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*Virginia Transportation Research Council*

# *research report*

## Evaluation of the Cargill SafeLane™ Surface Overlay

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<p><b>Abstract:</b></p> <p>A recent development in polymer concrete overlays is the Cargill SafeLane™ surface overlay (SafeLane overlay). The 3/8-in-thick overlay is constructed with epoxy and broadcast aggregates, as are typical multiple-layer epoxy overlays that are used to provide a skid-resistant wearing surface for bridge decks that protects the decks against intrusion by chloride ions. Reportedly, the SafeLane overlay is unique in that Cargill indicates that the limestone aggregate used in the overlay can absorb and store liquid deicing chemicals that are applied to the surface of the roadway.</p> <p>The purpose of this research was to compare the SafeLane overlay and the Virginia Department of Transportation (VDOT) modified EP-5 epoxy concrete overlay (hereinafter called the VDOT modified EP-5 overlay) based on an evaluation of their construction, initial condition, and effectiveness in preventing frost, ice, and snow formation on the surface of the roadway. The comparison was limited to overlays placed on four bridges on I-81 in 2004 and 2005 (two SafeLane and two VDOT modified EP-5 overlays) and on four sections of continuously reinforced concrete pavement on the Virginia Smart Road in 2006.</p> <p>The evaluation with respect to the initial condition of the overlays on I-81 was based on a comparison of the as-constructed properties, including aggregate properties, bond strength, permeability, skid resistance, and chloride content. The evaluation with respect to the initial condition of the overlays on the Smart Road was limited to skid resistance.</p> <p>The evaluation of the overlays with respect to their effectiveness in preventing frost, ice, and snow formation was based on visual observations and skid measurements of overlay surfaces under typical interstate winter conditions at the I-81 sites and under artificial snow and ice conditions at the Smart Road. In addition, the effectiveness of the overlays at the Smart Road in preventing frost, ice, and snow formation was compared with that of a bare-tined concrete surface.</p> <p>The evaluation indicated that the SafeLane overlay can provide a skid-resistant wearing and protective surface for bridge decks. The study was not able to determine the performance of the overlay with respect to providing a surface with less accumulation of ice and snow. Further, there has not been sufficient time to evaluate chloride penetration into the decks overlaid with SafeLane overlays in Virginia.</p>				

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Virginia Transportation Research Council  
(A partnership of the Virginia Department of Transportation  
and the University of Virginia since 1948)

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## ABSTRACT

A recent development in polymer concrete overlays is the Cargill SafeLane™ surface overlay (SafeLane overlay). The 3/8-in-thick overlay is constructed with epoxy and broadcast aggregates, as are typical multiple-layer epoxy overlays that are used to provide a skid-resistant wearing surface for bridge decks that protects the decks against intrusion by chloride ions. Reportedly, the SafeLane overlay is unique in that Cargill indicates that the limestone aggregate used in the overlay can absorb and store liquid deicing chemicals that are applied to the surface of the roadway.

The purpose of this research was to compare the SafeLane overlay and the Virginia Department of Transportation (VDOT) modified EP-5 epoxy concrete overlay (hereinafter called the VDOT modified EP-5 overlay) based on an evaluation of their construction, initial condition, and effectiveness in preventing frost, ice, and snow formation on the surface of the roadway. The comparison was limited to overlays placed on four bridges on I-81 in 2004 and 2005 (two SafeLane and two VDOT modified EP-5 overlays) and on four sections of continuously reinforced concrete pavement on the Virginia Smart Road in 2006.

The evaluation with respect to the initial condition of the overlays on I-81 was based on a comparison of the as-constructed properties, including aggregate properties, bond strength, permeability, skid resistance, and chloride content. The evaluation with respect to the initial condition of the overlays on the Smart Road was limited to skid resistance.

The evaluation of the overlays with respect to their effectiveness in preventing frost, ice, and snow formation was based on visual observations and skid measurements of overlay surfaces under typical interstate winter conditions at the I-81 sites and under artificial snow and ice conditions at the Smart Road. In addition, the effectiveness of the overlays at the Smart Road in preventing frost, ice, and snow formation was compared with that of a bare-tined concrete surface.

The evaluation indicated that the SafeLane overlay can provide a skid-resistant wearing and protective surface for bridge decks. The study was not able to determine the performance of the overlay with respect to providing a surface with less accumulation of ice and snow. Further, there has not been sufficient time to evaluate chloride penetration into the decks overlaid with SafeLane overlays in Virginia.

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## **INTRODUCTION**

Polymer concrete overlays with an established history of use and acceptance include multiple-layer epoxy, multiple-layer epoxy urethane, methacrylate slurry, and premixed polyester styrene.<sup>1-3</sup> Evaluations indicate that these overlays can provide skid resistance and protection against intrusion by chloride ions for 25 years and comprise an economical technique for extending the life of hydraulic cement concrete decks.<sup>1-3</sup>

A recent development in polymer concrete overlays is the Cargill SafeLane™ surface overlay (SafeLane overlay), developed by Cargill, Incorporated.<sup>4,5</sup> This 3/8-in-thick epoxy overlay includes limestone aggregate that, according to Cargill, acts like a rigid sponge, storing the commonly used salt-brine deicing solution and releasing it when needed, thus preventing frost formation and the bonding of ice and snow to the deck or pavement surface.<sup>5</sup> To be effective, liquid deicing chemicals must be applied to the overlay as a pretreatment, also known as anti-icing, before frost, ice, or snow has a chance to form. Subjective evidence supports anti-icing effectiveness up to 2 weeks after application provided no intervening precipitation occurs. Standard epoxy bridge overlays consist of a silica-basalt aggregate, which does not have such absorption capabilities.

To date, no objective research study has been conducted to determine if the SafeLane overlay is equivalent to existing polymer concrete overlay technology in providing acceptable skid resistance and protection against intrusion by chloride ions. Further, no objective evaluation of the ability of the SafeLane overlay to prevent frost, snow, and ice formation has been published.

## **PURPOSE AND SCOPE**

The purpose of this research was to compare the SafeLane overlay and the Virginia Department of Transportation (VDOT) modified EP-5 epoxy concrete overlay (hereinafter called the VDOT modified EP-5 overlay) based on an evaluation of their construction; initial condition; and effectiveness in preventing frost, ice, and snow formation on the surface of the roadway. The comparison was limited to overlays placed on four bridges on I-81 in 2004 and 2005 (two SafeLane and two VDOT modified EP-5 overlays) and on four sections of continuously reinforced concrete pavement (CRCP) on the Virginia Smart Road in 2006. The Smart Road is a full-scale test facility for transportation research, and evaluation located in Blacksburg, Virginia, and includes about 900 ft of CRCP, which is located adjacent to towers capable of making artificial snow.

The evaluation with respect to the initial condition of the overlays on I-81 was based on a comparison of their as-constructed properties, including aggregate properties, bond strength, permeability, skid resistance, and chloride content. The evaluation with respect to the initial condition of the overlays on the Smart Road was limited to skid resistance and macrotexture measurements

The evaluation of the overlays with respect to their effectiveness in preventing frost, ice, and snow formation was based on visual observations and skid measurements of overlay surfaces under typical interstate winter conditions at the I-81 sites and under artificial snow and ice conditions at the Smart Road. In addition, the effectiveness of the overlays at the Smart Road in preventing frost, ice, and snow formation was compared with that of a bare-tined concrete surface.

## **METHODOLOGY**

To accomplish the objectives of this study, three tasks were conducted:

1. The construction of the I-81 and Smart Road overlays was evaluated by comparing the construction of the SafeLane overlays to that of the VDOT modified EP-5 overlays.
2. The initial condition of the I-81 and Smart Road overlays was evaluated.
3. The effectiveness of the I-81 and Smart Road overlays in preventing the formation of frost, ice, and snow was evaluated.

## **Evaluation of Construction**

A total of eight overlays were placed on I-81 and the Smart Road. The overlays on I-81 were placed on four two-lane bridge decks, and the overlays on the Smart Road were placed on four one-lane sections of CRCP. Staff of VDOT's Staunton District monitored and recorded the construction of the overlays on I-81. Staff of the Virginia Tech Transportation Institute monitored and recorded the construction of the overlays on the Smart Road.

### **I-81 Overlays**

Four overlays were placed on bridge decks on I-81: two two-layer SafeLane overlays and two one-layer VDOT modified EP-5 overlays. Although the VDOT Special Provision for Epoxy Concrete Overlay (see Appendix A) specifies a two-layer overlay, a one-layer version was used on I-81 because the VDOT bridge engineer wanted to reduce the construction cost and determine if a one-layer version was cost-effective. The SafeLane overlays were placed in 2005: one on Structure 2037 Southbound (SB) at MP 219.78 (796 yd<sup>2</sup>) and one on Structure 2024 Northbound (NB) at MP 239.71 (1,467 yd<sup>2</sup>) in 2005. The one-layer VDOT modified EP-5 overlays were placed on Structure 2025 SB at MP 240 (1,467 yd<sup>2</sup>) in 2005 and on Structure 2036 NB at MP 219 (796 yd<sup>2</sup>) in 2004.

Approximately every 2 weeks, the overlays were pretreated with sodium chloride (salt) brine. Initially, a gravity feed tank equipped with a 9-ft-wide spray bar was used to apply the brine. The later applications were made with a 9-ft-wide pressurized spray bar. In both cases, this required the salt brine to be applied one lane at a time. In all cases, the salt brine was applied at a rate of approximately 30 gal per lane mile, which is the recommended rate for prevention of frost or black ice.<sup>6</sup>

### **Smart Road Overlays**

Four overlays were placed on sections of CRCP on the Smart Road (two two-layer SafeLane and two two-layer VDOT modified EP-5 overlays, as specified in the special provision [see Appendix A]). The two SafeLane overlays were pretreated with salt brine at a rate of 30 gal per lane mile. One of the VDOT modified EP-5 overlays was pretreated at the same rate per lane mile to provide an indication of the effect of pretreating versus not pretreating on the ability of the overlay to prevent the formation of frost, ice, and snow. Since the tests were scheduled events, the applications were made at least 3 days in advance of each test to allow time for the application to dry fully.



## Evaluation of Initial Condition of Overlays

### I-81 Overlays

The initial condition of the I-81 overlays was evaluated after construction by determining the following properties of the overlays:

1. aggregate performance (absorption, abrasion resistance, and soundness)
2. tensile bond strength
3. thickness
4. permeability of top 2 in of overlay and deck
5. skid resistance
6. chloride ion content of top 2 in of deck.

#### *Aggregate Performance*

Since limestone aggregates are used in the SafeLane overlay and silica and basalt aggregates are used in the VDOT modified EP-5 epoxy overlay, laboratory tests were conducted to allow comparisons of the aggregates and to identify any durability issues. Aggregate tests included absorption (American Society for Testing and Materials [ASTM] C127<sup>7</sup>), abrasion resistance (Canadian Standards Association [CSA] A23.2-23A<sup>8</sup>), and soundness (American Association of State Highway and Transportation Officials [AASHTO] T 103<sup>9</sup>).

#### *Bond Strength*

A modified version of Virginia Test Method (VTM) 92<sup>10</sup> was used to measure the initial bond strength of the four overlays on I-81.<sup>10</sup> The test is typically done on the deck, but the procedure was modified by removing cores 2.25 in in diameter and approximately 5 in long from the travel lane of each bridge and testing the cores in tension in the laboratory using a universal testing machine. The cores were tested in the laboratory to reduce the lane closure time required to do the tests on the deck, thus saving money, reducing congestion, and enhancing safety for the testing staff and motorists.

#### *Overlay Thickness*

The thickness of the overlays was determined by measuring their thickness at the top of the cores removed for other tests.

#### *Permeability*

The top 2 in of cores removed from the overlay and deck were tested for permeability to chloride ion (AASHTO T 277).<sup>11</sup>

### *Skid Resistance*

The skid resistance of the overlays was measured with a trailer (ASTM E274,<sup>12</sup> ASTM E524<sup>13</sup>).

### *Chloride Content of Decks*

The chloride ion content of the top 2 in of the decks was determined in accordance with AASHTO T 260.<sup>14</sup>

### **Smart Road Overlays**

The evaluation of the initial condition of the overlays on the Smart Road was based on the following:

1. initial friction tests and microtexture measurements
2. skid resistance tests.

The Dynamic Friction Tester (ASTM E1911<sup>12</sup>) and the VDOT friction trailer (ASTM E274<sup>15</sup>) were used to perform the friction tests. Macrottexture measurements were made with the VDOT Macrottexture Laser Profiler Van (ASTM E950<sup>16</sup>) and the Circular Track Meter (CT Meter) (ASTM E2157<sup>17</sup>).

Skid resistance was measured by the Dynamic Friction Tester (ASTM E1911<sup>12</sup>) and trailer (ASTM E274<sup>15</sup>).

## **Evaluation of Effectiveness of Overlays in Preventing Frost, Snow, and Ice Formation**

### **I-81 Overlays**

Surface friction testing using a Halliday Road Grip Tester (RGT) was done on Structures 2024 (SafeLane overlay) and 2025 (VDOT modified EP-5 overlay) during winter snow and ice conditions. This test was performed to determine differences in the surface friction of the SafeLane and VDOT modified EP-5 overlays. No standardized test has been developed to measure friction on snow- or ice-covered pavements, but the RGT has been shown to give accurate comparative grip readings at close intervals.<sup>18</sup> A description of the device is provided in Appendix B.

### **Smart Road Overlays**

At the Smart Road sites, surface friction testing using a RGT was done on the four overlays and the bare-tined concrete pavement under artificial winter snow and ice conditions. The snow-making equipment is described in Appendix C.<sup>19</sup>

A detailed testing protocol was developed (see Appendix D). The main steps included the following:

1. Measure the pavement temperature and start to produce snow.
2. Collect continuous friction data (RGT).
3. Produce snow at as slow a pace as feasible while driving vehicles on the section to simulate traffic.
4. Plow and apply chemicals to the road as necessary (based on friction readings) while continuing to make snow and measure friction.

Photographs of Steps 3 and 4 are provided in Figure 1.

The main analysis conducted at the Smart Road consisted of comparing each of the high-friction epoxy surfaces with the closest bare-tined concrete section. Although the researchers initially planned to compare the surfaces against each other, during the field experiments it was observed that the snow coverage was not uniform and this lack of uniformity affected the effectiveness of the snow fighting activities and consequently the friction readings.

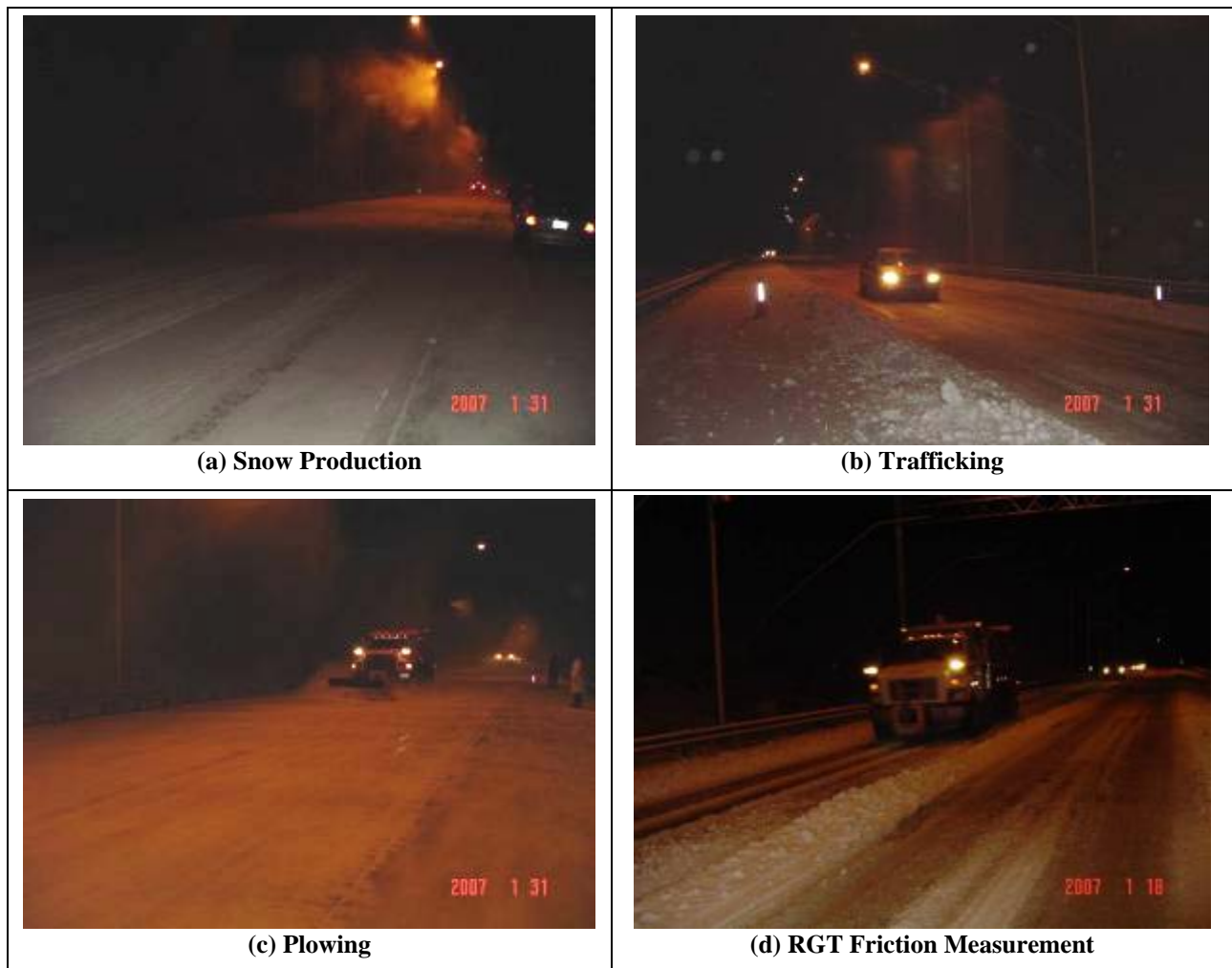


Figure 1. Selected Activities During Testing at Smart Road. RGT = Road Grip Tester.

## RESULTS AND DISCUSSION

### Construction of Overlays

#### I-81 Overlays

Table 1 provides an overview of the four overlays constructed on I-81. Table 2 provides the epoxy application rates and aggregate information for the two types of overlays placed on I-81 and the standard two-layer VDOT modified EP-5 overlay, which was not used on I-81.

**Table 1. Description of Overlays on I-81<sup>a</sup>**

Structure No.	Overlay	Date Placed	Aggregate
2037 SB	2-layer SafeLane	9/05	Travel and passing lanes: SafeLane aggregate
2024 NB	2-layer SafeLane	10/05	Spans 1-4 of passing lane: SafeLane aggregate
			Spans 1 and 2 of travel lane: 75% SafeLane aggregate; 25% silica aggregate slightly larger than that used in VDOT Modified EP-5 overlays (see Appendix A)
			Spans 3 and 4 of travel lane: 50% SafeLane aggregate; 50% silica aggregate slightly larger than that used in VDOT modified EP-5 overlays (see Appendix A)
2025 SB	1-layer VDOT modified EP-5	8/05	Silica specified for VDOT modified EP-5 overlay (see Appendix A)
2036 NB	1-layer VDOT modified EP-5	8/04	Silica specified for VDOT modified EP-5 overlay (see Appendix A)

<sup>a</sup> All overlays used modified EP-5 epoxy.

**Table 2. Epoxy and Aggregate Ingredients of Overlays on I-81 and Standard Two-Layer VDOT Modified EP-5 Overlay**

Ingredient	I-81 Overlays		Standard Two-Layer VDOT Modified EP-5 Overlay <sup>a</sup>
	One-Layer VDOT Modified EP-5 Overlay	SafeLane Overlay	
Epoxy layer 1 (gal/100 ft <sup>2</sup> )	≥4	≥4	≥2.5
Epoxy layer 2 (gal/100 ft <sup>2</sup> )	0	≥8	≥5
Thickness (in)	≥0.13	≥0.38	≥0.25
Aggregate type	Silica, basalt	Limestone <sup>b</sup>	Silica, basalt
Aggregate gradation	No. 4–No. 30	3/8 in–No. 30	No. 4–No. 30
Aggregate median size	No. 8 <sub>+</sub>	No. 4 <sub>+</sub>	No. 8 <sub>+</sub>

<sup>a</sup>This overlay represents the standard 2-layer VDOT modified EP-5 overlay constructed in accordance with the VDOT Special Provision on Epoxy Concrete Overlay (see Appendix A) and was not used for the overlays on I-81.

<sup>b</sup>Structure 2024 travel lane Spans 1 and 2 contained 25% silica aggregate, and Spans 3 and 4 contained 50% silica aggregate.

The application rates for the overlays on I-81 were as follows:

1. *One-Layer VDOT Modified EP-5 Overlays.* The epoxy application rate was 4 gal/100 ft<sup>2</sup>. Aggregate was broadcast to excess.
2. *SafeLane Overlays.* The epoxy application rate was 4 gal/100 ft<sup>2</sup> (Layer 1) and 8 gal/100 ft<sup>2</sup> (Layer 2). Aggregate was broadcast to excess. The quantity of aggregate

required for the SafeLane overlay was greater than for the one- and two-layer VDOT modified EP-5 overlays because of the larger size of the limestone aggregate and the greater thickness of the SafeLane overlay.

The construction sequence for the SafeLane overlays was as follows:

1. Close lane to traffic.
2. Shotblast the deck.
3. Mix and spread the epoxy for Layer 1.
4. Broadcast aggregate for Layer 1.
5. After approximately 1 hour, remove loose aggregate.
6. Mix and spread the epoxy for Layer 2.
7. Broadcast aggregate for Layer 2.
8. Cure overlay approximately 3 hours.
9. Remove loose aggregate.
10. Open lane to traffic.

The construction sequence for the one-layer VDOT modified EP-5 overlays was as follows:

1. Close lane to traffic.
2. Shotblast the deck.
3. Mix and spread the epoxy.
4. Broadcast aggregate.
5. Cure overlay approximately 3 hours.
6. Remove loose aggregate.
7. Open lane to traffic.

All four overlays were constructed between 9 P.M. and 7 A.M. The overlays on the travel lane and shoulder were placed on one night, and those on the passing lane and shoulder another night.

As discussed previously, the standard SafeLane overlay was placed on both lanes of Structure 2037 SB, as indicated in Tables 1 and 2. For Structure 2024 NB, placed in October 2005, all four spans of the passing lane were done with the standard SafeLane aggregate; Spans 1 and 2 of the travel lane were done with 25% of the SafeLane aggregate replaced with silica aggregate slightly larger than that used in VDOT overlays; and Spans 3 and 4 of the travel lane were done with 50% of the SafeLane aggregate replaced with the silica aggregate. The silica aggregate was substituted for a portion of the SafeLane aggregate to determine the impact on skid resistance and ice and snow melting performance. Figure 2 shows the SafeLane overlay being placed on Structure 2037.

A one-layer version of the VDOT modified EP-5 overlay was placed on I-81 Structure 2036 NB in 2004 and Structure 2025 SB in 2005.



**Figure 2. SafeLane Overlay Being Placed on Shoulder of I-81 Structure 2037**

The experience gained during the construction of the overlays indicated that the overlays could be constructed in accordance with the VDOT Special Provision for Epoxy Concrete Overlay (see Appendix A) with the following exceptions:

1. The epoxy application rates are greater for the SafeLane overlays to accommodate the larger aggregate size.
2. The epoxy application rates are greater for the one-layer version of the VDOT modified EP-5 overlay than required for the first layer of an overlay complying with the special provision (i.e., a two-layer overlay) because a second layer was not anticipated.
3. SafeLane overlays are constructed with a limestone dolomitic aggregate that was larger than the silica aggregate used in the VDOT modified EP-5 overlays.

The experience also showed that the overlays can be constructed with short lane closures at night and opened to traffic in the morning, thereby minimizing delays and inconvenience to the traveling public.

### **Smart Road Overlays**

The two SafeLane and two VDOT overlays were installed on September 23, 2006. The SafeLane overlays, 100 ft long by 12 ft wide, were placed within the area covered by the rain and snow-making equipment. The overlays were separated by 300 ft, one in the eastbound (EB) lane and the other in the westbound (WB) lane. The lane sections adjacent to the SafeLane

overlays were overlaid with the two-layer VDOT modified EP-5 overlay in accordance with the VDOT Special Provision for Epoxy Concrete Overlay (see Appendix A). The VDOT overlays were constructed identically to the SafeLane overlays except that they used smaller size aggregate and less epoxy, as can be seen in Figure 3. Figure 4 is a plan view of the sections. The bare-tined concrete pavement sections separating the overlaid sections were not overlaid and served as control sections.

Prior to the installation of the overlays, the CRCP surfaces were thoroughly cleaned with a steel shot blasting process to remove pavement markings and/or oil spots and clean the concrete surface, as shown in Figure 5a.

After air blowing any leftover particles from the surface of the pavement, the epoxy was applied with a squeegee as shown in Figure 5b. Both types of overlays used the same type of epoxy. The aggregates were applied by manually shoveling them on the epoxy coat from dump trucks, as can be seen in Figure 5c. After the epoxy was cured, loose aggregate was removed

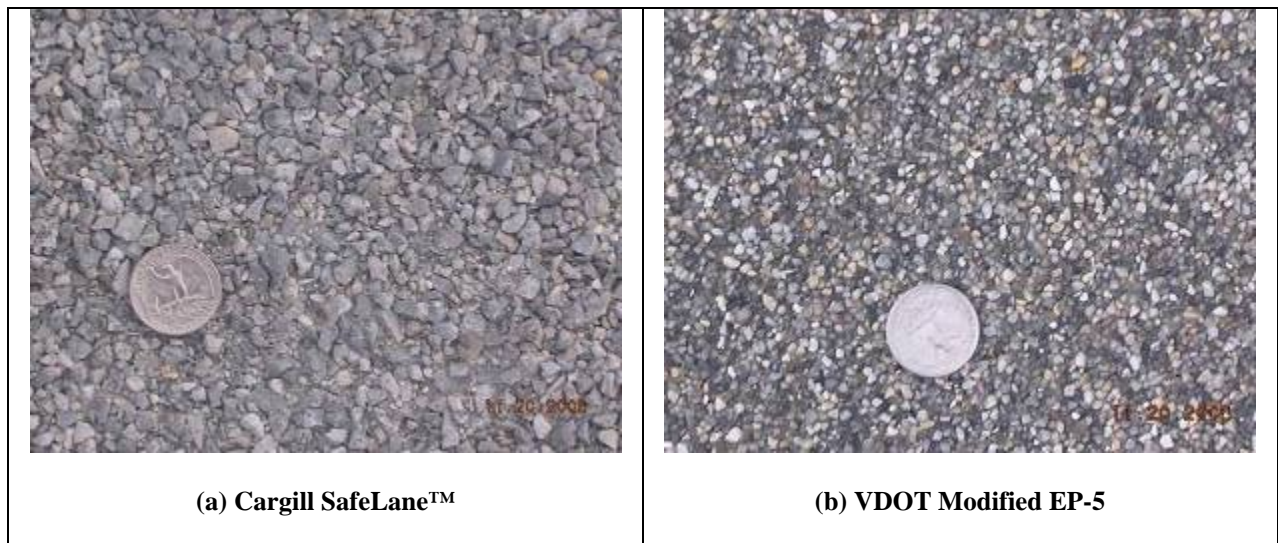


Figure 3. Comparison of Surface Texture of SafeLane and 2-Layer VDOT Modified EP-5 Overlays Constructed at Virginia Smart Road

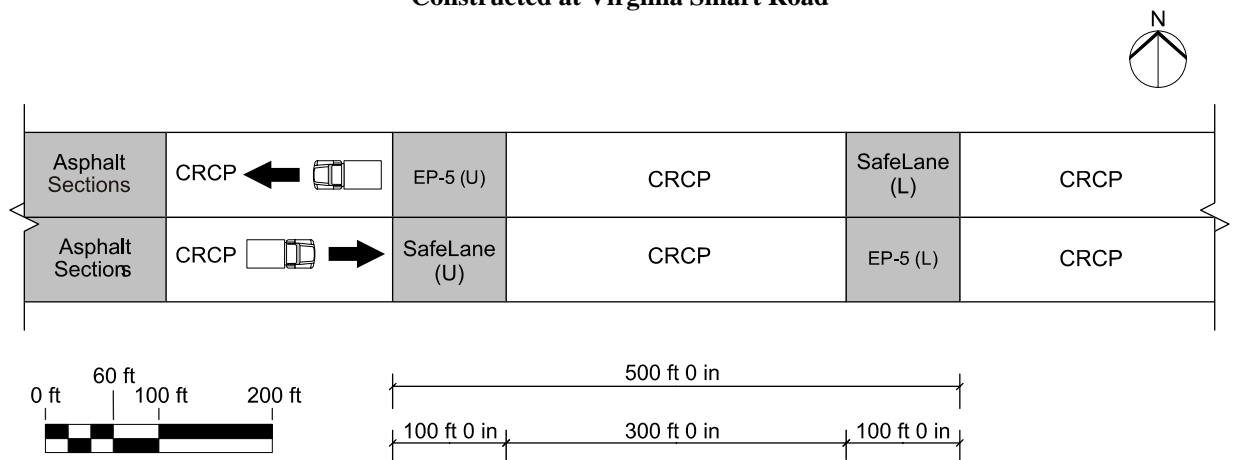


Figure 4. Layout of Experimental Sections at Virginia Smart Road. CRCP = continuously reinforced concrete pavement; EP-5 = 2-Layer VDOT modified EP-5 overlay; U = upper; L = lower.

with a power broom and/or air blowers as shown in Figure 5d and the second application of epoxy and aggregates was done.

Photographs of the overlaid sections are provided in section in Figure 6. The application rates were as follows:

- *VDOT Modified EP-5*: 2.5 gal/100 ft<sup>2</sup> (Layer 1) and 5 gal/100 ft<sup>2</sup> of epoxy (Layer 2) with aggregate placed to excess.
- *SafeLane*: 4 gal/100 ft<sup>2</sup> (Layer 1) and 8 gal/100 ft<sup>2</sup> (Layer 2) of epoxy with aggregate placed to excess.



Figure 5. Summary of Construction Sequence at Smart Road





Figure 6. Side-by-Side Comparison of Overlay Systems at Smart Road. (a) VDOT Modified EP-5 overlay, (b) SafeLane overlay.

### Initial Condition of Overlays

#### I-81 Overlays

##### *Aggregate Performance*

As stated in the “Methods” section, aggregate tests included absorption (ASTM C127<sup>7</sup>), abrasion resistance (CSA A23.2-23A<sup>8</sup>), and soundness (AASHTO T 103<sup>9</sup>). Aggregates used in epoxy overlays have a low absorption since moisture in the overlay can cause a loss of adhesion between the epoxy and the aggregate and premature deterioration of the aggregate; a high abrasion resistance so that the overlay can provide a high skid resistance over its life; and a high soundness to resist deterioration when subjected to cycles of freezing and thawing.

Table 3 shows the absorption test results. As would be expected the absorption was higher for the SafeLane aggregates because the higher absorption is needed to store more deicing chemicals.

Table 4 shows the abrasion test results. The SafeLane aggregate had an average size of a No. 4 sieve, and the VDOT modified EP-5 aggregate had an average size of a No. 8 sieve. The best comparison was the weight loss for a No. 10 sieve for both overlays. The abrasion resistance was similar for both overlays based on tests on aggregates retained on the No. 10 sieve.

Table 5 shows the soundness test results (AASHTO T 103). The test samples passed the No. 4 sieve and were retained on the No. 8 sieve. The quartz and basalt aggregates used in the one-layer VDOT modified EP-5 overlays had a very low weight loss. The SafeLane aggregate had a very high weight loss, which indicates a high potential for deterioration in a freezing and

##### . Table 3. Aggregate Absorption Test Results (ASTM C127)

Property	Quartz	Basalt	SafeLane
Specific gravity (dry)	2.594	2.980	2.684
Specific gravity (SSD)	2.612	2.993	2.730
Absorption, %	0.72	0.45	1.70

**Table 4. Aggregate Abrasion Results (CSA A23.2-23A)**

Property	Quartz	Basalt	SafeLane	SafeLane	Quartz
No. sieve retained on	10	10	6	10	10
Weight loss, %	5.64	8.30	2.06	5.73	6.83

**Table 5. Aggregate Soundness Results (% weight loss) (AASHTO T 103)**

No. 8 Quartz	No. 8 Basalt	No. 4 SafeLane (SL)	No. 4 75% SL and 25% Quartz	No. 4 50% SL, 50% Quartz	No. 4 Quartz
1.9	1.1	21.6	20.2	14.3	6.0

thawing environment. The larger size quartz aggregate blended with the SafeLane aggregate had a higher weight loss than did the smaller size quartz. The blended aggregate had weight losses that were reasonable based on the composition of the blends. Although the weight loss of the SafeLane aggregate was very high, the test results may or may not indicate a significant problem with the durability of the overlay. With the exception of the surface of the overlay, aggregates are surrounded by epoxy, which may prevent some absorption of water. The aggregates that absorb water should also absorb the liquid deicing chemicals and may not freeze. Any negative impact would likely be greatest in applications where temperatures were very low and the overlay was not pretreated.

It is important to note that the SafeLane aggregates used in the overlays in this study are no longer being used in SafeLane overlays (A. Hensley, Cargill Incorporated, personal communication, August 2008).

### *Bond Strength*

The bond strength of an overlay is important because the overlay must stay bonded to the concrete deck surface to provide a skid resistant wearing and protective surface. As noted in the “Methods” section, a modification of VTM 92 was used to measure the initial bond strength of the overlays in the laboratory.<sup>10</sup>

The average bond strength results expressed as tensile rupture strength (TRS) in pounds per square inch and failure location in percent with respect to the deck, the bond, and the overlay are provided in Table 6. The VDOT Special Provision for Epoxy Concrete Overlays (see Appendix A) specifies an initial bond strength greater than or equal to 250 psi or a failure area, at a depth of 1/4 in or more into the base concrete, greater than 50 percent of the test area. Long-lasting overlays typically have a bond strength greater than 200 psi.<sup>1-3</sup>

The average was based on 6 cores each from Structures 2037 (standard 2-layer SafeLane), 2025 (1-layer VDOT modified EP-5), and 2036 (1-layer VDOT modified EP-5) and 12 cores from Structure 2024 (2-layer SafeLane) (6 from Spans 1 and 2 [75% SafeLane and 25%

quartz aggregate blend] and 6 from Spans 3 and 4 [50% SafeLane and 50% quartz aggregate blend]). Core locations are shown in Appendix E.

The results in Table 6 indicate that with the exception of Structure 2024, the cores failed in the concrete deck (base). The bond strength was limited by the strength of the concrete. The cores from Structure 2024 failed predominately in the overlay, indicating the bond between the two layers was the weak link. The researchers suspect that the silica aggregate used to replace 25 and 50 percent of the SafeLane aggregate (Spans 1 and 2 and Spans 3 and 4, respectively) may have been damp, which would reduce the adhesion of the epoxy to the aggregate and cause the atypical failure in the overlay. However, there was no difference between the test results for 25 and 50 percent SafeLane aggregate replacement. All average TRSs were above 200 psi, indicating that acceptable performance can be anticipated and extensive delamination of the four overlays is not likely.<sup>1-3</sup> The bond strength of the two-layer SafeLane overlays was similar to that of the one-layer VDOT modified EP-5 overlays (see Appendix A).

**Table 6. Bond Strength Results (February 15, 2006)**

Structure No.	Overlay	Tensile Rupture Strength (psi)	Failure Location (%)			Thickness (in)
			Overlay	Bond	Base	
2037	2-layer SafeLane	205	0	0	100	0.49
2024	2-layer SafeLane <sup>a</sup>	218	56	21	23	0.46
2025	1-layer VDOT modified EP-5	274	0	0	100	0.10
2036	1-layer VDOT modified EP-5	230	3	2	95	0.10

<sup>a</sup> Aggregate blends: 75% SafeLane /25% quartz by weight for Spans 1 and 2 and 50% SafeLane/50% quartz for Spans 3 and 4.

### *Overlay Thickness*

Overlay thickness is important because the resistance to chloride penetration increases with thickness. Thicker overlays are less likely to wear through in the wheelpaths. Thermal stress increases with thickness so thicker overlays are more likely to be thermally incompatible with the deck and fail prematurely. The probability of decreased ride quality increases with thickness because of the greater change in elevation at each joint. Overlays  $\leq 0.5$  in in thickness have performed well with respect to thermal compatibility and ride quality.<sup>1-3</sup> The cost of the overlay increases with thickness, and the added cost is not necessarily a good buy except when the application is too thin to perform as in the case of a VDOT one-layer overlay.

Table 6 shows the average thickness of the overlays based on measurements on the cores. The thickness of the two-layer SafeLane overlays was approximately twice the 0.25-in thickness of the two-layer VDOT modified EP-5 overlays specified in the VDOT Special Provision for Epoxy Concrete Overlay (see Table 6 and Appendix A), which was not used on I-81, and the thickness of the one-layer VDOT modified EP-5 overlays used on I-81 was less than half the thickness specified for the two-layer VDOT modified EP-5 overlay. The one-layer overlays were not thick enough to perform, and a second layer had to be placed after 2 years in service because the single layer was wearing through in the wheelpaths after 2 years.

### *Permeability*

The permeability to chloride ion test (AASHTO T 277) has been used since the 1980s to provide an indication of the performance of overlays with respect to reducing the infiltration of chloride ions into decks and thereby extending the time to corrosion of the reinforcement and the life of the deck.<sup>11</sup> The top 2 in of cores with epoxy overlays that are at least 0.25 in thick typically have negligible permeability (<100 coulombs).<sup>1-3</sup>

The average permeability values of the top 2 in of cores taken in this study are shown in Table 7. The core locations are shown in Appendix E. The average was based on two cores each from Structures 2037 (standard 2-layer SafeLane), 2025 (1-layer VDOT modified EP-5), and 2036 (1-layer VDOT modified EP-5) and four cores each from Structure 2024 (two from Spans 1 and 2 [75% SafeLane and 25% quartz aggregate blend] and two from Spans 3 and 4 [50% SafeLane and 50% quartz aggregate blend]).

The average permeability of the two-layer SafeLane overlays was lower than that of the one-layer VDOT modified EP-5 overlay used and similar to that of the conventional two-layer VDOT modified EP-5 overlay, which typically has a negligible (0 to 100) permeability.<sup>1-3</sup>

**Table 7. Average Permeability Values (2/15/06)**

<b>Structure No.</b>	<b>Overlay</b>	<b>Thickness (in)</b>	<b>Permeability (coulombs)</b>
2037	2-layer SafeLane	0.54	23 (negligible)
2024	2-layer SafeLane <sup>a</sup>	0.45	246 (very low)
2025	1-layer VDOT modified EP-5	0.11	1367 (low)
2036	1-layer VDOT modified EP-5	0.11	1226 (low)

<sup>a</sup> Aggregate blends: 75% SafeLane/25% quartz by weight for Spans 1 and 2 and 50% SafeLane/50% quartz for Spans 3 and 4.

### *Skid Resistance*

The skid resistance of an overlay is important, and epoxy overlays are often placed on decks to improve the skid resistance of the surface. New multiple-layer epoxy overlays typically have skid numbers of approximately 60. The number typically drops to approximately 50 after 1 year and to approximately 45 after 2 years. The numbers typically level out to between 40 and 45 for the remaining life of the overlay.<sup>1-3</sup>

For the I-81 overlays, bald tire skid numbers corrected to 40 mph were determined in 2004 prior to construction and in 2005 after construction. The average numbers are provided in Table 8. The numbers in 2004 indicate that all four bridges needed a skid-resistant overlay to increase the numbers to desirable levels. The numbers in 2005 indicate that all four bridges had received a skid-resistant overlay that increased the numbers to desirable levels (corrective action is typically considered when numbers drop to 25). Structure 2036 had the lowest number in 2005 because the VDOT overlay was 14 months old at the time of the tests. The SafeLane numbers decreased immediately following the liquid chloride pretreatment but were still very good.

**Table 8. Bald Tire Skid Numbers for Travel Lanes of I-81 Before and After Installation of Overlays**

Structure No.	Overlay	Date Placed	Date of Test		
			6/28/04	10/31/05	12/7/05
2037	2-layer SafeLane	9/05	28	59	46 <sup>b</sup>
2024	2-layer SafeLane <sup>a</sup>	10/05	27	60	53 <sup>b</sup>
2025	1-layer VDOT modified EP-5	8/05	26	57	-
2036	1-layer VDOT modified EP-5	8/04	22	49	-

<sup>a</sup> Aggregate blends: 75% SafeLane/25% quartz by weight for Spans 1 and 2 and 50% SafeLane/50% quartz for Spans 3 and 4.

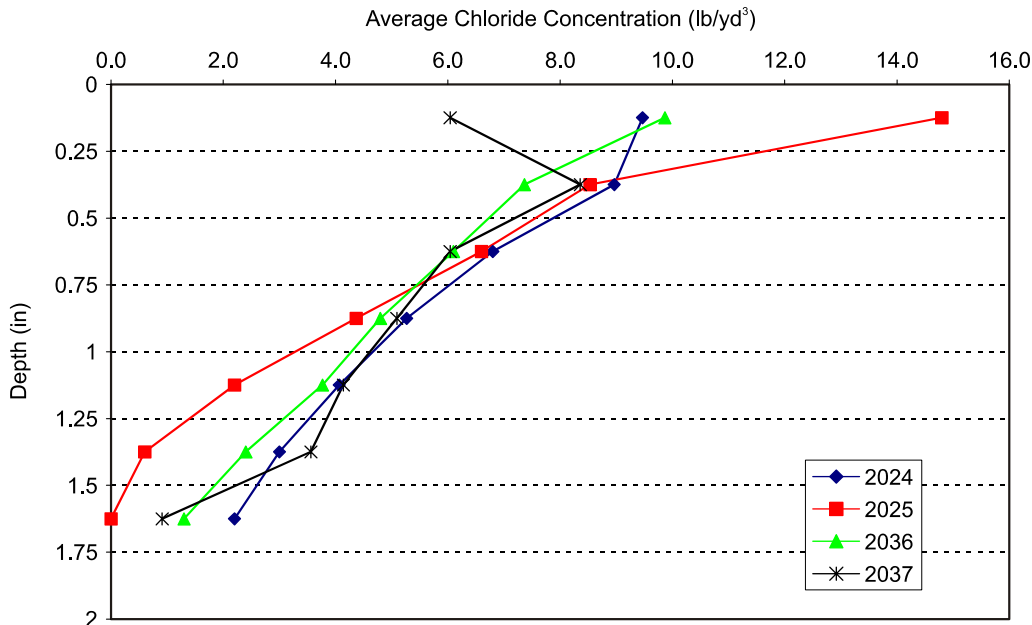
<sup>b</sup> After liquid chloride pretreatment.

### Chloride Content of Decks

The average chloride content at the top level of reinforcement (approximately 1.75 in from the deck surface) is important because corrosion of the reinforcement is likely when the content exceeds 2 pcy.

Samples of concrete were taken in February 2006 at three locations in the travel lane of Structures 2024, 2025, and 2036 and at two locations in the travel lane of Structure 2037. (See Table 8 for the compositions of the travel lanes.) The sample locations are shown in Appendix E. Samples were taken at 0.25-in increments of depth ranging from the surface to 1.75 in. Seven samples were taken at each location. As stated previously, samples were analyzed for acid soluble chloride ion content in accordance with AASHTO T 260.<sup>14</sup> Chloride profiles for each deck are shown in Appendix F.

Chloride content profiles based on the average of tests on the samples from the four bridges are shown in Figure 7. The chloride profiles were similar. The average chloride content



**Figure 7. Chloride Content Profiles for I-81 Decks Based on Cores Taken February 15, 2006. Numbers in box = structure numbers; 2-layer SafeLane structure numbers = 2024, 2037; 1-layer VDOT modified EP-5 structure numbers = 2025, 2036.**

at the top level of reinforcement (approximately 1.75 in from the surface) ranged from 0 to 2 pcy. As a consequence, corrosion of the reinforcement and spalling of the deck under the overlays should not be a problem. Corrosion would likely initiate at locations with higher chloride contents with further ingress of chlorides. The epoxy overlays were applied at a good time to preserve the decks. Fortunately, a second layer was placed on the one-layer overlays before they failed so that protection was maintained. It is anticipated that the overlays will prevent further intrusion of chloride ion and the life of the decks will be extended by the life of the overlays.<sup>1-3</sup> Chloride profiles prepared in the future can be compared to the ones in Figure 7 and Appendix F to determine if chloride from the pretreatments of the overlays or from routine winter maintenance applications penetrated the overlays.

## **Smart Road Overlays**

### *Initial Friction and Macrotexture Measurements*

As described in the “Methods” section, after construction of the overlays, a set of friction tests was performed with the Dynamic Friction Tester. Three tests were performed for each of the SafeLane and two-layer VDOT modified EP-5 overlay sections at 20-ft intervals inside each section, and three were performed in each of the control CRCP sections, totaling 18 tests. All tests were conducted on the left wheelpath of each lane (Figure 8a). Friction tests with a VDOT friction trailer were also performed (Figure 8b).

Macrotexture measurements were taken with the VDOT laser profiler (Figure 8c) and the CT Meter (Figure 8d). Table 9 compares the average initial friction and macrotexture values of the overlaid sections with those of the bare-tined CRCP sections. The average results from the initial friction tests are shown in Figure 9. These measurements showed that the SafeLane overlay had higher friction and macrotexture than the VDOT modified EP-5 overlay and bare-tined CRCP sections. The VDOT modified EP-5 overlay had a higher macrotexture value but similar friction levels when compared to the bare-tined CRCP sections.

### *Skid Resistance*

On November 20, 2006, both SafeLane sections and one of the VDOT modified EP-5 and CRCP sections were treated by a spray truck that applied salt (NaCl) brine liquid at a rate of 30 gal/lane-mile. The three sections (VDOT modified EP-5, CRCP, and SafeLane) on the WB lane were treated, and only the SafeLane section in the EB lane was treated. After the surfaces were dry, the skid trailer tester measured friction on these sections again. The truck covered an area only approximately 9 ft wide, and the application speed was low; thus, not all of the lane width was covered. The coverage was not very uniform; approximately 20 ft of the EB SafeLane section was not uniformly treated.



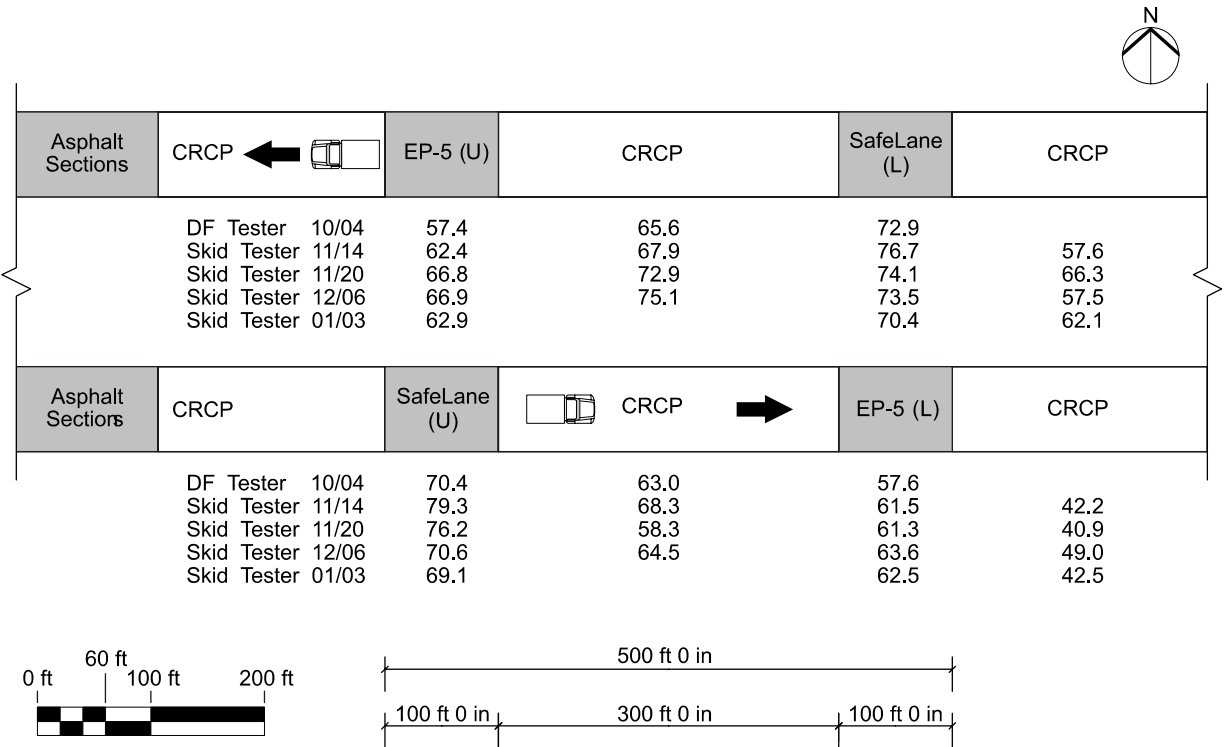
Figure 8. Friction and Macrotexture Measuring Devices Used

Table 9. Summary of Initial Friction and Macrotexture Measurements

Direction	Section	Friction		Macrotexture (mm)	
		Skid Tr. FN(40) (ASTM E204)	DFT <sup>a</sup> (ASTM E1911)	CTM (ASTM E2157)	ICC Texture
Downhill (Eastbound)	SafeLane (U)	79.3	70.4	2.15	1.63
	CRCP	68.3	63.0	0.63	0.70
	EP-5 (L)	61.5	57.6	1.52	1.21
Uphill (Westbound )	SafeLane (L)	76.7	72.9	2.26	1.47
	CRCP	67.9	65.6	0.92	0.90
	EP-5 (U)	62.4	57.4	1.47	1.25

Skid Tr. FN(40) = skid trailer friction number at 40 mph, DFT = Dynamic Friction Tester, CTM = Circular track meter, ICC = texture estimate from proprietary system developed by International Cybernetics Corporation, U = upper, L = lower.

<sup>a</sup>DFT value shown is the coefficient of friction ( $\mu$ ) interpolated for 40 mph [FN= 100 \*  $\mu$ ].



**Figure 9. Initial Friction Test Results at Smart Road. CRCP = continuously reinforced concrete pavement, U = upper, L = lower.**

Based on the experience gained during the first application, a revised procedure was developed:

1. The sections were marked with cones.
2. The liquid brine truck got up to speed on the flexible pavement section and the operator tried to keep the truck as centered as possible within the lane.
3. The operator started the application at the starting cone and closed it soon after the ending cone in each case.

Better results were obtained with the revised procedure, which produced a more uniform coverage of the treated sections. After the surfaces were dry, the skid trailer tester measured friction on these sections again. Figure 10 shows photographs taken during the application of the brine and the skid marks left after the ASTM E204 friction tests. The schedule of subsequent applications and friction tests is presented in Table 10. No friction tests were conducted during the second set of treatments during the winter of 2007-08.





(a) Brine spreader



(b) Brine application marks



(c) Close-up of application marks



(d) Skid test



(d) Skid mark



(e) Close-up of skid mark

Figure 10. Brine Application, Initial Friction Testing, and Skid Marks at Virginia Smart Road

**Table 10. Brine Application Schedule for SafeLane Sections at Smart Road**

<b>Date</b>	<b>Brine Application</b>	<b>Friction Measurements</b>
November 20, 2006	<b>Initial application (30 gal/mi)</b>	40 mph
December 6, 2006	Reapplication	20, 40, and 50 mph
January 3, 2007	Reapplication	20, 40, and 50 mph
January 17, 2007	Reapplication	Cancelled
January 31, 2007	Reapplication	Cancelled
February 14, 2007	Reapplication	20, 40, and 50 mph (2/28)
January 3, 2008	<b>Initial application (30 gal/mi)</b>	None
February 7, 2008	Reapplication	None
March 6, 2008	Reapplication	None

**Effectiveness in Preventing Frost, Ice, and Snow Formation**

**I-81 Overlays**

Information showing a difference between the two-layer SafeLane and one-layer VDOT modified EP-5 overlays was not obtained from the surface friction testing using the Halliday RGT to test Structures 2024 and 2025 during winter snow and ice conditions. Results for ice and snow melting performance for decks on I-81 were inconclusive because there were few ice and snow events since the overlays were placed in 2005.

**Smart Road Overlays**

*First Snow Experiment: January 18, 2007*

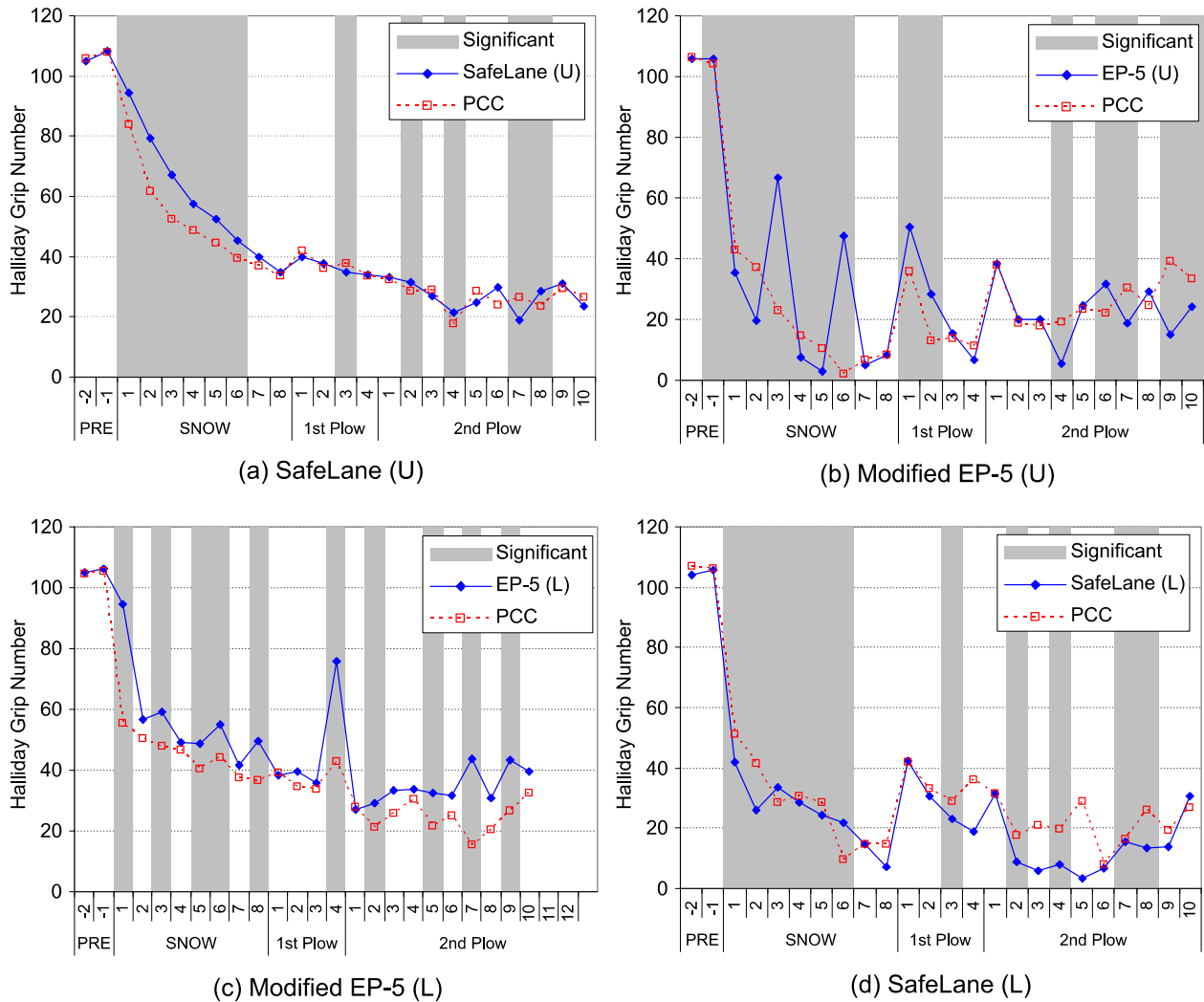
The first experiment was used to refine the testing protocol. The snow accumulated faster than natural snow would accumulate (Figure 11) and, thus, did not represent typical conditions under natural snow. As a result of this preliminary test, the snow nozzles were replaced before the final two tests in February to slow down the rate of snow accumulation.



**Figure 11. Snow Accumulation During First Snow Experiment (January 18, 2007) at Virginia Smart Road**

The experiment began at 11:00 P.M. (the snow generation started at 11:50 P.M.) and ended at 2:30 A.M. Several successive friction tests with the Halliday RGT were conducted. The tests included 4 passes on dry conditions, 8 passes with snow, 4 passes after the first plow, and 12 passes after the second plow.

The friction measurements are summarized and presented in Figure 12. The various plots compare the average friction results (measured every 0.1 sec) on the overlays with those of the closest bare-tined CRCP section. The shaded areas indicate the passes for which the results were found to be statistically significant using a *t*-test with a 5% level of significance. The results presented in Figure 12 show a statistically significant positive effect of both overlay treatments before the first plowing in the EB (downhill) direction. Both sections provided higher friction at the beginning of the experiment, which simulates the beginning of the precipitation storm before the snow-fighting crews begin treating the road. After the plowing, the friction values were similar. A consistent difference in friction was not found in the WB (uphill) direction. It is



**Figure 12. Friction Comparison for First Snow Experiment (January 18, 2007) at Smart Road. Significant = passes for which results were statistically significant using a *t*-test with a 5% level of significance; U = upper; PCC = portland cement concrete; L = lower.**

hypothesized that this could be due to the very fast accumulation of snow on this WB lane, which was closer to the snow-making towers. This was one of the factors prompting the decision to replace the nozzles to reduce the rate of snow generation as discussed previously.

*Second Snow Experiment: January 31, 2007 (A.M.)*

On January 31, the temperature was very low, and, as a consequence, the artificial snow produced during the experiment was of good quality. The pavement temperature at the start of the test was approximately 15° F. Unfortunately, it was very windy and a large portion of the snow produced did not fall on the road but rather was blown away from the road. Specifically, the upper sections did not get good snow coverage because of the wind. In addition, not all of the snow towers were working. Another difficulty was that it was not possible to save the 0.1-sec friction data; as a consequence, it was not possible to make detailed comparisons among the various sections.

*Third Snow Experiment: January 31, 2007 (P.M.)*

Another experiment was conducted on the evening of January 31. In this case, the pavement temperature was approximately 22° F. The snow coverage got heavier as the researchers moved downhill, and it was heavier in the uphill (WB) lane than in the downhill (EB) lane. The log of events for this experiment is presented in Table 11.

All sections were contaminated with salt because of the tests conducted earlier in the day. In addition, the snow coverage along the road was not uniform because not all of the nozzles were working (see Table 12), probably because of freezing of the water at the orifice or in the towers. In addition, there was some leaking of liquid water after the snow was stopped at the end of the test; the spraying was heavier in the uphill (WB) lane than in the downhill (EB) lane and was heavier as the crew moved down the road. The researchers decided to follow the procedure used in the morning in all future testing to minimize contamination by the residual water.

**Table 11. Sequence of Events During Third Snow Experiment (January 31, 2007)(P.M.)**

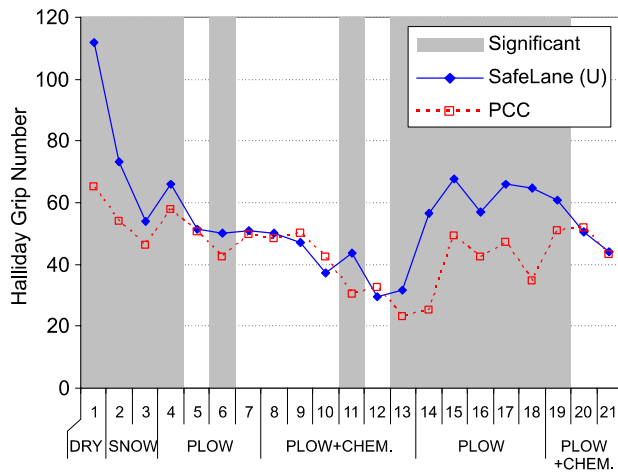
<b>Time</b>	<b>Event</b>	<b>Comments</b>
7:35 P.M.	Started to prepare pumps	Friction truck not ready; was a delay
8:00	Turned on lights	
8:30	First plowing (cut downhill string)	Air temperature: 22° F
8:50	Plow + chemical application	Approx. 240 l/lane-mile <sup>a</sup>
8:55	Friction measurement only Started to shut down snow (some water still running)	
8:58	Friction measurement	
9:10	Water still running on downhill (EB) lane	Air temperature: 19° F
9:24	Plow without chemical application	
9:30	Friction only after traffic	
9:48	Plow without chemical application	
10:15	Plow + chemical application	Approx. 240 l/lane-mile <sup>a</sup>

<sup>a</sup> 2-inch gate, 25 mph (2,000 RPM), control setting 7.

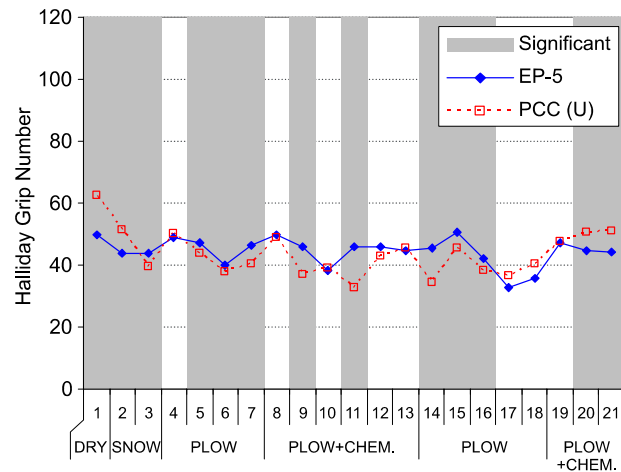
**Table 12. Working Nozzles During Third Snow Experiment (January 31, 2007) (P.M.)**

Tower	No. of Nozzles	Tower	No. of Nozzles	Tower	No. of Nozzles
50	4	57	4	64	4
51	3	58	4	65	4
52	2	59	4	66	0
53	2	60	4	67	4
54	4	61	2	68	2
55	3	62	4	69	4
56	1	63	4	70	4

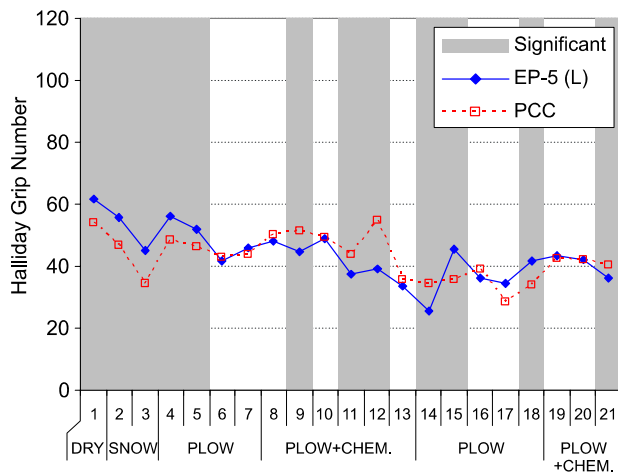
The friction measurements collected are summarized in Figure 13. The results are similar to those obtained in the first experiment; the SafeLane and VDOT modified EP-5 sections in the EB (downhill) direction maintained higher friction than their respective adjacent bare-tined



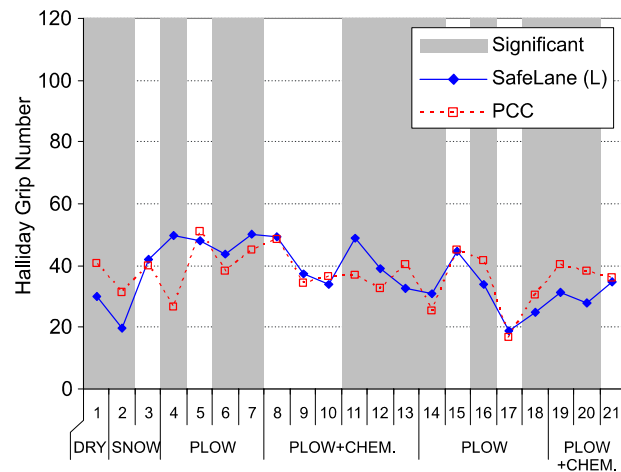
(a) SafeLane (U)



(b) Modified EP-5 (U)



(c) Modified EP-5 (L)



(d) SafeLane (L)

**Figure 13. Friction Comparison for Third Snow Experiment: January 31, 2007 (P.M.). Significant = passes for which results were statistically significant using a *t*-test with a 5% level of significance; U = upper; PCC = portland cement concrete; L = lower.**

concrete surfaces until the first plowing. Unfortunately, because of a problem with the friction measuring truck, the beginning of the data collection was slightly delayed and only three runs were conducted before plowing was necessary.

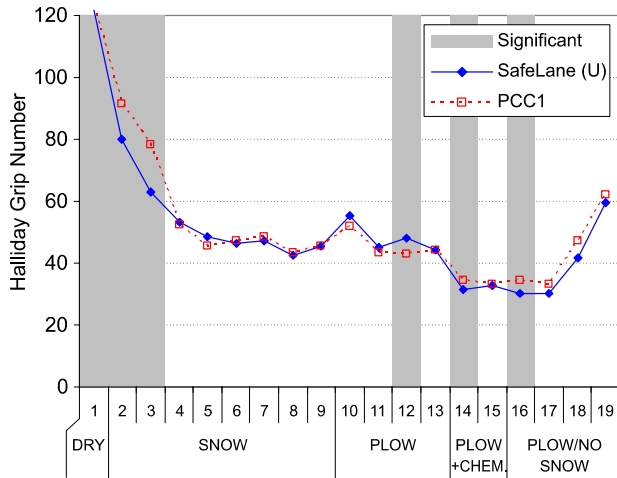
*Fourth Snow Experiment: February 17, 2007*

These tests were conducted using the smaller nozzles (No. 5005) and the final experimental protocol that called for the plowing to be triggered by the friction number (see Appendix D). Table 13 summarizes the experiment, and Figure 14 presents the friction measurements. No consistent significant skid resistance benefit in snow from the two-layer SafeLane or two-layer VDOT modified EP-5 overlay was found in this experiment.

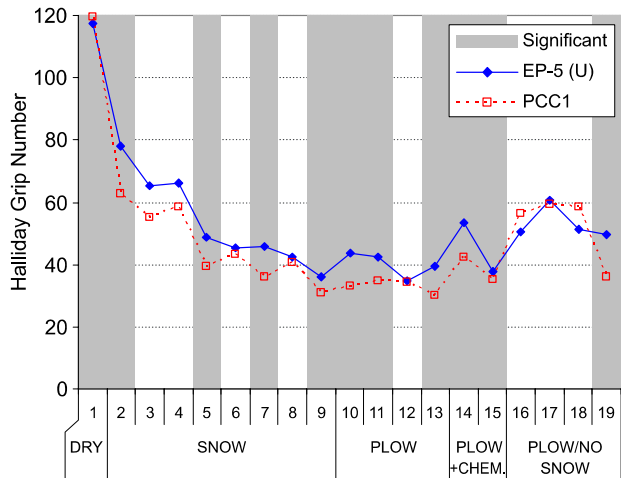
**Table 13. Sequence of Events During Fourth Snow Experiment on Smart Road: February 17, 2007 (P.M.)**

<b>Time</b>	<b>Event</b>	<b>Comments</b>
1:20 P.M.	Turned on lights and started collecting friction data	Pavement temperature: 14°-18° F
1:56	Started snow (pumps on at 1:36)	
1:58	First friction measurement on snow	
2:40	First plowing with no chemical	
3:00	Plow + chemical application	Approx. 240 l/lane-mile <sup>a</sup>
3:07	Plow + chemical application	Approx. 240 l/lane-mile <sup>a</sup>
3:08	Started to shut down snow	
3:43	Plow + chemical application	Approx. 240 l/lane-mile <sup>a</sup>

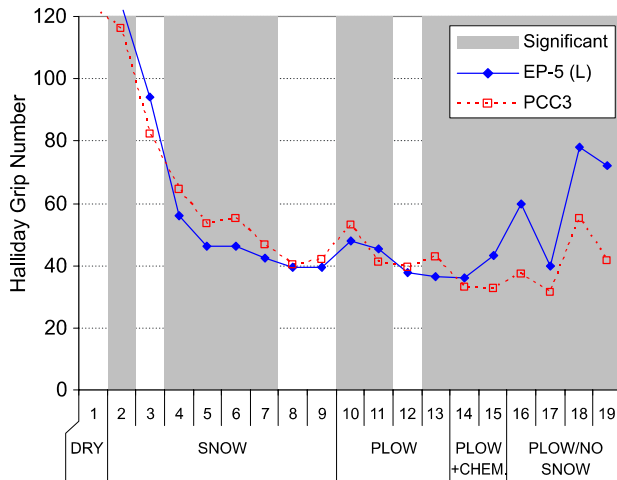
<sup>a</sup>2-inch gate opening, 25 mph (2,000 RPM), control setting 7.



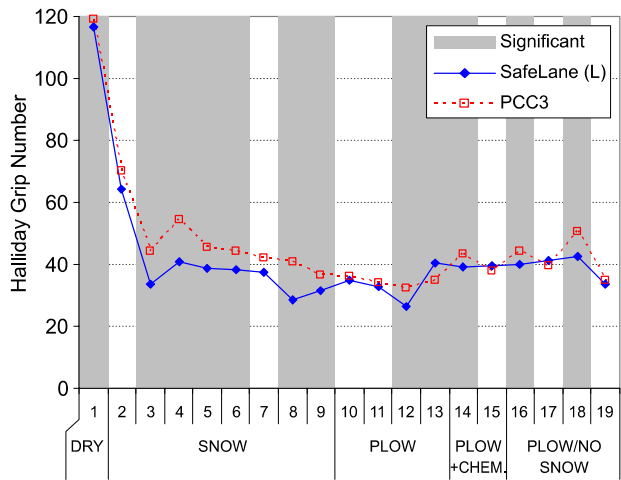
(a) SafeLane (U)



(b) Modified EP-5 (U)



(c) Modified EP-5 (L)

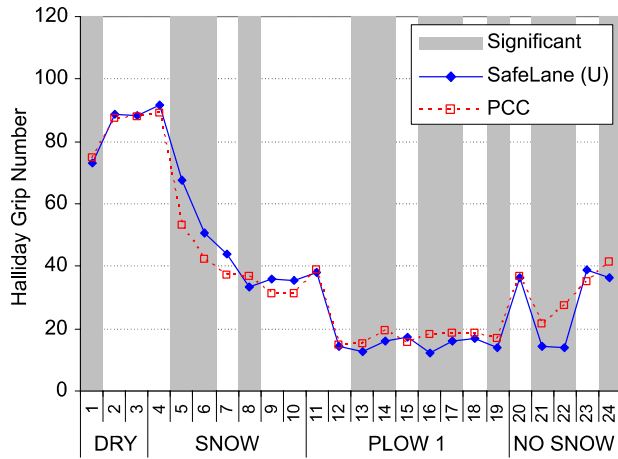


(d) SafeLane (L)

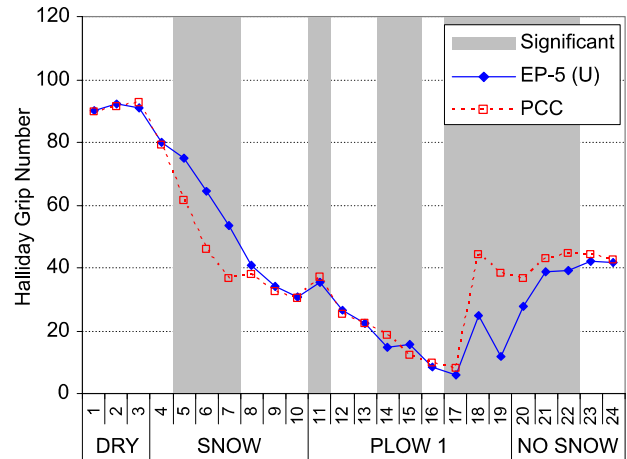
**Figure 14. Friction Comparison for Fourth Snow Experiment on Smart Road: February 17, 2007 (P.M.). Significant = passes for which results were statistically significant using a *t*-test with a 5% level of significance; U = upper; PCC1 = PCC adjacent to upper SafeLane section; PCC3 = PCC adjacent to lower SafeLane section, L = lower.**

*Fifth Snow Experiment: February 19, 2007*

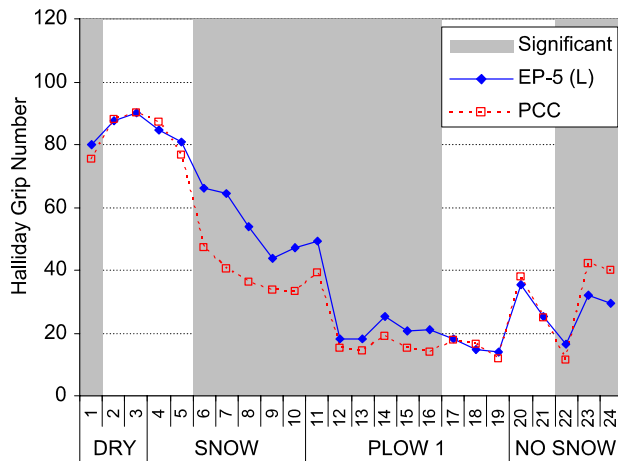
In the final test, the snow was of good quality, but, unfortunately, once more, not all towers were working and the snow coverage was not uniform. In this case, the downhill (WB) sections were getting more snow cover because of the wind. The measured friction values are presented in Figure 15, and the log with the main events of the test is summarized in Table 14. The friction measurements showed either no difference or a statistically significant improvement in the friction values before the first plowing in the four overlay sections investigated with respect to the corresponding adjacent bare-tined concrete sections. On the other hand, it is interesting to note that the first plowing was not effective on any of the surfaces as the friction values measured were lower after the plowing. Friction started to improve after the snow was stopped.



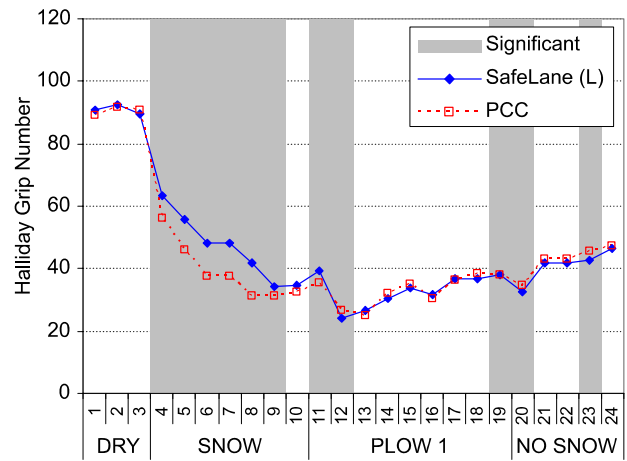
(a) SafeLane (U)



(b) Modified EP-5 (U)



(c) Modified EP-5 (L)



(d) SafeLane (L)

**Figure 15. Friction Comparison for Fifth Snow Experiment on Smart Road: February 19, 2007. Significant = passes for which results were statistically significant using *t*-test with 5% level of significance; U = upper; PCC = portland cement concrete; L = lower.**

**Table 14. Sequence of Events During Fifth Snow Experiment on Smart Road: February 19, 2007, P.M.**

Time	Event	Comments
7:30	Started preparations and friction measurements	Pavement temperature: 24°F in upper and 17°F in lower sections
8:00	Started making snow	
8:14	Cars started trafficking aligned in front of truck	
8:30	First plowing with chemical application	~ 240 l/lane-mile <sup>a</sup>
8:45	Began to start cutting snow	Some water still running
9:05	Snow stopped	
9:45	Plowed downhill lane	Friction increased on inner wheelpath
9:49	Measured friction on outer wheel track	One wheel on shoulder
10:07	Plowing with one wheel on shoulder to measure friction going downhill (approx. 30 mph)	
10:15	Stopped testing, plowing, and chemical application	

<sup>a</sup>2-inch gate, 25 mph (2,000 RPM), control setting 7, as calibrated 1/30/07.



Artificial “Black Ice” Experiment: February 27, 2008

A final testing event was performed to simulate the formation of ice on a road . For this purpose, a tractor with a liquid sprayer was retrofitted with small nozzles to spray a very fine mist of water that upon contact with the surface at freezing temperatures formed a very thin layer of ice on the road. Testing started when the pavement temperature reached 28° F. Two measurements were conducted on dry pavement before water was turned on to form the ice. Six passes with the water sprayer were made on the entire length of the testing sections (referred to as Full Application), which covered the four overlaid sections and the concrete pavement in between them. The continuous friction measurements (RGT) obtained during this first phase are presented in Figure 16. These measures show that at the beginning of the experiment the overlaid sections had lower friction than the adjacent bare concrete pavement. After the fourth or fifth pass water sprays, the friction of both overlaid sections started to improve.

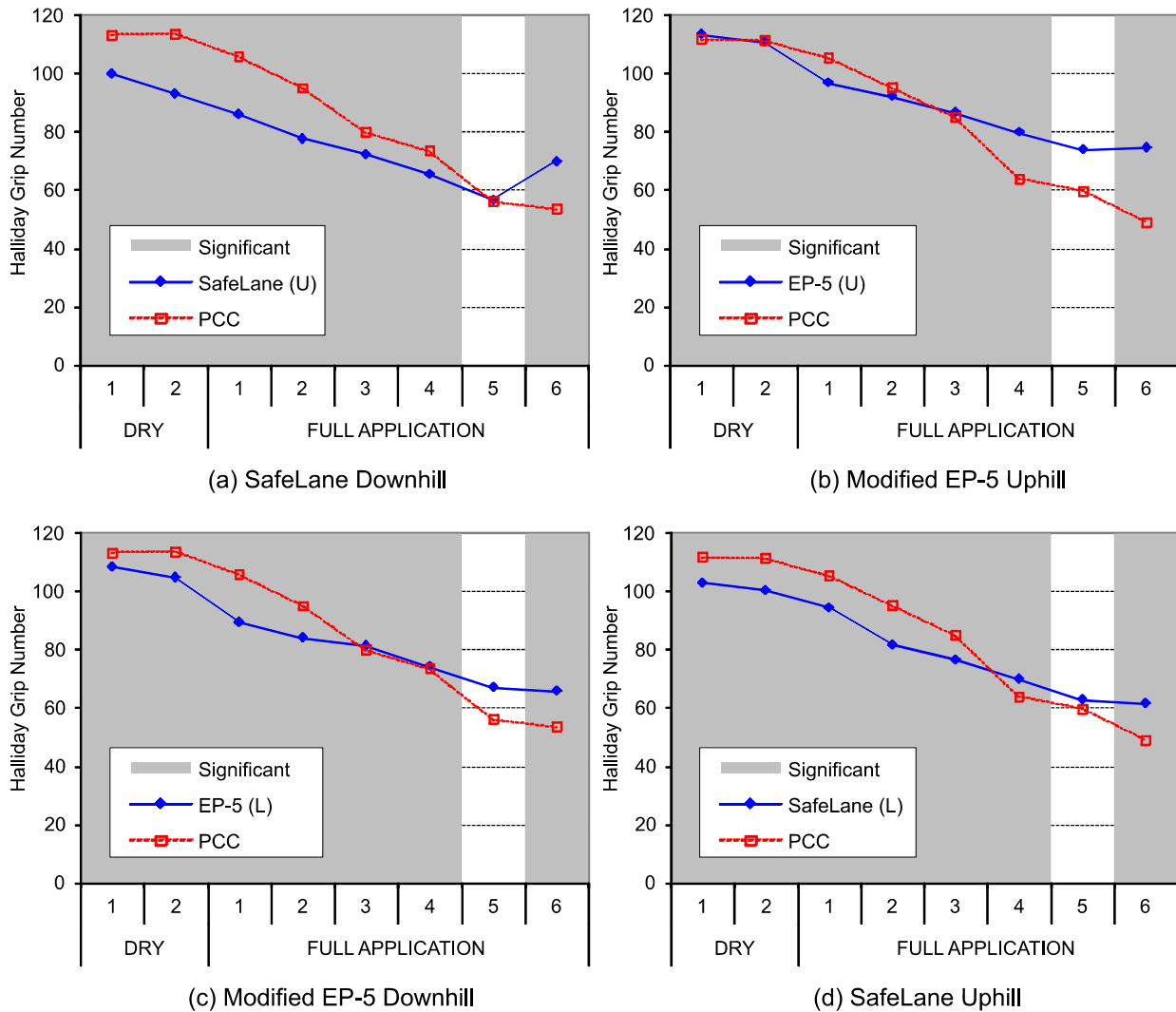


Figure 16. Friction Comparison for Ice Experiment, First Phase, 2/27/08. Significant = statistically significant; PCC = portland cement concrete; U = upper; L = lower.

Unfortunately, all the water deposit on the tractor was used before a significant ice layer was formed on all the sections, thus forcing the experiment to be halted and continued after the tank was refilled. Because spraying all the sections was consuming too much time, a decision was made to spray only the adjacent top overlay sections in a shorter loop maneuver. This was done to form a thicker layer of ice on the road at a quicker rate. Figure 17 compares the continuous friction measurements on the two top overlay sections for both phases (Full/Short Applications). No comparison was made with the adjacent concrete sections since they were not sprayed with water in the second phase of the experiment. The first three passes of the Short Application were not measured. The shaded areas indicate a significant difference among the average measurements. All statistical tests were performed using a two-tailed  $t$ -test with different standard deviations of the samples with a significance level of  $\alpha=0.05\%$ .

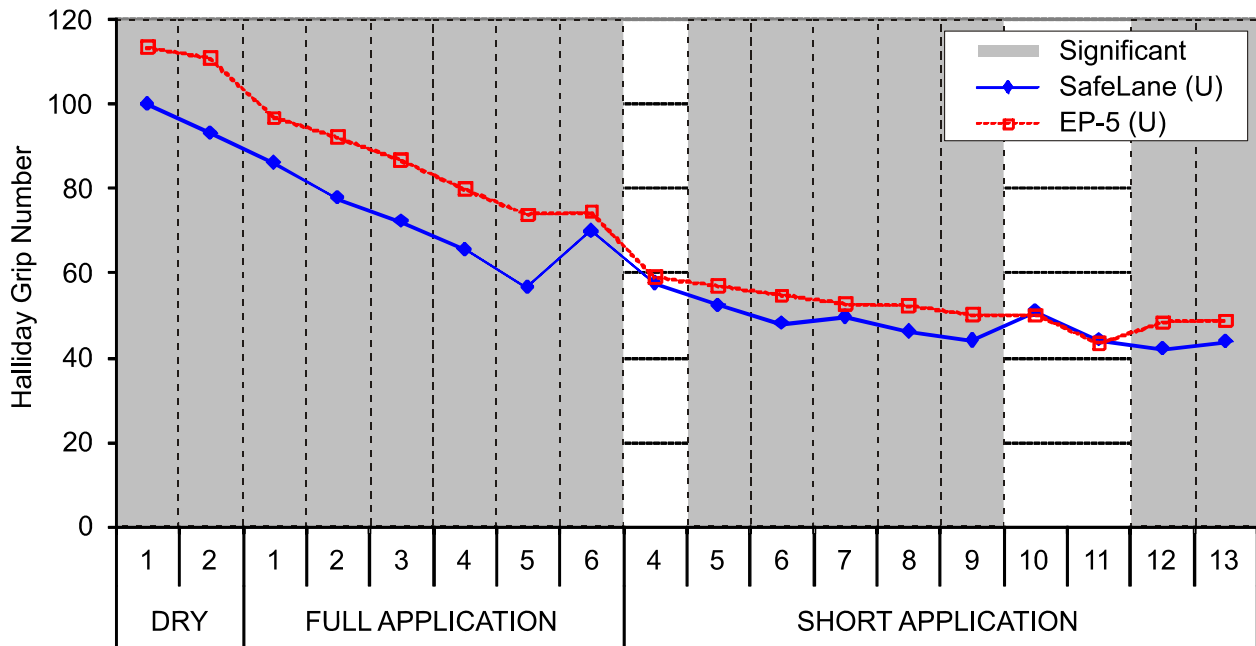


Figure 17. Friction Comparison for Ice Experiment, Second Phase, 2/27/08. Significant = Statistically significant, U = upper.

*Summary*

An analysis of the data collected in this first set of experiments (artificial snow) suggested that the two overlay treatments compared would improve the friction of bare-tined concrete pavements or bridge decks in the early stages of a storm before the snow-fighting crews can get to the location to start the winter maintenance operation. No consistent effect was observed after the initial plowing for the snow and traffic conditions encountered during the experiments. The experience gained through these experiments has allowed the defining of a detailed testing protocol and analysis methodology that would be useful for future tests. The main difficulties encountered were the production of uniform coverage with “natural” quality snow and the accurate location of the friction measurements.

The analysis confirmed that the RGT produces a wealth of information that is useful for investigating the effect of the snow and winter maintenance operations on the pavement surface. However, in their current format, the data have no global positioning system tag, and they are not efficient for supporting research such as that conducted in this study in which accurate location information is critical. The processing of data took an enormous amount of effort and time. It would be very useful for future experiments to be able to store global positioning system data in conjunction with the 0.1-sec data.

## CONCLUSIONS

- The construction of SafeLane overlays is similar to that of conventional VDOT epoxy overlays with the exception that more epoxy is required for SafeLane overlays because the aggregates are larger and the aggregates are different with respect to composition, size, and absorption.
- The initial condition of the SafeLane overlays is similar to that of the conventional VDOT epoxy overlays with respect to aggregate abrasion resistance, bond strength, permeability to chloride ion, and skid resistance.
- There has not been sufficient time to evaluate chloride penetration into the decks overlaid with SafeLane overlays in Virginia.
- SafeLane Overlays differ from conventional VDOT epoxy overlays with respect to aggregate properties and overlay thickness. The SafeLane overlay is thicker, the aggregate gradation is larger, the aggregate absorption is higher, and the aggregate weight loss in freezing and thawing is much higher.
- Based on the initial condition of the two SafeLane overlays on I-81, SafeLane overlays may provide a skid resistant wearing and protection overlay for decks that is comparable to that provided by conventional epoxy overlays. However, the aggregates used in the SafeLane overlays in this study are no longer being used in SafeLane overlays (A. Hensley, Cargill Incorporated, personal communication, August 2008). Therefore, future performance may vary because of the properties of the aggregates used in the overlay.
- The data collected at the Smart Road (artificial snow) suggest that the SafeLane and VDOT modified EP-5 overlays would improve the friction of bare-tined concrete pavements or bridge decks in the early stages of a storm before snow-fighting crews can get to the location to start the winter maintenance operation.

## RECOMMENDATION

1. VTRC should continue to evaluate the performance of the two SafeLane overlays on I-81 with respect to bond strength; skid resistance; chloride protection; and their ability to prevent the formation of frost, ice, and snow.

## COST AND BENEFITS ASSESSMENT

VDOT bid tabulations for FY 2008 indicated approximately one-third of bridge overlays were epoxy overlays and the average cost of epoxy overlays was approximately \$34 per yd<sup>2</sup>. The SafeLane overlay should cost approximately 30 percent more than a two-layer VDOT modified EP-5 overlay because of the greater thickness, which requires the use of more epoxy and aggregate. The higher cost can be justified only if the overlay reduces the number and severity of accidents. The results in this study were not sufficient to justify the higher cost. Additional evaluation is needed.

The cost of pretreatment was not included in this assessment; however, pretreating can save trips to the site during frost events and allow a longer response time for maintenance personnel at the beginning of storms. Both of these can be considered as cost savings.

## ACKNOWLEDGMENTS

The authors acknowledge the assistance of the staff from the following: Cargill, Incorporated; Lanford Brothers, Inc.; Ebond Epoxy, Inc.; VDOT Staunton District Bridge and Maintenance Sections; VDOT Materials Division and Non-Destructive Testing Section; and Virginia Transportation Research Council Concrete Laboratory. The report was edited by Linda Evans.

## REFERENCES

1. Sprinkel, M.M., Sellars, A., and Weyers, R. *Rapid Concrete Bridge Deck Protection, Repair, and Rehabilitation*. SHRP-S-344. Strategic Highway Research Program, Washington, D.C., 1993.
2. AASHTO AGC-ARTBA Task Force 34. *Guide Specifications for Polymer Concrete Bridge Deck Overlays*. American Association of State Highway and Transportation Officials, Washington, D.C., 1995.

3. Sprinkel, M.M. Twenty-Five Year Experience with Polymer Concrete Bridge Deck Overlays. In *Polymer in Concrete: The First Thirty Years*. SP-214-5. American Concrete Institute, Farmington Hills, Mich., 2003, pp. 51-61.
4. Cargill, Incorporated. *SafeLane Ice Prevention Overlay: Specification and Data Sheet*. Wayzata, Minn., 2005.
5. Cargill, Incorporated. SafeLane® Surface Overlay. <http://www.CargillSafeLane.com>. Accessed July 2007.
6. Ketchum, S. A., Minsk, D., Blackburn, R.R., and Fleege, E.J.. *Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel*. FHWA-RD-95-202. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H., 1996.
7. American Society for Testing and Materials. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Course Aggregate, ASTM C127. In *Annual Book of Standards*, Vol. 04.02. West Conshohocken, Pa., 2007.
8. Canadian Standards Association. *The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus*. CSA A23.2-23A. Toronto, Ontario, 2000.
9. American Association of State and Transportation Officials. Standard Method of Test for Soundness of Aggregate by Freezing and Thawing, AASHTO T 103-08. In *Standard Specification for Transportation Materials and Methods of Sampling and Testing*, 28th Edition, Part 2A: Tests. Washington, D.C., 2008.
10. Virginia Department of Transportation. *Virginia Test Method for Testing Epoxy Concrete Overlays for Surface Preparation and Adhesion*, VTM-92. Richmond, 1993.
11. American Association of State Highway and Transportation Officials. Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, AASHTO T 277-07. In *Standard Specification for Transportation Materials and Methods of Sampling and Testing*, 28th Edition, Part 2A: Tests. Washington, D.C., 2007.
12. American Society for Testing and Materials. Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, ASTM E274-07. In *Annual Book of Standards*, Vol. 04.03. West Conshohocken, Pa., 2007.
13. American Society for Testing and Materials. Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests, ASTM E524-82. In *Annual Book of Standards*, Vol. 04.03. West Conshohocken, Pa., 1994.
14. American Association of State Highway and Transportation Officials. Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials,

- AASHTO T 260-97. In *Standard Specification for Transportation Materials and Methods of Sampling and Testing*, 28th Edition, Part 2A: Tests. Washington, D.C., 1997.
15. American Society for Testing and Materials. Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester, ASTM E1911. In *Annual Book of Standards*, Vol. 04.03. West Conshohocken, Pa., 2007.
  16. American Society for Testing and Materials. Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference, ASTM E950. In *Annual Book of Standards*, Vol. 04.03. West Conshohocken, Pa., 2004.
  17. American Society for Testing and Materials. Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter, ASTM E2157. In *Annual Book of Standards*, Vol. 04.03. West Conshohocken, Pa., 2005.
  18. Engström, N. *Road Grip Test in Arjeplog*. Luleå University, Luleå, Sweden, 2008
  19. Flintsch, G.W. *Assessment of the Performance of Several Roadway Mixes Under Rain, Snow, and Winter Maintenance Activities*. VTRC 04-CR18. Virginia Transportation Research Council, Charlottesville, 2004.



**APPENDIX A**

**VIRGINIA DEPARTMENT OF TRANSPORTATION  
SPECIAL PROVISION FOR  
EPOXY CONCRETE OVERLAY**

May 31, 2001

**I. DESCRIPTION**

This work shall consist of furnishing and applying epoxy as an overlay over concrete bridge decks in accordance with this Specification, and within the specified tolerances for the lines, grades and details shown on the plans.

**II. MATERIALS**

**A.** The epoxy shall be modified type EP-5 conforming to Section 243 of the Specifications with the following exceptions:

<b>Property</b>	<b>Requirement</b>	<b>Test Method</b>
Pot life	15 to 45 minutes at 75°F	ASTM C881 (50 ml sample in paper cup)
Tensile strength	2,000 to 5,000 psi at 7 days	ASTM D638
Tensile elongation	30 to 70 percent at 7 days	ASTM D638
Viscosity	7 to 25 poises	ASTM D2393 (Model RVF Brookfield, Spindle No. 3 at 20 rpm)
Minimum compressive strength at 3 hrs.	1,000 psi at 75°F	ASTM C109 (Use plastic inserts)
Minimum compressive strength at 24 hrs	5,000 psi at 75°F	ASTM C109
Minimum adhesion strength at 24 hrs	250 psi at 75°F	VTM-92

**B.** Aggregate shall be angular grained silica sand or basalt having less than 0.2% moisture, and free of dirt, clay, asphalt and other foreign or organic materials.

The silica sand and basalt shall have a minimum Mohs' scale hardness of 7. Unless otherwise approved, silica sand and basalt shall conform to the following gradation:

**Percent by Weight of Material Passing**



<b>No. 4 Sieve</b>	<b>No.8 Sieve</b>	<b>No. 16 Sieve</b>	<b>No. 30 Sieve</b>
100	30-75	Max. 5	Max. 1

### **III. CONSTRUCTION METHODS**

#### **A. Safety Provisions**

Personnel shall be thoroughly trained in the safe handling of materials in accordance with the Manufacturer's recommendations.

#### **B. Storage of Materials**

Materials shall be stored in accordance with the requirements of Section 243 of the Specifications. MSDS and other information pertaining to the safe practices for the storage, handling and disposal of the materials, and to their health hazards shall be obtained from the manufacturer and posted at storage areas. A copy of such information shall be provided to the Engineer.

#### **C. Surface Preparation**

Prior to placing the first course, the Contractor shall determine the bridge deck cleaning method in accordance with VTM-92 to obtain the size of shot, flow of shot, forward speed of shotblast machine, and number of passes necessary to provide a tensile rupture strength greater than or equal to 250 psi or a failure area, at a depth of 1/4 inch or more into the base concrete, greater than 50 percent of the test area. A test result shall be the average of three tests on a test patch of at least 1.5 ft. x 3 ft. consisting of two courses. One passing test result must be obtained for each span or 300 square yard, whichever is the smaller area. Test patches shall be placed in wheel paths, the area between wheel paths or in other areas that represent a worst surface condition as determined by the Engineer. To provide assurance that the cleaning procedure, materials, installation procedure, and curing period will provide the desired overlay, test patches shall be installed with the same materials, equipment, personnel, timing, sequence of operations, and curing period prior to opening to traffic that will be used for the installation of the overlay. The cleaning method, materials, and installation procedure will be approved if one passing test result is obtained from each test area.

If the cleaning method, materials and installation procedure are not acceptable, the Contractor must remove failed test patches and make the necessary adjustments, and retest all test areas at no additional cost to the Department until satisfactory test results are obtained.

Before placement of the epoxy concrete overlay, the entire deck surface shall be cleaned by shotblasting and other means, using the approved cleaning method to remove asphaltic material, oils, dirt, rubber, curing compounds, paint carbonation, laitance,

weak surface mortar and other potentially detrimental materials, which may interfere with the bonding or curing of the overlay. Acceptable cleaning is usually recognized by a significant change in the color of the concrete and mortar, and the beginning exposure of coarse aggregate particles. Mortar, that is sound and soundly bonded to the coarse aggregate, must have open pores due to cleaning to be considered adequate for bond. Areas of asphalt larger than one inch in diameter, or smaller areas spaced less than six inches apart, shall be removed. Traffic paint lines shall be considered clean when the concrete has exposed aggregate showing through the paint stripe. A vacuum cleaner shall be used to remove all dust and other loose material. Brooms shall not be used and will not be permitted.

If the Engineer determines that an approved cleaning method has changed prior to the completion of the job, the Contractor must return to the approved cleaning methods and reclean the suspect areas or verify through tests at no additional cost to the Department that the altered method is acceptable.

Epoxy concrete overlay shall not be placed on hydraulic cement concrete that is less than 28 days old. Patching and cleaning operations shall be inspected and approved prior to placing each layer of the overlay. Any contamination of the deck or intermediate courses, after initial cleaning, shall be removed. Both courses shall be applied within 24 hours following the final cleaning and prior to opening the area to traffic.

There shall be no visible moisture present on the surface of the concrete at the time of application of the epoxy concrete overlay. Compressed air may be used to dry the deck surface.

#### **D. Equipment**

For mechanical applications, equipment shall conform to the requirements of Section 243 of the Specifications, and shall consist of no less than an epoxy distribution system, fine aggregate spreader, application squeegee and vacuum trucks, and a source of lighting if work will be performed at night. The distribution system or distributor shall accurately blend the epoxy resin and hardening agent, and shall uniformly and accurately apply the epoxy materials at the specified rate to the bridge deck in such a manner as to cover 100 percent of the work area. The fine aggregate spreader shall be propelled in such a manner as to uniformly and accurately apply the dry silica sand or basalt to cover 100 percent of the epoxy material. The vacuum truck shall be self-propelled.

For hand applications, equipment shall consist of calibrated containers, a paddle type mixer, squeegees, rollers and brooms, which are suitable for mixing the epoxy and applying the epoxy and aggregate in accordance with the requirements of Section 243 of the Specifications.

#### **E. Application**

Handling and mixing of the epoxy resin and hardening agent shall be performed in a safe manner to achieve the desired results in accordance with the requirements of Section 243 of the Specifications, and the manufacturer's recommendations as approved or directed by the Engineer. Epoxy concrete overlay materials shall not be placed when weather or surface conditions are such that the material cannot be properly handled, placed, spread and cured within the specified requirements of traffic control.

The epoxy overlay shall be applied in 2 separate courses in accordance with the following rate of application, and the total of the 2 applications shall not be less than 7.5 gals. per 100 square feet

<b>Course</b>	<b>Rate Gal./100 sq.ft.</b>	<b>Aggregate Lbs./Sq.Yd.</b>
1	No less than 2.5	10+
2	No less than 5.0	14+

\*Application of aggregate shall be of sufficient quantity to completely cover the epoxy.

After the epoxy mixture has been prepared for the epoxy concrete overlay, it shall be immediately and uniformly applied to the surface of the bridge deck with a squeegee or paint roller. The temperature of the bridge deck surface and all epoxy and aggregate components shall be 60°F or above at the time of application. Epoxy shall not be applied if the air temperature is expected to drop below 55°F within 8 hours after application, or the gel time is less than 10 minutes. The dry aggregate shall be applied in such a manner as to cover the epoxy mixture completely within 5 minutes. First course applications, which do not receive enough sand prior to gel, shall be removed and replaced. A second course insufficiently sanded may be left in place, but will require additional applications before opening to traffic. Each course of epoxy concrete overlay shall be cured until vacuuming or brooming can be performed without tearing or damaging the surface. Traffic or equipment shall not be permitted on the overlay surface during the curing period. After the course one curing period, all loose aggregate shall be removed by vacuuming or brooming and the next overlay course applied to completion. The minimum curing periods shall be as follows:

**Course    Average temperature of deck, epoxy and aggregate components in °F**  
                   60-64            65-69            70-74            75-79            80-84            85+

1	4 hrs.	3 hrs.	2.5 hrs.	2 hrs.	1.5 hrs.	1 hr.
2	6.5 hrs.*	5 hrs.	4 hrs.	3 hrs.	3 hrs.	3 hrs.

\*Course 2 shall be cured for 8 hrs. if the air temperature drops below 60°F during the curing period.

The Contractor shall plan and prosecute the work to provide the minimum curing periods as specified herein, or other longer minimum curing periods as prescribed by the manufacturer prior to opening to public or construction traffic, unless otherwise permitted. Course 1 applications shall not be opened to traffic.

Unless otherwise specified, the epoxy concrete overlay courses shall be applied over the expansion joints of the bridge deck. The expansions joints shall be provided with a bond breaker. Within 12 hours of application and prior to opening to traffic, the overlay shall be removed over each joint by removal of the bond breakers, or by scoring the overlay prior to gelling or by saw cutting after cure.

In the event the Contractor's operation damages or mars the epoxy concrete overlay, the Contractor shall remove the damaged areas by saw-cutting in rectangular sections to the top of the concrete deck surface and replacing the various courses in accordance with this Specification at no additional cost to the Department.

For each batch provided, the Contractor shall maintain and provide to the Engineer records including, but not limited to, the following:

1. Batch numbers and sizes
2. Location of batches as placed on deck, referenced by stations
3. Batch time
4. Gel time (50 ml sample)
5. Temperature of the air, deck surface, epoxy components, including aggregates
6. Loose aggregate removal time
7. Time open to traffic

**IV. MEASUREMENT AND PAYMENT**

Epoxy concrete overlay will be measured and paid for in square yards, which price shall be full compensation for deck preparation and testing, for furnishing and applying the overlay courses including saw cutting joints and any incidentals necessary to complete the work.

Payment will be made under:

<b>Pay Item</b>	<b>Pay Unit</b>
Epoxy Concrete Overlay	Square Yard



## APPENDIX B

### ROADWAY GRIP TESTER

This continuous friction measuring device records the friction capability of the road surface at any condition: wet, dry, or at any stage of plow and deicing operations. The RGT measures friction using a “fifth-wheel” permanently locked at a fixed angle of 1 to 2 degrees to the line of travel and quantifies the friction resistance of the tire. In this research, data were recorded continuously with two separate units: (1) a magnetic card that records friction, speed, temperature, real time, direction, GPS location information, etc., every 2 sec, and (2) a portable laptop that collects only friction, speed, and relative time records every one-tenth of a second. The 2-sec data actually represent the average of the 10 one-tenth-of-a-second measurements of the friction taken during 2 sec. Using the location information from the GPS data available, it was possible to locate one, and sometimes two, measurements for each of the overlaid sections of interest. These data, however, are like a single snapshot of the entire pass of the friction readings of the tests performed. The one-tenth-of-a-second data, obviously, had better coverage of the sections, but an operational problem was encountered when trying to match the data to the sections. The solution used was to reset the equipment at a known location at the beginning of each of the passes and match the readings recorded manually using the distances derived from the speed records.

Both methods produced abundant data. On a typical test day, about 3,000 records of 2-sec data and about 40,000 of the 0.1-sec data were recorded per hour. The RGT inside displays units are shown in Figure B1(a), and the friction wheel located under the truck in Figure B1(b).



(a) Inside display units



(b) Fifth wheel

**Figure B1. Road Grip Tester Installed in Plow Truck**



## APPENDIX C

### SNOW GENERATION AT THE VIRGINIA SMART ROAD

The Virginia Smart Road's snow-making equipment and facilities include a 500,000-gal water tank and 80 aluminum snow towers. The towers span approximately an 0.5-mile section of the road and are spaced at 33-ft (10 m) intervals. The towers can be adjusted for use at various heights, but they are most commonly used at a height of 25 ft. At full capacity, the towers can produce up to 1 ft of snow per hour. The snow-making system uses public drinking water; therefore, the water tank is used to avoid placing large burdens on municipal facilities during snow production. During snow making, water from the tank is pumped at 300 to 500 psi. During snow production, the chilled water is drained out of the tank into a wet well, from which it is drawn out by pumps to the snow towers.

The aluminum snow towers contain three nested pipes; the water flows through the outer pipe, and cooled and compressed air travels through the center pipe (the middle pipe is not generally used for snow making). The outer pipe is used to carry the water because it allows the cold air temperatures to transfer to the water, thus cooling the water further and combating any increases in temperature that may have occurred while the water flowed underground. The pipes feed four nozzles on the tip of the tower. When sprayed out of the nozzles, the water is hit with dry/cool air blown from air jets. The purpose of this cold, dry air is to atomize the water sprayed from the nozzles as finely as possible because smaller droplets freeze more easily. In addition, evaporative cooling caused by the atomization contributes to the freezing process. The quality and quantity of the snow produced depends largely on the ambient weather conditions. The ideal snow-making conditions are dry and cold. Temperatures of 21.2°F and below are optimal, regardless of the humidity level. Yet, as temperatures begin to rise, lower humidity levels are required to produce snow. For example, high-quality snow can be produced at temperatures as high as 28.4°F, but only under humidity levels of 20 percent or below.<sup>19</sup>

The nozzles used for this study were changed after the first few tests to reduce the rate of snow production. The first experiments were conducted using relatively larger nozzles (5010), which produced a significant amount of snow in a short period of time. These nozzles produced the snow too quickly to simulate natural storms. As a consequence, the final tests (in February) were conducted using smaller nozzles (5005).





## APPENDIX D

### FINAL PROTOCOL FOR TESTING AT THE VIRGINIA SMART ROAD ALL-WEATHER FACILITY

1. Mark section boundaries with cones.
2. Get together at VTTI at 12:00 AM.
3. Measure pavement surface temperature.
4. When pavement surface reaches 30°F, start the pumps. Record time \_\_\_\_\_.
5. Measure pavement surface temperature; take two measurements per section/lane with the infrared thermometer.
6. Set up video recording and start recording.
7. Start friction data (RGT) recording and record time \_\_\_\_\_.
8. Turn on lights (if needed) and record time \_\_\_\_\_.
9. Start snow at as slow a pace as feasible and record time \_\_\_\_\_.
10. Start traffic and record time \_\_\_\_\_.
11. Gather friction readings with RGT.
12. Record snow thickness.
13. Run caravan of vehicles through the snow area, led by the RGT truck.
14. Gather friction readings with the RGT using the computer connection. After the first round trip, offset the route of the RGT to run in the inner wheelpath.
15. Monitor readings through the four test and control sections. When  $H_n$  starts to drop rapidly (approximately below 50) on the last of the four sections, plow the road while continuing to make snow. Do NOT salt the road.
16. Repeat steps 12, 13, and 14, but salt the road.
17. Repeat steps 12, 13, and 14 and salt as necessary
18. Stop the snow (TRY NOT TO LEAVE WATER RUNNING) and continue friction measurements until the road is clean.
19. Take photographs of the various sections.

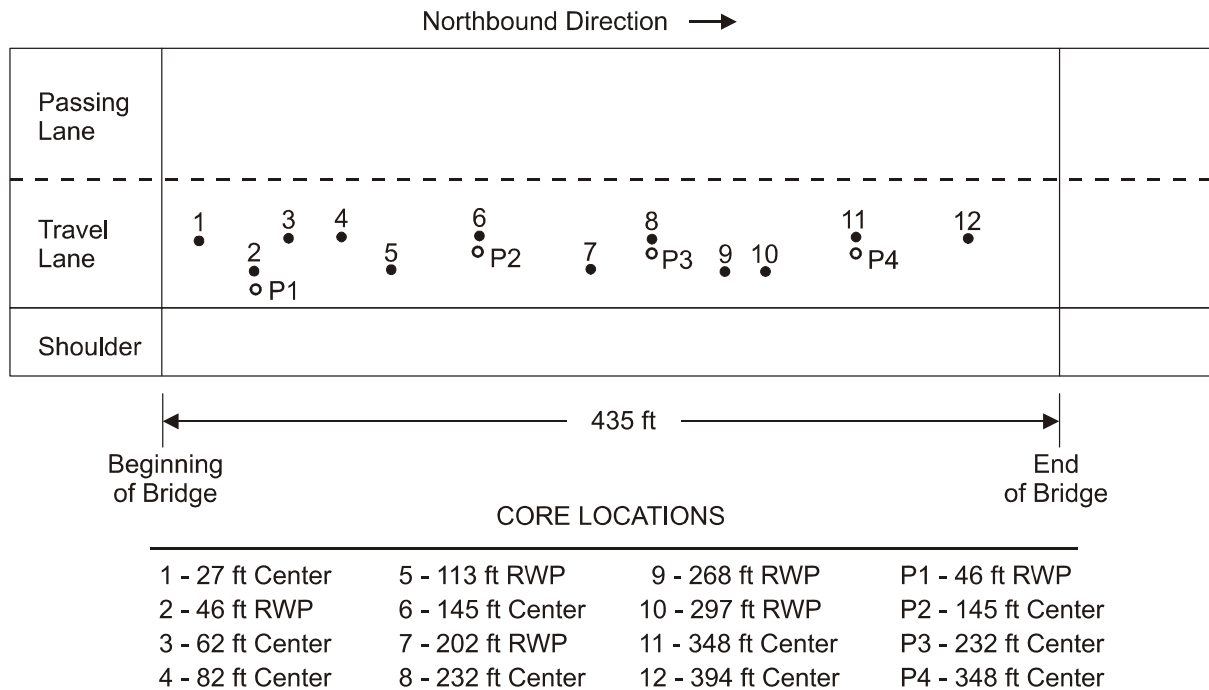


## APPENDIX E

### CORE LOCATIONS FOR TESTS OF BOND STRENGTH, PERMEABILITY, AND CHLORIDE CONTENT

Structure Number: 2024

Location: I-81 Northbound Direction, Mile Marker 240



Cores 1 - 12 => 2 1/4 in diameter cores for tensile strength testing

Cores P1 - P4 => 4 in diameter cores for permeability to chloride ion testing

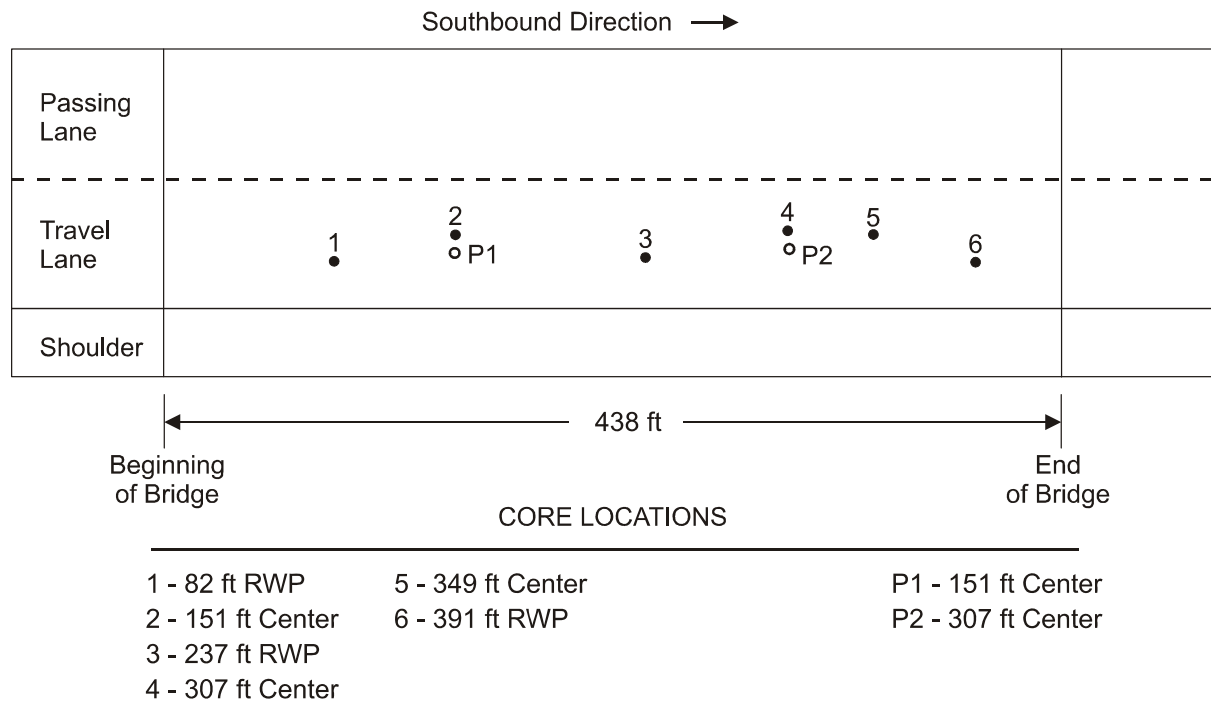
Cores taken on 2-15-06

RWP - Right Wheel Path

**Figure E1. Core Locations: I-81 Structure 2024 Northbound, SafeLane with Blended Aggregate**

Structure Number: 2025

Location: I-81 Southbound Direction, Mile Marker 240



Cores 1 - 6 => 2 1/4 in diameter cores for tensile strength testing

Cores P1 - P2 => 4 in diameter cores for permeability to chloride ion testing

Cores taken on 2-15-06

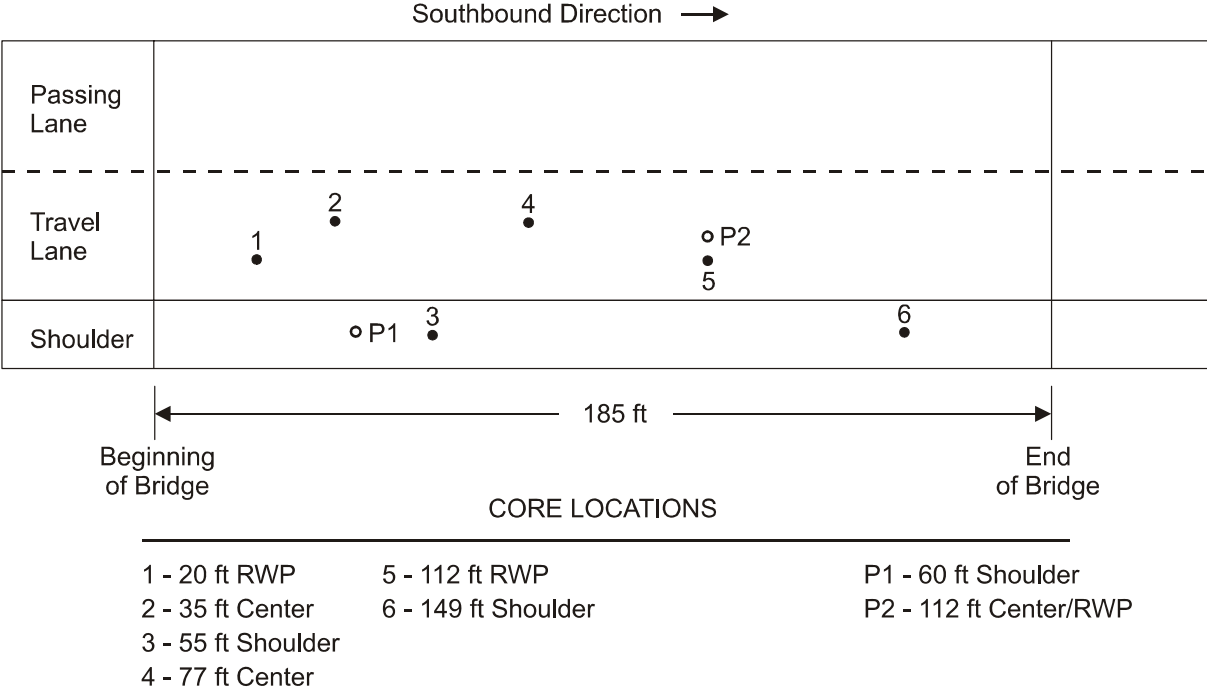
RWP - Right Wheel Path

**Figure E2. Core Locations: I-81 Structure 2025 Southbound, One-Layer VDOT Modified EP-5**



Structure Number: 2037

Location: I-81 Southbound Direction, Mile Marker 219



Cores 1 - 6 => 2 1/4 in diameter cores for tensile strength testing  
Cores P1 - P2 => 4 in diameter cores for permeability to chloride ion testing  
Cores taken on 2-15-06

RWP - Right Wheel Path

**Figure E4. Core Locations: I-81 Structure 2037 Southbound, Safe Lane**

## APPENDIX F

### CHLORIDE PROFILES FOR DECKS ON I-81

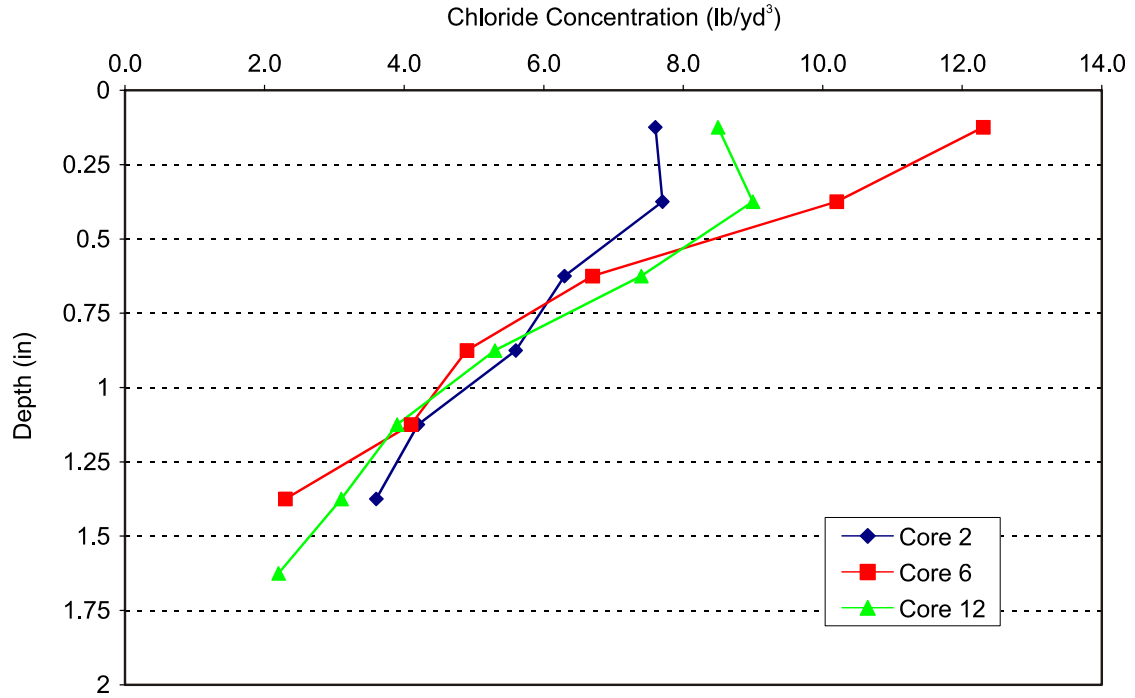


Figure F1. Chloride Profiles: I-81 NBL, Structure 2024, SafeLane with Blended Aggregate

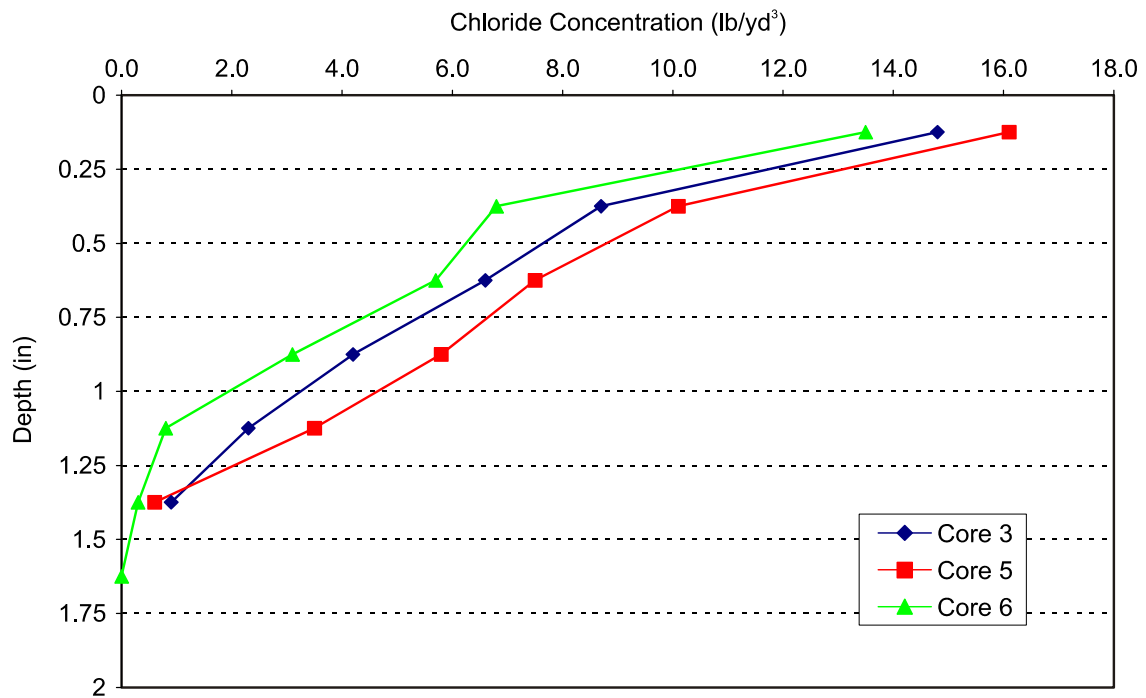


Figure F2. Chloride Profiles: I81 SBL, Structure 2025, One-Layer VDOT Modified EP-5



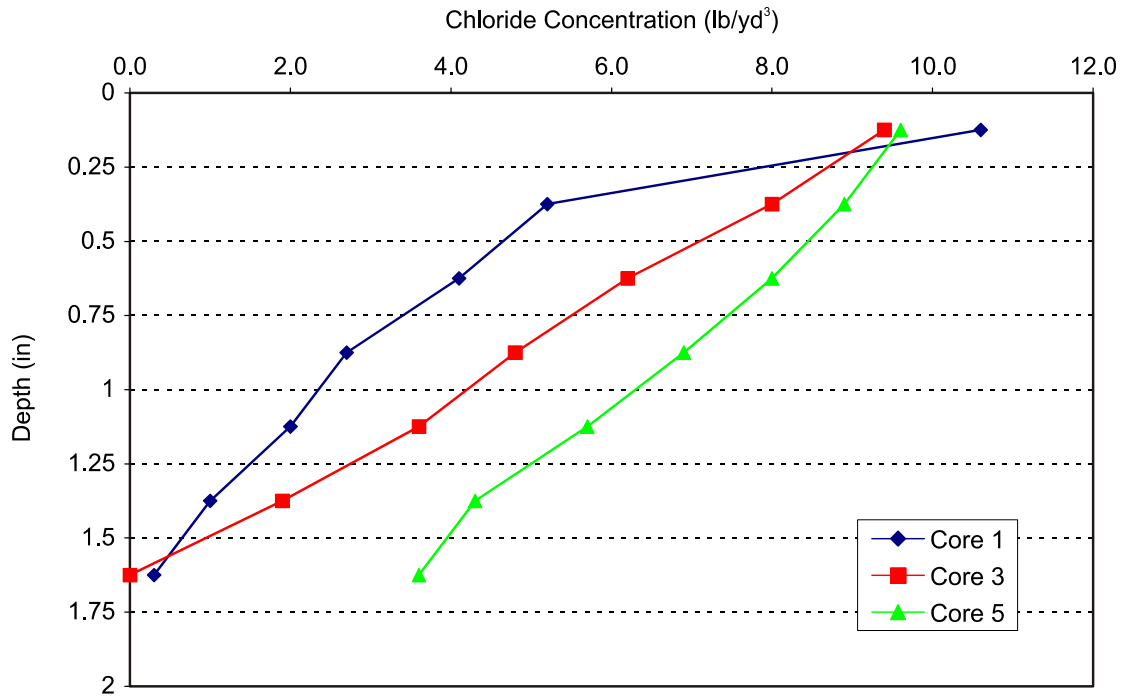


Figure F3. Chloride Profiles: I81 NBL, Structure 2036, One-Layer VDOT Modified EP-5

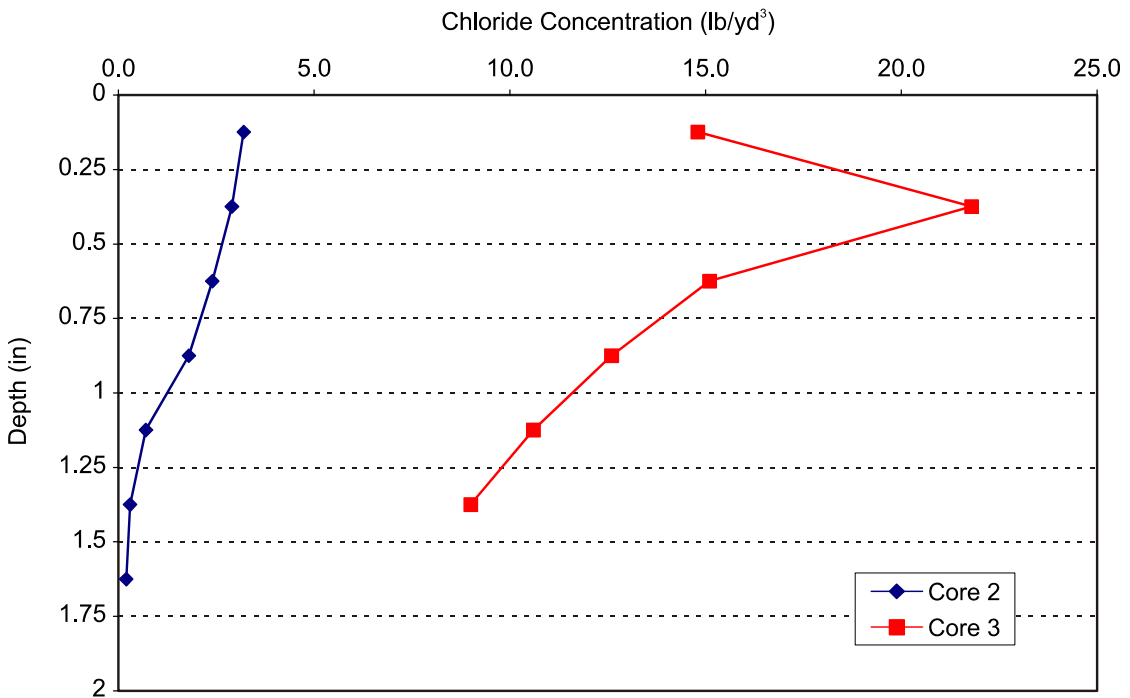


Figure F4. Chloride Profiles: I-81 SBL, Structure 2037, SafeLane