Thin Bonded Epoxy Overlays on Concrete Bridge Deck Surfaces

Word Count (Abstract 250; Manuscript 5410; Tables and Figures 1750)

Logan M. Young
Graduate Research Assistant
University of Colorado Denver
Department of Civil Engineering
Campus Box 113, P.O. Box 173364
Denver, CO 80217
Phone: (831) 818-1621
Fax: (303) 556-2368
Email: lyoung@sonic.net

Stephan A. Durham, Ph.D., P.E.
(Corresponding Author)
Associate Professor
University of Colorado Denver
Department of Civil Engineering
Campus Box 113, P.O. Box 173364
Denver, CO 80217
Phone: (303) 352-3894
Fax: (303) 556-2368
Email: stephan.durham@ucdenver.edu

Mary K. Bindel
Graduate Research Assistant
University of Colorado Denver
Department of Civil Engineering
Campus Box 113, P.O. Box 173364
Denver, CO 80217
Phone: (303) 352-3894
Fax: (303) 556-2368
Email: mary.bindel@email.ucdenver.edu

This revised paper based on reviewers comments is submitted for consideration in the
Transportation Research Record

November 14, 2011
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ABSTRACT
State Departments of Transportation are faced with a continuous problem of maintaining and replacing the wearing surfaces on bridge decks. Wearing surfaces are utilized on many bridge decks in an effort to maximize the life of the bridge deck, prevent the infiltration of water and aggressive chemicals such as chlorides from deteriorating the concrete surface and corroding the steel reinforcement. The Colorado Department of Transportation has recently begun to evaluate the performance of thin bonded epoxy overlays. This study evaluated two thin bonded epoxy overlays, SafeLane and Flexogrid. 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 installation cost. Mean texture depth and friction testing were shown to provide a durable wearing surface with adequate traction for both overlays. In addition, both overlays produced high bond strengths with the Flexogrid overlay showing varied failure modes. Chloride testing of the underlying concrete decks indicated that both overlays worked well to protect the bridge decks from chloride ingress. A reduction in traffic accidents was determined; however, further study is required. Final results indicate that the CDOT should consider using these thin bonded epoxy overlays to extend the service life of their bridge structures, decrease the presence of bonded ice during winter events and consequently increase traffic safety.
INTRODUCTION

The Federal Highway Administration’s (FHWA) National Bridge Inventory reports that of the 599,766 bridges in the national highway system, approximately 152,316 (25.4%) are structurally deficient or functionally obsolete (1). Furthermore, Colorado has 1,404 of its 8,366 bridges classified as structurally deficient or functionally obsolete. Approximately 580 Colorado bridges are structurally deficient. Though a structurally deficient bridge is not necessarily unsafe, it does identify the bridge as having a significant level of deterioration and/or damage to load carrying elements or adequacy of the waterway provided by the bridge. Much of the deterioration that occurs may be prevented in part by protecting the concrete (and the steel reinforcement) from water and aggressive chemicals.

Many state Departments of Transportation (DOTs) began incorporating future wearing surfaces to protect the concrete bridge decks from deterioration and prevent the infiltration of water and aggressive chemicals into the bridge decks and supporting structural elements. Bonded overlays are designed to provide a durable, cost effective wearing surface with low permeability to water and chlorides (2). In addition, it is expected that the overlay exhibit an appropriate level of skid resistance. Types of overlays that have been incorporated into highway bridge systems include: asphalt, portland cement concrete, non-reinforced polymer-modified concrete, and thin-bonded epoxy overlays.

It has become regular practice for State DOTs, and county and city road authorities to take a proactive approach in preventing the formation of snow and ice on roadways. One method that has been particularly effective is the use of anti-icing agents on roadway and bridge surfaces prior to the development of severe winter conditions. These anti-icing agents are liquid forms of salt compounds used to prevent the formation of ice on the pavement surface, thus ensuring proper snow/ice removal (3). These chemicals work by decreasing the freezing point of water. The CDOT currently uses magnesium chloride as a deicing agent on many of their bridge structures throughout the state. These chemicals can be detrimental to not only the steel reinforcement, but the concrete surface itself. Research has documented that the use of magnesium chloride can accelerate the scaling of concrete surfaces.

An innovative surface overlay product called SafeLane has won grants through the FHWA’s IBRC program in four different state transportation departments. This overlay combination of epoxy and aggregate is able to store liquid anti-icing chemicals within its structure and release them as conditions develop for the formation of ice and snow (4). The overlay product allows for a reduction in usage of deicing chemicals by reducing the amount that is ineffective and wasted, as well as providing a safer roadway by allowing the chemicals to be more fully effective when they are most needed. The product can also extend the life of roads and bridges by acting as a sealant that reduces the effects of chloride and water intrusion. The overlay can be installed over asphalt, concrete, steel, or wood and has traction characteristics better than asphalt and equal to concrete.

Another thin-bonded overlay system commonly used by many state DOTs is the PolyCarb, Inc. Flexogrid Bridge Overlay System. Flexogrid is a two part epoxy/urethane system that is applied to the surface of bridge decks (5). Typical thicknesses of this system are 0.25in (6.35mm). An aggregate mixture of silica quartz and aluminum oxide is applied to the epoxy/urethane system to increase friction of the thin-bonded overlay. This overlay is marketed...
as a strong and durable overlay that reduces reflective cracking on bridge decks. This overlay can be placed on bare-concrete bridge decks.

The performance of the two thin bonded overlays products were evaluated on two Colorado bridge decks. This was accomplished by physical testing of the overlay installations. In order to gain a better understanding, a literature review was conducted in which the types, functions, and materials of different thin bonded overlays in use by other state DOTs was examined. An experimental plan was developed to examine the performance of these overlays and included four specific physical and chemical tests: (1) mean texture depth, (2) friction, (3) bond strength, and (4) chloride. In addition, data was gathered through crash reports, and installation bids to examine the overlays performance in regards to traffic safety and cost.

LITERATURE REVIEW
Thin bonded overlays generally fall into one of two major categories; polymer based or hydraulic concrete based. In general, polymer concrete overlays are classified as an overlay that uses a polymer as the binding agent, while hydraulic concrete overlays are based upon portland cement.

Hydraulic Concrete Overlays
Thin bonded concrete overlays are typically defined as an overlay that is a 1in to 4in (25.4 to 101.6mm) concrete wearing surface above a structural deck. Several different types of concrete are used in thin bonded overlays including: low-slump dense concrete (LSDC), silica fume concrete (SFC) or micro silica modified concrete (MS or MSC), and latex-modified concrete (LMC) (6). LMCs have higher than normal tensile, flexure, and bond strengths as well as low permeability and provide excellent corrosion resistance (7).

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. Although these concrete mixtures are effective at stopping chloride intrusion, freeze-thaw durability presents potential problems.

Polymer Concrete Overlays
Polymer overlays are uniquely different from the hydraulic concrete overlays since they add very little material to the surface of the bridge deck by using a polymer binder and aggregate system. The most common types of binding agents are epoxies, coal tar modified epoxy, polyester, methyl methacrylate, and polyurethanes. This is advantageous, since it reduces the dead load while sealing the structural bridge deck from moisture and chemicals (8). The biggest disadvantage to polymer overlays is that surface preparation is extremely critical. Even the slightest moisture or debris on the surface can cause debonding of the overlay.

Polymer overlays can be divided into two categories depending on how they are applied; the broom and screed method, and the slurry and premixed methods (9). The broom and screed method first applies the binder, and then applies the aggregate by either manual or automatic broadcasting. The slurry method mixes all components together before being applied to the deck surface in thin sections by squeegees, where as, the premixed method typically consists of a binder, silica and basalt sand as the fine aggregate, gravel as the coarse aggregate, and admixtures placed by a paving machine in moderately thicker sections. Additionally, the
American Concrete Institute reports on the polymer-modified concretes and their physical properties (10). The two overlays examined in this study are the broom and screed method.

**SafeLane Overlay System**
SafeLane is an epoxy based polymer concrete overlay that was specifically developed to fill the role of an anti-icing/anti-skid overlay (4). It utilizes a patented combination of aggregate and binder to obtain these properties, while providing protection for bridge decks. The dolomite aggregate is a proprietary product that has been specially prepared to absorb deicing chemicals. It utilizes a specialty aggregate bonded to a pavement surface by an epoxy binder. To date, SafeLane has been installed in twenty-nine states (4).

**Flexogrid Overlay System**
Flexogrid is a polymer concrete overlay system for use on bridge decks (5). 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. Flexogrid consists of the Mark-371 aggregate and Mark-163 epoxy. The recommended Mark-371 aggregate is basalt quartzite granite. The Mark-163 urethane epoxy is a two part amber colored epoxy that is supplied by PolyCarb for the Flexogrid system.

**DEPARTMENTS OF TRANSPORTATION SURVEY**
A DOT survey was developed 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. The survey was targeted at materials engineers within each state DOT. Twenty-four state DOTs responded to the survey. Some states sent multiple responses from both bridge and materials engineers. A total of 30 responses were recorded.

Seven of the twenty-four states reported that they are currently using the SafeLane overlay system including: Vermont, Wisconsin, Idaho, New York, Mississippi, Minnesota, North Dakota, and Kentucky. Of particular note was Wisconsin, who reported 30 applications of thin-bonded epoxy overlays since 1999. Three of the 30 overlays in Wisconsin are the SafeLane overlay. Minnesota and Wisconsin noted that SafeLane reduced crashes on their bridge decks. Other DOT's did not have this information available.

Approximately half the respondents reported surface friction skid numbers greater than 35, which was classified as acceptable. One state reported a 20% reduction in the amount of deicing chemicals used for structures utilizing the SafeLane overlay. Other states reported no change, or that they did not utilize the anti-icing properties of the overlay.

Wisconsin DOT reported issues with mixing SafeLane prior to application and Minnesota reported decrease in surface friction with age. The majority of applications involving the SafeLane overlay have been on concrete surfaces. Two states reported using the SafeLane overlay on asphalt wearing surfaces. Two state DOTs responded that they had developed specifications for these types of overlays. Others stated that they are still in trial phases and are operating using special provisions. Additional thin bonded overlays that state DOTs are using include Flexolith 216, Flexogrid, Degussa, and Transpo T-48; these products were noted by the respondents as providing protection from chloride intrusion; however, do not have anti-icing properties.
From the DOT survey it was found that there is fairly little use of anti-icing/anti-skid thin bonded overlays, especially on asphalt surfaces. 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 seem to be localized to specific installations. Most states had not experienced significant issues, with the exception of installation problems.

Beyond the state DOT survey results, the Virginia DOT evaluated the SafeLane overlay compared to their modified EP-5 epoxy concrete overlay on four bridge decks. The results indicated the SafeLane overlay can provide a skid-resistant wearing and protective surface for bridge decks. (11).

EXPERIMENTAL PLAN
Several different sites were evaluated for installation of SafeLane and Flexogrid. The two chosen were based mainly on: traffic volume, location of a nearby weather station, bridge deck type and size. With the locations selected, a study plan was drafted to determine how the overlays were to be tested. Four physical and chemical tests were conducted before and after installation as a partial determination of overlay performance.

Site Location
Parker Road and I-225
The Colorado Department of Transportation selected the Denver/Aurora metropolitan area to test the SafeLane overlay. 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 an ideal structure for testing SafeLane. It has an average annual daily traffic (AADT) of 123,000. Currently, this site has no instrumentation or traffic cameras present on the structure. The SafeLane system was installed on the right and left lanes of the Parker Rd./I-225 bridge at two different times due to unfavorable temperatures. The older overlay was installed in the right lane in October 2009, while the left lane was installed in May 2010.

I-25 and I-225
The southbound I-25 to northbound I-225 interchange was selected as the location to test Flexogrid. Since Flexogrid has no inherent anti-icing properties, this location was used because of the anti-icing spray system installed at the same location. 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 125,000. The Flexogrid overlay was installed in October 2009.

The I-25/I-225 site is equipped with an ESI spray system manufactured by EnviroTech Services, Inc and was installed at the same time as the Flexogrid overlay. The system is automated, and releases deicing chemicals based upon deck temperature measured by an infrared thermometer.

Overlay Application Process
As with any bridge deck overlay, the application is critical and is one of the primary factors in
determining the longevity of the overlay. Both SafeLane and Flexogrid were installed using the broom and screed method. A unique aspect to the Flexogrid installation is that PolyCarb has specialty machines that are supplied to job sites for the application of Flexogrid.

There are several preparations that must occur before the epoxy can be applied to a bridge deck. First the roadway striping was removed to allow the epoxy to bond to the asphalt or concrete deck. See Figure 1a. The decking was then thoroughly cleaned using an abrasive blasting method (Figure 1b). Final preparation included cleaning the bridge deck with compressed air and a vacuum truck.

Shown in Figure 1c, the first step in the application process was to batch the epoxy. Spreading the epoxy was accomplished using a V- notched squeegee for the 1st layer application, and a straight edge squeegee for the 2nd layer (Figure 1d). Each batch of epoxy had a sample taken to monitor the setup and cure time. Cure time is a function of epoxy type and ambient conditions. Each manufacturer provides estimated cure times as a function of ambient temperature. Generally, the SafeLane overlay requires between 3 hours @ 29°C (85+ °F) and 6 hours @ 16°C (60 °F) to cure depending on application surface temperature (4). Each batch was finished at a straight demarcation line marked on the bridge deck, such that it was easier to determine where one batch ended and another began.

FIGURE 1 Thin Bonded Epoxy Overlay Installation Procedure (a) removal of striping, (b) sand blast surface preparation, (c) mixing of epoxy, (d) epoxy application, (e) aggregate placement, (f) final cleaning of deck surface with compressed air
The standard method of applying the aggregate was to use a shovel and disperse an even layer on top of the epoxy. See Figure 1e. Automatic spreaders are used to disperse aggregate for larger bridge decks. Generally, the aggregate should be spread a couple feet behind the wet edge of the epoxy to maximize aggregate distribution within the curing time, and to allow the aggregate to absorb the epoxy for a better bond.

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 (Figure 1f). After the first layer of SafeLane/Flexogrid was cured and cleaned, the second layer was applied. The second layer required more epoxy and aggregate due to the deeper texture of the aggregate from the previous layer. Once the second layer was cured, it was cleaned and traffic was allowed on the structure.

EXPERIMENTAL RESULTS

The primary objective was to determine the effectiveness of thin bonded epoxy overlays placed on concrete surfaces. As such, there were four tests performed on each structure and subsequent overlay to determine the performance characteristics: (1) bond strength, (2) friction, (3) texture depth, and (4) chloride content. In addition, the overlay thickness, anti-icing properties, and cost were evaluated to provide recommendations for these types of overlays usage on future structures.

Sand Patch Test

The sand patch test provides the mean texture depth of the pavement surface. This test was conducted on the Parker Rd/I-225 structure prior to installation (concrete surface), the left lane immediately after installation, the right lane at 8 months of age, and the right lane at 18 months of age. Figure 2 shows the texture depth measurements of Parker Rd./I-225 with age.
The SafeLane overlay produced a high mean texture depth (MTD) immediately after installation. Though the right lane was not tested immediately after installation, it was assumed that the MTD was similar to the initial left lane measurements. The right lane was tested for MTD in two subsequent years (2010 and 2011) which gave an indication of wearing over time. The results are surprising in that they show very little additional wearing after approximately 8 months in service. From these findings, it appears that no significant wearing occurs on SafeLane after one year of age. The SafeLane overlay utilizes a dolomite aggregate that is specially prepared using a proprietary method. Based on the responses from the state DOT survey, the long-term performance of this overlay is adequate as long as proper snow removal is conducted (rubber-tipped blades and no additional downward pressure).

Measurements for texture depth for the Flexogrid overlay were taken in March 2011 and are considered baseline measurements. The five data sets collected produced an average texture depth of 0.45in (11.4mm). No conclusions of long term performance of Flexogrid can be stated without future testing.

**Skid Resistance (Fixed-Wheel Tests)**

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. By measuring surface friction over time, the performance of a roadway can be tracked. It is expected that a pavement's surface friction will decrease over time, primarily due to wearing. Figure 3 shows the results of the skid resistance testing for the SafeLane and Flexogrid overlays.

![Graph showing skid number for SafeLane and Flexogrid overlays](image)

**FIGURE 3 Skid Resistance for SafeLane and Flexogrid Overlays**
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. The concrete surface on Parker Rd./I-225 had a high skid number and is approximately equal to the most recent SafeLane skid numbers (1 year of age), but still well above 35. The ribbed and smooth fixed-wheel results are close to one another for the SafeLane overlay; however, dissimilar for the Flexogrid overlay. The similarity between the ribbed and smooth fixed-wheel results for the SafeLane demonstrate good micro- and macro texture traction. This indicates that dry and wet weather performance should be ideal. The SafeLane installation on Parker Rd./I-225 is performing very well by maintaining high friction numbers over its initial study period. The data shows that Flexogrid maintains good skid numbers over time. As with SafeLane, a high skid number was initially seen, which slightly decreased over time. Flexogrid is showing good skid numbers and is performing at least as well as the concrete surface it replaced with regards to surface friction.

**Bond Tests**

Bond testing was conducted in March 2011 on both the SafeLane and Flexogrid overlays. The test was conducted using an ASTM C1583 certified device that measure bond strength in direct tension by pulling off a disk adhered to the test surface. According to Cargill's (SafeLane) specifications, the SafeLane is required to produce bond strengths above 250psi (1.72 MPa), with all failures within the concrete substrate, and none in the overlay or at the overlay/bridge deck interface. PolyCarb specifies that Flexogrid should have 100% failure in the concrete substrate. Figure 4 provides the results of the bond tests for the SafeLane and Flexogrid overlays.
Bond testing on the Parker Rd./I-225 (SafeLane Overlay) and I-25/I-225 (Flexogrid) bridge structures consisted of 2 tests at 4 locations along the structure for a total of eight bond tests. The test groups were located at 150ft (45.72 m) increments beginning at the abutment of the bridges. The eight bond tests on the SafeLane overlay produced an average bond strength of 370psi (2.55 MPa) with the lowest strength of 308 psi (2.13 MPa), which exceeds the 250 psi (1.72 MPa) minimum adhesive requirement for the SafeLane system.

Seven of the eight bond tests for Flexogrid yielded acceptable results. Bond tests F1 and F2 for the Flexogrid reached acceptable strengths, but failure was located at the overlay and bridge deck interface. Bond test F4 suffered de-bonding failure of the test epoxy before the overlay failed, thus negating any results for this test spot. Test F5 reached acceptable strengths, but failure was located at the overlay / bridge deck interface. Bond tests F6, F7, and F8 were successful per Flexogrid specifications due to failure in the concrete deck. Bond tests F1, F2, and F5 seem to indicate that the overlay will fail at these locations prior to the concrete deck; however, the strengths at which these samples failed makes it seem unlikely that an overlay failure would occur at these locations. 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. It seems likely that the epoxy for bond test F4 did not reach an adequate cure, thus failure was observed in the test epoxy. The failure type for tests F1 and F2, where failure occurred partially at the overlay/substrate interface and the substrate, may have been caused due to a moment applied to the pull device during testing which caused a peeling failure of the sample. This 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.

Overall the bond test results are mixed. The highest failure strengths were observed on the Flexogrid overlay; however, the failure modes were mixed. The SafeLane overlay produced bond strengths in excess of 250psi (1.72 MPa) with all failures occurring in the concrete substrate.

Chloride Content
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, this is accelerated through an autocatalytic process in which the chlorides attack and destroy this layer allowing further corrosion (12).

The main method to determine the chloride content of concrete is using ASTM C1152, which has many variations or AASHTO T 260. ASTM C1152 references ASTM C114 for actual laboratory procedure, which finds the PPM of chloride in a concrete sample by titration of the chlorides using Silver Nitrate (AgNO3). The test is a laboratory intensive procedure that requires significant preparation. Some of the variations utilized by DOTs use newer methods in which several of the ASTM C114 steps are condensed by use of specially developed equipment. Testing is typically performed using 2in (50.8mm) 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 0.5in (12.7mm) thereafter to provide adequate space for saw cutting. Newer mechanical methods take much smaller cuts, thus more sections per core are taken. 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.

Chloride content is determined as a function of sample depth. 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.

Figure 5 shows the chloride testing results from the two overlay sites. Chloride contents were determined prior to and 18 months after installation. The chloride contents presented in the figure represent the average of ten cored samples for the before and after of the Flexogrid overlay, ten cored samples for the before of the SafeLane overlay, and five cored samples for the after installation of the SafeLane overlay. The chloride contents for prior to the installations of the SafeLane and Flexogrid overlays were extremely high. A reduction in the chloride content was observed from cores taken from the bridge decks 18 months after the overlays were installed. It is hypothesized that this reduction is due to time between tests and differences in test depths. The results validate that both overlays are protecting the bridge deck from chloride intrusion. In addition, a decrease in the chloride content was measured with depth into the concrete bridge deck.

![Figure 5 Chloride Content with Depth Before and After Installation of the Overlays](image)

**FIGURE 5 Chloride Content with Depth Before and After Installation of the Overlays**

**Anti-Icing Properties**
The thin bonded overlays of this study present a unique case to vehicle safety. In each case, both overlays offer a form of anti-icing protection. The Flexogrid site uses an active system in the form of a spray system, while the SafeLane site utilizes a passive system that stores the deicing chemical for winter events.
Instrumentation in the form of deck sensors have yet to be installed at the Parker Rd./I-225 and I-25/I-225 bridge sites; however, anecdotal evidence collected at these sites suggest positive anti-icing benefits. The Aurora Police Department (APD) mentioned that the SafeLane overlay installed on the Parker Rd./I-225 flyover has reduced crashes at that location and increase driver safety. In addition, the APD mentioned wanting SafeLane installed at another local interchange they consider particularly troublesome.

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 an adequate view of the bridge deck during winter storms. Figure 6 shows the post-activation of the spray system during a winter event. The image shows the effects of the spray system that disperses chemicals across the deck from the right to left lane. The striping pattern seen in the centerline is a result of the deicing chemical flowing from one side of the roadway surface to the other. The figure indicates that the spray system coupled with Flexogrid provides good anti-icing capability.

Traffic Safety
One of the more important aspects of roadway safety is the surface upon which vehicle traffic travels. Roadway overlays, in general, seek to at least match or increase the surface traction of the surfaces they replace. Though surface roughness is a means to measure pavement friction, the only true method 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. There is a wealth of crash data prior to overlay installation at both sites; however, it is limited in the short time after. Data was evaluated by looking at total crashes at both sites.

Crash data for the Parker Rd./I-225 spans from 2002 to 2010. While this site has the shortest period of crash data, it has slightly more overall crashes. However, this means that per year, there are more crashes at the SafeLane site than the Flexogrid site. This site has the added issue of having SafeLane installed in each lane, at different times. Thus, data in the years that SafeLane was installed was split, so that before and after comparisons can be made. Based upon the limited amount of post-installation data and a large spike in 2010 crashes, it is difficult to
conclude whether there was an increase or decrease in accidents due to the SafeLane overlay. Mathematical trends show a decrease in crashes, but there is limited data to conclude this with certainty at this time.

Crash data for I-25/I-225 spans from 1997 to 2010. Its crash rate is slightly less than that of Parker Rd./I-225 for a similar volume of traffic. There is a decrease in total crashes since the installation of Flexgrid at I-25/I-225 in 2009 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, similar to the SafeLane site, post installation crash data are limited, and the site is being monitored over the next three years such that better data samples can be obtained prior to reaching any final conclusions regarding traffic safety.

Currently, there is not a sufficient amount of data to make final comparisons regarding how one overlay performs over another. However, comparing crash data at both sites show that Flexogrid and the ESI spray system are performing better than the SafeLane overlay.

Cost Analysis
A major factor that affects whether or not an overlay is selected for installation is cost. Since the Parker Rd./I-225 and I-25/I-225 bridges were bid as a single job, 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. 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 bridge deck areas and then multiply this ratio by the total quantity listed on the bid sheet for each item. The ratio was calculated by taking the area of the as-built structural plans and dividing by the total area of both bridges. After obtaining a representative quantity for each site, the quantity was multiplied by the contractors bid cost to obtain a dollar value for that particular item. Each bridge site was thus given an appropriate cost that could be presented as a cost per area. See Table 1.

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While each lane of the SafeLane overlay was installed at separate times, both were covered under the initial bid. The total cost for this installation was $9.32/ft$^2$ ($100.37/m^2$). Although this cost is more expensive than the majority of anti-skid thin bonded overlays in use today, it is on the lower end of other DOT SafeLane installations (13).

The Flexogrid installation at I-25/I-225 included the construction of the spray system. However, the spray system cost of $730,750 was more than twice the cost of the Flexogrid overlay itself and approximately a third of the total bid cost. When computing the cost per area, the Flexogrid overlay with the spray system cost $19.95/ft$^2$ ($214.74/m^2$). With the spray system omitted from the tabulations, the cost per square foot goes down to $6.58/ft^2$ ($70.83/m^2$). This is a much more reasonable cost compared to other thin bonded overlays (13; 14; 15); however, the Flexogrid without the spray system is only an anti-skid overlay without anti-icing properties. The
cost of the overlay itself is on the high side of what other state DOT's have reported for installing Flexogrid, but still a typical price for a thin bonded overlay.

Comparing the cost between each site shows that Flexogrid, without the spray system, is by far the cheapest of the overlays. Flexogrid is about 30% cheaper than SafeLane if the spray system is omitted from the cost calculations. The biggest difference between the two seems to be the material cost, which is quite high for the SafeLane overlay.

CONCLUSIONS

Two thin-bonded epoxy overlays were examined for the protection of Colorado bridge decks. One product, SafeLane, is an anti-icing/anti-skid overlay. The other product, Flexogrid is an anti-skid overlay. The durability of these two overlays were evaluated based on texture depth, surface friction, and bond strength. Protective ability was measured through chloride content before and after installation. Traffic safety was evaluated from crash data and installation cost was calculated to determine which overlay provided the best protection per surface area. Future testing should be performed to evaluate the long-term performance of these overlays. A summary of the results from this study are presented below.

- SafeLane was shown to have a high initial mean texture depth that dropped approximately 50% in the first year and then leveling out. Flexogrid has only one set of MTD measurements, and thus will require further testing in the future to determine a wearing pattern over the lifespan of the overlay.
- The SafeLane installation on Parker Rd./I-225 is showing very good skid numbers with both ribbed and smooth tires, even after 1 year of service. The Flexogrid overlay showed similar results, although lower smooth tire skid numbers were recorded, which is typical of most wearing surfaces.
- All bond test failures on Parker Rd./I-225 occurred in the concrete substrate and were above 250 psi (1.72 MPa). The results from Flexogrid were mixed with two tests failing at the overlay / substrate interface, and one failing at the overlay interface. Additional testing of bond strength should be performed on the Flexogrid overlay to confirm the results.
- Chloride content at both sites has decreased since the installation of the overlays. This indicates that the overlays are protecting the bridge decks by sealing it from moisture.
- Anecdotal and photographic evidence seems to suggest that both sites are offering anti-icing capabilities via the passive abilities of SafeLane, and the active ability of the ESI spray system.
- Weather related traffic accidents have decreased for both sites; however, additional and prolonged post-installation data needs to be gathered before any final conclusions can be made.
- Installation cost for SafeLane was high, but similar to the results reported by other DOTs. The cost for the Flexogrid overlay was similar to other DOTs and lower than the SafeLane overlay if the spray system is not included in the cost. If the spray system is included in installation cost, the price increased to approximately double that of the SafeLane overlay.
ACKNOWLEDGEMENTS
The authors wish to thank the Colorado Department of Transportation for funding this research, as well as the numerous CDOT personnel who have provided assistance with the installation and testing of the overlays.

REFERENCES