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PERFORMANCE OF THIN BONDED EPOXY OVERLAYS ON ASPHALT AND CONCRETE BRIDGE DECK SURFACES

Logan Michael Young
Stephan Durham
Rui Liu

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16. Abstract

This study is the evaluation of two thin bonded epoxy overlays: SafeLane (marketed by Cargill), and Flexogrid (developed by PolyCarb). SafeLane is advertised as an anti-skid/anti-icing overlay that stores deicing chemicals for release during winter events. Flexogrid is an anti-skid overlay. These two products were compared on the basis of physical properties, including mean texture depth, surface friction, bond strength, ability to stop chloride intrusion, and anti-icing properties, as well as traffic safety and cost. Both overlays worked as intended when they were initially applied on the bridge decks. Mean texture depth and friction testing have shown that they both provide a durable wearing surface with good traction. All the SafeLane bond tests exceeded 250 psi (1.72 MPa). Flexogrid had initial high bond strengths, but had varied failure modes. However, the delamination of the Flexogrid overlay was identified on the bridge deck even after this product was reapplied. Permeability and chloride testing of the underlying concrete decks indicated that both overlays work well to protect bridge decks from chloride ingress. Permeability was high, but the chloride counts did not increase with age. The anti-icing property of SafeLane is effective when pre-charged with deicing chemicals. The three sites evaluated in this study indicate a reduction in crashes, but further study is needed to monitor the long-term performance in crash reduction.

Implementation

CDOT should use the information contained within this report to develop construction specifications for thin bonded overlays. SafeLane can be considered for use on high crash rate bridges, where its high cost can be offset by an increase in traffic safety. If SafeLane is to be used as an anti-icing overlay, it should have deicing chemicals applied more often, and in smaller amounts. Pre-charging should be used when possible. Installation of Flexogrid should not be considered on bridges before the reasons causing the delamination are investigated. Studies of both overlays should continue so their long-term impacts on traffic safety can be analyzed.

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Performance of Thin Bonded Epoxy Overlays on Asphalt and Concrete Bridge Deck Surfaces

Submitted by

Logan Michael Young, M.S.

Stephan Durham, Ph.D. P.E., Associate Professor
University of Georgia

Rui Liu, Ph.D. P.E.
University of Colorado Denver

Submitted to
Colorado Department of Transportation
Applied Research and Innovation Branch
4201 E. Arkansas Ave., Shumate Building
Denver, CO 80222

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EXECUTIVE SUMMARY

The Colorado Department of Transportation (CDOT) has recently begun to experiment with thin bonded overlays in an effort to protect their bridge decks from deterioration by chemical attack and provide durable wearing surfaces with good skid resistance and anti-icing properties.

This study is the evaluation of two thin bonded epoxy overlays: SafeLane (marketed by Cargill), and Flexogrid (developed by PolyCarb). SafeLane is advertised as an anti-skid/anti-icing overlay that stores deicing chemicals for release during winter events. Flexogrid is an anti-skid overlay. These two products were compared on the basis of physical properties, including mean texture depth, surface friction, bond strength, ability to stop chloride intrusion, and anti-icing properties, as well as traffic safety and cost.

Both overlays worked as intended when they were initially applied on the bridge decks. Mean texture depth and friction testing have shown that they both provide a durable wearing surface with good traction. All the SafeLane bond tests exceeded 250 psi (1.72 MPa). Flexogrid had initial high bond strengths, but had varied failure modes. However, the delamination of the Flexogrid overlay was identified on the bridge deck even after this product was reapplied. Permeability and chloride testing of the underlying concrete decks indicated that both overlays work well to protect bridge decks from chloride ingress. Permeability was high, but the chloride counts did not increase with age. The anti-icing property of SafeLane is effective when pre-charged with deicing chemicals.

The three sites evaluated in this study indicate a reduction in crashes, but further study is needed to monitor the long-term performance in crash reduction.

IMPLEMENTATION

CDOT should use the information contained within this report to develop construction specifications for thin bonded overlays. Based on the findings of the study, SafeLane can be considered for use on high crash rate bridges, where its high cost can be offset by an increase in traffic safety. If SafeLane is to be used as an anti-icing overlay it should have deicing chemicals applied more often, and in smaller amounts. Pre-charging should be used when possible. Installation of Flexogrid should not be considered on bridges before the reasons causing the delamination are investigated. Studies of both overlays should continue so that their long-term impact on traffic safety can be analyzed.

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1. INTRODUCTION

Colorado is a state that receives a wide range of weather, from blizzard snowstorms to desert heat, and the roadways need to be able to handle everything from freezing ice subjected to deicing salts, to high heat. Initial research by CDOT into overlays has been sparse, with the majority being concentrated on different variations of whitetopping for pavement, the process by which existing flexible or rigid pavements are overlaid with 2 to 8 inches (5.08 to 20.32 cm) of concrete. With the advances in polymer materials in the last 40 years, many different options exist to protect bridge structures either through new construction or rehabilitation.

The focus of this study was to evaluate the performance of two epoxy-based thin bonded overlays on bridge decks. The overall goal was to further CDOT's expertise in the use of thin bonded overlays in order to increase safety and reduce maintenance costs. This was accomplished by two methods: conducting a survey of current literature on the subject, and physical testing of three overlay installations.

A survey with regards to the current state of the art of thin bonded overlays was completed and their use in Colorado was first examined. CDOT provides the majority of their research reports online and these were checked for relevant information. A second source of information on overlays was from the University of Colorado Denver. In order to gain a better understanding, a literature review was conducted in which the types, functions, materials, and costs of different epoxy-based thin bonded overlays in use by other state DOTs was examined.

This study seeks to determine real world performance of thin bonded overlays by evaluating SafeLane and Flexogrid on three Colorado bridge decks. An experimental plan developed to examine the performance of these overlays included five specific physical and chemical tests: (1) mean texture depth, (2) friction, (3) bond strength, (4) permeability, and (5) chloride. In addition, data was gathered through instrumentation, crash reports, and installation bids to examine the overlays' performance in regards to anti-icing capabilities, traffic safety, and cost.

This report is broken down into several chapters. Chapter 2 discuses background research with regards to thin bonded overlays in Colorado. Chapter 3 is a review of current literature, focusing on different types of thin bonded overlays as well as methods to test them. Chapter 4 is the problem statement. Chapter 5 is an overview of the three sites that were studied. Chapter 6 focuses on the installation of SafeLane and Flexogrid. Chapter 7 is the physical testing results. Chapter 8 is an analysis of the crash data. Chapter 9 is the breakdown of the installation costs. Chapter 10 contains the conclusions and recommendations.

2. BACKGROUND RESEARCH

Research on epoxy-based thin bonded overlays in the State of Colorado is fairly limited. CDOT-funded research into overlays has mainly been in the area of pavement whitetopping. Since 1998, two separate papers have been published on the topic of whitetopping in Colorado. The first report, CDOT-DTD-R-98-1, formed the basis for the design and usage of whitetopping by CDOT. The second report, CDOT-DTD-R-2004-12, investigated the instrumentation of, revised the design of, and increased the predicted performance of whitetopping from the 1998 report.

The University of Colorado Denver research into thin bonded overlays consisted of a single thesis by Bindel (2010) on the effects of surface treatment of pavements with respect to bond strength of overlays. The thesis title, "Effects of Concrete and Asphalt Surface Treatment on Bond Strength of Thin Bonded Overlays" investigated the adhesive properties of the binder used in the SafeLane system. In addition, Bindel's thesis included findings from a survey of Departments of Transportation (DOTs) which asked about usage of anti-icing/anti-skid thin bonded overlays.

2.1 Summary of Previous Work

2.1.1 University of Colorado Denver

Bindel's research on how surface preparation affects bond strength was the only research the University of Colorado Denver has performed on bonded overlays. Bindel performed in-depth background and literature research prior to designing and conducting bond tests. A DOT survey was sent to materials and bridge engineers, and yielded responses in relation to which states are using and testing thin bonded overlays. In addition, it provided insight into what their experiences have been with thin bonded overlays. Using information from the background research, literature review, and DOT survey, a test plan was created in which the bond between epoxy overlays and asphalt or concrete surfaces was tested.

2.1.1.1 Departments of Transportation Survey

The DOT survey was developed by Bindle (2010) to investigate which states have used anti-icing/anti-skid thin bonded overlays, and their levels of success with them. A web-based survey was created that asked a variety of questions which mainly focused on performance, installation experience, and products in use. A copy of the survey is provided in Appendix A.

The survey was targeted at materials engineers within each state DOT. Twenty-four out of the fifty state DOTs responded to the survey. Some states sent multiple responses from both bridge and materials engineers. A total of 30 responses were recorded. Figure 2.1.1.1.1 shows the states that responded.

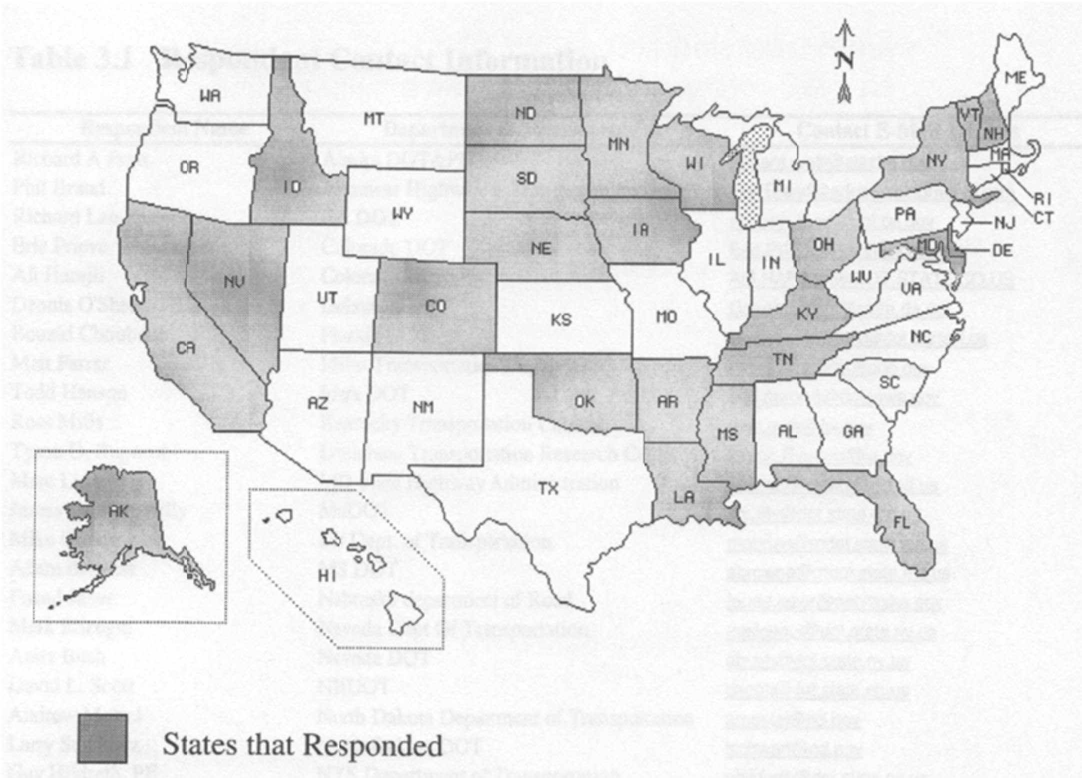


Figure 2.1.1.1.1: States That Responded to the DOT Survey (Bindel, 2010)

The first question was about who was responding, but the second question asked was whether or not the state DOT used an anti-icing thin bonded overlay such as SafeLane. Seven states said yes, including Vermont, Wisconsin, Idaho, New York, Mississippi, Minnesota, North Dakota, and Kentucky. Of particular note is Wisconsin, who reported that they had 30 applications of SafeLane since 1999.

The third question was if the state DOT has recorded a reduction in crashes with regards to their SafeLane installations. Only Minnesota and Wisconsin responded affirmatively that SafeLane reduced the crashes on their bridge decks. The other DOTs did not have this information available.

Question four examined typical skid numbers seen on thin bonded overlays by the DOTs. Around half the respondents reported it was greater than 35, which was classified as acceptable.

The fifth question was whether or not a reduction in the amount of deicing chemicals was seen in association with the use of anti-icing overlays. Only one state reported a 20% decrease in the amount used. The other states reported no change, or that they did not use the anti-icing properties of the overlay.

The next question was regarding failures of anti-icing overlays. Wisconsin reported that they had issues with mixing SafeLane prior to application and Minnesota reported that they had a decrease in friction, with a corresponding increase in the number of accidents after using SafeLane for several years.

Question seven asked whether any states created specifications for anti-icing overlays. Only two responded that they did. The others stated that they are still in trial phases.

The eighth question asked which other products were in use by state DOTs. They responded with Flexolith 216, Flexogrid, Degussa, and Transpo T-48.

The final question was if states had placed SafeLane on an asphalt surface. Only two reported that they had.

From the DOT survey it was found states that had used epoxy-based thin bonded overlays reported acceptable skid numbers, and a decrease in the amount of crashes. Some issues were reported with durability, but they seem to be localized to specific installations. Most states had not run into any significant issues, barring installation problems (Bindel, 2010).

2.1.1.2 Bond Testing

Bond testing was conducted on both on asphalt and concrete surfaces. Two asphalt samples were tested in which the surface was sand blasted or smooth. These samples were acquired from older roadways with cooperation of the City and County of Denver. The concrete samples were created specifically for testing and conformed to CDOT Class H specifications. Concrete sample surfaces were hand troweled, sand blasted, tined, or roughened. One set of tests that are of direct interest to this report was the testing of a full layer of SafeLane. Two samples from each concrete surface preparation category contained SafeLane, while the rest of the samples only had a layer of Unitex Pro-Poxy Type III DOT, which is the binder that the SafeLane system uses. Altogether, 21 samples were tested. The goal was to determine a correlation between surface preparation and bond strength.

Since all testing was conducted in the University of Colorado Material Laboratory, a unique test setup was devised to allow the samples to be precisely tested on the MTS 20-kip (89 kN) hydraulic testing machine. The samples were specially prepared to allow them to be tested in the machine. Since the concrete samples were created in-lab, they were cast with threaded dowels inside them so they could be bolted to the test setup. The asphalt samples were bolted with C-channel uni-struts.

Each sample was core drilled to a depth of 0.5 inches (1.27 cm) beneath the concrete surface by a 2 inch (5.08 cm) diameter core barrel in the center of the 12 x 12 x 6 inch

(30.48 x 30.48 x 15.24 cm) block. A 2 inch (5.08 cm) pipe cap was epoxied to the center of the drilled area. For the concrete samples, the blocks were placed into the test setup, bolted to the bottom plate, and then the top plate was bolted onto the block. A 2 inch (5.08 cm) diameter pipe was threaded onto the pipe cap. The top end of the 2 inch (5.08 cm) pipe was connected to the MTS machine by another pipe cap and threaded rod. The asphalt samples were bolted to the test stand by use of C-channel uni-strut.

The results from these bond tests were not encouraging and showed several problem areas related to the test setup. Bindel (2010) reported several problems related to both the sample preparation and test process. Of the 21 samples, 4 failed during preloading, a process in which a small amount of force (~10 lbs./44.5 N) is placed on the sample prior to running the full test. An additional sample had the pipe cap placed wrong and could not be attached to the testing machine. Out of the 16 remaining samples, 14 showed failures in the concrete or asphalt. Unfortunately, several of the results were below the generally accepted minimum of 250 (1.72 MPa) psi bond strength for polymer bonded overlays. Cargill uses the 250 psi (1.72 MPa) as its minimum bond strength for SafeLane. Although the majority of the bond strengths were below 250 psi (1.72 MPa), the failure mode of all the successful tests occurred in the asphalt or concrete layer, which shows that the Unitex epoxy was at least as strong as the surface it was adhered too. Bindel recommended additional testing with a larger sample size to get a true representative set of data (Bindel, 2010).

3. LITERATURE REVIEW

3.1 Why Thin Bonded Overlays?

In 2010, the Federal Highway Administration (FHWA) carried out an update of its extensive National Bridge Inventory (NBI) which monitors the location and structural condition of bridges across the United States. The FHWA has recorded over 604,493 bridges into the NBI and approximately 146,636 of those bridges are either structurally deficit or obsolete (FHWA, 2011). In Colorado alone, 1,399 of its 8,506 bridges fall under one of the categories above. Of particular concern are the 578 bridges in Colorado that are deemed structurally deficit (FHWA, 2011). While the FHWA terms structurally deficit as needing replacement, it does not necessarily mean that the bridge is unsafe, it may only be highly deteriorated.

One of the largest problems facing transportation departments around the United States is the deterioration of bridge decks and structural members (FHWA, 2011), especially in colder climates where the use of harsh deicing chemicals causes rapid erosion of steel reinforcement. Engineers have spent a considerable amount of time trying to determine effective and economical ways to combat the deterioration of bridges (FHWA, 2011). Bonded overlays allow engineers to place a wearing surface that not only provides anti-skid properties, but prevents chloride intrusion into the bridge structure by effectively sealing the bridge deck. With the mix of these properties, DOTs can be proactive in their maintenance of bridges, thus saving costs and increasing safety in the long term.

It is the combination of properties that make thin bonded epoxy overlays an attractive option for use on bridge decks. While other overlays may offer the same or better individual properties, very few offer the combination of properties that make thin bonded epoxy overlays exceptional. Namely, the combinations of curing time, cost, anti-skid properties, waterproofing, and deicing or anti-icing properties. Thin bonded epoxy overlays can combine each of these properties into a unique wearing surface that not only protects the bridge superstructure, but also increases safety.

An additional aspect, unique to some thin bonded epoxy overlays, is the reduced dead load on a structure by replacing an older, heavier overlay system with a thinner system. Thin bonded epoxy overlays also allow the roadway of a bridge to receive a new surface without raising the deck height appreciably, an important consideration when clearances on older overpasses are already close to specified limits. By far the majority of deck overlays are geared towards either an anti-skid or waterproofing role. However, newer overlays are starting to incorporate anti-icing roles into their functionality, all while providing a multi-year wearing surface.

Thin bonded overlays generally fall into one of three major categories; polymer based, concrete based, or asphalt based. There are many different types of overlays within each of these categories and several of them will be examined here. In general, polymer concrete overlays are classified as an overlay that uses a polymer as the binding agent. Concrete and asphalt overlays are defined similarly; each uses their respective materials as their binders.

3.2 Polymer Concrete Overlays

Polymer concrete overlays first appeared around the 1950s. These overlays were simply coal tar spread on a roadway with a fine aggregate broadcast across them. These coal tar epoxies, as they were commonly called, performed poorly and had a fairly short lifespan. Polymer concrete overlays received an upgrade in the 1960s with the development of polyester resins, epoxy resins, and methyl methacrylate (ACI, 1994). These new formulations allowed overlays to last longer and provided a much improved wearing surface. However they suffered from being too brittle, especially when exposed to the ultra-violet radiation of the sunlight. They also suffered de-bonding problems due to thermal incompatibility with the underlying concrete (ACI, 1994). This leads to cracking and eventual failure. Moisture tolerant polymers were introduced by the 1970s which allowed the overlays to seal the bridge decks, thus creating a longer-term wearing solution that also protected the bridge deck. Throughout the 1980s and 90s, much more flexible polymers came into use which increased durability, leading to an even longer lasting overlay. These are the same types of epoxies that are used in polymer concrete today, and are generally characterized by their lower modulus of elasticity and higher elongation tolerances (White et al., 1997).

Polymer overlays are uniquely different from the other two types since they add very little material to the surface of the bridge deck. This is advantageous, since it reduces the dead load on the bridge. This is ideal for older bridges, but even newer ones benefit from the economy of lighter sections. Polymer overlays have the added advantage of sealing the structural bridge deck from moisture and chemicals. Dinitz et al. (2010) compared polysulfide epoxy overlays to asphalt and concrete thin bonded overlays and noted that the air voids (up to 5%) in asphalt overlays contribute to freeze/thaw damage, while the epoxy overlays seal the deck surface, preventing this phenomenon. This helps to prolong bridge superstructure life as well as to provide a surface that can be removed and replaced if excessive wearing occurs. The biggest disadvantage to polymer overlays is that surface preparation is extremely critical. Even the slightest moisture or debris on the surface can cause de-bonding of the overlay (Dinitz et al.,2010).

The most common types of binding agents are epoxies, coal tar modified epoxy, polyester, methyl methacrylate, and polyurethanes. Several factors affect polymer overlays. Of utmost importance is surface preparation, followed by material selection. Some polymers can react to alkalis in the concrete and saponify, becoming little more than a soapy mixture (Scarpinato, 1996). Heating and cooling of the overlay can lead to differential shrinkage between the binder and structural surface underneath. The stresses induced by these temperature changes can lead to de-bonding of the overlay. Some of the first epoxies suffered from age hardening under ultraviolet light. However, newer epoxies based on specially modified polymers have a high strength and can resist UV age hardening making them ideal for bridge decks (Dinitz et al., 2010).

Polymer overlays can be divided into two categories depending on how they are applied. Stenko et al. (2001) describe the two methods as the broom and screed method, and the slurry or premixed method. For most bridges, polymer overlays are installed on site, however for new construction using pre-cast bridge deck panels, epoxy overlays can be installed at the pre-cast plant.

3.2.1 Premixed Polymer Concrete Overlays

Premixed Polymer Concrete Overlays (PMPCO) include any type of overlay that is installed using the slurry or premixed method (Maggenti, 2001). Typical installation procedure for a slurry or premixed type polymer overlay is very similar to traditional concrete methods. Most PMPCOs are mixed onsite in a special mixer, then placed on the deck surface by hand or using traditional slip form methods. Finishing is often performed by trowel, float and vibrating screed, with final texturing performed by tining. Some methyl methacrylate overlays use an aggregate broadcast as a final texturing step, while most polyester overlays use tining.

A typical premixed polymer concrete mix consists of a binder, silica and basalt sand as the fine aggregate, gravel as the coarse aggregate, and admixtures to improve various resin properties. An initiator is added during mixing to start the curing process (Ozolin, 2007).

The premixed method is considered faster and less labor intensive since it combines all the separate steps of the broom and screed into one step. Many different types of polymer binders use the premixed placement, however, only two types are the most commonly seen: polyester resin, and methyl methacrylate (MMA).

3.2.1.1 Polyester Polymer Concrete

Some of the first uses of polyester polymer concrete (PPC) was in the 1960s for use in pipes since the low permeability and high resistance to chemical attack make it ideal to transport liquids (Lang, 2005). Some of the first polyester concrete overlays were placed in California around 1983. Initially these were lightly traveled alpine roads, but by 1984-86 PPC overlays were installed on high traffic roads with good results (Glauz, 1993).

Polyester polymer concrete has many desirable properties for use as a pavement. It has very low permeability, excellent skid resistance depending on finish, and cures quickly with rapid strength development. PPC overlays are generally designed to be between 1/2" to 1" (1.27 to 2.54 cm) thick, depending on underlying surface conditions and can also have iron ore coke added to increase conductivity for cathodic protection or to act as a heating element for deicing. It can also be installed in a single pass, similar to traditional concrete. Expected life of PPC overlays ranges from 15 to 20 years and depends highly on the mixture, as well as surface preparation, both of which are extremely critical. (Sprinkel, 1990)

The cost for PPC varies greatly on who is placing it. Caltrans has extensive experience with PPC overlays and can place them at very low cost, between $1 and $3 per square foot ($10.76 to $32.29 per square meter), depending on project size (Caltrans, 2011). Oregon DOT recently started experimenting with PPC overlays and placed one for $4.44 per square foot ($47.79 per square meter) (ODOT, 2011).

3.2.1.2 Methyl Methacrylate Concrete

The other type of premixed polymer concrete uses a methyl methacrylate (MMA) binder instead of polyester. Early MMA overlays had excessively fast cure times that precluded spreading aggregate as a finish. This was fixed with better formulations of the MMA binders and initiators.

Methyl methacrylate overlays are very similar to polyester overlays, but are generally harder and have a compressively stronger surface that has excellent long-term friction characteristics. Due to the stronger characteristics, MMA overlays are sometimes broadcast with additional aggregate as a finish instead of tining. Although MMA overlays wear better, epoxy-based overlays tend to have superior bond characteristics, a feature that is very important for polymer overlays. To increase adhesive properties, MMA overlays are preceded by a MMA sealer which acts as a tack coat for the overlay (Wilson, 1995).

Oregon DOT has placed two different experimental MMA overlays in 1982 for $8.70 per square foot ($93.65 per square meter). However they estimated that larger overlays placed on a regular basis would cost around $6.40 per square foot($69.89 per square meter) (Quinn, 1984). WSDOT placed some larger overlays in 2007 for $7.20 per square foot ($77.50 per square meter) (WSDOT, 2007). Montana DOT has also experimented with MMA overlays and installed one in 1995 for $4.89 per square foot ($52.64 per square meter) (Johnson, 1997).

3.2.2 Broom and Screed Overlays

The broom and screed method first applies the binder, and then applies the aggregate by either manual or automatic broadcasting (Ozolin, 2007). Broom and screed typically has two layers of binder and aggregate, although three is specified by some manufacturers. The majority of epoxy-based overlays utilize the broom and screed method. This is because epoxy overlays tend to use an aggregate as the traction surface instead of a filler as polyester and MMA polymer concretes do. This allows the total overlay thickness to be thinner, usually around 3/8" to 3/4" (0.9525 cm to 1.905 cm) versus 1/2" to 1" (1.27 to 2.54 cm) for the other polymer overlay types. Epoxy overlays offer the same benefits as other polymer overlays, often in a thinner section.

3.2.2.1 SafeLane

SafeLane is an epoxy-based polymer concrete overlay that was specifically developed to fill the role of an anti-icing/anti-skid overlay (Cargill, 2007). It utilizes a patented combination of aggregate and binder to obtain these properties, while providing protection for bridge decks. The aggregate itself is a proprietary product that is specially prepared to absorb deicing chemicals.

Cargill Incorporated is the licensed patent holder for both the SafeLane system and the specialty aggregate. It is a private multinational corporation that mainly specializes in the agricultural and food related business. They also have branches in industrial, energy and pharmaceutical areas. SafeLane is an extension of their winter maintenance line of products which mainly includes de-icing salts.

The original inventor of SafeLane is Dr. Russ Alger. Dr. Alger was the director of the Institute of Snow Research at Michigan Technological University. The Institute of Snow Research is part of the Keweenaw Research Center. Development of SafeLane occurred over a period of 10 years until the right combination of aggregate and binder was found. SafeLane technology was licensed to Cargill Incorporated in 2003 (Perischetti, 2007).

SafeLane is a two-part anti-icing polymer surface overlay. It utilizes a specialty aggregate bonded to a pavement surface by an epoxy binder. Currently, there are two types of SafeLane products available (Cargill, 2007). The first, and more commonplace is Cargill SafeLane HDX Overlay, which is the main product used for roadways and bridges. The other product, Cargill SafeLane CA-48 Overlay is used for parking lots, garages, and sidewalks. Cargill is seeking approval for using SafeLane CA-48 on airport taxiways and parking aprons as well. They both use the same aggregate material; however SafeLane CA-48 uses a smaller aggregate size.

The epoxy binder used in SafeLane must be approved by Cargill. Cargill specifies an "epoxy resin base and hardener that is a modified Type III, two component system which meets requirements given by ASTM-C-881, Grade 1, Classes B & C." Table 3.2.2.1.1 shows the binder requirements from the technical specifications for SafeLane HDX (Cargill, 2010).

Table 3.2.2.1.1: Binder requirements for SafeLane HDX (Cargill, 2010)

Property	Requirement	Test Method
Pot Life	15 to 45 min at 75° F (24° C)	ASTM C881 (50 ml sample in paper cup)
Tensile Strength	2,000 to 5,000 psi at 7 days	ASTM D638
Tensile Elongation	40% to 80% at 7 days	ASTM D638
Viscosity	7 to 25 poises	ASTM D2393
Minimum Compressive Strength at 3 hours	1,000 psi at 75° F (24° C)	ASTM C579
Minimum Compressive Strength at 24 hours	5,000 psi at 75° F (24° C)	ASTM C579
Minimum Adhesive Strength at 24 hours	250 psi at 75° F (24° C)	ACI 503R

While the above general requirements are for any type of epoxy, the type most often used and recommended by Cargill is Unitex, Inc. SmartBond. Unitex describes SmartBond as, "a solvent-free, moisture insensitive, 100% solids, low modulus, two component bonding agent." The cure times for SmartBond are shown in Table 3.2.2.1.2 while the properties of SmartBond are shown in Table 3.2.2.1.3 from the Unitex SmartBond Technical Specifications.

Table 3.2.2.1.2: Cure times of Unitex SmartBond (Unitex, 2004)

Minimum Curing Times of SMARTBOND™

	Average Temperatures of Overlay Component & Substrate					
	60-64°F 16-18°C	65-69°F 19-21°C	70-74°F 22-23°C	75-79°F 24-26°C	80-84°F 27-29°C	85+°F 29+°C
Min. Cure Time	6-5 hrs	5 hrs	4 hrs	3hrs	3 hrs	3 hrs

Table 3.2.2.1.3: Unitex SmartBond resin properties (Unitex, 2004)

LABORATORY TESTS	RESULTS	ASTM C881 SPECIFICATIONS
Mix Ratio	1 : 1 by volume	None
D 695 Compressive Modulus	64,820	130,000 maximum
D 638 Tensile Strength	2,610 psi	None
D 638 Tensile Elongation	50%	30% minimum
C 882 Bond Strength (14 day cure)	3,470 psi	1,500 psi minimum
D 570 Water Absorption	0.19%	1.0% maximum
D 2471 Gel Time	15 Minutes	--
D 2393 Brookfield Visc. RV3 @ 20 rpms	1425 cps	2000 cps maximum
D 2240 Shore D Hardness	69	None
C 883 Effective Shrinkage	Pass	Pass
C 884 Thermal Compatibility	Pass	None
AASHTO T-277 Chloride Ion Permeability	0.9 coulombs	None

The SafeLane system uses a dolomite aggregate that has been specially prepared by a proprietary method. Dolomite is one of two minerals that can make up limestone; the other being calcite. By definition, dolomite is a limestone that contains more than 90% of the mineral dolomite. The mineral dolomite is composed of calcium, magnesium, and carbonate in the formulation of $CaMg(CO_3)_2$. While no specific data is given, Table 3.2.2.1.4 shows the Cargill specified aggregate gradations (Goodman, 1993).

Table 3.2.2.1.4: Gradation of SafeLane HDX aggregate (Cargill, 2010)

Gradation	% Passing
3/8" (9.5 mm)	98-100
#4 (4.75 mm)	50-80
#8 (2.36 mm)	0-15

SafeLane tends to be a more expensive overlay to install due to its current experimental nature. While many different SafeLane sites exist throughout the United States, the majority of these are DOTs testing the product. Several states reported fairly high installation costs, including North Dakota DOT which installed two experimental overlays in 2002 for between $10.96 and $12.72 per square foot ($117.97 to $136.92 per square meter) (Mastel, 2002). In addition, Virginia DOT installed two overlays for $6.00 per square foot ($64.58 per square meter) in 2005, however this was only material costs and does not include traffic control or other associated costs (Izzepi, 2010).

3.2.2.2 Flexogrid

Flexogrid is a polymer concrete overlay system for use on bridge decks. It uses an aggregate and two-part epoxy binder to create a thin bonded overlay and is developed and marketed as a lightweight, anti-skid, durable wearing surface (PolyCarb, 2009). Flexogrid was developed by PolyCarb, Inc. in the 1980s as a way to provide an anti-skid surface that can protect bridge decks from chemical intrusion.

PolyCarb, Inc., the distributor of the Mark-163 Flexogrid system, is a branch of Dow Formulated Systems, a business unit of Dow Chemical. Dow Chemical is a multinational corporation whose main focus is the development and manufacturing of chemical based products and systems. The specialty of PolyCarb, Inc. is the development and marketing of epoxy-based pavement and flooring systems.

Flexogrid consists of the Mark-371 aggregate and Mark-163 epoxy. The Mark-163 urethane epoxy is a two part amber colored epoxy that is supplied by PolyCarb for the Flexogrid system. It is 100% solids and is mixed in a 2:1 ratio of parts A and B. Urethane epoxy provides a strong yet flexible binder that can resist cracks from flexing as well as temperature changes in underlying materials. Table 3.2.2.2.1 below shows the properties of the cured Mark-163 epoxy.

Table 3.2.2.2.1: Cured properties of Mark-163 urethane epoxy (PolyCarb, 2009)

Adhesion of Concrete	100% Failure	ASTM D-4541/ACI-503R
Shore D Hardness	70 ± 5	ASTM D2240-75
Compressive Strength	48.3 – 62.1 MPa (7,000 - 9,000 psi)	ASTM C-109
Tensile Strength	>17.2 MPa (>2,500 psi)	ASTM D638-82
Tensile Elongation	30 ± 10	ASTM D638-82
Water Absorption - Max.	0.20%	ASTM D-570
Abrasion Resistance - Wear Index	75-85 milligrams	ASTM C-501
	CS-17 Wheel, 1,000 cycle, 1,000 gms	
Flexural creep at low temperature	0.165 mm, min.	California Test 419
	Total movement in 7 days (.0065 inches, min.)	
Flexural Yield Strength	> 5,000 psi	ASTM D-790

As with all epoxies, curing time varies with ambient and surface temperature. Flexogrid should not be installed below 50ºF (10 °C) to prevent installation and durability problems. Table 3.2.2.2.2 shows the approximate curing times, while Table 3.2.2.2.3 shows the maximum amount of time between epoxy application and broadcast of the aggregate.

Table 3.2.2.2.2: Approximate gel and cure times (PolyCarb, 2009)

Gel Time 25ºC (75º ± 2ºF)	22-31 minutes (100 gms.)
Gel Time 25ºC (75º ± 2ºF)	
(with aggregate)	1.5 hours
Initial Set 25ºC (75º ± 2ºF)	6 hours
Final Cure 25ºC (75º ± 2ºF)	48 hours-7 days

Table 3.2.2.2.3: Set times for Mark-163 epoxy (PolyCarb, 2009)

90ºF (32ºC)	10 minutes
80ºF (27ºC)	15 minutes
70ºF (21ºC)	20 minutes
60ºF (16ºC)	25 minutes
50ºF (10ºC)	35 minutes

The aggregate used with the Mark-163 epoxy can vary, but the recommended Mark-371 aggregate is basalt quartzite granite. Table 3.2.2.2.4 shows the following breakdown of Mark-371 by weight. Gradation of the aggregate is shown in Table 3.2.2.2.5.

Table 3.2.2.2.4: Breakdown of Mark-371 by weight (PolyCarb, 2009)

Component	Percent by weight
SiO_2	75.03
Al_2O_3	11.49
Fe_2O_3	3.57
CaO	2.84
MgO	1.59
Na_2O	2.58
K_2O	0.99
Combined alkali	1.11
Ignition loss	0.72

Table 3.2.2.2.5: Gradation of Mark-371 aggregate (PolyCarb, 2009)

US Standard Sieve Size	Percent passing by Weight
No. 6	100%
No. 10	10-35%
No. 20	0-3%

Due to the amount of time it has been around and the number of installations of Flexogrid, it is a relatively inexpensive epoxy overlay to install. Several DOTs around the United States have had experiences with Flexogrid. Alabama installed Flexogrid on an I-20 bridge in 1993 for $5.33 per square foot ($57.37 per square meter) (Ramey, 2003). Iowa DOT installed Flexogrid in 1986 for approximately $5.12 per square foot ($55.11 per square meter) (Adam, 2001). More recently, North Dakota installed Flexogrid in 2008 for an estimated $5.27 per square foot ($56.73 per square meter) (Mastel, 2009).

3.3 Hydraulic Concrete Overlays

The first documented use of any overlay dates back to 1918 when the city of Terra Haute, IN, used a layer of concrete on top of their existing asphalt road. This was relatively unheard of at the time, today it is commonly known as whitetopping. Through the 1950s and 1960s whitetopping was used rather sparingly and almost always in a rehabilitation or capacity upgrade role. It was relatively unheard of to use whitetopping as a preventative measure for bridge decks. It was not until the 1980s that overlays started to become common place. By the early 1990s whitetopping had become much more widespread and had evolved into ultra-thin whitetopping (UTW), a 2" to 4" (5.08 to 10.16 cm) overlay and thin-whitetopping (TWT) a 4" to 8" (10.16 to 20.32 cm) overlay (United States, 2011).

Thin bonded concrete overlays are typically defined as an overlay that is a 1" to 4" (2.54 to 10.16 cm) concrete wearing surface on top of a structural deck. Several different types of concrete are used in thin bonded overlays including: low-slump dense concrete (LSDC), silica fume concrete (SFC) also known as a micro silica modified concrete (MS or MSC), and latex-modified concrete (LMC). Shahrooz, et al. (2000) mentions a super-dense plasticized concrete (SDC) that is used in overlays (Ramey et al., 2003).

The goal of any of these concrete mixtures is to provide a concrete that resists chloride penetration while providing a durable wearing surface for traffic. By increasing density, you decrease the porosity of the concrete thus reducing the amount of moisture and chemicals able to penetrate the bridge deck. In addition to variations in concrete mixtures, some concrete overlays utilize an internally sealed layer that combines the wearing and strength of concrete with the water resistance of wax polymers. Although these concrete mixtures are effective at stopping chlorides leaching through, they still present problems with freeze/thaw. Conductive concrete overlays have been examined in which the concrete itself becomes a resistive heating element to prevent icing.

3.3.1 Low-Slump Dense Concrete

Low-slump dense concrete was first seen in the 1960s in Iowa and Kansas. Early LSDC overlays were approximately 1.25" (3.175 cm) thick, although now 2" (5.08 cm) overlays are the standard and can be used either as a new overlay, or as a rehabilitation overlay. While LSDC overlays use a relatively old technology, it has been highly effective for its cost. Some of the original overlays were in service for 20 to 25 years before needing replacement. Typical design life is around 25 years.

Typical LSDC overlays utilize a water to cement ratio of around 0.32. This creates a strong concrete with low permeability to resist chloride penetration. Surface roughness is gained by tining or texturing the concrete. De-icing is provided by chemical methods, although other methods could be utilized.

New York DOT conducted a study on 50 different LSDC overlays and found that 0.84% of the total deck area had any damage due to corrosion, delamination, spalling, or patching. Half of that area was around joints indicating that the overlays themselves were showing adequate performance. A survey of 153 LSDC overlays in 1991 by the Strategic Highway Research Program found that service life performance depends highly on the deck preparation. Sandblasting combined with removal of chloride saturated concrete was deemed the most effective method at prolonging service life (Russell, 2004).

Minnesota DOT performed an extensive review of LSDC overlays, particularly for bridge decks, and has found that they are able to place LSDC overlays for approximately $5 per square foot ($53.82 per square meter). For newer overlays going to bid, the engineers cost is typically around $4 per square foot ($43.06 per square meter). These costs are attributed to the fact that Mn/DOT places a fairly large volume of overlays, and that materials are fairly plentiful in the region. They also note that their bridge construction costs are cheaper than other states. The cost of $5 per square foot ($53.82 per square meter) is a good base for installing a LSDC overlay (Rowekamp, 2004).

3.3.2 Silica Fume Concrete

Silica fume concrete (SFC) was originally developed around the 1950s; however it was not until the development of high-range water reducing admixtures (HRWA) that placement of silica fume concrete became practical (Whiting et al., 1998). Ohio and New York were the first US states to experiment with silica fume concrete in overlays and full depth bridge decks. Ohio installed their first full depth bridge deck in 1987 while New York only placed an overlay on I-90.

Silica fume concretes have become a popular choice due to the increase in density, strength, and durability provided to concrete. Early placements of SFC overlays had problems with finishing and autogenous shrinking, or rapid drying of the concrete. The curing and finishing of silica fume concrete is especially important because of the lower water / cement ratio. In the plastic state before the concrete has fully hardened lack of water leads to desiccation and cracking, especially on the surface where moisture can evaporate quickly. The increased density of the concrete reduces pores found in normal concrete, making the evaporated water harder to replace. Cracking can also occur in cured concrete, since the increased density prevents water from being absorbed by the gel matrix. In normal concrete, this water helps to offset the effects of autogenous shrinkage, but in silica fume concrete this effect becomes greater due to less water. Overlays placed today rarely have this problem due to the understanding of how density affects the hydration of concrete.

Typically, silica fume replaces cement at rates between 5% and 12% in the concrete mixture. Whiting et al. (1998) found that between 6% and 8% is the optimal replacement range for bridge decks. Past this range, a plateau effect was seen on permeability. Greater strengths from increased silica fume content are not necessarily useful for a bridge deck overlay, nor economical. They also recommended immediate wet curing for at least 7 days; however, this is generally standard industry practice today.

Silica fume overlays tend to be slightly more expensive than normal concrete overlays due to the additional admixture costs. In 1994, Virginia DOT placed two silica fume concrete overlays; one regular, and one high early strength for $2.68, and $3.30 per square foot,($28.85 and $35.52 per square meter) respectively (Sprinkel, 2000). Montana DOT installed a trial silica fume overlay in 1996 for only $2.44 per square foot ($26.26 per square meter) (Johnson, 1997).

3.3.3 Latex Modified Concrete

While traditional concrete methods have been around for almost a century it was not until 1956 that Dow Chemical Company started experimenting with latex-modified concrete. Michigan Highway Department in cooperation with Dow Chemical placed the first latex-modified concrete overlay in 1958. Since about the 1960s, the majority of latex concretes utilize one of three types of latex; styrene-butadiene rubber, polyacrylic ester, or polyvinylidene chloride-vinyl chloride (Ramakrishnan, 1992). The typical polymer compound used is styrene butadiene latex, a mixture that separates in water to leave behind latex solids in the concrete matrix after curing.

Latex-modified concrete (LMC) is a concrete mixture that utilizes a latex polymer in the mixture. Ramakrishnan (1992) defines latex as, "a stable dispersion of organic polymer particles in an aqueous surfactant solution...” All latexes used in concretes are classified as nonionic since they carry no extra positive or negative electron charges in their molecular configuration. This is necessary, since negative or positively charged latex would adversely affect concrete and embedded reinforcing steel. During the production of latex, surfactants are added to the latex mixture to modify the surface tension and stability of the latex. These surfactants also provide key benefits to concrete including acting as water reducing admixtures which allows higher strengths to be achieved without significant losses in workability (Ramakrishnan, 1992).

Latex-modified concretes have higher than normal tensile, flexure, and bond strengths as well as increased freeze/thaw durability with a low permeability (Kuhlman, 1985). Research performed by Ramakrishnan (1992) shows that adding a latex polymer to concrete increase the flexure strength by as much as 150 to 200%. This is due to the latex film that forms in the concrete mixture during curing. The latex bonds the two sides of the micro cracks together thus helping to prevent crack propagation and applying a portion of its own tensile strength to the concrete. These same principals help increase the impact resistance, toughness, and abrasive resistance of the concrete all of which are valuable properties for a bridge deck overlay.

The latex in the voids helps to seal the concrete to moisture. Testing of LMC bridge deck overlays throughout the US have shown that LMC overlays all exhibit very low (less than 1000 coulombs) chloride permeability, even after multiple years. Freeze-thaw resistance also increases, as does resistance to scaling. The Indiana State Highway Commission tested LMC overlays for resistance to scaling and found that even after 50 freeze/thaw cycles, no scaling had occurred (Ramakrishnan, 1992).

In terms of workability, LMCs behave like normal concretes that have had water reducing admixtures added. Due to this effect, the compressive strength of LMCs is usually higher due to a reduced water cement ratio.

Typical LMC overlays are 1.25" to 2" (3.175 cm to 5.08 cm) thick and can be found on every type of project from new construction to major rehabilitations. The higher adhesive properties of LMC make it an ideal material to be used for rehabilitation projects. Anecdotal evidence from several state DOTs show that LMC overlays last upwards of 20 years or more. Several of these overlays were placed with high and very-high early strength concretes and allowed traffic on the overlay within 24 hours instead of the standard 4-7 days. Testing after one year showed these overlays were still providing excellent wear resistance.

LMC overlays are a relatively cheap overlay to install due to the fact that it is mainly concrete with a latex admixture. VDOT has extensive experience with LMC overlays, and placed two in 1994. One was a standard styrene-butadiene LMC that was placed for $3.00 per square foot ($32.29 per square meter), while another was a LMC modified for high early strength that was placed for $3.70 per square foot ($39.83 per square meter) (Sprinkel, 2000). In addition, North Carolina DOT has placed many LMC overlays. Several placed in 2010 cost $4.20 per square foot ($45.21 per square meter) (NCDOT, 2010).

3.3.4 Internally Sealed Concrete Overlay

Internally sealed concrete overlays are a fairly simple concept in which wax beads placed in the concrete during mixing are later melted using an external heat source. The theory is that the melted wax will flow into the pores of the concrete, sealing it. The concept of adding wax beads to concrete is credited to the Monsanto Research Corporation under a contract with the FHWA. Original development took place in the 1970s, and several states through the FHWA Demonstration Project 49 participated in field testing this new type of overlay (Toney, 1987). The majority of state DOTs that participated in the FHWA study used their normal bridge deck overlay concrete with the wax replacing a portion of the fine aggregate in a 1:1 ratio. The wax itself is a 25%/75% blend of montan and paraffin waxes. Montan wax has a melting point of 180 °F (82 °C), while paraffin is closer to 147 °F (64 °C). It was reported by several DOTs that the wax modified concrete does have lower compressive strength, but still above the 4000 psi (27.6 MPa) required by some states. Air entrainment is recommended for additional freeze/thaw resistance. Thorough mixing of the concrete is required to ensure even dispersal of the wax beads. Typical thickness of the concrete overlays is approximately 2" (5.1 cm) (Tyson, 1978).

The most important aspect of internally sealed concrete overlays is the curing and heating. Sufficient heat has to be put into the concrete to allow the bottom layer to reach the approximately 185 °F (85 °C) to melt the wax all the way through the overlay. However, heat cannot be applied too quickly, otherwise excessive spalling and cracking in the concrete due to rapid evaporation of moisture and shrinkage will occur. Washington State DOT evaluated four different methods of curing including hot air, electric fired infrared, electric infrared, and electric blanket. The first three methods caused spalling and cracking. Electric blankets provided enough control and power to properly heat the concrete, and are the recommended heating method. Heating is usually conducted over 7 to 10 hours depending on weather and overlay thickness. This process is repeated for several days to ensure that all the wax has melted and filled the pores (Tyson, 1978).

Results from several DOT studies all show similar trends. The first is that internally sealed concrete overlays are effective at stopping chloride penetration of concrete. Second is that cracking of the concrete overlay during the heating procedure is commonplace. Varied methods can be used to reduce and prevent this cracking, but it is unlikely to completely eliminate the cracks that develop.

Internally sealed concrete overlays can cost a bit more than regular concrete overlays to install. Oklahoma DOT mentioned that they were paying an extra $1.03 per square foot ($11.09 per square meter) for internally sealed concrete overlays versus normal concrete overlays. Idaho DOT reported that it cost them twice as much to place versus normal overlays (Toney, 1987).

Internally sealed concrete overlays are effective at stopping chloride penetration and protecting bridge structures, but their higher cost and their installation-critical performance make them a less popular option than other overlay types. No recent internally sealed concrete overlays have been placed, and it is likely this trend will continue until further research or newer heating methods are developed (Tyson, 1978).

3.3.5 Conductive Concrete Overlays

Deicing a roadway surface by using heat is not a new idea, but it does have a new twist in the form of conductive concrete. Two general methods are known for deicing a bridge deck using heat. The first is to embed resistive heating elements into the concrete and generate heat by running current though the elements. The second is to turn the concrete into the resistive element. Yehia et al. (2000) defined conductive concrete as, "...a cementitious admixture containing electrically conductive components to attain a high and stable electrical conductivity." They also mention that conductive concrete has also been used as anti-static flooring, electromagnetic shielding, and cathodic protection of steel. The power provided to the concrete can be either AC or DC with results being similar.

Conductive concrete is fairly simple in its composition. Generally, a standard concrete mix is used, and then steel fibers and shavings are added to provide the conductivity. Yehia et al. (1998) have also found that conductive concrete can be made with conductive aggregate such as black carbon or furnace coke; however less strength is developed due to a higher amount of water needed for the aggregates.

Yehia et al. (2000) developed a concrete mix that used 20% steel shavings and 1.5% steel fibers by volume, which met ASTM and AASHTO specifications. They cast a 3.5" (8.89 cm) slab using this mix and tested the de-icing, and anti-icing properties. It was found that the conductive concrete overlay performs both rolls adequately. Their results show that the cost to run the conductive overlay per hour was approximately \$0.056 to \$0.074 per square foot (\$0.60 to \$0.80 per square meter). On larger bridges, this could be prohibitively expensive.

3.4 Asphalt Concrete

Asphalt concrete, or bituminous pavement, is a bridge deck overlay and roadway material that is in widespread use. Asphalt is typically made of a petroleum binder and aggregate, although different materials have been added to improve certain qualities. Although asphalt pavement is not a thin bonded overlay, they are often installed on top of waterproofing membranes, which are very effective at sealing bridge decks. These membranes will be examined here.

Asphalt has been in use as a pavement and sealer since ancient times, when natural deposits were found and used for paving with bricks, or to seal water basins. It was not until the 1860s that it started to see use in the United States, originally as sidewalks, then as roadways. Most of these early asphalts were from natural sources, although just after the turn of the century refined petroleum binders became more common. Around the 1940s-50s is when the more modern types of asphalt started to become widespread, primarily with investment from the war effort as well as the state highway system (National Asphalt Pavement Association, 2011).

While asphalt is a very economical overlay due to economies of scale, it lacks the moisture sealing capabilities and resistance to certain chemicals that other overlays have. Several methods have been developed to deal with these deficiencies. The simplest method is to add a water resistant membrane between the asphalt overlay and the bridge deck.

The concept of protecting a bridge deck by applying a new overlay is relatively old; it was not until 1972 when the FHWA introduced polices requiring the protection of bridge superstructures from deicing chemicals. As a result of these polices many state DOTs looked for the fastest solutions to protect their bridge decks. Many had few to choose from, and the waterproofing membrane became commonplace. Today, the use of these membranes with concrete overlays is somewhat declining, mostly due to newer technologies. However, waterproofing membranes are still used extensively on bridges that have any sort of asphalt wearing surfaces.

While the membrane is referred to as a single layer, there are in fact multiple layers that make up a membrane system. At the base is the concrete bridge deck. A thin primer layer generally consists of a synthetic rubber, but can also be a resin type primer. The purpose of the primer layer is to provide greater adhesion of the membrane system to the concrete bridge deck. After the primer layer, some systems use an adhesive layer and/or ventilation layer. The adhesive layer provides additional bonding if necessary, while the ventilation layer provides a method for chemical vapors to disperse, preventing blistering. The actual waterproofing membrane layer is next, followed by a protection layer to help prevent damage to the membrane during construction. The final layer consists of a tack coat, which helps to bond the overlay or asphalt to the membrane and bridge deck. The overlay itself may be composed of a single or double layer of material, depending on the type used. Figure 3.4.1 shows a graphical breakdown of the possible layers in waterproofing membrane.

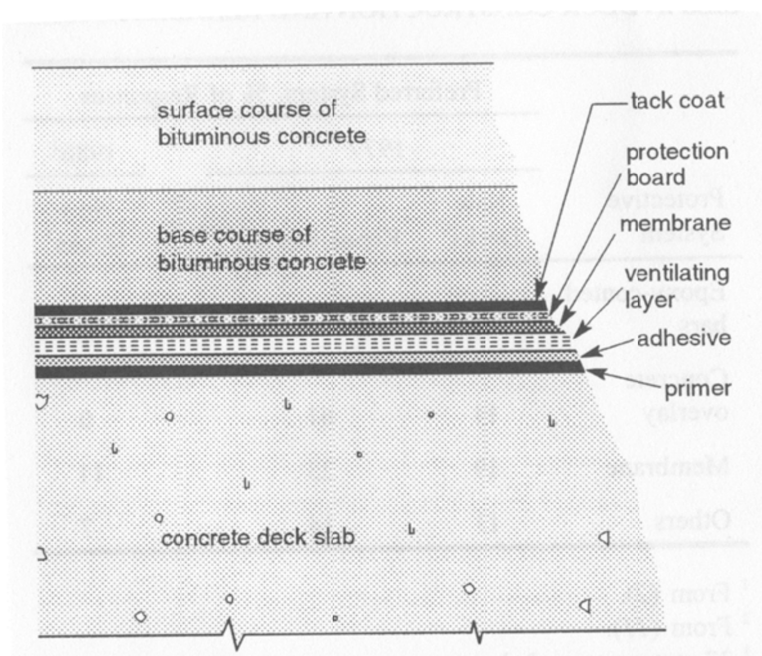


Figure 3.4.1: Membrane Layers (Manning, 1995)

The membranes themselves can be divided into two categories. Either they are a preformed system that is applied as a solid roll or sheet, or they are a liquid system that is applied by squeegee or in a similar manner. Further division of these depends on the material of the overlay. Figures 3.4.2 and 3.4.3 show the breakdown of these two divisions.

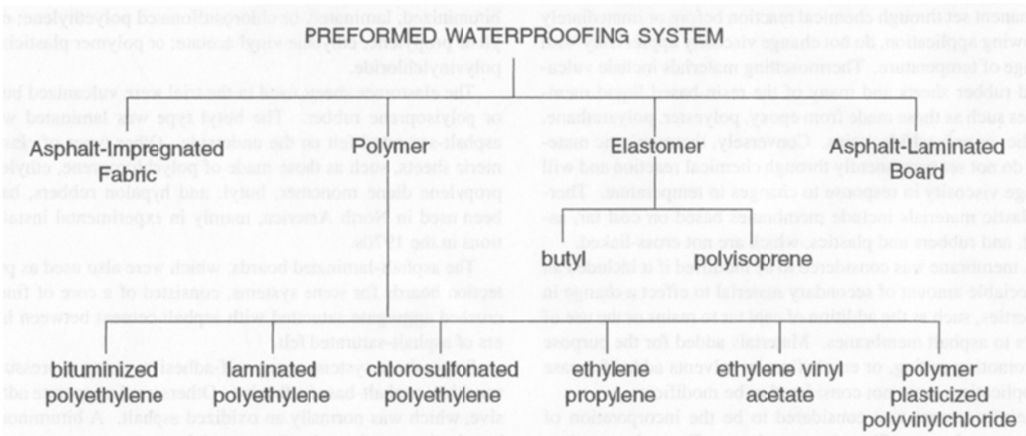


Figure 3.4.2: Division of Preformed Waterproofing Systems (Manning, 1995)

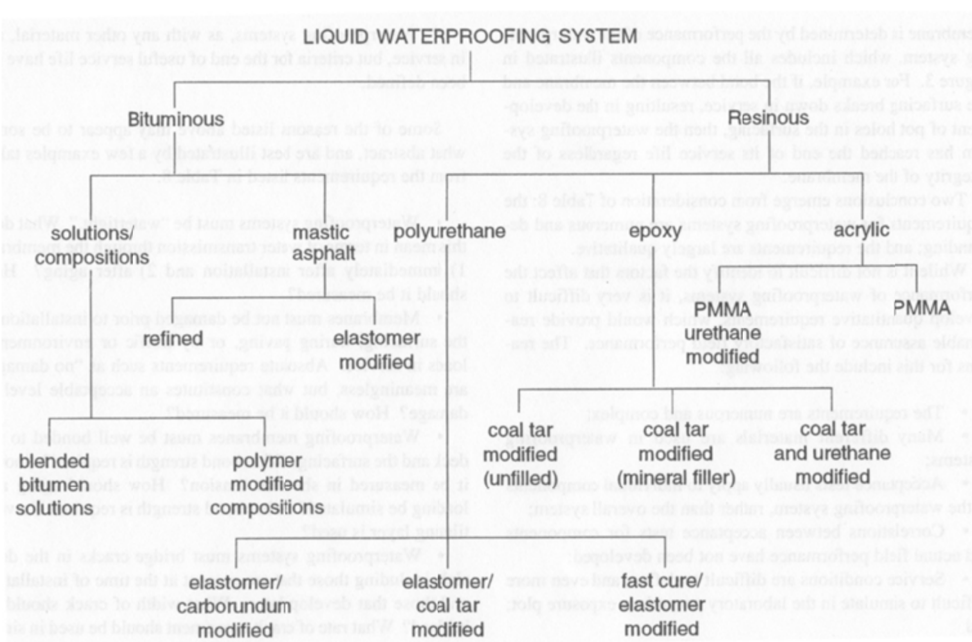


Figure 3.4.3: Division of Liquid Waterproofing Systems (Manning, 1995)

Due to its widespread use, asphalt concrete is cheap to place. Typical DOT costs are listed between $1.00 and $3.00 per square foot ($10.76 and $32.29 per square meter) depending on binder properties and desired thickness. In some ways the costs can be even lower since the equipment and personnel with experience are common enough that special training is not required. Waterproofing membranes cost an additional $1.00 to $2.00 per square foot ($10.76 to $21.53 per square meter) (CDOT, 2011).

3.5 Testing of Overlays

The primary way to determine the performance of any roadway surface is through testing. Over time, numerous test methods to determine different roadway properties have been developed. The majority of the physical properties tested are: texture depth, surface friction, bond strength, permeability, and chloride content. Each one of these properties has several different tests that can be conducted, each with different accuracies and precisions. The most common methods and the theory behind them are examined and discussed.

3.5.1 Texture Depth

The primary influence on pavement-tire surface interaction is pavement texture. The surface texture affects among other things; friction, noise, rolling resistance, and tire wear. The texture itself is the result of aggregate texture and gradation, pavement finish, and surface wearing. Surface texture is defined by two different characteristics, the amplitude, and wavelength (ACPA, 2007). The amplitude is the vertical measurement from the highest texture point, to the lowest. The wavelength is how often amplitude is repeated. Each has an effect on tire-pavement interaction. The size of the amplitude and wavelength can be used to divide pavement texture in four different categories: microtexture, macrotexture, megatexture, and roughness. Figure 3.5.1.1 shows the different texture classifications and how they influence different properties.

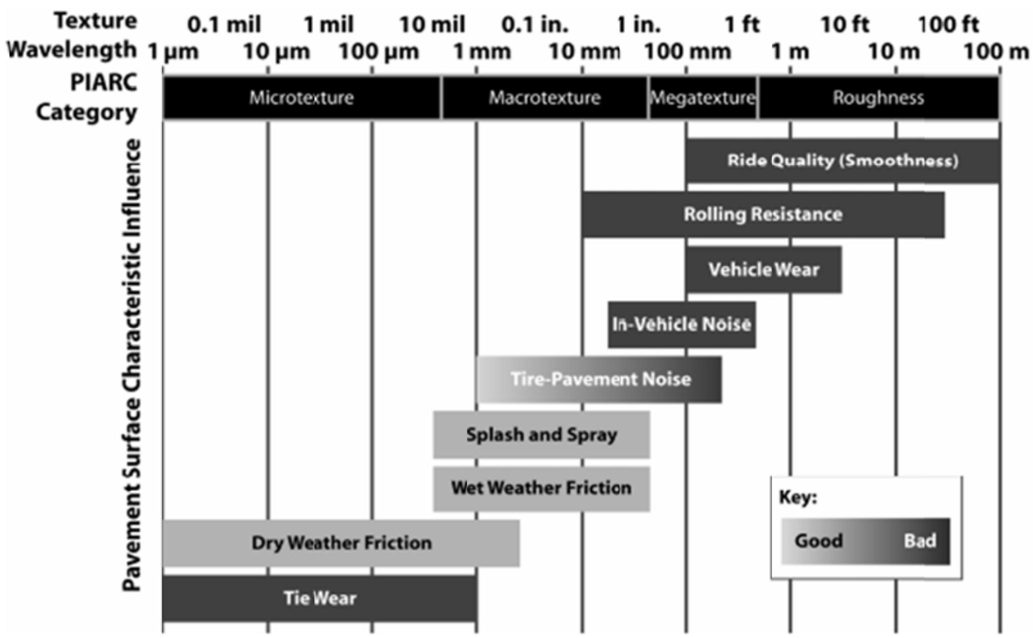


Figure 3.5.1.1: Surface Texture and Surface Characteristics (ACPA, 2007)

Microtexture is defined as having a wavelength less than 0.02" (0.508 mm), and amplitude less than 0.008" (0.2 mm). It is primarily responsible for stopping ability on dry pavement. It has some stopping ability on wet pavement, but only when vehicle speeds are less than 50 mph (80 kph). There is some difficulty in directly measuring microtexture due to its small size.

Macrotexture is 0.02" to 2" long (0.508 mm to 5.08 cm),with an amplitude of 0.004" to 0.8" (0.102 mm to 2.03 cm). It is the primary determinant of stopping power in the presence of water or ice on the roadway. This is because the larger peaks of the texture in this range sit above the water or ice level, and still provide traction.

Megatexture is between 2" and 20" (5.08 cm to 50.8 cm), with an amplitude between 0.004" and 2" (0.102 mm to 5.08 cm). Megatexture has no real effect on traction, but does affect vehicle wear. Texture variations in this range are typically the results of certain construction methods and practices. Unevenness is simply anything larger than megatexture and affects vehicles in the same way.

There are two broad methods for measuring surface texture. The first is used to find the mean texture depth (MTD) and is roughly used to measure macrotexture. The second is to find the mean profile depth (MPD), and is used to measure macrotexture through unevenness.

The mean texture depth is measured using a volumetric method commonly referred to as the sand patch test, which is described in detail in ASTM E965. It uses a known volume of sand spread on the roadway surface to determine the mean depth. The known volume of sand is spread in a circle on the roadway until the peaks in the texture are level with the sand. The diameter of the circle is measured multiple times, and an average is used to calculate the mean texture depth based on the known volume of sand.

The methods to find the mean profile depth differ depending on the type of equipment being used. To measure longitudinal road profiles, the oldest systems used physical displacements of multiple wheels to generate a profile graph of the roadway surface. The newest systems use lasers to directly measure the surface profile. (ACPA 2007)

Measuring texture depth is important for two reasons. The first is that for larger wavelengths, the surface ride can be determined, as well as problem spots in underlying roadbeds. The second is that comparing the mean texture depth over time helps to determine the durability of the road surface. Many thin bonded overlays use an aggregate wearing course that wears down over time. An overlay that sees a constant decrease in its mean texture depth will most often need replacing sooner than an overlay that is maintaining its mean texture depth. The mean texture depth depends highly on the type of overlay; the change in mean texture depth is what is important, not the magnitude.

3.5.2 Surface Friction

Surface friction (or skid resistance) is the force that develops at the pavement-tire interface to resist movements of the tire due to acceleration, deceleration (braking), and lateral forces (sliding). The higher the surface friction, the more resistance to slipping and sliding a vehicle has, and the safer a pavement surface is. By measuring surface friction over time, the performance of a roadway can be tracked. It is expected that a pavement surface friction will decrease over time, primarily due to wearing. Pavements that have a surface friction that decreases too quickly become unsafe and uneconomical, since they require replacement faster.

Several different factors determine the surface friction of a pavement. The two key ones are texture, and moisture. During dry weather, the microtexture provides the primary surface resistance. However, when the roadway becomes wet or icy, the microtexture is typically flooded and the macrotexture becomes the primary resistance surface (ACPA, 2007).

Moisture on roadways is typically found in the form of liquid water or ice. Water acts as a lubricant at the pavement-tire interaction, thus decreasing the resistance to movement of the tire. Ice acts in much the same way; it freezes to the texture of the surface thus completely negating the pavement-tire interface and functionally reducing the resistance to movement to zero (Caltrans, 2008).

It makes sense that any new overlay installation has its surface friction monitored. Typically, baseline values are obtained from the original surface prior to overlay placement. These values are then compared to the overlay values just after installation and at different intervals later on. It is desired that the overlay will maintain a higher surface friction than traditional pavement over the course of its service life, and several different methods are available to measure this.

3.5.2.1 Locked-Wheel Friction Test

The traditional method of measuring surface friction is using the locked-wheel trailer with either a ribbed or smooth tire. This method was first standardized as ASTM E274 in 1965. The locked-wheel test system simulates an emergency braking scenario by using a trailer with a locked wheel towed behind a truck. Figure 3.5.2.1 shows the trailer and test truck.

Figure 3.5.2.1.1: Locked-Wheel Friction Test System (ICC, 2006)

The force imparted on the locked wheel at a constant speed, usually 40 mph (65 kph), is measured and corresponding friction number is computed. The friction number is determined based upon the speed and weight of the trailer. It is calculated as 100 times the force to pull the trailer at the specified speed, divided by the weight of the wheel load. Most systems use water sprays to simulate emergency braking in wet weather. Both ribbed and smooth tires are used because they respond to the pavement differently. Figure 3.5.2.1.2 (a) shows a ribbed test tire, while (b) shows the smooth test tire.

(a) **(b)**

Figure 3.5.2.1.2: Locked-Wheel Test Tires (a) Ribbed, and (b) Smooth

The ribbed tire is fairly insensitive to water on the roadway and thus is a good indication of microtexture performance. The ribbed tires that are used have much larger flow channels for water than normal roadway tires, and often correspond poorly to real world vehicle performance during wet or icy conditions. Smooth tires make up for this deficiency by being more sensitive to macrotexture. The microtexture becomes slippery with moisture, forcing the smooth tire to grip the macrotexture. Because of this, smooth tire friction numbers are typically less than that of ribbed tires on the same roadway surface. The measured friction numbers should ideally be above 35 (Caltrans, 2008). Less than 35 usually mean the roadway becomes dangerous under wet conditions.

Two newer variations of the locked-wheel friction test exist. The fixed and variable slip systems attempt to simulate the use of anti-lock brakes. For the fixed slip system, this is performed by allowing the test wheel to experience limited slip, or slight movement on the order of 10-20%. The variable slip system automatically changes the slip percentage through a pre-defined set of levels during the test process. Neither system is in widespread use, most likely due to cost.

A variation of the locked-wheel test system is the side force tester. Side force testers are used to determine the ability of a vehicle to maintain control in curve and conform to ASTM E670. The test wheel is free to rotate, but is fixed in a plane, at a yaw angle to the direction of motion. The side force that is imparted on the tire perpendicular to its rotation is measured. These systems take continuous measurements instead of spot measurements at certain time intervals (Caltrans, 2008).

3.5.2.2 British Pendulum Tester

The British Pendulum Tester (BPT) is another method of measuring the friction of a roadway surface. It was originally developed to measure pavement friction in a laboratory setting, but has been finding use in the field due to its compact size and ability to measure smaller roadway lengths. Because the pendulum arm moves slowly, about 6 mph, the BPT is a good indicator of pavement microtexture, and thus dry weather performance (Caltrans, 2008). Figure 3.5.2.2 shows a pendulum tester.

Figure 3.5.2.2: British Pendulum Tester

The BPT operates on the conservation of energy principle. The swing arm is released and strikes the pavement surface at a designated point. The pavement surface absorbs some of the kinetic energy of the swing arm, slowing it down. As the contact pad on the swing arm breaks contact with the surface, it goes into a recovery stroke and pushes an indicator arm up a scale. The more speed at which the arm recovers from the pavement contact, the higher the indicator arm is pushed up the scale. The scale correlates the friction of the surface with the British Pendulum Number (BPN). The BPN has no applicability to other skid numbers generated by other test systems (Caltrans, 2008).

3.5.2.3 Dynamic Friction Tester

The Dynamic Friction Tester (DFT) is an additional method of measuring the surface friction of a roadway. It uses a spinning disk with 3 spring-loaded rubber feet that is lowered onto the roadway surface (Caltrans, 2008). Water is sprayed on the surface to reduce the friction. Figure 3.5.2.3 shows a typical DFT.

Figure 3.5.2.3: Dynamic Friction Tester (Caltrans, 2008)

As the disk is slowed by the surface friction, the torque is measured and a corresponding friction number is determined. The disk is usually spun up to 55 mph and decreases to about 3 mph. DFTs have the advantage of being able to report peak friction as well as being calibrated to report the friction number relative to the International Friction Index. However, the DFT cannot account for directional textures in pavements due to its rotational nature (Caltrans, 2008).

3.5.2.4 Surface Friction Values of Thin Bonded Overlays

Friction values for different road surfaces depend on the type of test used. Since the majority of DOTs in the United States use the locked-wheel test, the numbers presented here will be from that test. Normally, for any road surface, a friction number (FN) greater than 35 is deemed acceptable (Caltrans, 2008). Less than 35 usually mean the roadway needs replacement due to poor texture and skid resistance. Several states have evaluated

SafeLane and have published their data. Since SafeLane has really only been around since 2001, there is a limited number of available studies, but several are examined here.

Sprinkel (2003) has published results containing data from the previous 25 years of polymer overlays. Among the result is friction numbers for the majority of different polymer overlays. Figure 3.5.2.4.1 shows friction numbers corresponding to overlay types over time.

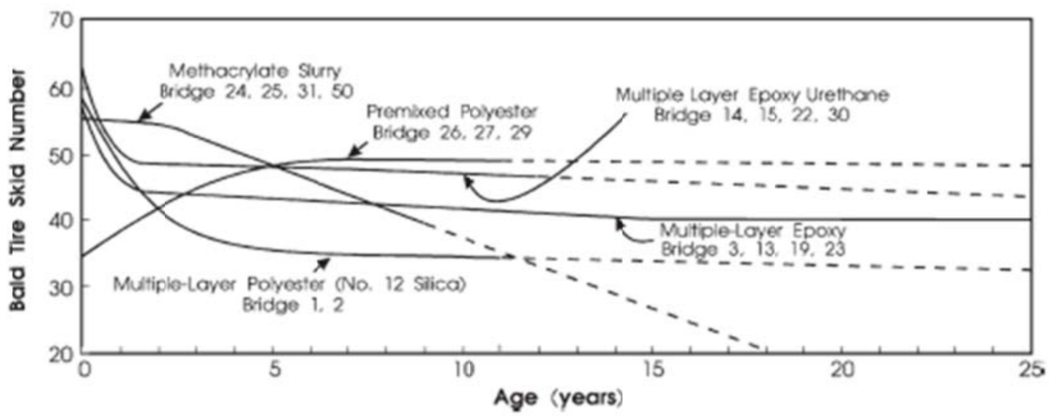


Figure 3.5.2.4.1: Friction Numbers of Polymer Overlays (Sprinkel, 2003)

The data shows that the majority of polymer overlays maintain their skid numbers over their service life. MMA overlays are shown to have reduced skid numbers over their lifespan, contrary to what has been found in literature.

VDOT installed several different hydraulic cement based overlay 1994. They tested these overlays with both with smooth and ribbed tires. The results from this study are shown in Table 3.5.2.4.1

Table 3.5.2.4.1: Skid results from VDOT trial overlays (Sprinkel, 2000)

Bridge No.	Overlay Type	1994 Bald Tire	1994 Treaded Tire	1999 Bald Tire	1999 Treaded Tire
1	SF	46	45	45	41
2	MMLMC	45	45	45	41
3	LMCHE	42	42	48	45
4	SFHE	51	51	51	51
5	ML	38	41	46	43
6	LMC	33	31	49	46

All the overlays tested showed fairly standard numbers for hydraulic concrete based overlays. Each overlay also shows that it was able to keep it skid numbers over 5 years. Interestingly enough, the LMC overlay actually improved its skid resistance. However, this could be due to wearing of the surface, which provides better traction, but ultimately less durability and chloride protection.

WSDOT has experimented with several epoxy and MMA type polymer overlays throughout the 80s and have a large amount of data including bond, friction, and permeability test results. The epoxy overlays used were PolyCarb Flexogrid on Chehalis and Snake roads, and Dural Flexolith on Thrall Rd. The MMA overlay was Degussa Degadur 330. The friction results are shown below in Figures 3.5.2.4.2 and 3.5.2.4.3.

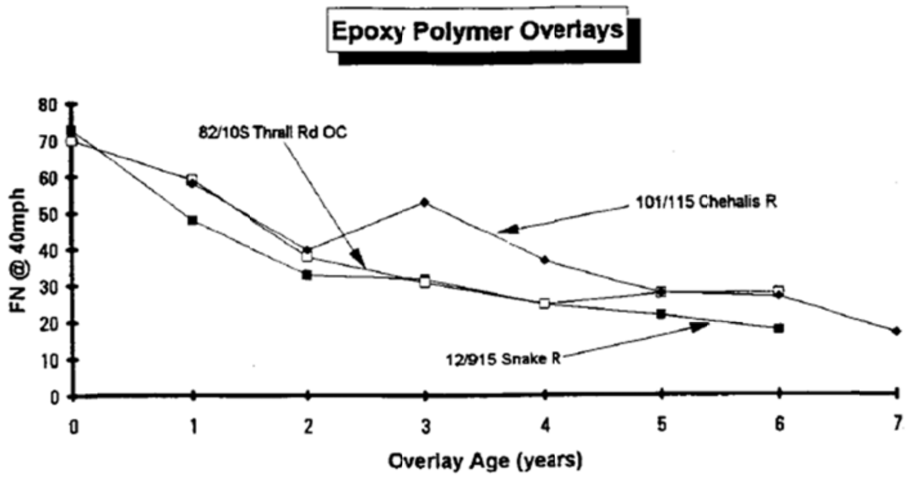


Figure 3.5.2.4.2: Skid Results from WSDOT Epoxy Overlays (Wilson, 1995)

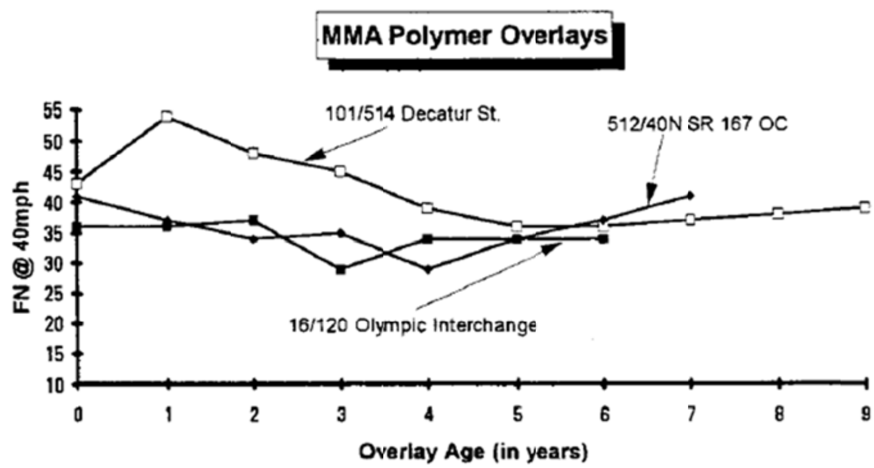


Figure 3.5.2.4.3: Skid Results from WSDOT MMA Overlays (Wilson, 1995)

The WSDOT results show that MMA overlays maintain, and in case of this study increase their surface friction over time. This is contrary to the Sprinkel (2003) results, but more in line with what traditional literature says. The epoxy overlays faired equal to the MMA overlays in the beginning, but quickly lost surface friction over time. It should be noted that these overlays were installed in the 80s and WSDOT revised their aggregate gradation specifications in 1991 to provide increased lifespan of their polymer overlays (Wilson, 1995).

VDOT has two different studies involving SafeLane. The first is a study of high friction surfaces that compares several different products. Unfortunately, their test methods in that report do not correspond well to the methods traditionally used, and which are presented here. A second report, solely on SafeLane was published in 2009. For the that study, VDOT used a standard SafeLane mix, a 75% SafeLane / 25% silica aggregate mix, and two VDOT modified EP-5 overlays. Table 3.5.2.4.2 shows the results of the skid resistance tests.

Table 3.5.2.4.2: VDOT skid numbers for SafeLane (Sprinkel, 2009)

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[b]
2024	2-layer SafeLane[a]	10/05	27	60	53[b]
2025	1-layer VDOT modified EP-5	8/05	26	57	-
2036	1-layer VDOT modified EP-5	8/04	22	49	-

[a] Aggregate blends: 75% SafeLane/25% quartz by weight for Spans 1 and 2 and 50% SafeLane/50% quartz for Spans 3 and 4.
[b] After liquid chloride pretreatment.

While the period between tests is fairly short, the VDOT study shows that SafeLane provides excellent skid numbers after installation. Even during wet conditions, the skid numbers remain very good.

Minnesota DOT installed SafeLane on four different sites in 2006 and 2007. Their data has shown mixed results. The skid resistance results from their study are shown in Figure 3.5.2.4.4.

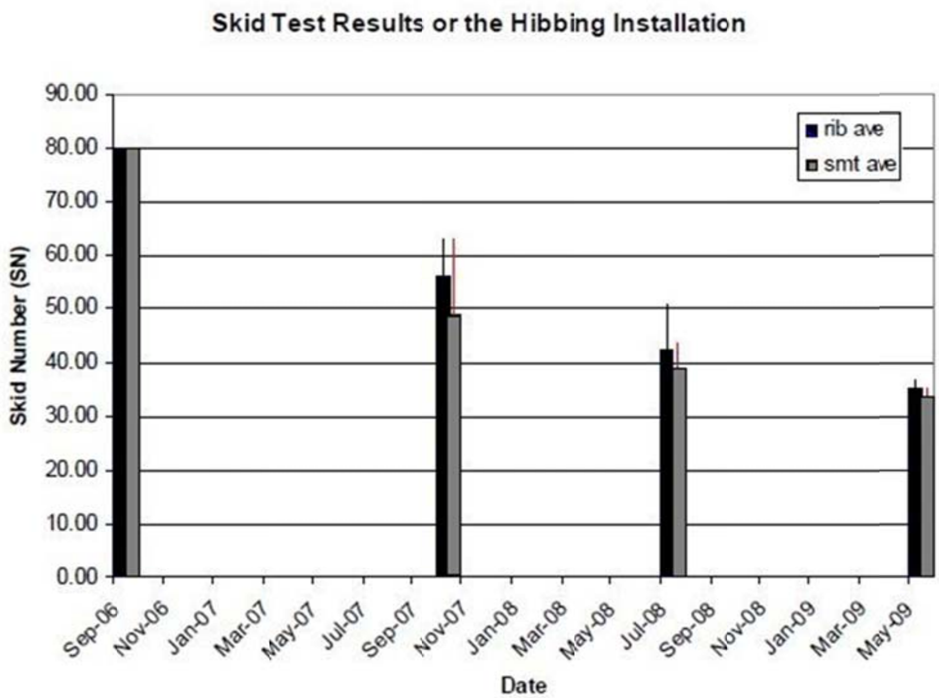


Figure 3.5.2.4.4: Mn/DOT Skid Numbers for SafeLane (Evans, 2010)

Mn/DOT reports a fairly steep decrease in skid numbers over the course of three years. While initial numbers were very good, they dropped to barely being acceptable. In the report, Evans (2010) notes that SafeLane, while not suffering de-bonding failures, tended to have the aggregate shear off. Figure 3.5.4.2.5 documents this effect.

Figure 3.5.2.4.5: Wearing of SafeLane After 26 Months (Evans, 2010)

One of the largest culprits of this effect was down force from snowplow blades. It should be noted that Cargill recommends not applying additional down force on plow blades for this exact reason. It is possible that better traction numbers may have been reported if less aggressive plowing was used (Evans, 2010).

3.5.3 Bond Strength

Bond testing is conducted to determine the bond strength of the aggregate to the polymer overlay, as well as the strength of the overlay to the bridge deck. The typical test used follows ASTM C1583 or ACI 503R. Almost all test systems used in bond testing have some sort of steel disk adhered to a scored circle on the roadway surface, and to which a hydraulic or threaded pull device is attached. Force is applied to the disk until the substrate, substrate/overlay interface, or overlay fail in tension according to ASTM C1583. Thin bonded overlays rely on the underlying bridge deck for structural support, and if that bond fails, the overlay will spall off. As such, bond testing of thin bonded overlays is highly critical. Figure 3.5.3.1 shows a standard test setup based upon ASTM C1583. Figure 3.5.3.2 shows the different failure modes from ASTM C1583.

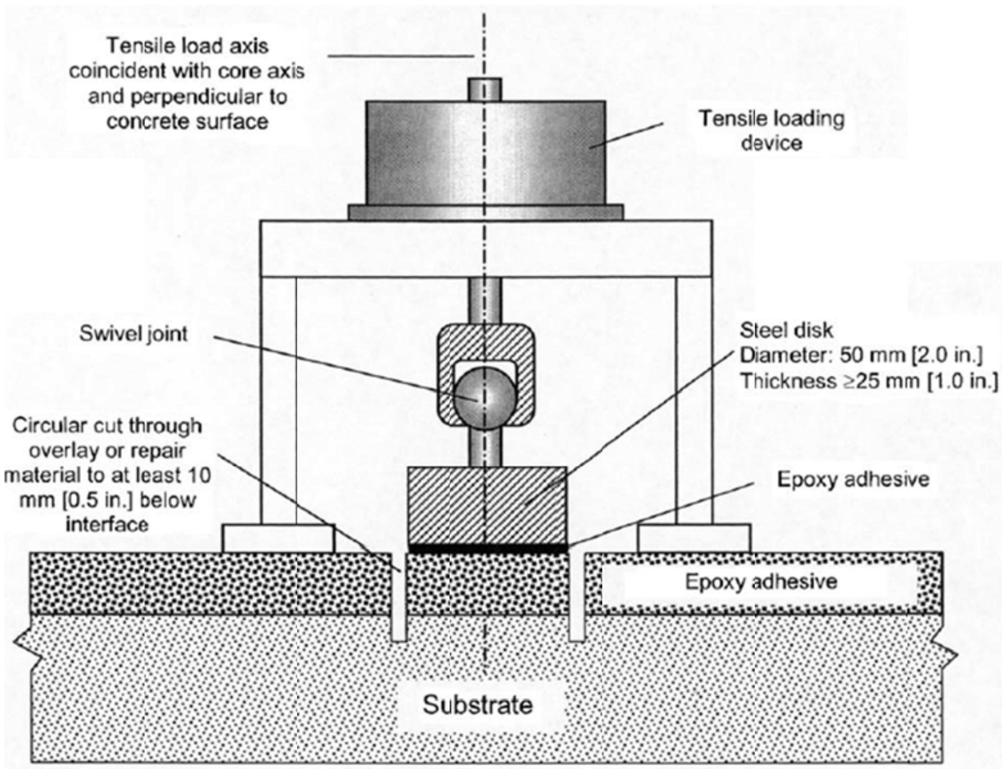


Figure 3.5.3.1: Typical Bond Test Setup According to ASTM C1583

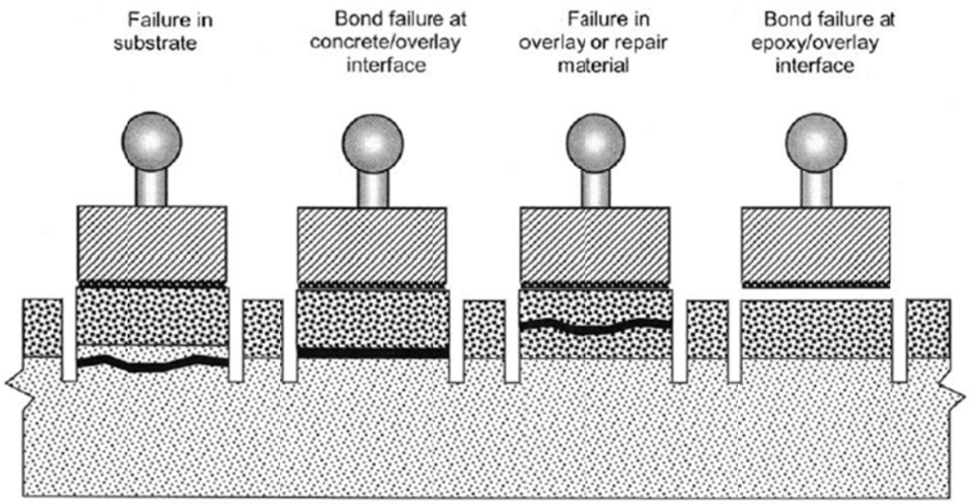
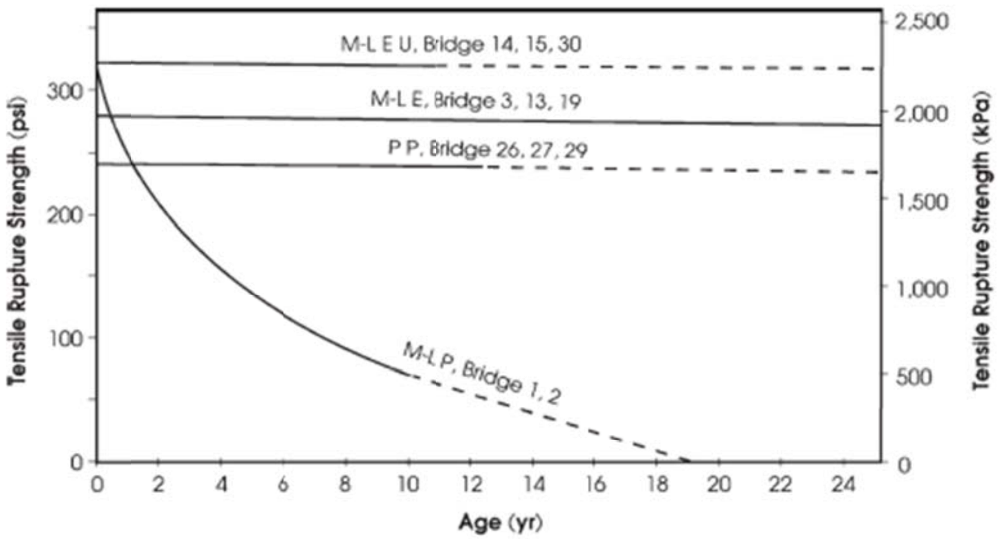


Figure 3.5.3.2: Bond Test Failure Modes According to ASTM C1583

AASHTO Task Force 34 found that 250 psi (1.72 MPa) should be the minimum acceptable bond strength for a polymer overlay. This value reflects a properly mixed and applied polymer concrete that will develop good adhesion. An examination of different polymer concrete systems shows that their manufacturers either specify 250 psi (1.72 MPa) or that the bond failure should occur in the substrate. SafeLane requires at least 250 psi (1.72 MPa), based upon ACI 503R at 24 hours. The T-48 epoxy overlay system by Transpo, Inc. requires the same. Based upon this examination, 250 psi (1.72 MPa) seems like a reasonable number to expect for a polymer based overlay (WSDOT, 1995).

3.5.3.1 Bond Strength of Thin Bonded Overlays

Sprinkel's (2003) report on different polymer overlays over the last 25 years included a tensile rupture test of thin bonded overlays. The bond tests were conducted using the Virginia Test Method 92, which is equivalent to ACI 503R. Figure 3.5.3.1.1 shows the results from the report.



M-L E U	Multiple Layer Epoxy Urethane
M-L E	Multiple Layer Epoxy
P P	Premixed Polyester
M-L P	Multiple Layer Polyester

Figure 3.5.3.1.1: Bond Strength of Different Polymer Overlays (Sprinkel, 2003)

Sprinkel's (2003) results show that bond strength for the majority of polymer overlay types slightly decreases with age. The two epoxy overlays show excellent bond strength, well above the recommended 250 psi (1.72 MPa). In addition, it is noteworthy that the multilayer epoxy urethanes, similar to what Flexogrid uses, has higher bond strength than straight epoxies, which SafeLane utilizes.

VDOT's 1994 testing on SF and LMC overlays also included bond testing. The original data was given in SI units, and for the sake of convenience; these numbers were converted before being presented below in Table 3.5.3.1.1.

Table 3.5.3.1.1: Bond strength of hydraulic concrete overlays (Sprinkel, 2000)

Property	Thickness				Bond Strength			
Date	1994		1999		1994		1999	
Overlay Type	inch	cm	inch	cm	psi	MPa	psi	MPa
SF	1.34	3.4	1.22	3.1	145	1.0	145	1.0
MMLMC	1.46	3.7	1.34	3.4	102	0.7	145	1.0
ML	1.3	3.3	1.26	3.2	58	0.4	189	1.3
LMCHE	1.65	4.2	1.57	4.0	87	0.6	189	1.3
SFHE	1.57	4.0	1.54	3.9	116	0.8	160	1.1
ML	1.3	3.3	1.18	3.0	131	0.9	131	0.9
LMC	1.5	3.8	1.38	3.5	116	0.8	203	1.4

Hydraulic cement based overlays seem to have lower adhesive bond strengths than polymer based overlays. None of the overlays tested by VDOT exceed the 250 psi (1.72 MPa) recommendation for polymer overlays. Sprinkel (2000) noted that all the failures were below the bond interface of the overlays. It was hypothesized that the low failure strengths of the underlying concrete decks was due to damage from the milling machine, and that the results may not be representative of the actual bond strength of the overlays.

The bond tests from the WSDOT report are shown in Table 3.5.3.1.2 for epoxy overlays and Table 3.5.3.1.3 for MMA overlays. They show several interesting results.

Table 3.5.3.1.2: Bond tests for WSDOT epoxy overlays (WSDOT, 1995)

Bridge Number	Brand Name	Year Applied	Initial Ave. Bond (psi) {no. of tests}	Latest Ave. Bond (psi) {no. of tests}	Overlay Age @ Latest Bond test
161/10	EPI/Flex III	1986	294 {10}	not tested	
82/115S	Concresive 3070	1987	392 {8}	276 {3}	3 years
5/316	EPI/Flex III	1990	363 {15}	266 {5}	4 years
82/10S	Flexolith	1985	359 {12}	355 {5}	3 years
900/12W	Flexolith	1986	201 {15}	327 {6}	5 years
101/115	Flexogrid	1984	399 {6}	191 {5}	4 years
12/915	Flexogrid	1986	259 {21}	252 {6}	3 years
167/102	Flexogrid	1987	267 {5}	377 {3}	1 year
167/104	Flexogrid	1987	215 {5}	257 {3}	1 year
167/106	Flexogrid	1987	342 {5}	287 {3}	1 year
104/5.2	Flexogrid	1988	308 {27}	244 {6}	4 years
529/20E	Flexogrid	1988	267 {5}	187 {6}	3 years
529/20W	Flexogrid	1988	207 {5}	not tested	
		Average	297	274	

Table 3.5.3.1.3: Bond tests for WSDOT MMA overlays (WSDOT, 1995)

Bridge Number	Brand Name	Year Applied	Initial Ave. Bond (psi)	Latest Ave. Bond (psi)	Overlay Age @ Latest Bond test
5/523E	Conkryl	1988	162	not tested	
82/114S	Concresive 2020	1987	284	258	3 years
27/3	Silikal R66	1990	229	not tested	
101/514	Degadur 330	1985	155	128	3 years
4/106A	Degadur 330	1986	113	85	5 years
167/21E	Degadur 330	1987	290	111	1 year
512/40N	Degadur 330	1987	259	135	1 year
16/120	Degadur 330	1988	189	not tested	
97/2	Degadur 330	1989	217	not tested	
		Average	211	143	

The WSDOT study shows several things. The first is that initial bond strengths are usually the highest, and that the bond strength of epoxy overlays decreases with time. Flexogrid in this study performed fairly well; 2 of the 8 averages failed to meet the 250 psi (1.72 MPa) requirement. It should be noted that Flexogrid does not have a 250 psi (1.72 MPa) bond requirement in their specifications, it is only specified that bond failures should occur in the concrete. However, the report fails to mention the location of bond failures. Also of interest is that epoxy overlays seem to have better long-term bond characteristics than MMA overlays. The MMA overlays had very low bond strengths in general, less than the recommended 250 psi (1.72 MPa).

The bond strength of SafeLane is expected to be comparative to other thin bonded overlay systems. Several different DOT reports conducted on SafeLane also included bond tests, and these results are examined here.

VDOT's 2009 study conducted bond testing on two different SafeLane overlays. Although they used their own VDOT Test Method 92, it is comparable to ACI 503R. Table 3.5.3.1.4 shows the results from the VDOT report.

Table 3.5.3.1.4: VDOT bond test results for SafeLane (Sprinkel, 2009)

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[a]	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

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

VDOT's results show that both SafeLane overlays failed at less than the recommended 250 psi (1.72 MPa). However, the results show that, with the exception of the mixed aggregate deck, all failures were within the concrete. The bond strength was a limitation of the tensile strength of the concrete, and not the overlay.

3.5.4 Permeability

Permeability is the ability of a material to allow a fluid or gas to move through it. It is an important aspect of bridge structural decks and wearing surfaces since it determines how well protected embedded reinforcing steel and underlying structural steel are protected from chloride attack. It is desirable for bridge deck materials to be as close to impermeable as possible to offer the best protection for structural steel.

Measuring the direct permeability of concrete is difficult since it is determined by the size, amount, and arrangement of the three-dimensional pore structure within the concrete. Because of this, several different methods have been developed to measure the permeability of concrete over time.

3.5.4.1 Ninety-Day Ponding Test

The first method developed was AASHTO T 259 (ASTM C1543), commonly known as the 90-day ponding test. As its name implies, the permeability of the concrete is measured indirectly through the amount of chloride that has penetrated the sample. A sample slab is obtained and moist cured for a period of either 14 days, with 28 days of drying (AASHTO T 259) or 14 days of each (ASTM C1543). The slab is then prepared by attaching dikes on the top, and waterproofing the sides. The top dikes are filled with a 3% saline solution which is maintained at a test level for 90 days. At the end of 90 days, the sample is cored and the chloride content is determined at different depths using ASTM C1152, or a similar method. Based upon the amount of chlorides measured, and the amount of time that they accumulated, the permeability can be determined.

The main advantage to this method is that it simulates the same mechanisms in which chlorides penetrate bridge decks. The disadvantage is that test takes 90 days at minimum, not including moist curing and drying times. For very low permeable concretes, the 90 days is often not enough time to allow sufficient ingress of chloride ions.

3.5.4.2 Rapid Chloride Permeability Test

The rapid chloride permeability test (RCPT) is an electrical method used to determine the approximate permeability of concrete based upon the flow of electrons through a sample saturated with sodium chloride on one side and sodium hydroxide on the other. The standard governing this test is the AASHTO T 277 or the similar ASTM C1202. Figure 3.5.4.2 shows the layout of the RCPT.

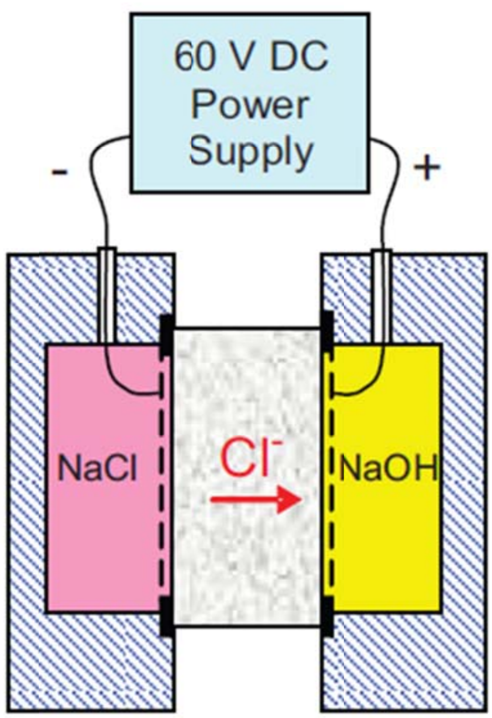


Figure 3.5.4.2.1: RCPT Basic Setup (Germann Instruments, 2010)

The RCPT does not directly measure the depth or penetration of the concrete sample by chloride ions. Instead, it applies a known voltage to the specimen and determines the current, based upon the resistance of the concrete. The chlorides are driven into the concrete by the voltage potential, which comes in contact with the NaOH solution and create an electric circuit. The number of coulombs is a function of the current and the time the test is run. The specifications call for 6 hours of voltage applied to the specimen; however similar results have been reported for running the test for 3 hours and doubling the recorded value. Table 3.5.4.2.1 below shows typical permeability levels with each type of concrete, as well as which coulomb range belongs to each classification.

Table 3.5.4.2.1: Permeability classification (Grace, 2006)

Charge Passed (Coulombs)	Chloride Permeability	Typical of
>4,000	High	High W/C ratio (>0.60) conventional PCC
2,000–4,000	Moderate	Moderate W/C ratio (0.40–0.50) conventional PCC
1,000–2,000	Low	Low W/C ratio (<0.40) conventional PCC
100–1,000	Very Low	Latex-modified concrete or internally-sealed concrete
<100	Negligible	Polymer-impregnated concrete, Polymer concrete

The advantage of the RCPT is the speed at which the test can be run. Including sample preparation time, the test can be run in 24 hours. Some test instruments allow up to 8 samples to be tested at once.

The biggest disadvantage of the RCPT is the significant variation of results. The same samples run twice will produce quite different results. According to ASTM C1202, the coefficient of variation for a single operator is 12.2%, which translates to up to a 42% difference between the same concrete samples, prepared the same way, from the same batch. Between different laboratories, the C.O.V. jumps to 18%, which leads to a difference of 51% between similar samples.

Many DOTs are starting to specify the RCPT coulomb value for a given concrete mix at certain days of age. This can lead to problems with mixes that specify certain admixtures. Depending on the type of admixture, the permeability of the concrete can be lower or higher than expected at a given age. Mixes that incorporate fly ash and/or blast furnace slag in particular, tend to take longer than 28 days to reach their final permeability level. While mixes that incorporate any type ionic salt including; calcium nitrite, calcium nitrate, calcium chloride, or sodium thiocyanate, tend to facilitate the transfer of chlorides and thus show higher coulomb counts than would otherwise be reported. Because of this, ASTM C1202 specifies that permeability should be based upon the qualitative terms in Table 3.5.4.2.1. (Grace, 2006)

3.5.4.3 Permeability of Thin Bonded Overlays

Many different reports exist on thin bonded overlays used by different states. Similar to other sections, VDOT and WSDOT have published extensive reports on their use of thin bonded overlays, and the results of their trials are examined here.

Sprinkel (2003) also tested permeability of polymer concrete overlays. His results are shown in Figure 3.5.4.3.1.

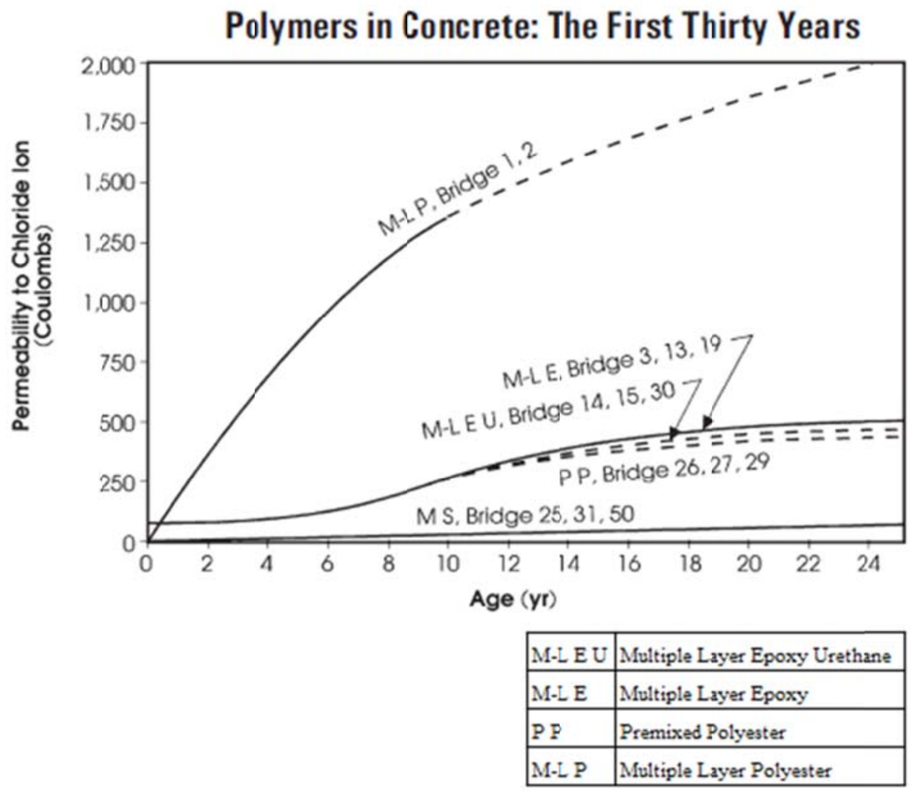


Figure 3.5.4.3.1: Permeability of Polymer Overlays Over Time (Sprinkel, 2003)

Sprinkel (2003) confirms what has been known; that polymer based overlays provide very low to negligible permeability. The multi-layer polyester overlays do not fare as well as the others, but still provide very low permeability for 6-8 years.

VDOT overlay tests from 1994 show that hydraulic concrete overlays can have low to very low permeability as well. Table 3.5.4.3.1 shows the results and differences between SF and LMC overlays over 5 years.

Table 3.5.4.3.1: RCPT results for hydraulic concrete overlays (Sprinkel, 2000)

Date	1994	1999
Overlay Type	Coulombs	
SF	1081	911
MMLMC	2533	795
ML	327	670
LMCHE	1665	513
SFHE	815	780
ML	1211	696
LMC	1296	454

Both LMC and SF overlays show excellent permeability results in the low to very low range. This is likely due to the increased density of both overlay types from the latex in the LMCs and the silica fume in the SF concretes. The results also validated that permeability decreases with age for hydraulic concrete overlays.

WSDOT also measured permeability for their overlays. Table 3.5.4.3.2 shows each overlay type they have installed, as well as measured permeability values.

Table 3.5.4.3.2: WSDOT overlay permeability results (Wilson, 1995)

Overlay Type	Range	Average
Polymer-Epoxy	0-6	3
Polymer-MMA	0-0	0
Latex Mod. concrete	101-1,117	365
Microsilica concrete	149-1,410	577
Low Slump concrete	438-2,400	1,443
Standard WSDOT bridge deck conc.	1,400-6,840	2,983

Similar to the VDOT results, Polymer overlays exhibit negligible permeability while the LMC and SF concrete overlays show low to very low permeability (Wilson, 1995).

VDOT's 2009 study conducted RCPT on two different SafeLane Overlays. Table 3.5.4.3.3 shows the results from the VDOT report.

Table 3.5.4.3.3: VDOT permeability values of SafeLane (Sprinkel, 2009)

Average Permeability Values (2/15/06)

Structure No.	Overlay	Thickness (in)	Permeability (coulombs)
2037	2-layer SafeLane	0.54	23 (negligible)
2024	2-layer SafeLane [a]	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)

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

As typically seen for polymer based overlays, and especially epoxy overlays, the permeability of the SafeLane overlay is negligible. The hybrid SafeLane overlay tested still recorded very low permeability, even though it uses a mix of aggregates.

3.5.5 Chloride Content

Chloride testing is done to determine the amount of chlorides in a given sample of concrete. This test differs from the RCPT in that it does not measure the permeability of a given sample, but rather the total amount of chlorides in the sample. This could be considered a component of the 90-day permeability test. Chloride testing is important for two reasons. It indirectly measures the permeability of concrete, and also lets engineers know at which point they can expect corrosion to occur.

In the absence of protection, steel rusts from exposure to moisture, the chemical process of corrosion. In normal concrete, the steel develops its own protection in form of a thin oxidation layer from the high alkalinity of concrete. When chlorides are present, the corrosion process is accelerated through an autocatalytic process in which the chlorides attack and destroy this layer (Kosmatka, 2002).

The main test methods to determine the chloride content of concrete are ASTM C1152 and AASHTO T 260. ASTM C1152 references ASTM C114 for the actual laboratory procedure, which finds the PPM of chloride in a concrete sample by titration of the chlorides using Silver Nitrate (AgNO3). In some cases, chloride content can be calculated to pounds per cubic yard. The test is a laboratory intensive procedure that requires significant preparation. Some of the variations put out by DOTs use newer methods in which several of the ASTM C114 steps are condensed.

Testing is typically performed using 2" (5.08 cm) core samples in which three sections at different depths are tested for their chloride content. Usually the first depth is at or just below the surface, with additional sections every 1/2" (1.27 cm) thereafter to provide adequate space for saw cutting. Figure 3.5.5.1 shows possible test locations.

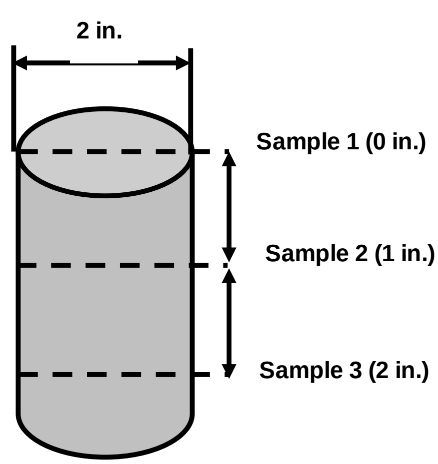


Figure 3.5.5.1: Typical Core Test Locations

Some newer mechanical methods can take much smaller cuts and thus take more sections per core. The cores are prepared by oven drying, and then ground into powder. The powder is placed into distilled water, boiled and filtered. This filtered solution is then titrated to produce the results. ASTM C114 requires silver nitrate to be added till 60 millivolts is read on a volt meter. Newer methods titrate the sample based upon color.

At the very least, chloride content is shown as a function of depth of the sample. The first slice, closest to the wearing surface should have the highest concentration; with each subsequent sample have less chlorides present. The most important sample is the one closest to the reinforcing steel, since this determines if corrosion will be occurring, termed critical chloride content threshold.

Critical chloride content threshold is the point at which there is sufficient chloride ions present around reinforcing steel to breach the protective film and cause corrosion. With some controversy, ACI 318 Build Code limits chlorides by percent by weight of concrete depending on the service conditions of the structural member. These values are shown in Table 3.5.5.1.

Table 3.5.5.1: ACI 318 Chloride Limits of Concrete (Kosmatka, 2002)

Type of Member	Maximum Water Soluble Chloride Ion ($C1^-$) in Concrete, Percent by Weight of Concrete
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

If the ACI 318 standards are followed, it is ideal for a bridge deck that the chloride content closest to the rebar does not exceed 0.15% chlorides by weight of concrete. Past this point it is likely that the chlorides will be in a high enough concentration to penetrate the protective coating of the steel reinforcement and start the corrosion process.

4. PROBLEM STATEMENT

One of the largest problems facing transportation departments within the United States is the deterioration of bridge decks and structural members. Specifically in cold weather climates where the use of harsh deicing chemicals results in rapid corrosion of steel reinforcement, engineers have spent a considerable amount of time trying to determine effective and economical ways to combat the deterioration of bridges. Beginning in the early 1960s engineers began to experiment by applying a thin layer of concrete or polymers onto bridge decks as a wearing surface. The thin bonded overlay was born.

The overall goal of this study is twofold. First, is to determine the viability of using the SafeLane system as an anti-skid/anti-icing and protective bridge deck overlay for concrete and asphalt bridge decks. Second, is to determine the effectiveness of Flexogrid as an anti-skid and protective overlay. Several different factors have been examined to make this determination including the application process and protection of the bridge deck, as well as durability, cost, and its effectiveness as an anti-skid/anti-icing surface. Extensive research and testing has been put into thin bonded bridge deck overlays, with SafeLane and Flexogrid being evaluated with regards to those lessons.

Durability and low weight are key advantages of thin bonded overlays. In general, thin bonded overlays are effective at stopping chemicals from reaching the underlying bridge superstructure and reinforcing steel. This study took a closer look at the effectiveness of thin bonded overlays, and more specifically at how effective SafeLane and Flexogrid are. Permeability and chloride tests were conducted to determine if SafeLane and Flexogrid were effective barriers against chemical attack.

Two locations were selected in Colorado for the installation of SafeLane, and one for Flexogrid. The first SafeLane location is the overpass of Interstate-76 and Weld County Road 53. This site was selected because of its asphalt bridge deck and the proximity of a weather station for instrumentation. The second site is the Parker Road, Interstate-225 southbound flyover on-ramp in Aurora, CO. This site was selected for its concrete bridge deck, high traffic volume, and moderate crash rate. The final site selected was for the Flexogrid installations the flyover ramp from southbound Interstate-25 to northbound Interstate-225. This ramp was selected because of its traffic volume, but also because of the automated spray system that was installed along with Flexogrid.

A large concern for thin bonded overlays is the high installation costs associated with them. The installation costs of thin bonded overlays were examined and due to their inherent high initial cost, it is important that thin bonded overlays have a high preventative maintenance value.

SafeLane and Flexogrid have been evaluated in several other states with mixed results. Since weather, methods, and organizations vary from state to state, this study looked at both systems in regards to Colorado. If they are found to be successful at prolonging bridge deck life, as well as increasing the safety of bridges during winter conditions, it is likely CDOT will recommend the use of thin bonded overlays for future bridge decks. This has the twofold effect of decreasing lifecycle maintenance costs through prolonging the service life of the bridge structures as well as increasing the safety of bridges through decreased weather related accidents.

5. EXPERIMENTAL PLAN

A major goal of this study is measuring the performance of the SafeLane and Flexogrid overlays installed on Colorado highways. Prior to installation and testing, a suitable location for each overlay needed to be found. Several different sites were evaluated based mainly on: traffic volume, location of nearby weather station, bridge deck type and size, nearby control bridge, and weather. With the locations selected, a study plan was drafted to determine how the overlays were to be tested. Five different tests were conducted before and at different times after installation as a partial determination of performance of the overlays.

5.1 Project Locations

5.1.1 I-76 and Weld County Road 53

Of the suitable candidates, the set of bridges numbered D-18-BK (west bound) and D-18-BJ (east bound) were selected. They are located approximately 4.5 miles (7.2 km) east of the town of Hudson, CO and approximately 2.5 miles (4.0 km) west of the town of Keenesburg, CO on Interstate-76. Both bridges serve as a grade crossings for I-76 over Weld County Road 53. The bridges are located approximately 40 miles (64.6 km) northeast of Denver, CO. Average annual daily traffic at the bridge is around 13,000. Figure 5.1.1.1 shows the site location with relation to Denver, CO. Figure 5.1.1.2 shows the site location in relation to Keenesburg, CO. Figure 5.1.1.3 shows an aerial view of the bridges along with the location of the weather station and deck sensors.

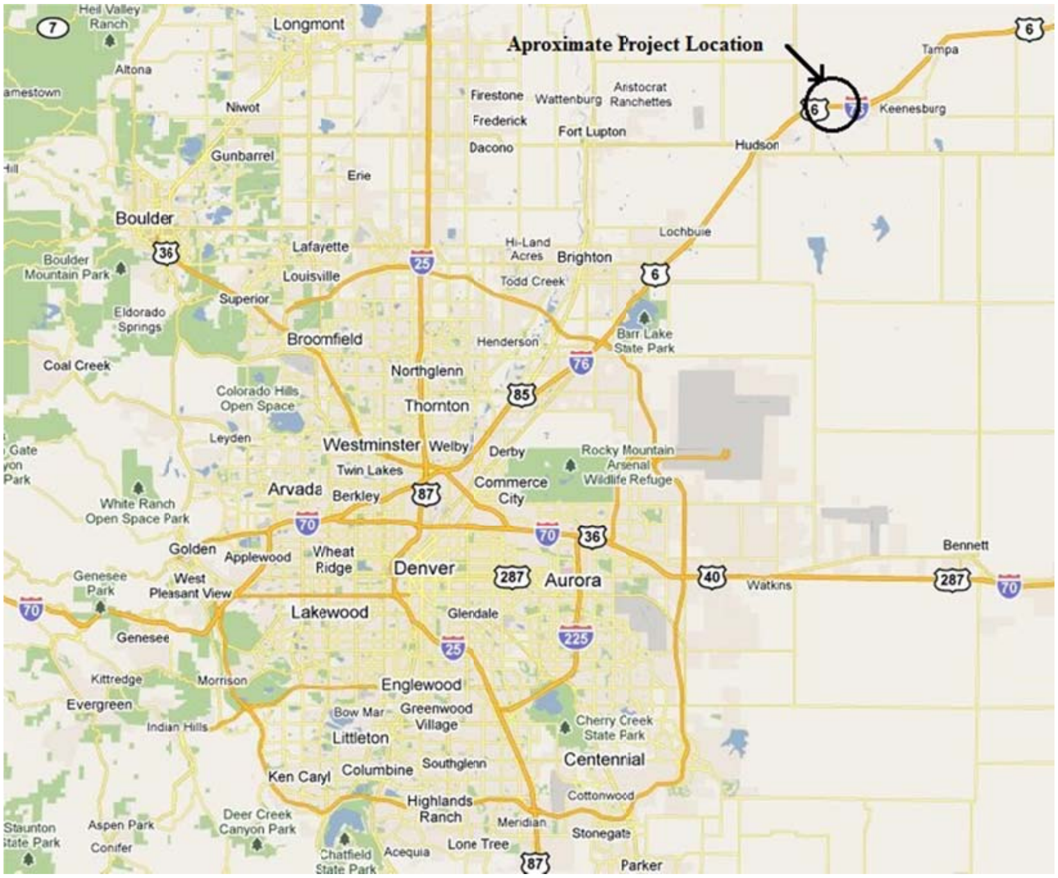


Figure 5.1.1.1: I-76 / WCR-53 in Relation to Denver, CO (Google, 2011)

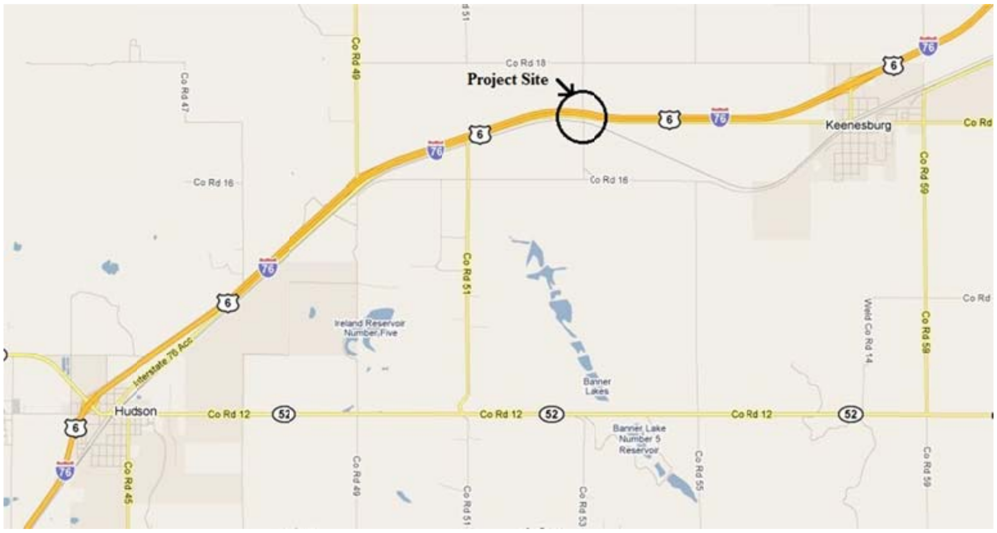


Figure 5.1.1.2: I-76 / WCR-53 in Relation to Keenesburg, CO (Google, 2011)

Figure 5.1.1.3: Aerial View of I-76 / WCR-53 (Google, 2011)

The site has extensive instrumentation including a weather station which measures wind speed and direction, as well as a Road Weather Information System (RWIS) which includes temperature, humidity, and barometric sensors. Figure 5.1.1.4 shows the weather station mast and wind sensor.

Figure 5.1.1.4: Weather Station at I-76 / WCR-53

In addition, the system includes a Weather Identifier and Visibility Sensor (WIVIS) that determines the type of weather present, from fog to snow. A camera is located on the mast to provide real time traffic and weather pictures. The road decks are wired with FP2000 deck sensors which measure surface temperature, type of chemical present, percent of chemical present, and depth of chemical solution. Figure 5.1.1.5 shows the FP2000 deck sensors (a) prior to installation, and (b) installed but not sealed.

(a) **(b)**

Figure 5.1.1.5: FP2000 Deck Sensor (a) prior to being installed, and (b) installed

The instrumentation data is acquired over the internet through a web browser. The data itself is stored on CDOT servers and all sensor data is recorded every 20 minutes. The camera takes still shots every 3 minutes. The servers store all the data which can be retrieved via the web interface. A sample of the data is presented in Appendix B.

5.1.2 Parker Road and I-225

In addition to the bridge in Weld County, CDOT decided to test SafeLane in the Denver/Aurora metropolitan area. Structure F-17-KK is the top level, two lane, flyover ramp going from northbound S. Parker Road to southbound Interstate 225. It was built in 2002 as part of the T-REX (TRansportation EXpansion) project to improve capacity and modernize the Interstate 25 corridor. This structure crosses over north and southbound I-225, an RTD light rail line, and S. Parker Road. Data shows that this structure is prone to icing and thus it would be an ideal structure for testing SafeLane. Its average annual daily traffic (AADT) is around 123,000. Figure 5.1.2.1 shows the project location relative to

Denver and Aurora main downtown areas. Figure 5.1.2.2 shows the structure itself along with in-place and future instrumentation. This site has no instrumentation at present.

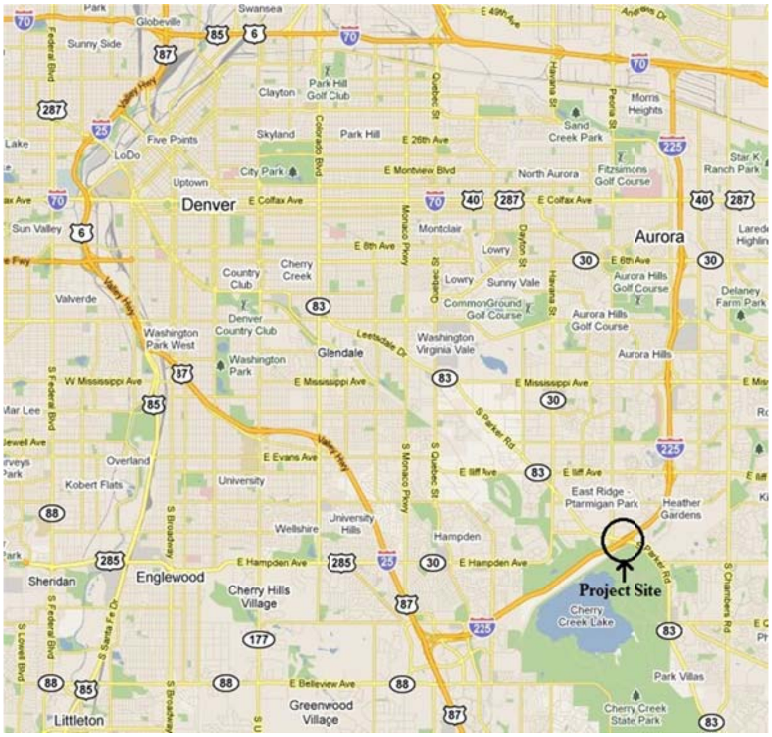


Figure 5.1.2.1: Parker Rd. / I-225 in Relation to Denver (Google, 2011)

Figure 5.1.2.2: Aerial View of Parker Rd. / I-225 (Google, 2011)

5.1.3 I-25 and I-225

The Interstate 25 and Interstate 225 interchange was selected as the location to install PolyCarb's Flexogrid overlay. Since Flexogrid has no inherent anti-icing properties, this location was used to test its properties because of the anti-icing spray system also installed. Structure F-17-OD was installed as part of the T-REX project. As such, it is a relatively new structure having been built in 2003. The average annual daily traffic (AADT) is around 125,000. Figure 5.1.3.1 shows the project location relative to the main downtown area. Figure 5.1.3.2 shows the structure itself along with in-place and future instrumentation.

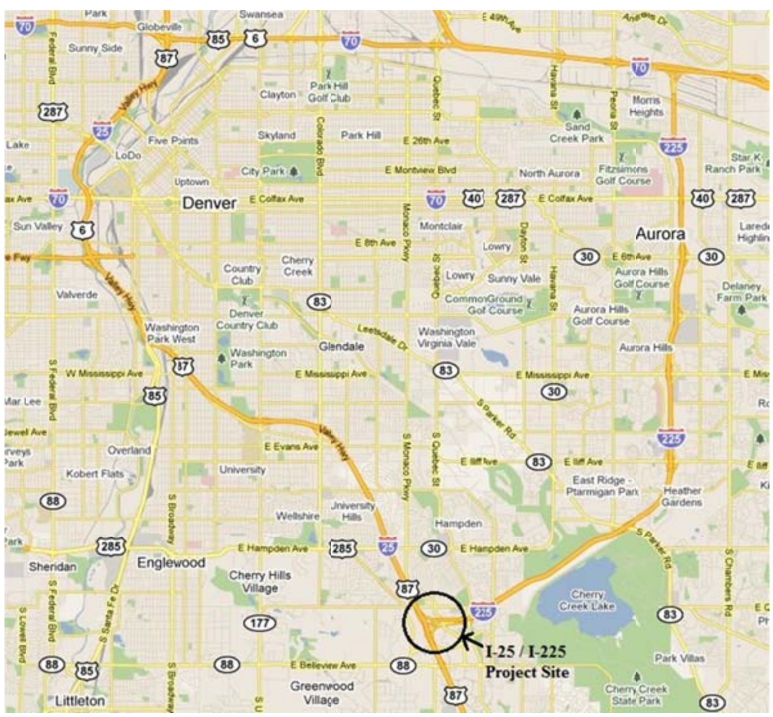


Figure 5.1.3.1: I-25 / I-225 in Relation to Denver, CO (Google, 2011)

Figure 5.1.3.2: Aerial View of I-25 / I-225 (Google, 2011)

The I-25 / I-225 site is equipped with an ESI spray system manufactured by EnviroTech Services, Inc. The system is automated, and releases deicing chemicals based upon deck temperature which is measured using an infrared thermometer. Figure 5.1.3.3 shows the (a) infrared sensor and (b) spray head.

(a) **(b)**

Figure 5.1.3.3: I-25 / I-225 Spray System (a) Infrared Sensor and (b) Spray Head

The spray system was installed at the same time as the Flexogrid overlay. This site consists of a camera that takes still photos of traffic on the bridge. Figure 5.1.3.4 shows both the (a) infrared sensor mast, and (b) camera mast.

(a) **(b)**

Figure 5.1.3.4: Sensor Masts on I-25 / I-225 (a) Infrared, and (b) Camera

5.2 Testing of Thin Bonded Overlays

The physical characteristics of the overlays were evaluated on five different properties: friction, texture depth, bond, permeability, and chloride content testing. Six different test methods were used. For the friction testing on I-25 / I-225 and Parker Rd. / I-225, a locked-wheel test system conforming to ASTM E274 was used. Friction testing on I-76 / WCR-53 was performed using a British Pendulum Skid Tester based upon ASTM E303. Texture depth was measured using the sand patch test which follows ASTM E965 -

Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique, while bond testing was conducted using a NDT James Bond Test System which conforms to ASTM C1583 Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension, and ACI 503R Use of Epoxy Compounds with Concrete. Permeability was measured using ASTM C1202 Rapid Ion Chloride Permeability method. Chloride content was measured using CDOT's in-house Laboratory 2104, which is a water soluble method based on AASHTO T291 - Standard Method of Test for Determining Water-Soluble Chloride Ion Content in Soil.

5.2.1 Sand Patch Test Method

The texture depth of the roadway was measured using the sand patch test. The test utilizes a known volume of sand then spreads it about the roadway surface in an approximate circle. When the diameter of the circle is measured, the texture depth of the roadway can be determined. This test follows the provisions of ASTM E965. The sand patch test works well on relatively flat roadways, but has difficulty on some roadways with super elevations, or in windy conditions.

The first step in conducting the sand patch test is to clean the designated area with compressed air. Next the known volume of sand is placed on the roadway surface. The sand is then spread using a flat object moved in a circular fashion. This is repeated until the tips of the surface texture match the top layer of sand. Figure 5.2.1.1 (a) shows the sand being smoothed out in a circular motion, (b) the patch ready for measuring, and (c) shows the test patch being measure on SafeLane.

(a) **(b)**

(c)

Figure 5.2.1.1: Sand Patch Test Process (a) Sand Being Spread on Test Surface, (b) Ready to Be Measured, and (c) Being Measured on SafeLane

The sand patch should be as close to a circle as possible. At least three diameter measurements are taken and then averaged to find a single value for a given test patch. The diameter is used to find the surface area of the sand patch, which is then divided into the known volume to determine the average roadway surface depth.

5.2.2 Friction Skid Test Method

5.2.2.1 Locked-Wheel Friction Test

The locked-wheel friction test was used to determine the friction numbers of the Parker Rd. / I-225 and I-25 / I-225 bridges. The system used was manufactured by International Cybernetics. Figure 5.2.2.1 shows a similar test system from ICC.

Figure 5.2.2.1.1: Locked-Wheel Friction Test System (ICC, 2006)

The locked-wheel friction tester is a trailer that is towed behind a truck. An operator in the vehicle signals one of the computers on board the trailer to begin the test, at which point one of the wheels on trailer locks the test tire at certain intervals, usually 1 second apart to simulate an emergency braking force. Water is sprayed in-front of the tire to simulate a worst-case scenario. The resistive force of the tire against the roadway is measured and an equivalent friction number is recorded based upon speed of the trailer, weight of the trailer, and resistive force being measured. A ribbed tire was used for the bare concrete decks as well as for the overlays. A smooth tire was only used on the overlays examined in this study.

5.2.2.2 British Pendulum Tester

Originally, the fixed wheel method was attempted at I-76/WCR-53. However accurate results were not able to be obtained due to the short length of the spans. A different method called the British Pendulum Test (BPT) was utilized instead. The test apparatus was manufactured by Munro Instruments and conforms to ASTM E303 standards. Figure 5.2.2.2.1 shows the British Pendulum Tester.

Figure 5.2.2.2.1: British Pendulum Tester

The first step in using the portable skid tester is to level the apparatus from the 3 set screws. A bull's eye bubble level is mounted on the apparatus to assist with this. Next the measurement stick is placed next to the device and the swing arm is lowered to determine the strike point on the pavement. The swing arm is raised or lowered so that it contacts the pavement at the first mark on the measurement stick and breaks contact at the second mark. The swing arm is set to the locked position and the indicator arm is reset to the same position as the swing arm. The pavement surface is wetted to provide a worst case friction value. Figure 5.2.2.2.2 (a) shows the swing arm being adjusted, (b) the pavement being wetted, (c) the arm in motion about to make contact, and (d) the result with the swing arm reset.

(a) **(b)**

(c) **(d)**

Figure 5.2.2.2.2: British Pendulum Test Process (a) Arm Being Adjusted, (b) Wetting of the Test Surface, (c) Swing Arm After Release, (d) Indicator Arm Showing Result

When the swing arm is released it moves the indicator arm with it. The foot of the swing arm contains a rubber pad that contacts the pavement surface at two measured points. Depending on the friction of the surface, the swing arm will only raise so far, pushing the indicator arm to a certain value. Generally, the test is repeated 3-5 times in several different spots to get an accurate average value.

5.2.3 Bond Test Method

The bond test was conducted using a handheld testing apparatus that is manufactured by James Instruments called the 007 James Bond Tester. The tester uses a hand screw to pull a plate attached to the testing surface. Mounted on the side of the device is a force gauge so that the pull strength at failure can be recorded. Figure 5.2.3.1 below shows the James Bond Tester.

Figure 5.2.3.1: James Bond 007 Tester (James Instruments, 2011)

The method of testing is fairly straight forward. First the site of the test is determined, and a core drill is used to notch the desired test area to a depth of approximately 1/4" (0.635 cm) into the pavement surface. For the notching, the core drill is run without water to prevent moisture from causing an early failure during the test. The depth of the overlay must be accounted for when determining the depth the core drill is at. If the overlay adds an additional 1/2" (1.27 cm), then the core drill must penetrate from the top of the overlay down to 3/4" (1.91 cm). After notching, the surface is cleaned with compressed air and prepared to receive epoxy. Figure 5.2.3.2 (a) shows the epoxy being mixed and applied to the test surface and, (b) shows the steel plate receiving epoxy.

(a) **(b)**

Figure 5.2.3.2: Bond Test Epoxy Application (a) On Test Surface, and (b) Disk

A steel plate either 2 inches (5.08 cm) (ASTM Standard) or 3 inches (7.62 cm) in diameter is attached to the center of the notched test area by using a high strength, quick curing epoxy. The 3 inch (7.62 cm) diameter disks provide a greater bonding area for the epoxy which decreases the chance of the disk pulling from the epoxy without an overlay failure. The test disks have a smooth side with a threaded screw, and grooved side. The epoxy is applied to the grooved side then pressed on the test surface that has had epoxy applied previously. With the disk applied to the test surface, any excess epoxy is removed. A small wire or stick is used to remove any epoxy that has been forced into the notch around the test area. Epoxy that hardens in this location will provide extra strength to the overlay and invalidate the results. Optionally, a torch is used to heat the disk to approximately 100 °F (37.8 °C) to speed up the epoxy curing in colder weather. The temperature is checked using a hand held infrared thermometer, this step can be omitted if the deck and ambient temperatures are sufficiently high enough to provide rapid curing on their own. Figure 5.2.3.3 (a) shows the disk placed on the test surface and excess epoxy being removed, and (b) shows the disk temperature being checked.

(a) **(b)**

Figure 5.2.3.3: Bond Test Disk Application (a)Excess Epoxy Removed, and (b) Disk Temperature Being Checked

A test alignment plate (the black ring with attached set screws in Figure 5.2.3.1) is placed over the test area after the epoxy has cured. The plate is leveled by three screws until it is flush with the surface of the test disk. Figure 5.2.3.4 (a) shows the test plate being leveled with respect to the test disk, and (b) the pulling device attached to the disk and the screw handle being turned. The pulling bolt is threaded onto the test disk until hand tight. The pulling machine slides onto the pulling bolt.

(a) **(b)**

Figure 5.2.3.4: Bond Test in Progress (a) Test Plate Being Checked Against the Disk, and (b) Pulling Device Attached and Screw Handle Being Turned

The screw handle is twisted until failure of the testing surface occurs. The force that is required for this failure is indicated on the gauge. This force divided by the area of the failure plane yields the failure in force per square area. The failure of the asphalt under the overlay is shown in Figure 5.2.3.8. The holes are patched with additional overlay material after the test area is cleaned (James Instruments, 2011).

Figure 5.2.3.5: Failure of the Asphalt Under SafeLane Overlay

5.2.4 Rapid Chloride Permeability Test Method

The rapid chloride permeability test (RCPT) was used due it is fast testing time and could be used to measure how well the thin bonded epoxy overlay can protect bridge decks from corrosion by chloride ions. The procedure followed ASTM C1202. When testing a structure that is already in place, a core sample must be taken to conduct the rapid ion permeability test. Typically a 4" (10.16 cm) diameter sample is core drilled from the deck surface. A 2" (5.08 cm) slice of the core sample is required for the test. Since the permeability of the overlay is assumed to be zero, the sample is cut approximately 0.75" (1.91 cm) below the top of the overlay into the concrete. The 2" (5.08 cm) measurement begins at this point. Any extra core after 2" (5.08 cm) is cut off and discarded.

To ensure that electrical conductivity will be present, the samples must be prepared by placing them into a saturated surface dry (SSD) state. This is done through the use of a vacuum pump and desiccation chamber. A number of samples are put into the desiccation chamber and placed under vacuum for three hours. At the end of 3 hours, the chamber is flooded with water by being drawn up the fill hose from the vacuum. Figure 5.2.4.1 shows the concrete samples in a flooded desiccation chamber while still under vacuum.

Figure 5.2.4.1: Samples in Flooded Desiccation Chamber Under Vacuum

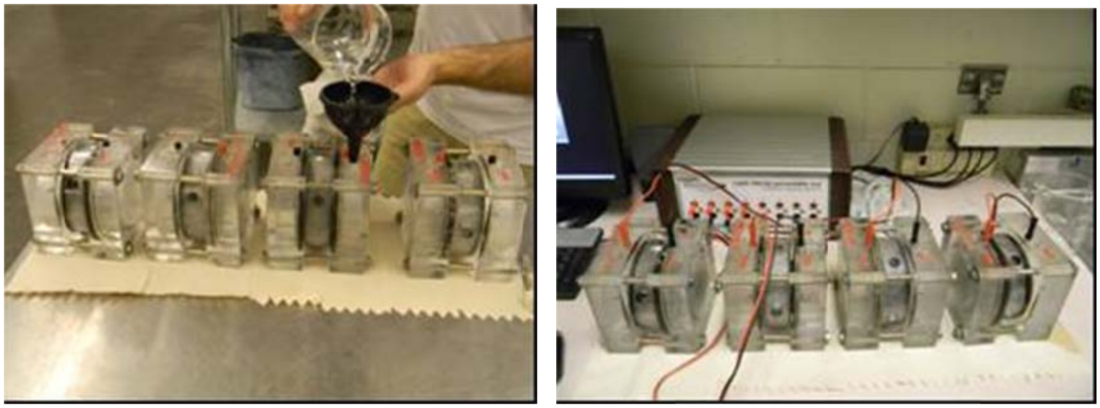
With the water level slightly above the top of the samples, the vacuum is reapplied. The samples sit under vacuum in water for 1 hour at which time the vacuum is released and the samples are left for a minimum of 18 hours. The samples are initially placed under vacuum without water so that the pores develop a negative pressure and any moisture in the concrete is pulled out of the voids. This negative pressure pulls water into pores when the desiccation chamber is filled and helps to reduce air trapped inside the water. The samples sit for at least 18 hours so they reach SSD conditions when removed from the chamber.

The SSD sample is then placed into the test apparatus. The apparatus consists of two acrylic plastic halves that have sockets for each end of the sample. Each half has a plug for the electrodes as well as a fill hole for the solution on each side. The concrete sample is fitted with a rubber gasket then sealed using silicon caulking. Figure 5.2.4.2 (a) shows the sample being caulked with silicon, while (b) shows the silicon being spread around the rubber gasket ring.

(a) **(b)**

Figure 5.2.4.2: RCPT Preparation (a) Silicone Caulk Being Applied to the Gasket, and (b) Silicon Being Spread by Hand

Each half of the test apparatus is fitted onto the rubber gaskets and then bolted together to create a single unit. The unit is filled with water to test for leaks. Once it is determined that no leaks are present, one side of the apparatus is filled with a 3% NaCl solution, while the other is filled with a 0.3M NaOH solution. Figure 5.2.4.3 (a) shows the apparatus being filled with water to find leaks, and (b) shows the units filled with solution and hooked to the test machine. The test units are connected to the power supply and 60 volts is run through the unit for 3 or 6 hours.



(a) (b)

Figure 5.2.4.3: RCPT Leak Testing (a) Unit Being Filled With Water, and (b) Units Hooked to Power Supply

If the unit is run for 3 hours, then the 3 hour coulomb value is doubled to obtain a 6 hour total. The lower the amount coulombs measured, means a higher permeability through a higher resistivity.

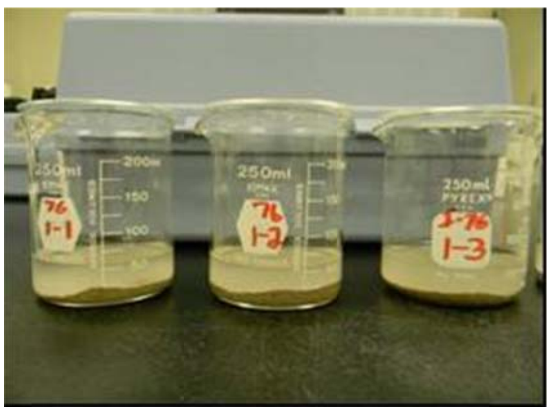
5.2.5 Chloride Content Test Method

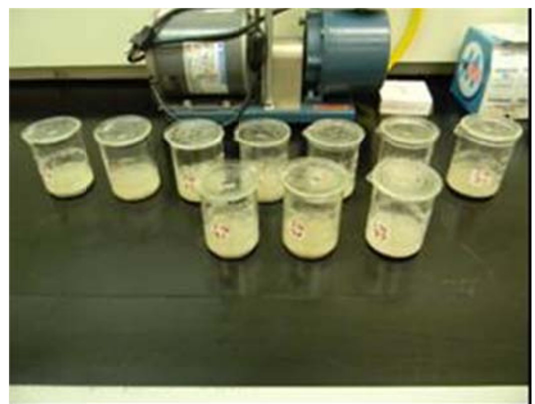
The method that was used to determine the chloride content of the concrete was derived in-house by CDOT and is called Colorado Procedure - Laboratory 2104. It is similar in method to AASHTO T291 - Determining Water-Soluble Chloride Ion Content in Soil and is found in Appendix B.

Typically the test is conducted using 2” (5.08 cm) cores taken from a deck or roadway. The core is cut into 3 sections each ¼” (0.635 cm) thick and about ½” (1.27 cm) apart. The top of first section is located about ¾” (1.91 cm) from the top of the overlay, with the top of each subsequent section located an additional 1/2" (1.27 cm) down. This is to ensure adequate room for the cutting blade width and to obtain a series of values for a given core. Figure 5.2.5.1 (a) shows the samples measured and ready to be cut. The ¼" (0.635 cm) sample discs are placed into a sample pan and then placed into an oven to dry overnight. Figured 5.2.5.1 (b) shows the samples in the tray in order of depth. After the samples are completely dry, they are ground into a fine powder. The sample is then sifted through a No. 4 sieve.

Ten grams of sample are weighed into a beaker and filled with 50 mL (1.69 oz) of distilled water. Figure 5.2.5.1 (c) shows the samples with the 50 mL (1.69 oz) of water added. The contents of the beaker are brought to a boil and kept there for 5 minutes to help breakdown the sample particles and release the chlorides. The sample beaker is set aside and allowed to stand undisturbed for 24 hours so that it can reach room. Figure 5.2.5.1 (d) shows the samples after being boiled for 5 minutes.

(a) **(b)**





(c) **(d)**

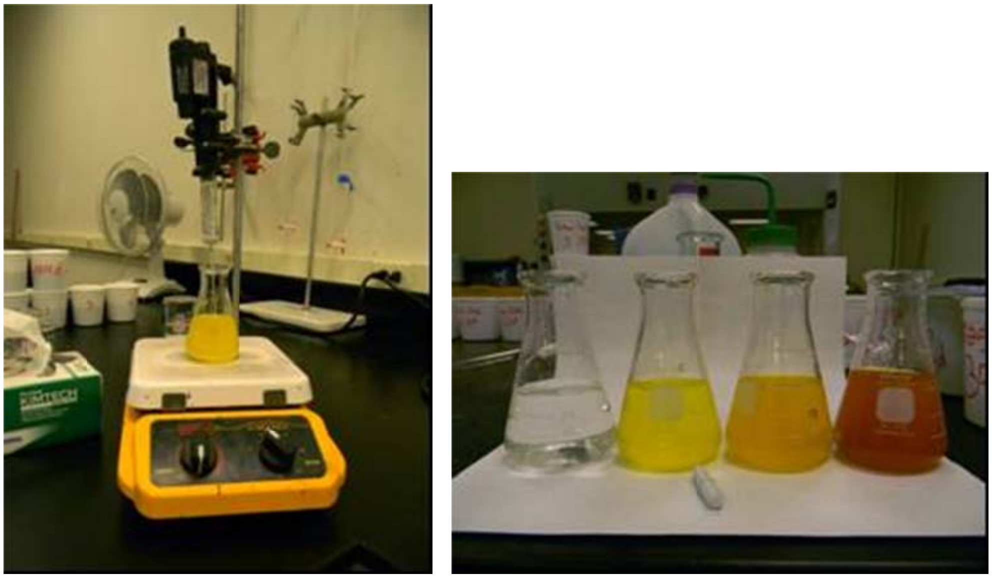
Figure 5.2.5.1: Chloride Test Sample Preparation (a) Marked and Ready to Cut, (b) Cut and in Tray According to Depth, (c) Ready to be Boiled, and (d) After Boiling

The sample solution is filtered through a 45 micron paper to remove the larger particles. The amount of sample solution titrated depends on the expected chloride results. For the I-25 / I-225 and Parker Rd. / I-225 bridges, the chloride content was expected to be high, so 5 mL (0.169 oz) of solution was used. For I-76 / WCR-53 it was expected to be low, so 50 mL (1.69 oz) of solution was used. Table 5.2.5.1 shows the amount of solution and titration cartridge for the expected amount of chloride.

Table 5.2.5.1: Sample size corresponding to Cl^- range

Range (mg/L as Cl^-)	Sample Volume (mL)	Titration Cartridge (N AgNO3)	Digital Multiplier
10-40	100	0.2256	0.1
25-100	40	0.2256	0.25
100-400	50	1.128	1
250-1000	20	1.128	2.5
1000-4000	5	1.128	10
2500-10000	2	1.128	25

The sample solution is transferred to a graduated cylinder and diluted with an additional amount of distilled water so that the total solution is 100 mL (3.38 oz). The contents of the graduated cylinder are then poured into a flask and a Chloride 2 Indicator Powder Pillow is swirled into the solution. The solution is titrated with silver nitrate until it turns from yellow to a reddish-brown color. Figure 5.2.5.4 (a) shows a sample being titrated, and (b) shows the flasks from left to right; before the indicator is added, with indicator, at the correct titrated color, and an over titrated sample. The small white device in front of the flasks is a magnetic wand that is placed into the flask for mixing the contents.



(a) **(b)**

Figure 5.2.5.2: Chloride Content Titration (a) Sample on stand, and (b) Flask Titration Steps from Left to Right

The number of drops required to make the color change multiplied by a digital factor and dilution multiplier determines the parts-per-million of chloride present in the sample. Dividing the PPM by 10000 yields the percent of chloride, by mass of sample (CDOT, 2011).

6. OVERLAY APPLICATION PROCESS

6.1 SafeLane Application

As with any bridge deck overlay, the application is of critical importance and is one of the primary factors in determining the longevity of the overlay. It is also highly desirable that an overlay has a quick application process to minimized costs and traffic disruption. The procedure for applying SafeLane is detailed using a flow chart in Figure 6.1.1. Each step of the procedure is discussed in detail as well.

6.1.1 Surface Preparation for SafeLane

Due to the nature of epoxy overlays, there are several preparations that must occur before the epoxy can be applied to a bridge deck. First the roadway striping must be removed to allow the epoxy to bind to asphalt/concrete deck. The decking must then be thoroughly cleaned using an abrasive blasting method. Final preparation included cleaning the bridge deck with a vacuum truck and compressed air. Figure 6.1.1.1 (a) shows the striping grinder and (b) the abrasive blasting equipment. Initial skid resistance and sand patch tests were performed on the bridge deck to determine their baseline values before SafeLane was applied. The sand patch test was performed to determine the average texture depth of the roadway. The skid test is used to determine the friction number of a simulated patterned tire on a wet roadway, a higher number is better. Figure 6.1.1.1 (c) shows the boundary of the overlay being taped and (d) shows the future location of a new in-deck sensor.

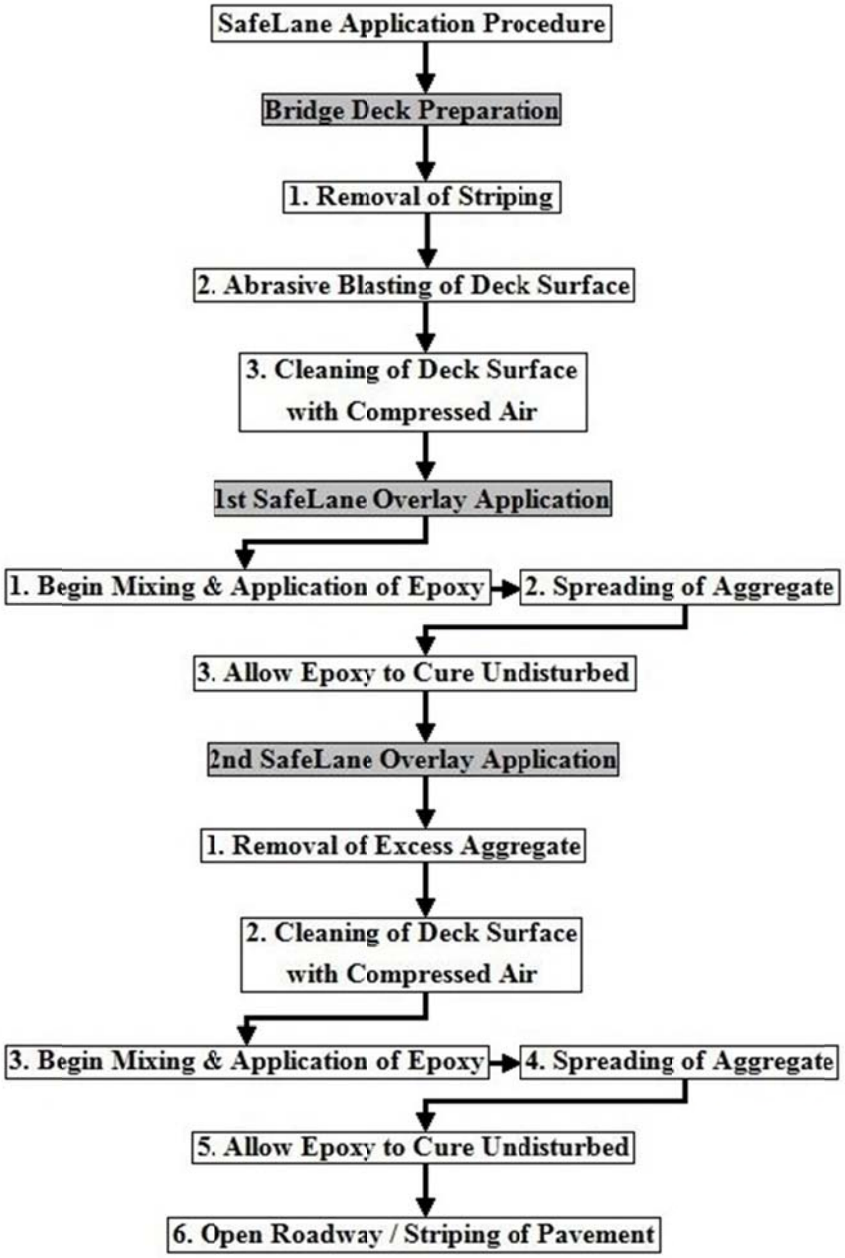


Figure 6.1.1: SafeLane Application Flow Chart

(a) **(b)**

(c) **(d)**

Figure 6.1.1.1: SafeLane Surface Preparation (a) Removal of Deck Striping, (b) Abrasive Blasting,(c) Taping Boundaries, and (d) Covering Features

6.1.2 Overlay Application

With the surface prepared to receive the overlay, the first step in the application process is to begin batching the epoxy. Generally, the aggregate should be spread only a couple feet behind the wet edge of the epoxy. This is to maximize aggregate distribution within the curing time of the epoxy while allowing the aggregate to absorb the epoxy for a better bond.

The epoxy used in the SafeLane system is SmartBond manufactured by Unitex, Inc. It is a low viscosity, low modulus, two-part bonding agent that is mixed in a 1:1 ratio. Generally, SmartBond requires between 3 hours at 85+ °F (29.4+ °C) and 6 hours at 60 °F (15.6 °C) to cure depending on application surface temperature. SmartBond is required to be mixed for a minimum of 3 minutes by a Jiffy-type drill attachment before being spread on the bridge deck surface (Unitex, 2004). Spreading of the epoxy is accomplished by using a V- notched squeegee for the 1st layer application, and a straight edge squeegee for the 2nd layer. Figure 6.1.2.1 (a) shows the Jiffy-type mixer, (b) SmartBond being mixed, (c) a V-notched squeegee blade, and (d) the epoxy being spread on the bridge deck.

(a) **(b)**

(c) **(d)**

Figure 6.1.2.1: Epoxy Mixing and Spreading Devices (a) Jiffy-type Mixer, (b) Mixing Barrel, (c) V-Notched Squeegee, and (d) Epoxy Deck Application

Each batch of epoxy should have a sample taken so that the setup and cure times can be monitored. Samples should be numbered in accordance with each batch. In addition, each batch of epoxy should be finished at a straight demarcation line marked on the bridge deck so that it is easier to determine where one batch ends and another begins.

With the first batch of epoxy spread evenly on the deck, the aggregate application can begin. The standard way of applying the aggregate is to use a shovel and disperse an even layer down. It is possible to use an auto-spreader to disperse aggregate for larger bridge decks. Aggregate should be placed until a few feet from the most freshly spread epoxy in a uniform manner. Figure 6.1.2.2 shows the epoxy leading the aggregate layer.

Figure 6.1.2.2: SafeLane Aggregate Being Placed by Hand

The curing time of the epoxy depends on the deck temperature. Once the epoxy has cured, the overlay can be swept, and then blown off with compressed air to clear any loose aggregate. When the first application of SafeLane is cleaned, the second layer can be applied. Generally, the second layer takes more epoxy and more aggregate due to the deeper texture of the SafeLane aggregate. Figure 6.1.2.3 (a) shows the vacuum truck picking cleaning the cured overlay, and (b) the overlay being blown off with compressed air.

(a) **(b)**

Figure 6.1.2.3: SafeLane Overlay Cleaning (a) Swept and Vacuumed, and (b) Compressed Air

With the first overlay cleaned, the application of the second overlay can begin. The process is the same as the placing the first overlay with two exceptions. The first is that straight bladed squeegees are used instead of the V-notched type, the second is that due to the increase surface area from the first overlay, more epoxy and aggregate are used which results in increase application time. Once the second layer is cured, it is cleaned the same as the first layer, by compressed air and sweeping/vacuuming. After cleaning, the overlay is ready for traffic. The skid resistance and sand patch tests were performed on the SafeLane overlay to get baseline values for future reference and to compare to a non-SafeLane overlay or regular bridge deck.

6.2 Flexogrid Application

Installation of Flexogrid is similar to any epoxy-based overlay. The surface is first prepared and cleaned, important roadway features are taped off, the epoxy is sprayed onto the roadway surface, and aggregate is broadcast onto the epoxy. Like SafeLane, PolyCarb requires Flexogrid to be installed in two layers. A unique aspect to the installation is that PolyCarb has specialty machines that they supply to job sites just for the application of Flexogrid. Figure 6.2.1 shows the flow chart for the application of Flexogrid.

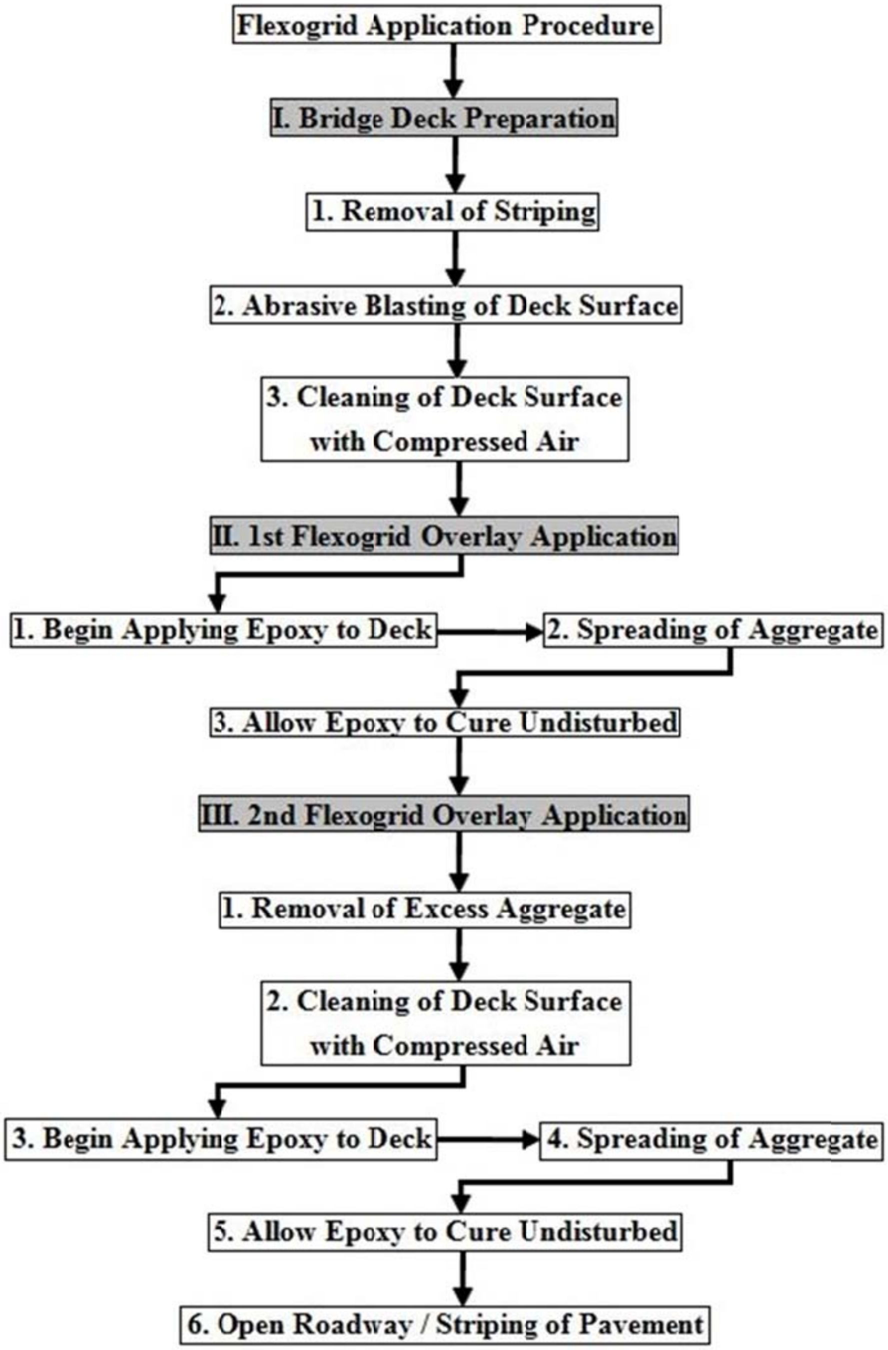


Figure 6.2.1: Flexogrid Application Flow Chart

6.2.1 Surface Preparation

The bridge deck surface is prepared similar to any other overlay. The road striping is removed and the deck surface is scoured with an abrasive air-blasting method. After blasting, small particles on the deck are swept and vacuumed to ensure that no particle reside remains behind. Important road features such as expansion joints, drainage grates, and in the case of the I-25 / I-225 bridge, spray heads are taped off. Figure 6.2.1.1 shows the taping of a drainage grate on the I-25 / I-225 structure.

(a) **(b)**

Figure 6.2.1.1: Flexogrid Installation Preparation (a) Taping of drainage inlet, and (b) Machine Being Readied

PolyCarb recommends that any cracks be repaired using their Mark-135 Safe-T-Seal product prior to overlay application. Installation can commence once the deck is cleaned and any roadway cracks are sealed.

6.2.3 Flexogrid Installation

PolyCarb Inc. has developed a unique machine for the installation of Flexogrid. While there are provisions for installing Flexogrid by traditional broom and screed methods, the majority of installations in the United States utilize the Flexogrid machines supplied by PolyCarb Inc. The I-25 / I-225 overlay was installed using the Flexogrid machines. The Flexogrid machines are tractor-trailer units that combine the epoxy mixing and aggregate spreading into a single platform. The epoxy is mixed in the first half of the trailer and pumped to hand held spray units. Workers apply the epoxy in front of the tractor-trailer unit, while the aggregate is spread from the back. The aggregate is loaded through the top of the unit and then conveyed by belt to the aggregate spreader which hangs off a boom about 20 feet (6.1 m) from the end of the trailer. The whole unit moves forward at a slow rate to ensure even distribution of epoxy and aggregate. Figure 6.2.3.1 (a) shows the Flexogrid machine in operation, while (b) shows the epoxy being sprayed on the deck by a crew. Figure 6.2.3.2 shows the whole Flexogrid machine with aggregate spreader off the back.

(a) **(b)**

Figure 6.2.3.1: Flexogrid Machine (a) Spreading Aggregate, and (b) Spraying Epoxy

Figure 6.2.3.2: Flexogrid Machine Aggregate Spreader (PolyCarb, 2010)

While the aggregate spreading units are efficient and allow a high rate of application with little downtime, they can miss some spots. To make up for this, aggregate is usually manually spread on the spots that have been missed, or require a little extra material. Figure 6.2.3.3 shows the aggregate being spread by a hand crew.

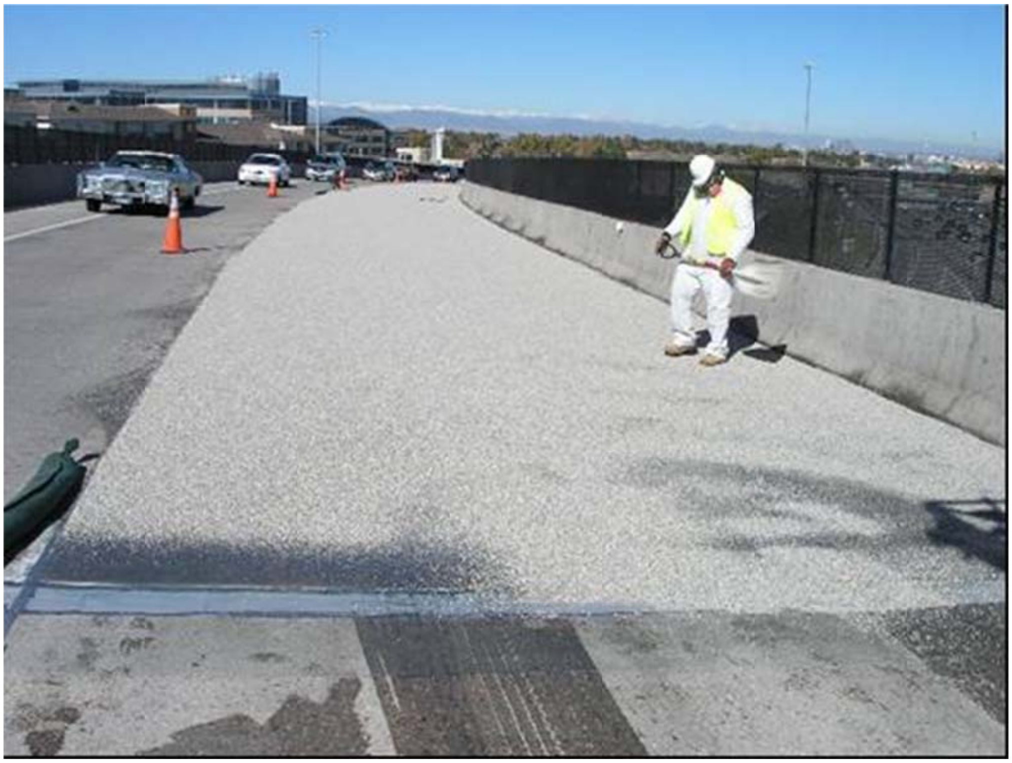


Figure 6.2.3.3: Flexogrid Aggregate Being Spread by Hand

After the first layer of aggregate has been applied, the overlay is allowed to cure before being swept and vacuumed. With the first layer cured and cleaned, the second layer can be applied. According to PolyCarb's specifications, the first layer requires an application rate of approximately 35 square feet of epoxy per gallon (0.86 square meters per L). Due to the extra texture from the first layer, the second layer application rate shrinks to 15-20 square feet per gallon (0.37-0.49 square meters per L). Aggregate is spread at a constant rate for both layers, about 15 pounds per square yard (79.8 N per square meter).

Once the second overlay is cured, it is cleaned the same as the first overlay, by sweeping/vacuuming and compressed air. After cleaning, the overlay is ready for traffic. The skid resistance and sand patch tests were performed on the Flexogrid overlay to get baseline values for future reference and to compare to a non-Flexogrid overlay or regular bridge deck.

7. EXPERIMENTAL RESULTS

The primary objective of this study was to determine the effectiveness of thin bonded overlays placed on asphalt and concrete surfaces. As such, there were five different tests that were conducted to determine different performance characteristics: (1) bond strength, (2) friction, (3) texture depth, (4) chloride content, and (5) permeability. Sections from the permeability cores were measured to determine the thickness of the overlays at each bridge site. In addition to the physical characteristics being tested, the anti-icing properties of the overlays were evaluated from the instrumentation data to determine their effectiveness in preventing bonded ice from forming on the bridge decks.

7.0.1 I-76 / WCR-53

The I-76 / WCR-53 overlay was originally scheduled to be installed in October 2009. Due to this, pre-installation testing was conducted to establish baseline values and included taking, two 4" (10.16 cm) permeability cores and two 2" (5.08 cm) chloride cores. Additional testing was conducted when the overlay was installed during June 7th to 9th, 2010, and included before and after texture depth and friction tests. Concrete permeability was tested at this location in October 2009. Since it is unlikely that the permeability would change within this time, and with the permeability classification from 2009 being “Low”, this test was omitted for this location at the time of the overlay installation. There was a timing issue with the second round of testing, and thus the sand patch, skid test, and coring were performed on the day of March 22, 2011, while the bond testing was conducted the morning of March 23, 2011.

By March 2011, the overlay had been in good shape and visual inspection showed a well-defined texture with almost no loose material. There were some plow blade marks on the shoulder, but these were inconsequential. Core measurements were based off cores taken during October 2009, when the overlay was originally scheduled to be installed. These measurements are shown in Table 7.0.1.1.

Table 7.0.1.1: I-76 physical core dimensions

	West		East	
	in	cm	in	cm
Asphalt Layer	2.286	5.81	1.85	4.70
Top of Rebar	1.99	5.05	1.482	3.76
Entire Core Height	5.67	14.40	5.54	14.07

However, subsequent inspection during the second round of testing in March, 2011 revealed the abutment cracks came back. Deck reflection cracks are also visible coming through the overlay. This is important since cracks in the overlay essentially negate its effect as bridge deck protection. Therefore, the study team decided to perform the visual inspection only in 2012. The visual inspection was completed in May 2012.

7.0.2 Parker Rd. / I-225

The SafeLane system installed on the Parker Rd. / I-225 bridge was installed at two different times. The older overlay was installed in the right-hand lane from October 7 - 10, 2009, while the left-hand lane was installed during May 21 – 23, 2010. Rapid chloride ion permeability and chloride content tests were performed in October 2009, when the first lane of the overlay was installed. Weather delayed the installation of the second lane to June 2010, which is when the skid and texture depth tests were performed.

Originally, the plan was to take 2" (5.08 cm) and 4" (10.16 cm) cores, and test the bond strength and texture depth on both lanes. However due to limitations in the amount of work that could be performed within the timeframe, it was decided that the older overlay in the right-hand lane would be tested. Testing was conducted the night of March 23, 2011. Friction testing was conducted in May 2011 using a fixed wheel tester. Both lanes were in good condition with no major cracking, spalling, or chipping. Another round of inspection and sampling was completed the night of October 1st, 2012. Visual inspection revealed a good condition of the SafeLane system at this site. A weather data puck was installed by Sturgeon at the same time. Eight 2” and eight 4” cores were collected on the left wheel path of the left-hand lane for chloride contents and permeability tests respectively. The two tests were completed in December, 2012. The last round of sample collection and testing was completed in June, 2013.

The overlay thickness was measured from the permeability cores taken in March 2011. Table 7.0.2.1 shows the measurements. Each was measured four times; once from each quadrant. The measurements were taken to the nearest 1/16th of an inch (0.15875 cm).

Table 7.0.2.1: Average thickness of Parker Rd. / I-225 SafeLane overlay

Sample No.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4	Average (in.)
1	0.5000	0.5000	0.5000	0.5000	0.5000
2	0.5000	0.5000	0.4375	0.5000	0.4844
3	0.5000	0.5000	0.5625	0.4375	0.5000
4	0.3750	0.5000	0.4375	0.4375	0.4375
5	0.5000	0.5625	0.5000	0.5000	0.5156
6	0.6250	0.5625	0.6250	0.6250	0.6094
			Total Average (in.):		0.5078
			Total Average (cm):		1.290

SafeLane is typically described as being 3/8" (0.9525 cm) thick. The overlay measured on Parker Rd. / I-225 consistently exceeds this, and is on the high side of 1/2" (1.27 cm) thick. This is consistent with other DOT installations. While this is not expected to decrease the durability of the overlay, it does slightly increase the expected dead load contributed to the structure by the overlay. The aggregate on the overlay at this site was spread by an automatic feeder, while it is possible that this contributed to increasing the thickness of the overlay, it is unlikely since standard installation instructions is to broadcast excess aggregate until all epoxy on the surface is covered.

7.0.3 I-25 / I-225

The first tests on Flexogrid at this location were conducted when the overlay was installed during October 16 - 17, 2009. The second round of testing at this location was conducted the night of March 24, 2011 with traffic control beginning at approximately 9:00 p.m. and ending around 4:30 a.m. on March 24, 2011. Similar to the Parker Rd. / I-225 site, time limitations meant that only one lane could be tested. The left-hand lane was chosen since it was expected that higher chloride values would be found on the lower side of the bridge. All tests were conducted on the overlay including, bond, and texture depth. Cores were taken for chloride and permeability testing. Friction testing occurred in May 2011, since the length of the bridge allowed the use of a fixed wheel tester. Both Flexogrid lanes were in good condition with no major cracking, spalling, or chipping. However, the delamination of the Flexogrid product was reported to Region 6 in 2012. Region 6 contacted the product supplier - Dow POLY-CARB to replace the delaminated Flexogrid layer. The supplier was responsible for all the costs except the traffic control. The replacement happened from Friday night, October 19, 2012 to Sunday, October 21,

2012. The contractor performed the sound test to establish the removal limits for defective materials. Then the deck was sandblasted for the overlay. The thin bonded overlay was applied on the deck with two stages. Finally, an additional overlay coat was applied to the materials left in place. Similar to Park Rd./I225 site, the study team collected eight 2" and eight 4" cores at left wheel path of the left-hand lane for chloride contents and permeability tests respectively. The two tests were completed in December, 2012. The last round of sample collection and testing was completed in June, 2013. The visual inspection during the sampling indicated the replaced overlay was intact. But it was found the overlay delaminated in the right lane approximately 800 feet from the north expansion joint.

Measurement of the overlay thickness was done using the permeability cores. Table 7.0.3.1 shows the results from the measurements. Measurements were taken similar to Parker Rd. / I-225, four per core, one in each quadrant of the sample, to the nearest 1/16th of an inch (0.15875 cm).

Table 7.0.3.1: Average thickness of I-25 / I-225 Flexogrid overlay

Sample No.	Quadrant 1	Quadrant 2	Quadrant 3	Quadrant 4	Average (in.)
1	0.5625	0.5000	0.5000	0.5625	0.5313
2	0.3125	0.4375	0.5000	0.3750	0.4063
3	0.5000	0.5625	0.5625	0.5625	0.5469
4	0.3125	0.4375	0.3750	0.3750	0.3750
5	0.2500	0.4375	0.3125	0.3750	0.3438
6	0.3750	0.4375	0.3750	0.3750	0.3906
7	0.5000	0.5000	0.5000	0.5625	0.5156
8	0.4375	0.5625	0.5000	0.6250	0.5313
			Total Average (in.)		0.4551
			Total Average (cm):		1.1559

Flexogrid is typically reported as being 0.25" (0.635 cm) thick. Measurements from the I-25 / I-225 installation show an overlay that is much thicker. In addition, the overlay was installed by mechanical means using specialized equipment. The Flexogrid overlay is thinner than the SafeLane overlay, but this is expected due to the smaller nominal aggregate size. The above measurements match other DOTs installations.

7.1 Problems During Installation and Testing

7.1.1 I-76 / WCR-53

Some specific preparations were needed due to the unique nature of the bridge deck on which the I-76 / WCR-53 SafeLane overlay was applied. Cracking of the asphalt bridge deck occurred at the approximate location of the bridge abutments and needed to be remediated prior to the overlay installation. The size of the cracks ranged from 0.5" to 1.0" (1.27 to 2.54 cm) wide to 1.0" (2.54 cm) deep, meaning that they had to be filled prior to the epoxy being placed. A solution devised by the Cargill representatives was to fill the cracks with SafeLane aggregate beforehand, thus providing filler for the epoxy to bind to. Figure 7.1.1.1 (a) shows the crack being filled and (b) shows the excess aggregate being swept off.

(a) (b)

Figure 7.1.1.1: Crack Filling with SafeLane (a) Filling of Deck Cracks and (b) Sweeping of Excess Aggregate

Subsequent inspection during the second round of testing revealed the abutment cracks came back. Deck reflection cracks are visibly coming through the overlay. This is important since cracks in the overlay essentially negate its effect as bridge deck protection. Figure 7.1.1.2 (a) shows the major cracks over the abutment and (b) the deck reflection cracking. The visual inspection in 2012 revealed the development of the abutment cracks and deck reflection cracks.

(a) (b)

Figure 7.1.1.2: SafeLane Cracking (a) Abutment, and (b) Reflection

Originally, skid resistance testing on the I-76 / WCR-53 bridge was attempted in September 2009. However it was discovered that the I-76 and WCR 53 bridge deck was too short to obtain quality data using the traditional fixed wheel skid tester. Figure 7.1.1.3 shows the skid resistance testing being performed. In April 2010 CDOT purchased a portable skid tester. This instrument was used to measure the skid resistance of the bridge deck prior to, and after overlay application between June 7 – 9, 2010.

Figure 7.1.1.3: Skid Resistance Testing on I-76 / WCR-53

While the I-76/WCR-53 bridge was too short, the Parker Rd. /I-225 and I-25/I-225 were of sufficient length that the fixed wheel skid tester was used on these bridges.

7.1.2 Parker Rd. / I-225

Weather related delays caused the SafeLane overlay at this location to have each lane installed at different times. The right lane was installed on October 7, 2009, while the left lane was installed on May 22, 2010.

When the right lane was installed in October 2009, the final epoxy batch was not mixed properly and did not cure correctly. That section of the overlay was stripped off and replaced by the contractor.

During the left lane installation in May 2010, the automated spreader broke with about 33% of the second aggregate course complete. The rest of the lane was finished using hand methods.

During testing the night of March 23, 2011, the core drill broke while permeability core number 6 was being drilled. This meant that 4" (10.16 cm) permeability cores 1 and 2, and the 2" (5.08 cm) chloride cores number 1 through 4 were not taken. The data results and analysis reflect the lesser number of cores.

During testing the night of June 4, 2013, it rained. The bonding test was not successfully performed in the field.

7.1.3 I-25 / I-225

No problems during installation or testing of the I-25 / I-225 overlay were recorded. All cores were taken, and inspection of the overlay shows that it was in good condition in 2011. The delamination of the Flexogrid product was reported in 2012. Figure 7.1.1.4 shows the delaminated area on the bridge. The overlay was replaced in October 2012. However, it delaminated again in July, 2013.

Figure 7.1.1.4 Delaminated Flexogrid Overlay

7.2 Sand Patch Test

7.2.1 I-76 / WCR-53

The sand patch test is used to determine the mean texture depth of the overlay and provides additional data regarding how the overlay wears over time. Initial measurements taken before and after installation of the overlay in June 2010 are shown in Table 7.2.1.1 and 7.2.1.2.

Table 7.2.1.1: June 2010 asphalt sand patch results

Sand Patch, I-76, Asphalt, June 2010				
Test Number	1	2	3	4
Sand Diameter (in.)	5.250	7.000	6.500	7.500
	5.500	6.250	6.500	8.000
	5.188	6.375	6.750	7.875
	6.000	7.000	6.250	8.000
Average Diameter (in.)	5.484	6.656	6.500	7.844
Area (sq. in.)	23.623	34.798	33.183	48.321
Average Depth (in)	0.063	0.043	0.045	0.031
Test Average (in.)	0.046			
Test Average (cm)	0.116			

Table 7.2.1.2: June 2010 SafeLane sand patch results

Sand Patch, I-76, Safe Lane, June 2010				
Test Number	1	2	3	4
Sand Diameter (in.)	3.375	3.500	3.500	3.375
	3.500	3.750	3.500	3.500
	3.625	3.750	3.500	3.375
	3.375	3.500	3.375	3.375
	2.500	2.750	3.000	2.750
	3.000	3.250	2.875	3.000
	2.875	3.125	2.875	2.875
	2.750	2.875	3.000	2.750
Average Diameter (in.)	3.469	3.625	3.469	3.406
Area (sq. in.)	9.450	10.321	9.450	9.113
Average Depth (in)	0.159	0.145	0.159	0.165
Test Average (in.)	0.157			
Test Average (cm)	0.398			

The mean texture depth (MTD) measurements taken after installation show that SafeLane initially has a fairly rough texture. This can be compared to the asphalt test by looking at the area the sand patches covered. For the asphalt test, the average circle size was 6.0 inches (15.24 cm). This drops to about 3.3 inches (8.382 cm) when the first measurements of SafeLane were taken. The larger the circle, the smaller the mean texture depth.

The initial measurements are compared to the second measurements taken in March 2011 to determine how quickly the surface of the overlay is wearing. The March 2011 results are shown in Table 7.2.1.3.

Table 7.2.1.3: March 2011 SafeLane sand patch

Sand Patch, I-76, SafeLane, March 2011					
Test Number	1	2	3	4	5
Sand Diameter (in.)	4.250	4.375	4.750	4.375	4.500
	4.500	4.500	5.000	4.675	4.675
	4.675	4.000	4.675	4.750	5.000
	4.250	4.675	4.500	4.500	4.500
Average Diameter (in.)	4.419	4.388	4.731	4.575	4.669
Area (sq. in.)	15.335	15.119	17.581	16.439	17.119
Average Depth (in)	0.098	0.099	0.085	0.091	0.088
Test Average (in.)	0.092				
Test Average (cm)	0.234				

The results from the March 2011 tests show that on average, 0.065 inches (0.1651 cm) of texture depth was lost since the installation of SafeLane; this was expected due to several factors.

The first measurement was taken directly after installation before any traffic had passed over the overlay. Thus any lightly bonded aggregate had not yet been worn off. Considering the total overlay depth is about 0.5 inches (1.27 cm), the reduction in the depth of the overlay is about 13% over the first year. While this seems like a large amount, the mean texture depth is still over double what the asphalt surface was prior to SafeLane being installed. Figure 7.2.1.1 shows a comparison of all texture depth measurements taken on I-76 / WCR-53.

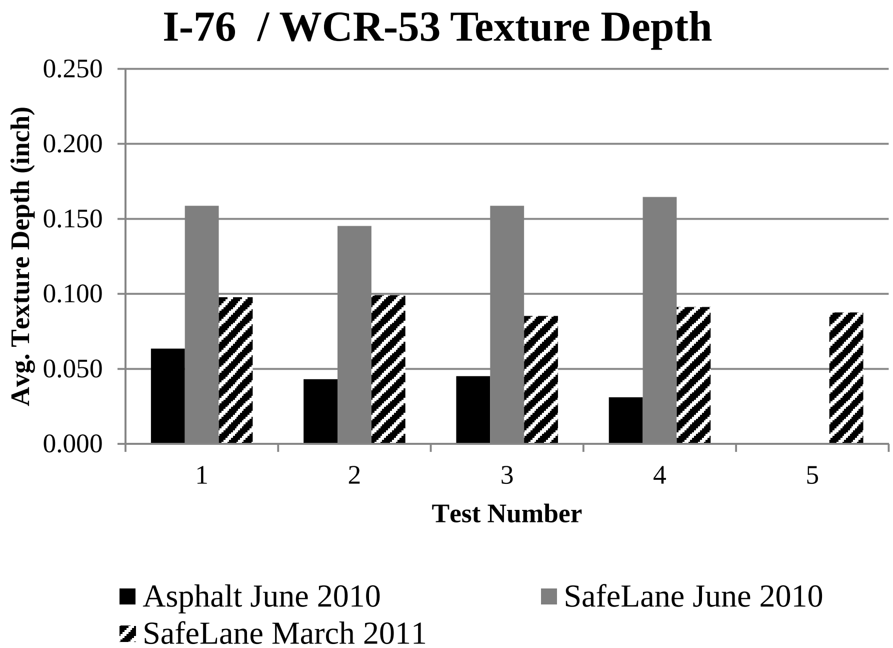


Figure 7.2.1.1: Mean Texture Depth of I-76 / WCR-53

The results show that even with one year's worth of wearing, the overlay still has a higher mean texture depth than the original asphalt surface. It is expected that over time, the rate of MTD loss will decrease to a steady state. Unlike the Parker Rd. / I-225 site, there is no difference in the installation dates of each lane, so a long-term comparison cannot be made at this point.

7.2.2 Parker Rd. / I-225

The first round of sand patch testing was performed on May 21, 2010, when the left-hand lane received the SafeLane overlay. At that time, the sand patch test was conducted on the bare concrete in the left lane, on the older SafeLane overlay in the right-hand lane, and another test in the left-hand lane after the installation of the new SafeLane overlay. Tables 7.2.2.1, 7.2.2.2 and 7.2.2.3 show the results obtained in June 2010 from the original concrete surface, 2009 SafeLane installation, and 2010 SafeLane Installation, respectively.

Table 7.2.2.1: June 2010 concrete sand patch results

Parker Rd. / I-225, Concrete Deck, May 21, 2010					
Test Number	1	2	3	4	5
Sand Diameter (in.)	7.500	8.000	5.500	9.500	6.500
	7.000	8.500	6.500	10.500	8.000
	8.500	8.000	6.250	10.500	8.000
	8.000	7.500	5.500	10.500	8.000
Average Diameter (in.)	7.750	8.000	5.938	10.250	7.625
Area (sq. in.)	47.173	50.265	27.688	82.516	45.664
Average Depth (in.)	0.032	0.030	0.054	0.018	0.033
Test Average (in.)	0.033				
Test Average (cm)	0.085				

Table 7.2.2.2: May 2010 right lane SafeLane sand patch results

Parker Rd. / I-225, RH SafeLane, May 21, 2010			
Test Number	1	2	3
Sand Diameter (in.)	5.250	4.000	4.500
	5.000	4.750	5.000
	5.250	4.000	4.750
	5.500	4.000	4.750
Average Diameter (in.)	5.250	4.188	4.750
Area (sq. in.)	21.648	13.772	17.721
Average Depth (in.)	0.069	0.109	0.085
Test Average (in.)	0.088		
Test Average (cm)	0.223		

Table 7.2.2.3: May 2010 left lane SafeLane sand patch results

Parker Rd. / I-225, LH SafeLane, May 21, 2010			
Test Number	1	2	3
Sand Diameter (in.)	3.250	3.500	3.000
	3.250	3.250	3.250
	3.250	3.250	3.250
	3.000	3.500	3.000
Average Diameter (in.)	3.188	3.375	3.125
Area (sq. in.)	7.980	8.946	7.670
Average Depth (in.)	0.188	0.168	0.196
Test Average (in.)	0.184		
Test Average (cm)	0.467		

The new SafeLane overlay tested in May 2010 (left lane) had a MTD greater than the new installation on I-76 / WCR-53. Each site is comparable in wearing. Of particular interest is the right lane which had been in place approximately half a year prior to when the measurements were taken. The MTD of the right lane is slightly higher than I-76 / WCR-53 March 2011 tests, which had been in service three months longer.

The right-hand lane was again tested in March 2011. Due to time constraints with testing, the left-hand lane was not tested. The time since the last test was approximately 10 months, which should give another indication of wearing over time. The results from the March test are shown in Table 7.2.2.4.

Table 7.2.2.4: March 2011 right lane SafeLane sand patch results

Parker Rd. / I-225 March 2011					
Test Number	1	2	3	4	5
Sand Diameter (in.)	5.125	4.750	5.250	4.500	4.500
	5.000	4.875	4.750	4.500	4.500
	5.000	4.750	5.250	4.375	4.625
	4.875	5.000	4.500	4.500	4.750
Average Diameter (in.)	5.000	4.844	4.938	4.469	4.594
Area (sq. in.)	19.635	18.427	19.147	15.684	16.574
Average Depth (in)	0.076	0.081	0.078	0.096	0.091
Test Average (in.)	0.084				
Test Average (cm)	0.215				

The March 2011 results are surprising in that they show very little additional wearing since the last test period. It makes sense that after the initial wearing period, the decrease in MTD would level off. Unfortunately MTD was not measured on the left-hand lane, but it is likely that it would have similar results to the right lane, and I-76 / WCR-53. It seems that no significant wearing occurs on SafeLane after one year.

The right-hand lane was tested in October, 2012. The results from the October test are shown in Table 7.2.2.5.

Table 7.2.2.5: October 2012 right lane SafeLane sand patch results

Parker Rd. / I-225 Left Wheel Path October 2012					
Test Number	1	2	3	4	5
Sand Diameter (in.)	4.00	4.88	4.50	4.88	5.00
	5.50	5.00	5.00	5.50	4.75
	3.88	4.75	4.25	5.00	5.25
	4.31	4.50	3.75	4.88	4.75
Average Diameter (in.)	4.42	4.78	4.38	5.07	4.94
Area (sq. in.)	15.35	17.95	15.03	20.14	19.14
Average Depth (in)	0.098	0.084	0.100	0.074	0.078
Test Average (in.)	0.087				
Test Average (cm)	0.220				

Comparing to the May, 2010 immediately after the installation of the SafeLane, the MTD was reduced 0.097 in over a period of 29 months. The majority wearing occurs in the initial wearing period.

In June 2013, the right-hand lane was tested again. The MTD at the right wheel path, center of lane, and left wheel path were measured. The results from the June 2013 test are shown in Table 7.2.2.6-7.2.2.8.

Table 7.2.2.6: June 2013 right lane SafeLane sand patch results (right wheel path)

Parker Rd. / I-225	Right Wheel Path	June 2013		
Test Number	1	2	3	4
Sand Diameter (in.)	5.15	5.29	5.12	5.49
	5.34	5.55	4.69	6.74
	4.82	5.81	5.43	5.02
	6.00	5.16	4.87	5.49
Average Diameter (in.)	5.33	5.45	5.03	5.69
Area (sq. in.)	22.27	23.35	19.84	25.38
Average Depth (in)	0.067	0.064	0.076	0.059
Test Average (in.)	0.067			
Test Average (cm)	0.169			

Table 7.2.2.6: June 2013 right lane SafeLane sand patch results (center of lane)

Parker Rd. / I-225	Center of Lane	June 2013		
Test Number	1	2	3	4
Sand Diameter (in.)	5.60	6.30	5.58	5.92
	5.81	6.24	6.65	4.78
	6.47	5.35	5.05	5.44
	6.04	6.54	5.79	5.05
Average Diameter (in.)	5.98	6.11	5.77	5.30
Area (sq. in.)	28.07	29.28	26.11	22.03
Average Depth (in)	0.053	0.051	0.057	0.068
Test Average (in.)	0.058			
Test Average (cm)	0.146			

Table 7.2.2.7: June 2013 right lane SafeLane sand patch results (left wheel path)

Parker Rd. / I-225 Left Wheel Path June 2013				
Test Number	1	2	3	4
Sand Diameter (in.)	6.93	5.19	4.69	6.29
	5.36	5.94	5.29	6.16
	5.56	5.05	5.39	6.38
	5.99	4.88	5.20	5.90
Average Diameter (in.)	5.96	5.26	5.14	6.18
Area (sq. in.)	27.90	21.73	20.77	30.00
Average Depth (in)	0.054	0.069	0.072	0.050
Test Average (in.)	0.061			
Test Average (cm)	0.156			

The data in the three tables show there is little additional wearing since the last test period, which confirms that after the initial wearing period, the decrease in MTD would level off. In addition, the MTDs at different locations in the left lane are very close to each other.

Comparing all the surfaces on Parker Rd. / I-225 to each other confirm what was found on I-76 / WCR-53, that after the initial wearing period of approximately one year, the SafeLane surface reaches a MTD that changes very little. The high initial losses were a cause for concern, but being able to see the right-hand lane of Parker Rd. / I-225 in service for about 1.5 years, show that the initial wearing was simply a breaking in period.

7.2.3 I-25 / I-225

The measurements taken in March 2011 for I-25 / I-225 are considered baseline measurements for the overlay at this location since no other texture depth testing was performed. Table 7.2.3.1 shows the results obtained in March 2011. The results show how the smaller aggregate size on I-25 / I-225 produces a smaller MTD.

Table 7.2.3.1: March 2011 Flexogrid sand patch test results

I-25 / I-225 March 2011					
Test Number	1	2	3	4	5
Sand Diameter (in.)	7.500	6.250	6.250	6.500	7.250
	6.000	6.250	6.250	6.375	7.000
	6.750	6.375	6.250	6.375	6.675
	6.750	6.375	6.625	6.250	7.000
Average Diameter (in.)	6.750	6.313	6.344	6.375	6.981
Area (sq. in.)	35.785	31.296	31.607	31.919	38.279
Average Depth (in)	0.042	0.048	0.047	0.047	0.039
Test Average (in.)	0.045				
Test Average (cm)	0.114				

Because the Flexogrid was replaced in October 2012, the sand patch test was not performed until June 2013. The MTDs at the right wheel path, center of lane, and left wheel path in the right lane was measured, which are summarized in Table 7.2.3.2-7.2.3.4.

Table 7.2.3.2: June 2013 Flexogrid sand patch test results (right wheel path)

I-25 / I-225 Right Wheel Path June 2013				
Test Number	1	2	3	4
Sand Diameter (in.)	5.76	5.36	5.14	5.12
	6.18	5.18	4.52	5.33
	5.09	5.02	4.93	5.59
	5.90	5.10	5.40	5.52
Average Diameter (in.)	5.73	5.16	5.00	5.39
Area (sq. in.)	25.80	20.94	19.61	22.79
Average Depth (in)	0.058	0.072	0.077	0.066
Test Average (in.)	0.068			
Test Average (cm)	0.173			

Table 7.2.3.3: June 2013 Flexogrid sand patch test results (center of lane)

I-25 / I-225 Center of Lane June 2013				
Test Number	1	2	3	4
Sand Diameter (in.)	4.87	5.21	4.92	4.77
	4.94	5.92	4.98	5.56
	4.76	5.51	5.50	4.69
	4.58	6.03	4.54	5.25
Average Diameter (in.)	4.79	5.67	4.98	5.07
Area (sq. in.)	17.98	25.20	19.50	20.15
Average Depth (in)	0.083	0.060	0.077	0.074
Test Average (in.)	0.074			
Test Average (cm)	0.187			

Table 7.2.3.3: June 2013 Flexogrid sand patch test results (left wheel path)

I-25 / I-225 Left Wheel Path June 2013				
Test Number	1	2	3	4
Sand Diameter (in.)	5.42	4.19	4.73	4.70
	5.01	5.12	5.94	5.17
	5.13	4.66	4.54	5.09
	5.02	4.68	5.77	5.38
Average Diameter (in.)	5.14	4.66	5.24	5.09
Area (sq. in.)	20.77	17.06	21.58	20.30
Average Depth (in)	0.072	0.088	0.069	0.074
Test Average (in.)	0.076			
Test Average (cm)	0.193			

Smaller MTDs are due to smaller aggregates. No conclusions of long-term performance of Flexogrid can be drawn without additional points of data.

7.3 Friction Tests

7.3.1 I-76 / WCR-53

Skid testing using the British Pendulum Test was performed to see how the friction value of the overlay changed since its installation in June 2010. Unfortunately, the British Pendulum Numbers (BPN) cannot be correlated to the locked-wheel test, so these results can only be compared to other British Pendulum Tests. Table and Figure 7.3.1.1 shows the skid test values that were obtained using the BPT.

Table 7.3.1.1: June 2010 portable skid test results on I-76 / WCR-53

Surface	Asphalt				SafeLane				SafeLane				
Test Date	June 2010				June 2010				March 2011				
Test Number	1	2	3	4	1	2	3	4	1	2	3	4	5
Skid Resistance Number	82	78	78	79	79	79	79	72	77	80	70	70	68
	81	77	78	79	94	73	77	79	77	81	70	71	70
	81	77	78	79	86	83	77	79	78	82	71	72	74
	81	77	79	79	85	83	78	81	79	86	74	72	73
	80	77	79	79	84	82	78	80	81	86	75	72	72
Average	81	77	78	79	86	80	78	78	78	83	72	71	71
Test Average	79				80				75				

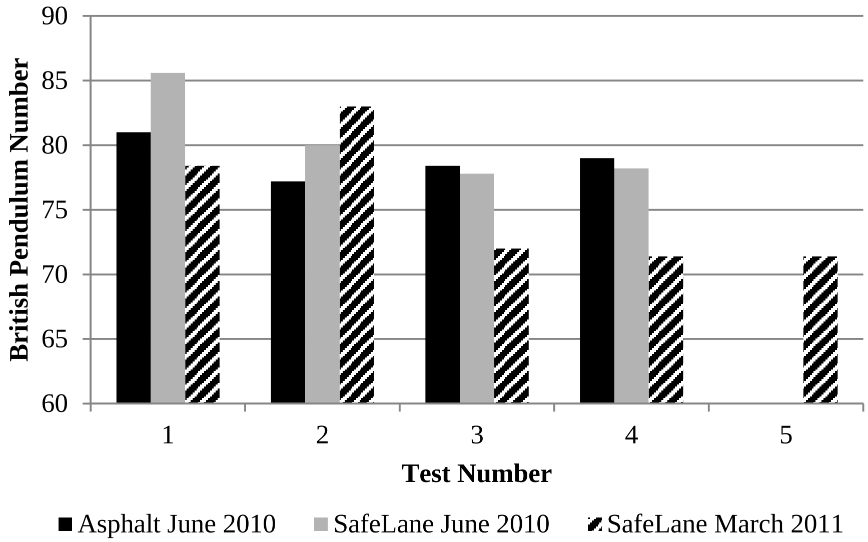


Figure 7.3.1.1: I-76 / WCR-53 Skid Resistance Numbers Over Time

The results indicate that the I-76 / WCR-53 overlay has held its traction capability over time. After 9 months in service, the BPN has dropped by 5, which is relatively small.

7.3.2 Parker Rd. / I-225

Parker Rd. / I-225 was measured with both a smooth and ribbed tire. The original concrete surface was only measured with a ribbed tire. The ribbed fixed-wheel results are shown in Table 7.3.2.1, with the smooth fixed-wheel results in Table 7.3.2.2. Figure 7.3.2.1 compares both wheel tests to all surfaces.

Table 7.3.2.1: Ribbed fixed wheel skid numbers on Parker Rd. / I-225

Surface	Concrete		SafeLane		SafeLane	
Date	October 2009		July 2010		May 2011	
Lane	Left	Right	Left	Right	Left	Right
Ribbed Tire Skid Number	56.1	58.2	83.5	66.2	69.8	55
	53.8	61.4	70.4	61.7	54.6	54.9
	53.5	58.6	71.5	60.7	54.9	48.9
	52.7	62.9	79.1	52.6	50.9	51.8
	57.9	62.3	-	65.4	55.9	53.8
	-	-	-	54.7	-	-
Average	54.8	60.68	76.13	61.32	57.22	52.88
Test Average	57.74		68.72		55.05	

Table 7.3.2.2: Smooth fixed wheel skid numbers on Parker Rd. / I-225

Surface	SafeLane			
Date	July 2010		May 2011	
Lane	Left	Right	Left	Right
Smooth Tire Skid Number	83.5	61	64.3	55.5
	71.2	54.1	50.7	50.7
	68.6	54.2	53.2	47.7
	76.4	51.8	48.1	51
	75	55.1	55.9	50.4
Average	74.94	55.24	54.44	51.06
Test Average	65.09		52.75	

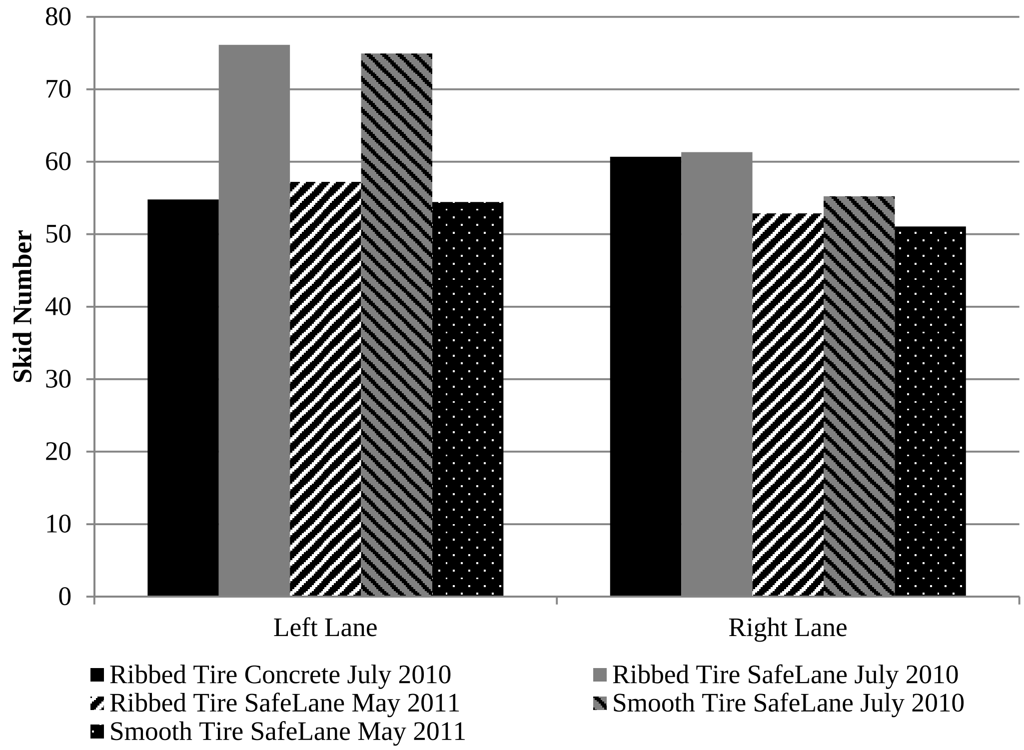


Figure 7.3.2.1: Parker Rd. / I-225 Skid Resistance Numbers Over Time

The data shows very good skid numbers. Traditionally, any skid number over 35 is deemed acceptable. In this case, the skid numbers easily exceed this baseline value. in addition, the concrete surface on Parker Rd. / I-225 had a high skid number. The latest SafeLane skid numbers are slightly below the concrete skid numbers, but still well above 35. The ribbed and smooth fixed-wheel results are very close to one another, showing good micro- and macrotexture traction. This indicates that dry and wet weather performance should be ideal.

Loss of skid number does not seem to be an issue as well. The older right lane SafeLane installation shows smaller decreases in skid numbers over time. The left lane seems to be matching the rate of decrease; within statistical variation as well.

The SafeLane installation on Parker Rd. / I-225 is performing very well by maintaining high friction numbers over its study period. However, any skid resistance increase achieved by the SafeLane was lost after the first year of service. Naturally, the overlays should continue to be monitored so that long-term performance can be determined.

7.3.3 I-25 / I-225

The same ribbed and smooth fixed-wheel tests were performed on Flexogrid. Since both lanes of Flexogrid were installed at the same time, it is expected that each lane should produce similar skid numbers. Table 7.3.3.1 and 7.3.3.2 show the ribbed and smooth wheel skid numbers, respectively. Figure 7.3.3.1 shows a comparison of all the results over time.

Table 7.3.3.1: Ribbed fixed wheel skid numbers on I-25 / I-225

Surface	Concrete		Flexogrid		Flexogrid	
Date	October 2009		July 2010		May 2011	
Lane	Left	Right	Left	Right	Left	Right
Ribbed Tire Skid Number	50.3	49.7	65.8	67.3	59.3	55.3
	46	50	69.3	66.3	53.9	57.1
	45.1	51.7	61.9	59.7	59.7	57.5
	51.2	49.8	64.4	61.9	53.6	57.5
	49.7	-	65.8	63.4	57.1	60.6
Average	48.46	50.3	65.44	63.72	56.72	57.6
Test Average	49.38		64.58		57.16	

Table 7.3.3.2: Smooth fixed wheel skid numbers on I-25 / I-225

Surface	Flexogrid			
Date	July 2010		May 2011	
Lane	Left	Right	Left	Right
Smooth Tire Skid Number	54.3	57.70	46.5	46
	59.5	50.80	43.3	46.8
	48.5	51.40	45	44.6
	60.1	50.60	41.8	43.8
	58.5	52.50	50.2	44
Average	56.18	52.6	45.36	45.04
Test Average	54.39		45.20	

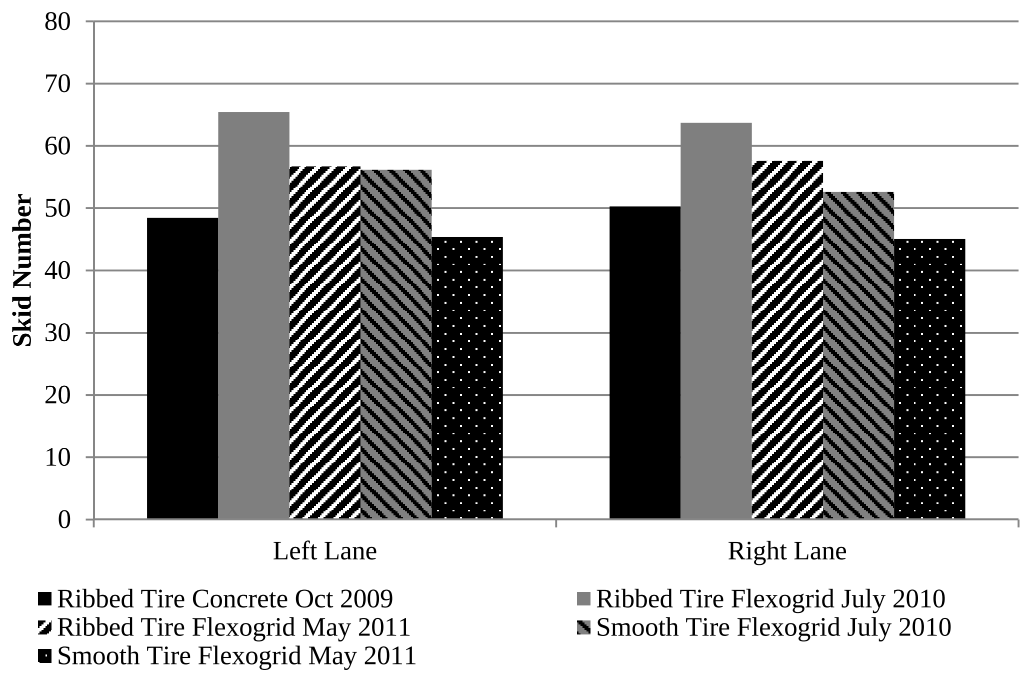


Figure 7.3.3.1: I-25 / I-225 Skid Resistance Numbers Over Time

The data shows that Flexogrid maintains good skid numbers over time as well. As with SafeLane, a high skid number was initially seen, which slightly decreased over time.

Both lanes are decreasing at the same rate, which indicates that they are both wearing evenly.

The ribbed vs. smooth locked wheel results are particularly interesting. The ribbed wheel results are quite high, higher than any other surface tested. This indicates a very good dry weather performance, since ribbed tires are primarily affected by the microtexture. The smooth tire results show worse, although still good, wet weather performance since the smooth tires are more affected by the overlay macrotexture. Flexogrid is showing good skid numbers and is performing at least as well as the concrete surface it replaced with regards to surface friction.

7.4 Bond Tests

Bond testing was conducted in March 2011 at the three sites using 3 in. steel disks, and performed again in June 2013 at I25/I225 in the field only using 2 in. steel disks. The James Bond Tester was borrowed from Cargill. Due to the rain on 6/4/2013, the bonding test was not successful at the Parker Rd./I225. According to Cargill's specifications, the ideal results for SafeLane should show bond strengths above 250psi (1.72 MPa), with all failures within the bridge deck surface, and none in the overlay or overlay/bridge deck interface. PolyCarb only specifies that Flexogrid should have 100% failure in the concrete substrate.

7.4.1 I-76 / WCR-53

While bond testing asphalt is usually not performed due to low failure strength, the author deemed it important to verify that the SafeLane overlay was meeting strength specifications. In addition, it provided a comparison for the SafeLane system in use on

Parker Rd. / I-225. Four bond tests were conducted in 2 pairs approximately 15 feet (4.572 m) from the center of the bridge in both the west and east directions inside the shoulder. The results from the bond test are shown in Table 7.4.1.1. Figure 7.4.1.1 shows the results of the bond testing with respect to the 250 psi (1.72 MPa) specified by Cargill. Patching of the holes was done with epoxy and extra SafeLane aggregate.

Table 7.4.1.1: I-76 / WCR-53 bond strength results

Location	Test No.	Failure Strength		Bond Strength		Failure Type
		lbs	kN	psi	MPa	
E1	1	800	3.56	118	0.18	Asphalt
	2	750	3.34	111	0.77	Asphalt
E2	3	800	3.56	118	0.18	Asphalt
	4	725	3.23	107	0.74	Asphalt

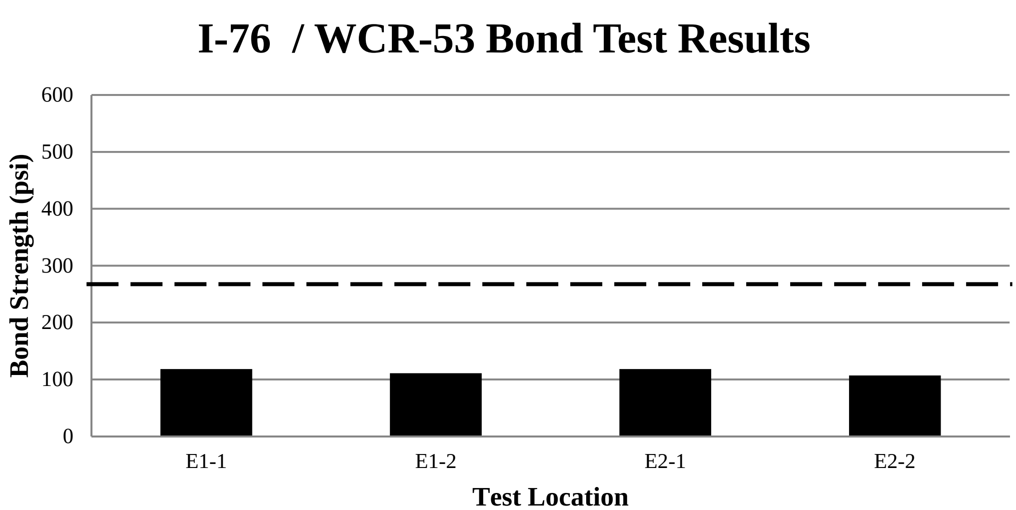


Figure 7.4.1.1: I-76 / WCR-53 Bond Strengths Compared to 250 PSI

At first glance, the overlay does not seem to meet the required 250 psi (1.72 MPa). However, because the I-76 / WCR-53 overlay is bonded to asphalt, it is expected that the total bond strength would be less than bridge decks made of concrete. The lower bond strength numbers are okay as long as the failure occurs in the asphalt deck, and not the asphalt/overlay bond, or in the overlay itself. The results from the bond test were good, showing a failure at all 4 locations in the asphalt surface instead of the overlay. The failure strengths are within the standard deviation of the mean, showing a good range of values for the test. Figure 7.4.1.2 shows the failure modes of the bond test.

Figure 7.4.1.2: Asphalt Bond Test Failure Modes

7.4.2 Parker Rd. / I-225

Bond testing on the Parker Rd. / I-225 bridge consisted of 2 sets of 4 locations, for 8 total bond tests. The test groups were located every 150 feet (45.72 m) from the beginning of the bridge. Adhesion of the disks to the overlay occurred between 9:30 p.m. and 11:30 p.m.. Final pull off was conducted starting at 4:00 a.m. to allow the epoxy enough time to cure. Table 7.4.2.1 shows the results of the test, while Figure 7.4.2.1 shows the results compared to the 250 psi (1.72 MPa) specification.

Table 7.4.2.1: Parker Rd. / I-225 bond strength results

Core ID	Failure Strength (lbs.)		Bond Strength (PSI)		Failure Type
	lbs	kN	psi	MPa	
R1 - 150 ft.	2800	12.5	432	2.98	Concrete
R2 - 300 ft.	2200	9.8	339	2.34	Concrete
R3 - 450 ft.	2400	10.7	370	2.55	Concrete
R4 - 600 ft.	2500	11.1	385	2.66	Concrete
R5 - 750 ft.	2300	10.2	354	2.44	Concrete
R6 - 900 ft.	2600	11.6	401	2.76	Concrete
R7 - 1050 ft.	2400	10.7	370	2.55	Concrete
R8 - 1200 ft.	2000	8.9	308	2.13	Concrete

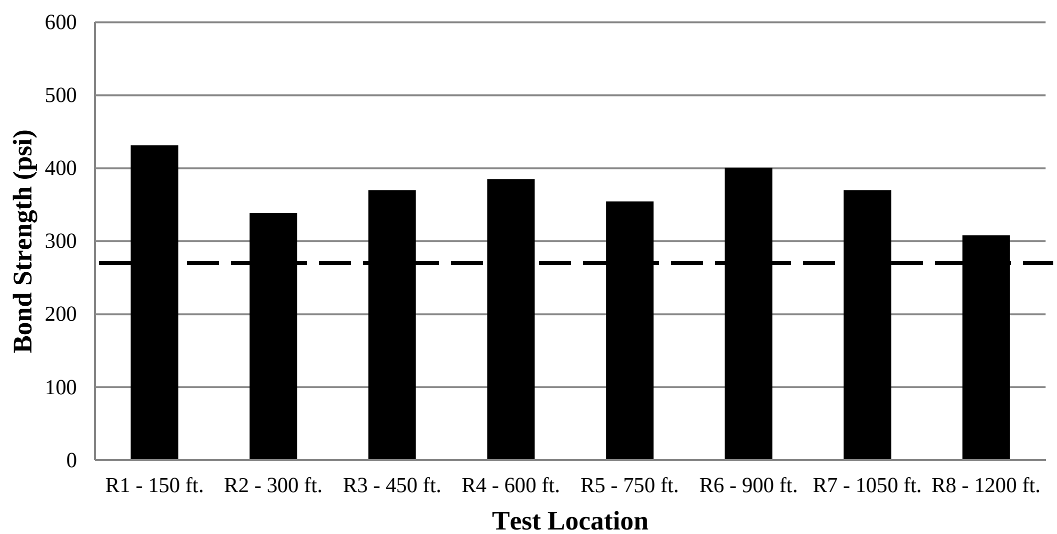


Figure 7.4.2.1: Parker Rd. / I-225 Bond Strengths Compared to 250 PSI

All 8 tests were successful, causing failures in the concrete deck. The lowest bond strength was 308 psi (2.13 MPa), which exceeds the 250 psi (1.72 MPa) minimum adhesive requirement for the SafeLane system. The first sample, R1 fell on the high side of the standard deviation of the mean. Figure 7.4.2.2 shows all the bond failures within the concrete.

Figure 7.4.2.2: Test Cores from Parker Road / I-225 Bond Testing

7.4.3 I-25 / I-225

In March 2011, bond testing on the I-25 / I-225 was the same as Parker Rd. / I-225, 2 sets at 4 locations, for 8 total bond tests. The test groups were located every 150 feet (45.72 m) from the beginning of the bridge. Adhesion of the disks to the deck occurred between 9:30 p.m. and 11:30 p.m.. Final pull off was conducted starting at 4:00 a.m. to allow the epoxy enough time to cure. Table 7.4.3.1 shows the results of the test, while Figure 7.4.3.1 shows which tests pass the minimum 250 psi (1.72 MPa).

Table 7.4.3.1: March 2011 Bond test results from I-25 / I-225

Core ID	Failure Strength (lbs.)		Bond Strength (PSI)		Failure Type
	lbs	kN	psi	MPa	
L1 - 150 ft.	3400	15.1	524	3.61	Overlay / Concrete
L2 - 300 ft.	2400	10.7	370	2.55	Overlay / Concrete
L3 - 450 ft.	3000	13.3	462	3.19	Overlay
L4 - 600 ft.	1200	5.3	185	1.28	Epoxy
L5 - 750 ft.	2200	9.8	339	2.34	Overlay
L6 - 900 ft.	2600	11.6	401	2.76	Concrete
L7 - 1050 ft.	2800	12.5	432	2.98	Concrete
L8 - 1200 ft.	3400	15.1	524	3.61	Concrete

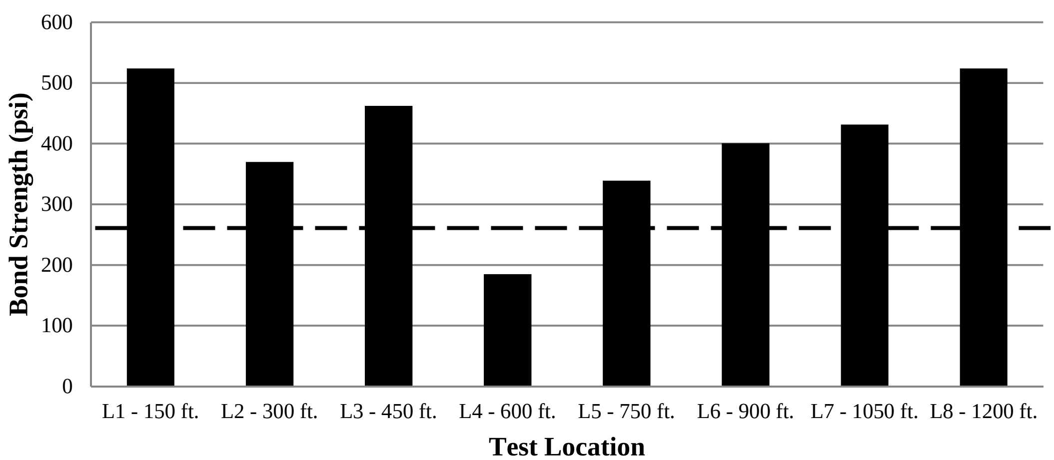


Figure 7.4.3.1: I-25 / I-225 Bond Strengths Compared to 250 PSI

Only 7 of the tests yielded useful data. Tests L1 and L2 reached acceptable strengths, but failure was partially between the overlay and bridge deck interface. Test L3 pulled some of the overlay off with it, but still managed to yield results. Test L4 suffered de-bonding failure of the bond test epoxy before the overlay failed, thus negating any results for this test spot. Test L5 also reached acceptable strengths, but was a complete overlay / bridge deck interface failure. Tests L6, L7, L8 were successful since they all failed in the concrete deck. Test L1, L2, and L5 seem to indicate that the overlay will fail at these locations before the deck. However the strengths at which these samples failed makes it seem unlikely that an overlay failure would occur at these locations. Figure 7.4.3.2 shows the failure modes of the bond tests.

Figure 7.4.3.2: Test Cores from I-25 / I-225 Bond Testing

Some possible sources of error are with execution of the test process. The testing was conducted at night with low temperatures, so a propane torch was used to heat the test disk to speed up curing of the epoxy. Due to inexperience on the part of the testers, it is possible that not all the disks reached a high enough temperature to sufficiently cure the epoxy. This seems to be the case with sample L4, although the other samples seem to have reached a high enough strength to cause failures elsewhere.

Failures of samples L1 and L2 are puzzling since they failed in both the overlay/substrate bond, and the substrate. The best explanation is that a moment was applied about the test device during testing which caused a peeling failure of the sample. That would mean the overlay/substrate bond failed first, with the failure plane moving into the substrate as lateral force is applied to the test device. This would be operator error.

If L4 is removed from the sample data, 5 of the samples fall within a standard deviation of the mean. The two outside the standard deviation, L1 and L8, fall on the high side, which shows exceptional bond strength at these locations, even though L1 was a partial overlay failure.

Overall the results are mixed. On one hand, the highest failure strengths out of all the bond tests were seen on I-25 /I-225. On the other hand, failures occurred where they should not have; in the overlay and in the overlay/substrate bond. While these failures indicate poor overlay adhesion, the strength they failed at does not.

In June 2013, bond testing on the I-25 / I-225 was performed again for the Flexgrid overlay replaced in October 2012. Eight samples were located every 150 feet (45.72 m) at the left wheel path of the left lane from the beginning of the bridge (expansion joint in the north). Adhesion of the 2 in. disks to the deck occurred between 9:30 p.m. and 11:30 p.m.. Final pull off was conducted starting at 1:00 a.m. to allow the epoxy enough time to cure. Table 7.4.3.2 and Figure 7.4.3.2 shows the results of the test.

Table 7.4.3.2: June 2013 Bond test results from I-25 / I-225

Core ID	Failure Strength		Bond Strength		Failure Type
	lbs	kN	psi	MPa	
L1 - 150 ft.	1450	6.45	462	3.18	Concrete
L2 - 300 ft.	2000	8.90	637	4.39	Overlay/Concrete
L3 - 450 ft.	-	-	-	-	Epoxy
L4 - 600 ft.	600	2.67	191	1.32	Overlay/Concrete
L5 - 750 ft.	630	2.80	201	1.38	Overlay/Concrete
L6 - 900 ft.	1200	5.34	382	2.63	Concrete
L7 - 1050 ft.	-	-	-	-	Epoxy
R8 - 1200 ft.	1000	4.45	318	2.20	Overlay/Concrete

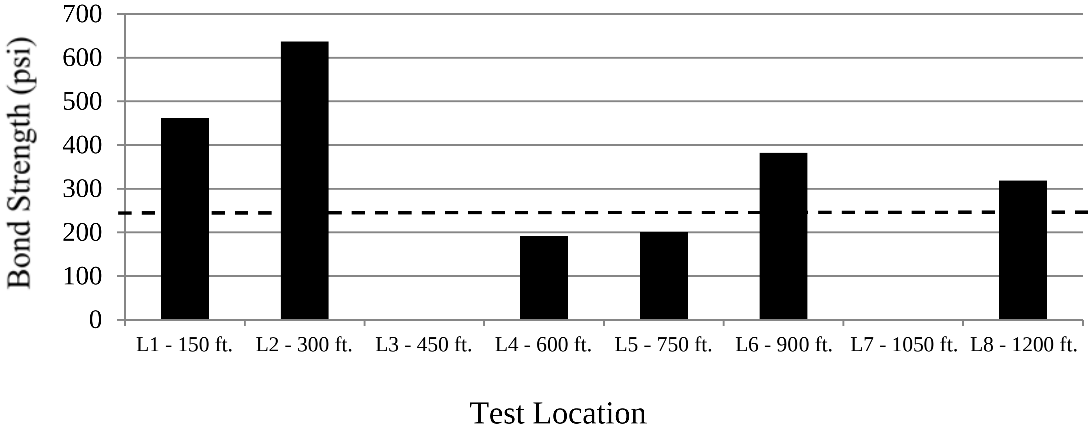


Figure 7.4.3.3: I-25 / I-225 Bond Strengths Compared to 250 PSI

There are two tests below 250 psi, which indicate are a poor adhesion of the overlay with the concrete deck. But four out of six successful tests have the same failure type, which occurs at the interface of the overlay and concrete. This may explain the delamination of the overlay observed again in July 2013.

7.5 Rapid Chloride Permeability Test

7.5.1 I-76 / WCR-53

The most recent permeability testing conducted at I-76 and WCR-53 was in October 2009 with the first set of chloride testing. Due to how recent the last permeability test results are, and the expectation that permeability of such an old bridge deck will not change significantly, they were not conducted again in March 2011 and the subsequent inspections. The results from the October 2009 test are show below in Figure 7.5.1.1 and Table 7.5.1.1.

Table 7.5.1.1: October 2009 I-76 / WCR-53 permeability results

Permeability, I-76, October 2009		
Sample ID	Reading (Coulombs)	Classification (ASTM 1202)
East 1	833	Very Low
West 1	1044	Low

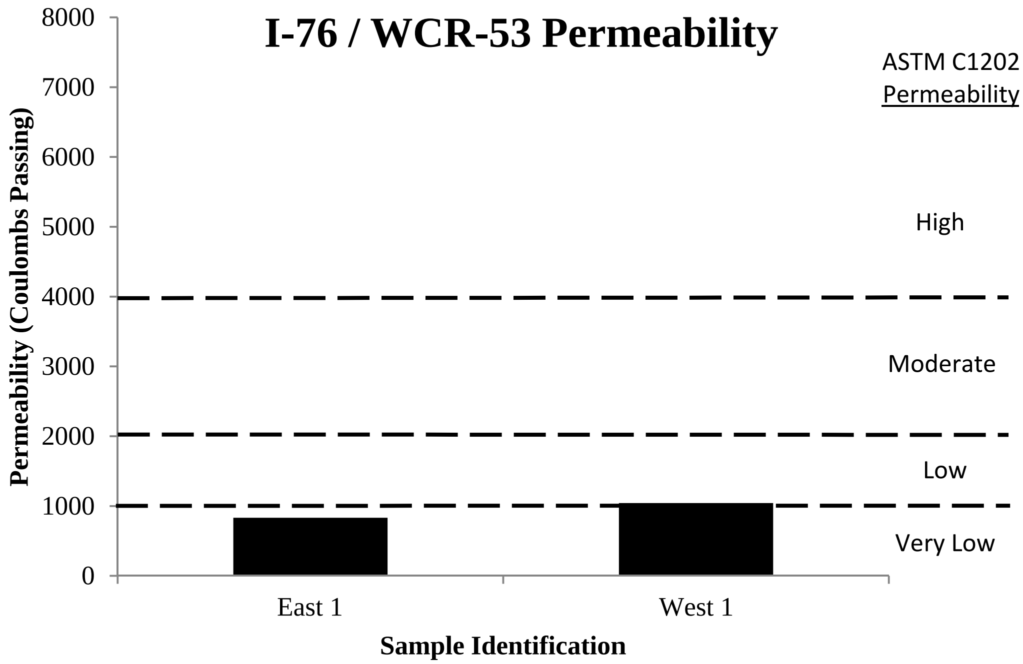


Figure 7.5.1.1: I-76 / WCR-53 Permeability Classification

The permeability results indicated a low to very low permeable concrete. Due to the age of the concrete deck (40 to 50 years old) this is no surprise. This also validates the low chloride contents measured from the bridge deck samples that is discussed in the next section.

7.5.2 Parker Rd. / I-225

Only six 4" (10.16 cm) diameter cores were taken from the deck in preparation for permeability testing due to the core drill breaking during the March 2011 testing. These cores were taken approximately every 150 feet (45.72 m) in the right-hand shoulder near the barrier. After removal of the cores, the holes were patched with standard concrete. Table 7.5.2.1 shows the results. Figure 7.5.2.1 shows the results with the classification.

Table 7.5.2.1: March 2011 Parker Rd. / I-225 permeability results

Parker Rd. / I-225		
Sample No.	6 Hour Value	Permeability Class
R1 - 150 ft.	-	-
R2 - 300 ft.	-	-
R3 - 450 ft.	6016	High
R4 - 600 ft.	4486	High
R5 - 750 ft.	6248	High
R6* - 900 ft.	4638	High
R7 - 1050 ft.	7358	High
R8 - 1200 ft.	5994	High
*Note: Over-current at 2:15, test stopped.		

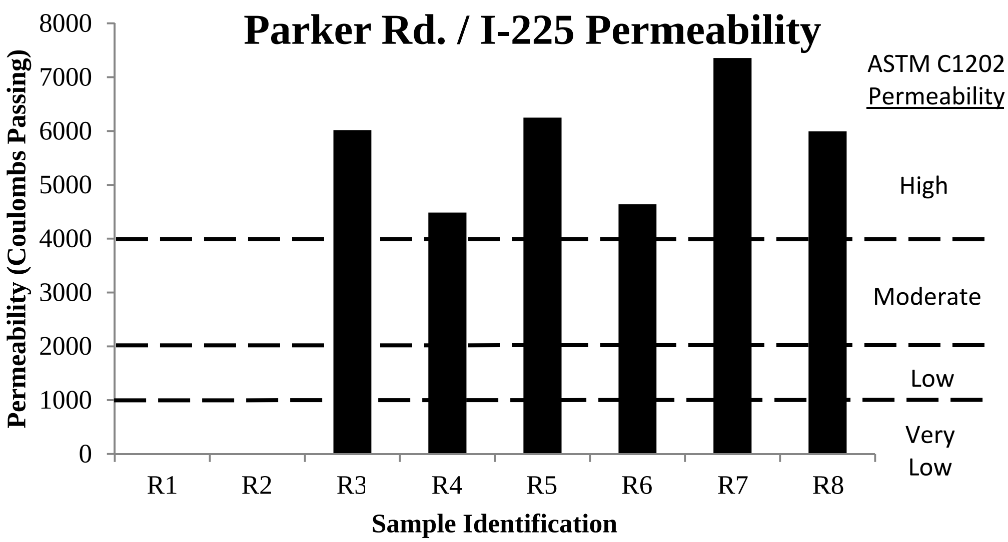


Figure 7.5.2.1: Parker Rd. / I-225 Permeability Classification

The permeability results for Parker Rd. / I-225 were rather surprising. The recorded values were extremely high, especially for CDOT Class D concrete, which has a coulomb passing requirement of 2000 at 28 days of age. This bridge deck is over 10 years old, having been constructed around 2002, and should be in the low to very low permeability class. The high permeability results indicate a problem with the test.

There are two possible sources of error that could explain these results. The first is that several of the samples had cracks running through them, which could have artificially shown a higher permeability. Figure 7.5.2.2 shows sample R7 with the crack.

Figure 7.5.2.2: Cracked Permeability Sample R7

These cracks were found before the test was conducted and additional silicon sealer was applied to the crack face. This should have reduced the permeability of the sample, however it seems to have been ineffective, as sample R7 had the highest measured permeability. Other samples did not have visible cracks, but permeability results remained high.

The second source of error is hypothesized to be from the high chloride contents of the bridge deck. Since the bare concrete that was tested for permeability was the wearing surface up until the installation of SafeLane, it received a significant amount of deicing chemicals. Although chloride content is shown in the next section, it was high enough that it may have influenced the test results. There is some literature that supports higher permeability values from the RCPT can be a result of high chloride contents of samples.

It is known that admixtures themselves can affect the apparent permeability, so it would make sense that free chlorides can as well. The free chloride would help increase the current flow, thus showing higher coulombs passed than what actually occurred.

Half the samples are outside the standard deviation, but this is not surprising since the RCPT has a high degree of variation, and hence why ASTM recommends that permeability be reported as a classification rather than a specific number. Regardless, the permeability of the concrete on Parker Rd. / I-225 is classified as high, which means a protective overlay is all the more important.

Eight 4" diameter cores which are 100' apart were collected at the left wheel path in the left lane in October, 2012. The permeability tests were completed in December, 2012. When the 2 in thick concrete slice samples were prepared, sample 2 and 8 cracked. Table 7.5.2.2 shows the results of other six samples.

Table 7.5.2.2: October 2012 Parker Rd. / I-225 permeability results

Parker Rd./I225		
No.	6 Hr Value	Class
1- 100 ft	1390	Low
2 - 200 ft	-	
3 - 300 ft	1886	Low
4 - 400 ft	597	Very low
5 - 500 ft	160	Very low
6 - 600 ft	1197	Low
7 - 700 ft	1370	Low
8 - 800 ft	-	

The permeability is in the low to very low permeability class as indicated in Table 7.5.2.2. However, there are big differences between this round and the previous round of testing. Therefore, the permeability testing was performed again in June 2013 to validate the testing results. Another eight 4” diameter cores were collected at the same locations on June 4, 2013. The permeability tests were completed in June, 2013. Table 7.5.2.3 shows the results of other six samples.

Table 7.5.2.3: June 2013 Parker Rd. / I-225 permeability results

Parker Rd./I-225		
No.	6 hr. Value	Class
1- 100 ft	4163	High
2- 200 ft	4381	High
3- 300 ft	2508	Moderate
4- 400 ft	5022	High
5- 500 ft	3570	Moderate
6- 600 ft	5337	High
7- 700 ft	4431	High
8- 800 ft	3223	Moderate

Based on the testing results, it can be concluded the permeability of the concrete deck at the Parker Rd./I225 is in the range of moderate and high. As discussed before, it might be caused by the high chloride contents of the bridge deck.

7.5.3 I-25 / I-225

Eight 4" (10.16 cm) diameter cores were taken from the deck in preparation for permeability testing. These cores were taken approximately every 150 feet (45.72 m) in the left-hand shoulder near the barrier. After removal of the cores, the holes were patched with standard concrete. Table 7.5.3.1 shows the permeability results. Figure 7.5.3.1 shows the results and their classification.

Table 7.5.3.1: March 2011 I-25 / I-225 permeability results

I-25 / I-225 Permeability Values		
Sample No.	6 Hour Value	Permeability Class
L1 - 150 ft.	3188	Moderate
L2 - 300 ft.	4400	High
L3 - 450 ft.	4214	High
L4 - 600 ft.	1976	Low
L5 - 750 ft.	2066	Moderate
L6 - 900 ft.	2884	Moderate
L7 - 1050 ft.	2850	Moderate
L8 - 1200 ft.	2114	Moderate

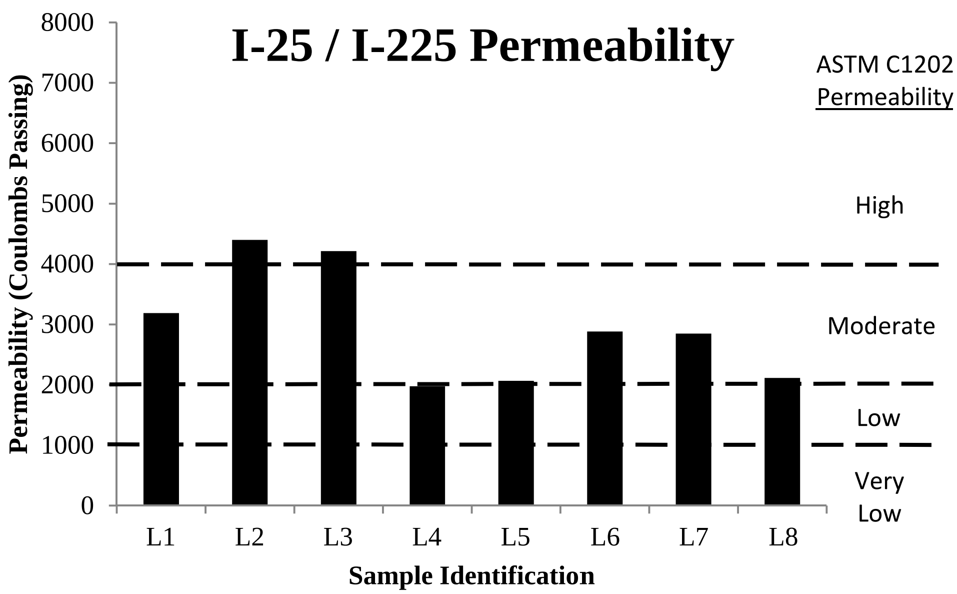


Figure 7.5.3.1: I-25 / I-225 Permeability Classification

Because Parker Rd. / I-225 had such high permeability, and since I-25 / I-225 was constructed around the same time, it was expected that the permeability of each would be similar. However, the permeability of I-25 / I-225 is less, and more in range with what would be expected. CDOT Class D concrete was specified for I-25 / I-225, so its results should be below 2000 coulombs. It is possible that the high permeability values are due to free chlorides in the deck, similar to Parker Rd. / I-225.

Cores L2 and L3 are the only two that were outside the standard deviation of the mean, which shows that the results are fairly consistent. The overall permeability classification of the concrete at I-25 / I-225 is low to high, with the majority being moderate.

In the second round of sample collection, eight 4" diameter cores were taken in October, 2012 from the deck in preparation for permeability testing. These cores were taken approximately every 100 feet at the left wheel path in the left lane. After removal of the cores, the holes were patched with standard concrete. Table 7.5.3.2 shows the permeability results.

Table 7.5.3.2: October 2012 I-25 / I-225 permeability results

I225/I25		
No.	6 Hr Value	Class
1- 100 ft	1781	Low
2 - 200 ft	2112	Moderate
3 - 300 ft	1499	Low
4 - 400 ft	1363	Low
5 - 500 ft	1454	Low
6 - 600 ft	894	Very Low
7 - 700 ft	1469	Low
8 - 800 ft	1678	Low

In June 5, 2013, another eight samples were collected at the same locations for the permeability testing. The results are summarized in Table 7.5.3.3. Compared to the previous data tested in 2011 and 2012, as expected, similar permeability was obtained.

Table 7.5.3.1: June 2013 I-25 / I-225 permeability results

I-25/I-225		
No.	6 hr. Value	Class
1- 100 ft	2177	High
2- 200 ft	1667	High
3- 300 ft	1519	Moderate
4- 400 ft	1964	High
5- 500 ft	1563	Moderate
6- 600 ft	1256	High
7- 700 ft	2831	High
8- 800 ft	1463	Moderate

7.6 Chloride Content

7.6.1 I-76 / WCR-53

The chloride penetration was measured using an approved CDOT chloride measurement test. The first chloride testing was performed in October 2009 with two different cores on the control bridge deck. For March 2011, four 2" (5.08 cm) diameter cores were taken from the deck. The cores were taken in groups of 2, approximately 15 feet (4.572 m) from the center of the bridge in the East and West directions, just inside the right-hand lane near the shoulder. The holes were patched with standard concrete. The results are shown in Table 7.6.1.1 for October 2009 and 7.6.1.2 for March 2011.

Table 7.6.1.1: October 2009 I-76 / WCR-53 chloride content

I-76 / WCR-53, Chloride Content, October 2009		
Core Number	Depth (in.)	Chloride Content (PPM)
East 1	0.75	24
	1.25	21
	1.75	13.5
West 1	0.75	12
	1.25	9
	1.75	0

Table 7.6.1.2: March 2011 I-76 / WCR-53 chloride content

I-76 / WCR-53, Chloride Content, March 2011		
Core Number	Depth (in.)	Chloride Content (PPM)
East 1	0.25	7.5
	0.75	0
	1.25	0
East 2	0.25	7.5
	0.75	5
	1.25	7.5
West 1	0.25	12.5
	0.75	5
	1.25	3.75
West 2	0.25	15
	0.75	7.5
	1.25	7.5

October 2009 results show very little chlorides in the bridge deck prior to overlay installation. This was expected since there is an asphalt wearing surface with an impermeable membrane beneath it. The March 2011 results verify the October results. It was expected that the March 2011 results would be similar since the waterproofing membrane was still in place, in addition to SafeLane. A comparison of both the October and March results is shown in Figure 7.6.1.1.

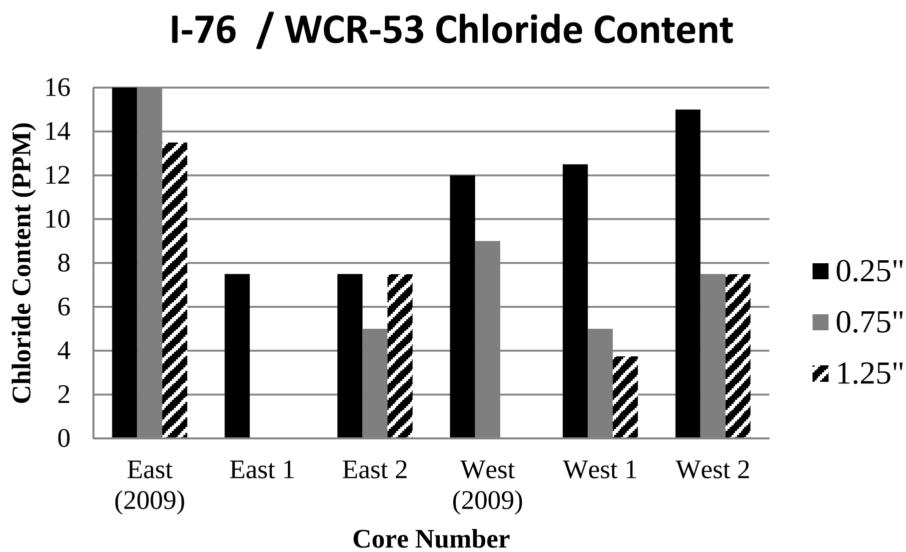


Figure 7.6.1.1: March 2011 I-76 / WCR-53 Chloride Content

Comparing the results from both chloride tests seems to show that the chlorides decreased in the first layer of concrete for the east side, and increased for the west side. However, the nature of the chloride test makes consistent results at small chloride contents difficult. For all intents and purposes, these results are close enough together, and small enough, that the chloride content near the reinforcing steel is not a problem.

Plotting the chloride vs. permeability should show increasing chloride with increase permeability; this validates higher chloride contents with higher permeability and is shown in Figure 7.6.1.2.

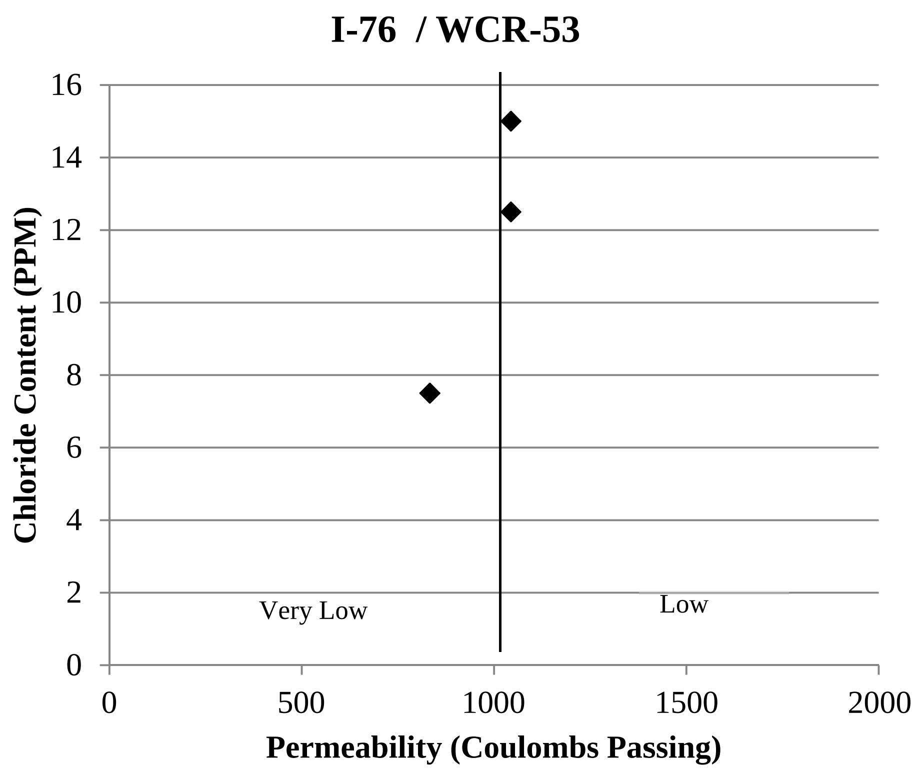


Figure 7.6.1.2: March 2011 I-76 / WCR-53 Chloride vs. Permeability

Comparing the west chloride samples vs. west permeability samples, and the east samples vs. east permeability show that the chloride content increased with the increase in permeability. Both east samples had a value of 7.5 PPM, so they are both represented by one point on the graph.

Due to the impermeable membrane at this site, it's not possible to say with any certainty that SafeLane has prevented the increase in chloride content, especially with the abutment and reflection cracking now present.

7.6.2 Parker Rd. / I-225

Only six 2" (5.08 cm) diameter cores were taken from the deck in preparation for chloride content testing due to the core drill breaking the night of testing. This is reflected in the data. This was the second round of chloride testing performed at this site. These cores were taken every 150 feet (45.72 m) in the right shoulder near the barrier. After removal of the cores, the holes were patched with standard concrete. Figure 7.6.2.1 shows the chloride content of Parker Rd. / I-225.

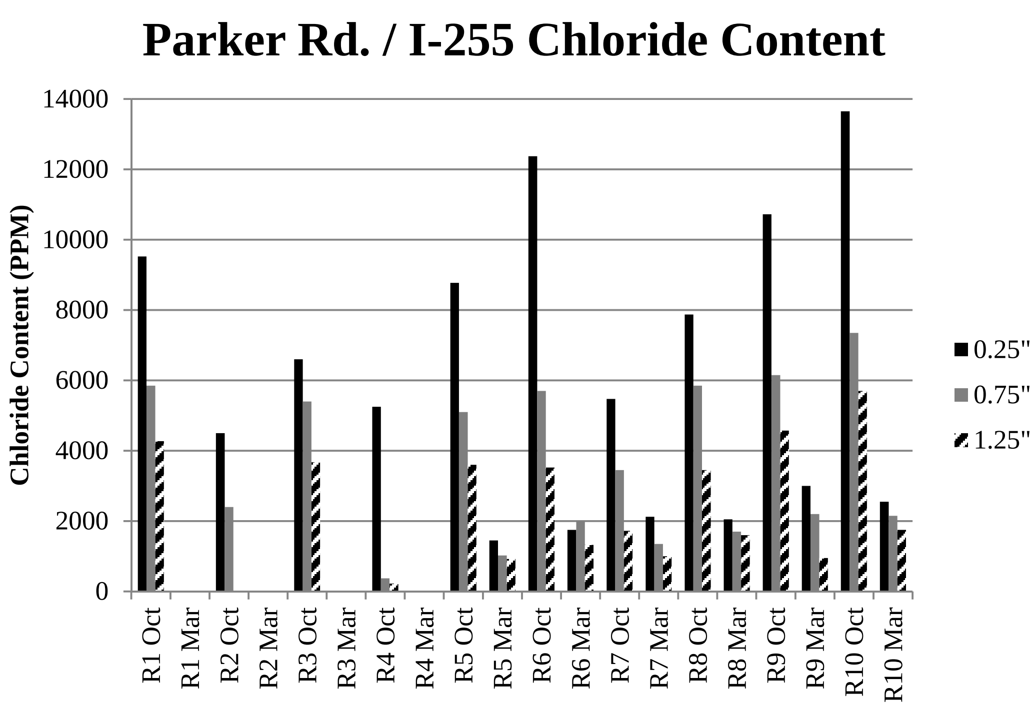


Figure 7.6.2.1: March 2011 Parker Rd. / I-225 Chloride Content

The chloride contents for October 2009 were very high compared to March 2011. While it is important that an increase is not seen, since that would indicated that the deck is not sealed properly, a large decrease as seen above was not expected. A possible cause for this discrepancy is due to the samples being tested at different locations. The October

2009 samples were taken before the overlay had been installed and were tested by a different technician. It is possible that they represent chloride contents closer to the surface of the concrete than the March 2011 samples. Regardless, the chloride content has not increased since application of the overlay, showing that it is providing good protection against chlorides.

Figure 7.6.2.2 is a comparison of the chloride content at each location with the associated permeability. By comparing the two, a verification of each measurement can be made, since it is expected that the chloride content would rise with the permeability.

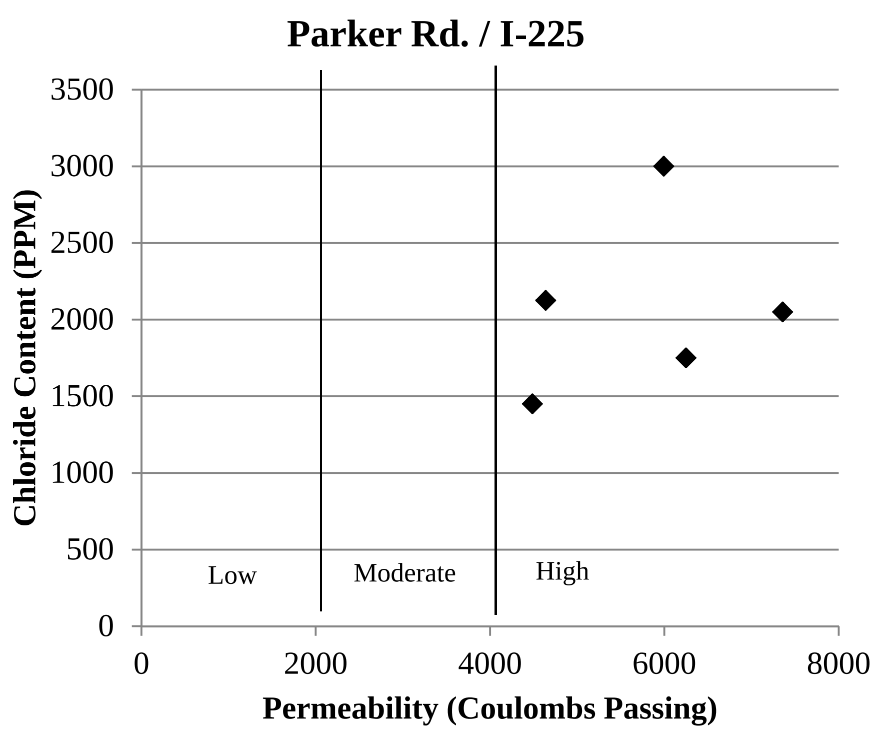


Figure 7.6.2.2: March 2011 Parker Rd. / I-225 Chloride vs. Permeability

The figure shows that the chloride content is generally increasing with the permeability. This helps to validate the results of both tests.

In October 2012 and June 2013, eight 2" diameter cores were taken each time from the deck in every 100 feet at the left wheel path in the left lane. The chloride testing was done in December 2012 and June 2013. After removal of the cores, the holes were patched with standard concrete. Table 7.6.2.1 and 7.6.2.2 show the chloride content of Parker Rd. / I-225 tested in December 2012 and June 2013.

Table 7.6.2.1: October 2012 Parker Rd./I-225 chloride content

Parker Rd/I225 Water Soluable Chloride Content (PPM)								
	100'	200'	300'	400'	500'	600'	700'	800'
0.25"	3100	2050	2300	3520	2910	3540	3590	2420
0.75"	2600	2220	4410	3280	4700	4110	4110	4250
1.25"	920	690	3020	1050	3900	2270	2650	4370

Note: 1000 ppm of chloride in concrete = 2.4 kg/m3 (4.05 lb/cy) of concrete

Table 7.6.2.2: June 2013 Parker Rd./I-225 chloride content

Parker Rd/I225 Water Soluable Chloride Content (PPM)								
	100'	200'	300'	400'	500'	600'	700'	800'
0.25"	2910	3980	3430	2820	3450	3570	3590	2410
0.75"	4010	4580	3110	2550	2570	2450	2990	1860
1.25"	1830	2910	1330	2480	770	770	1010	440

Note: 1000 ppm of chloride in concrete = 2.4 kg/m3 (4.05 lb/cy) of concrete

Comparable results were obtained in 2012 and 2013. The chloride content has not increased since application of the overlay, showing that it is providing good protection against chlorides.

7.6.3 I-25 / I-225

Ten 2" (5.08 cm) diameter cores were taken from the deck in preparation for chloride content testing. This was the second round of chloride testing performed at this site. These cores were taken every 150 feet (45.72 m) in the right shoulder near the barrier. After removal of the cores, the holes were patched with standard concrete. Figure 7.6.3.1 shows the chloride content from October 2009 and March 2011.

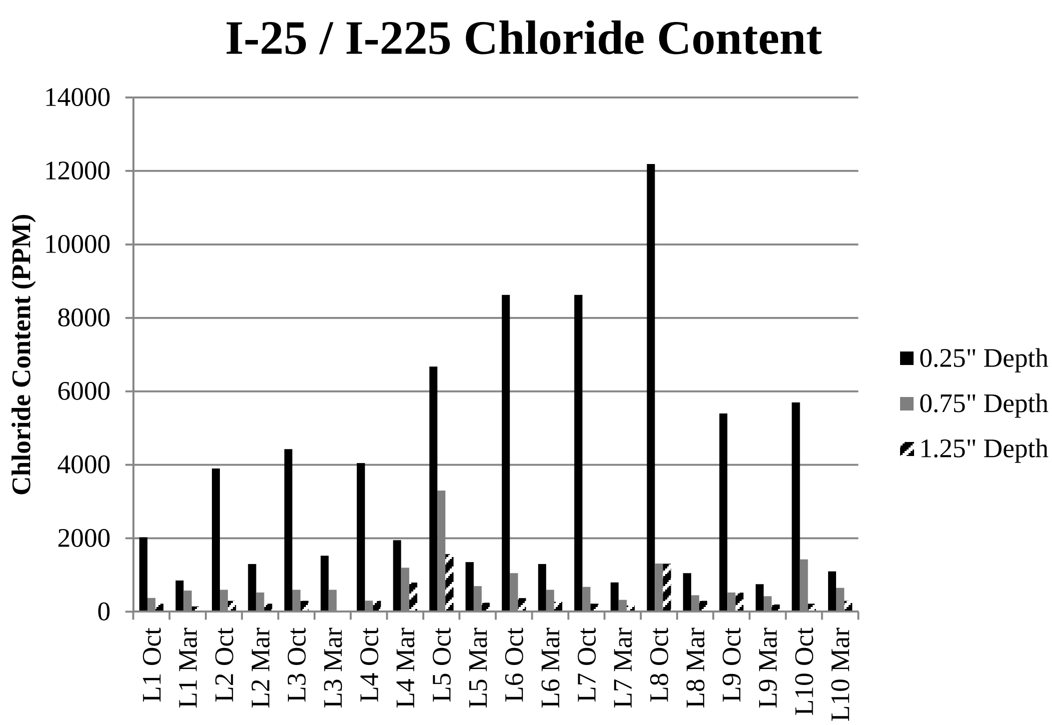


Figure 7.6.3.1: March 2011 I-25 / I-225 Chloride Content

The results are similar to Parker Rd. / I-225 in that the October 2009 values were very high, with the March 2011 values being much lower. The reasons are suspected to be same, namely a difference in the depths of the samples tested. Either way, the results show that there is not an increase in chloride on the bridge.

To validate both tests, chloride vs. permeability was plotted in Figure 7.6.3.2.

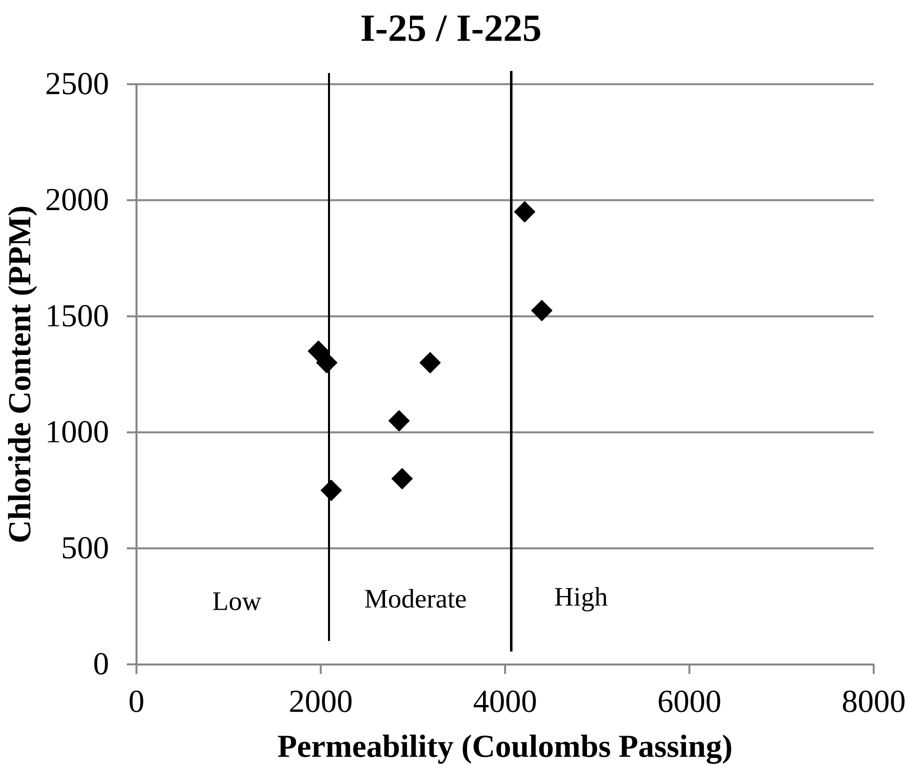


Figure 7.6.3.2: I-25 / I-225 Chloride vs. Permeability

Chloride vs. permeability also shows much the same results as the other two sites. The chloride is increasing as a result of the increasing permeability. While the permeability was out of the expected range, the amount of chlorides present was higher at the higher permeability locations.

Similar to Parker Rd./I-225, eight 2" diameter cores were taken each time from the deck in every 100 feet at the left wheel path in the left lane in October 2012 and June 2013. The chloride testing was done in December 2012. After removal of the cores, the holes were patched with standard concrete. Table 7.6.3.1 and 7.6.3.2 show the chloride content of I-25/ I-225 tested in December 2012 and June 2013.

Table 7.6.3.1: October 2012 Parker Rd./I-225 chloride content

I-25/I-225 water Soluable Chloride Content (PPM)								
	100'	200'	300'	400'	500'	600'	700'	800'
0.25"	2850	2840	2600	2160	4010	3540	3030	3900
0.75"	2850	4140	3260	3330	1880	2970	2980	3550
1.25"	1070	1920	740	1110	420	1420	670	900

Table 7.6.3.2: October 2012 Parker Rd./I-225 chloride content

I-25/I-225 water Soluable Chloride Content (PPM)								
	100'	200'	300'	400'	500'	600'	700'	800'
0.25"	3480	2810	3710	4580	4210	3180	3720	4240
0.75"	3240	3310	1830	2200	1310	2530	3550	3720
1.25"	980	1790	380	630	290	850	1440	1950

Comparing to the 2011 results, the chloride content has not increased since application of the overlay.

7.7 Anti-Icing Properties

The thin bonded overlays of this study present a unique case to vehicle safety. In each case, both overlays offer anti-icing protection. The differences between these overlays are that Flexogrid uses an active system in the form of an ESI spray system, wherein SafeLane utilizes a passive system that stores the deicing chemical for a winter event. The cost of these associated systems is discussed in detail in the next chapter.

The EnviroTech Services, Inc. spray system uses infrared sensors that measure deck temperature and then determine when to activate the spray system. The spray system has evenly spaced spray heads along the length of the elevated flyover ramp and spray from the high side of the structure. This allows the liquid deicing chemical to flow to the lower side of the roadway for more complete coverage.

The SafeLane system uses a proprietary aggregate that stores deicing chemicals until moisture is present on the overlay, in which case the chemicals are released by the moisture. The idea is that the anti-icing properties of the overlay are activated upon first snow, thus preventing the snow from freezing to the roadway. The anti-icing characteristics of these sites will be evaluated with instrumentation.

The weather instrumentation at I-76 / WCR-53 is extensive and will allow analysis of the anti-icing properties at that site. Crash data in Chapter 8 of this study provides some insight into the effectiveness of SafeLane's anti-icing properties on Parker Rd. / I-225.

While I-25 / I-225 does not contain any instrumentation itself, it does have an automated spray system that disperses deicing chemical based upon surface temperature taken via an infrared thermometer. Attempts were made to link into this system to analyze the data it collects, but these attempts were unsuccessful. The instrumentation at this site was never completed. Since no instrumentation was installed at Parker Rd. / I-225 and I-25 / I-225, only a cursory examination of their anti-icing properties will be looked at, including any anecdotal or photographic evidence. Since I-76 / WCR-53 does have instrumentation, it was the primary source to determine the anti-icing effectiveness of SafeLane.

7.7.1 I-76 / WCR-53

Through instrumentation at the site, the anti-icing properties of SafeLane were evaluated. Data was gathered through three deck sensors and a weather station. There are deck sensors in the eastbound and westbound bridge decks as well as a sensor in the eastbound approach. The eastbound deck has the SafeLane application, while the westbound deck is functioning as the control deck.

The deck sensors record multiple data streams including, temperatures, moisture, chemicals, and condition as indicated by the Scan Systems Inc. (SSI) programming. The two conditions of most interest are "Ice Watch" and "Ice Warning". SSI defines Ice Watch as "Thin or spotty film of moisture at or below freezing (32°F / 0°C)." Ice Warning is defined as a "Continuous film of ice and water mixture at or below freezing (32°F / 0°C) with insufficient chemical to keep the mixture from freezing." Ice warning is the more serious of the two conditions. This is important to keep in mind since the SafeLane acts as a sponge, absorbing moisture and deicing chemicals.

SafeLane is an effective anti-icing overlay when adequate deicing chemical is applied. Due to the nature of the SafeLane aggregate, it has a tendency to absorb water which can lead to problems when deicing chemicals are not applied. Figure 7.7.1.1 shows the SafeLane deck in ice warning conditions after snowing during warmer temperatures. The snow melted before a rapid temperature drop. Since no deicing chemical was applied since 1/20/2011 10:00 a.m., the deck sensor reported an ice warning. The aggregate seems to have absorbed the moisture, and then froze, leaving snow / ice on the deck.

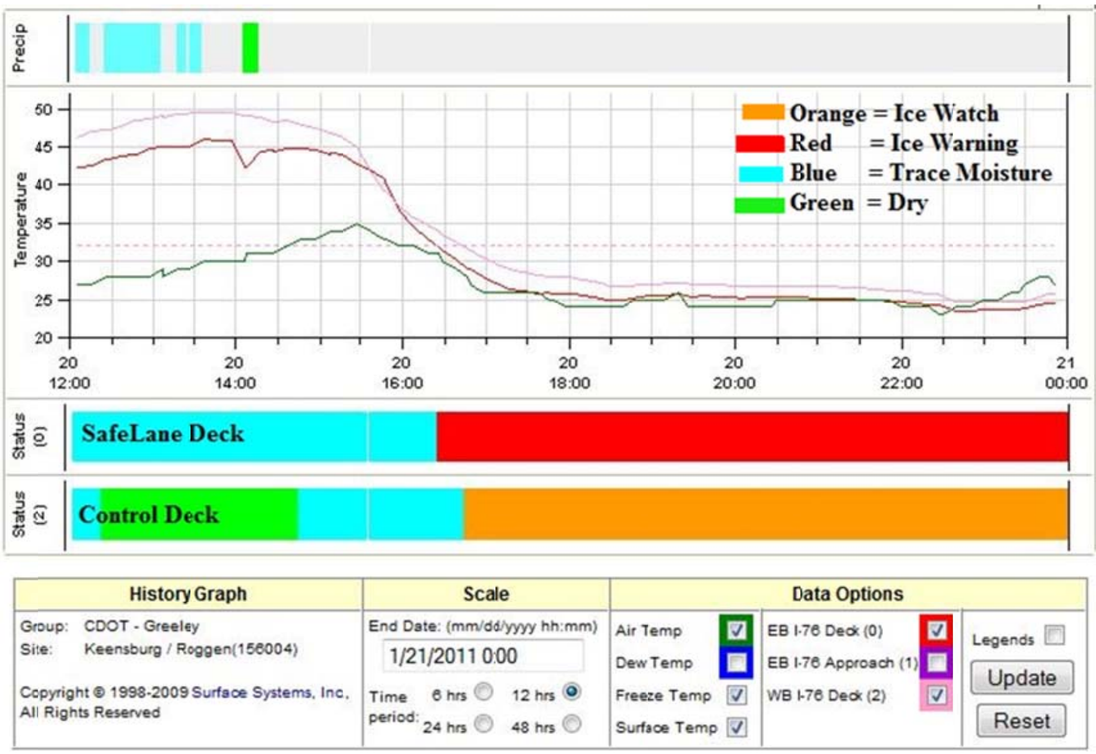


Figure 7.7.1.1: SafeLane with Ice Warning Condition

SafeLane performs exceptionally well when the overlay is dry or has minimal moisture prior to a freezing condition. Figure 7.7.1.2 shows this exact case. Prior to the displayed time period, both bridges had minimal moisture reported. As the temperature dropped below freezing, the SafeLane overlay maintained its ice watch status, while the control deck went into ice warning. The SafeLane aggregate absorbed the moisture, while on the control deck the moisture stayed on the surface. It was not until deicing chemical was applied (at approximately 12:30 PM) that both decks became wet due to thawing.

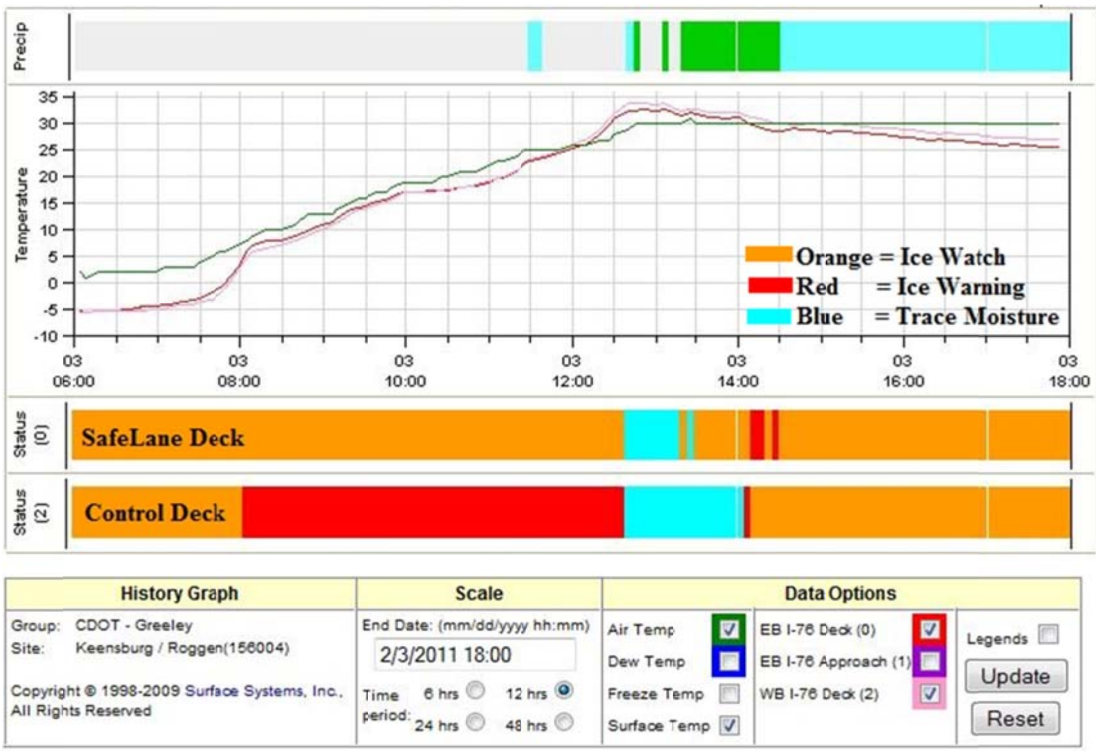


Figure 7.7.1.2: SafeLane Maintaining Ice Watch Conditions

At negative temperatures with no chemical initially present, the SafeLane deck stays in Ice Watch conditions while the control deck varies between Ice Watch and Ice Warning depending on when chemical is added. It is possible that moisture is freezing inside the SafeLane aggregate instead of on the surface, preventing the moisture from reaching the deck sensor. During these conditions, visual evidence shows snow builds up on the deck, even though the sensor does not report ice conditions. See Figure 7.7.1.3.

Figure 7.7.1.3: Surface Conditions Around 15 °F on 2/8/2011 at 10:26 AM

Examination of the sensor data indicate that SafeLane also performs well if it is pre-charged. Pre-charging is the act of placing deicing chemical on the overlay prior to a storm. Figure 7.7.1.4 shows the effectiveness of pre-charging. Both decks were pre-charged with deicing chemical prior the freezing temperatures. The SafeLane deck had a reported 5-10% chemical factor around the early morning of March 7, 2011. The control deck was reported to have around 30-45% chemical factor at the same time. Both decks stayed in ice warning condition until 9 a.m., at which point the temperature had raised enough to prevent ice formation. Around 9 p.m. on March 7, 2011 the temperature dropped significantly enough to freeze the control deck and place it into Ice Warning. The SafeLane deck stayed in Ice Watch throughout the night.

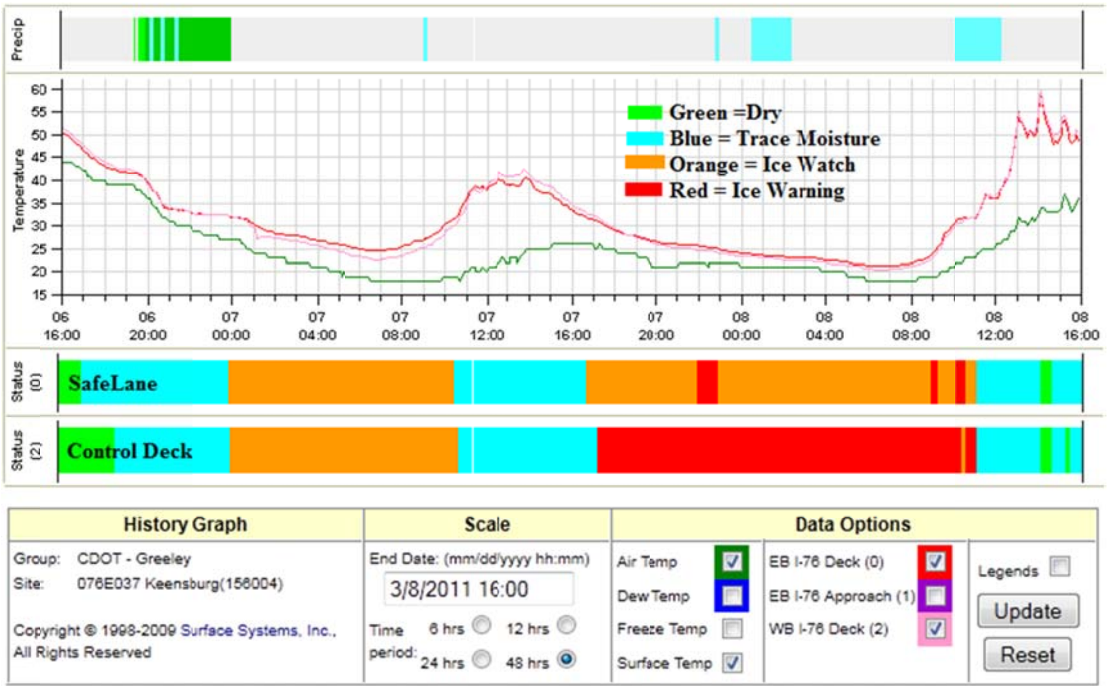


Figure 7.7.1.4: SafeLane Pre-Charge Effectiveness

This sequence of events shows that pre-charging of SafeLane is effective. The sensor data also shows that SafeLane is effective with less chemical present, however this is debatable since the SafeLane aggregate could be soaking up the deicing chemical, leaving less of it to be measured by the sensor.

It is worth noting that the conditions the sensor reports and the actual conditions at the top of the overlay, where vehicle traffic comes into contact could vary quite a bit. SafeLane uses a large aggregate with a correspondingly large texture depth. The sensor was installed in the deck prior to SafeLane, and thus is installed at the same level as the asphalt surface. So where the sensor is located may indeed contain ice or water, the top wearing area of SafeLane may be dry, or ice free.

SafeLane seems to be particularly effective when there is little to no moisture except deicing chemicals prior to experiencing freezing conditions. The overlay begins to have issues when there is excessive moisture, or when freezing and thawing cycles occur. In each case, deicing chemicals present are washed out of the overlay, or diluted beyond use. If this occurs with another drop in temperature, the sensor will report an Ice Warning condition.

SafeLane does work as an anti-icing overlay provided that it is properly supported by deicing chemicals. Proper support in this case means pre-charging, or recharging if a particularly wet storm is present. Sensor data shows that if no deicing chemical is applied to SafeLane, then it seems to perform worse than a traditional asphalt surface.

7.7.2 Parker Rd. / I-225

Only anecdotal evidence of anti-icing performance recorded at Parker Rd. / I-225 was evaluated, which was provided by the Aurora Police Department (APD). It seems to point to SafeLane being more effective than reported by the sensors on I-76 / WCR-53. APD mentioned that the additional SafeLane overlay installed on the Parker Rd. / I-225 flyover has reduced crashes at that location and increase driver safety. APD also mentioned wanting SafeLane installed on northbound I-225 over westbound I-25, an area they consider particularly troublesome.

7.7.3 I-25 / I-225

Only photographic evidence exists for anti-icing performance at I-25 / I-225. CDOT maintains a camera at this site for traffic evaluation use. The camera provides a good view of the bridge deck during winter storms. Figure 7.7.3 shows the post-activation of the spray system during a winter event.

Figure 7.7.3: I-25 / I-225 Spray System Activation (CDOT, 2010)

The image shows the spray system nozzles dispersing deicing chemicals across the deck from the right lane to the left. The striping pattern seen in the centerline is a result of the deicing liquid flowing from one side of the roadway to another. It is interesting to note that the road lanes are completely clear of accumulated snow and ice, and the shoulders are not. While it appears that the deck surface is ice-free, this cannot be confirmed without knowing the deck surface temperature. The figure indicates that the spray system coupled with Flexogrid provides good anti-icing capability.

8. TRAFFIC SAFETY

One of the more important aspects of roadway safety is the surface upon which vehicle traffic rides. It is no mystery why a smoother surface leads to an increase in crashes, while a rougher surface leads to a decrease. Roadway overlays in general seek to at least match, or increase the surface traction of the surfaces they replace. Thin bonded overlays are no exception. While the surface roughness can, and is, measured; this measurement becomes useless if the roadway sees no decrease in vehicle crashes. The only way to determine if the roadway becomes safer after an overlay installation is to directly record, and determine, the causes of crashes at the site of interest.

In Colorado, all reported vehicle crashes are logged by the Colorado Department of Revenue. They file crash reports that include location, type, persons involved, and accident factors. These reports are used more for legal matters than crash recording. CDOT works closely with the Department of Revenue to record more traffic safety oriented data. From this data, they determine which roadways are the most dangerous and may warrant improvement. This data can also be used to compare the how the safe the roadway is between improvements, or in this case, overlay installations.

Generally, it takes multiple years of data, both before and after roadway changes, to determine if there is a net increase or decrease in traffic safety for a given section of roadway. Due to the compressed time scale upon which this study was carried out, minimal post-installation crash data was available to use. This period of data collection was further decreased by the time between transferring crash reports from the Department of Revenue to CDOT. At the time of this report, only crash data to the end of 2012 is available. The I-25 / I-225 ramp and the left-hand lane of Parker Rd. / I-225 were both installed in October of 2009. Post installation crash data for the I-25 / I-225 ramp is thus available from this date. The rest of the Parker Rd. / I-225 ramp was installed in May 2010, and I-76 / WCR-53 was installed June 2010. Thus, these two sites can be evaluated from these dates.

There is a wealth of crash data prior to overlay installation at all three sites and this tabulated data is presented in Appendix C. Data was evaluated by looking at weather related, non-weather related, and total crashes. Only crashes that correspond to the roadway bridges being studied are included for traffic safety analysis. This data can further be filtered by weather, although crash causes can be misrepresented. Some crashes that were double counted in the data due to one causing the other, were only counted once for analysis. For example, one vehicle spun out, and several minutes later another vehicle hit it. These are fairly easy to spot since they occur around the same time, and the second crash involves a parked vehicle. The second crash skews the data since it's usually not a loss of traction that caused it, so these data points are dismissed.

8.1 I-76 / WCR-53

Due its relatively straight alignment and short span, the I-76 / WCR-53 bridge has seen the least amount of accidents. This is not surprising, considering it generally receives about 10 times less traffic than the other two overlay sites. It also has the largest data set, spanning from 1995 to 2010.

The crash data was first sorted by distance from the bridge. Crashes that were flagged 0.06 miles (96.56 m) in both directions from the mile marker of the bridge were included for analysis. Initially, an attempt was made to differentiate weather related crashes and all the crashes, however eliminating the data that did not correspond to the bridge location left identical results. This is somewhat expected because of the simple geometry of the bridge. All the crashes at I-76 / WCR-53 bridge are weather related. Figure 8.1.1 shows all crashes by year.

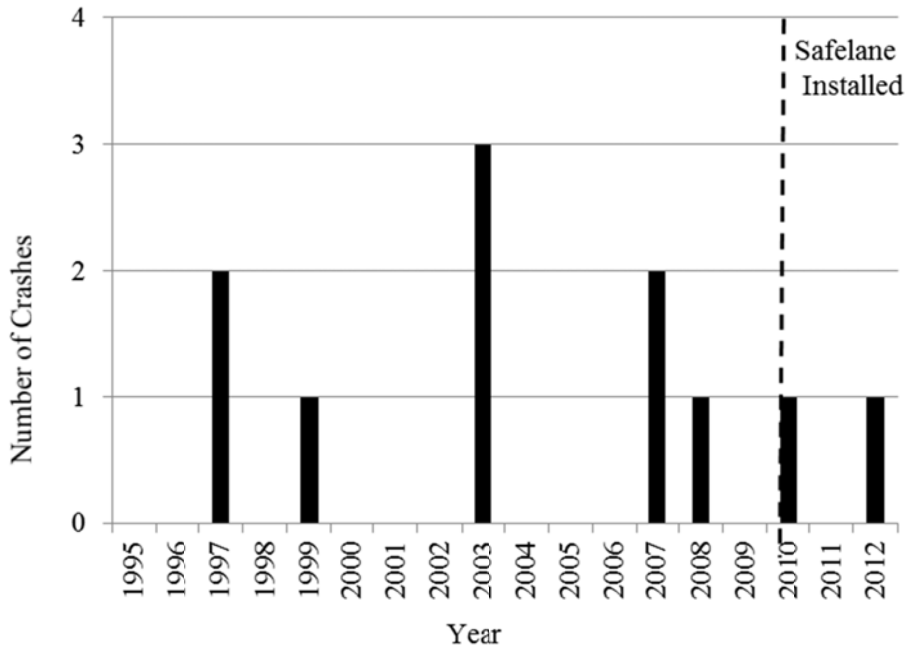


Figure 8.1.1: All Crashes on I-76 / WCR-53

I-76 / WCR-53 has a low number of crashes that make analysis of traffic safety with regards to SafeLane hard to gauge. Part of the difficulty is that there are several years in which no crashes have occurred. Another part is that there is only several months' worth of data available after the installation of SafeLane. An examination of the crash dates show that the majority occurred between October and March. The last crash data for this site was in March of 2012. For I-76 / WCR-53, no conclusions can be drawn about of

SafeLane until additional time has passed. At that point, there may be enough crash information to make a determination of its effectiveness.

8.2 Parker Rd. / I-225

Crash data for Parker Rd. / I-225 spans from 2002 to 2012. While this site has the shortest period of crash data, it has slightly more overall crashes, and slightly less weather related crashes. However, this means that in either category per year, there are more crashes at Parker Rd. / I-225 than any other site evaluated. This site has the added issue of having SafeLane installed in each lane, at different times. Thus the data in the years that SafeLane was installed was split, so that before and after comparisons can be made. Figure 8.2.1 shows the weather related crashes. The dotted lines represent the overlay installation dates of each lane.

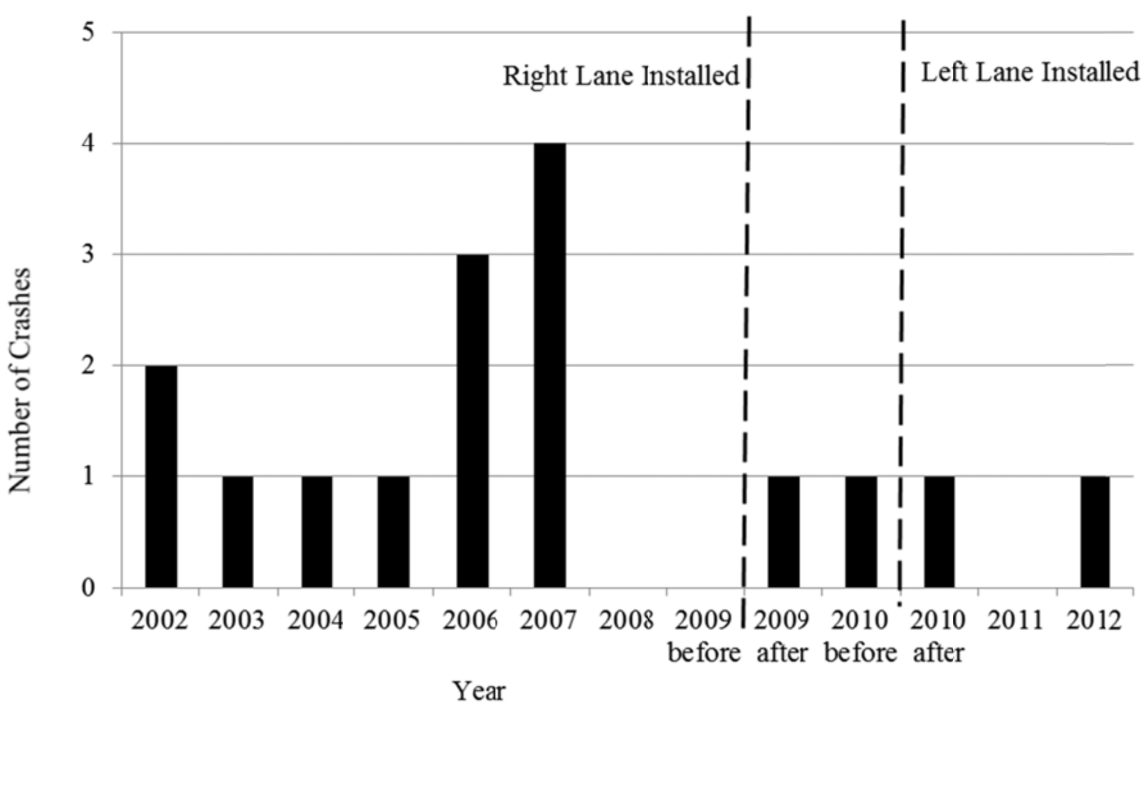


Figure 8.2.1: Weather Related Crashes on Parker Rd. / I-225

Based upon weather related crashes only, the results are somewhat encouraging and show a decrease in crashes after the right-hand lane was installed. The 2009 crash that occurred after the right lane installation was a two vehicle accident in icy conditions involving a passenger van that hit a parked combination vehicle over 10,000 pounds (44.5 kN). The crash occurred the morning after the right-hand lane was installed. By all appearances, SafeLane has reduced weather related crashes at this location.

Non-weather related crashes corresponding to the Parker Rd. / I-225 structure was included for a comparison. Figure 8.2.2 shows non-weather related crashes.

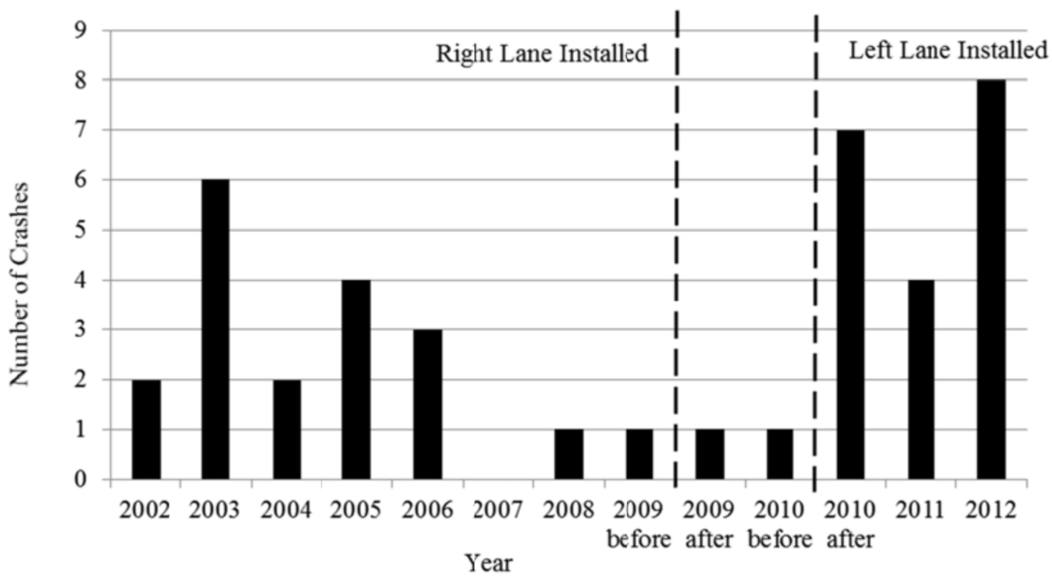


Figure 8.2.2: Non-Weather Related Crashes on Parker Rd. / I-225

SafeLane seems to have had no initial effect on non-weather related crash levels. There was a large spike of crashes in 2012. A closer look shows that all the crashes in 2012 occurred between June and October. Over time, the crashes seem to dip to a low point in

2008, then start rising again in 2009. The installation of SafeLane seems to have no effect on dry weather crashes.

Total crashes are also examined for relevance to traffic safety. Figure 8.2.3 shows all crashes that have occurred on Parker Rd. / I-225 within the study period.

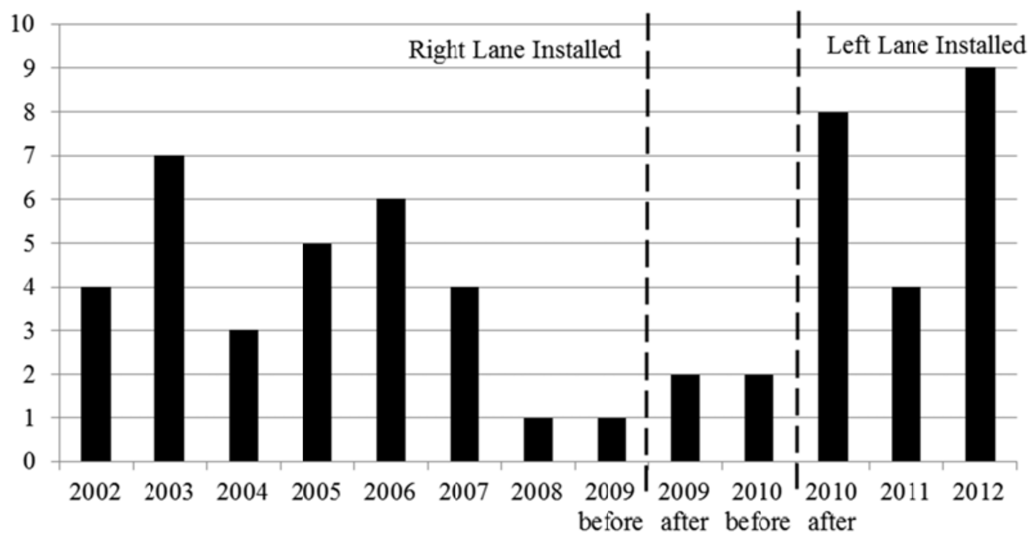


Figure 8.2.3: Total Crashes on Parker Rd. / I-225

Total crashes show much the same thing as non-weather related crashes that SafeLane does not seem to have an effect on reducing crash rates. Since Total Crashes includes both weather and non-weather related causes and part of this increasing trend is heavily influenced by the fact that the non-weather crashes showed a large increase.

Based upon the limited amount of post-installation data and the large spike in 2010 and 2012 crashes, it is hard to come to a common conclusion regarding the increasing or decreasing of accidents due to SafeLane. Perhaps the most important graph, weather related crashes, shows a decrease over time. However non-weather related crashes show a large increase. Overall, mathematical trends show markedly decrease in crashes, but there is not enough data to conclude this with certainty.

8.3 I-25 / I-225

Crash data for I-25 / I-225 spans from 1997 to 2012. Its crash rate is slightly less than that of Parker Rd. / I-225 for a similar volume of traffic. Since the mile marker of this bridge is 0, only crashes up to mile point 0.25 were included, since past this point the crash was no longer on the bridge. The entire Flexogrid overlay was installed at one time, so only 2009 is divided into before and after crashes. The bridge at this location has a spray system for deicing, so reduced crash rates are expected. Non-weather related crash rates are expected to be less over time as well. Figure 8.3.1 shows the weather related crashes. The dotted line represents the overlay installation date.

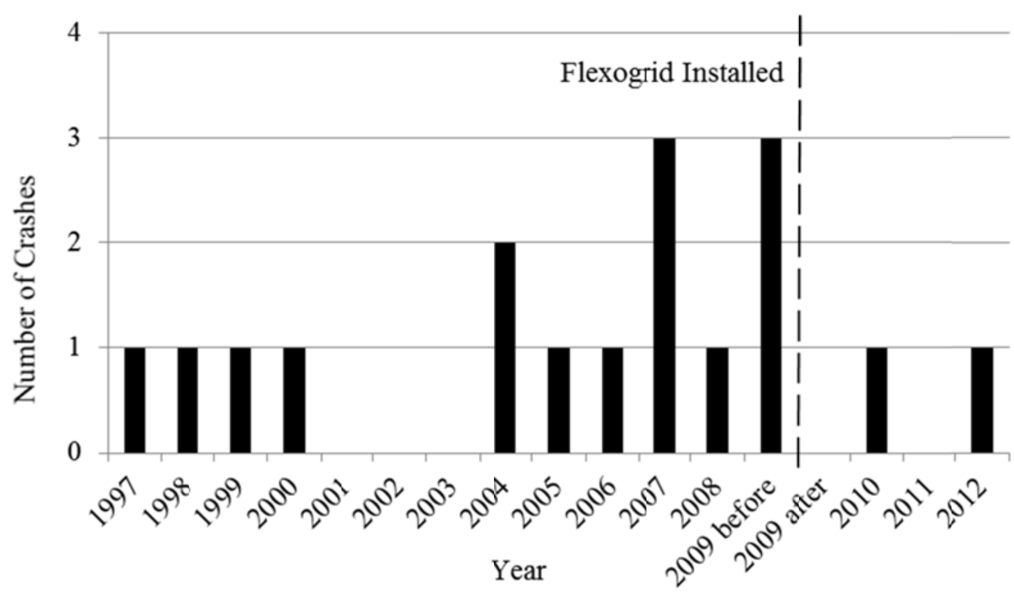


Figure 8.3.1: Weather Related Crashes on I-25 / I-225

Flexogrid and the fixed spray system seem to have decreased the weather related crashes at I-25 / I-225.Only two weather related crashes are reported after the installation. Prior to installation, there were several crashes in the years leading up to the installation of Flexogrid. Flexogrid and the fixed spray system show a solid decrease in the amount of crashes at I-25 / I-225.

Non-weather related crashes were also examined to determine if Flexogrid provides an increase in safety due to its anti-skid properties. Figure 8.3.2 shows the non-weather related crashes.

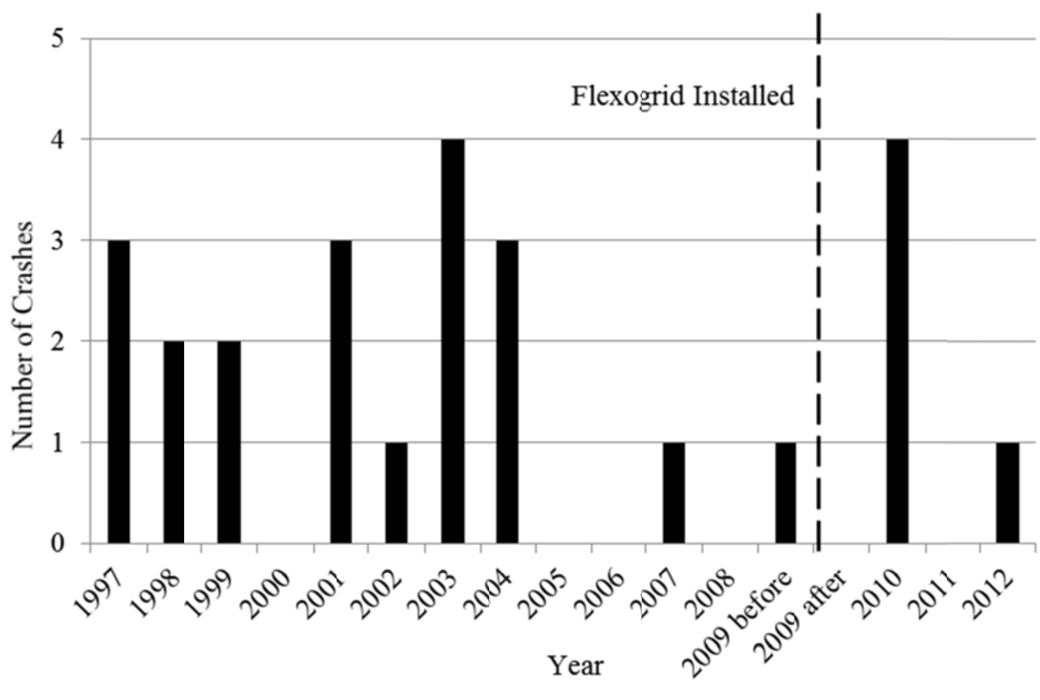


Figure 8.3.2: Non-weather Related Crashes on I-25 / I-225

The non-weather related crashes slightly decrease after the installation of Flexogrid if the whole data set is taken into consideration. The largest crash rate was between 2001 and 2004, with a sharp reduction in non-weather related crashes reported for 2005 to 2008, accompanied by a small increase in 2010. Overall, the trend is towards decreasing crash rates. Flexogrid does not seem to have an effect on non-weather related crashes in the short term.

Total crashes are shown to determine the overall effectiveness of the Flexogrid system. Figure 8.3.3 shows the total crashes for I-25 / I-225.

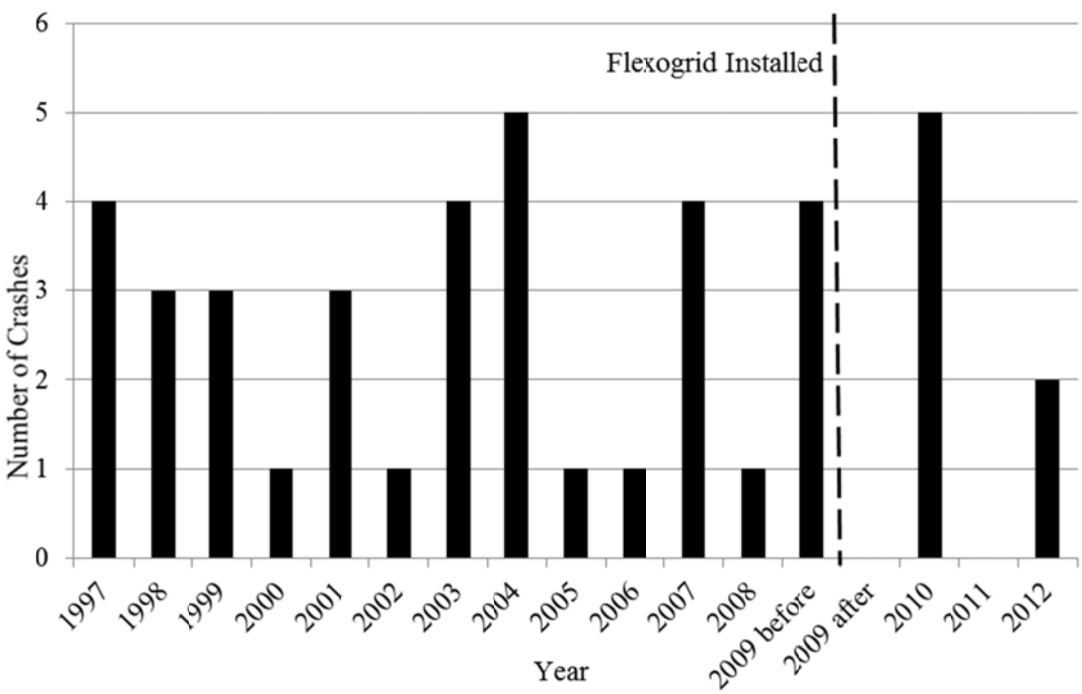


Figure 8.3.3: All Crashes on I-25 / I-225

There is a decrease in total crashes since the installation of Flexogrid at I-25 / I-225. The largest decrease seems to come from the weather related crashes which indicates that a fixed spray system working in tandem with an anti-skid overlay is effective at reducing crash rates on bridge decks. However, like the other sites, the post installation crash data is short, and the site should be monitored so that a better sampling of data can be obtained prior to reaching any final conclusions.

8.4 Comparison of Site Crash Data

There currently is not enough data to make any final comparisons about how one overlay performs over another. However, some trends are showing. Comparing all crashes at all sites, show that Flexogrid and the ESI spray system are performing better than either SafeLane overlay. If the data is broken down into weather related and non-weather related crashes, then the data seems to show a different conclusion. On I-25 / I-225 the sharpest decrease in crashes has been those that are weather related, while the non-weather related saw an increase. On Parker Rd. / I-225, a similar trend is followed, where weather related crashes are reduced, but non-weather related are not.

Two conclusions can be drawn from these comparisons. The first is that SafeLane is effective in the anti-icing role, and that the same can be said for the spray system on I-25 / I-225. The second is that neither overlay seemed to reduce crashes under dry conditions. This is counter to the MTD and surface friction data, which indicates that there should be a reduction in all crashes. It is possible that crashes in dry weather are being caused by external factors to the overlays, and thus are artificially raising the crash counts related to overlay performance.

9. COST ANALYSIS

Besides traffic safety, the other major factor that affects whether or not an overlay is selected for installation is cost. Traditionally, projects such as overlays and roadwork beyond minor repairs are put to bid and then completed by a contractor. In the case of the three bridge sites, this was only true for the bridges in the Denver-Aurora metro area (I-25 / I-225 and Parker Rd. / I-225). Due to the short length and relatively straight alignment of the I-76 and Weld Country Road 53 bridge, it was decided that the local CDOT maintenance shop in Hudson, CO would install the SafeLane overlay at this location. They were supervised by representatives from Cargill. The other two overlays were bid on as a single package. ABCO Contracting Company, Inc. won the bid and thus was responsible for installation of the overlays at both sites.

Since the Parker Rd. / I-225 and I-25 / I-225 bridges were bid on as a single item, many of the bid items were listed as large quantities with no distinction between how much of a given quantity was used at which site. The exception to this is the overlay materials which were each listed separately on the tabulation sheet. Due to this, a method was developed to distribute the lump costs to each site in a representative manner. The most straightforward means of doing so was to create a ratio of the areas of both bridge sites and then multiply this ratio by the total quantity listed on the bid sheet for each item. The area was determined from the as-built structural plans which are presented in Appendix E. The ratio was calculated by taking the area of the bridge and dividing by the total area of both bridges. After obtaining a representative quantity for the site, the quantity was multiplied by the contractors bid cost to obtain a dollar value for that item. Each bridge site was thus given an appropriate cost that could be broken down into a cost per square foot. Table 9.0.1 shows each bid item with the contractor cost, the full bid is shown in Appendix F.

CDOT requires a full life-cycle cost analysis to be completed if the total paving project is over $2,000,000. However the complete project at Parker Rd. / I-225 and I-25 / I-225 was only $1,562,460.74. Also, LCCAs are used to account for future maintenance and repair. Besides an occasional sweeping/vacuuming for SafeLane, epoxy overlays do not require any short-term direct maintenance. One of the downsides for epoxy overlays is that once they spall or crack, it is very difficult to perform repairs. Usually the overlay is removed and replaced, which is the cost of a new installation. An LCCA for the two epoxy overlays would be somewhat meaningless since there is functionally zero maintenance cost, and the repair cost would be equal to a full replacement. The costs presented here are only installation costs.

Each overlay site was evaluated on installation cost separately, including: material, labor, and traffic control. A final cost per square foot was determined. Finally, each cost was compared to determine the most cost-effective thin bonded overlay.

Table 9.0.1: Bid item list with associated contractor costs

Bid Item		Quantity	Unit	ABCO Contracting, Inc. Prices	
				Unit Price ($/Unit)	Amount ($)
202-00250	Rem Pavement Marking	233.0	SF	3.15	733.95
203-01597	Potholing	30.0	HR	184.00	5520.00
208-00002	Erosion Log (12 in)	75.0	LF	3.70	277.50
208-00034	Gravel Bag	100.0	LF	6.85	685.00
208-00045	Conc Washout Str	1.0	EA	578.00	578.00
208-00050	Storm Drain Inlet Protection	10.0	EA	210.00	2100.00
208-00070	Stabilized Construction En	1.0	EA	1314.00	1314.00
208-00205	Erosion Control Supervisor	60.0	HR	68.35	4101.00
304-06009	ABC (CL 6) (Spec)	130.0	TN	60.40	7852.00
409-05011	Thin Bonded Polymer Overlay	54621.0	SF	5.08	277535.37
409-05100	Anti-Icing Polymer Overlay	51034.0	SF	7.78	397044.52
607-53001	Fence CL (PVC)	90.0	LF	16.30	1467.00
607-60116	16 Ft Gate	1.0	EA	447.00	447.00
614-86756	Anti-Icing System	1.0	LS	730750.00	730750.00
620-00020	Sanitary Facility	1.0	EA	1050.00	1050.00
626-00000	Mobilization	1.0	LS	81035.00	81035.00
627-00005	Epoxy Pvmt Mkg	54.0	GAL	67.30	3634.20
627-02010	Preform Plastic Pvmt Mkg	496.0	SF	9.75	4836.00
630-00003	Uniformed Traf Cntrl	96.0	HR	52.55	5044.80
630-00012	Traf Ctrl Mgmt	25.0	DY	510.00	12750.00
630-00025	Traf Ctrl Vehicle	96.0	HR	21.05	2020.80
630-80001	Flash Beacon	4.0	EA	158.00	632.00
630-80335	Barricade (3 M-A) (Temp)	12.0	EA	42.05	504.60
630-80341	Const Traf Sign (A)	22.0	EA	42.05	925.10
630-80342	Const Traf Sign (B)	60.0	EA	42.05	2523.00
630-80343	Const Traf Sign (C)	8.0	EA	42.05	336.40
630-80344	Const Traf Sign (Spec)	160.0	SF	15.75	2520.00
630-80355	Port Mesg Panel	2.0	EA	2103.00	4206.00
630-80358	Flash Arrow Panel (C Ty)	4.0	EA	210.00	840.00
630-80360	Drum Channel Dev	50.0	EA	15.75	787.50
630-80380	Traffic Cone	200.0	EA	5.25	1050.00
630-85040	Impact Atten (T-M-A) (Temp)	2.0	EA	3680.00	7360.00
				Total:	$1,562,460.74

9.1 I-76 / WCR-53

The SafeLane installation at this location was installed by the regional CDOT maintenance personnel with supervision from Cargill. The purpose for this was two-fold. Due to the small size, it was thought that that it would be more cost-effective to have the overlay installed by CDOT employees. This was also a chance to determine if future thin bonded overlays can be installed by CDOT. For this site, there is only three major installation costs involved; traffic control, materials, and CDOT labor.

Traffic control was initially estimated at $8400 for four days' worth of equipment and labor by Northern Colorado Traffic Control, Inc. This also included alternate lane closures and overnight signage. Due to speed at which the overlay was installed, only 2.5 days of traffic control were required. The final traffic control cost was only $5,654.

Since all installation equipment and labor were provided by CDOT Region 4 maintenance, the total cost for equipment and personnel came to $15,337. The materials for the SafeLane installation were bought directly from Cargill at a total cost of $6 per square foot ($64.58 per square meter). With the area of the bridge being approximately 3555 square feet (330.3 square meters), the total material cost comes to $21,372.12. Table 9.1.1 shows the break down for each item and computes this down to a final cost per square foot.

Table 9.1.1: Installation cost of the I-76 / WCR-53 overlay

I-76 / WCR-53 Cost Breakdown				
Traffic Control	Material	Labor	Total	Total per Sq. Ft.
$5,654	$21,327.12	$15,337	$42,318.12	$11.91

The final cost per square foot of $11.91 ($128.20 per square meter) is fairly high for a thin bonded overlay for several reasons. The first is that the installation was not put to bid as with other projects. While this showed that CDOT can install an overlay itself, it may still be cheaper for a contractor to install for future sites. This would be especially true if the same contractor provided traffic control. The overlay was installed by hand as well, while on the other overlays motorized methods were used. Had motorized methods been used at this site, a decrease in installation time would have undoubtedly been seen with an associated reduction in cost. While this cost is not excessive for a research overlay and is in fact close to costs that other states have reported for SafeLane. It is expensive for an overlay that is being evaluated against other systems for use statewide.

9.2 Parker Rd. / I-225

Parker Road and I-225 is a straightforward SafeLane installation. While each lane was installed at separate times, both were covered under the initial bid. The area ratio determined for this site was 0.4812. Multiplying total bid quantities by this yielded a representative quantity for the Parker Road / I-225 site. Table 9.2.1 shows the cost break down for the Parker Road / I-225 site, including the total cost per square foot.

The total cost per square foot for the Parker Road / I-225 installation was less than the I-76 installation. This was largely due to the larger area that needed to be covered which lowered the traffic control, and equipment costs relative to the amount of overlay being installed. Competitive bidding also helped as well. Although $9.32 per square foot ($100.32 per square meter) is cheaper than the I-76 SafeLane installation, it is still more expensive than the majority of overlays in use today. This cost is on the lower end of other SafeLane installations as well. The Parker Rd. / I-225 installation costs is probably most representative of actual cost to install SafeLane at other sites around the state.

Table 9.2.1: Installation cost of the Parker Rd. / I-225 overlay

Bid Item		Quantity	Unit	Parker Rd. / I-225		
				Quantity	Unit	Total Item Price ($)
202-00250	Rem Pavement Marking	233.0	SF	112.120	SF	353.18
203-01597	Potholing	30.0	HR	14.436	HR	2656.22
208-00002	Erosion Log (12 in)	75.0	LF	36.090	LF	133.53
208-00034	Gravel Bag	100.0	LF	48.120	LF	329.62
208-00045	Conc Washout Str	1.0	EA	0.481	EA	278.13
208-00050	Storm Drain Inlet Protection	10.0	EA	4.812	EA	1010.52
208-00070	Stabilized Construction En	1.0	EA	0.481	EA	632.30
208-00205	Erosion Control Supervisor	60.0	HR	28.872	HR	1973.40
304-06009	ABC (CL 6) (Spec)	130.0	TN	62.556	TN	3778.38
409-05100	Anti-Icing Polymer Overlay	51034.0	SF	51034.000	SF	397044.52
607-53001	Fence CL (PVC)	90.0	LF	43.308	LF	705.92
620-00020	Sanitary Facility	1.0	EA	0.481	EA	505.26
626-00000	Mobilization	1.0	LS	0.481	LS	38994.04
627-00005	Epoxy Pvmt Mkg	54.0	G	25.985	G	1748.78
627-02010	Preform Plastic Pvmt Mkg	496.0	SF	238.675	SF	2327.08
630-00003	Uniformed Traf Cntrl	96.0	HR	46.195	HR	2427.56
630-00012	Traf Ctrl Mgmt	25.0	DY	12.030	DY	6135.30
630-00025	Traf Ctrl Vehicle	96.0	HR	46.195	HR	972.41
630-80001	Flash Beacon	4.0	EA	1.925	EA	304.12
630-80335	Barricade (3 M-A) (Temp)	12.0	EA	5.774	EA	242.81
630-80341	Const Traf Sign (A)	22.0	EA	10.586	EA	445.16
630-80342	Const Traf Sign (B)	60.0	EA	28.872	EA	1214.07
630-80343	Const Traf Sign (C)	8.0	EA	3.850	EA	161.88
630-80344	Const Traf Sign (Spec)	160.0	SF	76.992	SF	1212.62
630-80355	Port Mesg Panel	2.0	EA	0.962	EA	2023.93
630-80358	Flash Arrow Panel (C Ty)	4.0	EA	1.925	EA	404.21
630-80360	Drum Channel Dev	50.0	EA	24.060	EA	378.95
630-80380	Traffic Cone	200.0	EA	96.240	EA	505.26
630-85040	Impact Atten (T-M-A) (Temp)	2.0	EA	0.962	EA	3541.63
				Total:		$472,440.79
				Area (Sq. ft.)		50665.2
				$/Sq. ft.		$9.32

9.3 I-25 / I-225

A unique aspect to the Flexogrid installation at I-25 and I-225 is that the bid tabulation included a spray system. The spray system services the flyover ramp with the overlay was well as a tunnel beneath the flyover ramp. However the spray system cost $730,750, which was more than two times the cost of the overlay, and approximately 1/3rd the total bid cost. When computed into the cost per square foot, it came out to $19.95 per square foot ($214.74 per square meter). This is an unreasonable number to use for comparison to other overlay products, and thus the spray system was omitted from the analysis so that usable data could be obtained. The ratio of the area that was used to determine the associated costs was 0.5188. Table 9.3.1 shows the bid items as well as the quantities adjusted for the I-25 / I-225 site. Table 9.3.2 is similar, but includes the cost of the ESI spray system.

Table 9.3.1: Installation cost of the I-25 / I-225 overlay w/o spray system

Bid Item		Quantity	Unit	I-25 / I-225		
				Quantity	Unit	Total Item Price ($)
202-00250	Rem Pavement Marking	233.0	SF	120.880	SF	380.77
203-01597	Potholing	30.0	HR	15.564	HR	2863.78
208-00002	Erosion Log (12 in)	75.0	LF	38.910	LF	143.97
208-00034	Gravel Bag	100.0	LF	51.880	LF	355.38
208-00045	Conc Washout Str	1.0	EA	0.519	EA	299.87
208-00050	Storm Drain Inlet Protection	10.0	EA	5.188	EA	1089.48
208-00070	Stabilized Construction En	1.0	EA	0.519	EA	681.70
208-00205	Erosion Control Supervisor	60.0	HR	31.128	HR	2127.60
304-06009	ABC (CL 6) (Spec)	130.0	TN	67.444	TN	4073.62
409-05011	Thin Bonded Polymer Overlay	54621.0	SF	54621.000	SF	277535.37
607-53001	Fence CL (PVC)	90.0	LF	46.692	LF	761.08
607-60116	16 Ft Gate	1.0	EA	1.000	EA	447.00
620-00020	Sanitary Facility	1.0	EA	0.519	EA	544.74
626-00000	Mobilization	1.0	LS	0.519	LS	42040.96
627-00005	Epoxy Pvmt Mkg	54.0	GAL	28.015	GAL	1885.42
627-02010	Preform Plastic Pvmt Mkg	496.0	SF	257.325	SF	2508.92
630-00003	Uniformed Traf Cntrl	96.0	HR	49.805	HR	2617.24
630-00012	Traf Ctrl Mgmt	25.0	DY	12.970	DY	6614.70
630-00025	Traf Ctrl Vehicle	96.0	HR	49.805	HR	1048.39
630-80001	Flash Beacon	4.0	EA	2.075	EA	327.88
630-80335	Barricade (3 M-A) (Temp)	12.0	EA	6.226	EA	261.79
630-80341	Const Traf Sign (A)	22.0	EA	11.414	EA	479.94
630-80342	Const Traf Sign (B)	60.0	EA	31.128	EA	1308.93
630-80343	Const Traf Sign (C)	8.0	EA	4.150	EA	174.52
630-80344	Const Traf Sign (Spec)	160.0	SF	83.008	SF	1307.38
630-80355	Port Mesg Panel	2.0	EA	1.038	EA	2182.07
630-80358	Flash Arrow Panel (C Ty)	4.0	EA	2.075	EA	435.79
630-80360	Drum Channel Dev	50.0	EA	25.940	EA	408.56
630-80380	Traffic Cone	200.0	EA	103.760	EA	544.74
630-85040	Impact Atten (T-M-A) (Temp)	2.0	EA	1.038	EA	3818.37
				Total:		$359,269.95
				Area (Sq. ft.)		54625
				$/Sq. ft.		$6.58

Table 9.3.2: Installation cost of the I-25 / I-225 overlay w/spray system

Bid Item		Quantity	Unit	I-25 / I-225		
				Quantity	Unit	Total Item Price ($)
202-00250	Rem Pavement Marking	233.0	SF	120.880	SF	380.77
203-01597	Potholing	30.0	HR	15.564	HR	2863.78
208-00002	Erosion Log (12 in)	75.0	LF	38.910	LF	143.97
208-00034	Gravel Bag	100.0	LF	51.880	LF	355.38
208-00045	Conc Washout Str	1.0	EA	0.519	EA	299.87
208-00050	Storm Drain Inlet Protection	10.0	EA	5.188	EA	1089.48
208-00070	Stabilized Construction En	1.0	EA	0.519	EA	681.70
208-00205	Erosion Control Supervisor	60.0	HR	31.128	HR	2127.60
304-06009	ABC (CL 6) (Spec)	130.0	TN	67.444	TN	4073.62
409-05011	Thin Bonded Polymer Overlay	54621.0	SF	54621.000	SF	277535.37
607-53001	Fence CL (PVC)	90.0	LF	46.692	LF	761.08
607-60116	16 Ft Gate	1.0	EA	1.000	EA	447.00
614-86756	Anti-Icing System	1.0	LS	1.000	LS	730750.00
620-00020	Sanitary Facility	1.0	EA	0.519	EA	544.74
626-00000	Mobilization	1.0	LS	0.519	LS	42040.96
627-00005	Epoxy Pvmt Mkg	54.0	GAL	28.015	GAL	1885.42
627-02010	Preform Plastic Pvmt Mkg	496.0	SF	257.325	SF	2508.92
630-00003	Uniformed Traf Cntrl	96.0	HR	49.805	HR	2617.24
630-00012	Traf Ctrl Mgmt	25.0	DY	12.970	DY	6614.70
630-00025	Traf Ctrl Vehicle	96.0	HR	49.805	HR	1048.39
630-80001	Flash Beacon	4.0	EA	2.075	EA	327.88
630-80335	Barricade (3 M-A) (Temp)	12.0	EA	6.226	EA	261.79
630-80341	Const Traf Sign (A)	22.0	EA	11.414	EA	479.94
630-80342	Const Traf Sign (B)	60.0	EA	31.128	EA	1308.93
630-80343	Const Traf Sign (C)	8.0	EA	4.150	EA	174.52
630-80344	Const Traf Sign (Spec)	160.0	SF	83.008	SF	1307.38
630-80355	Port Mesg Panel	2.0	EA	1.038	EA	2182.07
630-80358	Flash Arrow Panel (C Ty)	4.0	EA	2.075	EA	435.79
630-80360	Drum Channel Dev	50.0	EA	25.940	EA	408.56
630-80380	Traffic Cone	200.0	EA	103.760	EA	544.74
630-85040	Impact Atten (T-M-A) (Temp)	2.0	EA	1.038	EA	3818.37
				Total:		$1,090,019.95
				Area (Sq. ft.)		54625
				$/Sq. ft.		$19.95

With the spray system omitted from the tabulations, the cost per square foot goes down to $6.58 ($70.83 per square meter). This is by far the smallest of the costs, and a much more reasonable cost compared to other thin bonded overlays. It is on the high side of the cost that other state DOTs have reported for installing Flexogrid, but still within a reasonable price given the difference between DOT costs.

9.4 Site Cost Comparison

Comparing the cost between each site shows that Flexogrid, without the spray system, is by far the cheapest of the overlays, with the Parker Rd. / I-225 SafeLane installation and I-76 / WCR-53 installations coming after. Table 9.4.1 shows a comparison of the areas, along with their respective costs.

Table 9.4.1: Comparison of cost per area for each site

Site	Area		Total Cost (USD)	Cost per Area	
	Sq. ft.	Sq. m		$ / Sq. ft.	$ / Sq. m
I-76 / WCR-53	3554.2	330.2	$42,318.12	$11.91	$128.16
Parker Rd. / I-225	50665.2	4706.95	$472,440.79	$9.32	$100.37
I-25 / I-225 w/o Spray	54625	5134.77	$359,269.95	$6.58	$69.97
I-25 / I-225 w/ Spray	54625	5134.77	$1,090,019.95	$19.95	$212.28

As shown above, Flexogrid is about 30% cheaper than SafeLane if the spray system is omitted from the cost calculations. This is a fair amount if the anti-icing properties of SafeLane are not taken into account. The Parker Rd. / I-225 cost was reduced due to having a smaller area as well. Since a representative cost was established based upon a ratio of the areas, the SafeLane site has a smaller proportional cost than the Flexogrid site. The biggest difference between the two seems to the be the material cost, which is quite high for SafeLane. However, it is the material that is responsible for the anti-icing performance of SafeLane.

10. CONCLUSIONS

Many DOTs around the United States are faced with deteriorating infrastructure. Bridges are a critical and expensive part of any infrastructure system, and protection of their structures ensures increased safety, and life span coupled with decreased maintenance costs. A critical part of bridge protection is the structural deck on which all traffic is carried. The bridge decks should be protected from deterioration by chemical attack, and be provided with a durable wearing surface with good skid resistance and anti-icing properties.

This study examined two thin bonded epoxy polymer overlays for the protection of bridge decks. One product, SafeLane, is an anti-icing / anti-ski epoxy polymer overlay. The other product, Flexogrid is an anti-skid urethane epoxy polymer overlay. These two overlays were evaluated on several different characteristics. Overlay performance was measured by testing the texture depth, surface friction, and bond strength. Protective ability was measured through permeability and chloride content tests. Anti-icing ability was determined from on-site instrumentation. Traffic safety was evaluated from crash data over the last decade. Installation cost was calculated to determine which overlay could provide the best protection per square foot. Results from this study are summarized below.

10.1 Texture Depth

The mean texture depth was measured using the sand patch test. SafeLane was shown to have a high initial mean texture depth that dropped about 50% in the first year. Results from the SafeLane installation over a year old, show that it holds at this reduced level. This indicates that after the initial wearing period, the MTD of SafeLane levels off and is expected to maintain a similar if not smaller MTD over the course of its service life. Flexogrid has only had two set of MTD measurements. But the Flexogrid overlay debonded twice. It will require further testing in the future to determine a wearing pattern over the lifespan of the overlay.

10.2 Surface Friction

Surface friction was measured with the British Pendulum Tester of I-76 / WCR-53, and with a locked-wheel test trailer on the other two overlay sites. Results from the BPT show the SafeLane installation on I-76 / WCR-53 to be mostly maintaining its friction surface, with some slight wear in the first year. BPN is not equivalent to any other testing method, and thus a comparison of overlay resistance at this site is unable to be done. The SafeLane installation on Parker Rd. / I-225 is showing very good skid numbers with both ribbed and smooth tires, even after 2-3 years. After the first year skid resistance was similar to the concrete deck it covered up. It is expected that SafeLane will continue to be an excellent wearing surface for at least several more years. The Flexogrid overlay showed similar results, although lower smooth tire skid numbers were recorded, which is typical of the majority of wearing surfaces.

10.3 Bond Strength

Bond strength was measure at all three sites with a device conforming to ACI 503R. I-76 / WCR-53 had low bond strength due to the overlay being placed on asphalt. All bond failures at this site occurred in the asphalt, with good accuracy. It is expected that no bonding problems will occur at I-76 / WCR-53. Parker Rd. / I-225 held similar results for the bond test. All failures occurred in the concrete substrate and were above 250 psi (1.72 MPa). The results from Flexogrid in March, 2011 were mixed. All successful tests exceeded 250 psi (1.72 MPa), but 2 tests had a mixed failure of overlay interface / substrate, and one failed fully at the overlay interface. While the failure modes indicate problems with the overlay bond, the failure strengths were all exceedingly high. Error by the testers may have contributed to the variation in failure modes. But the delamination of the Flexogrid identified in 2012 and 2013 indicates the weak bonding strength between the overlay and the substrate.

10.4 Permeability

Permeability of the concrete decks was measured using the rapid chloride permeability test. RCPT values for I-76 / WCR-53 were in the low to very low classification. Values for Parker Rd. / I-225 were all classified as moderate to high. I-25 / I-225 on average was moderate. It is thought that the high values were potentially from high chloride contents present in the concrete samples as literature seems to indicate concretes containing high chloride contents experiencing higher rapid chloride permeability values.

10.5 Chloride Content

Chloride content at all sites has not increased. At I-76 / WCR-53 the chloride contents are in the negligible range due to the waterproofing membrane installed between the asphalt and concrete deck, and the SafeLane overlay installed on top of the asphalt surface. Chloride values for Parker Rd. / I-225, and I-25 / I-225 have shown a decrease since the installation of their respective overlays. This shows that all overlays are protecting their respective bridge deck by sealing it from moisture.

10.6 Anti-Icing Properties

The anti-icing properties of SafeLane were evaluated using instrumentation installed at I-76 / WCR-53. The instrumentation shows that the ability of SafeLane to prevent icing of the roadway surface is mixed. SafeLane requires regular intervals of deicing solution to be applied prior to, and during events, especially when there is a wet storm. Excess moisture has a tendency to wash the deicing chemicals off the overlay, or dilute them beyond usefulness, and then freeze on the roadway. Pre-charging the overlay is particularly effective. Additional testing should be completed to determine if less deicing chemical can be used to obtain the same level of anti-icing effectiveness.

10.7 Traffic Safety

Because of the short time period available after the material installation and the relatively small number of crashes, statistically-valid conclusions were not possible, but all sites show a decrease in weather-related crashes at varying degrees. SafeLane has shown the largest decrease in weather-related crashes. Flexogrid with the spray system has shown to decrease weather-related crashes as well. Non-weather related crash rates for both overlays have slightly increased.

10.8 Installation Cost

Installation cost for both SafeLane sites was high, but similar to the results reported by other DOTs. I-76 / WCR-53 was $11.91 per square foot ($128.20 per square meter), while Parker Rd. / I-225 was $9.32 per square foot ($100.32 per square meter). The cost for only the Flexogrid installation was $5.58 ($60.06 per square meter), also similar to other DOTs. If the spray system is included in installation cost, the price jumps to $19.95 per square foot ($214.74 per square meter).

10.9 Recommendations

Based upon the conclusions above, several recommendations can be made:

- SafeLane should be considered for use on high crash rate bridges, where its high cost can be offset by an increase in traffic safety.
- If SafeLane is to be used as an anti-icing overlay it should have deicing chemicals applied more often, and in smaller amounts. Pre-charging should be used when possible.
- Installation of Flexogrid should not be considered on bridges before the reasons causing the delamination are identified.
- Study of both overlays should continue so that their long-term impact on traffic safety can be analyzed.

APPENDIX A

A.1: DOT Survey (Bindel, 2010)

1. Thin Bonded Overlays with Anti Wear and Icing On Bridge Decks

The University of Colorado Denver is conducting a research study funded by the Colorado Department of Transportation evaluating the effectiveness of thin-bonded overlays in decreasing the wear of concrete bridge decks, reducing the development of snow and ice during winter conditions, and provide a safe drivable surface.

The following questionnaire will aid in obtaining knowledge that will assist in the selection, placement, and monitoring of a thin-bonded overlay with anti-skid and anti-icing properties on a Colorado bridge deck in the Fall 2009. We greatly appreciate your response to this questionnaire, and any additional comments, suggestions, or concerns that you might have. This questionnaire contains ten questions.

If you have any questions, please contact Dr. Stephan Durham at the University of Colorado Denver at (303)352-3894 or by e-mail at stephan.durham@ucdenver.edu.

2. Contact Information

*** 1. Questionnaire Completed by:**

Name:

Company:

Job Title / Division:

Address:

City/Town:

State: -- select state --

ZIP/Postal Code:

Email Address:

Phone Number:

3. Thin-Bonded Overlays With Anti-Icing and Anti-Skid Properties

2. Does your State DOT utilize thin-bonded overlays with anti-icing and anti-skid properties such as Cargill SafeLane.

Yes

No

If yes, provide an approximate number of applications and years of service.

4. Thin-Bonded Overlays with Anti-Icing and Anti-Skid Properties

3. Has the number of winter weather related accidents been reduced on bridge decks using SafeLane (or other Anti-Icing/Anti-Skid overlays)?

Yes

No

Same

Data Not Available

If yes, how much of a reduction?

4. What is the typical skid number (SK) that your DOT has observed on these types of overlays.

>60

50-60

40-50

30-40

<30

5. Approximately what percent reduction in the amount of deicing chemicals applied to these types of bridge decks has been experienced when compared to decks without Anti-Icing/Anti-Skid overlays?

0%

20%

40%

60%

80%

Other (please specify)

6. Has there been any major failures or performance issues when using this type of overlay. Any concerns? Please specify.

7. Are there any special specifications your state uses when applying overlays with Anti-Icing/Anti-Skid properties?

5. Other Overlays

8. Has your State DOT observed if any of the overlay products listed below exhibit anti-icing properties? Check all that apply.

E-Bond 526

Sikadur 22, LO-MOD

Euclid Chemical Flexolith 216

Unitex Propoxy Type IIIDOT

Poly-Carb Flexogrid Mark- 163

Degussa Building Systems Trafficguard EP35

Transpo T-48 epoxy

Other (please specify)

9. Please indicate (check all that apply) the type of deck surface each of the products listed below (and utilized by your State DOT) are placed on within your state's bridge inventory. For example, is the thin-bonded overlay product applied to only Asphalt Wearing Surfaces, only Bare Concrete Decks, or both.

	Asphalt Wearing Surface	Bare Concrete Deck Surface
E-Bond 526		
Sikadur 22, LO-MOD		
Euclid Chemical Flexolith 216		
Unitex Propoxy Type IIIDOT		
Poly-Carb Flexogrid Mark-163		
Degussa Building Systems		
Trafficguard EP35		
Transpo T-48 epoxy		
Cargill SafeLane		

Has your State DOT experienced performance problems with any of the overlay products listed above? If so, explain.

10. Additional Comments

Thank you!

APPENDIX B

B.1: Sample Data

Atmospheric Data										
Date/Time (MST)	AirTemp	RH	Dewpoint	AvgWindSpeed	GustWindSpeed	WindDirection	PrecipType	PrecipIntensity	PrecipAccumulation	PrecipRate
3/1/2011 0:06	41	11	-9	12	14	SE	None	None	0	0
3/1/2011 0:06	41	11	-9	13	14	SE	None	None	0	0
3/1/2011 0:16	42	11	-9	10	15	SE	None	None	0	0
3/1/2011 0:26	40	11	-10	0	12	SE	None	None	0	0
3/1/2011 0:26	40	11	-9	1	12	SE	None	None	0	0
3/1/2011 0:36	35	12	-12	5	6	NW	None	None	0	0
3/1/2011 0:46	31	11	-17	4	6	N	None	None	0	0
3/1/2011 0:47	31	12	-15	2	6	N	None	None	0	0
3/1/2011 0:56	31	11	-16	4	6	E	None	None	0	0
3/1/2011 1:05	33	11	-15	0	4	SE	None	None	0	0
3/1/2011 1:06	33	11	-15	0	3	SE	None	None	0	0
3/1/2011 1:16	35	12	-12	0	5	W	None	None	0	0
3/1/2011 1:26	29	11	-18	0	4	NW	None	None	0	0
3/1/2011 1:26	29	11	-18	0	4	NW	None	None	0	0
3/1/2011 1:36	27	11	-19	0	0	N	None	None	0	0
3/1/2011 1:46	28	12	-18	0	0	E	None	None	0	0
3/1/2011 1:46	28	12	-18	0	0	N	None	None	0	0
3/1/2011 1:56	26	12	-19	0	0	SW	None	None	0	0
3/1/2011 2:06	27	11	-19	0	0	E	None	None	0	0
3/1/2011 2:06	27	12	-19	0	0	E	None	None	0	0
3/1/2011 2:16	25	12	-21	0	4	S	None	None	0	0
3/1/2011 2:26	24	12	-20	0	0	SE	None	None	0	0
3/1/2011 2:26	24	12	-20	0	0	SE	None	None	0	0
3/1/2011 2:36	24	13	-20	0	4	SW	None	None	0	0
3/1/2011 2:46	23	12	-21	2	7	S	None	None	0	0
3/1/2011 2:46	23	12	-21	2	7	S	None	None	0	0
3/1/2011 2:56	24	12	-20	4	6	S	None	None	0	0
3/1/2011 3:06	24	12	-20	4	4	SE	None	None	0	0
3/1/2011 3:06	24	13	-20	3	4	SE	None	None	0	0
3/1/2011 3:16	22	13	-21	6	8	SE	None	None	0	0
3/1/2011 3:26	23	13	-20	5	6	S	None	None	0	0

EB Deck Sensor																
SfStatus	SfTemp	PvtTemp	SubTemp	FreezeTemp	ChemFactor	ChemPercent	WaterDepth	IceThickness	IcePercent	Conductivity	Salinity	FrictionIndex	PrecipType	PrecipIntensity	Accumulation	PrecipRate
Dry	35.8		38		0								None	None	0	0
Dry	36		38		0								None	None	0	0
Dry	36		38		0								None	None	0	0
Dry	35.8		38		0								None	None	0	0
Dry	35.8		38		0								None	None	0	0
Dry	34.9		38		0								None	None	0	0
Dry	34		39		0								None	None	0	0
Dry	34		39		0								None	None	0	0
Dry	33.8		39		0								None	None	0	0
Dry	33.6		39		0								None	None	0	0
Dry	33.6		39		0								None	None	0	0
Dry	33.4		39		0								None	None	0	0
Dry	32.5		39		0								None	None	0	0
Dry	32.5		39		0								None	None	0	0
Dry	32.2		39		0								None	None	0	0
Dry	32		39		0								None	None	0	0
Dry	32		39		0								None	None	0	0
Dry	31.5		39		0								None	None	0	0
Dry	31.1		39		0								None	None	0	0
Dry	31.1		39		0								None	None	0	0
Dry	30.4		39		0								None	None	0	0
Dry	30		39		0								None	None	0	0
Dry	30		39		0								None	None	0	0
Dry	29.8		39		0								None	None	0	0
Dry	29.3		39		0								None	None	0	0
Dry	29.3		39		0								None	None	0	0
Dry	29.1		39		0								None	None	0	0
Dry	28.9		39		0								None	None	0	0
Dry	28.9		39		0								None	None	0	0
Dry	28.4		39		0								None	None	0	0
Dry	28.2		39		0								None	None	0	0

EB Approach Sensor																
SfStatus	SfTemp	PvtTemp	SubTemp	FreezeTemp	ChemFactor	ChemPercent	WaterDepth	IceThickness	IcePercent	Conductivity	Salinity	FrictionIndex	PrecipType	PrecipIntensity	Accumulation	PrecipRate
Dry	34.9		38		0								None	None	0	0
Dry	34.9		38		0								None	None	0	0
Dry	34.9		38		0								None	None	0	0
Dry	34.9		38		0								None	None	0	0
Dry	34.9		38		0								None	None	0	0
Dry	34		38		0								None	None	0	0
Dry	33.3		39		0								None	None	0	0
Dry	33.1		39		0								None	None	0	0
Dry	33.1		39		0								None	None	0	0
Dry	32.9		39		0								None	None	0	0
Dry	32.9		39		0								None	None	0	0
Dry	32.7		39		0								None	None	0	0
Dry	32		39		0								None	None	0	0
Dry	32		39		0								None	None	0	0
Dry	31.5		39		0								None	None	0	0
Dry	31.3		39		0								None	None	0	0
Dry	31.3		39		0								None	None	0	0
Dry	30.9		39		0								None	None	0	0
Dry	30.6		39		0								None	None	0	0
Dry	30.6		39		0								None	None	0	0
Dry	30.2		39		0								None	None	0	0
Dry	29.8		39		0								None	None	0	0
Dry	29.8		39		0								None	None	0	0
Dry	29.5		39		0								None	None	0	0
Dry	29.1		39		0								None	None	0	0
Dry	29.1		39		0								None	None	0	0
Dry	28.9		39		0								None	None	0	0
Dry	28.8		39		0								None	None	0	0
Dry	28.8		39		0								None	None	0	0
Dry	28.4		39		0								None	None	0	0
Dry	28.2		39		0								None	None	0	0
Dry	28		39		0								None	None	0	0

WB Deck Sensor																
SfStatus	SfTemp	PvtTemp	SubTemp	FreezeTemp	ChemFactor	ChemPercent	WaterDepth	IceThickness	IcePercent	Conductivity	Salinity	FrictionIndex	PrecipType	PrecipIntensity	Accumulation	PrecipRate
Dry	36.5		38		0								None	None	0	0
Dry	36.5		38		0								None	None	0	0
Dry	36.5		38		0								None	None	0	0
Dry	36.1		38		0								None	None	0	0
Dry	36.1		38		0								None	None	0	0
Dry	35.2		38		0								None	None	0	0
Dry	34.7		39		0								None	None	0	0
Dry	34.7		39		0								None	None	0	0
Dry	34.3		39		0								None	None	0	0
Dry	34.3		39		0								None	None	0	0
Dry	34.2		39		0								None	None	0	0
Dry	33.8		39		0								None	None	0	0
Dry	33.1		39		0								None	None	0	0
Dry	33.1		39		0								None	None	0	0
Dry	32.5		39		0								None	None	0	0
Dry	32.2		39		0								None	None	0	0
Dry	32.4		39		0								None	None	0	0
Dry	31.8		39		0								None	None	0	0
Dry	31.5		39		0								None	None	0	0
Dry	31.5		39		0								None	None	0	0
Dry	30.9		39		0								None	None	0	0
Dry	30.4		39		0								None	None	0	0
Dry	30.4		39		0								None	None	0	0
Dry	30		39		0								None	None	0	0
Dry	29.7		39		0								None	None	0	0
Dry	29.7		39		0								None	None	0	0
Dry	29.3		39		0								None	None	0	0
Dry	29.1		39		0								None	None	0	0
Dry	29.1		39		0								None	None	0	0
Dry	28.8		39		0								None	None	0	0
Dry	28.6		39		0								None	None	0	0

Precipitation Data										
PrecipType	PrecipIntensity	PrecipRate	StartTime	EndTime	10min Accum	1hr Accum	3hr Accum	6hr Accum	12hr Accum	24hr Accum
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0
None	None	0	02/25/2011 07:08	02/25/2011 07:15	0	0	0	0	0	0

APPENDIX C

C.1: Colorado Procedure - Laboratory 2104

Colorado Procedure – Laboratory 2104

Standard Method of Test for

Determining Water-Soluble Chloride Ion Content in Soil

1. SCOPE

1.1 This method covers the procedures for preparing and testing soil for chloride ion content.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:
T291 Determining Water-Soluble Chloride Ion Content in Soil.

2.2 Colorado Procedures:
CP 30 Sampling of Aggregates
CP 32 Reducing Field Samples of Soil and Aggregate to Testing Size.

2.3 Other Procedures:
HACH Method 8207 Silver Nitrate Method (10 to 10000 mg/L as Cl-).

Note 1: This method was adapted from AASHTO T291 and HACH Method 8207.

3. SIGNIFICANCE AND USE

3.1 This method is capable of detecting chloride concentrations in the range of 10 to 10000 mg/L as Cl-.

4. APPARATUS

4.1 Balance that reads a minimum of 500 g, accurate to 0.1 g.

4.2 Oven capable of drying samples at a temperature not exceeding 140°F.

4.3 Sieve – 2.00mm (No. 10) and a pan.

4.4 Sample Splitter – Meeting the requirements of CP 32.

4.5 Pulverizing Apparatus

4.6 HACH digital titrator and delivery tube.

4.7 Chloride 2 Indicator Powder Pillows.

4.8 Silver Nitrate titrate cartridges, 0.2256 N and 1.128 N.

4.9 Sulfide Inhibitor Reagent Powder Pillow.

4.10 Deionized water.

4.11 Graduated cylinder.

4.12 Erlenmeyer Flask.

5.0 PROCEDURE

5.1 Obtain a sample according to CP 30.

5.2 Dry the sample to a constant weight at a temperature not exceeding 140°F.

5.3 Process the material over a No. 10 sieve being careful to avoid breaking down the natural size of the particles and removing any material adhering to the aggregate particles.

5.4 Split the processed soil into a 100 g sample and place it into a sealable sample cup.

5.5 Add 300 mL of distilled water (3:1 dilution).

5.6 Seal the container and shake vigorously for 20 +/- 1 seconds.

5.7 Let the sample sit at room temperature for 1 hour and then repeat the shaking process and let the sample sit for another hour.

5.8 If the sample exhibits turbidity after the completion of Subsection 5.7 then filter the sample through a 0.45 micron membrane filter.

5.9 Check the pH with a meter or with phydrion paper. If the pH is in the range of six through eight, proceed immediately to the next step. If the pH is below six add sodium bicarbonate to adjust to the pH to the six through eight ranges; if the pH is above 8, add nitric acid to adjust the pH to the six through eight ranges.

5.10 Select the sample volume and Silver Nitrate Titration Cartridge corresponding to the expected chloride concentration from *Table 1.*

5.11 Insert a clean delivery tube into the titration cartridge. Attach the cartridge to the titrator body.

5.12 Turn the delivery knob to eject a few drops of titrant. Reset the counter to zero and wipe the tip.

5.13 Use a graduated cylinder or pipet to measure the sample volume from *Table 1.* Transfer the sample into a clean 250mL Erlenmeyer flask. Dilute to 100-mL with deionized water.

5.14 Add the contents of one Chloride 2 Indicator Powder Pillow and then swirl to mix.

5.15 Place the delivery tube tip into the solution and swirl the flask while titrating with silver nitrate until the solution changes from a yellow to a red-brown color. Record the number of digits required from the digital titrator.

6. CALCULATION

6.1 Use the following formula to calculate the concentration of chloride in the soil sample. (Digits Required) x (Digital Multiplier) x (Dilution Factor) = mg/L or parts-per-million (ppm) Chloride)

6.2 Divide the ppm obtained from the calculation and divide by 10,000 to obtain the percent chloride in soil by mass.

7. INTERFERENCES

7.1 Iron in excess of 10 mg/L masks the endpoint.

7.2 Orthophosphate in excess of 25 mg/L will precipitate the silver.

7.3 Sulfite in excess of 10 mg/L will cause interference. If sulfite interference is suspected, eliminate it by adding three drops of 30% hydrogen peroxide in Subsection 5.5.

7.4 If sulfide interference is suspected, eliminate it by adding the contents of one Sulfide Inhibitor Reagent Powder Pillow to approximately 125 mL of sample, mixing for one minute, and then filtering through a folded filter paper.

7.5 Cyanide, iodide, and bromide interfere directly and while titrating it may appear as chloride. No attempt to remove these interferences is made because they are usually present in insignificant quantities compared to chloride.

Table 1: **Concentrations**

Range (mg/L as Cl-)	Sample Volume (mL)	Titration Cartridge (N AgNO3)	Digital Multiplier
10-40	100	0.2256	0.1
25-100	40	0.2256	0.25
100-400	50	1.128	1.0
250-1000	20	1.128	2.5
1000-4000	5	1.128	10.0
2500-10000	2	1.128	25.0

APPENDIX D

D.1: I-76 / WCR-53 Crash Data

hwy	mp	loc01	dist	loc02	date	time	sev	serial	location	road_desc
076A	036.10				6/17/1995	0135	PDO	95054163	OFF LEFT	NON-INTERSECTION
076A	036.80				10/14/1995	0011	PDO	95097951	ON	NON-INTERSECTION
076A	036.10				2/25/1997	2030	INJ	97031176	OFF RIGHT	NON-INTERSECTION
076A	036.50				10/24/1997	1330	PDO	97139085	OFF LEFT	NON-INTERSECTION
076A	037.00				11/9/1997	2225	INJ	97139127	OFF LEFT	NON-INTERSECTION
076A	036.60				11/13/1997	1825	INJ	97139201	OFF LEFT	NON-INTERSECTION
076A	036.84				3/7/1998	0040	PDO	98036341	OFF LEFT	NON-INTERSECTION
076A	036.76				5/25/1998	2020	INJ	98064811	ON	NON-INTERSECTION
076A	036.10				6/28/1998	0430	PDO	98075938	OFF LEFT	NON-INTERSECTION
076A	036.88				8/16/1998	0030	INJ	98095737	OFF RIGHT	NON-INTERSECTION
076A	036.44				1/4/1999	1130	FAT	99006702	OFF RIGHT	NON-INTERSECTION
076A	036.60				7/27/1999	2020	PDO	99086364	ON	NON-INTERSECTION
076A	036.80				8/16/1999	1635	INJ	99107152	OFF RIGHT	NON-INTERSECTION
076A	036.03				10/17/1999	1525	INJ	99127279	OFF LEFT	NON-INTERSECTION
076A	036.40				10/24/1999	0225	INJ	99127293	OFF RIGHT	NON-INTERSECTION
076A	036.90	COLORADO 76 FRONTAGE RD	00.10MW	MM 37	5/22/2001	0808	INJ	01313493	OFF RIGHT	NON-INTERSECTION
076A	036.90	COLORADO 76	00.10MW	MM 37	8/16/2001	1700	PDO	01324934	OFF LEFT	NON-INTERSECTION
076A	036.70	COLORADO 76	00.30MW	MM 37	8/21/2001	0615	PDO	01324770	OFF LEFT	NON-INTERSECTION
076A	036.70	COLORADO 76	00.30MW	MM 37	11/26/2001	0615	PDO	01335145	OFF LEFT	NON-INTERSECTION
076A	036.30	COLORADO 76 WESTBOUND	00.30ME	MILEPOST 36	3/8/2002	1415	PDO	02306017	OFF LEFT	NON-INTERSECTION
076A	036.50	EASTBOUND COLORADO 76	00.50ME	MILEPOST 36	3/20/2003	1400	PDO	03308939	OFF LEFT	NON-INTERSECTION
076A	036.54	CO 76	AT	MP 37	3/20/2003	1000	PDO	03308926	ON	NON-INTERSECTION
076A	036.54				3/20/2003	1337	PDO	03025702	ON	NON-INTERSECTION
076A	036.80	COLORADO 76	00.20MW	MILEPOST 37	3/27/2004	1730	PDO	04309698	ON	NON-INTERSECTION
076A	036.70	COLORADO 76	00.30MW	MILEPOST 37	2/13/2005	2210	INJ	05332585	OFF LEFT	NON-INTERSECTION
076A	036.99	I-76	00047FW	MM 37	3/5/2006	0820	INJ	06307339	OFF RIGHT	NON-INTERSECTION
076A	036.90	I-76	00.10MW	MM 37	7/1/2006	1630	PDO	06320832	OFF LEFT	NON-INTERSECTION
076A	037.00	I-76	AT	MM 37	8/20/2006	1225	PDO	06326258	ON	NON-INTERSECTION
076A	036.59	I-76	00.59ME	MM 36	1/11/2007	0635	INJ	07379272	OFF LEFT	NON-INTERSECTION
076A	036.50	I-76	00.50ME	MM 36	1/14/2007	1300	PDO	07374596	ON	NON-INTERSECTION
076A	036.00	I-76	AT	MM 36	3/29/2007	2007	PDO	07031799	OFF RIGHT	NON-INTERSECTION
076A	037.00	I76	AT	MM 37	8/7/2007	1830	PDO	07058027	OFF LEFT	NON-INTERSECTION
076A	036.00	I-76	AT	MM 36	1/9/2008	1813	PDO	08317398	OFF RIGHT	NON-INTERSECTION
076A	036.00	I-76 WB	AT	MM 36	3/5/2008	0300	PDO	08020811	OFF LEFT	NON-INTERSECTION
076A	036.90	I-76	00.10MW	MM 37	6/13/2008	0940	PDO	08316654	ON	NON-INTERSECTION
076A	036.60	I-76	00.40MW	MM 37	8/12/2008	0135	PDO	08310811	ON	NON-INTERSECTION
076A	036.60	I-76	00.40MW	MM 37	8/12/2008	0135	INJ	08310810	OFF RIGHT	NON-INTERSECTION
076A	036.70	I-76	00.30MW	MM 37	11/12/2008	1820	PDO	08322059	ON	NON-INTERSECTION
076A	036.70	I-76	00.30MW	MM 37	11/12/2008	1820	PDO	08322060	ON	NON-INTERSECTION

hwy	mp	street	date	time	sev	location	road_desc	vehicles	contour	condition
076A	37		2/24/2010	1830	PDO	ON	NON-INTERSECTION	1	STRAIGHT ON-LEVEL	DRY
076A	36		3/1/2010	0720	PDO	ON	NON-INTERSECTION	2	HILLCREST	ICY
076A	36.54		6/11/2010	1714	PDO	OFF RIGHT	NON-INTERSECTION	1	STRAIGHT ON-LEVEL	WET
076A	36.2		6/23/2010	1330	PDO	OFF RIGHT	NON-INTERSECTION	1	CURVE ON-LEVEL	DRY
076A	37		7/23/2010	1530	PDO	OFF LEFT	NON-INTERSECTION	1	STRAIGHT ON-LEVEL	DRY

vehicles	contour	condition	lighting	weather	ramp	acctype	dir_1
1	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	OVERTURNING	E
2	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	SIDESWIPE (OPPOSITE DIRECTION)	W
1	CURVE ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	OVERTURNING	E
1	CURVE ON-LEVEL	WET	DAYLIGHT	SNOW/SLEET/HAIL	N	EMBANKMENT	W
1	STRAIGHT ON-LEVEL	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	OVERTURNING	E
1	STRAIGHT ON-LEVEL	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	OVERTURNING	W
1	STRAIGHT ON-LEVEL	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	DELINEATOR POST	E
2	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	WIND	N	SIDESWIPE (SAME DIRECTION)	W
1	CURVE ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	OVERTURNING	E
1	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	DELINEATOR POST	W
1	CURVE ON-LEVEL	DRY	DAYLIGHT	NONE	N	OVERTURNING	E
2	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	SIDESWIPE (SAME DIRECTION)	W
1	STRAIGHT ON-GRADE	DRY	DAYLIGHT	NONE	N	OVERTURNING	W
1	CURVE ON-LEVEL	DRY	DAYLIGHT	NONE	N	EMBANKMENT	W
1	CURVE ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	OVERTURNING	E
1	CURVE ON-LEVEL	DRY	DAYLIGHT	NONE	N	OVERTURNING	W
1	STRAIGHT ON-LEVEL	WET	DAYLIGHT	RAIN	N	CULVERT/HEADWALL	E
1	CURVE ON-GRADE	DRY	DAYLIGHT	NONE	N	DELINEATOR POST	W
1	STRAIGHT ON-GRADE	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	GUARD RAIL	W
1	CURVE ON-LEVEL	ICY	DAYLIGHT	SNOW/SLEET/HAIL	N	OTHER NON-COLLISION	W
1	STRAIGHT ON-LEVEL	SLUSHY	DAYLIGHT	NONE	N	INVOLVING OTHER OBJECT	E
2	STRAIGHT ON-LEVEL	SNOWY	DAYLIGHT	NONE	N	SIDESWIPE (SAME DIRECTION)	E
1	UNKNOWN	UNKNOWN	DAYLIGHT	NONE	N	INVOLVING OTHER OBJECT	E
1	HILLCREST	DRY	DAYLIGHT	NONE	N	OVERTURNING	E
1	STRAIGHT ON-LEVEL	DRY	DARK-UNLIGHTED	NONE	N	OVERTURNING	W
1	STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	N	OVERTURNING	W
1	CURVE ON-GRADE	WET	DAYLIGHT	RAIN	N	DELINEATOR POST	E
2	STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	N	INVOLVING OTHER OBJECT	W
1	STRAIGHT ON-LEVEL	DRY	DAWN OR DUSK	NONE	N	OVERTURNING	W
2	CURVE ON-LEVEL	ICY	DAYLIGHT	SNOW/SLEET/HAIL	N	REAR END	W
1	STRAIGHT ON-LEVEL	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	OVERTURNING	E
2	STRAIGHT ON-LEVEL	WET	DAYLIGHT	RAIN	N	SIDESWIPE (SAME DIRECTION)	E
1	STRAIGHT ON-LEVEL	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	DELINEATOR POST	W
1	STRAIGHT ON-LEVEL	WET	DARK-UNLIGHTED	SNOW/SLEET/HAIL	N	OVERTURNING	W
1	STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	N	WILD ANIMAL	W
2	STRAIGHT ON-LEVEL	WET	DARK-UNLIGHTED	NONE	N	PARKED MOTOR VEHICLE	E
1	STRAIGHT ON-LEVEL	WET	DARK-UNLIGHTED	NONE	N	GUARD RAIL	E
1	CURVE ON-GRADE	DRY	DARK-UNLIGHTED	NONE	N	WILD ANIMAL	W
1	CURVE ON-GRADE	DRY	DARK-UNLIGHTED	NONE	N	WILD ANIMAL	E

lighting	weather	ramp	loc01	dist	loc02	acctype	dir_1
DARK-UNLIGHTED	NONE	N	I-76	AT	MM 37	WILD ANIMAL	W
DAYLIGHT	NONE	N	I-76	AT	MM 36	REAR END	W
DAYLIGHT	NONE	N	I-76	AT	CR 53	OVERTURNING	E
DAYLIGHT	NONE	N	I-76	00.20ME	MM 36	OVERTURNING	E
DAYLIGHT	NONE	N	I-76	AT	MM 37	OVERTURNING	E

vehicle_1	alcohol_1	drugs_1	factor_1	speed_1	veh_move_1	dir_2
PICKUP TRUCK/UTILITY VAN	Y	N	DRIVER FATIGUE	65	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	Y	N	NONE APPARENT	50	OTHER	E
PASSENGER CAR/VAN	N	N	NONE APPARENT	70	GOING STRAIGHT	
HIT & RUN - UNKNOWN	N	N	NONE APPARENT	50	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	N	N	DISTRACTED/OTHER	75	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	50	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	NONE APPARENT	55	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	75	GOING STRAIGHT	W
HIT & RUN - UNKNOWN	N	N	NONE APPARENT	75	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	75	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	75	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	85	PASSING	W
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	75	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	N	N	DISTRACTED/OTHER	75	GOING STRAIGHT	
PASSENGER CAR/VAN	Y	N	NONE APPARENT	75	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	DISTRACTED/PASSENGER	70	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	70	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	60	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	50	GOING STRAIGHT	
VEH COMBO (10,001 LBS AND OVER)	N	N	DISTRACTED/OTHER	40	GOING STRAIGHT	
VEH COMBO (10,001 LBS AND OVER)	N	N	DISTRACTED/OTHER	75	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	60	GOING STRAIGHT	E
PICKUP TRUCK/UTILITY VAN	N	N		75	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	NONE APPARENT	75	GOING STRAIGHT	
PASSENGER CAR/VAN	Y	N	ASLEEP AT THE WHEEL	85	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	80	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	NONE APPARENT	75	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	NONE APPARENT	75	GOING STRAIGHT	W
PASSENGER CAR/VAN	N	N	NONE APPARENT	55	AVOIDING OBJECT IN ROAD	
PASSENGER CAR/VAN	N	N	NONE APPARENT	70	GOING STRAIGHT	W
PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	OTHER FACTOR	65	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	OTHER FACTOR	75	SPUN OUT OF CONTROL	E
PASSENGER CAR/VAN	Y	N	NONE APPARENT	55	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	65	GOING STRAIGHT	
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	75	GOING STRAIGHT	
PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	60	GOING STRAIGHT	E
PASSENGER CAR/VAN	N	N	ASLEEP AT THE WHEEL	82	GOING STRAIGHT	
SUV	N	N	NONE APPARENT	70	GOING STRAIGHT	
SUV	N	N	NONE APPARENT	70	GOING STRAIGHT	

vehicle_1	alcohol_1	drugs_1	factor_1	limit_1	speed_1	veh_move_1
PASSENGER CAR/VAN	N	N	NONE APPARENT	75	75	GOING STRAIGHT
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	75	50	SPUN OUT OF CONTROL
SUV	N	N	OTHER FACTOR	65	UK	SPUN OUT OF CONTROL
PICKUP TRUCK/UTILITY VAN	N	N	ASLEEP AT THE WHEEL	75	70	OTHER
PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	DRIVER INEXPERIENCE	75	65	SPUN OUT OF CONTROL

vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2
VEH COMBO (10,001 LBS AND OVER)	N	N	NONE APPARENT	65	GOING STRAIGHT
VEH COMBO (10,001 LBS AND OVER)	N	N	NONE APPARENT	70	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	75	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	60	GOING STRAIGHT
VEH COMBO (10,001 LBS AND OVER)	N	N	NONE APPARENT	75	GOING STRAIGHT
SUV	N	N	NONE APPARENT	50	SLOWING
PASSENGER CAR/VAN	N	N	OTHER FACTOR	75	SPUN OUT OF CONTROL
PASSENGER CAR/VAN	N	N	NONE APPARENT	00	PARKED

dir_2	vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	30	GOING STRAIGHT

D.2: Parker Rd. / I-225 Crash Data

hwy	mp	loc1	dist	loc 2	date	time	sev	serial	location	road_desc	vehicles	contour
225A	003.70	I-225 SB FLYOVER RAMP	X	S PARKER RD	1/4/2002	1000	PDO	02300369	ON	RAMP	2	UNKNOWN
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	1/8/2002	1930	PDO	02005345	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	3/2/2002	0642	PDO	02027026	OFF RIGHT	RAMP	1	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	5/5/2002	0000	INJ	02046947	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	11/24/2002	2213	PDO	02128352	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	11/24/2002	2220	PDO	02128351	ON	RAMP	3	STRAIGHT ON-LEVEL
225A	003.90	I-225 SB FLYOVER RAMP	00.10MS	MILEPOST 4	1/16/2003	0815	INJ	03301818	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	AT	S PARKER RD	5/11/2003	0600	INJ	03313203	OFF RIGHT	RAMP	1	CURVE ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	00.05MS	MILEPOST 4	5/31/2003	0240	PDO	03314562	OFF RIGHT	RAMP	1	CURVE ON-GRADE
225A	003.92	I-225 SB FLYOVER RAMP	00085FS	S PARKER RD	7/9/2003	1745	INJ	03319352	OFF RIGHT	RAMP	2	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	8/13/2003	1430	PDO	03079540	OFF LEFT	RAMP	1	STRAIGHT ON-LEVEL
225A	003.95	I-225 SB FLYOVER RAMP	AT	MILEPOST 4	10/6/2003	0840	PDO	03328243	ON	RAMP	2	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	S PARKER RD	10/11/2003	1657	INJ	03101848	OFF LEFT	RAMP	1	STRAIGHT ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	AT	S PARKER RD	2/21/2004	0105	PDO	04041608	OFF LEFT	RAMP	1	CURVE ON-GRADE
225A	003.62	I-225 SB FLYOVER RAMP	AT	RTD SB SLIP RAMP	6/20/2004	1545	PDO	04318715	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.75	I-225 SB FLYOVER RAMP	X	S PARKER RD	9/7/2004	0630	PDO	04326804	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	AT	S PARKER RD	11/11/2004	0718	INJ	04105734	OFF RIGHT	RAMP	1	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	AT	S PARKER RD	11/25/2004	1333	PDO	04109294	OFF RIGHT	RAMP	1	CURVE ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	X	PARKER RD	2/13/2005	0130	PDO	05160764	OFF LEFT	RAMP	1	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	HWY 83	3/19/2005	2213	PDO	05013502	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	00030FN	PARKER RD	4/17/2005	1950	INJ	05312954	OFF LEFT	RAMP	1	CURVE ON-GRADE
225A	003.74	I-225 SB FLYOVER RAMP	00.20MS	PARKER RD	4/24/2005	2246	PDO	05313071	OFF RIGHT	RAMP	1	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	PARKER RD	9/13/2005	1315	PDO	05189552	ON	RAMP	2	CURVE ON-LEVEL
225A	003.95	I-225 SB FLYOVER RAMP	X	PARKER RD	2/16/2006	1928	INJ	06011418	OFF LEFT	RAMP	1	STRAIGHT ON-GRADE
225A	003.74	I-225 SB FLYOVER RAMP	00.20MS	PARKER RD	2/17/2006	0910	PDO	06306052	OFF LEFT	RAMP	1	CURVE ON-GRADE
225A	003.74	I-225 SB FLYOVER RAMP	00.20MS	PARKER RD	2/17/2006	1645	INJ	06306838	OFF LEFT	RAMP	2	CURVE ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	PARKER RD	3/8/2006	1250	PDO	06019262	OFF LEFT	RAMP	1	STRAIGHT ON-LEVEL
225A	003.94	I-225 SB FLYOVER RAMP	AT	PARKER RD	4/25/2006	0310	INJ	06314390	OFF LEFT	RAMP	1	CURVE ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	AT	PARKER RD	4/25/2006	0315	PDO	06314391	OFF RIGHT	RAMP	3	CURVE ON-GRADE
225A	003.94	I-225 SB FLYOVER RAMP	X	PARKER RD	5/25/2006	0758	PDO	06040873	ON	RAMP	2	CURVE ON-GRADE
225A	3.96	I-225 SB FLYOVER RAMP	AT	PARKER RD	1/22/2007	2031	PDO	07017345	ON	RAMP	1	STRAIGHT ON-LEVEL
225A	003.50	I-225	00.50MS	MILEPOST 4	5/23/2007	1730	PDO	7386015	OFF RIGHT	RAMP	1	STRAIGHT ON-GRADE
225A	003.95	I-225 SB FLYOVER RAMP	X	PARKER RD	9/18/2007	1837	PDO	7002698	ON	RAMP	2	STRAIGHT ON-GRADE
225A	003.94	I-225 ON RAMP	AT	PARKER RD	12/28/2007	1024	PDO	07085272	ON	RAMP	3	STRAIGHT ON-GRADE
225A	004.00	I-225 SB ON RAMP	01.00ME	PARKER RD S	12/28/2007	1134	PDO	07085268	ON	RAMP	3	CURVE ON-GRADE
225A	003.95	I-225 SB ON RAMP	00025FE	PARKER RD	9/18/2008	1630	PDO	08055086	ON	RAMP	2	CURVE ON-GRADE

hwy	mp	date	time	sev	serial	location	road_desc	vehicles	contour	condition	lighting	weather
225A	3.94	10/10/2009	0724	PDO	09055829	ON	RAMP	2	CURVE ON-GRADE	ICY	DAYLIGHT	SNOW/SLEET/HAIL
225A	3.94	7/30/2009	1044	PDO	09041715	OFF LEFT	RAMP	1	STRAIGHT ON-GRADE	DRY	DAYLIGHT	NONE
225A	3.94	11/13/2009	1455	PDO	09065519	OFF LEFT	RAMP	1	STRAIGHT ON-GRADE	DRY	DAYLIGHT	NONE
225A	3.97	11/1/2009	1921	PDO	09061038	ON	RAMP	2	CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE

hwy	mp	street	date	time	sev	location	road_desc	vehicles	contour	condition	lighting	weather
225A	3.44	I	3/24/2010	0443	PDO	OFF LEFT	RAMP	2	CURVE ON-GRADE	ICY	DARK-LIGHTED	SNOW/SLEET/HAIL
225A	3.63	I	6/22/2010	1850	PDO	OFF LEFT	RAMP	1	STRAIGHT ON-GRADE	WET	DAYLIGHT	RAIN
225A	3.94	I	6/23/2010	1607	PDO	ON	RAMP	2	STRAIGHT ON-GRADE	DRY	DAYLIGHT	NONE
225A	3.94	I	7/30/2010	1958	PDO	OFF RIGHT	RAMP	1	CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE
225A	3.94	I	9/13/2010	1833	INJ	OFF LEFT	RAMP	1	CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE
225A	3.94	I	10/12/2010	0511	PDO	OFF RIGHT	RAMP	1	CURVE ON-GRADE	DRY	DAYLIGHT	NONE
225A	3.95	I	10/24/2010	2322	PDO	ON	RAMP	2	STRAIGHT ON-GRADE	DRY	DARK-LIGHTED	NONE

condition	lighting	weather	ramp	acctype
UNKNOWN	UNKNOWN	UNKNOWN	Y (I)	SIDESWIPE (SAME DIRECTION)
DRY	UNKNOWN	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)
ICY W/VIS ICY ROAD TREATMENT	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DAWN OR DUSK	NONE	Y (I)	REAR END
SNOWY W/VIS ICY ROAD TREATMENT	DARK-UNLIGHTED	SNOW/SLEET/HAIL	Y (I)	SIDESWIPE (SAME DIRECTION)
ICY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (I)	PARKED MOTOR VEHICLE
DRY	DAYLIGHT	NONE	Y (I)	REAR END
ICY	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DARK-LIGHTED	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DAYLIGHT	NONE	Y (I)	GUARD RAIL
DRY	DAYLIGHT	NONE	Y (I)	REAR END
DRY	DAYLIGHT	NONE	Y (I)	CRASH CUSHION/TRAFFIC BARREL
DRY	DARK-LIGHTED	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DAYLIGHT	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)
DRY	DAYLIGHT	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)
ICY	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DARK-LIGHTED	NONE	Y (I)	BRIDGE STRUCTURE
DRY	DARK-UNLIGHTED	NONE	Y (I)	REAR END
DRY	DAYLIGHT	NONE	Y (I)	BRIDGE STRUCTURE
WET	DARK-LIGHTED	RAIN	Y (I)	GUARD RAIL
DRY	DAYLIGHT	NONE	Y (I)	REAR END
DRY	DARK-LIGHTED	NONE	Y (I)	CRASH CUSHION/TRAFFIC BARREL
SNOWY W/VIS ICY ROAD TREATMENT	DAYLIGHT	SNOW/SLEET/HAIL	Y (I)	GUARD RAIL
SNOWY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (I)	SIDESWIPE (SAME DIRECTION)
WET	DAYLIGHT	SNOW/SLEET/HAIL	Y (I)	CRASH CUSHION/TRAFFIC BARREL
ICY	DARK-LIGHTED	NONE	Y (I)	CONCRETE HIGHWAY BARRIER
ICY	DARK-LIGHTED	NONE	Y (I)	PARKED MOTOR VEHICLE
DRY	DAYLIGHT	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)
ICY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (I)	OVERTURNING
WET	DAYLIGHT	RAIN	Y (I)	CONCRETE HIGHWAY BARRIER
DRY	DAWN OR DUSK	NONE	Y (I)	REAR END
SNOWY	DAYLIGHT	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)
WET	DAYLIGHT	SNOW/SLEET/HAIL	Y (I)	REAR END
DRY	DAYLIGHT	NONE	Y (I)	SIDESWIPE (SAME DIRECTION)

ramp	acctype	event_1	event_2	event_3
Y (I)	PARKED MOTOR VEHICLE	PARKED MOTOR VEHICLE		
Y (I)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		
Y (I)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		
Y (I)	SIDESWIPE (SAME DIRECTION)	SIDE TO SIDE (SAME DIRECTION)	CONCRETE HIGHWAY BARRIER	

ramp	loc01	dist	loc02	acctype
Y (I)	I-225 SB ON RAMP	00.50MS	S PARKER RD NB	CONCRETE HIGHWAY BARRIER
Y (I)	I-225 SB ON RAMP	99999FN	RAMP ON (FROM NB SH 083A) GORE	CONCRETE HIGHWAY BARRIER
Y (I)	S PARKER RD NB OFF RAMP TO I-225	00.10ME	I-225 INTERCHANGE	SIDESWIPE (SAME DIRECTION)
Y (I)	I-225 SB ON RAMP (FLYOVER)	AT	S PARKER RD SB OFF RAMP	CONCRETE HIGHWAY BARRIER
Y (I)	I-225 SB ON RAMP (FLYOVER)	AT	S PARKER RD	CONCRETE HIGHWAY BARRIER
Y (I)	I-225 SB ON RAMP (FLYOVER)	AT	S PARKER RD	BRIDGE STRUCTURE
Y (I)	I-225 SB ON RAMP (FLYOVER)	99999FN	S PARKER RD	SIDESWIPE (SAME DIRECTION)

dir_1	vehicle_1	alcohol_1	drugs_1	factor_1	speed_1
S		N	N		00
W	PASSENGER CAR/VAN	N	N	DRIVER UNFAMILIAR W/AREA	20
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	25
W	PICKUP TRUCK/UTILITY VAN	Y	N	DISTRACTED/OTHER	UK
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	45
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	20
S	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	40
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	40
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	80
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	70
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	45
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	10
W	MOTORCYCLE	Y	N	DRIVER UNFAMILIAR W/AREA	00
S	PASSENGER CAR/VAN	N	N		UK
S	VEH COMBO (10,001 LBS AND OVER)	N	N	DISTRACTED/OTHER	35
S	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	50
W	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	55
W	PASSENGER CAR/VAN	Y	N		45
S	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	45
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	45
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	45
S	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	50
W	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	30
W	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	55
S	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	25
S	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	25
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	40
W	PASSENGER CAR/VAN	N	N	NONE APPARENT	30
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	00
W	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	45
NW	PASSENGER CAR/VAN	N	N	DRIVER UNFAMILIAR W/AREA	30
S	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	45
N	SUV	N	N	NONE APPARENT	50
NW	PASSENGER CAR/VAN	N	N	OTHER FACTOR	40
SW	PICKUP TRUCK/UTILITY VAN	N	N	OTHER FACTOR	UK
NW	PASSENGER CAR/VAN	N	N	NONE APPARENT	25

dir_1	vehicle_1	alcohol_1	drugs_1	factor_1	speed_1
N	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	UK
N	PASSENGER CAR/VAN	N	N	OTHER FACTOR	UK
W	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	45
W	PASSENGER CAR/VAN	N	N	DUI, DWAI, DUID	55

event_1	event_2	event_3	mhe	dir_1	vehicle_1
CONCRETE HIGHWAY BARRIER	FRONT TO REAR		FRONT TO REAR	S	PASSENGER CAR/VAN
CONCRETE HIGHWAY BARRIER			CONCRETE HIGHWAY BARRIER	SW	PASSENGER CAR/VAN
SIDE TO SIDE (SAME DIRECTION)	VEHICLE DEBRIS OR CARGO		SIDE TO SIDE (SAME DIRECTION)	W	PASSENGER CAR/VAN
CONCRETE HIGHWAY BARRIER			CONCRETE HIGHWAY BARRIER	SW	PASSENGER CAR/VAN
CONCRETE HIGHWAY BARRIER	OVERTURNING		OVERTURNING	N	MOTORCYCLE
BRIDGE STRUCTURE			BRIDGE STRUCTURE	S	PASSENGER CAR/VAN
SIDE TO SIDE (SAME DIRECTION)			SIDE TO SIDE (SAME DIRECTION)	N	PASSENGER CAR/VAN

veh_move_1	dir_2	vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2
CHANGING LANES	S		N	N		UK	GOING STRAIGHT
CHANGING LANES	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	15	GOING STRAIGHT
GOING STRAIGHT							
GOING STRAIGHT	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
SLOWING	W		N	N		UK	UNKNOWN
GOING STRAIGHT	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
GOING STRAIGHT	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
GOING STRAIGHT							
GOING STRAIGHT							
GOING STRAIGHT	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	45	GOING STRAIGHT
AVOIDING OBJECT IN ROAD							
GOING STRAIGHT	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
CHANGING LANES							
GOING STRAIGHT							
CHANGING LANES	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	35	GOING STRAIGHT
GOING STRAIGHT	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	50	GOING STRAIGHT
GOING STRAIGHT							
GOING STRAIGHT							
GOING STRAIGHT							
GOING STRAIGHT	N	PASSENGER CAR/VAN	N	N	NONE APPARENT	35	GOING STRAIGHT
OTHER							
GOING STRAIGHT							
GOING STRAIGHT	W	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
GOING STRAIGHT							
GOING STRAIGHT							
GOING STRAIGHT	S	PASSENGER CAR/VAN	N	N	NONE APPARENT	35	GOING STRAIGHT
GOING STRAIGHT							
GOING STRAIGHT							
PARKED	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	25	GOING STRAIGHT
WEAVING	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	45	GOING STRAIGHT
SPUN OUT OF CONTROL							
GOING STRAIGHT							
CHANGING LANES	N	PICKUP TRUCK W Trailer	N	N	NONE APPARENT	20	
SPUN OUT OF CONTROL	NW	PASSENGER CAR/VAN	N	N	OTHER FACTOR	40	GOING STRAIGHT
AVOIDING OBJECT IN ROAD	SW	PASSENGER CAR/VAN	N	N	NONE APPARENT	20	AVOIDING OBJECT IN ROAD
CHANGING LANES	NW	PASSENGER CAR/VAN	N	N	NONE APPARENT	45	GOING STRAIGHT

veh_move_1	dir_2	vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2	dir_3	vehicle_3
SPUN OUT OF CONTROL	N	VEH COMBO (10,001 LBS AND OVER)	N	N	NONE APPARENT	00	PARKED		
SPUN OUT OF CONTROL									
CHANGING LANES									
PASSING	W	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT		

alcohol_1	drugs_1	factor_1	limit_1	speed_1	veh_move_1	dir_2	vehicle_2	alcohol_2	drugs_2
N	N	NONE APPARENT	35	55	SPUN OUT OF CONTROL	S	PASSENGER CAR/VAN	N	N
N	N	NONE APPARENT	65	45	SPUN OUT OF CONTROL				
N	N	DRIVER INEXPERIENCE	45	45	CHANGING LANES	W	PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N
N	N	AGRESSIVE DRIVING	UK	UK	GOING STRAIGHT				
N	N	DUI, DWAI, DUID	45	60	MAKING LEFT TURN				
N	N	NONE APPARENT	40	40	GOING STRAIGHT				
N	N	DRIVER UNFAMILIAR W/AREA	45	65	CHANGING LANES	N	PASSENGER CAR/VAN	N	N

loc01	dist	loc02
I-225 SB ON RAMP	AT	S PARKER RD NB / WB
I-225 SB ON RAMP	AT	S PARKER RD NB / WB
I-225 SB ON RAMP	AT	S PARKER RD NB / WB
I-225 SB FLYOVER RAMP	AT	S PARKER RD

factor_2	speed_2	veh_move_2
NONE APPARENT	55	GOING STRAIGHT
NONE APPARENT	45	GOING STRAIGHT
NONE APPARENT	45	GOING STRAIGHT

D.3: I-25 / I-225 Crash Data

hwy	mp	loc01	dist	loc02	date	time	sev	serial	location	road_desc	vehicles
225A	000.45				4/9/1997	0130	PDO	97039437	OFF LEFT	RAMP	1
225A	000.00				7/23/1997	2330	PDO	97080420	OFF LEFT	RAMP	1
225A	000.00				8/2/1997	2320	PDO	97087717	ON	RAMP	2
225A	000.00				8/2/1997	2330	PDO	97087787	ON	RAMP	2
225A	000.00				12/2/1997	1600	PDO	97146749	ON	RAMP	2
225A	000.00				1/23/1998	1750	PDO	98009765	ON	RAMP	2
225A	000.28				10/6/1998	1515	PDO	98113949	ON	RAMP	2
225A	000.00				11/4/1998	0217	INJ	98134895	OFF LEFT	RAMP	1
225A	000.00				1/21/1999	0107	INJ	99005513	OFF LEFT	RAMP	1
225A	000.00				10/18/1999	2121	PDO	99121522	ON	RAMP	2
225A	000.28				10/23/1999	1200	PDO	99120348	ON	RAMP	1
225A	000.30				3/31/2000	0700	PDO	00023957	ON	RAMP	3
225A	000.06	I-25 SB LEFT FLYOVER		I-225 NB	5/11/2001	0030	PDO	01048367	ON	RAMP	2
225A	000.00				5/27/2001	0355	PDO	01055595	OFF LEFT	RAMP	1
225A	000.05				7/28/2001	1921	INJ	01080250	OFF LEFT	RAMP	1
225A	000.34	I 225 NB		EXIT S TAMARAC PKWY	2/4/2002	2150	INJ	02002841	OFF RIGHT	RAMP	1
225A	000.01	I-25-SB Left Exit		I225 NB	3/5/2002	1958	INJ	02017722	ON	RAMP	2
225A	000.02	SB I 25		NB I 225	1/17/2003	0253	INJ	03004116	ON	RAMP	3
025A	200.09	SB I 25 FLYOVER RAMP		NB I 225	12/13/2003	1000	PDO	03121828	OFF LEFT	RAMP	1
225A	000.00	SB I 25 FLYOVER		NB I 225	12/18/2003	1315	PDO	3122161	OFF RIGHT	RAMP	1
025A	200.45	I25 SB		I225 NB	12/31/2003	0230	PDO	03129696	ON	RAMP	2
225A	000.05	NB I25	AT	I225	3/28/2004	1519	PDO	04022602	ON	RAMP	2
225A	000.27	I225 NB	AT	S TAMARAC	4/23/2004	2200	INJ	04029654	OFF RIGHT	RAMP	1
225A	0.37	I225 WB FLYOVER	AT	S TAMARAC ST	4/25/2004	1504	INJ	04029747	ON	RAMP	2
225A	000.03	I25 SB	AT	I225 NB	4/30/2004	2315	PDO	04047140	OFF RIGHT	RAMP	1
225A	000.07	I25SB-I225 NB FLYOVER	00.60MS	TAMARAC ST	5/24/2004	2337	INJ	04044666	OFF RIGHT	RAMP	1
225A	000.05	I25 SB	AT	I225 NB RAMP	6/5/2004	0229	INJ	04074131	ON	RAMP	2
225A	000.12	SB I 25 FLYOVER	AT	NB I 225	9/7/2004	1352	PDO	4073627	OFF RIGHT	RAMP	1
225A	000.28	SB I25 OFF RAMP	AT	TO NB I225	11/21/2004	0304	PDO	04108647	OFF LEFT	RAMP	1
225A	000.10	I-25	AT	I-225 RAMP	4/29/2005	0135	PDO	05169509	ON	RAMP	2
225A	000.22	I-225A	AT	QUEBEC ST	6/25/2005	1150	PDO	05416282	OFF DIVIDED HIG	RAMP	2
225A	000.28	I-225A	AT	TAMARAC ST EXIT	8/6/2005	1045	PDO	05422073	ON	RAMP	2
225A	000.00	I-25 SB OFF RAMP	AT	I-225 NB ON RAMP	3/31/2006	2205	PDO	06024373	OFF RIGHT	RAMP	1
225A	000.30	I-225 SB OFF RAMP	00.70MW	MM 1	12/26/2006	0745	PDO	06139553	ON	RAMP	2
225A	000.41	I-225 SB OFF RAMP	00.10MN	I-25 SB ON RAMP	1/14/2007	2000	PDO	07012687	ON	RAMP	1
225A	000.00	I-25 SB OFF RAMP	AT	I-225 NB ON RAMP	1/22/2007	1140	PDO	7014829	OFF LEFT	RAMP	1
225A	0.10	I-25	AT	I-225 FLYOVER	3/29/2007	1911	PDO	07025890	OFF LEFT	RAMP	2
025A	200.00	I-25	AT	I-225 NB FLYOVER	4/6/2007	1956	PDO	07030859	OFF RIGHT	RAMP	1
225A	000.00	I-25 SB OFF RAMP	AT	I-225 ramp NB FLYOVER	10/15/2007	1545	PDO	07030199	ON	RAMP	2
025A	200.47	SB I 25 FLYOVER RAMP	00200FS	E QUINCY AVE	11/22/2007	0310	PDO	07076947	OFF RIGHT	RAMP	1
225A	000.00	I-225 NB ON RAMP	AT	I-25 SB OFF RAMP	3/2/2008	1150	PDO	08014693	ON	RAMP	1

hwy	mp	date	time	sev	serial	location	road_desc	vehicles	contour	condition	lighting
225A	0	1/12/2009	1318	PDO	09001709	OFF RIGHT	RAMP	1	CURVE ON-GRADE	SLUSHY	DAYLIGHT
225A	0.22	1/12/2009	1318	PDO	09001714	ON	RAMP	2	CURVE ON-GRADE	SLUSHY	DAYLIGHT
225A	0.01	1/28/2009	1340	INJ	09004731	OFF RIGHT	RAMP	1	STRAIGHT ON-GRADE	DRY	DAYLIGHT
225A	0.22	4/27/2009	0720	PDO	09021953	OFF RIGHT	RAMP	1	CURVE ON-GRADE	SLUSHY	DAYLIGHT
225A	0.38	4/30/2009	0715	PDO	09022105	OFF RIGHT	RAMP	1	STRAIGHT ON-LEVEL	DRY	DAYLIGHT
225A	0	6/8/2009	0355	PDO	09030496	OFF LEFT	RAMP	1	STRAIGHT ON-LEVEL	DRY	DARK-LIGHTED

hwy	mp	street	date	time	sev	location	road_desc	vehicles	contour	condition	lighting
225A	0	F	3/20/2010	0831	PDO	ON	RAMP	2	STRAIGHT ON-LEVEL	SLUSHY W/VIS ICY ROAD TREATMENT	DAYLIGHT
225A	0.45	F	4/12/2010	1545	PDO	ON	RAMP	2	STRAIGHT ON-GRADE	DRY	DAYLIGHT
225A	0	F	4/13/2010	1310	PDO	ON	RAMP	2	STRAIGHT ON-LEVEL	DRY	DAYLIGHT
225A	0.09	F	8/2/2010	1305	PDO	ON	RAMP	1	STRAIGHT ON-GRADE	DRY	DAYLIGHT
225A	0.39	F	8/10/2010	1729	PDO	ON	RAMP	2	STRAIGHT ON-GRADE	DRY	DAYLIGHT
225A	0.76	F	12/17/2010	0303	PDO	OFF RIGHT	RAMP	1	STRAIGHT ON-LEVEL	DRY	DARK-LIGHTED

contour	condition	lighting	weather	ramp	acctype
STRAIGHT ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
CURVE ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	UNKNOWN	DAWN OR DUSK	SNOW/SLEET/HAIL	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	DRY	DAWN OR DUSK	NONE	Y (F)	REAR END
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	ICY	DARK-LIGHTED	NONE	Y (F)	BRIDGE STRUCTURE
CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
STRAIGHT ON-LEVEL	WET	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	INVOLVING OTHER OBJECT
CURVE ON-GRADE	ICY	DAYLIGHT	NONE	Y (F)	REAR END
CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	EMBANKMENT
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	GUARD RAIL
CURVE ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
CURVE ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	REAR END
CURVE ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	REAR END
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	OVERTURNING
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	CRASH CUSHION/TRAFFIC BARREL
CURVE ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
CURVE ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
STRAIGHT ON-LEVEL	UNKNOWN	DARK-LIGHTED	NONE	Y (F)	LIGHT/UTILITY POLE
STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	Y (F)	REAR END
CURVE ON-GRADE	ICY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (F)	BRIDGE STRUCTURE
STRAIGHT ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
STRAIGHT ON-GRADE	DRY	DARK-LIGHTED	NONE	Y (F)	REAR END
STRAIGHT ON-GRADE	DRY	DAYLIGHT	NONE	Y (F)	EMBANKMENT
STRAIGHT ON-GRADE	WET	DARK-UNLIGHTED	SNOW/SLEET/HAIL	Y (F)	CONCRETE HIGHWAY BARRIER
CURVE ON-GRADE	ICY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (F)	REAR END
STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	Y (F)	REAR END
STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	Y (F)	GUARD RAIL
STRAIGHT ON-LEVEL	WET W/VIS ICY ROAD TREATMENT	DAYLIGHT	NONE	Y (F)	REAR END
CURVE ON-GRADE	ICY	DARK-LIGHTED	NONE	Y (F)	CONCRETE HIGHWAY BARRIER
STRAIGHT ON-LEVEL	SLUSHY W/VIS ICY ROAD TREATMENT	DAYLIGHT	NONE	Y (F)	CONCRETE HIGHWAY BARRIER
CURVE ON-GRADE	ICY	DARK-UNLIGHTED	SNOW/SLEET/HAIL	Y (F)	PARKED MOTOR VEHICLE
CURVE ON-GRADE	ICY	DARK-LIGHTED	SNOW/SLEET/HAIL	Y (F)	CONCRETE HIGHWAY BARRIER
STRAIGHT ON-LEVEL	DRY	DAYLIGHT	NONE	Y (F)	SIDESWIPE (SAME DIRECTION)
STRAIGHT ON-LEVEL	DRY	DARK-LIGHTED	NONE	Y (F)	GUARD RAIL
CURVE ON-GRADE	ICY	DAYLIGHT	SNOW/SLEET/HAIL	Y (F)	CONCRETE HIGHWAY BARRIER

weather	ramp	acctype	event_1	event_2	event_3
NONE	Y (F)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		
NONE	Y (F)	REAR END	FRONT TO SIDE		
NONE	Y (F)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		
SNOW/SLEET/HAIL	Y (F)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		
NONE	Y (F)	CRASH CUSHION/TRAFFIC BARREL	CRASH CUSHION/TRAFFIC BARREL		
NONE	Y (F)	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER		

weather	ramp	loc01	dist	loc02	acctype
NONE	Y (F)	I-225 NB OFF RAMP GORE POINT	AT	I-25 SB	SIDESWIPE (SAME DIRECTION)
NONE	Y (F)	I-225 NB FROM SB I-25	AT	LANE MERGE POINT	SIDESWIPE (SAME DIRECTION)
NONE	Y (F)	I-225 NB OFF RAMP GORE POINT	AT	I-25 SB	SIDESWIPE (SAME DIRECTION)
NONE	Y (F)	I-225 NB FROM SB I-25	00500FE	I-25 SB	OVERTURNING
NONE	Y (F)	I-25 SB OFF RAMP TO NB I-225	AT	LANE MERGE POINT AFTER DTC BLV	SIDESWIPE (SAME DIRECTION)
NONE	Y (F)	I-25 SB OFF RAMP TO I-225	99999FN	MERGE POINT WITH RAMP FROM NB	SIGN

dir_1	vehicle_1	alcohol_1	drugs_1	factor_1	speed_1	veh_move_1	dir_2
E	PASSENGER CAR/VAN	Y	N	ASLEEP AT THE WHEEL	UK	GOING STRAIGHT	
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	MAKING LEFT TURN	
N	HIT & RUN - UNKNOWN	N	N	NONE APPARENT	UK	GOING STRAIGHT	N
N	HIT & RUN - UNKNOWN	N	N	NONE APPARENT	55	CHANGING LANES	N
E	PICKUP TRUCK/UTILITY VAN	N	N	DRIVER INEXPERIENCE	UK	GOING STRAIGHT	E
UK	PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT	UK
N	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	55	CHANGING LANES	N
E	PICKUP TRUCK/UTILITY VAN	N	N	DRIVER INEXPERIENCE	55	GOING STRAIGHT	
E	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	PASSING	
S	HIT & RUN - UNKNOWN	N	N	DISTRACTED/OTHER	00	CHANGING LANES	S
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	AVOIDING OBJECT IN ROAD	
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	30	GOING STRAIGHT	N
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	70	MAKING LEFT TURN	N
S	HIT & RUN - UNKNOWN	N	N		UK	GOING STRAIGHT	
SE	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	60	OTHER	
N	PASSENGER CAR/VAN	Y	Y	DISTRACTED/OTHER	UK	GOING STRAIGHT	
SE	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	50	GOING STRAIGHT	NE
E	PASSENGER CAR/VAN	N	N	NONE APPARENT	20	GOING STRAIGHT	E
S	PICKUP TRUCK/UTILITY VAN	N	N	DRIVER UNFAMILIAR W/AREA	UK	GOING STRAIGHT	
E	PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	SLOWING	
S	PICKUP TRUCK/UTILITY VAN	N	N		00	CHANGING LANES	S
NE	HIT & RUN - UNKNOWN	N	N		UK	CHANGING LANES	NE
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT	
NE	PASSENGER CAR/VAN	N	N		UK	GOING STRAIGHT	NE
S	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT	
E	PASSENGER CAR/VAN	Y	N	NONE APPARENT	35	GOING STRAIGHT	
S	PASSENGER CAR/VAN	Y	N	NONE APPARENT	UK	GOING STRAIGHT	S
E	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT	
E	PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	05	AVOIDING OBJECT IN ROAD	
S	PASSENGER CAR/VAN	N	N		UK	GOING STRAIGHT	S
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	40	GOING STRAIGHT	S
N	PASSENGER CAR/VAN	N	N	DISTRACTED/OTHER	UK	GOING STRAIGHT	N
S	HIT & RUN - UNKNOWN	N	N		UK	MAKING LEFT TURN	
E	PASSENGER CAR/VAN	N	N	NONE APPARENT	20	GOING STRAIGHT	E
S	SUV	N	N	DISTRACTED/PASSENGER	UK	GOING STRAIGHT	
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	50	SPUN OUT OF CONTROL	
S	PASSENGER CAR/VAN	N	N	OTHER FACTOR	UK	SPUN OUT OF CONTROL	S
S	SUV	N	N	DISTRACTED/OTHER	55	SPUN OUT OF CONTROL	
S	PASSENGER CAR/VAN	N	N	NONE APPARENT	55	CHANGING LANES	S
S	PASSENGER CAR/VAN	Y	N	DUI, DWAI, DUID	UK	GOING STRAIGHT	
SE	PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT	

dir_1	vehicle_1	alcohol_1	drugs_1	factor_1	speed_1	veh_move_1	dir_2
N	PASSENGER CAR/VAN	N	N	NONE APPARENT	30	AVOIDING OBJECT IN ROAD	
N	SUV	N	N	NONE APPARENT	UK	SPUN OUT OF CONTROL	N
S	PASSENGER CAR/VAN	N	N	DRIVER UNFAMILIAR W/AREA	65	SPUN OUT OF CONTROL	
S	SUV	N	N	NONE APPARENT	UK	SPUN OUT OF CONTROL	
S	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	00	CHANGING LANES	
S	PASSENGER CAR/VAN	N	N	DRIVER INEXPERIENCE	50	GOING STRAIGHT	

event_1	event_2	mhe	dir_1	vehicle_1	alcohol_1	drugs_1	factor_1
SIDE TO SIDE (SAME DIRECTION)		SIDE TO SIDE (SAME DIRECTION)	S	PASSENGER CAR/VAN	N	N	NONE APPARENT
SIDE TO SIDE (SAME DIRECTION)		SIDE TO SIDE (SAME DIRECTION)	N	SUV	N	N	NONE APPARENT
OTHER NON-COLLISION	CONCRETE HIGHWAY BARRIER	CONCRETE HIGHWAY BARRIER	S	HIT & RUN - UNKNOWN	N	N	NONE APPARENT
OVERTURNING		OVERTURNING	E	PICKUP TRUCK/UTILITY VAN	N	N	DRIVER INEXPERIENCE
SIDE TO SIDE (SAME DIRECTION)		SIDE TO SIDE (SAME DIRECTION)	S	PICKUP TRUCK/UTILITY VAN W/TRAILER	N	N	NONE APPARENT
SIGN		SIGN	E	SUV	N	N	ASLEEP AT THE WHEEL

vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2
PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT
PASSENGER CAR/VAN	N	N		55	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	50	MAKING LEFT TURN
PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
PASSENGER CAR/VAN	N	N	NONE APPARENT	55	MAKING LEFT TURN
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
PASSENGER CAR/VAN	N	N	NONE APPARENT	00	STOPPED IN TRAFFIC
PASSENGER CAR/VAN W/TRAILER	N	N	NONE APPARENT	55	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	40	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	20	SLOWING
PASSENGER CAR/VAN	N	N	DRIVER UNFAMILIAR W/AREA	UK	AVOIDING OBJECT IN ROAD
PICKUP TRUCK/UTILITY VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	35	SLOWING
PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT
PASSENGER CAR/VAN	N	N	NONE APPARENT	25	SLOWING
PASSENGER CAR/VAN	N	N	NONE APPARENT	00	PARKED
PASSENGER CAR/VAN	N	N	NONE APPARENT	55	GOING STRAIGHT

vehicle_2	alcohol_2	drugs_2	factor_2	speed_2	veh_move_2	dir_3	vehicle_3
PASSENGER CAR/VAN	N	N	NONE APPARENT	UK	GOING STRAIGHT		

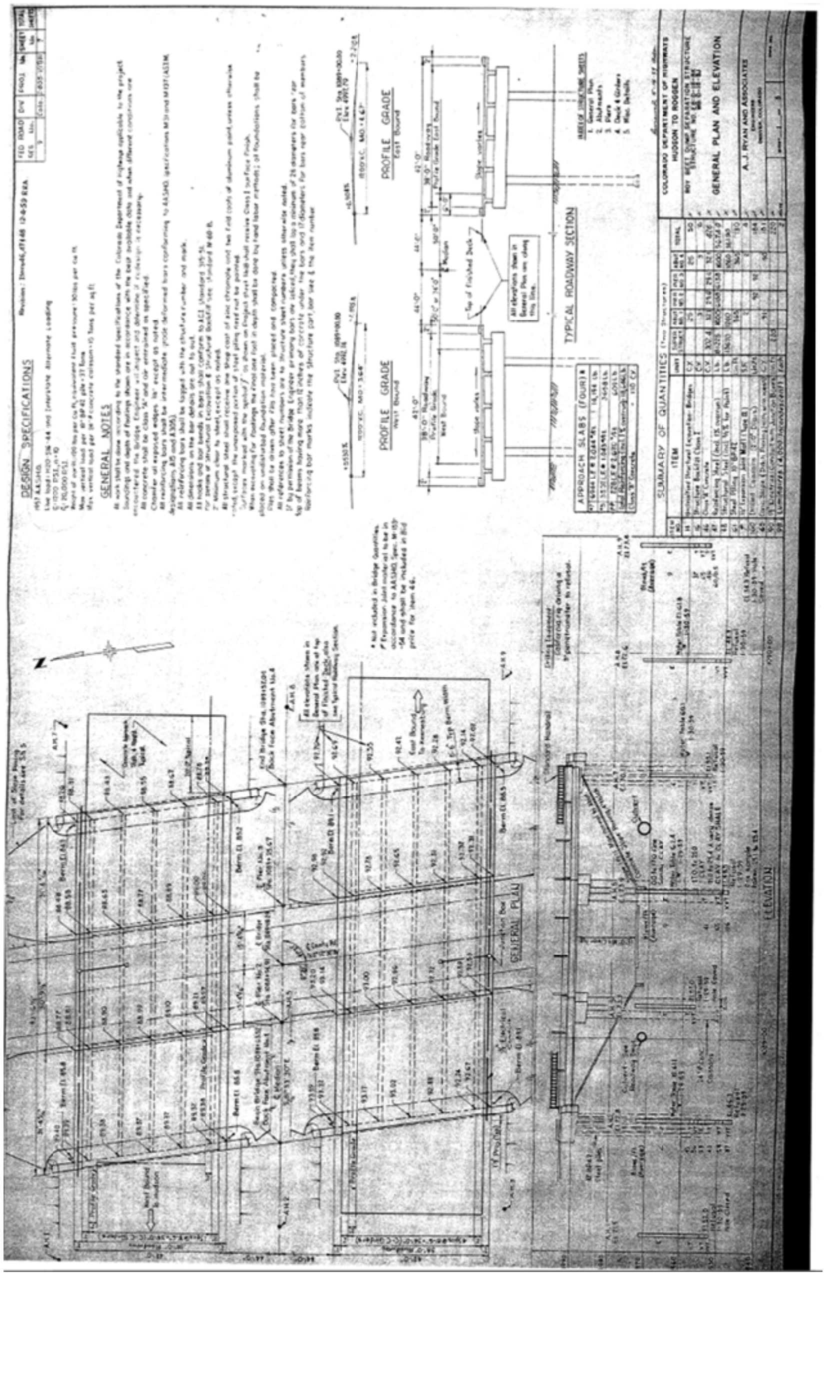
limit_1	speed_1	veh_move_1	dir_2	vehicle_2	alcohol_2	drugs_2	factor_2
55	45	CHANGING LANES	S	VEH COMBO (10,001 LBS AND OVER)	N	N	NONE APPARENT
55	50	GOING STRAIGHT	N	PASSENGER CAR/VAN	N	N	NONE APPARENT
65	00	CHANGING LANES	S	PASSENGER CAR/VAN	N	N	NONE APPARENT
55	55	SPUN OUT OF CONTROL					
55	10	GOING STRAIGHT	S	SUV	N	N	NONE APPARENT
55	40	GOING STRAIGHT					

loc01	dist	loc02
I-25 SB RAMP TO I-225	AT	I-25
I-225 NB ON RAMP	AT	FLYOVER
I-25	AT	I-225
RAMP ON FROM SB I-25 TO EB I-2	09999FE	I-25
I-225 EB ON RAMP	AT	OFF RAMP TO DTC BLVD
I-225 NB ON RAMP	AT	I-25 FLYOVER

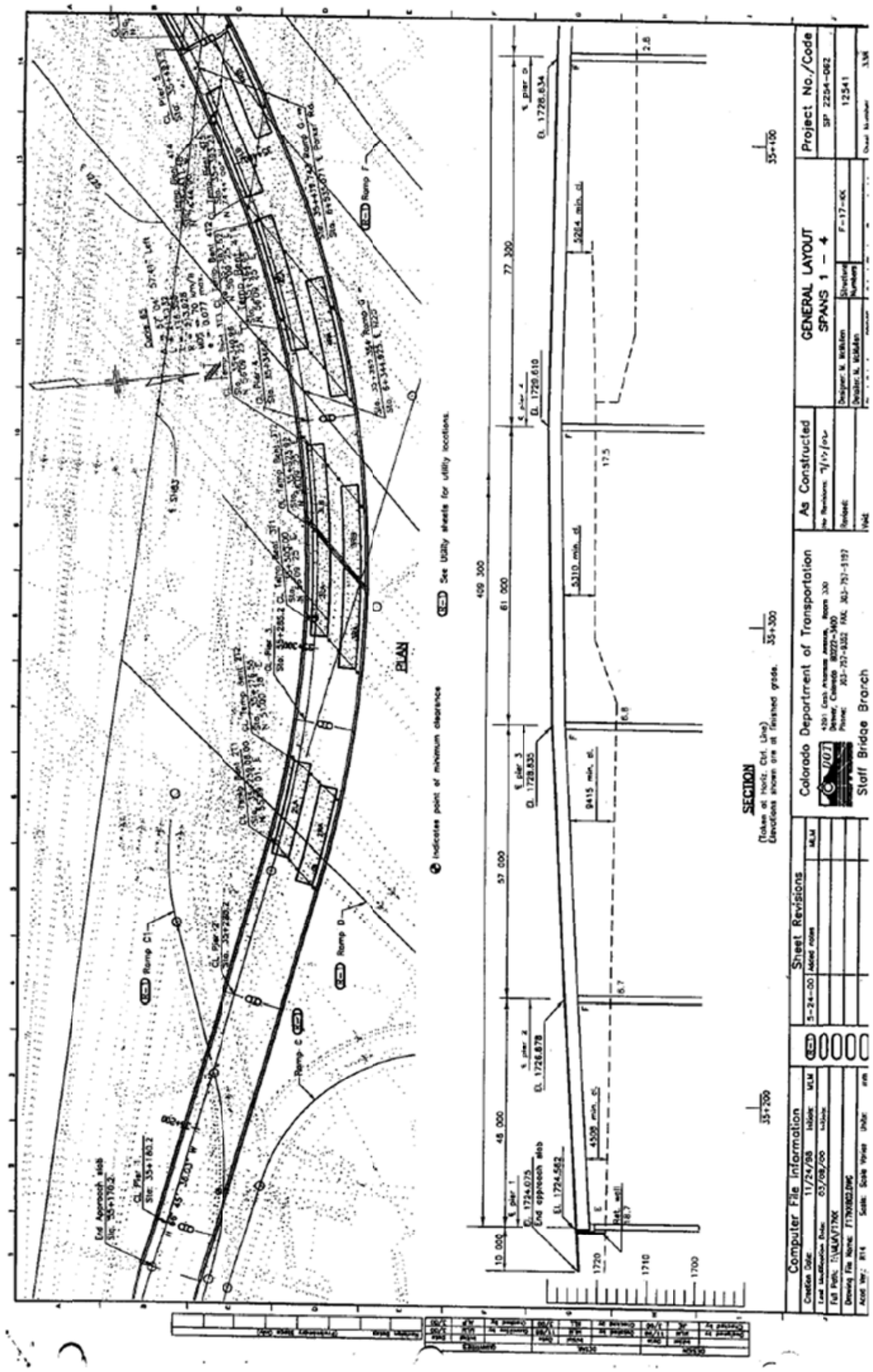
limit_2	speed_2	veh_move_2	limit_3
55	05	GOING STRAIGHT	
55	50	GOING STRAIGHT	
65	55	AVOIDING OBJECT IN ROAD	
55	15	CHANGING LANES	

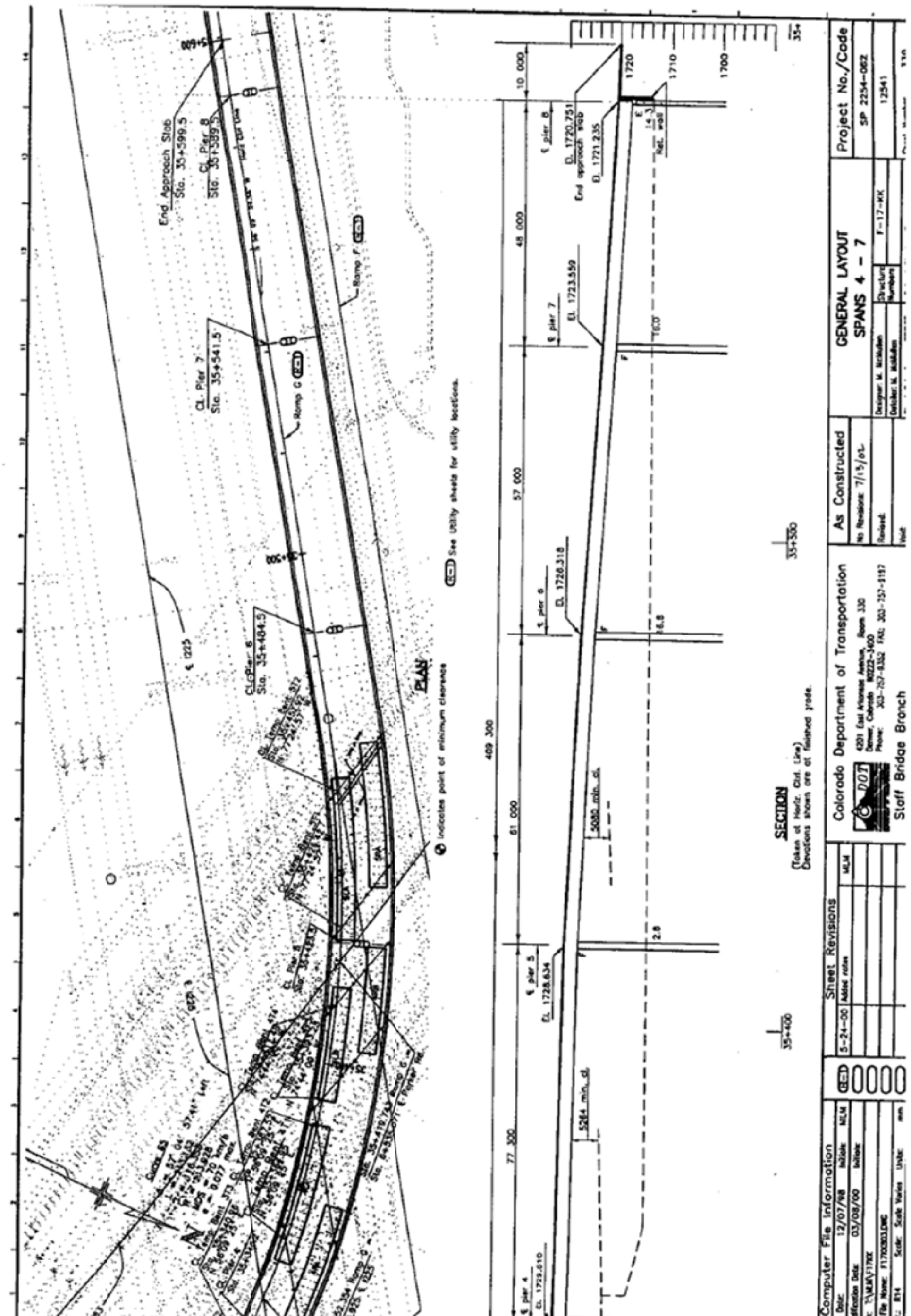
APPENDIX E

E.1: I-76 / WCR-53 Structure Plans

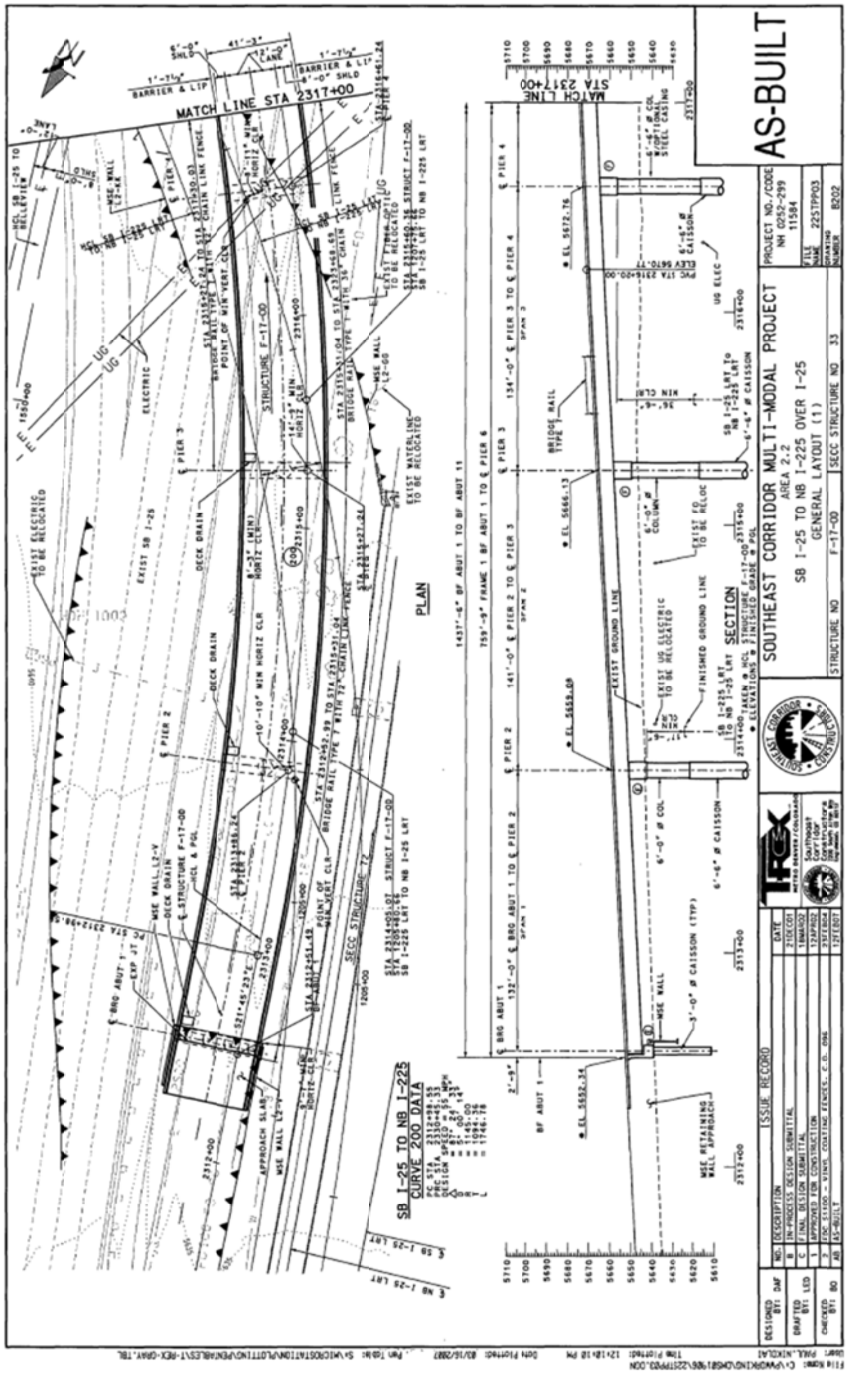


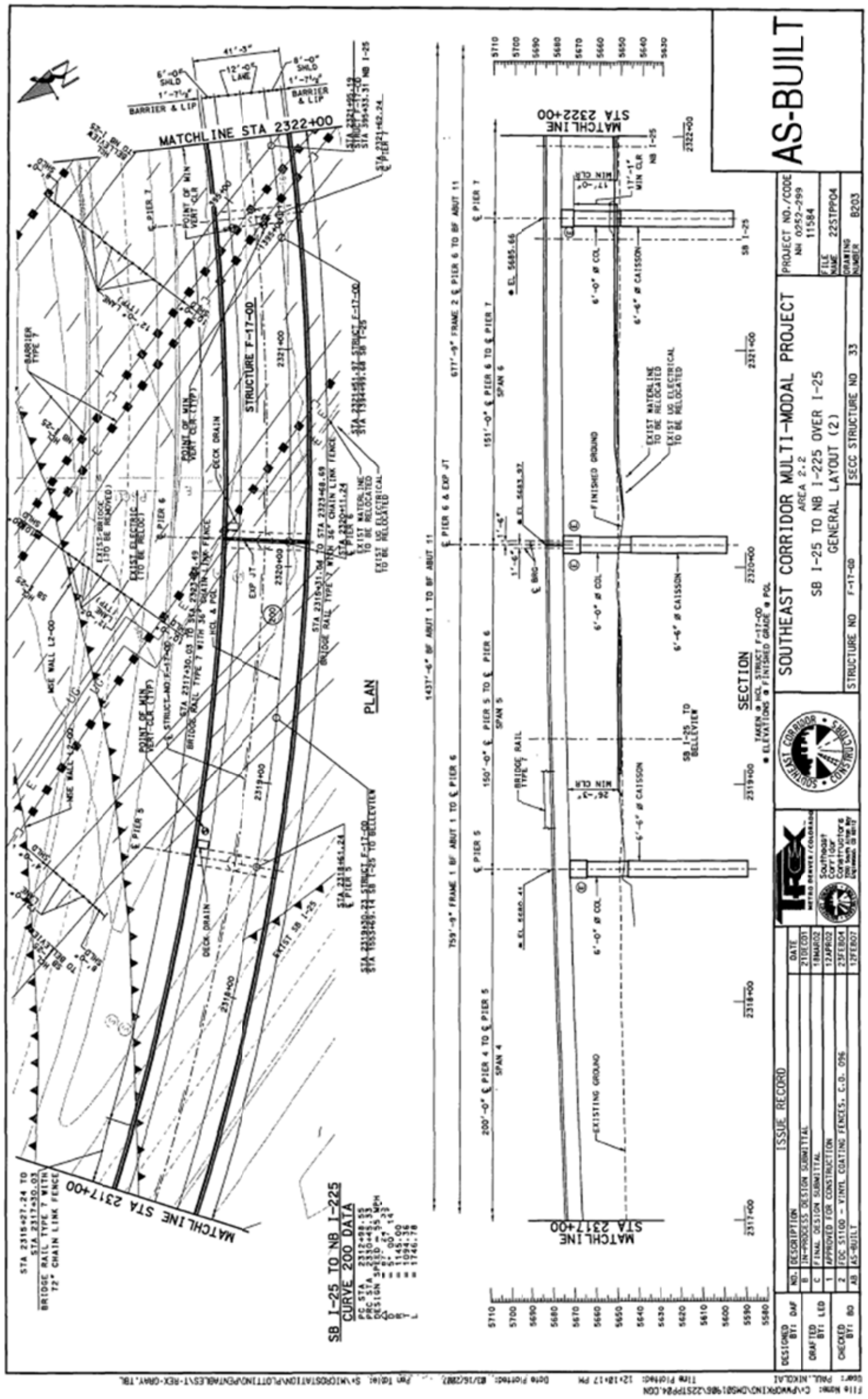
E.2: Parker Rd. / I-225 Structure Plans

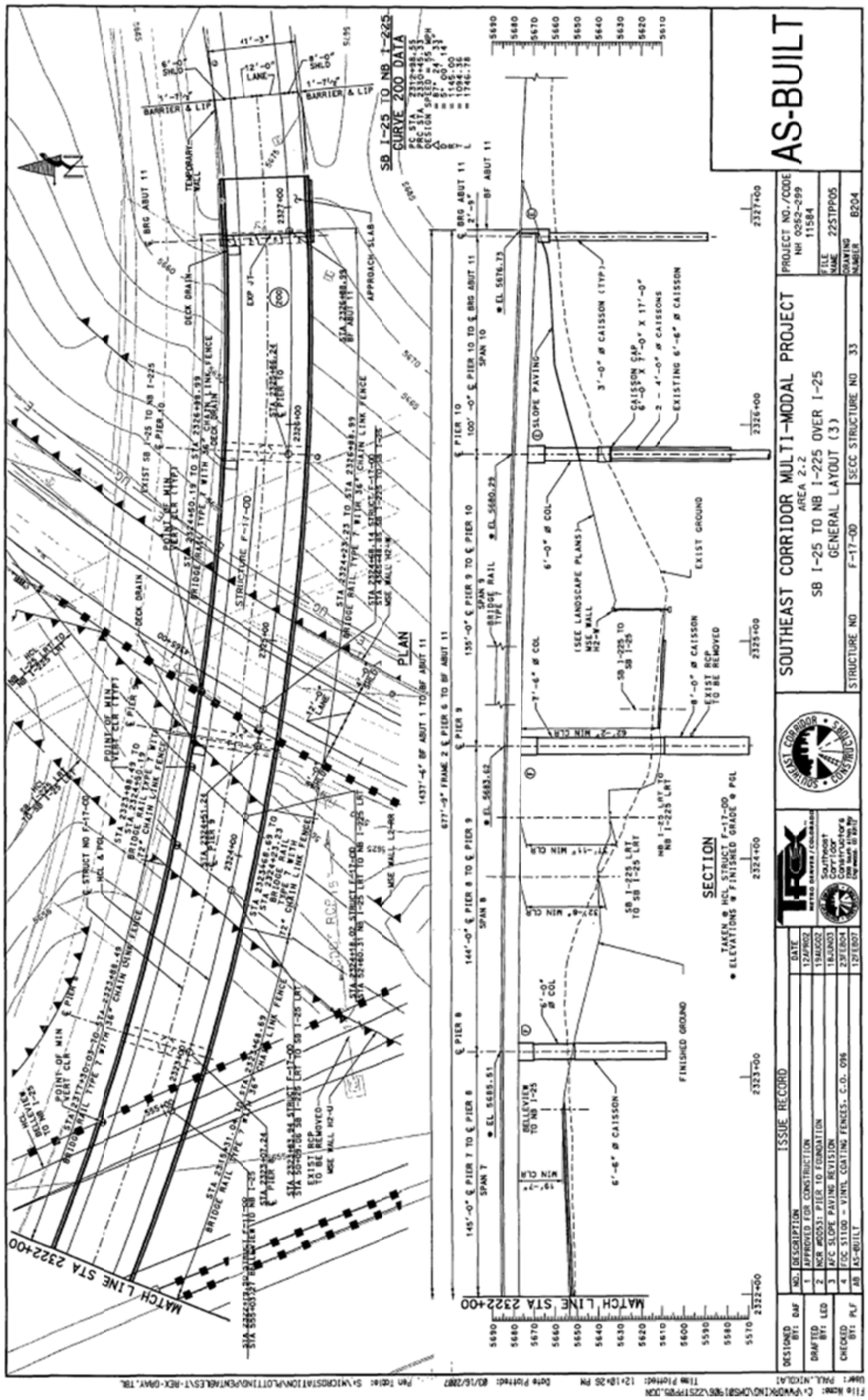



PLAN
SECTION
(Taken at Horiz. Ctrl. Line)
Elevations shown are of finished grade.
See Utility sheets for utility locations.
Indicates point of minimum clearance
Computer File Information
Sheet Revisions
Colorado Department of Transportation
Staff Bridge Branch
As Constructed
GENERAL LAYOUT
SPANS 4 - 7
Project No./Code
SP 2254-062
12541

E.3: I-25 / I-225 Structure Plans




AS-BUILT
SOUTHEAST CORRIDOR MULTI-MODAL PROJECT
AREA 2.2
SB I-25 TO NB I-225 OVER I-25
GENERAL LAYOUT (2)
PLAN
SECTION
MATCHLINE STA 2322+00
MATCHLINE STA 2317+00
ISSUE RECORD


AS-BUILT
SOUTHEAST CORRIDOR MULTI-MODAL PROJECT
AREA 2.2
SB I-25 TO NB I-225 OVER I-25
GENERAL LAYOUT (3)
PLAN
SECTION

APPENDIX F

F.1: Parker Rd. / I-225 and I-25 / I-225 Bid Data

COLORADO DEPARTMENT OF TRANSPORTATION

DATE : 09/03/09
PAGE : 005 -1

TABULATION OF BIDS

LETTING NO. : 20090903	CONTRACT ID : C16807	COUNTIES : ARAPAHOE, REGION 6
LETTING DATE : 09/03/09	REGION : 6	
LETTING TIME : 10:00 AM	CONTRACT TIME : 55 WORK DAYS	
	TERRAIN : URBAN	PROJECT(S) : IMR600-321

CONTRACT DESCRIPTION :
To install a fixed automated anti-icing system (FAST) on Structures F-17-OD and F-17-FW (I25/I225 Flyover and I225/I25 Tunnel); install an anti-icing treatment, Safelane by Carghill, to structure F-17-KK (Parker Rd/I225 Flyover); install traction enhancement product to STR F-17-OD.

A MANDATORY PRE-BID CONFERENCE WILL BE HELD ON AUGUST 14, 2009 BEGINNING AT 12:30 TO 2:30 AT THE REGION 6 LARGE MAINTENANCE CONFERENCE ROOM.

RANK	VENDOR	VENDOR NAME		TOTAL BID	% OF LOW BID	% OF EST
0	-EST-	ENGINEER'S ESTIMATE	$	1,505,115.00	96.3298%	100.0000%
1	905A	ABCO CONTRACTING, INC.	$	1,562,460.74	100.0000%	103.8101%
2	720A	MYR GROUP, INC. dba Sturgeon Electric	$	1,610,468.00	103.0725%	106.9997%
3	525A	GIBSON & ASSOCIATES, INC	$	1,761,906.90	112.7649%	117.0613%
4	450A	TETRA TECH CONSTRUCTION SERVICES, INC.	$	1,875,184.50	120.0148%	124.5875%
5	232A	AMERICAN CIVIL CONSTRUCTORS INC AND SUBSIDIARY	$	2,097,176.00	134.2226%	139.3366%

			(0) -EST- ENGINEER'S ESTIMATE		(1) 905A ABCO CONTRACTING, INC.		(2) 720A STURGEON ELECTRIC COMPANY	
ITEM CODE	ITEM DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT
SECTION 0001	BID ITEMS							
202-00250	Rem Pavement Marking	233.000 SF	3.0000	699.00	3.1500	733.95	6.0000	1398.00
203-01597	Potholing	30.000 HOUR	165.0000	4950.00	184.0000	5520.00	157.0000	4710.00
208-00002	Erosion Log (12 In)	75.000 LF	6.0000	450.00	3.7000	277.50	7.0000	525.00
208-00034	Gravel Bag	100.000 LF	8.0000	800.00	6.8500	685.00	7.0000	700.00

ITEM CODE	ITEM DESCRIPTION	QUANTITY		(0) -EST- ENGINEER'S ESTIMATE UNIT PRICE	AMOUNT	(1) 905A ABCO CONTRACTING, INC. UNIT PRICE	AMOUNT	(2) 720A STURGEON ELECTRIC COMPANY UNIT PRICE	AMOUNT
208-00045	Conc Washout Str	1.000	EACH	400.0000	400.00	578.0000	578.00	555.0000	555.00
208-00050	Storm Drain Inlet Protecti	10.000	EACH	200.0000	2000.00	210.0000	2100.00	187.0000	1870.00
208-00070	Stabilized Construction En	1.000	EACH	1250.0000	1250.00	1314.0000	1314.00	1660.0000	1660.00
208-00205	Erosion Control Supervisor	60.000	HOUR	60.0000	3600.00	68.3500	4101.00	81.0000	4860.00
304-06009	ABC (CL 6) (Spec)	130.000	TON	30.0000	3900.00	60.4000	7852.00	40.0000	5200.00
409-05011	Thin Bonded Polymer Overla	6069.000	SY	55.0000	333795.00	45.7300	277535.37	54.0000	327726.00
409-05100	Anti-Icing Polymer Overlay	51034.000	SF	9.5000	484823.00	7.7800	397044.52	9.0000	459306.00
607-53001	Fence CL (PVC)	90.000	LF	20.0000	1800.00	16.3000	1467.00	55.0000	4950.00
607-60116	16 Ft Gate	1.000	EACH	400.0000	400.00	447.0000	447.00	1310.0000	1310.00
614-86756	Anti-Icing Syst	1.000	L S	500000.0000	500000.00	730750.0000	730750.00	690000.0000	690000.00
620-00020	Sanitary Facility	1.000	EACH	1000.0000	1000.00	1050.0000	1050.00	1060.0000	1060.00

COLORADO DEPARTMENT OF TRANSPORTATION

TABULATION OF BIDS

DATE : 09/03/09
PAGE : 005 -2

LETTING NO. : 20090903
LETTING DATE : 09/03/09
LETTING TIME : 10:00 AM

CONTRACT ID : C16807
REGION : 6

COUNTIES : ARAPAHOE, REGION 6

ITEM CODE	ITEM DESCRIPTION	QUANTITY		(0) -EST- ENGINEER'S ESTIMATE UNIT PRICE	AMOUNT	(1) 905A ABCO CONTRACTING, INC. UNIT PRICE	AMOUNT	(2) 720A STURGEON ELECTRIC COMPANY UNIT PRICE	AMOUNT
626-00000	Mobilization	1.000	L S	75000.0000	75000.00	81035.0000	81035.00	35815.0000	35815.00
627-00005	Epoxy Pvmt Mkg	54.000	GAL	80.0000	4320.00	67.3000	3634.20	160.0000	8640.00
627-02010	Preform Plastic Pvmt Mkg (	496.000	SF	10.0000	4960.00	9.7500	4836.00	13.0000	6448.00
630-00003	Uniformed Traf Ctrl	96.000	HOUR	60.0000	5760.00	52.5500	5044.80	58.0000	5568.00
630-00012	Traf Ctrl Mgmt	25.000	DAY	500.0000	12500.00	510.0000	12750.00	535.0000	13375.00
630-00025	Traf Ctrl Vehicle	96.000	HOUR	18.0000	1728.00	21.0500	2020.80	34.0000	3264.00
630-80001	Flash Beacon (Port)	4.000	EACH	750.0000	3000.00	158.0000	632.00	284.0000	1136.00
630-80335	Barricade (3 M-A) (Temp)	12.000	EACH	175.0000	2100.00	42.0500	504.60	97.0000	1164.00
630-80341	Const Traf Sign (A)	22.000	EACH	60.0000	1320.00	42.0500	925.10	24.0000	528.00
630-80342	Const Traf Sign (B)	60.000	EACH	60.0000	3600.00	42.0500	2523.00	38.0000	2280.00
630-80343	Const Traf Sign (C)	8.000	EACH	60.0000	480.00	42.0500	336.40	50.0000	400.00
630-80344	Const Traf Sign (Spec)	160.000	SF	18.0000	2880.00	15.7500	2520.00	19.0000	3040.00
630-80355	Port Mesg Panel	2.000	EACH	4000.0000	8000.00	2103.0000	4206.00	2446.0000	4892.00
630-80358	Flash Arrow Panel (C Ty)	4.000	EACH	1000.0000	4000.00	210.0000	840.00	672.0000	2688.00
630-80360	Drum Channel Dev	50.000	EACH	40.0000	2000.00	15.7500	787.50	28.0000	1400.00
630-80380	Traffic Cone	200.000	EACH	8.0000	1600.00	5.2500	1050.00	7.0000	1400.00
630-85040	Impact Atten (T-M-A) (Temp	2.000	EACH	16000.0000	32000.00	3680.0000	7360.00	6300.0000	12600.00
SECTION TOTALS				$	1,505,115.00	$	1,562,460.74	$	1,610,468.00

CONTRACT TOTALS			$ 1,505,115.00		$ 1,562,460.74		$ 1,610,468.00

COLORADO DEPARTMENT OF TRANSPORTATION

TABULATION OF BIDS

DATE : 09/03/09
PAGE : 005 -3

LETTING NO. : 20090903
LETTING DATE : 09/03/09
LETTING TIME : 10:00 AM

CONTRACT ID : C16807
REGION : 6

COUNTIES : ARAPAHOE, REGION 6

ITEM CODE	ITEM DESCRIPTION	QUANTITY	(3) 525A GIBSON & ASSOCIATES, INC UNIT PRICE	AMOUNT	(4) 450A TETRA TECH CONSTRUCTION S UNIT PRICE	AMOUNT	(5) 232A AMERICAN CIVIL CONSTRUCTO UNIT PRICE	AMOUNT
SECTION 0001	BID ITEMS							
202-00250	Rem Pavement Marking	233.000 SF	3.3000	768.90	8.0000	1864.00	4.0000	932.00
203-01597	Potholing	30.000 HOUR	180.0000	5400.00	221.0000	6630.00	200.0000	6000.00
208-00002	Erosion Log (12 In)	75.000 LF	6.0000	450.00	30.0000	2250.00	12.0000	900.00
208-00034	Gravel Bag	100.000 LF	3.3000	330.00	14.0000	1400.00	13.0000	1300.00
208-00045	Conc Washout Str	1.000 EACH	880.0000	880.00	1140.0000	1140.00	600.0000	600.00
208-00050	Storm Drain Inlet Protecti	10.000 EACH	275.0000	2750.00	244.0000	2440.00	175.0000	1750.00
208-00070	Stabilized Construction En	1.000 EACH	1320.0000	1320.00	4545.0000	4545.00	1600.0000	1600.00
208-00205	Erosion Control Supervisor	60.000 HOUR	50.0000	3000.00	45.0000	2700.00	85.0000	5100.00
304-06009	ABC (CL 6) (Spec)	130.000 TON	96.0000	12480.00	91.0000	11830.00	53.0000	6890.00
409-05011	Thin Bonded Polymer Overla	6069.000 SY	46.0000	279174.00	99.9000	606293.10	66.5000	403588.50
409-05100	Anti-Icing Polymer Overlay	51034.000 SF	8.0000	408272.00	10.6000	540960.40	11.7500	599649.50
607-53001	Fence CL (PVC)	90.000 LF	21.0000	1890.00	49.0000	4410.00	25.0000	2250.00
607-60116	16 Ft Gate	1.000 EACH	462.0000	462.00	1814.0000	1814.00	600.0000	600.00
614-86756	Anti-Icing Syst	1.000 L S	813000.0000	813000.00	599291.0000	599291.00	900000.0000	900000.00
620-00020	Sanitary Facility	1.000 EACH	900.0000	900.00	2442.0000	2442.00	700.0000	700.00
626-00000	Mobilization	1.000 L S	177600.0000	177600.00	14848.0000	14848.00	100000.0000	100000.00
627-00005	Epoxy Pvmt Mkg	54.000 GAL	71.0000	3834.00	89.0000	4806.00	80.0000	4320.00
627-02010	Preform Plastic Pvmt Mkg (	496.000 SF	11.0000	5456.00	13.0000	6448.00	12.0000	5952.00
630-00003	Uniformed Traf Ctrl	96.000 HOUR	55.0000	5280.00	67.0000	6432.00	65.0000	6240.00
630-00012	Traf Ctrl Mgmt	25.000 DAY	534.0000	13350.00	625.0000	15625.00	700.0000	17500.00
630-00025	Traf Ctrl Vehicle	96.000 HOUR	22.0000	2112.00	32.0000	3072.00	25.0000	2400.00
630-80001	Flash Beacon (Port)	4.000 EACH	165.0000	660.00	435.0000	1740.00	200.0000	800.00
630-80335	Barricade (3 M-A) (Temp)	12.000 EACH	44.0000	528.00	143.0000	1716.00	52.0000	624.00
630-80341	Const Traf Sign (A)	22.000 EACH	44.0000	968.00	83.0000	1826.00	52.0000	1144.00
630-80342	Const Traf Sign (B)	60.000 EACH	44.0000	2640.00	60.0000	3600.00	52.0000	3120.00

630-80343	Const Traf Sign (C)	8.000 EACH	44.0000	352.00	147.0000	1176.00	52.0000	416.00
630-80344	Const Traf Sign (Spec)	160.000 SF	17.0000	2720.00	23.0000	3680.00	20.0000	3200.00
630-80355	Port Mesg Panel	2.000 EACH	2200.0000	4400.00	2753.0000	5506.00	3000.0000	6000.00
630-80358	Flash Arrow Panel (C Ty)	4.000 EACH	220.0000	880.00	463.0000	1852.00	300.0000	1200.00
630-80360	Drum Channel Dev	50.000 EACH	17.0000	850.00	36.0000	1800.00	20.0000	1000.00
630-80380	Traffic Cone	200.000 EACH	6.0000	1200.00	10.0000	2000.00	7.0000	1400.00
630-85040	Impact Atten (T-M-A) (Temp	2.000 EACH	4000.0000	8000.00	4524.0000	9048.00	5000.0000	10000.00
SECTION TOTALS			$	1,761,906.90	$	1,875,184.50	$	2,097,176.00
CONTRACT TOTALS			$	1,761,906.90	$	1,875,184.50	$	2,097,176.00

APPENDIX G

G.1: Cargill SafeLane HDX Overlay

SafeLane™ Surface Overlay

SafeLane® HDX overlay

Protecting people, bridges and roads™

Technical Specification – Anti-icing Polymer Surface Overlay
Tradename: Cargill SafeLane® HDX Overlay

A. Description

Project scope includes providing epoxy, aggregate and application procedures described herein to place an anti-icing polymer overlay system. This specification includes guidelines for appropriate preparation of the surface to which the overlay will be applied as well as guidelines for furnishing and installing the anti-icing overlay system in accordance with the requirements and specifications herein, as well as those of the epoxy manufacturer and the project Owner/Engineer.

Cargill SafeLane® HDX overlay is a proprietary product and must be installed by a contractor with an appropriate license from Cargill, Incorporated. Parties interested in obtaining a license should contact Cargill at 866-900-7258 or send an email to safelane@cargill.com.

B. Materials

The licensed Contractor must purchase all SafeLane® overlay materials from or through Cargill, Incorporated.

B.1 Epoxy

Provide a Cargill-approved epoxy resin base and hardener that is a modified Type III, two component system which meets requirements given by ASTM-C-881, Grade 1, Classes B & C. The epoxy shall be stored according to the manufacturer's specifications. The epoxy shall have the properties listed below:

Table 1

Property	Requirement	Test Method
Pot Life	15 to 45 min at 75° F (24° C)	ASTM C881 (50 ml sample in paper cup)
Tensile Strength	2,000 to 5,000 psi at 7 days	ASTM D638
Tensile Elongation	40% to 80% at 7 days	ASTM D638
Viscosity	7 to 25 poises	ASTM D2393
Minimum Compressive Strength at 3 hours	1,000 psi at 75° F (24° C)	ASTM C579
Minimum Compressive Strength at 24 hours	5,000 psi at 75° F (24° C)	ASTM C579
Minimum Adhesive Strength at 24 hours	250 psi at 75° F (24° C)	ACI 503R

B.2 Aggregate

Provide a Cargill-approved aggregate that is free from dirt, clay, asphalt and other foreign or organic materials. The aggregate shall be surface dry and shall be shipped and stored in mini-bulk bags, which shall be packaged to limit moisture intrusion. Once a bag has been opened or the outer protective shroud has been removed, the aggregate must be stored in order to ensure the aggregate remains dry.

Typical SafeLane® HDX overlay aggregate size gradation specifications are shown in Table 2.

Table 2

Gradation	% Passing
3/8" (9.5 mm)	98-100
#4 (4.75 mm)	50-80
#8 (2.36 mm)	0-15

(01/08) Page 1 of 5

To learn more: www.CargillSafeLane.com 866-900-7258

Cargill

C. Construction

Only licensed contractors may install the SafeLane® HDX overlay system. Contractors interested in obtaining a license should contact Cargill at 866-900-7258 or send an email to safelane@cargill.com. Shot blasting, surface preparation, cleaning and crack repair may be subcontracted or provided by the party purchasing the system, but must be directed and approved by the licensed Contractor.

C.1 Equipment

For mechanical applications, equipment shall consist of not less than an epoxy distribution system, aggregate spreader, application squeegee, moisture- and oil-free compressed air and a lighting source if work will be performed at night. The epoxy distribution system shall accurately blend the epoxy materials according to the manufacturer's specifications and distribute epoxy to the road surface or bridge deck at the specified application rates and in such a manner as to cover 100 percent of the work area. The aggregate spreader shall be propelled in such a manner as to uniformly and accurately apply the aggregate.

For manual applications, equipment shall consist of calibrated containers for measuring epoxy volumes, a paddle-type mixer, squeegees, brooms and shovels which are suitable for mixing the epoxy and applying the epoxy and aggregate at the specified application rates.

C.2 Surface Preparation

Prior to installing the overlay on any pavement section, the Owner/Engineer must inspect the entire surface. The licensed Contractor should be present at this inspection. The inspection is designed to identify any areas of pavement that are in need of repair before applying the overlay. These areas may include delaminations in the concrete or asphalt, potholes, large cracks or breakouts. These areas should be properly marked and must be repaired before the overlay can be installed. It is the Owner/Engineer's responsibility to decide on the best means for surface repair prior to installation. It is recommended that the Owner/Engineer consult with a Cargill representative prior to performing repairs to ensure the compatibility of products used for patching or repair with the SafeLane® HDX overlay system.

Preparation of Concrete Surfaces

Before placing the overlay, the entire concrete bridge deck or road surface shall be thoroughly cleaned by steel shot blasting to ensure proper bonding between the epoxy and the concrete substrate. A final surface texture meeting the International Concrete Repair Institute's (ICRI) concrete surface profile numbers 5 through 7 shall be achieved as defined in ICRI Guideline No. 03732 and as shown by Surface Profile Samples available from ICRI (http://www.icri.org). Shot blasting is meant to expose the coarse aggregate and the surface shall be free of asphalt material, oil, 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. Loosely bonded patches shall be removed and repaired. Traffic marking lines shall also be removed or protected as directed by the Owner/Engineer. Moisture- and oil-free compressed air or high volume leaf blowers shall be used to remove all dust and other loose material. Mechanical brooms, without water, may be used after a rain event to remove any residual dust that adheres to the prepared surface after it has been blown off with compressed air. The surface must then be blown again with moisture- and oil-free compressed air or high volume leaf blowers.

Adhesion bond strength testing may be required by the Owner/Engineer before surface preparation is considered acceptable. See ACI 503R, Appendix A of the ACI Manual of Concrete Practice or Virginia Test Method 92 for guidelines.

SafeLane® HDX overlay shall not be placed on Portland Cement Concrete that is less than 28 days old unless otherwise approved by the Owner/Engineer. The overlay may be placed on fast curing and quick set patching materials using the manufacturer's recommended curing times and with approval from the Owner/Engineer.

Preparation of Asphalt Surfaces

Asphalt surfaces may be sandblasted or planed and textured to a depth approved by both the Owner/Engineer and the licensed Contractor. Surfaces should be free of oil, dirt, rubber, curing compounds, paint carbonation, weak surface mortar and other potentially detrimental materials, which may interfere with the bonding or curing of the overlay. Moisture- and oil-free compressed air or high volume leaf blowers shall be used to remove all dust and other loose material. Mechanical brooms, without water, may be used after a rain event to remove any residual dust that adheres to the prepared surface after it has been blown off with compressed air. The surface must then be blown again with moisture- and oil-free compressed air or high volume leaf blowers.

SafeLane® HDX overlay shall not be placed on asphalt that is less than six months old.

The overlay should be placed as soon as possible after surface preparation is completed. It is recommended to keep traffic closed on a fully prepared surface until the overlay has been placed and allowed to fully cure.

Application of SafeLane® HDX overlay on any pavement surface or structure that is not elevated may be subject to premature delamination due to moisture or pore pressure caused by moisture that may be present at the pavement surface in those environments.

C.3 Overlay Application

Application Conditions

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 these specifications and with the manufacturer's recommendations as approved or directed by the Owner/Engineer. SafeLane® HDX overlay materials shall not be applied when weather or surface conditions are such that the material cannot be properly handled, placed and cured within the specified requirements for project sequencing or traffic control, or when rain is imminent within the manufacturer's recommended cure times. The prepared surface must be completely dry at the time of epoxy application. Moisture-and oil-free heat sources or torches may be used to dry the surface. The temperature of the deck surface and all epoxy and aggregate components shall be a minimum of 55°F (13°C) at the time of application. Epoxy shall not be applied if the gel time is less than five minutes or if pavement temperatures exceed 115°F (46°C). In situations where road closures are not under strict time constraints, epoxy may be applied at lower temperatures with the Owner/Engineer's approval.

Double Pass Method

SafeLane® HDX overlay is applied using a double pass method. The double pass method calls for applying the epoxy and aggregate in two separate layers at the corresponding application rates shown in Table 3 below. Total epoxy application rates should be no less than 10 gallons per 100 square feet and typically range from 10 – 11 gallons per 100 square feet.

Table 3

Double Pass Method	Epoxy Rate Gal/100 sq. ft.* (liters/sq meter)	Aggregate lbs/sq ft.** (kg/sq. meter)
1st course	2.0 to 4.0 (0.8 to 1.6)	1-2 (4.9 - 9.75)
2nd course	6.0 to 8.5 (2.4 to 3.4)	3-4 (14.6 - 19.5)
* Total epoxy applied must equal no less than 10 gal/100 sq ft. (4.1 liters/sq meter)		
**Application of aggregate shall be of sufficient quantity to completely cover the epoxy.		

The epoxy must be mixed at a volume ratio of 1 Part A: 1 Part B and mechanically stirred by a paddle type mixer for three minutes or according to the epoxy manufacturer's recommendations. After the epoxy has been properly mixed, it shall be immediately and uniformly applied to the pavement surface with a 3/16 to 1/4 inch (4.8-6.4mm) V-notched squeegee. The aggregate shall be applied in such a manner as to cover the epoxy mixture while the epoxy is still fluid. First course applications that do not receive enough aggregate prior to gelling shall be removed and replaced.

Each course of epoxy overlay shall be cured before removing the excess unbonded aggregate to prevent tearing or damaging of the surface. Oil- and moisture-free compressed air or high volume leaf blowers, vacuum or mechanical broom can be used to remove excess aggregate. After all loose aggregate is removed any remaining dust must also be removed using the methods described above. The first course shall not be opened b traffic without the Owner/Engineer's approval. Application of the second course may begin after all dust is removed. Under no circumstances shall traffic be permitted on the overlay until it has been cured sufficiently to prevent damage from wheel loads. Typical curing times are specified below in Table 4.

Table 4

Course	Average Temperature of Deck, Epoxy, and Aggregate Components in °F (°C)					
	60-64 (16-18)	65-69 (18-21)	70-74 (21-23)	75-79 (24-26)	80-84 (27-29)	*85+ (29+)
1	4 hr	3 hr	2.5 hr	2 hr	1.5 hr	1 hr
2	6.5 hr	5 hr	4 hr	3 hr	3 hr	≤ 3 hrs

*Refer to manufacturer's recommendation

The second course shall be applied at the rates specified in Table 3. Epoxy will be applied using a flat-bladed squeegee. The aggregate shall be applied in such a manner as to cover the epoxy mixture before polymerization. Special care must be taken to ensure that the wet epoxy does not coat the wear surface (top) of the aggregate. Once the epoxy is cured, all loose aggregate shall be removed from the surface by oil- and moisture-free compressed air or high volume leaf blowers, vacuum or mechanical broom. After all loose aggregate is removed, and if there are any areas where the top surface of the stone has been coated with epoxy, the excess epoxy must be removed using a light shot or sand blast.

Prior to installing SafeLane® HDX overlay, the licensed Contractor may be required to submit an overlay construction work plan for approval. The work plan should include, but not be limited b, materials, equipment, anticipated schedule for traffic control, patching, crack repair, surface preparation, sequencing of the overlay placement, as well as lest reports, documentation, explanation and justification to support the proposed work plan. The work plan shall also be in accordance with the epoxy manufacturer's specifications. Any deviations from the guidelines prescribed by this specification shall be explained and are subject to approval by the Owner/Engineer.

The licensed Contractor shall plan and execute the work to allow for the minimum curing periods specified herein, or longer curing periods as prescribed by the manufacturer, prior to opening the surface to public or construction traffic.

Unless otherwise specified by the Owner/Engineer, the overlay shall not be applied over the expansion joints of a bridge deck. The expansion joints shall be coated with a bond breaker (e.g., duct tape) that can adequately seal the joints from the epoxy. Duct tape may also be used to delineate application areas. It is recommended that all taped areas or bond breakers be removed before epoxy starts to harden. Epoxy may also be removed by scoring the overlay prior to gelling or by saw cutting after cure.

Should the licensed Contractor's operations or actions damage or mar the overlay, the Contractor shall remove the damaged areas and reapply the overlay to the Owner/Engineer's satisfaction. In the event that part of the epoxy mixture does not cure, all portions of the overlay shall be completely removed from the affected area and discarded. Any residual epoxy remaining on the pavement must be completely removed by mechanical means such as steel shot or abrasive blasting or scarifying before the overlay can be reapplied.

For each batch applied, the licensed Contractor may be asked to maintain, and provide to the Owner/Engineer, records including but not limited to the following:

- Number of batches mixed and volume per batch
- Location of batches as placed on deck, referenced by stations
- Batch time
- Gel time (50 ml sample)
- Temperature of the air, deck surface and epoxy components
- Loose aggregate removal time
- Time open to traffic

D. MEASUREMENT

Project area shall be measured by square feet of installed overlay. Project area shall be identified and marked by the Owner/Engineer and agreed to by the licensed Contractor and the material supplier (Cargill, Incorporated).

E. PAYMENT

The Owner will pay for the project at the agreed upon quantities and at the contract unit price under the following bid item:

Item Number	Description	Unit
xxxxx	SafeLane® HDX Overlay	Square feet

Payment is full compensation for furnishing and hauling all materials, including epoxy and pre-bagged aggregate; preparing the pavement surface and applying SafeLane® HDX overlay as described in the above specifications; providing traffic control during surface preparation and overlay installation and curing; removing and disposing of all excess materials; and for furnishing all equipment, labor, tools, and incidentals necessary to complete the contract work.

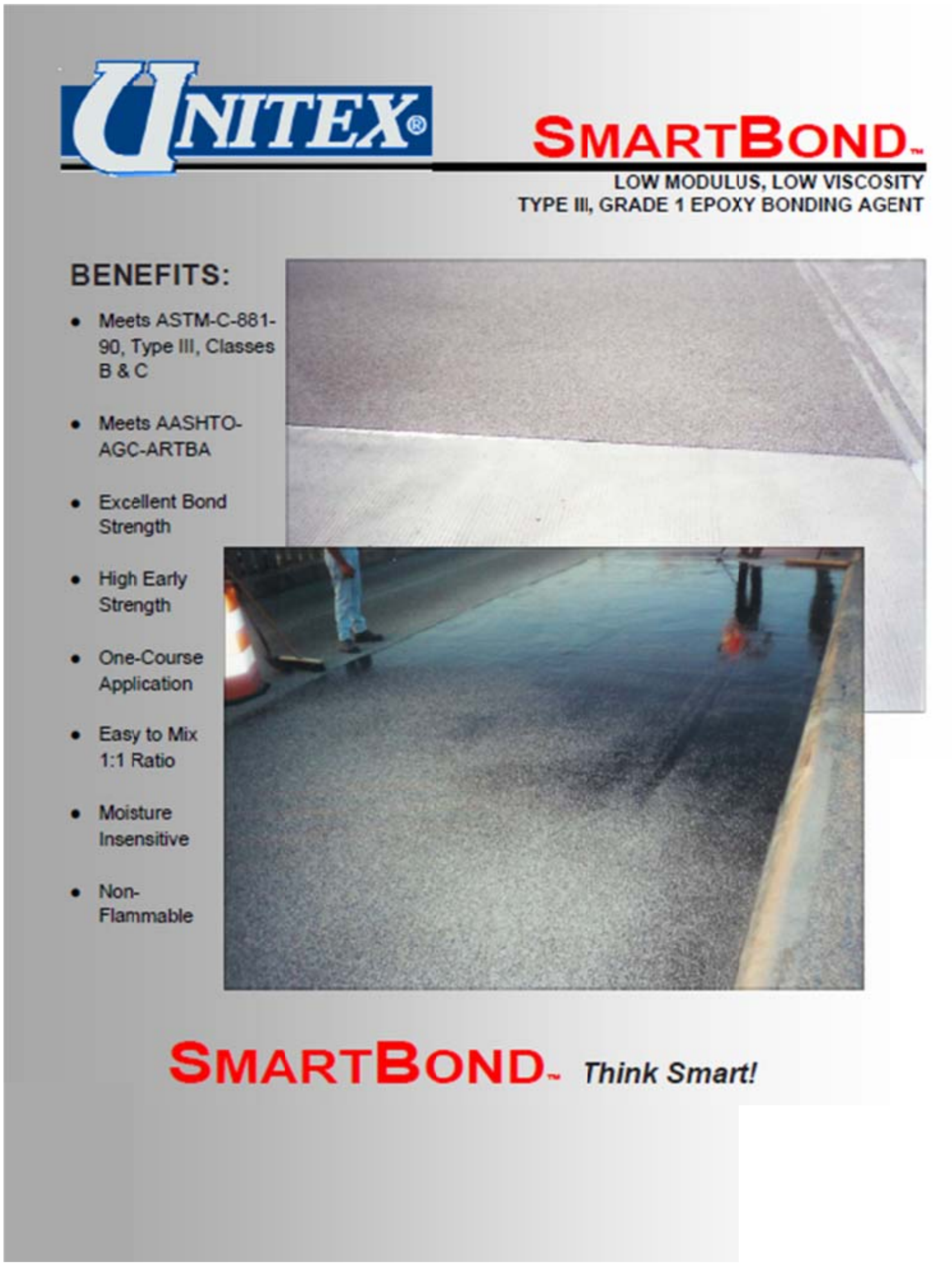
For additional information contact:

Cargill, Incorporated
3030 E. Market Street
York, PA 17402

Phone: Toll free 866-900-7258 or 717-757-5823
Email: safelane@cargill.com
Web: www.cargillsafelane.com

Note: To request a version of this document that can be modified or used for developing project specifications, call 866-900-7258 or send an email to safelane@cargill.com.

G.2: Unitex SmartBond



UNITEX®

SMARTBOND™

LOW MODULUS, LOW VISCOSITY
TYPE III, GRADE 1 EPOXY BONDING AGENT

DESCRIPTION

UNITEX SMARTBOND™ is a solvent-free, moisture insensitive, 100% solids, low modulus, two component bonding agent. It meets ASTM-C-881 Type III, Grade 1, Classes B & C. It also meets USDA specifications for use in food processing areas. Excellent for use as binder for concrete skid-resistant overlays on bridges and elevated slabs.

USES

- Bonding skid-resistant overlays to bridges and elevated slabs
- Patching concrete as epoxy mortar

PROPERTIES and TESTING

RESIN PROPERTIES

LABORATORY TESTS	RESULTS	ASTM C881 SPECIFICATIONS
Mix Ratio	1 : 1 by volume	None
D 695 Compressive Modulus	64,820	130,000 maximum
D 638 Tensile Strength	2,610 psi	None
D 638 Tensile Elongation	50%	30% minimum
C 882 Bond Strength (14 day cure)	3,470 psi	1,500 psi minimum
D 570 Water Absorption	0.19%	1.0% maximum
D 2471 Gel Time	15 Minutes	--
D 2393 Brookfield Vsc. RV3 @ 20 rpms	1425 cps	2000 cps maximum
D 2240 Shore D Hardness	69	None
C 883 Effective Shrinkage	Pass	Pass
C 884 Thermal Compatibility	Pass	None
AASHTO T-277 Chloride Ion Permeability	0.9 coulombs	None

PACKAGING

1 gal / 3.8 L units (2 – .5gal cans)
2 gal / 7.6 L units (2 – 1gal cans)
10 gal / 37.9 L units (2 – 5gal pails)
110 gal / 416.4 L units (2 – 55gal drums)

COVERAGE

Minimum Epoxy/Aggregate Coverage Rates

Epoxy Rate	Aggregrate Rate
1 gal./40 sq. ft. (1 L/m^2)	10 lbs./sq. yd. (5.4 kg/m^2)

SMARTBOND™

LOW MODULUS, LOW VISCOSITY
TYPE III, GRADE 1 EPOXY BONDING AGENT

Application

Bonding Skid-Resistant Overlays:

1. Repair delamination, potholes and cracks with PRO-POXY 2500.
2. Clean surface by shotblasting to remove all contaminants. Remove dust and debris by blowing off with oil-free compressed air.
3. Mechanically mix component A with component B 1:1 by volume with Jiffy type mixer and low-speed variable drill at 300 rpm for a minimum of 3 minutes. Mix only the quantity that can be used within its gel time.
4. Apply neat SMARTBOND™ by notched squeegee at the specified rate.
5. Broadcast select aggregate to refusal.
6. After initial cure, remove excess aggregate. Do not open to traffic.
7. Allow to cure following the table below. Open to traffic.

Minimum Curing Times of SMARTBOND™

	Average Temperatures of Overlay Component & Substrate					
	60-64°F 16-18°C	65-69°F 19-21°C	70-74°F 22-23°C	75-79°F 24-26°C	80-84°F 27-29°C	85+°F 29+°C
Min. Cure Time	6-5 hrs	5 hrs	4 hrs	3hrs	3 hrs	3 hrs

SMARTBOND™

LOW MODULUS, LOW VISCOSITY
TYPE III, GRADE 1 EPOXY BONDING AGENT

LIMITATIONS
- Concrete must be saturated surface dry(SSD) before applying SMARTBOND™.
- Material is a vapor barrier after curing.
- Do not thin with solvents.
- Minimum age of concrete must be 28 days prior to applying SMARTBOND™ as an overlay.

CAUTION
- Component A – Irritant
- Component B – Corrosive
- Product is a strong sensitizer. Use of safety goggles and chemical resistant gloves is recommended.
- Use of a NIOSH/MSHA organic vapor respirator is recommended if ventilation is inadequate.
- Avoid breathing vapors.
- Avoid skin contact.

FIRST AID
EYE CONTACT: Flush immediately with water for at least 15 minutes. Contact physician immediately.
RESPIRATORY CONTACT: Remove person to fresh air.
SKIN CONTACT: Remove any contaminated clothing.
Remove epoxy immediately with a dry cloth or paper towel. Solvents should not be used as they carry the irritant into the skin. Wash skin thoroughly with soap and water.
CURED EPOXY RESINS ARE INNOCUOUS.

CLEANUP
EQUIPMENT: Uncured material can be removed with Unitex CITRI-CLEAN or other approved solvent. Cured material can only be removed mechanically.
MATERIAL: Collect with absorbent material. Flush area with water. Dispose of in accordance with local, state, and federal disposal regulations.

UNITEX® www.unitex-chemicals.com · email: mail@unitex-chemicals.com
3101 Gardner Avenue. Kansas City, MO 64120 · 800-821-5846

G.3: PolyCarb Mark-163 Flexogrid

DESCRIPTION

MARK-163 FLEXOGRID Overlay System is a hybridized copolymer formulated through a unique chemical combination of epoxy and urethane molecules specially designed to provide a flexible, yet strong waterproofing and de-slicking system for highway bridge decks.

MARK-163 FLEXOGRID Overlay System is placed as an overlay over the entire deck at a minimum thickness of 6.35mm – 9.53mm (1/4" – 3/8").

MARK-163 FLEXOGRID Overlay System is designed to accommodate slight movements of the concrete structure due to heavy traffic and extreme changes in weather conditions. Flexibility is least affected by normal summer and winter temperature changes.

MARK-163 FLEXOGRID Overlay System consists of a 100% solids, two-part liquid polymer system to be mixed on the job site and a blend of specially selected aggregate to be broadcast on the spread liquid.

MARK-163 FLEXOGRID Overlay System is available for application at temperatures of 10°C (50°F) and above.

RECOMMENDED USES

MARK-163 FLEXOGRID Overlay System is used for the waterproofing and skid proofing of:

* Bridge decks, parking decks and observation decks.
* Other weather-exposed concrete structures requiring waterproofing and skid resistant qualities along with flexibility to accommodate any minor movements under the overlay, such as vibrations, thermal shock, freeze and thaw cycle, and expansion or contraction due to weather.
* High abuse, heavy traffic industrial floors.
* Asphalt and concrete entrance and exit ramps.
* Steel plate or filled grid decks.

MARK-163

FLEXOGRID

Non-Skid Flexible Hybridized Co-polymer Overlay

FEATURES

- * Completely non-porous
- * A 100% solids system hence does not have solvent fumes
- * Excellent bond to metal, concrete and asphalt surfaces
- * Maintains skid number well above 50 for an extended period of time
- * Application methods do not require troweling; therefore, the density of the overlay is independent of troweling pressures and techniques.
- * Fast curing system allows traffic to be resumed within hours
- * Variety of textures and non-skid qualities can be obtained by varying the aggregate
- * Due to inherent flexibility, allows absorption of shocks and minor crack movement
- * Flexibility is least affected at extremely low temperatures

TECHNICAL DATA

Properties of MARK-163 Part A and Part B

	PART A	PART B
Color	Amber	Amber
Mixing Ratio	2 volumes	1 volume
Percent Solid	100%	100%
Shelf Life	2 years	2 years

Properties of MARK-163 Mixed Part A and Part B

Color	Amber
Gel Time 25°C (75° ± 2°F)	22-31 minutes (100 gms.)
Gel Time 25°C (75° ± 2°F) (with aggregate)	1.5 hours
Initial Set 25°C (75° ± 2°F)	6 hours
Final Cure 25°C (75° ± 2°F)	48 hours-7 days

(See Section 6 under "Application" for curing properties at various temperatures)

Properties of Cured MARK-163

Adhesion of Concrete		100% Failure	ASTM D-4541/ACI-503R
Shore D Hardness		70 ± 5	ASTM D2240-75
Compressive Strength	48.3 – 62.1 MPa	(7,000 - 9,000 psi)	ASTM C-109
Tensile Strength	>17.2 MPa	(>2,500 psi)	ASTM D638-82
Tensile Elongation		30 ± 10	ASTM D638-82
Water Absorption - Max.		0.2%	ASTM D-570
Abrasion Resistance - Wear Index CS-17 Wheel, 1,000 cycle, 1,000 gms		75-85 milligrams	ASTM C-501
Flexural creep at low temperature Total movement in 7 days		0.165 mm, min. (.0065 inches, min.)	California Test 419
Flexural Yield Strength		> 5,000 psi	ASTM D-790

SELECTION OF AGGREGATE

Choice of aggregates would depend on the wear and skid resistance qualities required. The type of aggregate recommended for the bridge overlay system is:

MARK-371

Glacial Gravel	Basalt Quartzite Granite % by Weight
SiO_2	75.03
Al_2O_3	11.49
Fe_2O_3	3.57
CaO	2.84
MgO	1.59
Na_2O	2.58
K_2O	0.99
Combined alkali	1.11
Ignition loss	0.72

MARK-371
Passing U.S. Standard Sieve

Glacial Gravel	Basalt Quartzite Granite % by Weight
% No. 6	100%
% No. 10	10-35%
% No. 20	0-3%

METHOD OF APPLICATION

MATERIAL CONTAINERS ARE RECOMMENDED TO BE STORED IN A TEMPERATURE RANGE OF 75°F TO 85°F (24°C TO 30°C) FOR AT LEAST 24 HOURS PRIOR TO USAGE TO ENSURE PROPER MIXING AND APPLICATION PROPERTIES.

Surface Preparation: The entire deck or concrete surface in question must be sounded for subsurface delaminations. The delaminated areas are marked and repaired.

Concrete: The entire deck shall be shotblasted (using equipment such as Turboblast) to remove the contaminated concrete as well as any weak surface layer in the case of newly placed concrete. Sandblasting can be used as an alternative to shotblasting although the sandblasting methods DOES NOT provide a uniform and dust-free surface. Therefore, sandblasting should only be used where the shotblasting method is not practical or possible.

Asphalt: The entire area must be power washed 20.7 – 48.3 MPa (3,000 - 7,000 psi) to remove all dirt, grime, and loose contaminants, at least 24 hours prior to application of **FLEXOGRID**.

Steel: The steel surface shall be sand blasted or shot blasted to "near white - SSPC-SP10". All cleaned surfaces shall be blown with dry compressed air and overlayed before any "flash" rusting is observed.

Repair of Cracks: If excessive cracks are observed on concrete decks, then it is recommended that **POLY-CARB's MARK-135 SAFE-T-SEAL** be used. **SAFE-T-SEAL** is a gravity fed crack welding system that is 100% solids, free of any solvents or toxic fumes and odor. **SAFE-T-SEAL** is also recommended for steel grid filled with concrete decks as a pre-treatment prior to application of **FLEXOGRID**.

Repair of Spalled Areas: All weak and spalled concrete areas shall be marked and a one to two inch saw cut shall be made prior to jackhammering the non-structural concrete. Care should be taken not to slice or cut the steel rebar while saw cutting the marked area. These areas shall be sandblasted followed by an air blast to remove any loose dust.

For very large and massive patches, **MARK-205** (Superplasticized Concrete) with an epoxy-bonding agent (**MARK-253**) is recommended.

Magnesium phosphate concrete is not recommended for patching prior to the application of **MARK-163 FLEXOGRID** overlay due to the incompatibility resulting in poor bond between the **FLEXOGRID SYSTEM** and the magnesium phosphate concrete.

APPLICATION OF FLEXOGRID OVERLAY

The overlay system shall be applied on all deck areas using metering, mixing, and distribution machinery approved by the hybridized co-polymer manufacturer. The application machine shall feature positive displacement volumetric metering pumps. Controlled by a hydraulic system and having a 37.85 liters (10 gallon) per minute minimum total output. The resin shall be stored in temperature controlled reservoirs and maintaining 37.8°C ± 4°C (100°F ± 10°F) to insure optimum mixing. In line mixing shall be motionless so as to not overly shear the material.

Mixing: For manual application, mix two volumes of Part A with one volume of Part B (2A: 1B) in a clean, dry metal container. A 1.27 cm (1/2 inch) high torque slow speed drill (300 R.P.M. max.) with a jiffy mixer is recommended. Take care to not entrap air in the system during mixing. Three to four minutes of thorough mixing is recommended.

The mixed material should be transferred into another clean and dry container to carry to the job. The remainder in the original container should be scraped out and transferred into the fresh batch. This process reduces chances of transferring small pockets of unmixed material on the concrete deck.

Application: Use the following steps for application of mixed material and aggregate.

1. Spread the mixed material on the surface using squeegees covering $0.86\ m^2/\ell$ (35 square feet) per gallon in the first of two coats. It is recommended that the area shall be pre-marked to guide the use of mixed material providing recommended coverage.

2. The aggregate shall be broadcasted at a rate of $8.14\ kg/m^2$ (15 lbs./$yd.^2$) on the freshly placed hybridized co-polymer material within approximate time limits under the existing temperature conditions as described below in No. 6. For best results, the aggregate shall be broadcasted by truck mounted pneumatic or mechanical equipment capable of dispensing the aggregate onto the deck in a uniform manner as directed by the hybridized co-polymer manufacturer.

For smaller areas a garden fertilizer spreader may be used for spreading the aggregate. A lateral type unit is preferred to a circular spreader. The entire liquid surface shall be covered completely (to saturation) with the aggregate.

3. If required, as recommended by the manufacturer, the applied aggregate shall be uniformly compacted by the use of a lightweight, hand-driven roller.

4. Once this coat obtains the initial set, excess aggregate must be removed. A high-powered vacuum or sweeper may be used for aggregate cleanup.

5. The second application of mixed Parts A and B Overlay System shall be applied at a rate of 0.37 – 0.49 m^2/ℓ (15-20 $ft.^2/gal.$), followed by the broadcasting of aggregate at a rate of 8.14 kg/ m^2 (15 pounds per $yard^2$).

6. The maximum time allowed between application and broadcast of aggregate at temperature of:

90°F (32°C)	10 minutes
80°F (27°C)	15 minutes
70°F (21°C)	20 minutes
60°F (16°C)	25 minutes
50°F (10°C)	35 minutes

7. The minimum ambient temperature required for proper curing: 10°C (50°F).

NOTE: *Any exceptions* to the above specified procedure must have the approval of **POLY-CARB, INC.**

COVERAGE

FLEXOGRID Overlay

- **Liquid****
  1st application – 0.86 m^2/ℓ (35 $ft.^2$/gallon)
  2nd application – 0.37 m^2/ℓ (15 $ft.^2$/gallon)

** The coverage rate is a good first estimate. This presupposes a flat deck, the specified aggregate, and a temperature of 80°F. A grooved deck or a colder temperature may require more material.

- **Aggregate**
  1st application – 8.14 kg/m^2 (15 $lbs./yd^2$)
  2nd application – 8.14 kg/m^2 (15 $lbs./yd^2$)

PACKAGING

FLEXOGRID Overlay

- Liquid

Bulk Tank	11355ℓ (3,000 gallons) (machine applications only)
189.2ℓ (50 gallon) containers	567.7ℓ (150 gallon) unit
18.9ℓ (5 gallon) container	56.8ℓ (15 gallon) unit

- Aggregate

  MARK-371

45.4kg (100 lb.) bags	30 bags/pallet
Bulk	1360.8 kg (3,000 lbs)/bag

<u>CLEAN UP</u>

Cleaning of all equipment and tools is recommended before the gel time of the system expires. **MARK-306** is specially designed for this purpose. A lacquer solvent or xylol can also be used for the same purpose.

<u>LIMITATIONS</u>

* Should not be used over magnesium phosphate-type of patching material.
* Use washed and dried aggregate only.
* At the time of application, the substrate and air temperature should be at least 10°C (50°F) and expected to rise to 15.6°C (60°F) or above.
* Do not thin the hybridized co-polymer with any solvent, as this will prevent proper curing.
* Excessive moisture on the concrete surface at time of application can interfere with proper bonding due to vapor pressure.

<u>IMPORTANT NOTE</u>

With this technical data sheet, we are making every effort to communicate to you, our valued customer, the proper procedures, properties and limitations of this product to ensure you a successful installation. This is considered to be an exotic material, which is controlled by temperature, proper mixing, surface preparation, and other application conditions. It is most IMPERATIVE that these instructions are understood by all and followed correctly. It is our appeal to you, in case of the slightest doubt, that you call our office and express your concerns to one of our technical service representatives. This action will ensure that all doubts, discrepancies, or misunderstandings are cleared up to aid in the completion of a successful application. Please call us toll free at 1-800-CALL MIX. We are ready to serve you.

PLEASE READ AND THOROUGHLY UNDERSTAND THE <u>MATERIAL SAFETY DATA SHEET</u> PROVIDED WITH EACH ORDER PRIOR TO BEGINNING WORK. THIS IS INTENDED FOR <u>YOUR</u> SAFETY.

Direct contact with the skin should be avoided as it can cause skin irritation. Protective clothing, goggles, and gloves are recommended. In the event of direct contact with the eyes, flush immediately with plenty of water and report to a doctor. FATAL IF TAKEN INTERNALLY. KEEP AWAY FROM OPEN FLAME AND FROM FREEZING TEMPERATURES.

KEEP OUT OF REACH OF CHILDREN

The VOC contents per EPA test method 24 (40 CFR 59) do not exceed 150 g/L.

G.4: ESI Spray System

Introducing ESI Spray™

EnviroTech Services' **ESI Spray™** systems are the anti-icing solution that picks up where all other spray systems have failed. **ESI Spray™** offers the latest technologies available in the industry for delivering motorist safety on bridges, parking decks and roadways.

DISTRIBUTED BY:

Features and Benefits

- Vaisala Spectro Non-Contact Friction Sensor
- Self Diagnosis and Alarm Callout on System Status
- Remote Monitoring of Systems
- Compatible with Virtually all Deicing Products
- Unrivaled Maintenance and Service

ESI Spray Product Overview

ESI Spray™ offers state-of-the-art, non-invasive, real-time road friction measurement technology and customized spray deicing systems. The systems can be customized and made fully automatic, offering the most accurate road condition assessment and self diagnosis capabilities for both new and existing systems. These systems can even be equipped to send status alarms when attention is needed. **ESI Spray**™ systems are dependable and compatible, and can be engineered to meet the viscosity of all de-icing liquids available.

Uses and Application

EnviroTech Services, Inc. provides the design, installation, selling and servicing of **ESI Spray**™ technology. This system can be designed for any location where slick surfaces hinder the safety of traveling motorists. **ESI Spray**™ can be integrated into new bridge deck systems, parking garages, etc. or retrofitted to existing structures to reduce or eliminate accidents. EnviroTech Services, Inc. offers unrivaled maintenance services for both new and existing installations.

Performance

ESI Spray™ systems provide the superior technology of Vaisala road condition detection devices, including non-invasive sensors that detect the actual friction condition of the surface being inspected. These remotely mounted sensors provide precise, real-time measurement of such factors as actual pavement temperature and can uniquely report on the friction capabilities and grip reduction on road surfaces. **ESI Spray**™ is fully automated and can be monitored over a user friendly host website with remote control, reducing the use of personnel and equipment for additional treatment of problem areas.

Maintenance

EnviroTech Services, Inc. provides unmatched customer service and design consultation, installation, and post-sale servicing for all of its **ESI Spray**™ systems. **ESI Spray**™ systems are sold only in areas where EnviroTech Services, Inc. can provide its customers with service and maintenance. In addition, **ESI Spray**™ can provide for the maintenance, service and upgrading of all existing systems, including those it did not manufacture.

910 54th Avenue, Suite 230 ■ Greeley, CO 80634 ■ (t) 1-800-369-3878 ■ (f) 1-970-346-3959 ■ www.EnviroTechServices.com

BIBLIOGRAPHY

ACI. *Guide for Polymer Concrete Overlays*. Rep. no. ACI 548.5R-94. Farmington Hills, MI: American Concrete Institute, 1994. Print.

ACPA. *Current Perspectives on Pavement Surface Characteristics*. Issue brief no. 8.02. Skokie, IL: American Concrete Pavement Association, 2007. Print.

Adam, John F., and Elijah Gansen. *Performance of PolyCarb, Inc. Flexogrid Overlay System*. Tech. MLR-86-04. Ames, IA: Iowa Department of Transportation, 2001. Print.

Bindel, Mary K. *Effects of Concrete and Asphalt Surface Treatments on Bond Strength of Thin bonded Overlays*. Thesis. University of Colorado Denver, 2010. Denver, CO: University of Colorado, 2010. Print.

Caltrans. *2010 Contract Cost Data*. Sacramento, CA: State of California Department of Transportation, 14 Jan. 2011. PDF.

Caltrans. *Maintenance Technical Advisory Guide*. 2nd ed. Vol. II. Sacramento, CA: State of California Department of Transportation, 2008. Print.

Cargill, Incorporated. *Technical Specification – Anti-icing Polymer Surface Overlay Tradename: Cargill SafeLane® HDX Overlay*. York, PA: Cargill, Incorporated, 2007. Print.

CDOT. *2010 Construction Cost Data Book*. Denver, CO: Colorado Department of Transportation, 22 Feb. 2011. PDF.

Dinitz, Arthur M., and Michael S. Stenko. "The Successful Use of Thin Polysulfide Epoxy Polymer Concrete Overlays on Concrete and Steel Orthotropic Bridge Decks." *Proceedings of the 2010 Structures Congress*. Structures Congress 2010, Orlando, FL. Reston, VA: American Society of Civil Engineers, 2010. 530-540. Print.

Evans, John F. *Evaluation of the SafeLane Overlay System for Crash Reduction on Bridge Deck Surfaces*. Rep. no. MN/RC 2010-13. St. Paul, MN: Minnesota Department of Transportation, 2010. Print.

FHWA. *Bridges by Posting Status 2010*. Washington, DC: Federal Highway Administration, 06 Apr. 2011. Excel.

GERMANN INSTRUMENTS, Inc. *PROOVE'it*. Evanston, IL: GERMANN INSTRUMENTS, 2010. Print.

Glauz, Doran L., and Ric Maggenti. "Bonded Polyester Concrete Overlays Used in California." *Structural Engineering in Natural Hazards Mitigation*. Proc. of 1993 Structures Congress, Hyatt Regency Irvine, Irvine, CA. Vol. 2. American Society of Civil Engineers, 1993. 1002-007. Print.

Goodman, Richard E. *Engineering Geology: Rock in Engineering Construction*. New York, NY: J. Wiley and Sons, 1993. Print.

Google. Google Maps. Digital image. *Google Maps*. Google, Incorporated, 1 Jan. 2011. Web. 3 June 2011. <http://maps.google.com>.

Grace. *Understanding AASHTO T277 and ASTM C1202 Rapid Chloride Permeability Test*. TB-0100. Cambridge, MA: W.R. Grace & CO., 2006. Print.

ICC. *Friction Tester*. Clearwater, FL: International Cybernetics Corporation, 2006. Print.

Izeppi, Edgar De Leon, Gerardo W. Flintsch, and Kevin McGhee. *Field Performance of High Friction Surfaces*. Tech. no. VTRC 10-CR6. Richmond, VA: Virginia Department of Transportation, 2010. Print.

Johnson, Dave R., and Jerry E. Stephens. *Monitoring and Evaluations of Thin Bonded Overlays and Surface Laminates for Bridge Decks*. Rep. no. FHWA/MT-97/96015-1. Helena, MT: Montana Department of Transportation, 1997. Print.

Kosmatka, Steven H., Beatrix Kerkhoff, and William C. Panarese. *Design and Control of Concrete Mixtures*. 14th ed. Skokie, IL: Portland Cement Association, 2002. Print.

Kuhlmann, L. A. "Latex Modified Concrete for the Repair and Rehabilitation of Bridges." *The International Journal of Cement Composites and Lightweight Concrete* 7.4 (1985): 241-47. Print.

Lang, Gerhard. "Case Histories OF Polymer Concrete Applications in the US." *No-dig 2005*. Proc. of North America No-dig Conference, Orlando, FL. Liverpool, NY: North American Society for Trenchless Technology, 2005. Print.

Maggenti, Ric. *Polyester Concrete in Bridge Deck Overlays*. Rep. no. O4-ALA/SF-80-VAR. Sacramento, CA: State of California Department of Transportation, 2001. Print.

Manning, David G. (1995). "Waterproofing Membranes for Concrete Bridge Decks." *NCHRP Synthesis 220, Transportation Research Board*, Washington, DC.

Mastel, Andrew. *Bridge Deck and Roadway Surface Treatments*. Tech. ND 07-02. Bismarck, North Dakota: North Dakota Department of Transportation, 2009. Print.

National Asphalt Pavement Association. "History of Asphalt." *History of Asphalt*. National Asphalt Pavement Association. Web. 29 June 2011. <http://www.hotmix.org/index.php?option=com_content&task=view&id=21&Itemid=41>.

North Carolina Department of Transportation. *Purchase Order Contract Bridge Replacement*. 20 May 2010. Bid Tab for Project# WBS 42579.3.6.

ODOT. *Oregon DOT Weighted Average Item Price - Calendar Year 2010*. Oregon Department of Transportation, 18 Apr. 2011. PDF.

Ozolin, Brett, and Stephen T. Muench. *Rapid Pavement Construction Tools, Materials and Methods*. Tech. WA-RD 670.1. Seattle, WA: University of Washington, 2007. Print.

Perischetti, Bob. "New Technology Keeps Ice Away and Drivers Safe." *Concrete International* Feb. 2007: 52-55. Print.

PolyCarb, Incorporated. *Mark-163 TDS (Technical Data Sheet)*. Solon, OH: PolyCarb, Incorporated, 2009. Print.

Quinn, William J., Leon G. Brock, and Gordon W. Beecroft. *Type A Polymer Concrete Field Trials*. Rep. no. 84-. Salem, OR: Oregon State Highway Division, 1984. Print.

Ramakrishnan, V. (1992). "Latex-Modified Concretes and Mortar." *NCHRP Synthesis 179, Transportation Research Board*, Washington, DC.

Ramey, George E., and John P. Derickson. "Performance of Bonded Bridge Deck Overlays in Alabama." *Practice Periodical on Structural Design and Construction* 8.1 (2003): 13-21. Print.

Rowekamp, Paul A. "The Minnesota Department of Transportation's Experience with High Performance Concrete Bridge Decks." *2004 Concrete Bridge Conference: Building a New Generation of Bridges*. Proc. of 2004 Concrete Bridge Conference: Building a New Generation of Bridges, Charlotte, North Carolina. Federal Highway Administration, Jan.-Feb. 2004. Web. 14 June 2011. <http://www.cement.org/bookstore/profile.asp?store=main&pagenum=3&pos=50&catID=1&id=7225&cat2ID=2>.

Russell, Henry G. *Concrete Bridge Deck Performance*. Washington DC: Transportation Research Board, 2004. Print. NCHRP Synthesis 333.

Scarpinato, E. J. "Thin Polymer Concrete Bridge Deck Overlays." *Concrete Construction* Aug. 1984. Print.

Shahrooz, Bahram M., Arnol J. Gillum, Jeremiah Cole, and Ahmet Turer. "Bond Characteristics of Overlays Placed over Bridge Decks Sealed with High-Molecular-Weight Methacrylate." *Transportation Research Record 1697* (2000): 24-30. Print.

Sheehan, Matthew J., Scott M. Tarr, and Shiraz Tayabji. *Instrumentation and Field Testing of Thin Whitetopping Pavement in Colorado and Revision of the*

Existing Colorado Thin White Topping Procedure. Rep. no. CDOT-DTD-R-2004-12. Denver, CO: Colorado Department of Transportation, 2004. Print.

Sprinkel, Michael M. *Evaluation of Latex-Modified and Silica Fume Concrete Overlays Placed on Six Bridges in Virginia*. Rep. no. VTRC 01-R3. Charlottesville, VA: Virginia Transportation Research Council, 2000. Print.

Sprinkel, Michael M. *Premixed Polymer Concrete Overlays*. Tech. VTRC 90-R8. Charlottesville, VA: Virginia Transportation Research Council, 1990. Print.

Sprinkel, Michael M. "Sampling and Testing of Latex-Modified Concrete for Permeability to Chloride Ion." *Transportation Research Record 2113* (2009): 47-52. Print.

Sprinkel, Michael M. *Twenty-Five-Year Experience with Polymer Concrete Bridge Deck Overlays*. Publication no. SP214-05. Farmington Hills, MI: American Concrete Institute, 2003. Print.

Stenko, Michael S., and Arif J. Chawalwala. "Thin Polysulfide Epoxy Bridge Deck Overlays." *Transportation Research Record 1749* (2001): 64-67. Print.

Tarr, Scott M., Matthew J. Sheehan, and Paul A. Okamoto. *Guidelines For The Thickness Design of Bonded Whitetopping Pavements in the State of Colorado*. Rep. no. CDOT-DTD-R-98-10. Denver, CO: Colorado Department of Transportation, 1998. Print.

Toney, Carl A. *Internally Sealed Concrete Using Wax Beads*. Rep. no. WA-RD 132.1. Olympia, WA: Washington State Transportation Commission, 1987. Print.

Tyson, Samuel S. *Internally Sealed Concrete for Bridge Deck Protection*. Rep. Charlottesville, VA: Virginia Highway and Transportation Research Council, 1978. Print.

United States. Department of Transportation. Office of Pavement Technology. *Whitetopping - Innovations - Highways for LIFE - FHWA*. By Suneel Vanikar. Federal Highway Administration, 4 Apr. 2011. Web. Winter 2011. <nhttp://www.fhwa.dot.gov/hfl/innovatios/whitetopping.cfm>.

Unitex. *Unitex SmartBond*. Kansas City, MO: Unitex, 2004. Print.

Washington State Department of Transportation. *Bid Check Report*. 11 June 2007. Bid Check Report for Contract Number 007360.

WSDOT. *Thin Polymer Bridge Deck Overlays*. Rep. no. WA-RD 374.1. Olympia, WA: Washington State Department of Transportation, 1995. Print.

White, David, and Richard Montani. "Thin bonded Polymer Concrete Overlays For Exposed Concrete Bridge Deck Protection And Maintenance." *Transportation Research Board Library*. Proc. of Eighth AASHTO/TRB Maintenance

Management Conference, Saratoga Springs, NY. Washington, DC: Transportation Research Board, 1997. 99-106. *Transportation Research Integrated Database (TRID)*. Web. 3 June 2011. <http://trid.trb.org/view.aspx?id=575426>.

Whiting, D., and R. Detwiler. (1998). "Silica Fume Concrete for Bridge Decks." *NCHRP Report 410, Transportation Research Board*, Washington DC.

Wilson, DeWayne L., and Edward H. Henley, Jr. *Thin Polymer Bridge Deck Overlays*. Tech. WA-RD 374.1. Lacey, WA: Washington State Department of Transportation, 1995. Print.

Yehia, Sherif A., and Christopher Y. Tuan. "Bridge Deck Deicing." *1998 Transportation Conference Proceedings*. Crossroads 2000 Conference, Iowa State University, Ames, IA. Ames, IA: Iowa State University, 1998. 51-57. Print.

Yehia, Sherif A., and Christopher Y. Tuan. "Thin Conductive Concrete Overlay for Bridge Deck Deicing and Anti-Icing." *Transportation Research Record 1698* (2000): 45-53. Print.