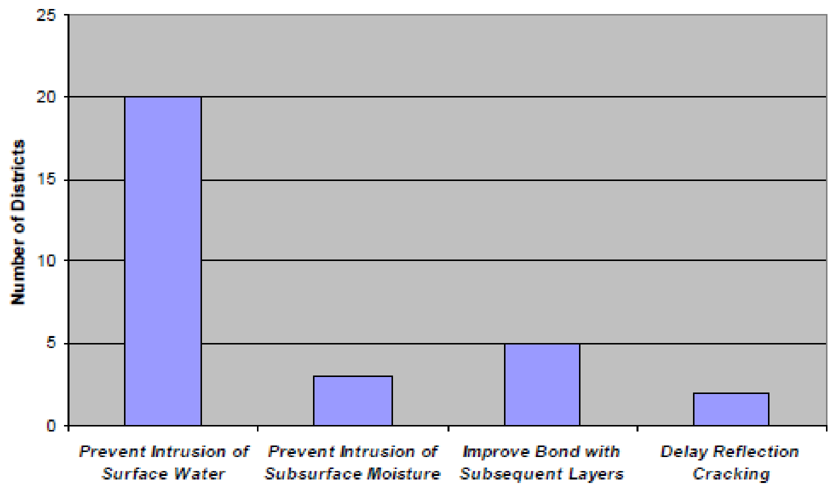



**Figure 2-9. Function of Underseals as Cited by TxDOT Districts (*19*).**

# CHAPTER 3
# SURVEY RESULTS

This chapter presents the result of the survey on the use and perceived performance of bonding and sealing treatments. In April 2016, the survey was sent to the director of construction or director of maintenance at each district. The overall response rate was 60 percent (15 out of 25 districts). The questionnaire is in Appendix A.

## TREATMENT USAGE

Figure 3-1 presents district use of bonding and sealing treatments. The most popular treatment by far was a traditional tack coat, with 87 percent of districts using them often or very often. In comparison, about 22 percent used trackless tack coat often and very often, and 17 percent had never used them. Spray paver membranes were the least common. Thirteen percent of districts used them often, but 35 percent have never placed a spray paver membrane. At the time of the survey, many districts did not have local contractors that owned a spray paver. Underseals had a range of use. Nine percent of districts did not use them while 46 percent used them often and very often.

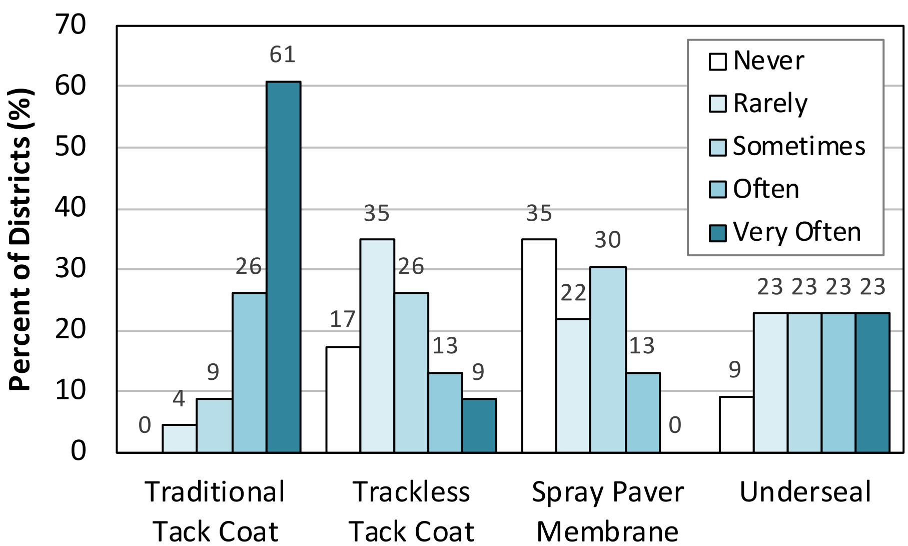



**Figure 3-1. District Use with Bonding and Sealing Treatments.**

In Figure 3-2, the districts expressed which treatments were recommended for different surface conditions. Traditional tack was recommended the highest for the most surface types. Traditional and trackless tack were the top recommended treatments for new HMA, low distress HMA, and surface treatment. Underseal was the most recommended treatment for moderate- to high-severity distress, followed by a spray paver membrane. There was not clear consensus on the best treatment for milled HMA or for concrete. Some districts recommended no treatment for new HMA, surface treatment, and concrete.

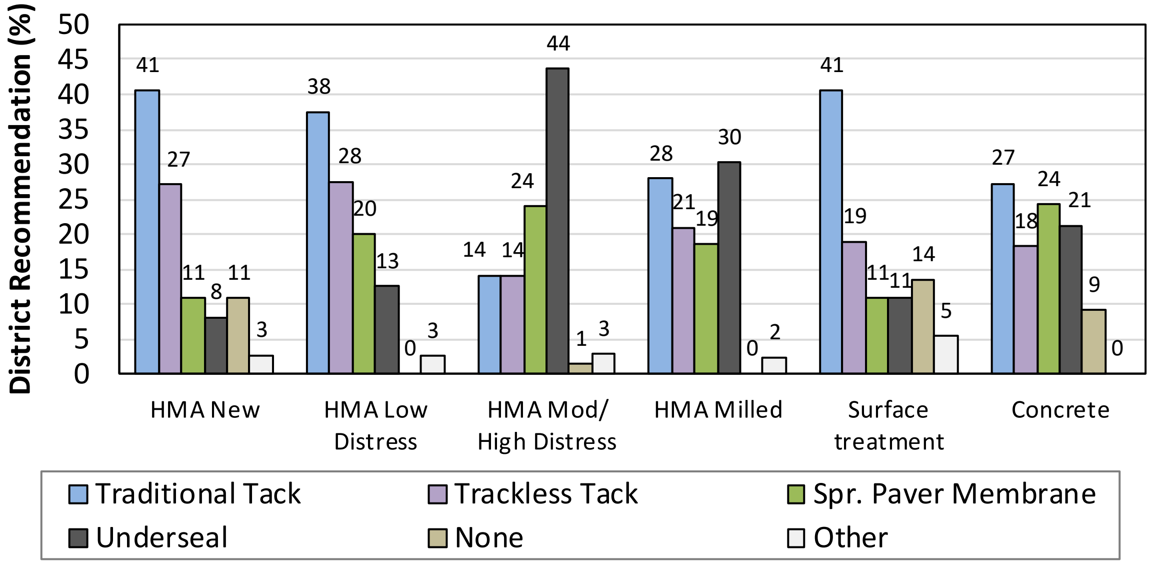



**Figure 3-2. Recommended Technology for Existing Surface Layer.**

The recommended treatment also changed for different overlay types (Figure 3-3). For dense-graded HMA, traditional tack had the highest recommendation, followed by trackless tack and underseal. There was no clear consensus for gap-graded HMA. Underseals were clearly recommended for PFC overlays. Finally, for surface treatment, most districts said no treatment was needed, while almost 30 percent still recommended tack coat.

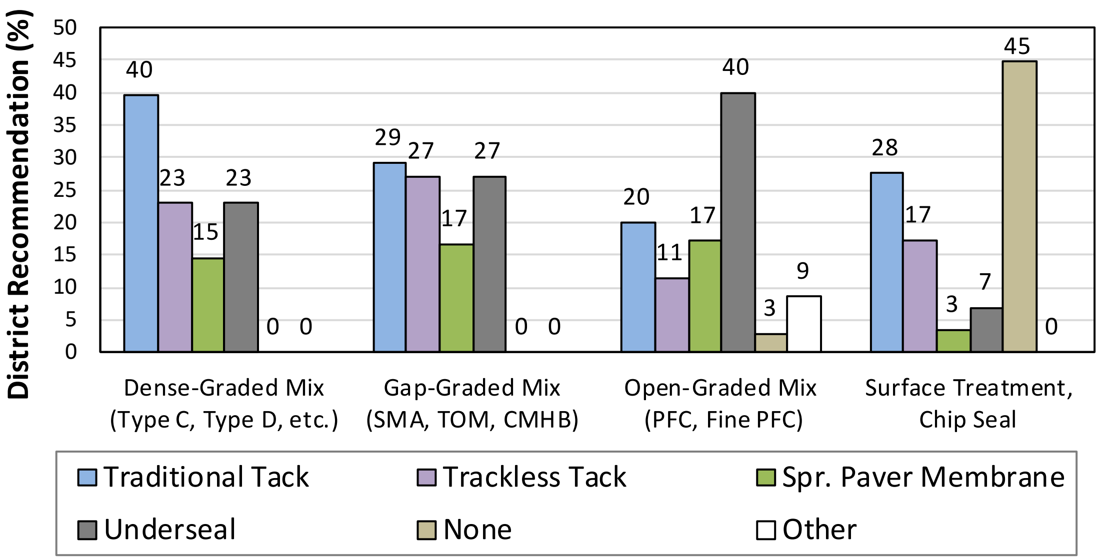



**Figure 3-3. Recommended Technology Based on Overlay Type.**

## MATERIALS

General asphalt and emulsion use by district is shown in Figure 3-4. Emulsions are most commonly used for a tack coat. Trackless tack is mostly polymer-modified emulsion. Spray paver membranes predominantly used polymer-modified and regular emulsion. Surface treatments mostly used polymer-modified asphalt, though all the other products have been used to some degree for this treatment. As shown in Figure 3-5, Grade 4 is the most common aggregate size for seal coats (95 percent). Grades 5 and 3 had similar usage at 40 to 50 percent. (Figure 3-5). Both precoated and uncoated aggregate are used, about 75 and 60 percent, respectively (not illustrated here.)

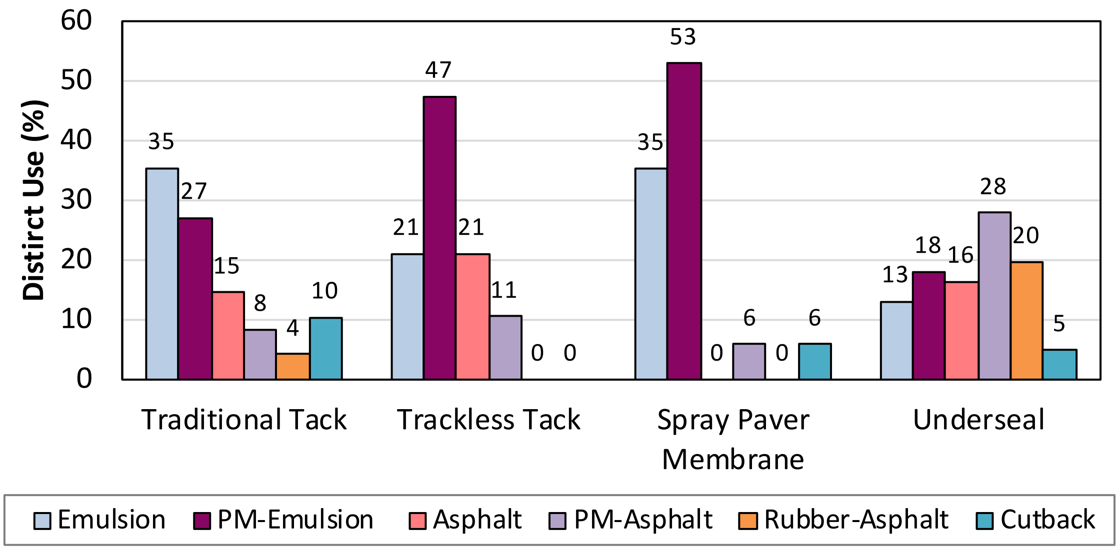



**Figure 3-4. Asphalt Material Use.**

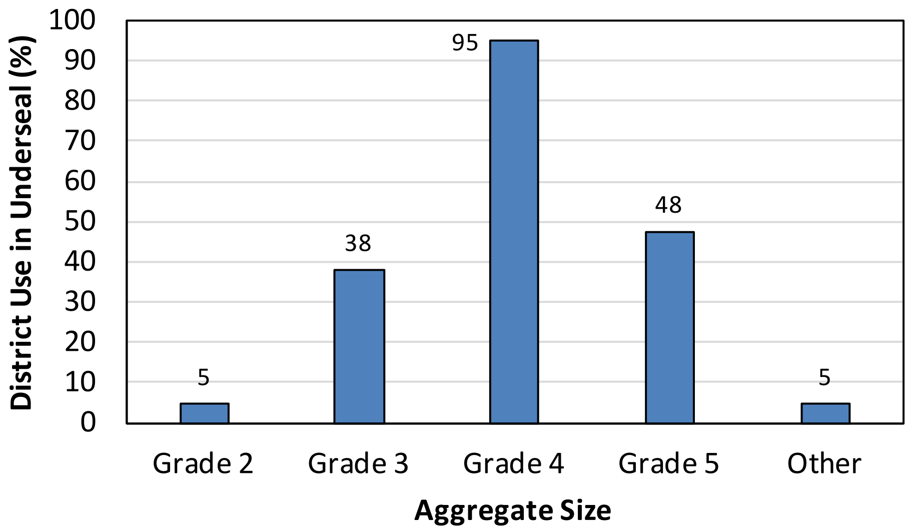



**Figure 3-5. Aggregate Size for Underseals.**

Districts also reported the recommended minimum and maximum residual rates of binder for each treatment type (Table 3-1). Traditional and trackless tack coats ranged from 0.04 to 0.09 gal/sy. Spray paver membranes had rates from 0.15 to 0.23 gal/sy and underseals from 0.21 to 0.28 gal/sy. Based on the research team's experience, the suggested underseal rates are too low and the tack coat rates are slightly too high.

**Table 3-1. District Recommended Residual Rates.**

| Treatment | Residual Rate (gal/sy) | | |
|---|---|---|---|
| | Avg. Minimum | Average | Avg. Maximum |
| Traditional Tack coat | 0.04 | 0.07 | 0.09 |
| Trackless Tack coat | 0.05 | 0.07 | 0.09 |
| Spray Paver Membrane | 0.15 | 0.19 | 0.23 |
| Underseal | 0.21 | 0.25 | 0.28 |

## PERFORMANCE PERCEPTION

Figure 3-6 through Figure 3-9 illustrate the perceived advantages and disadvantages of each bonding and sealing treatment. The properties are ordered from advantageous to disadvantageous.

Districts perceive traditional tack coat as having the greatest advantage in terms of cost, equipment availability, local experience, and constructability. The major disadvantages were performance related to reduce reflection cracking, resist moisture, and extending overlay service life. Districts were not clear about bond performance or overlay service life.

For trackless tack coat, the advantages were constructability, shear bond strength, equipment availability, and extending the serviceability of the pavement. Disadvantages were cost, reflection cracking reduction, lack of experience, and moisture barrier performance.

Districts rated underseals as having clear advantages in every category except for initial cost, for which over 75 percent of districts said this was a disadvantage. As will be shown in this project, the shear bond strength of underseals is actually lower than other treatments; however, the high residual rate gives the bond high resilience.

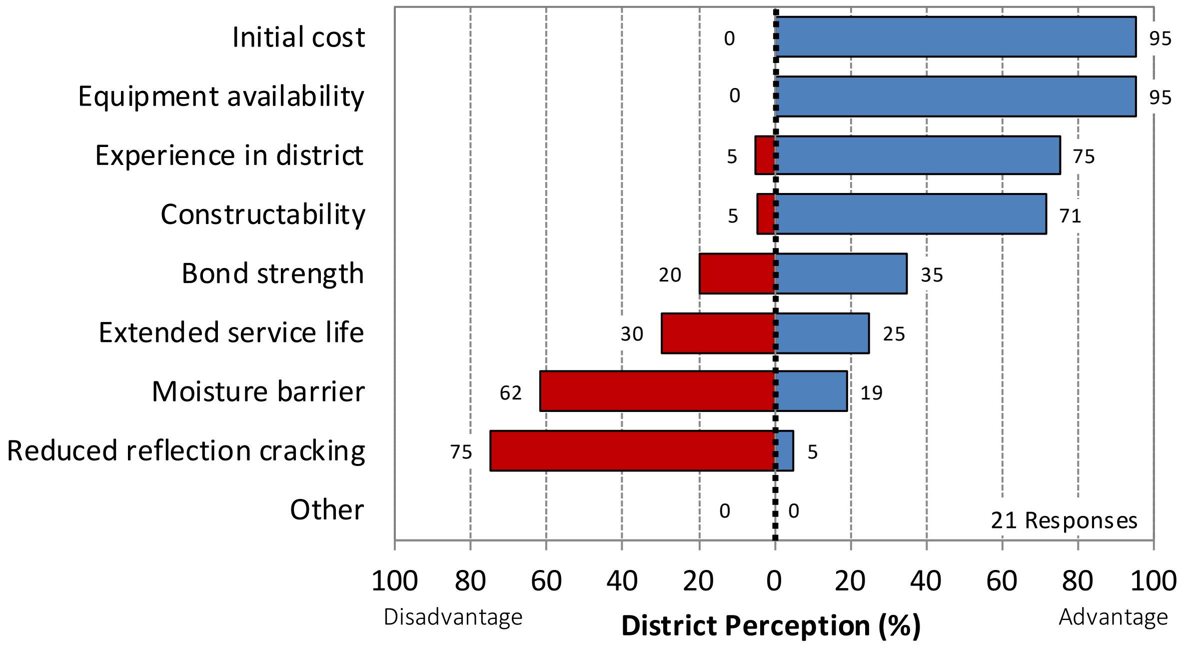



**Figure 3-6. Perceived Advantages and Disadvantages of Traditional Tack Coat.**

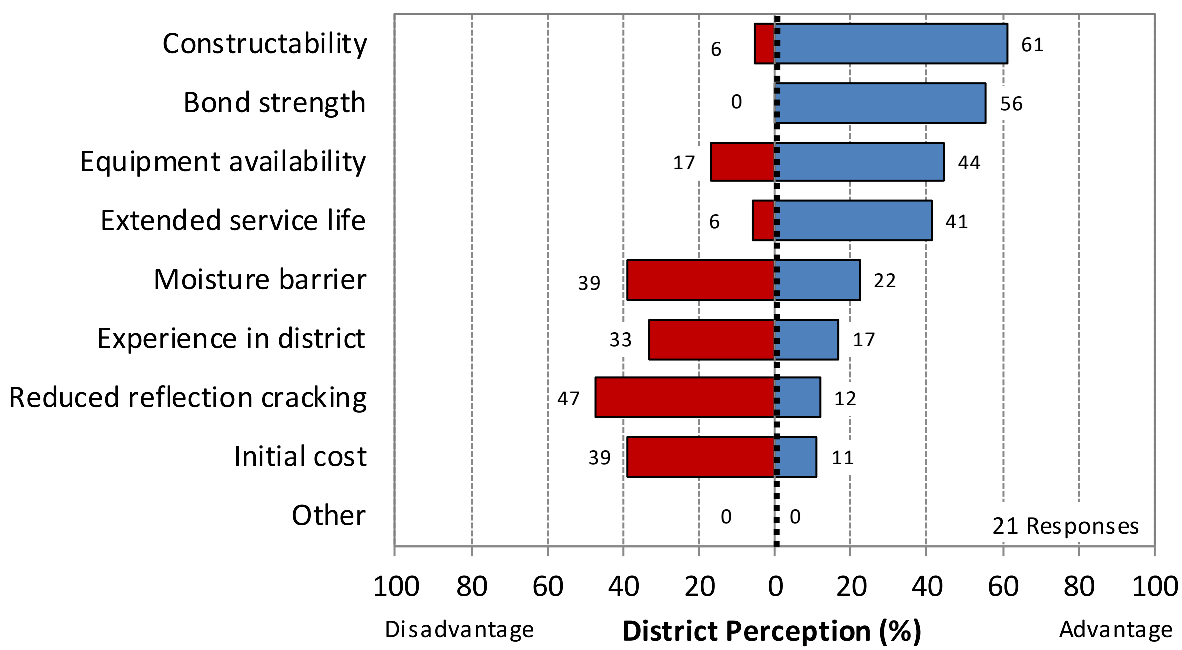



**Figure 3-7. Perceived Advantages and Disadvantages of Trackless Tack Coat.**

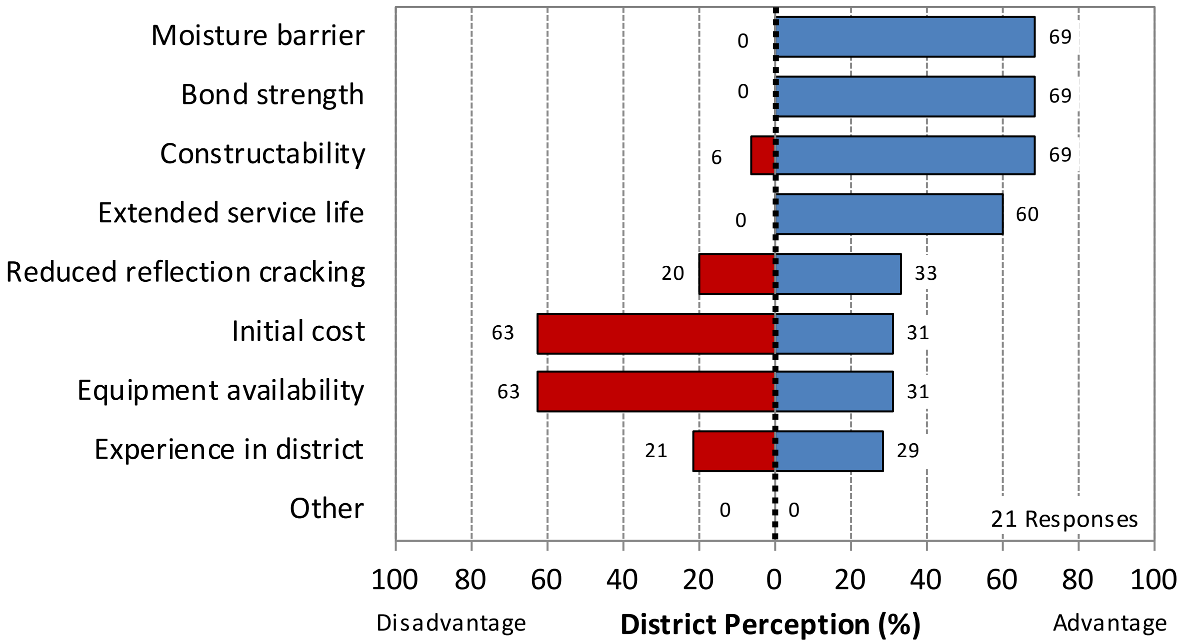



**Figure 3-8. Perceived Advantages and Disadvantages of Underseal Membrane.**

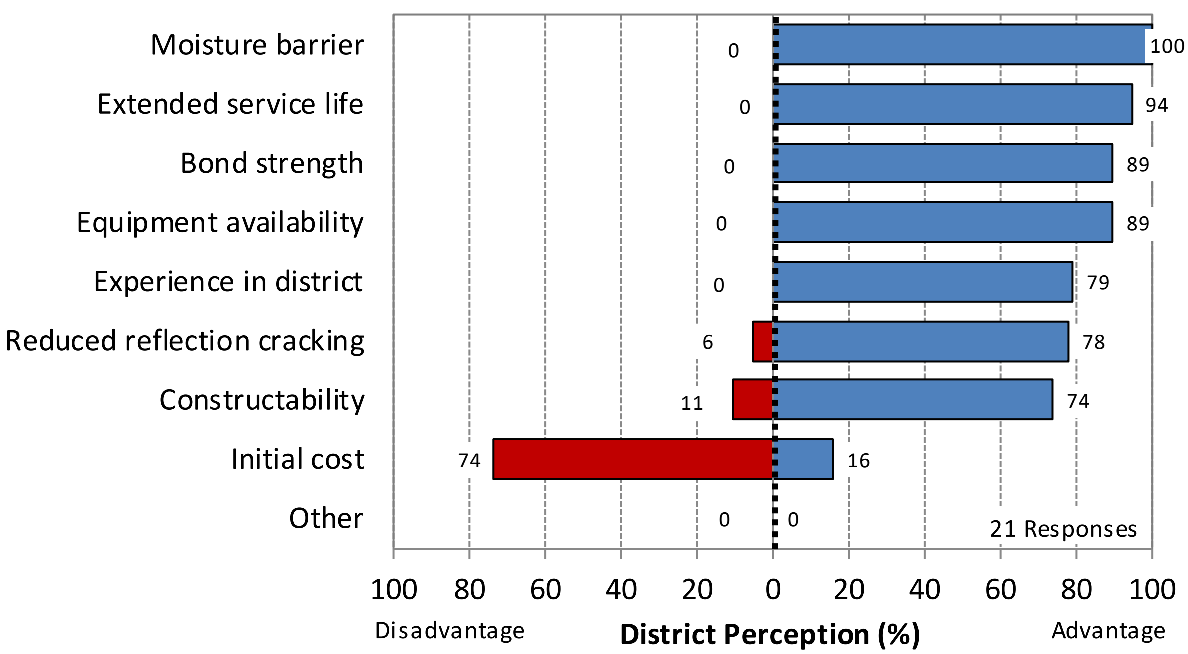



**Figure 3-9. Perceived Advantages and Disadvantages of Underseal.**

# CHAPTER 4
# LABORATORY TESTING

This chapter reports on the laboratory testing plan, testing method, and results. A significant part of this task was the development of a laboratory tack spray system.

## TESTING PLAN

The laboratory study (Table 4-1) looked at bond strength, cracking resistance, and permeability performance for different treatments. The bond strength tests were done with the interface shear tester, cracking resistance with a modified overlay test and compact tension test, and permeability with a falling-head permeability test. The treatments considered conventional tack, emulsion trackless tack, hot-applied trackless tack, spray paver membrane, and underseal. Control samples included no tack and a worst-case scenario using Vaseline. Three samples were used for each measurement, except for some field core samples that were damaged in preparation.

**Table 4-1. Laboratory Samples.**

| Tests | Surface Type | Overlay Type | Treatment Type | Application Rate (gal/sy) |
|---|---|---|---|---|
| Shear Bond Strength | Type D (lab molded) | TOM C | None | 0 |
| | | | Vaseline | NA |
| | | | Conventional Tack (CSS-1H) | 0.08 |
| | Aged seal coat (US 79 cores) | SP Type D | Trackless Tack (Emulsion) | 0.08 |
| | | | Trackless Tack (Hot applied) | 0.14 |
| | | | Spray Paver Membrane | 0.20 |
| | | | Underseal | 0.30 |
| Cracking Resistance (Overlay Test & Compact Tension Test) | Type D (lab molded) | TOM C | None | 0 |
| | | | Conventional Tack (CSS-1H) | 0.08 |
| | Aged seal coat (US 79 cores) | SP Type D | Trackless Tack (Emulsion) | 0.08 |
| | | | Trackless Tack (Hot applied) | 0.14 |
| | | | Spray Paver Membrane | 0.20 |
| | | | Underseal | 0.30 |
| Permeability | PFC-Ty F | PFC-Ty F | None | 0 |
| | | | Conventional Tack (CSS-1H) | 0.07 |
| | | | | 0.14 |
| | | | Trackless Tack (Hot applied) | 0.14 |
| | | | Spray Paver Membrane | 0.20 |
| | | | Underseal | 0.3 |

# METHODS

## Spray Machine Development

The first step in the laboratory study was to design and build a tack spray machine. The machine would be used for applying thick or thin tack coats and seal coats. Key components of the system were:

- Pneumatically driven spray bar and nozzles.
- Asphalt gear pump and circulation system.
- Asphalt heating tank and heated hose.
- Programable logic computer (PLC) and user interface.
- Housing to contain overspray.

Pump rate, bar speed, and heating capabilities were identified. The pump has a maximum rate of 1,700 rpm, though normal operational limits are between 1,000 and 1,300 rpm. The bar speed is between 150 and 250 fps. The maximum tank temperature is 375°F, and the maximum hose temperature is 400°F. Within this project, the system was unable to evenly spray the high viscosity materials like AC-20xp and hot-applied trackless tack. Researchers suspect a pump with high pressure output and a better-controlled shut-off return value may resolve the issue.


Figure 4-1. Tack Spray System.

## Sample Preparation

Figure 4-2 illustrates the general sample preparation method. The first step was to prepare the substrates. All substrate types were prepared to a height of 2 inches (51 mm). New HMA substrate was molded as a slab with an InstroTek asphalt roller compactor. The mixture was Dense-Graded Type D. Aged substrate samples were cores taken from the US 79-Oakwood project before overlay construction. The surface was an aged seal coat over HMA. The cores were carefully trimmed to height and, as needed, were leveled with gypsum plaster. For permeability testing, PFC with a nominal aggregate size of No. 4 (4.75 mm) was molded with a Superpave gyratory compactor with 30 gyrations.

Bonding and sealing treatments were applied with the spray machine when possible (CSS-1H and trackless tack) or by hand (underseal [AC-20xp], spray paver membrane [pm-emulsion], and hot-applied trackless tack). Aggregate for the underseal was loosely spread by hand. Control samples had no treatment and worst-case scenario samples had a thin application of Vaseline.

For bond strength and cracking resistance samples, the overlay was compacted with the InstroTek asphalt roller compactor. The typical overlay material was Thin Overlay Mix (TOM) Type-C. Some samples were also molded with Superpave Type-D from the US 79 project. When compacting over field cores, samples were placed inside a metal frame that was flush with the sample height as illustrated in Figure 4-2. For permeability samples, the same PFC mixture was used for the overlay and was compacted in the Superpave gyratory compactor with 30 gyrations. Specific sample configurations are detailed in the following section.

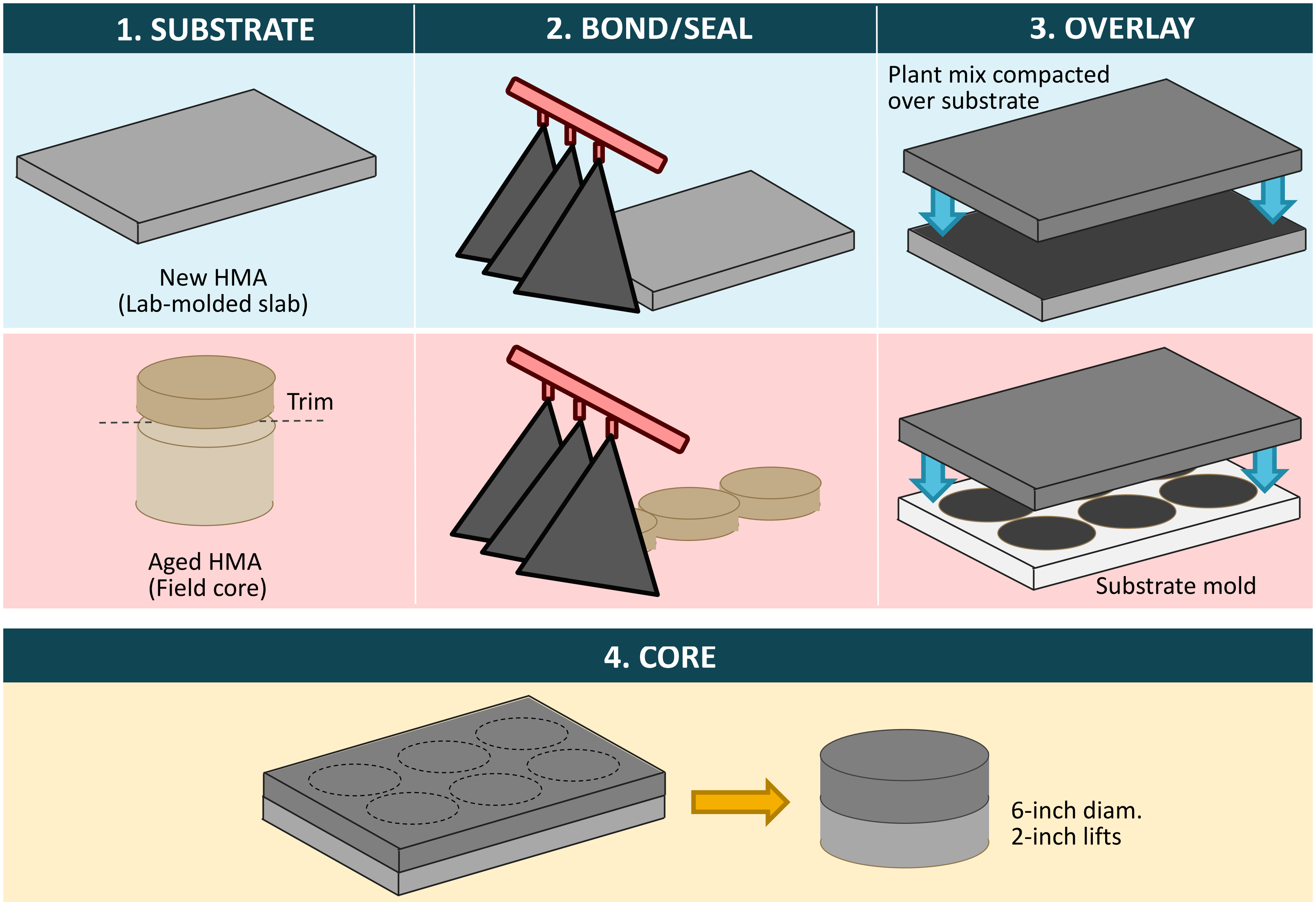



**Figure 4-2. General Sample Preparation Methods.**

## Sample Testing

*Interface Shear Bond Strength Test*

Shear testing was done in general accordance with Tex-249-F (Shear Bond Strength Test) using a PINE shear test apparatus (Figure 4-3). One half is ridged and holds the sample in place while the other is free to slide vertically. A load is applied to the free-sliding side in a loading frame until failure and the maximum stress is recorded. Samples were conditioned to 68°F (20°C) and loaded at 0.2 inch (0.5 mm)/minute to failure.

**Figure 4-3. Interface Shear Bond Strength Test.**

*Modified Texas Overlay Test*

The Texas Overlay tester device is used to simulate reflection cracking of an HMA overlay laid over thermally active cracks or joints. The bottom of a sample is adhered to two metal plates; one is fixed and the other slides horizontally. The sliding plate applies a cyclic triangular tensile strain to a maximum displacement of 0.025 inches in 10 seconds. The test is run until the maximum load in the cycle has decreased by 93 percent. Testing is done at 77°F (25°C).

Overlay samples were cored from the bonded slabs. A modified sample design was used as shown in Figure 4-4. The length and width dimensions were the same as the standard test, but the total thickness was increased to 2.5 inches. The bottom was notched to 0.75 inches, so the tip was slightly below the bonded interface. The thickness between the notch tip and the top of the sample was 1.5 inches.

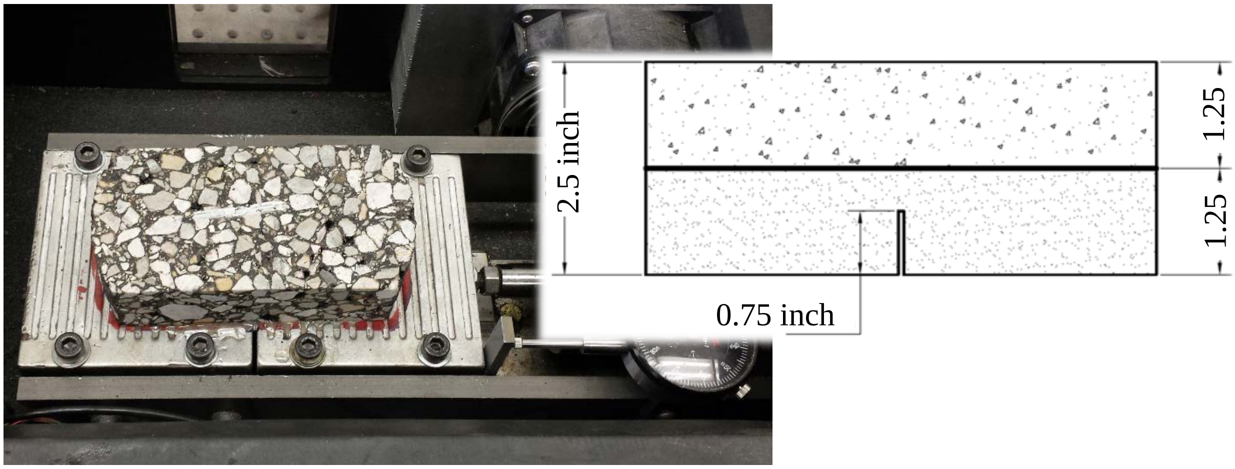



**Figure 4-4. Modified Texas Overlay Test.**

*Compact Tension Test*

The compact tension test was developed at the University of Illinois at Urbana-Champaign to measure bond energy at the interface based on the ASTM D7313 (Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry). (*20*) A core sample is trimmed to the dimensions in Figure 4-5. Through the two drilled holes, steel rods are inserted to pull the sample apart, inducing tensile stress at the notch. In our study, the sample was loaded at a rate of 0.017 mm/s (0.00067 inch/s) monotonically until sample failure. The fracture energy is calculated as the area under the load-displacement curve over the ligament area (D×t).

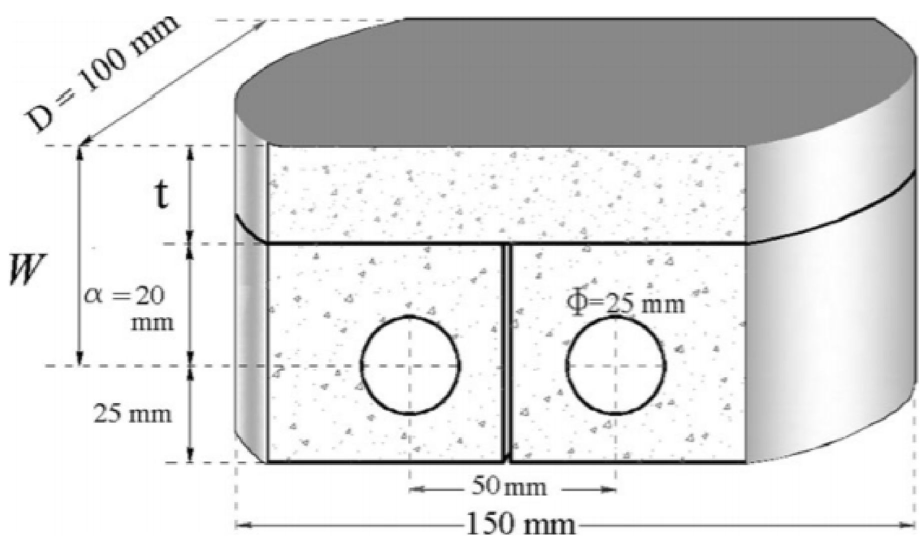



**Figure 4-5. Compact Tension Test Sample Geometry.**

*Florida Falling-Head Permeameter Test*

The permeability of the bonding and sealing treatments was assessed using the Florida falling-head permeameter (Figure 4-6). Testing was done in general accordance with FM 5-513 (Florida Method of Test for Coefficient of Permeability – Falling Head Method). Samples were first submerged in water overnight. To seal the voids between the sample and the apparatus, Vaseline was spread on the sides of the sample and a pressurized membrane was inflated to 15 psi around the sides. Water was flowed through the top of the sample and out the bottom for a few minutes before testing. The test measurement was the time it took for a 24.5-inch (62-cm) column of water to drain through the sample. Three measurements were made for each sample and the average of three samples constituted the permeability of the treatment.

**Figure 4-6. Florida Falling-Head Permeameter.**

## Statistical Analysis

Analyses of variance (ANOVAs) were performed on each data set to quantify the influence of treatment type and surface type on bond, cracking resistance, and permeability performance. A *p*-value of 0.05 was used to define statistical significance.

## RESULTS

Table 4-2 summarizes the statistical results for bond strength, cracking resistance, and permeability. Treatment type had a significant influence on performance in all cases. Surface type affected bond strength, but not cracking resistance as measured by the overlay test. The models also had strong $R^2$ values ranging from 0.68 to 0.93. The modeled results are shown in the subsequent discussion.

**Table 4-2. Statistical Results for Laboratory Sample Testing.**

| Test | Response Variable | Explanatory Variable | Model $R^2$ | Model *p*-value | Variable *p*-value |
|---|---|---|---|---|---|
| Shear Bond | Max. bond strength (psi) | Treatment Type | 0.9325 | <0.001 | <0.001 |
| | | Surface Type | | | <0.001 |
| Mod. Texas Overlay | log(cycles) | Treatment Type | 0.7239 | <0.001 | <0.001 |
| | | Surface Type | | | 0.791 |
| Compact Tension | Bond Energy ($J/kN^2$) | Treatment Type | 0.686 | <0001 | <0.001 |
| Permeability | Permeability ($cm/sec^2 \times 10$^-5 ) | Treatment Type | 0.836 | <0.001 | <0.001 |

**Bond Strength**

Figure 4-7 presents the model for samples molded on new HMA versus existing surface treatment. Substrate type, treatment type, and the interaction were significant. The strongest bond was from hot-applied trackless tack followed by emulsion trackless tack. Statistically, there was no difference among no tack, CSS-1H, and emulsion trackless tack. The lowest strengths were from spray paver membrane and underseal. New HMA substrate samples were 60 to 110 percent stronger than existing surface treatment substrates, except for spray paver membranes and underseals. For these latter treatments, which had significantly thicker tack applications, the substrate did not influence the bond strength.

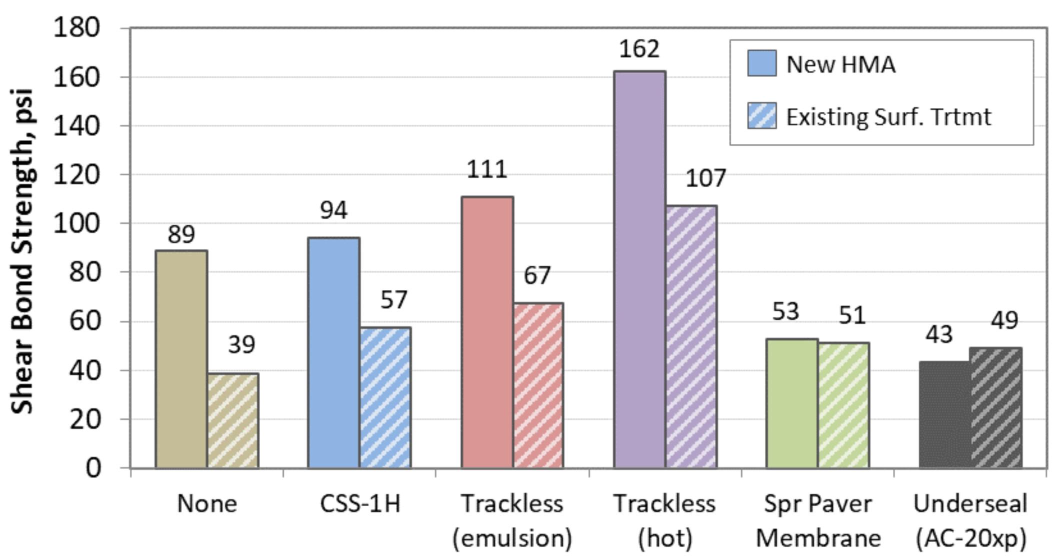



**Figure 4-7. Bond Strength by Treatment Type and Surface Type.**

### Cracking Resistance

Figure 4-8 shows the effect of cracking resistance with the overlay tester. Treatment type had a significant influence, but substrate type did not. The model shown here does not consider substrate type. Because of high variability inherent in the overlay test, several groups of samples were not statistically unique. Hot applied trackless tack, underseal, and no tack had the best performance. The lowest performance was from Vaseline and emulsion trackless tack. There was also no difference between no tack, spray paver membrane, CSS-1H, and emulsion trackless tack. Another way to consider the test is the manner of the break. Cracks propagated up through the overlay in most samples except for underseal, some of the spray paver membrane samples, and Vaseline. In these cases, the crack turned horizontally at the interface, relieving all cracking strain. This may be helpful for reducing reflection cracking.

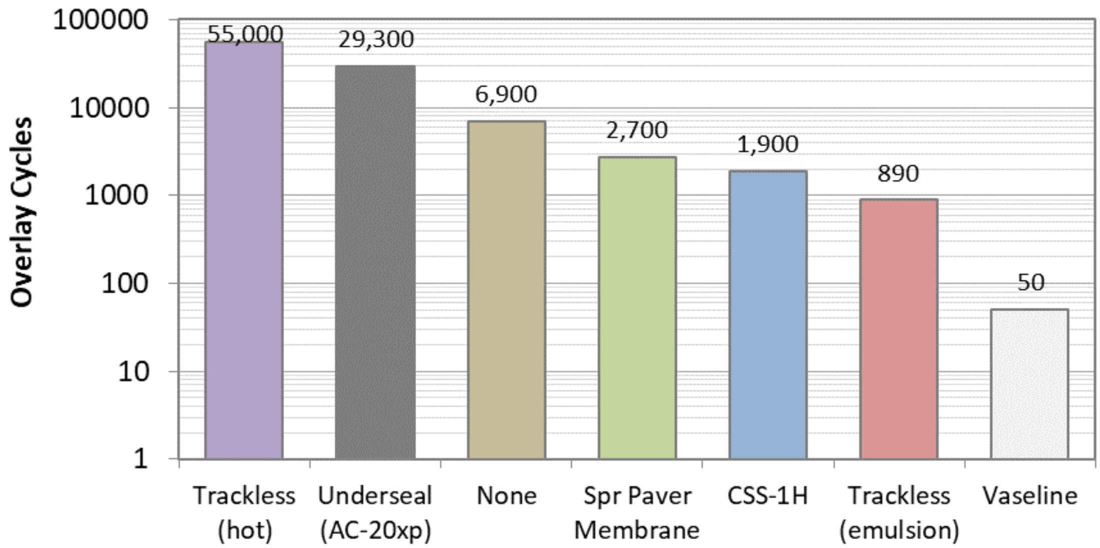



**Figure 4-8. Overlay Cracking Resistance by Treatment Type.**

The compact tension showed a relatively similar ranking of cracking resistance, though the ranking here is more intuitive (Figure 4-9). Bond energy is highest from samples with high stiffness and/or high toughness. The high residual treatments (underseal, spray paver membrane, and hot-applied trackless tack) had the most fracture energy (580–830 $J/m^2$). The lowest energy was for Vaseline (290 $J/m^2$), which was statistically similar to all treatments up through hot-applied trackless tack. This test also had a lot of data scatter, making it hard to distinguish among treatment types. Researchers feel this test better captures the expected resistance to reflection cracking than the overlay test. All treatments cracked through the mixture (Figure 4-10) except Vaseline.

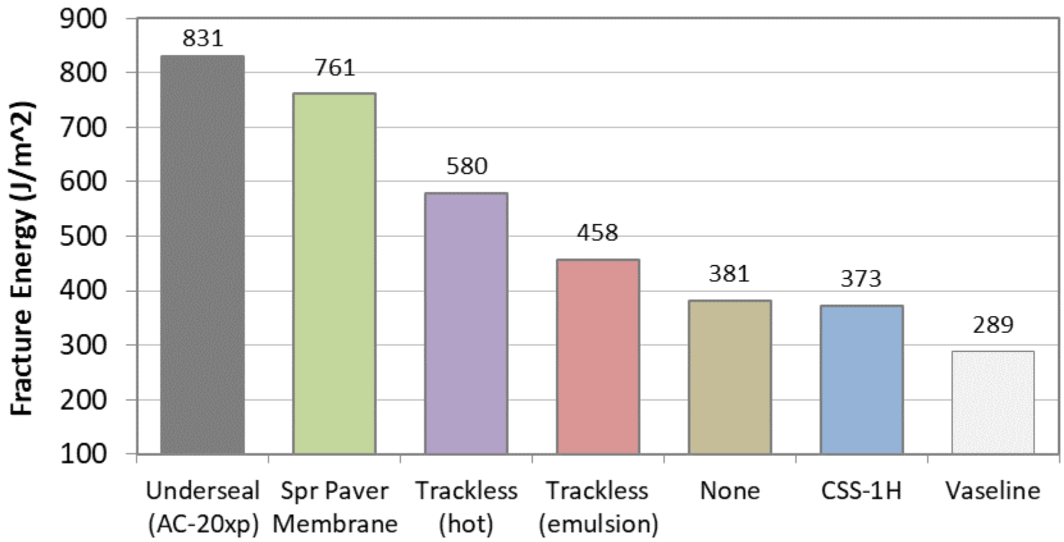



**Figure 4-9. Compact Tension Cracking Resistance by Treatment Type.**


**Figure 4-10. Reflection Cracking through Different Sample Types.**

**Permeability**

Low permeability is desirable to limit top-down and bottom-up moisture infiltration. Treatment type had a significant impact on permeability performance (Figure 4-11). Moderate and high applications of CSS-1H were no different from the no treatment control (1,500–1,875 cm/sec$^2$*10$^{-5}$). The lowest permeability was from hot-applied trackless tack, underseal, spray paver membrane (470–1,030 cm/sec$^2$*10$^{-5}$), and, because of high variability in the measurements, also the high application of CSS-1H treatment.

The actual values from this test are different from what is expected in the field since this test was done with PFC as the top and substrate layers. In practice, the substrate would be a cracked dense-graded layer with considerably less permeability than a new laboratory molded PFC.

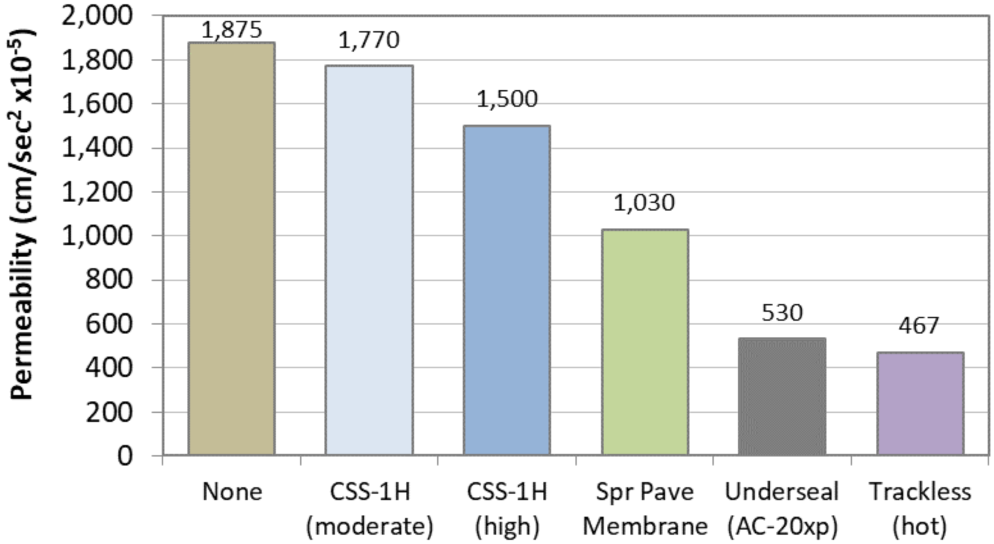



**Figure 4-11. Permeability by Treatment Type.**

# CHAPTER 5
# FIELD TEST SECTIONS

This chapter reports on the construction of test sections, sampling, testing, and data analysis.

## TESTING PLAN

Five field projects were evaluated, each consisting of multiple test sections. Table 5-1 summarizes these. The first project on US 79-Oakwood was a comprehensive test section comparing all the treatment types at the recommended applicate rates over an existing distressed seal coat. US 84-Leon Co. and Burnet-TOM were constructed during this study but only considered a subset of the treatments (spray paver membrane vs. underseal, and spray paver membranes vs. hot-applied trackless tack). Then two existing projects with test sections constructed during research project 0-6814 were reevaluated. The first of these, US 183-Cedar Park, compared different trackless tacks at various application rates over different surface types. The last, SH 336-McAllen, compared emulsion trackless tack to a cut-back tack.

All sites were sampled and tested for bond strength. The newly constructed sites were also testing for cracking resistance. Some sites were tested initially and again after time in service.

**Table 5-1. Field Samples.**

| Project | Surface Type | Overlay Type | Treatment Type | Application Rate (gal/sy) | Age | Tests |
|---|---|---|---|---|---|---|
| US 79-Oakwood | Seal coat, cracked | SP Type D | None | 0 | New<br>1-mo.<br>9-mo. | Bonding<br>Cracking<br>(Overlay) |
| | | | Conventional Tack (CSS-1H) | 0.08 | | |
| | | | Trackless Tack (Emulsion) | 0.08 | | |
| | | | Trackless Tack (Hot applied) | 0.14 | | |
| | | | Spray Paver Membrane | 0.20 | | |
| | | | Underseal | 0.29<br>Rock: 1 cy/121 sy | | |
| US 84-Leon Co. | Seal coat, cracked | SP Type D | Spray Paver Membrane | NA | New | Bonding<br>Cracking<br>(Overlay) |
| | | | Underseal | NA | | |
| Burnet-TOM | Milled | TOM-C | Spray Paver (AC-15p) | 0.13, 0.15, 0.17 | New | Bonding<br>Cracking<br>(Overlay) |
| | | | Trackless Tack | NA | | |
| | | | Spray Paver (PM-Emulsion) | NA | | |
| US 183-Cedar Park | Milled<br>New HMA<br>Aged HMA | TOM-C | None | 0 | New<br>13-mo. | Bonding |
| | | | Trackless Tack (Emulsion) A | 0.04, 0.07, 0.10 | | |
| | | | Trackless Tack (Emulsion) B | | | |
| | | | Trackless Tack (Emulsion) C | | | |
| SH 336-McAllen | Aged HMA | Type D | None | 0 | New<br>17-mo. | Bonding |
| | | | Trackless Tack (Emulsion | 0.05, 0.07, 0.10 | | |
| | | | RC-250 | 0.05, 0.07, 0.09 | | |

## METHODS

### Test Section Construction and Sampling

*US 79-Oakwood*

The project was located on US 79 just west of Oakwood starting at a bridge by Oliver St. (Figure 5-1). The section is a rural principal arterial with two undivided lanes, 12 ft wide with 10-ft paved shoulders. The average annual daily traffic (AADT) was approximately 5,000 in 2015, and the speed limit was 70 mph.


**Figure 5-1. Project Location on US 79 by Oakwood.**

The existing pavement was several inches of HMA surfaced with a seal coat. The seal coat was aged and exhibited minor flushing. The surface had low-severity transverse cracking, 20 ft apart on average (Figure 5-2), and some longitudinal cracking. The cracks, though previously sealed, had since opened. A summary of the distresses in each test area is given in Table 5-2. The pavement structure, initially assumed uniform, had a distinct change in thickness and likely material composition where the spray paver section was placed.

**Figure 5-2. US 79 Existing Condition.**

**Table 5-2. Existing Distress Summary.**

| Section | Transverse Cracking | | | Longitudinal Cracking Length (ft) | |
|---|---|---|---|---|---|
| | Length (ft) | Count (ft) | Avg. Spacing (ft) | In wheel path | Between wheel path |
| Spray Paver Membrane | 474 | 42 | 24 | 488 | 0 |
| Trackless tack (hot applied) | 603 | 54 | 19 | 869 | 25 |
| CSS-1H | 576 | 53 | 19 | 337 | 40 |
| Trackless tack (emulsion) | 741 | 66 | 15 | 388 | 134 |
| Underseal | 774 | 68 | 15 | 377 | 30 |

The comprehensive test on US 79 consisted of five different sections: CSS-1H, emulsion trackless tack, hot-applied trackless tack, spray paver membrane, and a traditional underseal. Figure 5-3 shows the section layout and application rates.

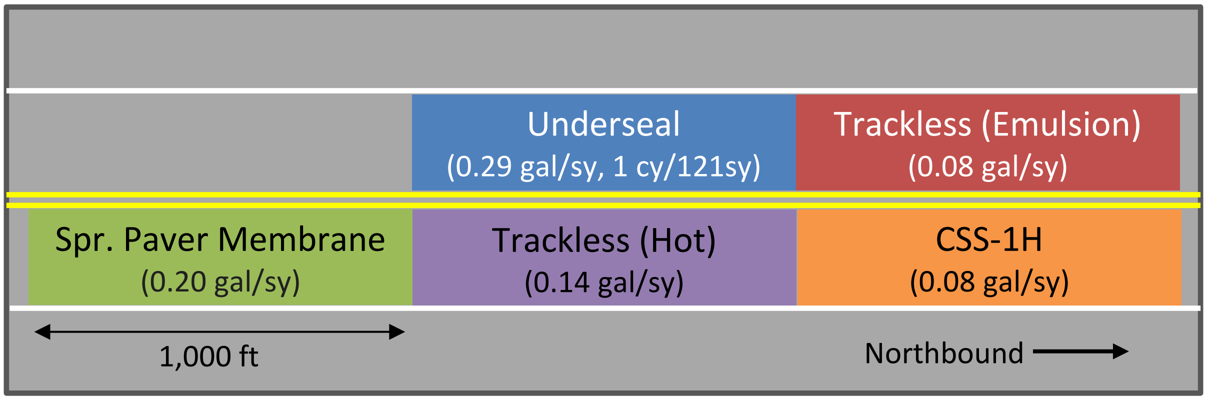



**Figure 5-3. Section Layout on US 79-Oakwood.**

Construction occurred in August 2017. The project was a 2-inch dense-graded Type D overlay. The surface was first swept clean. Researchers directed the tack and seal operators to place each section. The application rates were measured using ASTM D2995 (Standard Practice for Estimating Application Rate and Residual Application Rate of Bituminous Distributors) in the field. No measurements were made on the spray paver section, but the rate was verified based on material yields. HMA delivery trucks were allowed to drive over the exposed tack as they would under regular paving operations. The HMA was loaded directly into a material transfer vehicle (not windrowed), and a spray paver was used to lay mix on all sections. The spray bar was shut off for all but the spray paver section (Figure 5-4).

**Figure 5-4. US 79 Paving Train.**

Only one section, spray paver membrane, was sampled at the time of construction. All sections were sampled after 1 month, including the spray paver section again. This way any initial bond strength gain would be completed. Core samples were obtained between the wheel paths spaced 300 ft apart. Two cores from each location were collected, one for the shear bond test and the other for the overlay cracking test. The first and last 100 ft were excluded from sampling. Some cores were also taken over the no-tack areas left by the tack rate measurements as control samples. After 9-months in service, the sections were sampled again for bond strength, this time in the wheel path.

*US 84-Leon County*

This project was located on US 84 in Leon County, between FM 489 and US 79 (Figure 5-5). The section is a rural minor arterial with two undivided lanes, 12 ft wide with 10-ft paved shoulders. The AADT was approximately 3,000 in 2015, and the speed limit was 70 mph.

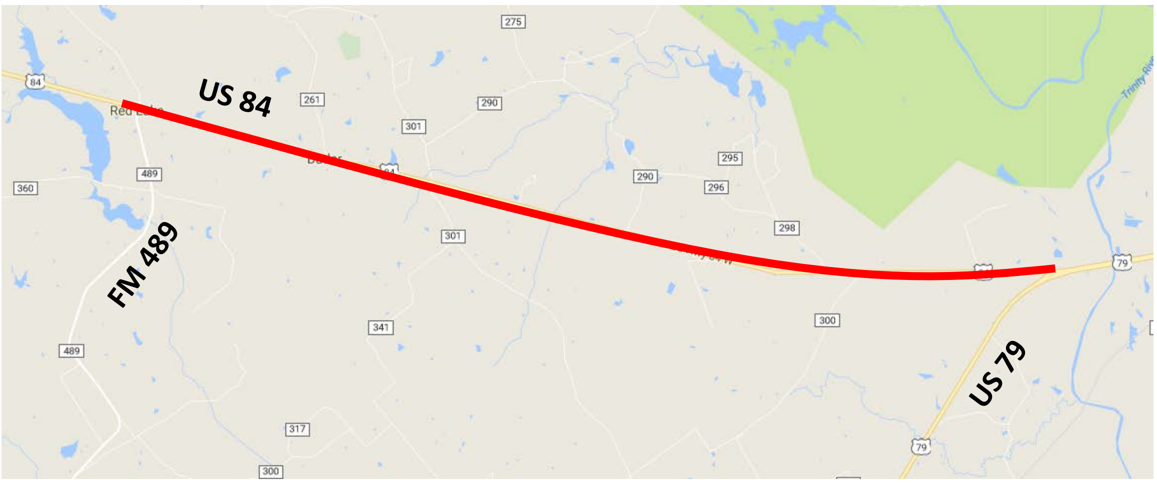



**Figure 5-5. Project Location on US 84.**

The existing pavement was 10 in. lime treated subbase, 8 in. cement treated flexible base, and 3 in. HMA Ty D. The existing seal coat surface had transverse and longitudinal cracking. Two test sections were placed: one with a traditional underseal using AC-20xp and another with a spray paver membrane. These were constructed by the contractor before TTI researchers could make on-site measurements of application rates. The typical asphalt rate for the underseal is 0.30 gal/sy and for the spray paver membrane is 0.20 gal/sy.

Five cores from each section were sampled. Three were used for bond shear testing and two for overlay testing.

*Burnet-TOM*

Near Burnet, Angel Brothers constructed a TOM using different bonding technologies. Table 5-3 summarizes these. The project compared three tack types (AC-15p, hot applied trackless tack, and polymer-modified emulsion for a spray paver membrane). The surface was milled and AC-15p was placed at three different tack rates. Other specific details about this project are not available as the researchers were not present during construction.

Six samples were taken from each section, three for bond shear testing and three for overlay testing.

**Table 5-3. Burnet-TOM Testing Plan.**

| Tack Type | Surface Type | Target Shot Rate (gal/sy) |
|---|---|---|
| Spray paver membrane (AC-15p) | Milled | 0.13 |
| | | 0.15 |
| | | 0.17 |
| Spray paver membrane (pm-emulsion) | | NA |
| Trackless Tack (hot) | | NA |

*US 183-Cedar Park*

This project location is on US 183, between FM 1431 and Osage Drive (Figure 5-6). US 183 is a four-lane principal arterial that runs through an urban area on the south and lighter urban area on the north. The south half has closely spaced signals and an AADT of 35,000 with 9 percent trucks, while the north half has few signals and an AADT of 23,000 with 9 percent trucks.

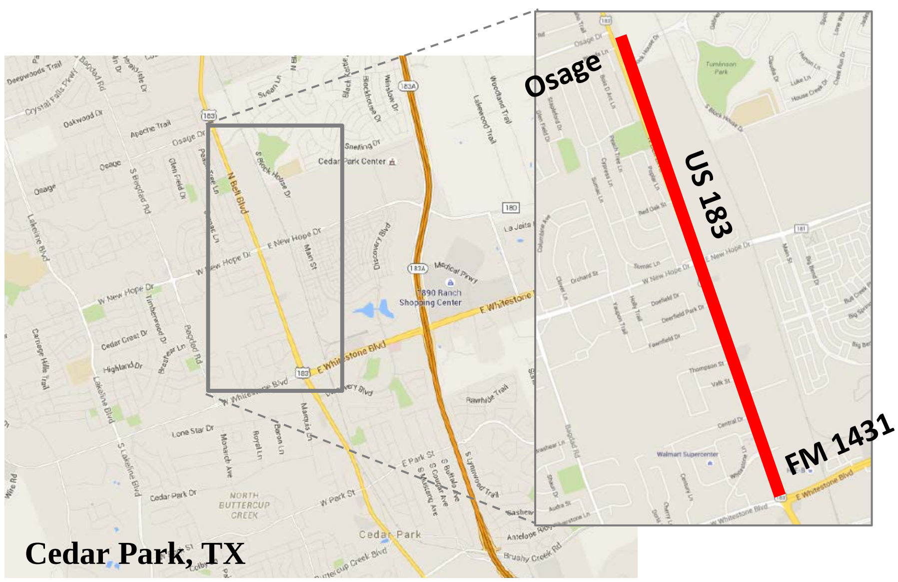



**Figure 5-6. Project Location on US 183 in Cedar Park.**

This project was built in June 2015. It was a TOM overlay over three different surface types, new HMA, milled HMA, and existing un-distressed HMA. Three emulsion trackless tack types (labeled A, B, and C) were placed at three target tack rates (low, moderate, and high), as shown in Figure 5-6. At the time, extensive testing was done on all sections. One year later, July 2016, a subset of the original sections were sampled again as shown in Table 5-4 to measure the effect of age on bond performance. The sampled sections included three emulsion trackless tack types (labeled A, B, and C), three surface types (existing, new, and milled), and three target tack rates (low, moderate, and high). In the follow up testing, the influence of application rate was only studied for Trackless B. The significance of surface type was investigated for all treatment types. Cracking resistance was not studied for this project.

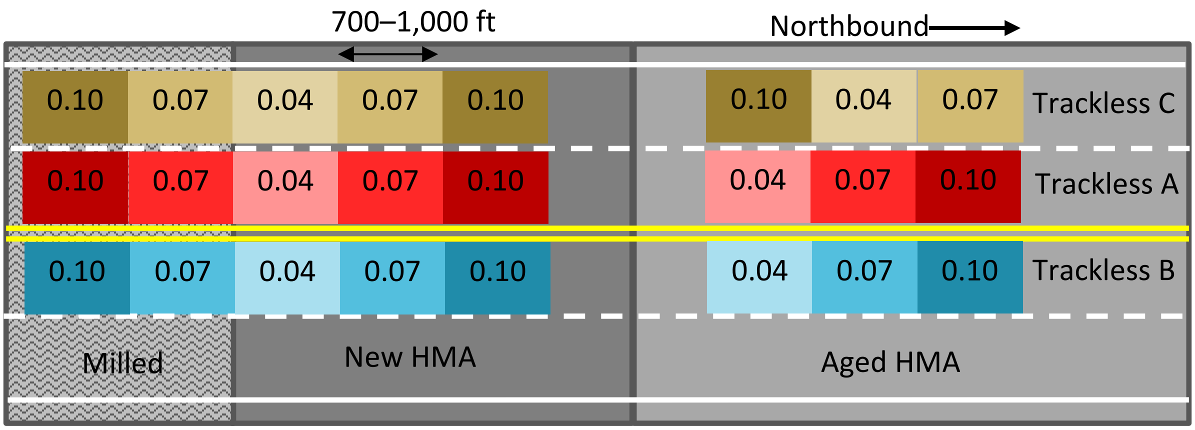



**Figure 5-7. Section Layout on US 183-Cedar Park.**

**Table 5-4. US 183 Testing Plan.**

| Tack Type | Surface Type | Tack Rate (gal/sy) | |
|---|---|---|---|
| | | Level | Avg. Residual |
| None | Existing | - | 0 |
| | New | - | 0 |
| | Milled | - | 0 |
| Trackless A | Existing | Moderate | 0.05 |
| | New | Moderate | 0.05 |
| | Milled | Moderate | 0.06 |
| Trackless B | Existing | Low | 0.02 |
| | | Moderate | 0.04 |
| | | High | 0.07 |
| | New | Moderate | 0.05 |
| | Milled | Moderate | 0.05 |
| Trackless C | Existing | Moderate | 0.05 |
| | New | Moderate | 0.05 |
| | Milled | Moderate | 0.06 |

*SH 336-McAllen*

Figure 5-8 shows the area of the test site located on SH 336 in McAllen, Texas. This test section was built previously in November 2016 and was resampled in April 2017. The project compared emulsion trackless tack to an RC-250 cutback tack. Only one surface type was studied: an aged and polished gravel surface with low texture. Three tack rates were used for each material (Table 5-5).

In 2017, 18 cores were sampled including cores from a small no-tack section where the tack rates were measured. The samples were tested for shear bond strength.


**Figure 5-8. Project Location on SH 336-McAllen.**

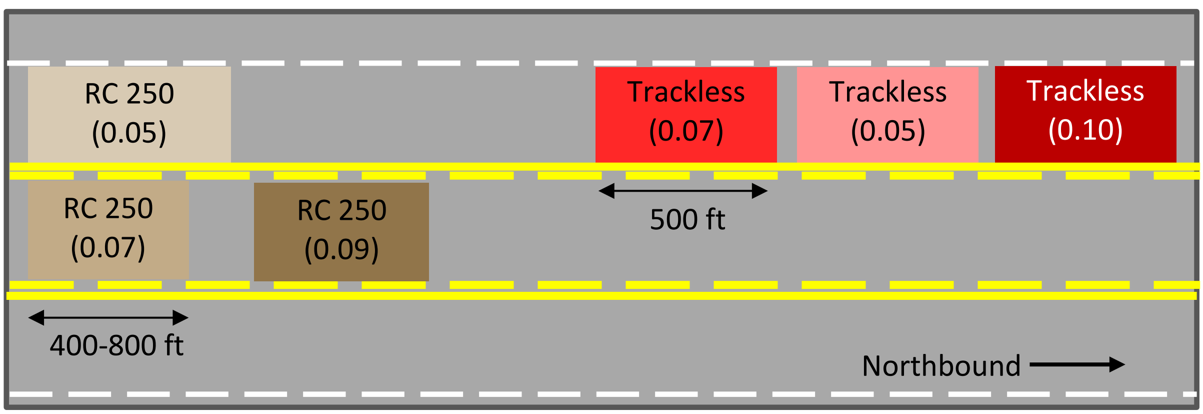



**Figure 5-9. Section Layout on SH 336-McAllen.**

**Table 5-5. SH 336-McAllen Testing Plan.**

| Treatment Type | Surface Type | Tack Rate (gal/sy) | | |
|---|---|---|---|---|
| | | Level | Average Residual | Residual at Core Location |
| Trackless A (emulsion) | Existing | Low | 0.04 | 0.04 |
| | | Moderate | 0.04 | 0.05 |
| | | High | 0.09 | 0.10 |
| RC-250 | | Low | 0.04 | 0.04 |
| | | Moderate | 0.06 | 0.05 |
| | | High | 0.07 | 0.07 |

### Laboratory Testing

The primary test performed on field cores was shear bond testing. The same methods used for laboratory samples were used for these samples. Most projects were also tested for cracking resistance using the modified overlay test. Again, the same methods were used as previously described. The only deviation was that some overlays were thinner than the 1.25 inches used in the laboratory test plan. In these cases, the notch in the substrate was not as deep to maintain a total of 1.5-inch thickness.

### Statistical Analysis

Several statistical analyses were performed to identify which variables were influential in changing the bond and cracking performance from field cores. Some of the analyses with US 183 data were compared to the previous lab results as well. Table 5-6 through Table 5-9 summarize the different analyses that were performed. Because the data set is not full factorial and unbalanced, each analysis could only use a subset of the data.

**Table 5-6. ANOVA Data Set for Comparing the Effect of Different Project-Treatment Types: (a) Bond Strength and (b) Cracking Resistance (Overlay).**

**(a)**

| Response Variable | Test Variable | Data Used for Analysis | Sample Size |
|---|---|---|---|
| Shear Bond Strength, psi | Project + Treatment Type | Project + Treatment Type:<br>US 79-Oakwood<br>None<br>Conventional (CSS-1H)<br>Trackless Tack (Emulsion)<br>Trackless Tack (hot applied)<br>Membrane (Spray paver)<br>Underseal (AC-20xp)<br>US 84<br>Membrane (Spray paver)<br>Underseal (AC-20xp)<br>Burnet<br>Trackless Tack (hot applied)<br>Membrane (Spray paver-Emulsion)<br>Membrane (Spray paver-AC 15p)<br>US 183-Cedar Park<br>None<br>Trackless Tack<br>SH 336-McAllen<br>None<br>Trackless Tack<br>RC 250<br>Bond Age:<br>New (1 month for US 183) | 83 |

**(b)**

| Response Variable | Test Variable | Data Used for Analysis | Sample Size |
|---|---|---|---|
| log(Cycles) | Project + Treatment Type | Project + Treatment Type:<br>US 79-Oakwood<br>None<br>Conventional (CSS-1H)<br>Trackless Tack (Emulsion)<br>Trackless Tack (hot applied)<br>Membrane (Spray paver)<br>Underseal (AC-20xp)<br>US 84<br>Membrane (Spray paver)<br>Underseal (AC-15xp)<br>Burnet<br>Trackless Tack (hot applied)<br>Membrane (Spray paver-Emulsion)<br>Membrane (Spray paver-AC 15p)<br>Bond Age:<br>New (1 month for US 183) | 30 |

**Table 5-7. ANOVA Data Set for Comparing Bond Strength and Cracking Resistance of Field and Lab Molded Samples.**

| Response Variable | Test Variable | Data Used for Analysis | Sample Size |
|---|---|---|---|
| Shear Bond Strength, psi<br><br>log(Cycles) | Field vs. Lab Molded<br><br>Treatment Type | Project:<br>US 79 cores<br>US 79 cores with lab overlay<br>Treatment Type:<br>None<br>Conventional (CSS-1H)<br>Trackless Tack (Emulsion)<br>Trackless Tack (hot applied)<br>Membrane (Spray paver)<br>Underseal (AC-20xp)<br>Bond Age:<br>New | 35<br><br>25 |

**Table 5-8. ANCOVA Data Set for the Effect of Age on Bond Strength.**

| Response Variable | Test Variable | Data Used for Analysis | Sample Size |
|---|---|---|---|
| Shear Bond Strength, psi | Age<br><br>Project + Treatment Type | Project + Treatment Type:<br>US 79-Oakwood<br>Conventional (CSS-1H)<br>Trackless Tack (Emulsion)<br>Trackless Tack (hot applied)<br>Membrane (Spray paver)<br>Underseal (AC-20xp)<br>US 183-Cedar Park<br>None<br>Trackless Tack<br>SH 336-McAllen<br>None<br>Trackless Tack<br>RC 250<br>Bond Age:<br>0–17 months (continuous) | 159 |

**Table 5-9. ANCOVA Data Set for Bond Analyses on US 183-Cedar Park.**

| Response Variable | Test Variable | Data Used for Analysis | Sample Size |
|---|---|---|---|
| Shear Bond Strength, psi | Age<br>Treatment Type<br>Surface Type | Project:<br>US 183-Cedar Park<br>Treatment Type:<br>Trackless Tack A<br>Trackless Tack B<br>Trackless Tack C<br>None<br>Surface Type<br>New HMA<br>Milled HMA<br>Existing HMA<br>Bond Age:<br>0 months, 9 months | 68 |
| | Application Rate | Project:<br>US 183-Cedar Park<br>Treatment Type:<br>Trackless Tack B<br>Surface Type<br>Existing HMA<br>Application Rate<br>Low, Moderate, High<br>Bond Age:<br>0 months, 9 months | 18 |

## RESULTS

The results in this section are the results from the statistical analyses and show the modeled data, not the direct measured results. The details for measurements and each statistical analysis are in Appendix B and Appendix C, respectively.

### Project + Treatment Type

Figure 5-10 compares all field projects. These data are for initial bond strength only and do not consider strength gain over time. The column pattern is associated with different field projects, and the column color represents different treatments. Overall, US 79-Oakwood had the highest bond strengths, followed by US 84-Freestone, Burnet-TOM, then US 183-Cedar Park, and finally SH 336-McAllen. Several of these projects had similar treatments, like trackless tack (emulsion), yet had significantly different strengths. There are many factors that make up bond strength, like surface condition, hot mix temperature, and compaction effort. These factors are independent of the treatment used. Trackless tack (hot) had the highest strength in the US 79-Oakwood and Burnet-TOM projects. No tack had moderate performance in the US 79-Oakwood and SH 336-McAllen, and low performance on US 183-Cedar Park. Underseal had the lowest performance on US 79-Oakwood but the highest performance on US 84-Freestone.

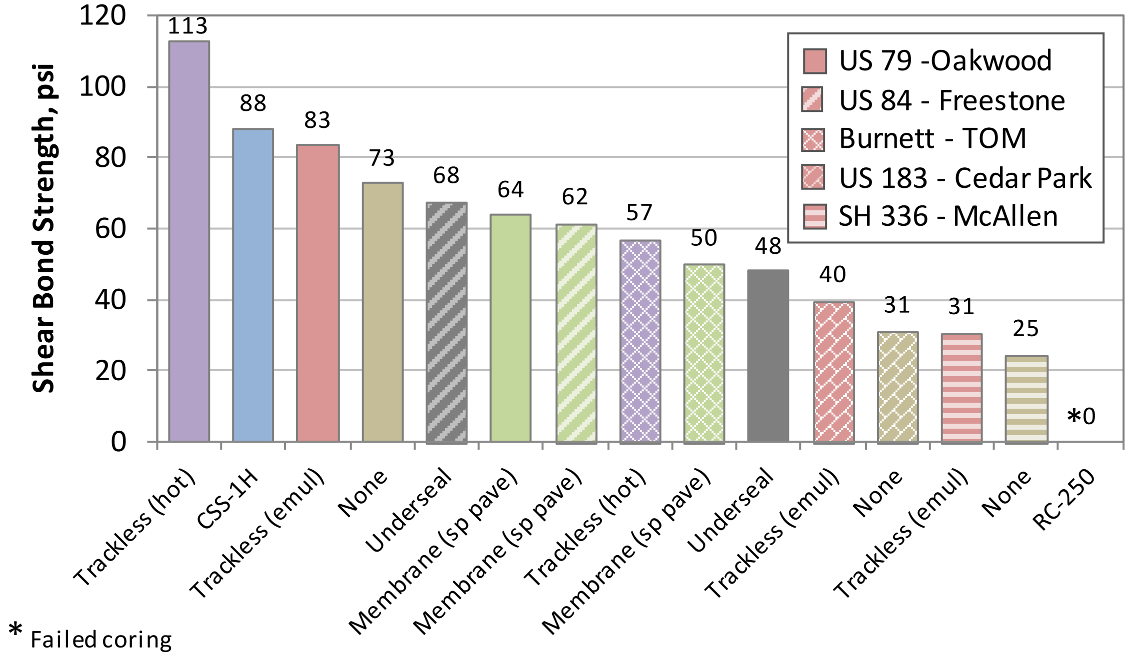



**Figure 5-10. Bond Strength by Project-Treatment Type.**

Figure 5-11 shows the cracking resistance by project + treatment type. The US 84-Freestone test sections had the highest number of predicted cycles in the overlay test, followed by US 79-Oakwood, and then Burnet-TOM. Most samples were not found to be statistically unique, except that the extreme highs (>30,000 cycles) were considered different than the extreme lows (<1,000 cycles). What was more interesting was the unique manner that the samples failed. Samples with no tack, tack coat, and trackless tack coat failed with the cracks propagating up through the sample, while the softer seals (membrane and underseal), had cracks that turned horizontally and more closely followed the seal interface (Figure 5-12). This may suggest that reflective cracking can be mitigated with the later products.

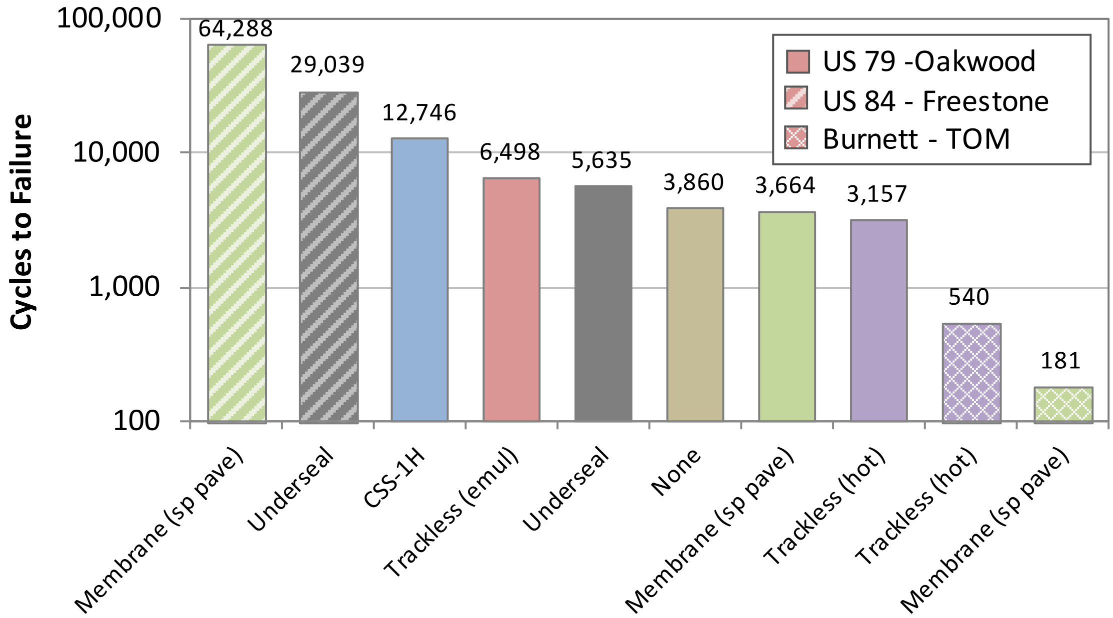



**Figure 5-11. Overlay Cracking Resistance by Project-Treatment Type.**

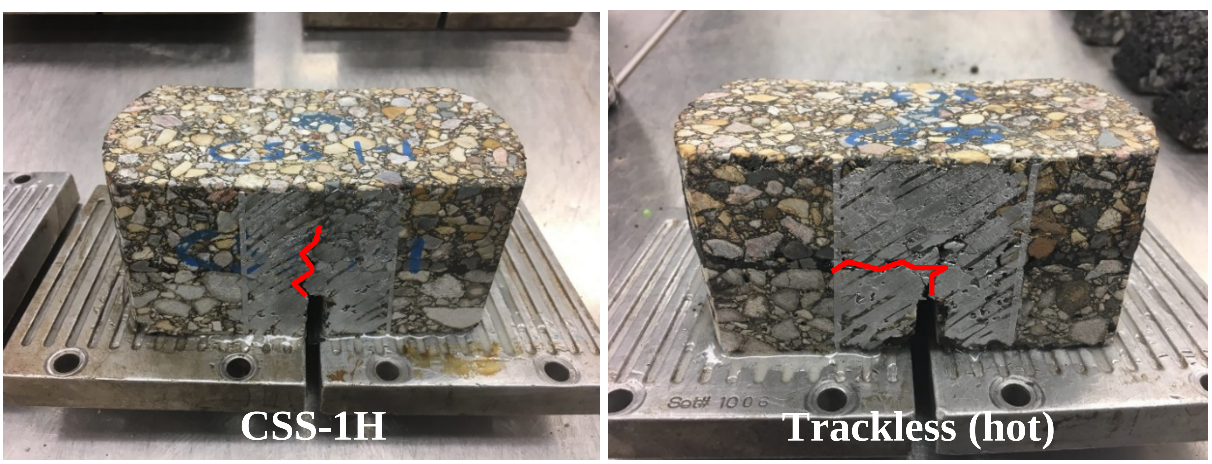



**Figure 5-12. Reflection Cracking through Different Sample Types.**

**Section Age**

The effect of age and the interaction between age and project_treatment type on bond strength were significant. Bond strength increases with time and also the rate of increase is unique for different projects. In Figure 5-13, the different projects are represented by symbols and line types (solid, dashed, and dotted). The different treatment types are represented by different colors. On average, bond strength increased by 80 percent over 12 months. The following were predicted to increase by roughly 100 psi over 20 months: US 79_Trackless (hot), US 79_Trackless (emulsion), US 183_Trackless (emulsion)., US 183_None, and SH 336_RC250. The sample with the least bond strength increase was SH 336_None, which was predicted to have negligible increase over 20 months.

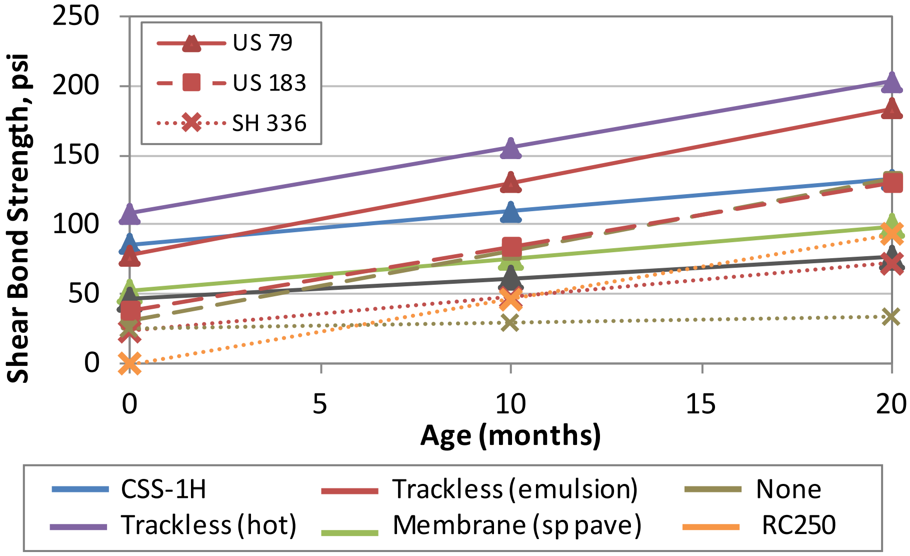



**Figure 5-13. Bond Strength by Age and Treatment Type.**

One critical item is that the analysis of covariance (ANCOVA) model used linear regression, which is likely not the best fit for these data. More likely, most of the bond strength develops early in life and then stabilizes. This is illustrated by the US 79_Membrane (spray paver) (Figure 5-14). This was the only test section with initial, short-term, and long-term bond strength measurements available. This trend may be most applicable for emulsion treatment treatments that have water that will escape over time. However, even the hot applied trackless tack on US 79 also showed significant increase over time.

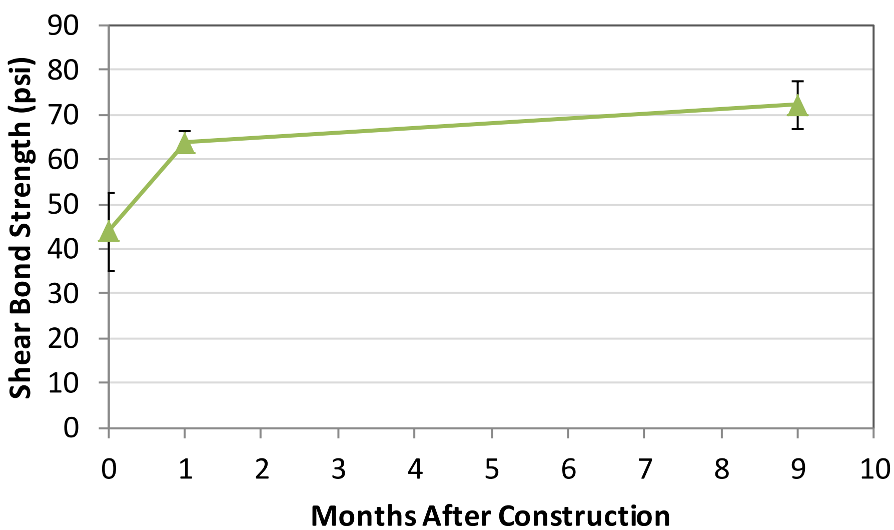



**Figure 5-14. Initial, Short-Term, and Long-Term Bond Strength of US 79 Spray Paver Membrane Test Section.**

## Surface Type

Figure 5-15 presents the model for samples molded on new HMA versus existing surface treatment. Substrate type, treatment type, and the interaction were significant. The substrate type had a very significant impact for all treatments except for membrane underseals and traditional underseals. In the former cases, changing from an existing surface treatment substrate to new HMA increased the bond by 60 to 110 percent. For membrane underseals and underseals, which had significantly thicker tack applications, the substrate did not influence the bond strength.

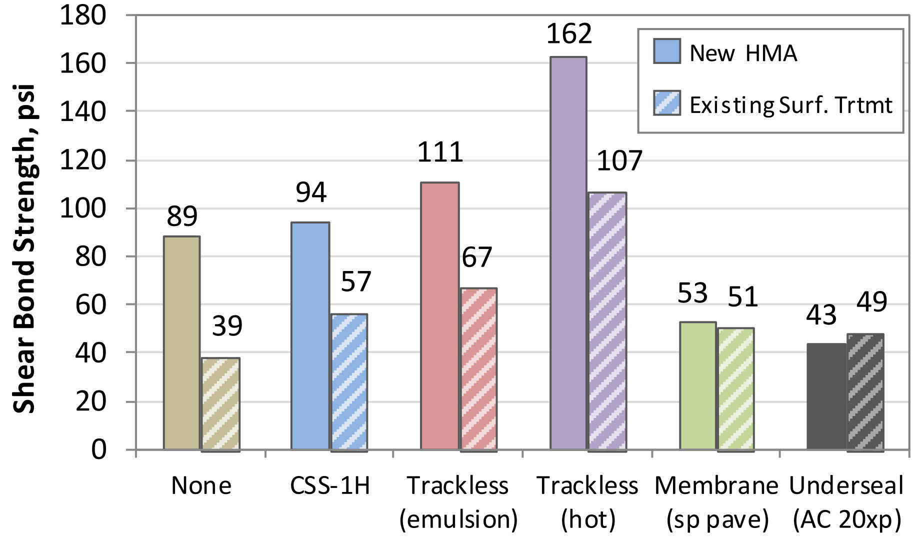



**Figure 5-15. Bond Strength of New Substrate vs. Aged Substrate Samples.**

## Lab and Field Compaction

The analysis comparing the effects of field compaction versus lab compaction showed that lab compacted samples had higher bond strengths (Figure 5-16). This trend has been noted several times in previous TTI research and in the literature. The controlled high temperatures and thorough compaction effort yield consistently better bonding than the field compaction process. The cracking resistance results from the overlay test were inconclusive. The model was not significant because of the high variability in the test, making it not possible to state whether the field or lab molded samples had different cracking properties.

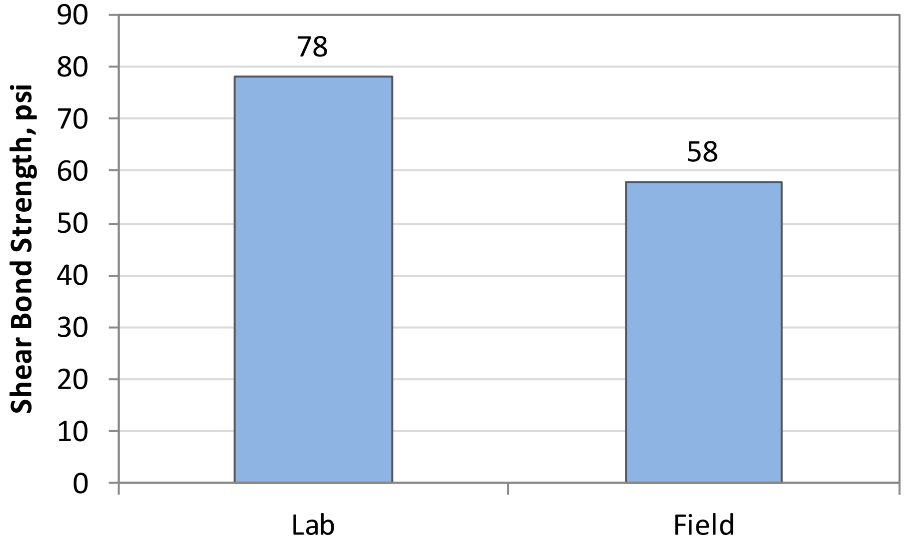



**Figure 5-16. Bond Strength by Sample Compaction Type.**

**US 183-Cedar Park**

The model for bond strength vs tack type, surface type, age, and tack type*surface type was significant and is shown in Figure 5-17. Tack A and B had the highest strength, followed by no tack and lastly Tack C. Overall, the new HMA and milled HMA surfaces had the highest bond strength. The most influential factor, however, was age. On average, bond strength after 9 months in service was 80 percent higher than at the time of construction.

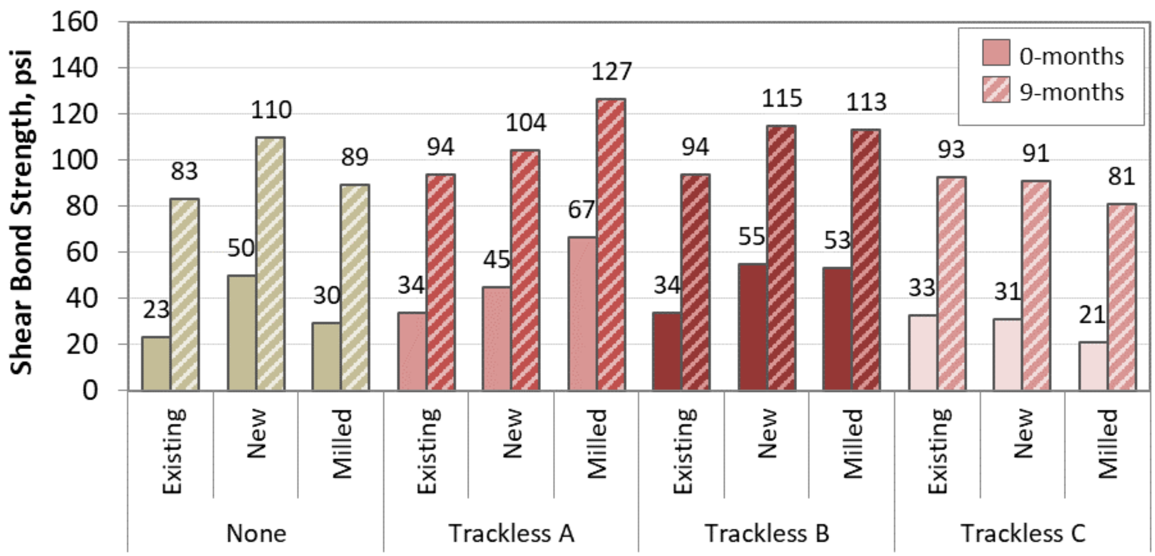



**Figure 5-17. Shear Bond Strength for Different Tack Type and Surface Type.**

Another analysis was done on the effect of application rate and age on bond strength for Trackless Tack B over existing HMA. The results in Table 5-10 indicate that, while age was significant, tack rate was not. For this overlay mixture on this surface, there was no difference between applying 0.04 and 0.1 gal/sy of trackless tack.

**Table 5-10. Statistical Analysis of Surface Type and Tack Type on Bond Results.**

| **Explanatory Variable** | **Bond Strength** | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Application Rate | 0.8092 | <0.001 | 0.520 |
| Age | | | <0.001 |

# CHAPTER 6
# PERFORMANCE PREDICTION AND LIFE-CYCLE COST ANALYSIS

Researchers conducted a LCCA of the US 79-Oakwood test sections. This process included 1) predicting critical strains versus bond condition with a linear-elastic model, 2) predicting rutting and reflection cracking life versus bond condition with a mechanistic-empirical model, 3) transforming laboratory bond strength to the modeled shear modulus parameter to predict treatment service life, and 4) finding the total costs of construction, maintenance, and rehabilitation for each treatment.

## PERFORMANCE PREDICTION

The models from this research are helpful to illustrate the general influence of bond condition. The results are not expected to perfectly predict actual performance. The most significant shortcoming of these models in the connection between laboratory shear bond strength and the field shear reaction modulus. In a previous project, researchers established a qualitative conversion between the two (*3*). A similar approach was used in this project; and some discussion of the shortcomings of this approach are discussed.

### Linear-Elastic Modeling with BISAR

The pavement structure of US 79-Oakwood was simulated for analysis in the linear-elastic analysis software, BISAR, developed by the Shell Co. The analysis predicts the critical horizontal stains at the bottom of the AC overlay and vertical strains on the surface of subgrade. The bond condition was varied from full slip to fully bonded conditions to simulate different interlayer bond strengths.

The pavement structure was modeled as a simple multilayer elastic system. Layer properties were determined based on historic structural data, ground penetrating radar testing, falling weight deflectometer (FWD) testing, and coring. One test section, the spray paver underseal membrane, was built on a different pavement structure than the other treatments. The other structure may have had flex base over cement-treated base, according to FWD analysis. For the purpose of this study, however, researchers assume all pavement structures were the same. Table 6-1 and Figure 6-1 present the pavement layer properties used in the analysis.

**Table 6-1. Pavement Structure Properties for BISAR.**

| Layers | Thickness (mm) | Modulus (MPa) | Poisson's Ratio |
|---|---|---|---|
| AC Overlay | 50 | 3500 | 0.35 |
| Tack Coat | NA | NA | NA |
| Existing AC | 200 | 5500 | 0.35 |
| Cement-Treated Base | 280 | 2800 | 0.25 |
| Subgrade | NA | 60 | 0.35 |

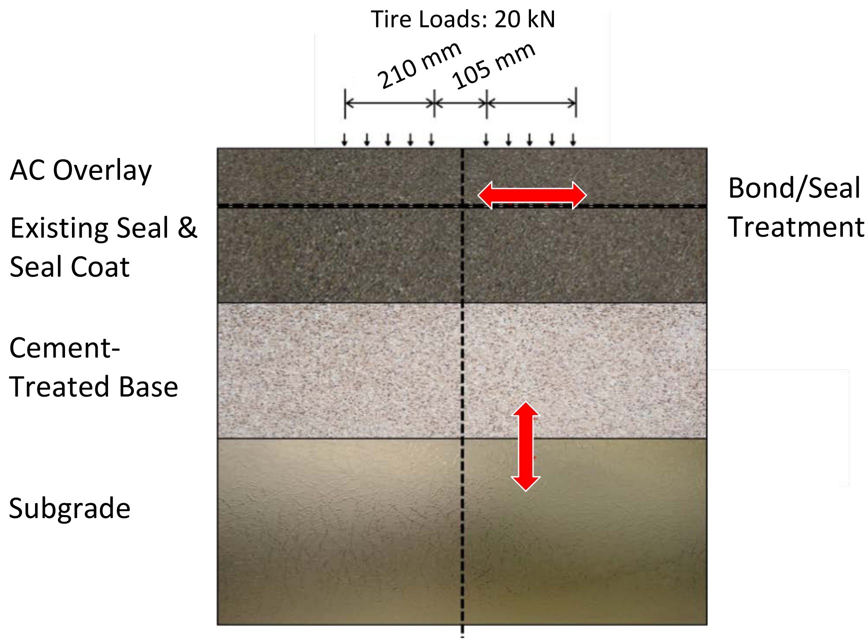



**Figure 6-1. Schematic of Multilayer Elastic Analysis in BISAR.**

The tack coat layers in the pavement were treated as interface layers and not structural layers. The bond condition at the tack coat interface is quantified by the horizontal shear reaction modulus (Ks), which is defined following Goodman's constitutive law (*21*):

$$\tau = K_s(\Delta U) \quad \text{Equation 1}$$

where
τ = shear stress at the interface.
Δu = relative horizontal displacement of the two faces at the interface.
Ks = horizontal shear (interface) reaction modulus.

Figure 6-2 illustrates the horizontal strains in the AC overlay versus bond condition. The overlay is subject to high tensile strains until log(Ks)=7, after which the strains decrease and enter compression around log(Ks)=12. One might assume, therefore, that below 7 is associated with fully sliding and above 12, fully bonded. However, the location of the sigmoidal graph actually changes based on the pavement layer thicknesses and moduli. Therefore, the effect of bond condition must be evaluated on a case-by-case basis.

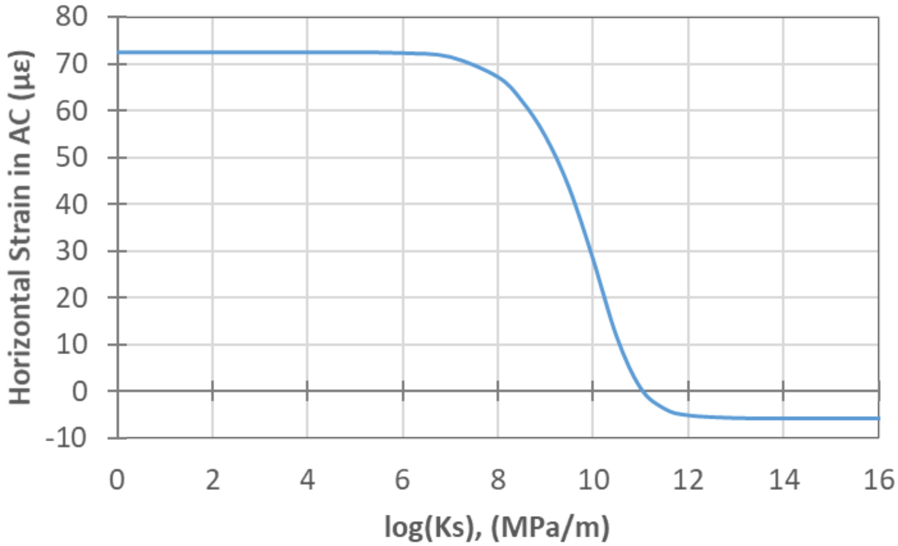



**Figure 6-2. Tensile Strains in the AC Layer for Different Bond Conditions.**

Figure 6-3 shows the vertical strains on the subgrade versus bond condition. Again, there is a dramatic change in strains between log(Ks)=7 and 12. A lower bond condition is associated with higher strains.

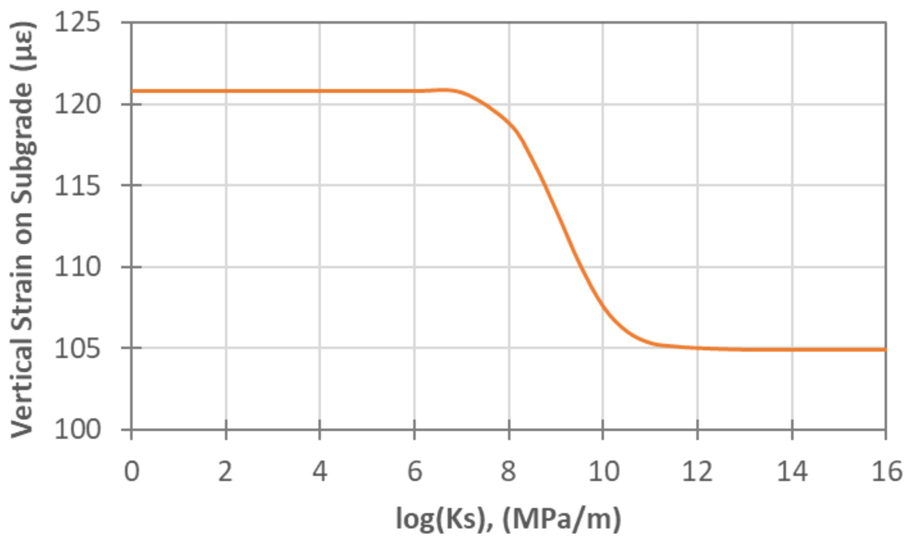



**Figure 6-3. Vertical Compressive Strains for Different Bond Conditions.**

With the critical strains determined, the predicted axle load repetitions to failure for fatigue and rutting could be estimated with the Asphalt Institute equations and corresponding fatigue cracking (Equation 2) and rutting (Equation 3) criteria. Figure 6-4 shows these. Fatigue cracking is a significant concern for bond conditions lower than $\log(K_s)=10.5$. Cracking is predicted to occur in less than a year. With better bonding, the bottom of the asphalt layer is in compression, resulting in no fatigue cracking. Rutting is not a concern on this project. As stated earlier, the modeling and the Asphalt Institute equations are not intended to predict actual performance, but more to illustrate general trends. On that note, the project is likely not at high risk of premature fatigue failure.

$$N_f = 0.0796(\varepsilon_t)^{-3.291}|E^*|^{-0.854} \qquad \text{Equation 2}$$

where
$N_f$ = allowable number of load repetitions to control fatigue cracking.
$\varepsilon_t$ = tensile strain at the bottom of AC layer.
$|E^*|$ = dynamic modulus of the asphalt mixture.

$$N_d = 1.365 \times 10^{-9}(\varepsilon_c)^{-4.477} \qquad \text{Equation 3}$$

where
$N_d$ = allowable number of load repetitions to control permanent deformation (rutting).
$\varepsilon_c$ = vertical compressive strain on the surface of subgrade.

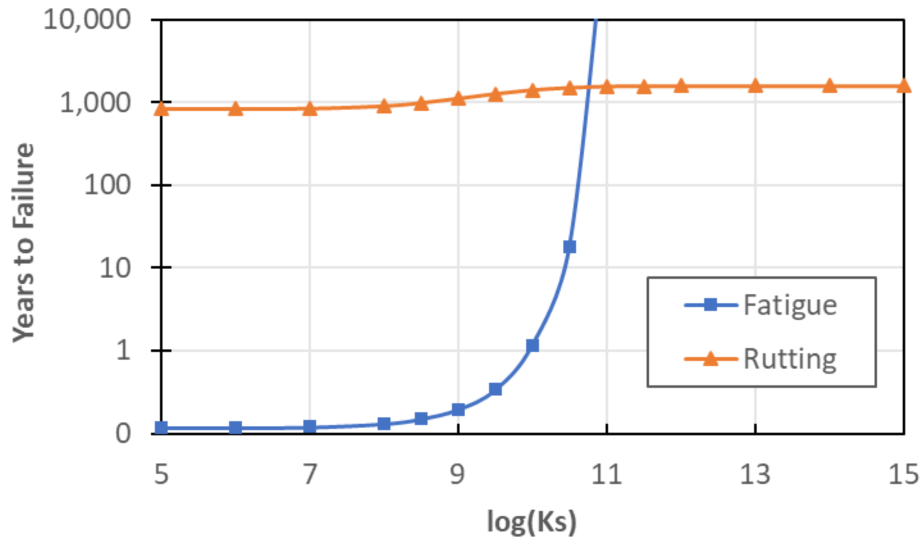



**Figure 6-4. Predicted Fatigue and Rutting Life vs. Bond Condition with AI Equations.**

**Mechanistic-Empirical Analysis with TxACOL**

The mechanistic-empirical analysis was done using the software TxACOL. The software predicts performance over time, in terms of reflection cracking and rutting. Reflection cracking rates are predicted by calculating the stress intensity factors at the crack tip as it progresses upward throughout the analysis. A detailed discussion of the theory and calculations for this process are found in previous research (*22*).

The model allows for more detailed material parameters including the dynamic modulus of AC and fracture properties for crack initiation and crack growth. Detailed climate conditions are modeled using historic hourly climate data over several years of the analysis. Traffic data are modeled as individual axles with a distribution of loads to represent the amount and type of truck traffic on the rural principal arterial. Table 6-2 shows details of the inputs for the US 79-Oakwood project.

**Table 6-2. Pavement, Climate, and Traffic Inputs for TxACOL.**

| **STRUCTURAL PROPERTIES** | | | | |
|---|---|---|---|---|
| **Layers** | **Thickness (mm)** | **Modulus (MPa)** | **Poisson's Ratio** | **Other** |
| AC Overlay | 50 | 3500 | 0.35 | Fracture properties |
| Tack Coat | NA | NA | NA | Bond Condition (log(Ks)): 7-11 |
| Existing AC | 200 | Dynamic Modulus | 0.35 | |
| Subbase | 280 | 2800 | 0.25 | |
| Subgrade | - | 60 | 0.35 | |
| Crack Load Transfer Efficiency | - | - | - | 70% |
| **CLIMATE CONDITION** | | | | |
| Data from weather center located near Oakwood, Leon County, TX | | | | |
| **TRAFFIC CONDITION** | | | | |
| 2016 AADT | 2035 AADT | % Truck | | |
| 5,750 | 9,450 | 24.8 | - | - |

Figure 6-5 and Figure 6-6 show the rate of reflection cracking and rutting for different bond conditions. Both properties decrease with improved bonding. In the case of reflection cracking, there appears to be an optimum bond condition with the greatest life. This scenario may indicate that a moderate bond is able to relieve thermally induced stress. For rutting, improved bonding consistently improved performance.

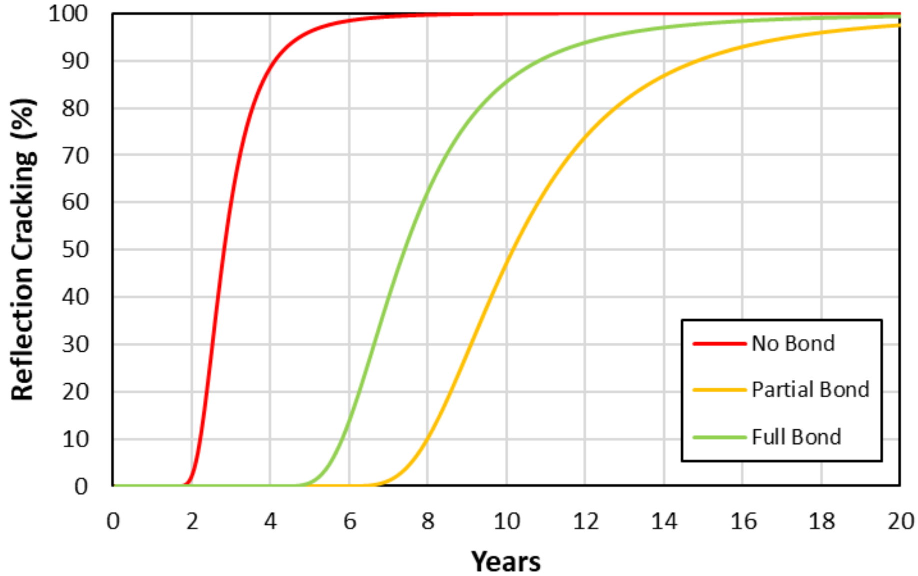



**Figure 6-5. Predicted Reflection Cracking Performance.**

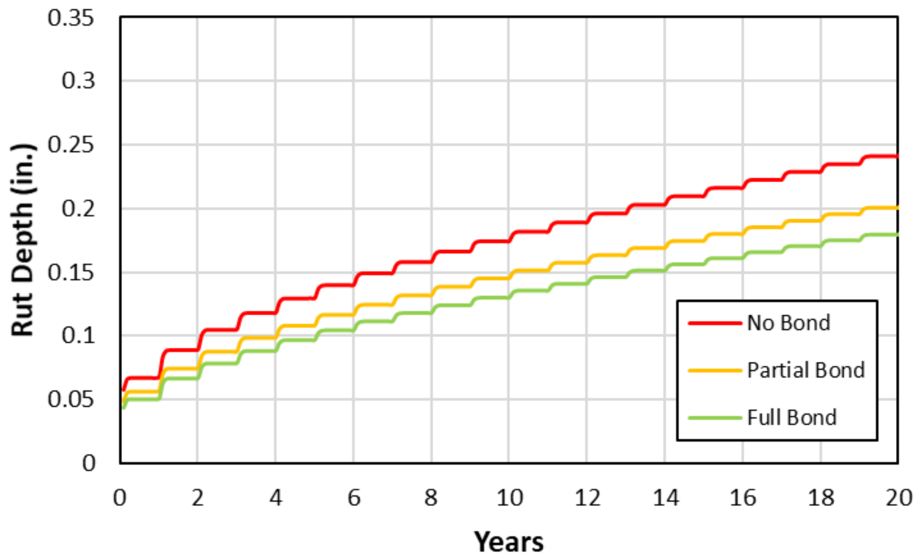



**Figure 6-6. Predicted Rutting Performance.**

## Strength Transformation and Performance Prediction

The preceding analysis considered overlay performance versus the interface shear modulus, log($K_s$). Since the project scope did not include laboratory testing of the actual shear modulus, but rather bond strength, researchers developed a transformation function between laboratory shear bond strength and log($K_s$) to evaluate the performance of the US 79 test sections. The transformation is a qualitative mapping of the lower and upper bounds for bond strength onto the log($K_s$) scale, correlating with similar no-bond and full-bond conditions, and fitted with a sinusoidal curve. Table 6-3 describes the mapping assumptions, and Figure 6-7 gives the transformation graph. This transformation is specific to the pavement structure on the US 79-Oakwood test sections and will vary for different pavements.

**Table 6-3. Justification for Shear Bond Strength to log($K_s$) Transformation.**

| Shear Bond Strength* (psi) | log($K_s$) | Justification |
|---|---|---|
| 0 | 7 | No bond. |
| 8 | 7 | Lowest bond strength observed from a sample that did not break in coring. TTI |
| 16 | 7.1 | Lowest bond strength observed near delaminated areas.** NCAT (*23*) |
| 35 | 7.3 | Recommended bond strength threshold in Texas.<br>Highest bond strength observed near delaminated areas.** NCAT (*23*) |
| 41 | 7.5 | Average of new field samples.*** TTI |
| 45 | 7.5 | Lowest bond strength observed on projects away from delaminated areas.** NCAT (*23*) |
| 65 | 10 | Average of aged underseal and spray paver membrane projects. TTI |
| 90 | 11.2 | Average of aged traditional and trackless tack projects. TTI |
| 155 | 11.7 | Maximum observed from field cores. TTI |
| 180 | 12 | Maximum observed from lab samples. TTI |
| 220 | 12 | Highest observed bond and internal HMA strength.** TTI (*3*) |

* Tested at rate of 0.2 inch/min
** Converted to rate of 0.2 inch/min
*** Excludes data from samples that could not be cored.

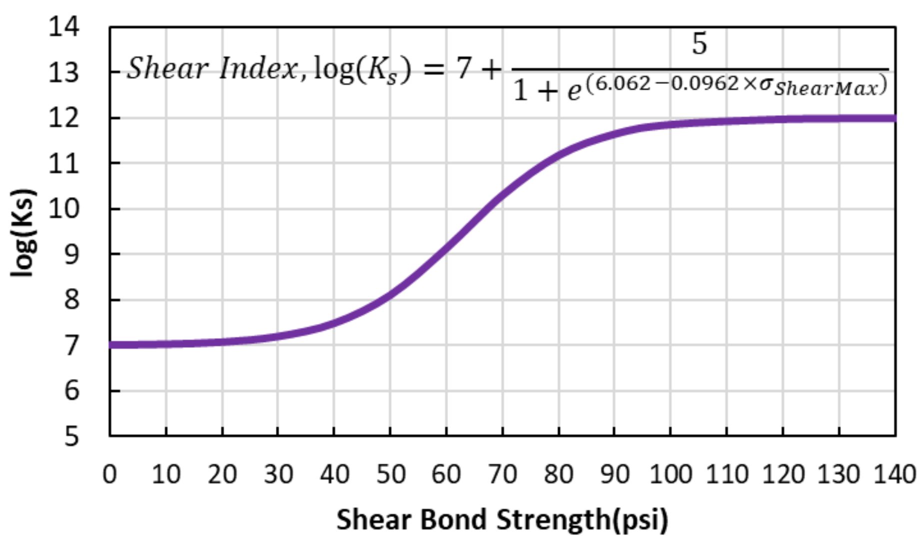



**Figure 6-7. Shear Bond Strength to log($K_s$) Transformation.**

Using the above transformation, the performance of each treatment section with respect to reflection cracking was produced. Figure 6-8 shows the expected life until 50 and 90 percent of the reflection cracks surface. Traditional tack and the two trackless tacks, which had the highest bond strength and were considered fully bonded, also had the lowest crackling life at 7 years for 50 percent cracking and about 11 years for 90 percent cracking. The spray paver membrane and underseal sections had lower bond strength, which actually results in greater service life. These sections had about 9 years and over 13 years life for 50 and 90 percent cracking, respectively. This trend is likely because the lower bond strength of these treatments helps relieve horizontal stress from thermal cycling. According to the models, rutting and fatigue cracking do not govern performance on this project.

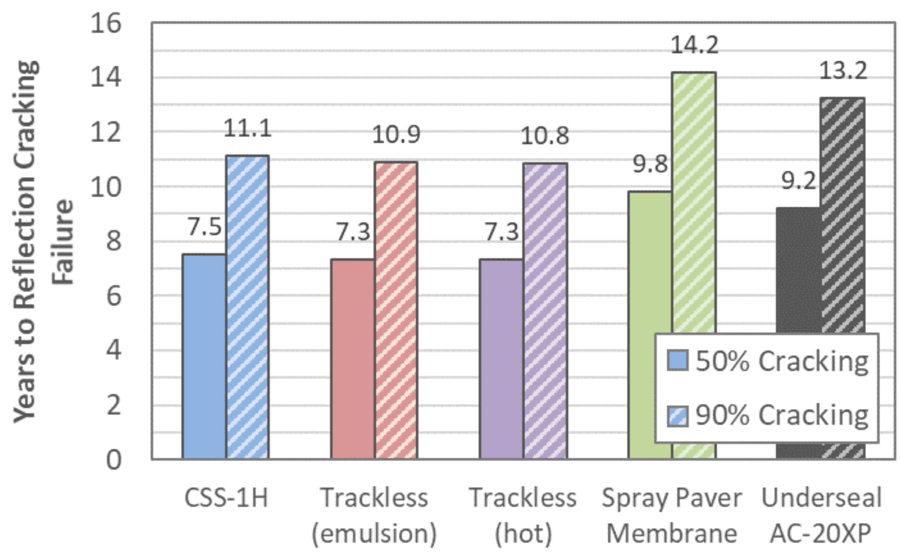



**Figure 6-8. Predicted Life to Reflection Cracking Failure.**

## LIFE-CYCLE COST ANALYSIS

The LCCA was conducted using RealCost Version 2.5 developed by the Federal Highway Administration. The analysis considered the following test sections: traditional tack (CSS-1H), trackless tack (emulsion), trackless tack (hot applied), polymer modified asphalt for spray paver membranes, and an AC-20xp underseal. The costs were for initial construction, routine crack seal maintenance, rehabilitation at failure, user delays, minus the remaining salvage value (Table 6-4). The material costs were obtained from TxDOT bidding history and from material vendors. Failure when rehabilitation would take place was defined at 90 percent reflection cracking. No other performance metrics were considered. An analysis period of 25 years was used.

**Table 6-4. Material Costs Used in Life-Cycle Cost Analysis.**

| Item | Approx. Cost | Rate | Quantity (12-ft lane-mile) | Total Cost |
|---|---|---|---|---|
| Surface HMA<br>SP Ty-D (SAC A) | $90/ton | 220 lb/sy | 775 ton | $69,750 |
| Milling Asphalt (2") | $0.95/sy | - | 7,040 sy | $6,700 |
| CSS-1H | $2.25/gallon | 0.08 gal/sy | 564 gal | $1,250 |
| Trackless (emulsion) | $2.75/gallon | 0.08 gal/sy | 564 gal | $1,550 |
| Trackless (hot applied) | $5.50/gallon | 0.14 gal/sy | 986 gal | $5,400 |
| Polymer-Modified Tack (emulsion) | $2.50/gallon | 0.20 gal/sy | 1,400 gal | $3,500 |
| Underseal<br>Polymer-Mod. Binder<br>Aggregate | $2.75/gallon<br>$80/cy | 0.30 gal/sy<br>1 cy/125 sy | 2,100 gal<br>30 cy | $8,400 |
| Crack Seal | $1.75/linear-ft | 264** cracks/mile | 3168 ft** | $5550** |
| Tack Transportation* | $0.90/mile/1000 gal | - | - | - |

*For reference. Already included in the tack cost
**For fully developed cracking. Analysis uses different crack rates over time.

Table 6-6 shows a schedule of activities and the rate of cracking for each treatment by year. Once cracking starts, crack seal was scheduled every three years until 90 percent cracking was achieved, at which point rehabilitation was scheduled.

Not included in this analysis is the cost of a spray paver. Table 6-5 summarizes new and retrofitted paver costs. While the equipment represents a substantial upfront investment, the cost should be distributed across several years of paving.

**Table 6-5. Paving Equipment Costs. ({Wilson, 2017 #450})**

| Equipment | Manufacturer | Cost (1,000 dollars) |
|---|---|---|
| Standard Paver | NA | $400–$450 |
| Spray Paver | Roadtec | $875–$950 |
| | Vogel | $925 |
| | Caterpillar (Integral dx) | $740–$800 |
| Spray Paver Retrofit* | Caterpillar (Integral dx) | $350 |

*Available for limited models

**Table 6-6. Schedule Activities and Rate of Cracking.**

| Treatment | Percent Reflection Cracking by Year (%) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| **CSS-1H** | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 |
| **Trackless (emulsion)** | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 |
| **Trackless (hot)** | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 | 15 | 40 | 60 | 80 | 85 | 0 | 0 | 0 | 0 | 0 |
| **Spray Paver Membrane** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 45 | 60 | 75 | 80 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 45 | 60 |
| **Underseal AC-20XP** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 45 | 60 | 75 | 80 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 45 | 60 |

Construction    Maintenance    Rehabilitation

Figure 6-9 shows the life-cycle costs for each treatment type on US 79-Oakwood. The chart shows the total cost by agency and user costs. Agency costs are for materials while user costs are associated with construction delays. The total life-cycle costs range between $135,000 to $169,000/lane-mile. The lowest cost treatment was the spray paver membrane, which had comparable material costs as other treatments but longer predicted life with respect to reflection cracking. The underseal also had longer service life, but because material costs are higher, the total cost is similar to treatments with lower service life. The most expensive treatment was hot-applied trackless tack. Using a spray paver membrane instead of a traditional tack saves 15 percent to the agency and users over 25 years.

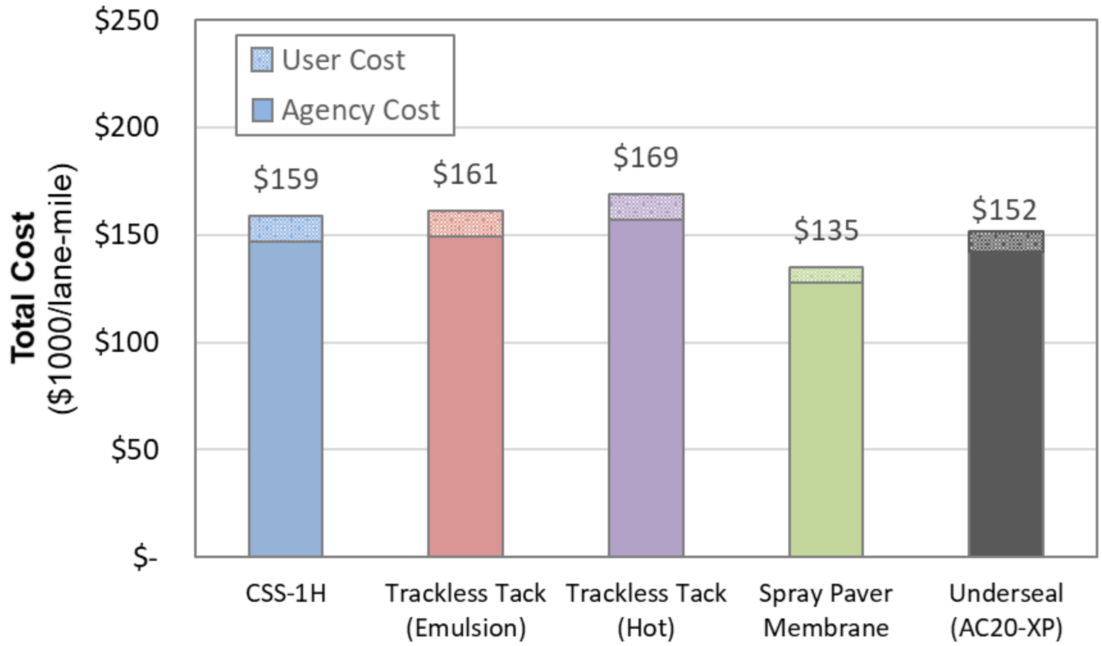



**Figure 6-9. Total Life-Cycle Cost.**

These life-cycle costs are specific to the US 79-Oakwood pavement structure and existing distressed surface. Reflection cracking was the governing failure mechanism and was reduced by a more flexible interface treatment. Applications over different pavement structures with a different surface conditions will likely be constrained by other performance criteria like fatigue cracking or rutting. In these cases, a stiffer bond is likely to perform better, and the resulting LCCA could favor different treatments.

# CHAPTER 7
# CONCLUSION

## REPORT SUMMARY

Several bonding and sealing treatments are available to prepare a surface prior to an asphalt overlay, including: traditional tack coats, trackless tack coats, spray paver underseal membranes, and traditional underseals. These provide varying levels of bonding and sealing performance, but these benefits have not been sufficiently quantified, and neither has the overall impact on the asphalt overlay service life. Consequently, for a given overlay scenario, there is confusion about which treatment provides the best long-term performance for the lowest possible cost.

This study:

1. Evaluated the performance of different bonding and sealing treatments for:
    - Shear bond strength.
    - Resistance to reflection cracking.
    - Permeability.
2. Estimated the life-cycle cost for each treatment.
3. Provided a reference guide for bonding and sealing treatments.

TxDOT districts were surveyed about their experience with each treatment.

Researchers measured the performance of each treatment in the laboratory using a shear bond strength test, modified Texas overlay test, compact tension test, and Florida falling-head permeability test. To assist in sample fabrication, a laboratory tack spray system was developed.

Test sections with different treatment types, surface types, and application rates were evaluated for bond strength and cracking resistance. New sections were built on three projects, US 79 near Oakwood, near Burnet, and on US 84 in Freestone Co. Test sections on two existing projects, US 183-Cedar Park and SH 336-McAllen, were revaluated. The long-term performance of the US 79-Oakwood test sections was predicted using the mechanistic-empirical program TxACOL. The overlay service life was governed by reflection cracking. Based on the predictions, an LCCA was performed considering the cost of initial construction, maintenance, rehabilitation, and user delay costs.

## FINDINGS

The TxDOT survey results are as follows:

- Traditional tack is clearly the most common bonding treatment with 87 percent of Districts reporting frequent use. Trackless tack has modest usage at about 22 percent.

Spray paver membranes are used often only 13 percent of the time. Underseals are also common with almost 50 percent reporting frequent use.

- Traditional tack was recommended in the most surface types. Trackless tack was mostly recommended for new and low-distress HMA. Underseals followed by spray paver membranes were recommended for heavily distressed HMA.
- For dense-graded overlay, traditional tack coat is most recommended, while for PFC, an underseal is recommended. No tack was most recommended for surface treatment.
- Initial cost, equipment availability, experience in districts, and constructability are advantages of traditional tack coat. The disadvantages are poor performance as moisture barrier and reduction of reflection cracking.
- Constructability, shear bond strength, equipment availability, and extending the service life are the advantages of trackless tack coat. The disadvantages are initial cost, poor performance as moisture barrier and reduction of reflection cracking.
- Spray paver membrane advantages are moisture barrier, shear bond strength, constructability, and extended service life. The disadvantages are initial cost, equipment availability, and experience in district.
- The only disadvantage of underseal is initial cost. The biggest advantage with this treatment was as a moisture barrier followed by extended service life, bond strength, equipment availability, experience in district, resistance to reflection cracking, and constructability.

Results of laboratory testing are:

- Bond strength was influenced by treatment type, surface type (new HMA versus existing surface treatment), and the interaction. Hot-applied trackless tack was strongest and spray paver membrane and underseal were the weakest. In most cases, new HMA samples were 60 to 110 percent stronger than existing surface treatment samples.
- Cracking resistance from the modified Texas overlay test showed that treatment type was influential, but surface type was not. The compact tension better distinguished among samples and showed that high-residual treatments (underseal, spray paver membrane, and hot-applied trackless tack) had the highest bond energy. The lowest bond energy was from Vaseline, CSS-1H, and no tack samples.
- Permeability was influenced by treatment type. The lowest permeability was for hot-applied trackless tack, underseal, spray paver membrane, and, because of high scatter in the data, the high-application of CSS-1H. Highest permeability was for no tack and high and low applications of CSS-1H.

The following findings were made from tests of field test sections:

- Bond strengths varied significantly among the different projects, even for the same treatment. US 79 had the highest shear bond strengths (48–113 psi), US 84 had acceptable strengths (62–68 psi), and Burnet had low to acceptable strengths (27–58 psi).

- The highest strength treatments for each project were hot-applied trackless tack on US 79-Oakwood (113 psi) and Burnet-TOM (68 psi), underseal on US 84-Freestone (57 psi), trackless tack on SH 336-McAllen (31 psi), and emulsion trackless tack on US 183-Cedar Park (40 psi). The lowest initial bond strength was on spray paver membranes, underseal membranes, no tack, and RC 250.
- The overlay tester suggested the Burnet-TOM test sections (spray paver membranes and an underseal) had the best cracking resistance, followed by the US 79-Oakwood sections, and lastly the US 84-Freestone sections.
- The age of the sample was a significant influence for bond strength. On average, projects had an 80 percent strength increase after one year Strength gain rates were also unique for different treatment types. Most of the bond strength is likely gained in the first month.
- Samples with a new HMA substrate had higher bond strength than aged seal coat substrate samples.
- Bond strength varied significantly between lab compacted and field compacted samples, with lab compacted samples being stronger. There was no noticeable difference between these groups in cracking resistance with the overlay test.
- Focusing just on the US 183 sections, bonding was strongest for Trackless Tack A and B, and over new and milled surfaces. The most influential factor was age, bond strength after 9 months was 80 percent higher than at the time of construction. Application rates between 0.04 and 0.1 gal/sy was not significant.

The findings from performance modeling and the LCCA are as follows:

- The US 79-Oakwood pavement structure was first modeled in BISAR. Critical strains were sensitive to an interface shear modulus, log(Ks), between 7 and 11.
- Higher interface shear modulus increased the resistance to fatigue cracking and rutting. Fatigue failure could be a considerable risk at low bond strengths. Rutting failure for all bond conditions was well above the practical service life and will not govern the pavement life.
- From a mechanistic-empirical modeling program, TxACOL rutting and reflection cracking decrease with increased bonding.
- There is an optimum bond condition between no bond and full bond that delays reflection cracking the most. This is explained by the lower-stiffness interface providing relief from thermally induced stress.
- To transform laboratory bond strength to shear modulus, the lower and upper bounds for bond strength were mapped onto the log(Ks) scale and fitted with a sinusoidal curve.

Low bond strengths were defined below 30 psi and high bond strengths were greater than 100 psi (as tested at 0.2 inch/min.)

- For US 79-Oakwood, both trackless tack and CSS-1H sections were fully-bonded after 9 months and the predicted life was 11 years in terms of reflection cracking (90 percent criteria). The spray paver membrane and underseal sections were partially bonded and had predicted service lives of 14 and 13 years, respectively.
- From an LCCA, the spray paver membrane was the most cost-effective treatment on US 79-Oakwood and, compared to traditional tack, would save 15 percent to the agency and users over 25 years. The analysis did not consider equipment costs.
- The LCCA result is specific to the US 79-Oakwood pavement structure and existing distressed surface, which was constrained by reflection cracking performance. Other applications may be constrained by rutting or fatigue and so different treatments are likely to prove more cost-effective.

## RECOMMENDATIONS

TxDOT should continue to promote trackless tack as having the best bond strength, though other treatment types can also have high bond strength especially after short-term strength gain. TxDOT should decrease the emphasis of spray paver membranes and underseals for bonding, and rather promote their ability relieve reflection cracking stress. TxDOT should promote treatments with high residual rates of 0.14 gal/sy and greater (underseal, some spray paver membranes, and hot-applied trackless tack) as capable of sealing existing distress. Tack coats do not seal cracks.

District engineers should understand that the existing surface, overlay mixture type, and compaction temperature will influence bond strength. Therefore, a strong bond may be achieved by a treatment on one project and have much lower bond strength on another. Strength gain over time is very significant, especially over the first month in service, so a project with initially low bond strength may be fine with time to cure.

A bonding and sealing treatment guide was developed that incorporates recommendations on where to apply each treatment. The recommendations are repeated here for convenience (Table 7-1).

Researchers recommend long-term evaluation of the test sections studied during this project. Further study is also warranted on the bond strength to interface shear modulus transformation. In this research, bond strength is assumed to directly relate to the interface shear modulus; however, another parameter (e.g., fracture energy as measured by the compact tension test) may be a more appropriate test parameter, which would rank the treatment performance differently.

**Table 7-1. Recommended Bonding and Sealing Treatment Applications.**

| | Construction Scenario | Recommended Bonding and Sealing Treatments and Residual Asphalt Rates, gal/sy | | | | | Comments |
|---|---|---|---|---|---|---|---|
| | | Traditional Tack Coat | Trackless Tack Coat | | Spray Paver Underseal Membrane | Traditional Underseal | |
| | | | Emulsion | Hot-Applied | | | |
| Surface Type | New HMA | 0.02–0.03 | 0.02–0.03 | - | - | - | |
| | Aged HMA, Good Condition | 0.03–0.05 | 0.03–0.07 | 0.10–0.20 | 0.10–0.15 | - | |
| | Aged HMA, Moderate to Severe Cracking | - | - | - | 0.12–0.18 | 0.25–0.40 | |
| | Aged HMA, Bleeding | 0.02–0.05 | 0.02–0.07 | - | - | - | Reduce rate in wheel paths. |
| | Aged HMA, Severe Polishing | - | 0.03–0.07 | 0.10–0.20 | - | - | Gravel surfaces are hardest to bond to. |
| | Milled HMA | - | 0.04–0.07 | 0.10–0.20 | 0.10–0.15 | - | |
| | Aged Concrete | - | - | 0.10–0.20 | 0.12–0.15 | 0.25–0.40 | Rubber-modified asphalt. |
| Overlay Type | Thin Overlay | - | 0.02–0.07 | 0.10–0.20 | 0.10–0.15* | 0.25–0.40* | *Low initial shear strength. Limit use near stop-go traffic. |
| | Permeable Friction Course | - | 0.04–0.07 | 0.10–0.20 | 0.10–0.15 | | |
| | Seal Coat | None | | | | | |
| | Slurry Seal/Microsurfacing | None | | | | | |

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# APPENDIX A: SURVEY FORM

TEXAS A&M UNIVERSITY

## Survey Purpose

Several options are available for preparing a surface prior to an asphalt overlay. These include:

- Traditional tack coats,
- Non-tracking tack coats,
- Thicker spray-applied underseal membranes, and
- Traditional underseals.

The overall impact of these technologies on asphalt overlay service life have not been sufficiently quantified, and there is confusion about when and how to apply each technology. These issues are being addressed by the Texas A&M Transportation Institute (TTI) in TxDOT research project 0-6908: Comparative Analysis of Tack Coat, Underseal Membrane, and Underseal Technologies.

In this 18-question survey, we ask you to describe your District's experience with these technologies. This survey should take about 30 minutes to complete. Please complete the survey within a week.

Thank you!

Sincerely,

Bryan Wilson and Dr. Maryam Sakhaeifar

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TEXAS A&M UNIVERSITY

Respondent Information
*(This information is kept confidential and only used for internal purposes.)*

| | |
|---|---|
| Respondent name | |
| TxDOT District / Division | |
| TxDOT position | |
| Phone number | |
| E-mail | |

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** Please review the following definitions before proceeding.*

**Tack coat**
A thin bituminous emulsion, cutback, or liquid asphalt layer applied to existing HMA layer before an overlay.

**Trackless tack coat**
A type of tack coat that has the property of reduced tracking under vehicle tires.

**Underseal Membrane**
A thick coat of polymer-modified emulsion placed immediately before an overlay.
This application requires a spray-paver.

**Underseal (NOT seal coat)**
A thick application of asphalt binder (emulsion or hot applied) with a loose covering of coarse aggregate, placed before an overlay.

**Spray-Paver**
A specialized HMA paver that incorporates a tack reservoir and spray system. The tack is sprayed down immediately before the HMA. Thicker tack applications are possible with a spray-paver.

☐ I have reviewed the definitions

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HOW OFTEN do you use the following technologies on overlay projects in your District?

| | Never | Rarely | Sometimes | Often | Very Often |
|---|---|---|---|---|---|
| Conventional Tack Coat | ○ | ○ | ○ | ○ | ○ |
| Trackless Tack Coat | ○ | ○ | ○ | ○ | ○ |
| Underseal Membrane | ○ | ○ | ○ | ○ | ○ |
| Underseal | ○ | ○ | ○ | ○ | ○ |

0% 100%

Which technologies do you USE / RECOMMEND for these different existing **Surface Types** in preparation for an HMA overlay? (Select all that apply.)

| | Conventional Tack Coat | Trackless Tack Coat | Underseal Membrane | Underseal | None (No tack/seal) | Other |
|---|---|---|---|---|---|---|
| New HMA (<1-yr old) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aged HMA<br>Little to no distress<br>(no milling) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aged HMA<br>Mod-severity cracking<br>(no milling) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Aged HMA<br>High-severity cracking<br>(no milling) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Milled HMA | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Surface treatment, Chip seal | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Concrete | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

0% 100%

You selected "Other". Please specify..

0% 100%

Which treatments do you USE / RECOMMEND prior to these **Overlay Types**? (Select all that apply.)

| | Conventional Tack Coat | Trackless Tack Coat | Underseal Membrane | Underseal | None (No tack/seal) | Other |
|---|---|---|---|---|---|---|
| Dense-Graded Mix (Type C, Type D, etc.) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Gap-Graded Mix (SMA, TOM, CMHB) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Open-Graded Mix (PFC, Fine PFC) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Surface Treatment, Chip Seal | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

0% 100%

HOW OFTEN do you perform **Milling** prior to the following technologies in your District?

| | Never | Rarely | Sometimes | Often | Very Often |
|---|---|---|---|---|---|
| Conventional Tack Coat | ○ | ○ | ○ | ○ | ○ |
| Trackless Tack Coat | ○ | ○ | ○ | ○ | ○ |
| Underseal Membrane | ○ | ○ | ○ | ○ | ○ |
| Underseal | ○ | ○ | ○ | ○ | ○ |

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What **Environmental Restrictions** are placed on the application of these technologies, BEYOND restrictions for HMA overlay construction? (Select all that apply.)

| | Conventional Tack Coat | Trackless Tack Coat | Underseal Membrane | Underseal |
|---|---|---|---|---|
| None | ☐ | ☐ | ☐ | ☐ |
| Minimum ambient / pavement temperature | ☐ | ☐ | ☐ | ☐ |
| Paving season | ☐ | ☐ | ☐ | ☐ |
| Impending rainfall | ☐ | ☐ | ☐ | ☐ |
| Wet / damp surface | ☐ | ☐ | ☐ | ☐ |
| Surface cleanliness | ☐ | ☐ | ☐ | ☐ |
| Other ______ | ☐ | ☐ | ☐ | ☐ |

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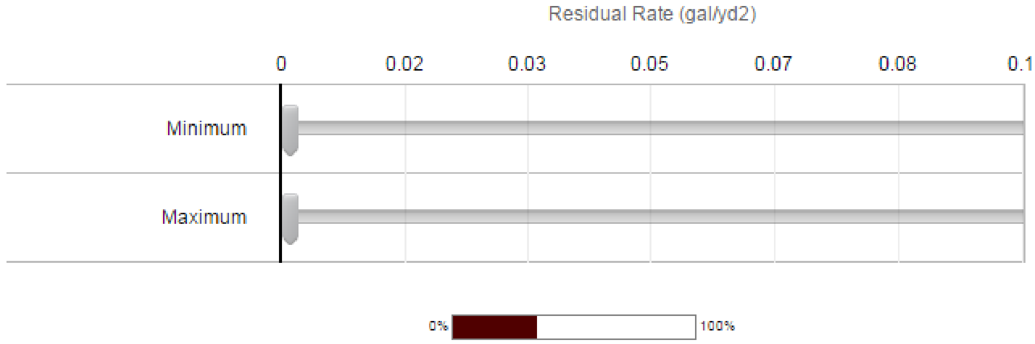
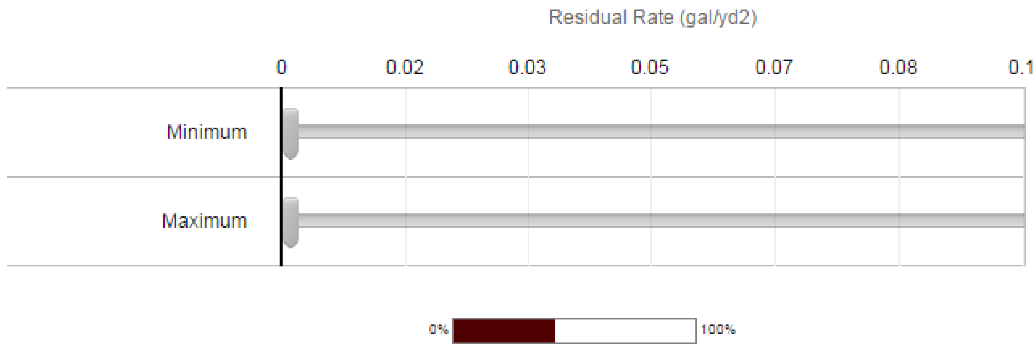
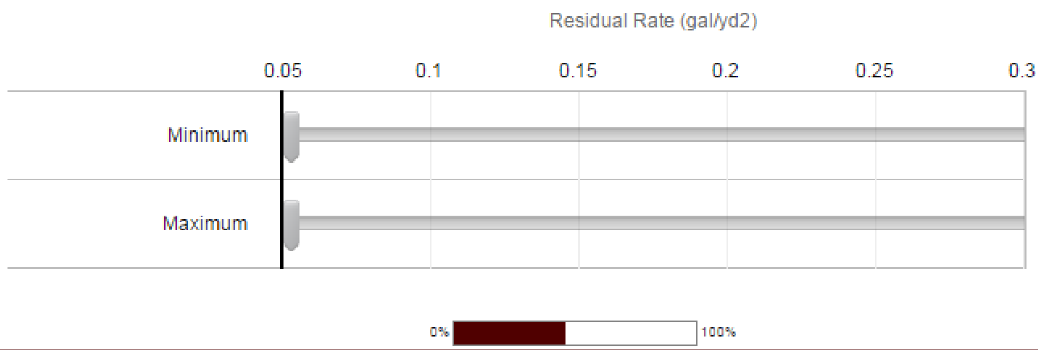
What is an appropriate range of RESIDUAL (not application) rates (gal/yd2) for a **Conventional Tack Coat**?




What is an appropriate range of RESIDUAL (not application) rates (gal/yd2) for a **Trackless Tack Coat**?




What is an appropriate range of RESIDUAL (not application) rates (gal/yd2) for an **Underseal Membrane**?



What is an appropriate range of RESIDUAL (not application) rates (gal/yd2) for an **Underseal**?

Residual Rate (gal/yd2)

| | 0.05 | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 |
|---|---|---|---|---|---|---|
| Minimum | | | | | | |
| Maximum | | | | | | |

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What **Asphalt Materials** are used in your District for the following technologies? (Select all that apply.)

| | Emulsion (Traditional) | Emulsion (Poly-Mod.) | Asphalt (Neat) | Asphalt (Poly-Mod.) | Asphalt (Rubber-Mod) | Cutback | Other |
|---|---|---|---|---|---|---|---|
| Conventional Tack Coat | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Trackless Tack Coat | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Underseal Membrane | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Underseal | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

0% 100%

You selected "Other". Please specify.

0% 100%

What **Aggregate Size** do you use for **Underseals** in your District? (Select all that apply.)

- ☐ Grade 2
- ☐ Grade 3
- ☐ Grade 4
- ☐ Grade 5
- ☐ Other ________

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Do you use **Uncoated** or **Precoated Aggregate** for **Underseals** in your District? (Select all that apply.)

- ☐ Uncoated aggregate
- ☐ Precoated aggregate

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What is a typical AGGREGATE APPLICATION RATE for **Underseals** in your District?

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HOW MANY **Spray Pavers** does your District and contractors within your District have access to?

- ○ None
- ○ 1 or 2
- ○ 3 to 5
- ○ More than 5

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What are the ADVANTAGES or DISADVANTAGES of using a **Conventional Tack Coat**?

| | Disadvantage | Neutral | Advantage |
|---|---|---|---|
| Initial cost | ○ | ○ | ○ |
| Equipment availability | ○ | ○ | ○ |
| Constructibility | ○ | ○ | ○ |
| Experience in district | ○ | ○ | ○ |
| Bond strength | ○ | ○ | ○ |
| Moisture barrier | ○ | ○ | ○ |
| Reduced reflection cracking | ○ | ○ | ○ |
| Extended service life | ○ | ○ | ○ |
| Other | ○ | ○ | ○ |

0% 100%

What are the ADVANTAGES or DISADVANTAGES of using a **Trackless Tack Coat**?

| | Disadvantage | Neutral | Advantage |
|---|---|---|---|
| Initial cost | ○ | ○ | ○ |
| Equipment availability | ○ | ○ | ○ |
| Constructibility | ○ | ○ | ○ |
| Experience in district | ○ | ○ | ○ |
| Bond strength | ○ | ○ | ○ |
| Moisture barrier | ○ | ○ | ○ |
| Reduced reflection cracking | ○ | ○ | ○ |
| Extended service life | ○ | ○ | ○ |
| Other | ○ | ○ | ○ |

0% 100%

What are the ADVANTAGES or DISADVANTAGES of using an **Underseal Membrane**?

| | Disadvantage | Neutral | Advantage |
|---|---|---|---|
| Initial cost | ○ | ○ | ○ |
| Equipment availability | ○ | ○ | ○ |
| Constructibility | ○ | ○ | ○ |
| Experience in district | ○ | ○ | ○ |
| Bond strength | ○ | ○ | ○ |
| Moisture barrier | ○ | ○ | ○ |
| Reduced reflection cracking | ○ | ○ | ○ |
| Extended service life | ○ | ○ | ○ |
| Other ______ | ○ | ○ | ○ |

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What are the ADVANTAGES or DISADVANTAGES of using an **Underseal**?

| | Disadvantage | Neutral | Advantage |
|---|---|---|---|
| Initial cost | ○ | ○ | ○ |
| Equipment availability | ○ | ○ | ○ |
| Constructibility | ○ | ○ | ○ |
| Experience in district | ○ | ○ | ○ |
| Bond strength | ○ | ○ | ○ |
| Moisture barrier | ○ | ○ | ○ |
| Reduced reflection cracking | ○ | ○ | ○ |
| Extended service life | ○ | ○ | ○ |
| Other ______ | ○ | ○ | ○ |

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# APPENDIX B: LABORATORY AND FIELD DATA

## Bond Strength Data.

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low | 0.13 | 0.13 | 26 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low | 0.13 | 0.13 | 31 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low | 0.13 | 0.13 | 18 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low | 0.13 | 0.13 | 32 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low-Moderate | 0.15 | 0.15 | 34 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low-Moderate | 0.15 | 0.15 | 47 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low-Moderate | 0.15 | 0.15 | 36 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Low-Moderate | 0.15 | 0.15 | 40 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Moderate | 0.17 | 0.17 | 47 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Moderate | 0.17 | 0.17 | 44 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Moderate | 0.17 | 0.17 | 47 |
| Burnet-TOM | Underseal membrane | AC-15p | New | 0 | Milled | HMA | TOM | Moderate | 0.17 | 0.17 | 41 |
| Burnet-TOM | Underseal membrane | PM-Emulsion | New | 0 | Milled | HMA | TOM | Moderate | 0.2 | NA | 72 |
| Burnet-TOM | Underseal membrane | PM-Emulsion | New | 0 | Milled | HMA | TOM | Moderate | 0.2 | NA | 56 |
| Burnet-TOM | Underseal membrane | PM-Emulsion | New | 0 | Milled | HMA | TOM | Moderate | 0.2 | NA | 45 |
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | New | 0 | Milled | HMA | TOM | Moderate | 0.15 | NA | 60 |
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | New | 0 | Milled | HMA | TOM | Moderate | 0.15 | NA | 67 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | New | 0 | Milled | HMA | TOM | Moderate | 0.15 | NA | 45 |
| Lab | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 59 |
| Lab | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 42 |
| Lab | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 45 |
| Lab | Underseal | AC-20-XP | New | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 34 |
| Lab | Underseal | AC-20-XP | New | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 40 |
| Lab | Underseal | AC-20-XP | New | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 36 |
| Lab | Underseal | AC-20-XP | New | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 64 |
| Lab | Tack coat | CSS-1H | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 64 |
| Lab | Tack coat | CSS-1H | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 51 |
| Lab | Tack coat | CSS-1H | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 57 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Low-Moderate | 0.06 | NA | 29 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Low-Moderate | 0.06 | NA | 67 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Low-Moderate | 0.06 | NA | 88 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Low | 0.04 | NA | 50 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Low | 0.04 | NA | 68 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 95 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 82 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 101 |
| Lab | Tack coat | CSS-1H | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 98 |
| Lab | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 57 |
| Lab | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 45 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lab | Underseal membrane | PM-Emulsion | New | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 48 |
| Lab | Underseal membrane | PM-Emulsion | New | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 58 |
| Lab | Underseal membrane | PM-Emulsion | New | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 53 |
| Lab | Underseal membrane | PM-Emulsion | New | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 52 |
| Lab | None | No Tack | New | 0 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 46 |
| Lab | None | No Tack | New | 0 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 41 |
| Lab | None | No Tack | New | 0 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 29 |
| Lab | None | No Tack | New | 0 | New | HMA-TyD | TOM | None | 0 | 0 | 81 |
| Lab | None | No Tack | New | 0 | New | HMA-TyD | TOM | None | 0 | 0 | 76 |
| Lab | None | No Tack | New | 0 | New | HMA-TyD | TOM | None | 0 | 0 | 109 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 94 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 85 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 80 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 161 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 163 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 181 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 144 |
| Lab | Trackless tack coat | Trackless B | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 64 |
| Lab | Trackless tack coat | Trackless B | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 65 |
| Lab | Trackless tack coat | Trackless B | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 73 |
| Lab | Trackless tack coat | Trackless B | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 108 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lab | Trackless tack coat | Trackless B | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 127 |
| Lab | Trackless tack coat | Trackless B | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 87 |
| Lab | Trackless tack coat | Trackless B | New | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 121 |
| Lab | NA | Vaseline | New | 0 | New | HMA-TyD | TOM | NA | NA | NA | 30 |
| Lab | NA | Vaseline | New | 0 | New | HMA-TyD | TOM | NA | NA | NA | 37 |
| Lab | NA | Vaseline | New | 0 | New | HMA-TyD | TOM | NA | NA | NA | 33 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 23 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 8 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 18 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 36 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 16 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 41 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.07 | 18 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.07 | 27 |
| SH 336 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.07 | 25 |
| SH 336 | None | No Tack | New | 0 | Existing | HMA | SP or DG Ty D | None | 0 | 0 | 14 |
| SH 336 | None | No Tack | New | 0 | Existing | HMA | SP or DG Ty D | None | 0 | 0 | 30 |
| SH 336 | None | No Tack | New | 0 | Existing | HMA | SP or DG Ty D | None | 0 | 0 | 30 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 40 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 82 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 63 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 65 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 51 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.05 | 55 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.09 | 74 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.09 | 93 |
| SH 336 | Trackless tack coat | Trackless A | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.1 | 0.09 | 61 |
| SH 336 | None | No Tack | Old | 17 | Existing | HMA | SP or DG Ty D | None | 0 | 0 | 32 |
| SH 336 | None | No Tack | Old | 17 | Existing | HMA | SP or DG Ty D | None | 0 | 0 | 32 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 0 |
| SH 336 | Tack coat | RC-250 | New | 0 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 0 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | Low | 0.05 | 0.04 | 20 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 76 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 74 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | Moderate | 0.07 | 0.06 | 68 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 123 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 94 |
| SH 336 | Tack coat | RC-250 | Old | 17 | Existing | HMA | SP or DG Ty D | High | 0.09 | 0.07 | 100 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 51 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 37 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 62 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 46 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 55 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 52 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.04 | 38 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.04 | 48 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.04 | 42 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 49 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 47 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 43 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 41 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 41 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 44 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 54 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 44 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 39 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 55 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 48 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | High | 0.1 | 0.04 | 54 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | High | 0.1 | 0.04 | 43 |
| US 183 | Trackless tack coat | Trackless B | New | 0 | New | HMA | TOM | High | 0.1 | 0.04 | 50 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 29 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 33 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 20 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 24 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 22 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 28 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 24 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 31 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 32 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 49 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 52 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 47 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 41 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 40 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 42 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 65 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | High | 0.1 | 0.05 | 33 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | High | 0.1 | 0.05 | 50 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | High | 0.1 | 0.05 | 52 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.04 | 37 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.04 | 42 |
| US 183 | Trackless tack coat | Trackless A | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.04 | 45 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 29 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 30 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 34 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.03 | 30 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.03 | 33 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | Low | 0.04 | 0.03 | 32 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 36 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 30 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Existing | HMA | TOM | High | 0.1 | 0.05 | 28 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 34 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 37 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 31 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 40 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 35 |
| US 183 | Trackless tack coat | Fastset | New | 0 | Milled | HMA | TOM | High | 0.1 | 0.06 | 41 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 39 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 35 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Low | 0.04 | 0.02 | 38 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 35 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 35 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 39 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | High | 0.1 | 0.06 | 42 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | High | 0.1 | 0.06 | 51 |
| US 183 | Trackless tack coat | Fastset | New | 0 | New | HMA | TOM | High | 0.1 | 0.06 | 39 |
| US 183 | None | No Tack | New | 0 | Existing | HMA | TOM | None | 0 | 0 | 27 |
| US 183 | None | No Tack | New | 0 | Existing | HMA | TOM | None | 0 | 0 | 21 |
| US 183 | None | No Tack | New | 0 | Existing | HMA | TOM | None | 0 | 0 | 20 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 183 | None | No Tack | New | 0 | Milled | HMA | TOM | None | 0 | 0 | 36 |
| US 183 | None | No Tack | New | 0 | New | HMA | TOM | None | 0 | 0 | 35 |
| US 183 | None | No Tack | New | 0 | New | HMA | TOM | None | 0 | 0 | 42 |
| US 183 | None | No Tack | New | 0 | New | HMA | TOM | None | 0 | 0 | 38 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 86 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 100 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Low | 0.04 | 0.02 | 94 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 81 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 75 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.03 | 67 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | High | 0.1 | 0.04 | 76 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | High | 0.1 | 0.04 | 101 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Existing | HMA | TOM | High | 0.1 | 0.04 | 99 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 113 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 124 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 124 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 119 |
| US 183 | Trackless tack coat | Trackless B | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.03 | 125 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 115 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 82 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 99 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 139 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 122 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.04 | 136 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 100 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 119 |
| US 183 | Trackless tack coat | Trackless A | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 105 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 103 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 89 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Existing | HMA | TOM | Moderate | 0.07 | 0.04 | 92 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 91 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 62 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | Milled | HMA | TOM | Moderate | 0.07 | 0.03 | 51 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 87 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 65 |
| US 183 | Trackless tack coat | Trackless C | Old | 13 | New | HMA | TOM | Moderate | 0.07 | 0.05 | 106 |
| US 183 | None | No Tack | Old | 13 | Existing | HMA | TOM | None | 0 | 0 | 78 |
| US 183 | None | No Tack | Old | 13 | Existing | HMA | TOM | None | 0 | 0 | 100 |
| US 183 | None | No Tack | Old | 13 | Existing | HMA | TOM | None | 0 | 0 | 64 |
| US 183 | None | No Tack | Old | 13 | Existing | HMA | TOM | None | 0 | 0 | 92 |
| US 183 | None | No Tack | Old | 13 | Milled | HMA | TOM | None | 0 | 0 | 81 |
| US 183 | None | No Tack | Old | 13 | Milled | HMA | TOM | None | 0 | 0 | 105 |
| US 183 | None | No Tack | Old | 13 | Milled | HMA | TOM | None | 0 | 0 | 76 |
| US 183 | None | No Tack | Old | 13 | New | HMA | TOM | None | 0 | 0 | 127 |
| US 183 | None | No Tack | Old | 13 | New | HMA | TOM | None | 0 | 0 | 100 |
| US 183 | None | No Tack | Old | 13 | New | HMA | TOM | None | 0 | 0 | 117 |
| US 183 | None | No Tack | Old | 13 | New | HMA | TOM | None | 0 | 0 | 129 |
| US 79 | Underseal | AC-20-XP | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 52 |
| US 79 | Underseal | AC-20-XP | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 47 |
| US 79 | Underseal | AC-20-XP | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 44 |
| US 79 | Tack coat | CSS-1H | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 87 |
| US 79 | Tack coat | CSS-1H | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 93 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 79 | Tack coat | CSS-1H | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 85 |
| US 79 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 46 |
| US 79 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 34 |
| US 79 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 51 |
| US 79 | Underseal membrane | PM-Emulsion | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 67 |
| US 79 | Underseal membrane | PM-Emulsion | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 63 |
| US 79 | Underseal membrane | PM-Emulsion | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 62 |
| US 79 | None | No Tack | New | 1 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 70 |
| US 79 | None | No Tack | New | 1 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 76 |
| US 79 | None | No Tack | New | 1 | Existing | Surface treatment | SP Ty D | None | 0 | 0 | 72 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 111 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 99 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 129 |
| US 79 | Trackless tack coat | Trackless B | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 76 |
| US 79 | Trackless tack coat | Trackless B | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 84 |
| US 79 | Trackless tack coat | Trackless B | New | 1 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 90 |
| US 79 | Underseal | AC-20-XP | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 59 |
| US 79 | Underseal | AC-20-XP | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 53 |
| US 79 | Underseal | AC-20-XP | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 65 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 79 | Underseal | AC-20-XP | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 63 |
| US 79 | Tack coat | CSS-1H | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 120 |
| US 79 | Tack coat | CSS-1H | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 97 |
| US 79 | Tack coat | CSS-1H | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 104 |
| US 79 | Underseal membrane | PM-Emulsion | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 78 |
| US 79 | Underseal membrane | PM-Emulsion | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 68 |
| US 79 | Underseal membrane | PM-Emulsion | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.29 | 0.29 | 71 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 154 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 144 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.14 | 0.14 | 154 |
| US 79 | Trackless tack coat | Trackless B | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 129 |
| US 79 | Trackless tack coat | Trackless B | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 133 |
| US 79 | Trackless tack coat | Trackless B | Old | 9 | Existing | Surface treatment | SP Ty D | Moderate | 0.08 | NA | 115 |
| US 84 | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.3 | 0.3 | 72 |
| US 84 | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.3 | 0.3 | 62 |
| US 84 | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.3 | 0.3 | 65 |
| US 84 | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.3 | 0.3 | 70 |
| US 84 | Underseal | AC-20-XP | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.3 | 0.3 | 70 |
| US 84 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 42 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age | Age Month | Substrate 1 | Substrate2 | Overlay | Tack Level | App. Rate | Resid. Rate | Bond Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| US 84 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 64 |
| US 84 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 53 |
| US 84 | Underseal membrane | PM-Emulsion | New | 0 | Existing | Surface treatment | SP Ty D | Moderate | 0.2 | NA | 89 |

## Modified Texas Overlay Data.

| Project | Tack/Seal Type | Tack_Asphalt Type | Age Months | Substrate1 | Substrate2 | Top Layer | Tack Level | Application Rate | Max Laod | Num. of Cycles |
|---|---|---|---|---|---|---|---|---|---|---|
| Lab | None | No Tack | 0 | New | HMA-TyD | TOM | None | 0 | 596 | 27785 |
| Lab | None | No Tack | 0 | New | HMA-TyD | TOM | None | 0 | 437 | 746 |
| Lab | None | No Tack | 0 | New | HMA-TyD | TOM | None | 0 | 297 | 8093 |
| Lab | Tack coat | CSS-1H | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 331 | 977 |
| Lab | Tack coat | CSS-1H | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 186 | 1778 |
| Lab | Tack coat | CSS-1H | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 213 | 1756 |
| Lab | Trackless tack coat | Trackless B | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 364 | 1107 |
| Lab | Trackless tack coat | Trackless B | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 216 | 251 |
| Lab | Trackless tack coat | Trackless B | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 213 | 425 |
| Lab | Trackless tack coat | Trackless B | 0 | New | HMA-TyD | TOM | Moderate | 0.08 | 292 | 741 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 629 | 174637 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 653 | 173575 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 528 | 103980 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | 0 | New | HMA-TyD | TOM | Moderate | 0.14 | 745 | 70888 |
| Lab | Underseal membrane | PM-Emulsion | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | 183 | 3384 |
| Lab | Underseal membrane | PM-Emulsion | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | 112 | 82104 |
| Lab | Underseal membrane | PM-Emulsion | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | 262 | 709 |
| Lab | Underseal membrane | PM-Emulsion | 0 | New | HMA-TyD | TOM | Moderate | 0.2 | 251 | 360 |
| Lab | Underseal | AC-20-XP | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 175 | 52989 |
| Lab | Underseal | AC-20-XP | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 150 | 61877 |
| Lab | Underseal | AC-20-XP | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 248 | 38914 |
| Lab | Underseal | AC-20-XP | 0 | New | HMA-TyD | TOM | Moderate | 0.29 | 257 | 26819 |
| Lab | None | No Tack | 0 | Aged | Surface Treatment | TOM | None | 0 | 97 | 8756 |
| Lab | None | No Tack | 0 | Aged | Surface Treatment | TOM | None | 0 | 348 | 2630 |
| Lab | None | No Tack | 0 | Aged | Surface Treatment | TOM | None | 0 | 241 | 29031 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age Months | Substrate1 | Substrate2 | Top Layer | Tack Level | Application Rate | Max Laod | Num. of Cycles |
|---|---|---|---|---|---|---|---|---|---|---|
| Lab | Tack coat | CSS-1H | 0 | Aged | Surface Treatment | TOM | Moderate | 0.08 | 148 | 4715 |
| Lab | Trackless tack coat | Trackless B | 0 | Aged | Surface Treatment | TOM | Moderate | 0.08 | 214 | 684 |
| Lab | Trackless tack coat | Trackless B | 0 | Aged | Surface Treatment | TOM | Moderate | 0.08 | 142 | 1514 |
| Lab | Trackless tack coat | Trackless B | 0 | Aged | Surface Treatment | TOM | Moderate | 0.08 | 135 | 5129 |
| Lab | Trackless tack coat (hot) | Hard-Pen Asphalt | 0 | Aged | Surface Treatment | TOM | Moderate | 0.014 | 534 | 2800 |
| Lab | Underseal | AC-20-XP | 0 | Aged | Surface Treatment | TOM | Moderate | 0.29 | 311 | 8252 |
| Lab | Underseal | AC-20-XP | 0 | Aged | Surface Treatment | TOM | Moderate | 0.29 | 169 | 58611 |
| Lab | Underseal | AC-20-XP | 0 | Aged | Surface Treatment | TOM | Moderate | 0.29 | 135 | 12103 |
| Burnet-TOM | Underseal membrane | AC-15p | 0 | Milled | HMA | TOM | Low | 0.13 | 753 | 24 |
| Burnet-TOM | Underseal membrane | AC-15p | 0 | Milled | HMA | TOM | Low | 0.13 | 499 | 40 |
| Burnet-TOM | Underseal membrane | AC-15p | 0 | Milled | HMA | TOM | Low-Moderate | 0.15 | 683 | 90 |
| Burnet-TOM | Underseal membrane | AC-15p | 0 | Milled | HMA | TOM | Moderate | 0.17 | 610 | 140 |
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | 0 | Milled | HMA | TOM | Moderate | 0.15 | 215 | 244 |
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | 0 | Milled | HMA | TOM | Moderate | 0.15 | 810 | 116 |
| Burnet-TOM | Trackless tack coat (hot) | PM-Asphalt | 0 | Milled | HMA | TOM | Moderate | 0.15 | 227 | 5552 |
| Burnet-TOM | Underseal membrane | PM-Emulsion | 0 | Milled | HMA | TOM | Moderate | 0.2 | 644 | 924 |
| Burnet-TOM | Underseal membrane | PM-Emulsion | 0 | Milled | HMA | TOM | Moderate | 0.2 | 347 | 3125 |
| US 84 | Underseal membrane | PM-Emulsion | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.2 | 342 | 85410 |
| US 84 | Underseal membrane | PM-Emulsion | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.2 | 344 | 116548 |
| US 84 | Underseal membrane | PM-Emulsion | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.2 | 420 | 166210 |
| US 84 | Underseal membrane | PM-Emulsion | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.2 | 432 | 203350 |
| US 84 | Underseal membrane | PM-Emulsion | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.2 | 464 | 3264 |
| US 84 | Underseal | AC-20-XP | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.3 | 399 | 47360 |
| US 84 | Underseal | AC-20-XP | 0 | Aged | Surface treatment | SP Ty D | Moderate | 0.3 | 348 | 17805 |
| US 79 | None | No Tack | 1 | Aged | Surface Treatment | SP Ty D | None | 0 | 767 | 5724 |
| US 79 | None | No Tack | 1 | Aged | Surface Treatment | SP Ty D | None | 0 | 441 | 8144 |
| US 79 | None | No Tack | 1 | Aged | Surface Treatment | SP Ty D | None | 0 | 449 | 1234 |

| Project | Tack/Seal Type | Tack_Asphalt Type | Age Months | Substrate1 | Substrate2 | Top Layer | Tack Level | Application Rate | Max Laod | Num. of Cycles |
|---|---|---|---|---|---|---|---|---|---|---|
| US 79 | Tack coat | CSS-1H | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.08 | 490 | 7772 |
| US 79 | Tack coat | CSS-1H | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.08 | 446 | 20902 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.14 | 638 | 4396 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.14 | 703 | 1101 |
| US 79 | Trackless tack coat (hot) | Hard-Pen Asphalt | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.14 | 603 | 6499 |
| US 79 | Trackless tack coat | Trackless B | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.08 | 443 | 6507 |
| US 79 | Trackless tack coat | Trackless B | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.08 | 372 | 6489 |
| US 79 | Underseal membrane | PM-Emulsion | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.2 | 420 | 1440 |
| US 79 | Underseal membrane | PM-Emulsion | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.2 | 455 | 9321 |
| US 79 | Underseal | AC-20-XP | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.29 | 459 | 1957 |
| US 79 | Underseal | AC-20-XP | 1 | Aged | Surface Treatment | SP Ty D | Moderate | 0.29 | 263 | 16227 |

## Compact Tension Test Data.

| Tack/Seal Type | Tack_Asphalt Type | Age | Substrate1 | Substrate2 | Overlay | Tack Level | Application Rate | Residual Rate | Fracture Energy (J/m2) |
|---|---|---|---|---|---|---|---|---|---|
| None | No Tack | New | New | HMA-TyD | TOM | None | 0 | 0 | 441 |
| None | No Tack | New | New | HMA-TyD | TOM | None | 0 | 0 | 372 |
| None | No Tack | New | New | HMA-TyD | TOM | None | 0 | 0 | 331 |
| NA | Vaseline | New | New | HMA-TyD | TOM | NA | NA | NA | 328 |
| NA | Vaseline | New | New | HMA-TyD | TOM | NA | NA | NA | 247 |
| NA | Vaseline | New | New | HMA-TyD | TOM | NA | NA | NA | 326 |
| NA | Vaseline | New | New | HMA-TyD | TOM | NA | NA | NA | 253 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 322 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 627 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 228 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 266 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 452 |
| Tack coat | CSS-1H | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 341 |
| Trackless tack coat | Trackless B | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 568 |
| Trackless tack coat | Trackless B | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 432 |
| Trackless tack coat | Trackless B | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 400 |
| Trackless tack coat | Trackless B | New | New | HMA-TyD | TOM | Moderate | 0.08 | NA | 430 |
| Trackless tack coat (hot) | Hard-Pen Asphalt | New | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 540 |
| Trackless tack coat (hot) | Hard-Pen Asphalt | New | New | HMA-TyD | TOM | Moderate | 0.14 | 0.14 | 620 |
| Underseal membrane | PM-Emulsion | New | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 711 |
| Underseal membrane | PM-Emulsion | New | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 771 |
| Underseal membrane | PM-Emulsion | New | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 867 |
| Underseal membrane | PM-Emulsion | New | New | HMA-TyD | TOM | Moderate | 0.2 | NA | 696 |
| Underseal | AC-20-XP | New | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 636 |
| Underseal | AC-20-XP | New | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 1154 |
| Underseal | AC-20-XP | New | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 1060 |
| Underseal | AC-20-XP | New | New | HMA-TyD | TOM | Moderate | 0.29 | 0.29 | 475 |

## Permeability Data.

| Tack/Seal Type | Tack_Asphalt Type | Tack Level | Application Rate | Residual Rate | CoefPerm (cm/sec$^2$*10$^{-5}$) | Average Coefficient of Permeability, (in/sec$^2$) |
|---|---|---|---|---|---|---|
| None | No Tack | None | 0 | 0 | 2089 | 0.082 |
| None | No Tack | None | 0 | 0 | 1917 | 0.075 |
| None | No Tack | None | 0 | 0 | 1618 | 0.064 |
| Underseal Membrane | PM-Emulsion | Moderate | 0.2 | NA | 807 | 0.032 |
| Underseal Membrane | PM-Emulsion | Moderate | 0.2 | NA | 962 | 0.038 |
| Underseal Membrane | PM-Emulsion | Moderate | 0.2 | NA | 1322 | 0.052 |
| Tack Coat | CSS-1H | Low | 0.04 | 0.03 | 1584 | 0.062 |
| Tack Coat | CSS-1H | Low | 0.04 | 0.03 | 1638 | 0.064 |
| Tack Coat | CSS-1H | Low | 0.04 | 0.03 | 2087 | 0.082 |
| Tack Coat | CSS-1H | High | 0.08 | 0.05 | 1855 | 0.073 |
| Tack Coat | CSS-1H | High | 0.08 | 0.05 | 1724 | 0.068 |
| Tack Coat | CSS-1H | High | 0.08 | 0.05 | 921 | 0.036 |
| Trackless tack coat (hot) | Hard-Pen Asphalt | Moderate | 0.14 | 0.14 | 646 | 0.025 |
| Trackless tack coat (hot) | Hard-Pen Asphalt | Moderate | 0.14 | 0.14 | 578 | 0.023 |
| Trackless tack coat (hot) | Hard-Pen Asphalt | Moderate | 0.14 | 0.14 | 175 | 0.007 |
| Underseal | AC-20-XP | Moderate | 0.3 | 0.3 | 353 | 0.014 |
| Underseal | AC-20-XP | Moderate | 0.3 | 0.3 | 705 | 0.028 |
| Underseal | AC-20-XP | Moderate | 0.3 | 0.3 | 530 | 0.021 |

# APPENDIX C: STATISTICAL ANALYSES

## Laboratory Shear Test Results

Multiple comparison tests, Tukey's HSD

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| New | 91.7 | A | |
| Existing | 57.0 | | B |

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | | | |
|---|---|---|---|---|---|
| Trackless (hot) | 127.2 | A | | | |
| Trackless (emulsion) | 89.8 | | B | | |
| CSS-1H | 75.9 | | B | C | |
| None | 63.7 | | B | C | D |
| Membrane (sp pave) | 46.2 | | | C | D |
| Underseal (AC 20xp) | 43.3 | | | | D |

## Laboratory Modified Overlay Test Results

Multiple comparison tests, Tukey's HSD

| Sample Type | Cycles | Grouping | |
|---|---|---|---|
| New | 91.7 | A | |
| Existing | 57.0 | | B |

| Sample Type | Cycles | Grouping | | | |
|---|---|---|---|---|---|
| Trackless (hot) | 55000 | A | | | |
| Underseal | 29300 | A | B | | |
| None | 6900 | A | B | C | |
| Spray Paver Membrane | 2700 | | B | C | |
| CSS-1H | 1900 | | | C | |
| Trackless (emulsion) | 890 | | | C | D |
| Vaseline | 50 | | | | D |

## Laboratory Compact Tension Test Results

Multiple comparison tests, Tukey's HSD

| Sample Type | Fracture Energy (J/m$^2$) | Grouping | | |
|---|---|---|---|---|
| Underseal (AC 20xp) | 831 | A | | |
| Spray Paver Membrane | 761 | A | B | |
| Trackless (hot) | 580 | A | B | C |
| Trackless (emulsion) | 458 | | B | C |
| None | 381 | | B | C |
| CSS-1H | 373 | | | C |
| Vaseline | 289 | | | C |

## Laboratory Permeability Test Results

Multiple comparison tests, Tukey's HSD

| Sample Type | Permeability (cm/sec$^2$×10$^{-5}$) | Grouping | | |
|---|---|---|---|---|
| None | 1,875 | A | | |
| CSS-1H (Moderate) | 1,770 | A | B | |
| CSS-1H (High) | 1,500 | A | B | |
| Membrane (sp pave) | 1,030 | | B | C |
| Underseal (AC 20xp) | 530 | | | C |
| Trackless (hot) | 467 | | | C |

## ANOVA Results for Bond Strength vs. Sample Compaction Type and Treatment Type.

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Sample Compaction Type | 0.8425 | <0.001 | <0.001 |
| Treatment Type | | | <0.001 |

| Parameter | Estimate |
|---|---|
| Constant | 68.1 |
| Sample Compaction Type | |
| Field | -10.1 |
| Lab | 10.1 |
| Treatment Type | |
| None | -12.3 |
| CSS-1H | 4.6 |
| Trackless (emulsion) | 7.3 |
| Trackless (hot) | 31.5 |
| Membrane (sp pave) | -11.4 |
| Underseal (AC 20xp) | -19.7 |

Multiple comparison tests, Tukey's HSD

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| Lab | 78.1 | A | |
| Field | 58.0 | | B |

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | | | |
|---|---|---|---|---|---|
| Trackless (hot) | 99.5 | A | | | |
| Trackless (emulsion) | 75.4 | | B | | |
| CSS-1H | 72.7 | | B | C | |
| Membrane (sp pave) | 56.6 | | | C | D |
| None | 55.8 | | | | D |
| Underseal (AC 20xp) | 48.3 | | | | D |

**ANOVA Results for Overlay Cracking Resistance vs. Sample Compaction Type and Treatment Type.**

| Explanatory Variable | Cracking Resistance, log(cycles) | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Sample Compaction Type | 0.254 | 0.444 | 0.908 |
| Treatment Type | | | 0.352 |

| Parameter | Estimate |
|---|---|
| Constant | 3.7195 |
| Sample Compaction Type | |
| Field | -0.0119 |
| Lab | 0.0119 |
| Treatment Type | |
| None | 0.0447 |
| CSS-1H | 0.2459 |
| Trackless (emulsion) | -0.2517 |
| Trackless (hot) | -0.2273 |
| Membrane (sp pave) | 0.3320 |
| Underseal (AC 20xp) | -0.1437 |

Multiple comparison tests, Tukey's HSD

| Sample Type | Avg. Cracking Resistance (cycles) | Grouping |
|---|---|---|
| Lab | 5,386 | A |
| Field | 5,100 | A |

| Sample Type | Avg. Cracking Resistance (cycles) | Grouping |
|---|---|---|
| Underseal (AC-20xp) | 11258 | A |
| CSS-1H | 9233 | A |
| No Tack | 5810 | A |
| Membrane (sp pave) | 3765 | A |
| Trackless (hot) | 3106 | A |
| Trackless (emulsion) | 2936 | A |

## ANCOVA Results for Bond Strength vs. Age and Proj_Treatment Type.

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Project_Treatment Type | 0.8465 | <0.001 | <0.001 |
| Age | | | <0.001 |
| Age * Project_Treatment Type | | | <0.001 |

| Parameter | Estimate | Std Error | *p*-value |
|---|---|---|---|
| Intercept | 48.9 | 2.56 | 0 |
| US 79_Tack coat | 36.9 | 9.59 | 0.0002 |
| US 79_Trackless tack coat | 29.2 | 9.59 | 0.0028 |
| US 79_Trackless tack coat (hot) | 59.2 | 9.59 | 0 |
| US 79_Underseal membrane | 3.3 | 6.63 | 0.6186 |
| US 79_Underseal | -2.5 | 9.58 | 0.7981 |
| US 183_None | -17.5 | 5.93 | 0.0037 |
| US 183_Trackless tack coat | -10.3 | 3.48 | 0.0036 |
| SH 336_Trackless tack coat | -25.4 | 5.36 | 0 |
| SH 336_None | -24.1 | 8.56 | 0.0055 |
| SH 336_Tack coat | -48.9 | 5.36 | 0 |
| Slope | 3.34 | 0.37 | 0 |
| US 79_Tack coat | -0.98 | 1.49 | 0.5098 |
| US 79_Trackless tack coat | 1.93 | 1.49 | 0.1968 |
| US 79_Trackless tack coat (hot) | 1.42 | 1.49 | 0.3432 |
| US 79_Underseal membrane | -1.01 | 1.23 | 0.4126 |
| US 79_Underseal | -1.84 | 1.40 | 0.1904 |
| US 183_None | 1.71 | 0.64 | 0.0085 |
| US 183_Trackless tack coat | 1.26 | 0.45 | 0.0062 |
| SH 336_Trackless tack coat | -0.90 | 0.54 | 0.0951 |
| SH 336_None | -2.90 | 0.84 | 0.0008 |
| SH 336_Tack coat | 1.32 | 0.56 | 0.0192 |

Multiple comparison tests, Tukey's HSD

| Project_Treatment Type | Shear Bond Strength Slope (psi/month) | Grouping | |
|---|---|---|---|
| US 79_Trackless (emulsion) | 5.27 | A | B |
| US 183_None | 5.05 | | B |
| US 79_Trackless (hot) | 4.76 | A | B |
| SH 336_RC 250 | 4.66 | | B |
| US 183_Trackless (emulsion) | 4.60 | | B |
| SH 336_Trackless (emulsion) | 2.44 | A | B |
| US 79_CSS-1H | 2.36 | A | B |
| US 79_Membrane (sp pave) | 2.33 | A | B |
| US 79_Underseal | 1.50 | A | B |
| SH 336_None | 0.45 | A | |

## ANOVA Results for Bond Strength vs. Proj_Treatment Type.

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Project_Treatment Type | 0.904 | <0.001 | <0.001 |

| Parameter | Estimate |
|---|---|
| Constant | 55.5 |
| US 79_None | 17.2 |
| US 79_CSS-1H | 32.6 |
| US 79_Trackless (emulsion) | 27.8 |
| US 79_Trackless (hot) | 57.3 |
| US 79_Membrane (sp. pave) | 8.3 |
| US 79_Underseal | -7.6 |
| US 183_None | -24.1 |
| US 183_Trackless | -15.6 |
| US 84_Membrane (sp. pave) | 6.3 |
| US 84_Underseal | 12.3 |
| Burnet-TOM_Underseal | -5.3 |
| Burnet-TOM_Trackless (hot) | 1.8 |
| SH 336_Trackless (emulsion) | -24.6 |
| SH 336_None | -30.8 |
| SH 336_RC-250 | -55.5 |

Multiple comparison tests, Tukey's HSD

| Project | Treatment Type | Avg. Shear Bond Strength (psi) | Grouping | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| US 79-Oakwood | Trackless (hot) | 112.9 | A | | | | | | | |
| | CSS-1H | 88.1 | A | B | | | | | | |
| | Trackless (emul) | 83.3 | | B | C | | | | | |
| | None | 72.7 | | B | C | D | | | | |
| US 84-Freestone | Underseal | 67.8 | | B | C | D | | | | |
| US 79-Oakwood | Membrane (sp pave) | 63.8 | | B | C | D | | | | |
| US 84-Freestone | Membrane (sp pave) | 61.8 | | | C | D | | | | |
| Burnet-TOM | Trackless (hot) | 57.4 | | | C | D | E | | | |
| | Membrane (sp pave) | 50.2 | | | | D | E | F | | |
| US 79-Oakwood | Underseal | 47.9 | | | | D | E | F | G | |
| US 183-Cedar Park | Trackless (emul) | 39.9 | | | | | E | F | G | |
| | None | 31.4 | | | | | E | | G | |
| SH 336-McAllen | Trackless (emul) | 30.9 | | | | | | F | G | |
| | None | 24.8 | | | | | | | G | |
| | RC-250 | 0 | | | | | | | | H |

**ANOVA Results for Overlay Cracking Resistance vs. Proj_Treatment Type.**

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Project_Treatment Type | 0.720 | <0.001 | <0.001 |

| Parameter | Estimate |
|---|---|
| Constant | 3.658 |
| Burnet-TOM_Underseal | -1.401 |
| Burnet-TOM_Trackless (hot) | -0.926 |
| US 84_Membrane (sp. pave) | 1.150 |
| US 84_Underseal | 0.805 |
| US 79_None | -0.071 |
| US 79_CSS-1H | 0.447 |
| US 79_Trackless (hot) | -0.159 |
| US 79_Trackless (emulsion) | 0.155 |
| US 79_Membrane (sp. pave) | -0.094 |
| US 79_Underseal | 0.093 |

Multiple comparison tests, Tukey's HSD

| Project | Treatment Type | Cycles | Statistical Grouping* | | |
|---|---|---|---|---|---|
| US 84-Freestone | Membrane (sp pave) | 64288 | A | | |
| | Underseal | 29039 | A | B | |
| US 79-Oakwood | CSS-1H | 12746 | A | B | C |
| | Trackless (emul) | 6498 | A | B | C |
| | Underseal | 5635 | A | B | C |
| | None | 3860 | A | B | C |
| | Membrane (sp pave) | 3664 | A | B | C |
| | Trackless (hot) | 3157 | A | B | C |
| Burnet-TOM | Trackless (hot) | 540 | | B | C |
| | Membrane (sp pave) | 181 | | | C |

*Tukey's HSD

## ANOVA Results for Bond Strength vs. Surface Type and Treatment Type.

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Treatment Type | 0.9325 | <0.001 | <0.001 |
| Surface Type | | | <0.001 |

| Parameter | Estimate |
|---|---|
| Constant | 75.1 |
| Surface | |
| New | 16.9 |
| Existing | -16.9 |
| Treatment Type | |
| None | -11.4 |
| CSS-1H | 0.6 |
| Trackless (emulsion) | 14.0 |
| Trackless (hot) | 49.1 |
| Membrane (sp pave) | -23.4 |
| Underseal (AC 20xp) | -29.0 |
| Surface*Treatment Type | |
| New*None | 8.0 |
| Existing*None | -8.0 |
| New*CSS-1H | 1.6 |
| Existing*CSS-1H | -1.6 |
| New*Trackless (emul) | 4.9 |
| Existing*Trackless (emul) | -4.9 |
| New*Trackless (hot) | 21.1 |
| Existing*Trackless (hot) | -21.1 |
| New*Membrane (sp. pave) | -16.1 |
| Existing*Membrane (sp pave) | 16.1 |
| New*Underseal | -19.6 |
| Existing*Underseal | 19.6 |

Multiple comparison tests, Tukey's HSD

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| New | 91.7 | A | |
| Existing | 57.0 | | B |

| Sample Type | Avg. Shear Bond Strength (psi) | Grouping | | | |
|---|---|---|---|---|---|
| Trackless (hot) | 127.2 | A | | | |
| Trackless (emulsion) | 89.8 | | B | | |
| CSS-1H | 75.9 | | B | C | |
| None | 63.7 | | B | C | D |
| Membrane (sp pave) | 46.2 | | | C | D |
| Underseal (AC 20xp) | 43.3 | | | | D |

**ANOVA Results for Overlay Cracking Resistance vs. Surface Type and Treatment Type.**

| Explanatory Variable | Cracking Resistance | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Treatment Type | 0.7239 | <0.001 | <0.001 |
| Surface Type | | | 0.791 |

| Parameter | Estimate |
|---|---|
| Constant | 3.486 |
| Surface | |
| New | 0.031 |
| Existing | -0.031 |
| Treatment Type | |
| None | 0.356 |
| Vaseline | -1.788 |
| CSS-1H | -0.212 |
| Trackless (emulsion) | -0.538 |
| Trackless (hot) | 1.255 |
| Membrane (sp pave) | -0.054 |
| Underseal (AC 20xp) | |

**ANOVA Results for Bond Strength on US 183-Cedar Park vs. Tack Type, Surface Type, and Age.**

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Tack Type | 0.8803 | <0.001 | <0.001 |
| Surface Type | | | 0.001 |
| Age | | | <0.001 |
| Tack Type*Surface Type | | | 0.002 |

| Parameter | Estimate |
|---|---|
| Constant | 69.5 |
| Tack Type | |
| No Tack | -5.4 |
| Trackless A | 8.8 |
| Trackless B | 7.7 |
| Trackless C | -11.2 |
| Surface Type | |
| Existing HMA | -8.7 |
| New HMA | 5.6 |
| Milled HMA | 3.1 |
| Age | |
| 0-months | -29.9 |
| 9-months | 29.9 |
| Tack Type*Surface Type | |
| No Tack*Existing | -2.3 |
| No Tack*New | 10.0 |
| No Tack*Milled | -7.7 |
| Trackless A*Existing | -5.9 |
| Trackless A*New | -9.3 |
| Trackless A*Milled | 15.2 |
| Trackless B*Existing | -4.9 |
| Trackless B*New | 2.1 |
| Trackless B*Milled | 2.8 |
| Trackless C*Existing | 13.1 |
| Trackless C*New | -2.8 |
| Trackless C*Milled | -10.3 |

Multiple comparison tests, Tukey's HSD

| Tack Type | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| Trackless A | 78.3 | A | |
| Trackless B | 77.2 | A | |
| No Tack | 64.1 | | B |
| Trackless C | 58.2 | | B |

| Surface Type | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| New HMA | 75.0 | A | |
| Milled HMA | 72.5 | A | |
| Existing HMA | 60.8 | | B |

| Age | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| 9-months | 99.4 | A | |
| 0-months | 39.6 | | B |

**ANOVA Results for Bond Strength on US 183-Cedar Park vs. Tack Type, Surface Type, and Age.**

| Explanatory Variable | Bond Strength | | |
|---|---|---|---|
| | Model $R^2$ | Model *p*-value | Variable *p*-value |
| Application Rate | 0.8092 | <0.001 | 0.520 |
| Age | | | <0.001 |

| Parameter | Estimate |
|---|---|
| Constant | 67.3 |
| Tack Type | |
| No Tack | 3.6 |
| Trackless A | -3.7 |
| Trackless B | 0.1 |
| Age | |
| 0-months | -19.4 |
| 9-months | 19.4 |

Multiple comparison tests, Tukey's HSD

| Surface Type | Avg. Shear Bond Strength (psi) | Grouping |
|---|---|---|
| Low | 71.0 | A |
| High | 67.4 | A |
| Moderate | 63.7 | A |

| Age | Avg. Shear Bond Strength (psi) | Grouping | |
|---|---|---|---|
| 9-months | 86.7 | A | |
| 0-months | 48.0 | | B |