

Evaluation of Tyregrip® High-Friction Surfacing -- Final Report

WA-RD 788.2

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Experimental Feature Report

Final Report

Experimental Feature 10-02

Evaluation of Tyregrip® High-Friction Surfacing – Final Report

SR-14

SE 164th Ave Interchange

MP 7.93

014 S2 00794 Ramp

SE 164th Ave Southbound to SR 14 Westbound



Engineering and Regional Operations
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Introduction

The ramp carrying southbound traffic from SE 164th Avenue to westbound SR 14 has recorded 27 collisions in three years. Traffic on SE 164th Avenue travels down hill before entering the sharp horizontal curve of the ramp that merging onto SR 14. Warning signs were installed to alert motorists to the hazard, but there continued to be a high occurrence of collisions. The majority of the collisions involved a single vehicle and 20 of the 27 occurred during wet weather. Increasing the frictional properties of the pavement was proposed as a possible solution to the problem given the ramp geometry and single vehicle wet condition collisions that are occurring.

There are several ways to increase friction on a hot-mix asphalt (HMA) pavement. These include replacing the pavement, placing a surface treatment such as a chip seal or grooving the pavement by diamond grinding. The chip seal is not a good option for this location due to the potential for the loss of aggregate from the sharp turning motions of vehicles on the ramp. All of these methods are costly and the existing HMA pavement is only 15 years old and not due for rehabilitation until 2027. A less costly solution would be to install a thin, high-friction surface over the existing pavement.

Tyregrip® is one of a number of high-friction surface treatment (HFST) systems that many state DOT's have used with some success. Tyregrip® is a resurfacing system that consists of a two-part epoxy resin top dressed with calcined bauxite aggregate. Calcined bauxite is produced by heating bauxite to 1000 to 1200°C to drive off moisture, thereby increasing the alumina content. The aggregate produced is durable and provides a high friction surface.

This is the first use of Tyregrip® by WSDOT and this experimental feature will document the construction and performance of this system for a minimum of five years.

Literature Review

A number of states including WSDOT used thin polymer overlay systems as waterproof membranes on bridge decks in the 1980's and 1990's. The overlays consisted of epoxy resin or methyl methacrylate binders top dressed with small sized aggregates. The aggregates were generally selected for their durability and not necessarily for their frictional properties although

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the overlays tended to have good friction resistance. The purpose of the overlays was to prevent the intrusion of deicing salts into the deck, which corrode the embedded steel reinforcement.

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WSDOT placed 61 thin polymer bridge deck overlays in the late 1980's and early 1990's (Wilson et.al., 1995). Sixty percent of the applications used methyl methacrylate (MMA) binders and the remainder epoxy resin binders. Performance was evaluated on 23 of the overlays (13 MMA's and 10 epoxy resin) with friction tests using an ASTM E-274 tester with a ribbed tire. The friction test results spanned a monitoring period of 2 to 8 years with the average being 5.6 years. Initial friction numbers right after application averaged 48 for the MMA systems and 59 for the epoxy resin systems. Friction numbers at the end of the various evaluation periods averaged 40 for the MMA's and 31 for the epoxy systems. The average friction number for six of the ten epoxy overlays were in the 16 to 22 range with individual tests as low as 13 (ice has a friction number of 10). The low friction results were due to the loss of aggregate from the epoxy binder. As a result, WSDOT changed the specifications to use a higher rate of 1/2 inch aggregate (two types of aggregate were used, 5/8 inch to 1/2 inch and No. 6 to No. 10). The report indicates construction problems were significant on a number of bridges. Debonding and spalling were also documented on completed overlays. Wear was not measured; however, the report states that most of the overlays would need to be redone every five to ten years, indicating wear was an issue.

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In 1999, the Wisconsin Department of Transportation installed Italgrip® at five locations. Four of the installations were on bridge decks that had high crash histories due to wet/icy roadway surface conditions and one was placed on a segment of highway that had a history of crashes due to the formation of black ice (Bischoff, 2008). Two additional installations were constructed on bridge decks in 2002. The Italgrip® system uses a two-part epoxy binder and steel slag aggregate. After five years, the friction numbers at the original five sites were 38 percent higher than the pre-installation friction numbers. There were 93 percent fewer crashes in the three years following the installation as compared to the three years prior to installation. After five or six years, the surface loss varied between six percent and 37 percent. Installation

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cost of the Italgrip® was \$13 per square yard but prices at the time of the report (2008) were in the \$16 to \$20 per square yard range. The report recommended that Italgrip® be considered for use in Wisconsin on short sections of roadway with high crash rates where low friction may be a problem.

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The Florida Department of Transportation studied the effectiveness of Tyregrip® at reducing crashes on a ramp to I-75 (Savolainen et.al, 2008). Tyregrip® (installed in 2006) increased the friction number from 35 prior to installation to 104 after installation as measured with an ASTM E-274 locked wheel friction tester using a ribbed tire. Insufficient crash data prevented the authors from making a significant conclusion regarding the efficiency of the overlay in reducing crashes. What was noted was that speeds decreased and drivers made fewer excursions onto the shoulders during wet weather conditions. It was theorized that the change in speed might be caused by drivers reacting to the different surface texture of the Tyregrip®. The reduction in wet weather encroachments was attributed to drivers being able to maintain lane position due to the higher friction provided by the Tyregrip®. No information was provided on the long-term durability of the Tyregrip®.

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The Federal Highway Administration (FHWA) created a national demonstration program in 2008 to promote HFST. The Surface Enhancements at Horizontal Curves (SEaHC) program provided assistance in site selection, installation and long-term measurements of friction and texture for a limited number of pilot states. As of March 2014 HFST had been installed in 10 states with a total of 23 installations. Information on the study is being compiled and reported by The Transtec Group, see web site at this link [SEaHC Program](#). Evaluations have been completed in Colorado (3 sites), Kansas (4 sites), Montana (2 sites) and North Carolina (1 site). On-going evaluations are taking place in Alabama (1), California (1), Iowa (2), Michigan (3), Texas (1), Utah (1), and Wisconsin (1).

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The Virginia Department of Transportation (VDOT) reported on the field performance of a number of HFST applications among them SafeLane® (Izeppi et.al, 2010). The SafeLane®

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system uses an epoxy binder and limestone aggregate. The study concluded, based on initial friction data, that the SafeLane® overlay can provide a skid-resistant wearing and protective system for bridge decks. However, the authors pointed out that the aggregates used in the SafeLane overlays in the study are no longer being used in SafeLane® overlays (A. Hensley, Cargill Incorporated, personal communication, August 2008). Therefore, future performance may vary because of the properties of the aggregates used in the overlay. No data was provided on the long-term durability of the SafeLane® overlay system.

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The Oregon Department of Transportation (ODOT) evaluated eight epoxy overlay systems on sixteen bridge decks with each system applied to two decks (Soltesz, 2010). All of the systems were applied in the summer of 2007. The 2010 final results showed that five of the overlays had worn through in small areas to the underlying bridge deck after as little as 1.3 million vehicles. One of the applications that wore through was Tyregrip®; however, it did maintain good friction values throughout the study.

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The Texas Department of Transportation conducted a study in 2012 to quantify the potential benefits of applying HFST's on curves (Brimley and Carlson, 2012). A literature search revealed that a 20 to 30 percent reduction of all crashes and a 50-percent reduction in wet-weather crashes could be reasonably expected for HFST applications. Targeting curves with high crash rates yields the most benefits. The report cites that the cost of a fatal crash is considered to be in excess of \$4,000,000; therefore, averting even one fatal crash has high economic benefits. The relative low cost of HFST applications can result in a return of 100 times the original investment. The authors recommend the use of HFST to reduce crashes and save lives.

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The Federal Highway Administration's Every Day Counts (EDC) initiative promotes the identification and use of innovations in three areas: (1) shortening project delivery, (2) enhancing safety, and (3) improving environmental sustainability. One focus area of the EDC-2 initiated in 2013-2014 was High Friction Surface Treatments (HFST). States are encouraged to develop and

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initiate plans to install HFST at locations that experience a high number of collisions or run off the road crashes. California, Kentucky and West Virginia are listed as case studies on the EDC website. Additional information on the EDC program can be found at this link: <http://www.fhwa.dot.gov/innovation/everydaycounts/edc-2/hfst.cfm> Brief descriptions of each state's HFST program are included below.

California

In 2011, the Caltrans Roadway Departure Safety Plan identified 179 locations and approximately 50 other locations where HFST has been or will be placed. Ten HFST locations have been treated to date with an additional 50 are planned. The end of on ramps and curves on two-lane roadways make up the majority of these applications. One case study involved an on-ramp, a primary exit point from the Los Angeles Airport, which was often closed during rain events to prevent expected crashes. Since Caltrans applied HFST to about 1,300 feet of the ramp, it has not been closed. The friction values before treatment averaged 32 and 60 after treatment.

Kentucky

The Kentucky Transportation Cabinet (KTC) has a program to use HFST on problem curves with high numbers of roadway departure crashes. The selection criteria calls for HFST using calcined bauxite for the aggregate on any half-mile roadway section having eight or more wet weather crashes over a 5-year period. One such case involved a roadway with a horizontal curve that experienced 53 wet weather and three dry weather crashes over a 3-year period (19.67 average crashes/year). After treatment, the roadway experienced five wet weather and no dry weather crashes over a period of 3.18 years (1.57 average crashes/year).

West Virginia

West Virginia initiated the application of HFST at locations that experience high numbers of run-off-the-road crashes. They are using a three-year before and after criteria to measure the success of the installation. At this time, several installations have been completed, but no crash statistics are available to evaluate the success of the HFST treatments.

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The National Center for Asphalt Technology (NCAT) published a report in 2015 that summarized the testing of alternative aggregate sources for HFST applications (Heitzman et al, 2015). The alternative aggregates tested were granite, flint, basalt, silica sand, steel slag, emery, and taconite. Laboratory and field studies using the NCAT test track did not find any of the aggregate sources to be equal to calcined bauxite with respect to friction. Two of the aggregates, granite and flint, along with calcined bauxite were installed on the test track. Locked wheel friction tester results over a 24 month period showed the bauxite dropping from 70 to 63, the granite dropping from 54 to 40 and the flint dropping from 54 to 43.

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A 2016 study was conducted by Wilson and Mukhopadhyay on the Florida Department of Transportation's (FDOT) program of installing HFST on tight curves and intersections. The program began in 2006 with a total of 47 individual HFST installations examined. The rate of total crashes was reduced by 32% and wet-weather crashes by an average of 75%. The average total unit cost of the HFST (including traffic control, repairs, striping, etc.) was between \$36 and \$113/yd². Seventy percent of the projects were in good and fair condition and 22 percent in poor and failed condition. The average locked wheel friction FN40R values for the in-service HFST sections were 73. The study found that HFST is a cost-effective treatment for tight curves with a history of crashes, but not cost-effective on wide curves/tangents with no history of crashes. The evidence was inconclusive on the effectiveness of HFST at intersections/approaches. With respect to the performance of the HFST, aggregate loss was the most prominent distress followed by uncured binder failure. The study is very comprehensive and is recommended for those interested in additional information.

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WSDOT's Northwest Region installed HFST on two on-ramps, one that moves traffic from 148th Avenue SE to westbound I-90 in Eastgate, and the other that moves traffic from SR 526 eastbound to I-5 southbound south of Everett. Kwik Bond's PPCTM HFST was installed at these two locations in June of 2015. Table 1 lists the crash statistics for the two locations. Wet surface collision rates were reduced by 93 to 96 percent for both sites. The pavement friction

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resistance for both sites increased from values in the high 30's to values in the low to middle 70's after installation.

Table 1. Before and after crash statistics for NWRegion HFST installations.

	5-Year Average July-June	July 2015- June 2016	Percent Reduction
148th Avenue SE			
All Collisions	25.6	3	88
Wet Surface Collisions	23.2	1	96
SR 526 Eastbound			
All Collisions	17.6	7	60
Wet Surface Collisions	13.8	1	93

In summary, the older information on the performance of Tyregrip® or other HFST applications was confined primarily to their use as waterproof membranes on bridge decks. The more recent information is focused on roadway applications to reduce run-off-the-road crashes and is much more pertinent to our study. FHWA's Every Day Counts initiative and Surface Enhancement at Horizontal Curves demonstration project have lead to many states becoming more involved in the use of HFST. Performance results are, in general, very positive on the reduction of crashes. Performance of the HFST overlays has been generally good, but there are problems cited with aggregate loss and various forms of cracking, delamination and other surface defects.

Project Objectives

The three objectives of the study are:

- To measure the long-term performance of the Tyregrip® overlay with respect to friction resistance, wear and aggregate retention.
- To measure any reduction in collisions.
- To develop a recommendation regarding the use of Tyregrip® on WSDOT roadways.

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Project Description

Tyregrip® was installed on the 014 S2 00793 Ramps (SE 164th Ave Southbound to SR 14 Westbound) at the approximate limits shown in Figure 1. SE 164th Avenue carries high volumes of traffic (17,000 AADT) from the southeast Vancouver area (Mill Plain) heading south to connect with SR-14 westbound toward downtown Vancouver and the junction of I-205. The length of the installation was 500 feet and the width 22 feet for a total of 1,200 square yards. Only the outside lane (Lane 2) and outside shoulder of the two lane ramp received the Tyregrip® treatment. The inside lane (Lane1) retained the original hot-mix asphalt (HMA) that also underlies the Tyregrip® overlay.



Figure 1. Approximate limits of Tyregrip® installation on SR 14 S2 00793 ramp.

Construction

The following sections of the report on the materials, equipment, and construction process used to place the Tyregrip® overlay.

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Materials/Equipment

Tyregrip®, as described previously, is composed of a two part epoxy based binder that spread on the roadway and then covered with aggregate. The aggregate is fractured 100 percent and is approximately No. 10 (2 mm) size material. For this project a machine application process was used which consists of a vehicle equipped with two feeder tanks (one for each epoxy component), a mixing unit, a spreader bar, and an aggregate storage system (Figure 2).



Figure 2. Vehicle used to mix and place epoxy binder and aggregates.

The feeder tanks hold a thermoset two part epoxy which, when mixed together, create the epoxy based binder. These components are mixed at a ratio of 1:1. Component A is slightly thicker than Component B and is mixed at a temperature of 105 °F while Component B is mixed at 95 °F during production (Figure 3).

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Figure 3. Temperature of Component A (left) and Component B (right) prior to production.

The mixed epoxy resin is then pumped through a series of hoses to the spreader bar (Figure 4). The 12-foot long spreader bar is vertically adjustable and is positioned approximately two inches from the pavement surface, which allows the epoxy binder to flow uniformly onto the pavement at a rate of approximately 12 gallons per foot of travel.



Figure 4. Supply hoses and spreader bar prior to production.

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Crushed bauxite aggregate is then dropped onto the extruded epoxy from a spreader box in a manner similar to that of a bituminous surface treatment. The aggregate is stored in a holding bin, which feeds the spreader box located on the back of the application vehicle (Figure 5). According to the equipment operator, the rate of aggregate application varies but they try to place it in a manner where the epoxy will not quite bleed through. Figure 6 shows the aggregate being dropped on top of the extruded epoxy binder.

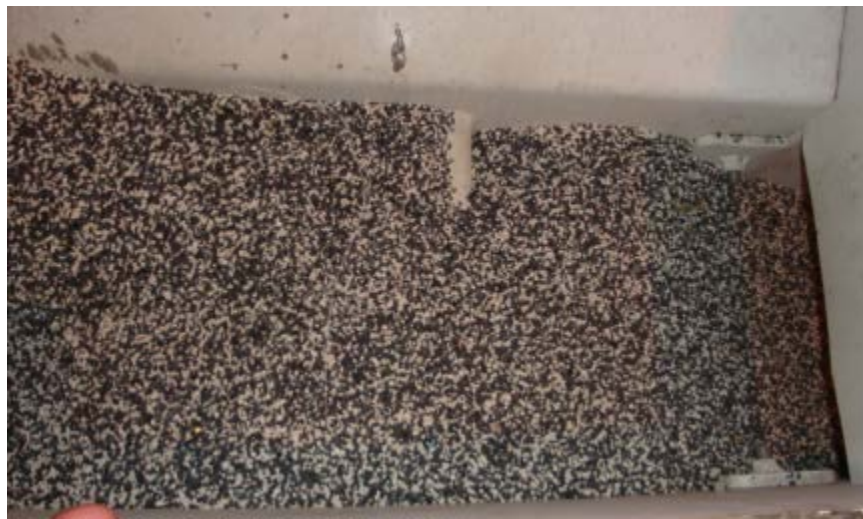


Figure 5. Aggregate in spreader box prior to production.



Figure 6. Aggregate dropping onto the extruded epoxy binder.

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First Application

The first application took place on the night of August 30, 2010. The pavement surface was cleaned using two passes of a broom/vacuum vehicle prior to the application of the overlay. Roofing tar paper was placed at the startup and finish locations of the installation to prevent material from sticking to the pavement and to ensure that the distribution of the epoxy was uniform across the spreader bar prior to starting the section. Figure 7 shows the initial epoxy binder being extruded from the spreader bar onto the roofing fabric.



Figure 7. Epoxy resin extruded from the spreader plate onto the roofing material at the startup location.

Distribution of the aggregate was slightly uneven at the start of the placement because the left side of the spreader box did not distribute sufficient aggregate to the left side of the lane. This was addressed by hand placing aggregate onto the epoxy binder. As the paving continued, distribution was rather consistent until there was a problem with the spreader that prevented placement of sufficient aggregate resulting in a rather large area not receiving enough aggregate material. Again, hand placement was needed and at this location, the aggregate was not as uniformly placed across the pavement surface. There were two other locations that required hand placement of the aggregate. Once all the equipment was operating correctly, placement of the aggregate on top of the epoxy binder was uniform. Figures 7 to 10 show the non-uniformity of the aggregate placement at various locations and Figure 11 an area with uniform aggregate

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placement. The plan was to place two lifts of material on the first night; however, due to problems with the equipment, the second lift was applied the following night.



Figure 8. Hand placement of aggregate at beginning of project.

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Figure 9. Location where aggregate spreader limited placement of material.



Figure 10. Streaking surface caused by inconsistency of the aggregate spreader.

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Figure 11. Illustration of uniform aggregate placement.

The second lift of the first application was placed on September 1, 2010. Figures 12 and 13 illustrate the condition of the surface prior to the second application of the Tyregrip®. The biggest problem with the first lift was the lack of aggregate coverage mainly at the beginning of the project. The remaining areas of insufficient aggregate cover resulted in only slight surface irregularities as shown in Figure 13.



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Figure 12. Startup location after first night placement.



Figure 13. Streaking in aggregate coverage.

Prior to placement of the second lift, the surface was again swept clean using the motorized broom/vacuum. Construction techniques were the same as the previous night. Rain between the two nights of construction resulted in the aggregate being substantially wetter than the first night. As a result, the aggregate flowed less freely out of the spreader box and the flow roller bar had to be continuously cleaned during placement. This resulted in streaks of epoxy binder, which needed to be covered with hand placed aggregate. This did not appear to have any adverse effect on the surface (the epoxy binder was completely covered).

Friction Test Results

Friction testing was performed on the pavement surface prior to and after the Tyregrip® application. The pre-application friction numbers for the entire outside lane of the ramp, taken on May 20, 2010, averaged 47.4 with a range of 43.2 to 52.0. These values are not indicative of a pavement with low friction resistance; however, sharp horizontal curves have a higher friction demand than straight and flat roadways. The current policy directive (Appendix A) regarding low friction numbers indicates that locations with values under 30 will be retested. Solutions will be implemented for locations with values less than 26 following guidance provided by the

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Manual of Uniform Traffic Control Devices (MUTCD). Location with values between 26 and 30 will be evaluated for possible solutions again based on guidance from the MUTCD such as signage. The Region tried signage to alert motorist of the change in alignment and advisor speed, but motorist continued to drive at speeds that resulted in losing control and leaving the roadway.

The post-application tests for the Tyregrip® performed on November 4, 2010, two months after the installation, averaged 54.1 with a range of 52.7 to 56.3. The friction numbers for the untreated portion of the ramp located before and after the Typrgrip® section averaged 44.1 with a range of 41.9 to 46.3. The modest increase in the friction numbers of the Tyregrip® section was very disappointing to the supplier and as a result, they requested that WSDOT allow them to apply another coat at no cost provided WSDOT would supply the lane closure traffic control.

Second Application

The second application occurred on May 18, 2011. Note: Total Highway Maintenance (THM) was the company that placed the first and second applications described previously. They were purchased by Interstate Road Management Corporation (IRM) and then DeAngelo Brothers Incorporated purchased and became the parent company of IRM. Therefore, Deangelo Brothers Incorporated placed the second application of Tyregrip®. DeAngelo Brothers Incorporated does bridge cleaning, street sweeping, graffiti removal, tunnel washing & high-pressure cleaning, line painting, durable markings, pavement marking removal, markers, parking lot maintenance and sign installation and replacement.

The equipment and procedures for applying the material were the same as the previous applications. As with the first application, two passes were required to cover the lane and shoulder. The spreader bar and hoses are detached after each pass and discarded. New hoses and spreader bar are then placed onto the application vehicle and paving resumes after placing roofing fabric as noted above. The process of removing and replacing the spreader bar and hoses took approximately 45 minutes when conducted in 2010. This process only took 10 minutes when done by employees of IRM.

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Two days prior to construction, the surface was cleaned using a broom/vacuum vehicle. On the night of installation, employees from IRM used a blower to remove excess debris from the roadway. When complete, roofing fabric was placed at the startup location of the roadway to collect errant material from coming in contact with the pavement and to ensure homogenous and even distribution of the epoxy.

At startup, distribution of the aggregate began a short distance after the start of the epoxy binder. This was addressed by hand placing aggregate onto the epoxy binder. Distribution of the aggregate was consistent throughout the remainder of the application, which was completed within approximately 15 minutes. The Supervisor for IRM mentioned that they target an application rate of approximately 47 ft/min. For this section the target rate was slightly less because the material was being installed on a downhill corner with a significant super elevation. Although the installation was slower than that typically targeted, it was substantially faster than the two prior placements. Figures 14 to 20 capture the essence of the construction sequence.



Figure 14. Tar paper placed at the start of the 500 foot test section.

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Figure 15. Application vehicle at start of the test section.



Figure 16. Calcined bauxite aggregate ready for distribution.

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Figure 17. Aggregate in spreader box prior to production.



Figure 18. Multiple hoses used to distribute epoxy binder from the mixer to the spreader.

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Figure 19. Aggregate being applied to epoxy after being placed on the pavement surface.



Figure 20. Close-up of spreader bar distributing epoxy binder and aggregate spreader dropping material on top of the epoxy.



Figure 21. Completed installation prior to the removal of the excess aggregate.

Friction Test Results

A second series of friction tests were run on May 31, 2011 to determine if the third application succeeded in increasing the friction resistance. The average friction number for the test section was 76.7 with a range of values from 75.7 to 79.3, a substantial increase over the measurements after the first and second applications.

The history of the friction results are summarized in Table 1. For the untreated section, the May 20, 2010 results are for the entire length of the ramp; the November 4, 2010 results taken after the first Tyregrip® application are on the untreated portion of the ramp; and the May 31, 2011 results taken after the second Tyregrip® application, are again on the untreated portion of the ramp. For the Tyregrip® section the November 4, 2010 results are for the first application and the May 31, 2011 for the second application

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Table 2. Summary of friction test results.

Location	Date	Average (FN)	Range (FN)
Untreated	May 20, 2010 (entire Lane 2)	47.4	43.2 – 52.0
	November 4, 2010 (portion of Lane 2)	44.1	42.0 – 46.3
	May 31, 2011 (portion of Lane 2)	44.5	38.3 – 47.9
Tyregrip®	November 4, 2010	54.1	52.7 – 56.3
	May 31, 2011	76.7	75.7 – 79.3

Cost

The bid price for the initial application was \$43,800 before tax (see Appendix B). The section was 500 feet long and 22 feet wide for a total of 1,200 square yards. The cost was therefore \$36.50 per square yard. The initial installation in 2010 was two lifts (75 mils, 13 lb/sy). The reinstallation in 2011 was only one lift (60 mils, 14 lb/sy). The cost is considerably higher than the Italgrip® used in Wisconsin, which was indicated to cost \$16 to \$20 per square yard in 2008, however, the WSDOT installation may not be representative due to its small size.

Discussion of Results

The first application did not run as smoothly as planned and as a result, a second application was needed in order to achieve the level of friction resistance promised by the supplier. This did not come as a surprise given WSDOT's experience with epoxy and methyl methacrylate bridge deck overlay systems. Overlay systems that use fast setting epoxy components are difficult to apply evenly. It is also difficult to get the correct amount and distribution of aggregates across the entire wetted surface of the binder. Inexperienced application personnel can result in applications that are not uniform leading to lower than expected friction resistance results. However, it appears that the second application had the equipment, materials and personnel needed to successfully achieve a uniform application with sufficient aggregate cover to provide an improved level of friction resistance for this ramp.

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Long-Term Performance

The performance of the Tyregrip® was evaluated using friction resistance measurements, visual observations, and crash reduction statistics as noted in the experimental feature work plan (see Appendix C).

Friction Resistance

The friction measurements recorded in Table 2 are on the Tyregrip® and adjacent untreated pavement beginning immediately after the second installation of the Tyregrip® and once per year for the five-year life of the overlay. A locked wheel skid tester and rib tire meeting ASTM E274-06 and ASTM E501-94 standards, respectively, was used to measure the friction resistance. The measurements are also shown in graphic form in Figure 22. The values were exceptionally high for the Tyregrip® from initial to the final readings in the low to high 70's.

Table 3. Friction resistance measurements. Values are friction numbers (FN) at 40 mph.

Lane	May 2011	Jan 2013	June 2013	May 2014	June 2015	May 2016
Lane 1	44.3	49.9	46.1	47.3	44.2	44.3
Lane 2*	44.5	54.1	46.4	47.2	46.9	45.1
Tyregrip®	76.7	77.9	72.8	71.1	74.7	73.9

*Only 500 feet of Lane 2 received the Tyregrip® treatment, therefore it was possible to measure the friction on the original pavement.

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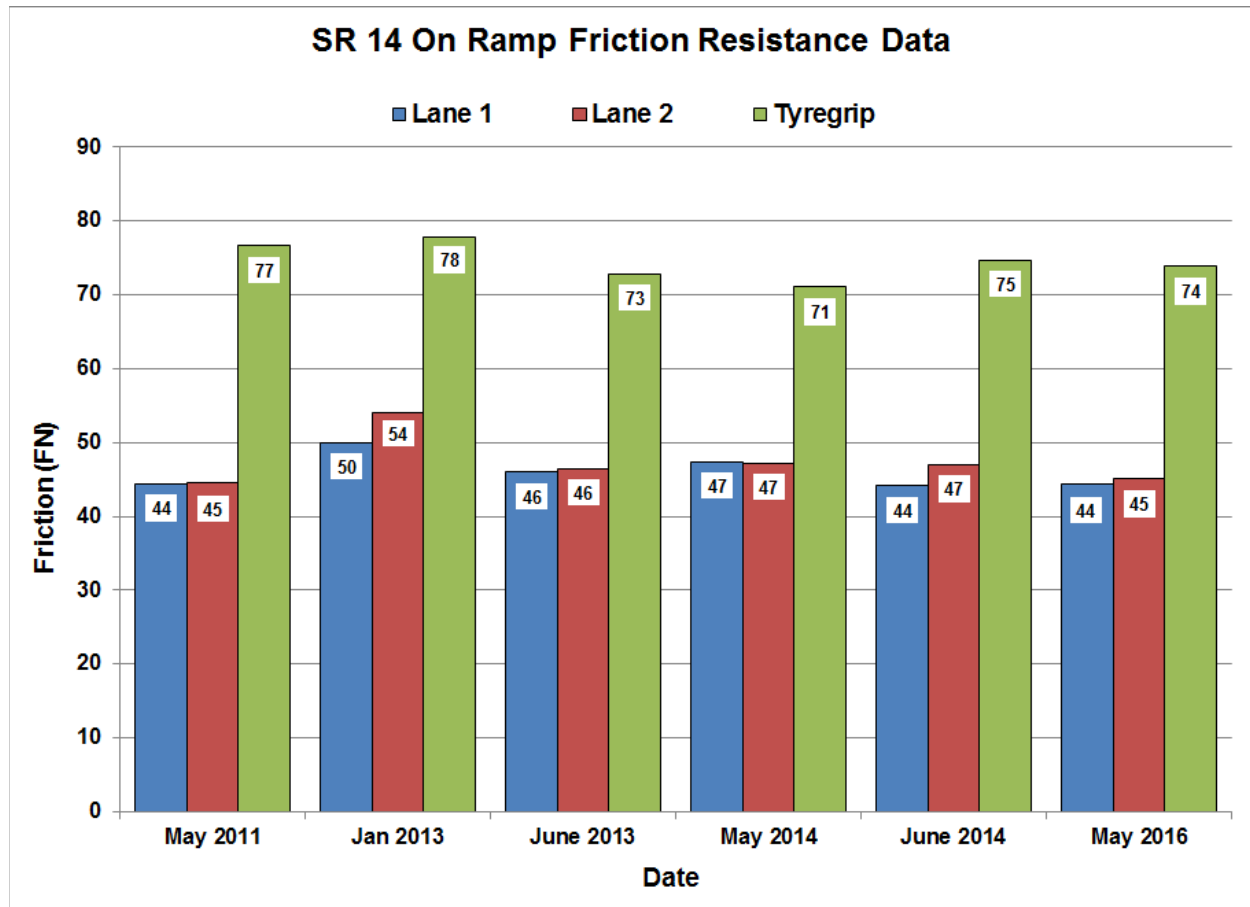


Figure 22. Friction resistance measurements, FN at 40 mph.

Visual Observation

Photographs were acquired immediately after installation, 2 years and five years after installation as shown in the following sets of figures. The photos show that cracking and delamination of the Tyregrip® overlay began in 2013, 2 years after installation, and increased significantly in severity and extent by the end of the five-year evaluation period.

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After Installation



Figure 23. Tyregrip® with excess aggregate on top.



Figure 24. Finished Tyregrip®.



Figure 25. Excess aggregate on overlay.



Figure 26. Streaky final product.

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Two Years After Installation



Figure 27. Longitudinal joint delamination.



Figure 28. Random delamination.



Figure 29. Longitudinal and transverse cracking and minor delamination.



Figure 30. Transverse crack and delamination.



Figure 31. Wheel path delamination.



Figure 32. Transverse crack.

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Five Years After Installation



Figure 33. Wheel path delamination.



Figure 34. Wheel path delamination.



Figure 35. Delamination across lane.



Figure 36. Delamination across lane.



Figure 37. Delamination and transverse crack.



Figure 38. Delamination close-up.

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Discussion of Tyregrip® Performance

The problems with cracking and delamination of the Tyregrip® may have been caused in part by the poor condition of the underlying pavement. A FHWA brochure on high friction surface treatments (HFST) indicates that they can be installed on both asphalt and concrete surfaces. The pavement must be in good structural condition with no or few cracks that are correctable by remedial sealing (FHWA, 2016). AASHTO PP 79-14, Standard Practice for High-Friction Surface Treatment for Asphalt and Concrete Pavements, recommends that all cracks greater than 1/4 inch in width and depth be filled with the mixed resin binder to be used for the overlay (AASHTO, 2016).

The delamination problem may also have been caused by placing the overlay on a pavement that was contaminated by oils dripping from vehicles. The Contractor used a broom/sweeper to clean the pavement prior to the installation of Tyregrip® on this project. AASHTO recommends that surfaces that are contaminated with oils, greases, or other deleterious materials be washed with a mild detergent solution, rinsed with clean water, and dried prior to a general cleaning with mechanical sweepers and high pressure air. There is no proof one way or the other regarding contamination but merely mentioned as a possibility.

The other possibilities are that the epoxy resin used in the process did not develop a sufficient bond with the underlying pavement. However, the Region reported that there was HMA sticking to the bottom of the HFST that was removed, which would indicate adequate bond.

The final possibility is that the HFST caused a shallow substrate failure in the underlying HMA (Wilson and Mukhopadhyay, 2016)¹. Wilson and Mukhopadhyay describe this type of failure can be in two modes: (1) top-down tearing, and (2) shallow horizontal tearing. Possible causes include; (1) HFST applied to an already weakened pavement, (2) the location has traffic that is stopping or making slow turns, (3) stress induced by temperature, and (4) a thick and stiff HFST application. Top-down tearing occurs when the HFST is applied to a weak pavement. The shear transfer from vehicles breaking and turning accelerates deterioration in the underlying

¹ A 14 page summary of this study entitled “High Friction Surface Treatment Guidelines” is available from the Florida Department of Transportation by contacting Charles Holzschuher at Charles.Holzschuher@dot.state.fl.us or by phone at 352-955-6341

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pavement resulting in shallow cracks. Shallow horizontal tearing (see Figure 39) can be caused by thermal incompatibility or stripping (moisture accumulation in the pavement)

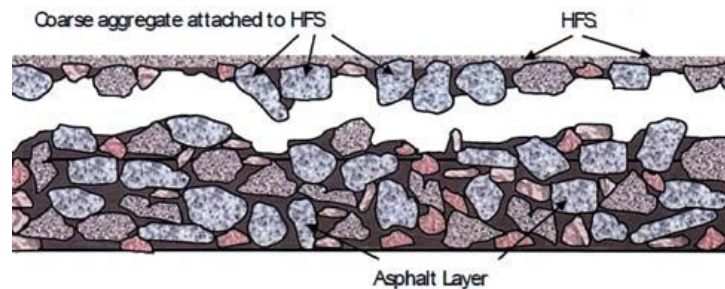


Figure 39. Shallow tearing (Wilson and Mukhopadhyay, 2016).

Crash Statistics

Before and after crash statistics for the on-ramp are listed in Table 3. The project was officially completed in May of 2011. Collision data for a five-year period before and after this date were used to compare the performance of the Tyregrip®.

Before

A total of 34 collisions were recorded in the five-year period before the installation. Seven of these resulted in evident or possible injury. Twenty-four of the 34 were run off the road type crashes that occurred on wet pavement. The other 10 crashes occurred mostly on dry pavement and included sideswipes and rear end collisions. Two of these 10 were also run off the road types; however, the drivers lost control on ice, which is not a type of crash that could have been prevented by a high friction surface treatment. In total, 71 percent (24 out of 34) of the collisions before the installation of Tyregrip® were vehicles losing control on wet pavement.

After

A total of 14 collisions were recorded in the five-year period after the installation. None of these collisions resulted in fatal or serious injury, and only one evident injury. Five of the crashes were run off the road collisions on wet pavement. Nine were merging and rear end

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collisions on dry pavement with one losing control on ice. In total, 36 percent (5 out of 14) were vehicles losing control on wet pavement.

Table 4. Crash statistics for the HFST on ramp.

164 th On-Ramp to WB SR 14	Run Off Road Wet Weather	All Others – Dry or Ice Roadway	All Injuries
Number of Crashes Before HFST	24	10	7
Number of Crashes After HFST	5	9	1
Percent Reduction	79	10	86

Note: Under Federal Law, 23 United States Code Section 409, reports, surveys, schedules, lists, or data compiled or collected for the purpose of identifying, evaluating, and planning for safety enhancements or for developing safety projects which may be implemented using Federal-aid highway funds shall not be subject to discovery or admitted into evidence in Federal or State court proceedings.

Summary

The before/after analysis showed that wet roadway crashes were reduced by 79 percent. The non-wet weather crashes remained relative unchanged with a decrease of only 10 percent. Crashes that resulted in injury were reduced by 86 percent.

Discussion of Results

The following are the primary results regarding the performance of the Tyregrip® HFST on this project.

- The frictional properties of the portion of the 164th to SR 14 WB on ramp treated with Tyregrip® were significantly increased and maintained throughout the five-year evaluation period of the study.
- The wet surface collision rate for the on ramp was reduced by 79 percent by the installation of the Tyregrip®.
- The Tyregrip® cracked and delaminated resulted in the loss of significant portions of the overlay during the five-year evaluation period.

Conclusion

Tyregrip® HFST is a viable solution for roadways that experience high numbers of run-off-the-road crashes.

Recommendations

The Tyregrip® demonstrated excellent performance in the reduction of wet surface collision rates and is recommended, along with other HFST products, for roadways with high rates of wet weather run-off-the-road crashes.

The cause of the cracking and delamination of the HFST has not been positively determined but the evidence points to a substrate failure caused either by the accumulation of moisture in the underlying HMA or high shear forces developing in the HMA from vehicle tires on the HFST's higher friction surface.

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References

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Appendix A

Skid Collision Reduction Program (with headers and footers deleted)

Skid Collision Reduction Program

I. Introduction

A. Purpose

This Policy Statement provides guidance for the use of pavement friction tests collected by the Pavement Branch of the State Materials Laboratory in Tumwater.

B. Supersession

This Policy Statement supersedes Interim Directive ID 55-77 Skid Collision Reduction Program dated September 29, 1994. All references to the superseded ID 55-77 now reference P 2035.00.

C. What Has Changed

Direction is reworded to be more concise and clear. Direction to employees remains the same.

II. Background

The October 5, 1992 amendment to the December 1991 federal aid Policy Guide Section 23 CFR 626.5 suggests that each state's skid collision reduction program should include, "...a systematic process to identify, analyze, and correct hazardous skid locations."

In literature on pavement friction tests and skid collision location identification, there are limited studies that suggest correlation between wet weather collision rates and skid numbers below 26. No studies suggest a correlation between wet weather collision rates and skid numbers at or above 26. This information was considered in the current Skid Collision Reduction Program.

The literature maintains that collision histories are the best indicators of the cause of wet weather collisions. Wet pavement collisions may be caused by complex interactions among many roadway, vehicle, human, and environmental factors. Collisions also may occur because of unpredictable factors and random variables such as unforeseen events or obstacles.

III. Policy Statement

It is the policy of the Washington State Department of Transportation (WSDOT) to minimize the risk of wet weather skidding collisions using the Skid Collision Reduction Program as follows.

IV. Information to Carry Out This Policy Statement

A. Test Pavement Friction Every Two Years

Pavement friction tests must be conducted on state routes every two years at one mile intervals to help identify potential skid collision locations.

1. Undivided roads are tested only in one direction.
2. Divided roads with fewer than three lanes are tested in both directions in the outer lane.
3. Divided roads with more than three lanes are tested in both directions in the second lane from the outside.

B. Identify and Rank Safety Needs

Use these two primary sources to identify and rank statewide safety needs.

1. Crash history analysis.
2. Roadway geometric/condition modeling that uses skid number assessment. Skid numbers are considered in the development of appropriate solutions to address both collision history and potential collision locations.

C. Locations with Skid Numbers at or Below 30

Locations with skid numbers at or below 30 must be retested promptly. These retests must be completed within the same calendar year and reported to regional authorities. Corrective actions may be required depending on analyses and site inspection.

D. State Materials Laboratory:

The State Materials Laboratory is responsible for the following.

1. Test pavement friction on a systematic basis (ASTM E-274-Rib Tire) throughout the state highway system on a two-year cycle.
2. Test newly constructed or overlaid pavement that is one lane mile or longer one month or more after completion before the construction season ends, unless prevented by weather conditions.
3. Retest locations with skid numbers at or below 30 promptly.
 - a. Retests consist of at least five friction tests taken within one quarter mile of the point of the skid number at or below 30.
 - b. Retests report the original low skid number.
 - c. Retests report the average of the five retests.
4. Provide the pavement friction test results to the Region Administrators.

E. Region Administrator

The Region Administrator is responsible for the following.

1. Manages the Skid Reduction Program within the Region to ensure compliance with this Policy Statement.
2. Provide the pavement friction test results to the Region Operations Engineer.
3. In the absence of the Region Operations Engineer designates a position to carry out those responsibilities, and inform the Assistant Secretary.

F. Regional Operations Engineer or Designee

The Region Operations Engineer or designee is responsible for the following.

1. Reviews friction test results.
2. Compare prior pavement friction test results at or below 30 with current friction test results. Determine whether or not adverse collision history has developed at these locations. If so, check whether or not improvements have been scheduled or completed.
3. Review pavement friction test results with skid numbers at or below 30 with the Region Maintenance Engineer and Region Traffic Engineer.
4. When tests reviews indicate it is needed coordinate construction improvements with the Region Maintenance Area Superintendent or with the Region Project Development Office.

G. Region Maintenance Area Superintendent

The Region Maintenance Area Superintendent is responsible for the following.

1. Conduct joint field reviews with the Region Traffic Engineer at each site that has skid numbers at or below 30.
2. Schedule construction of the appropriate surface treatment to improve skid resistance.
 - a. Use state forces or contract.
 - b. Inform the Region Operations Engineer or designee.
3. Remove any “Slippery When Wet” signs installed and inform the Region Traffic Engineer.

H. Regional Traffic Engineer

The Region Traffic Engineer is responsible for the following.

1. Conduct joint field reviews with the Region Maintenance Area Superintendent at each site that has skid numbers are or below 30.

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2. Analyze traffic data records to determine high or potentially high risk or wet weather collision rates in those areas with skid numbers at or below 30.
3. At locations where crash rates or roadway/roadside modeling indicates that a problem exists, recommend solutions either to the Region Operations Engineer or the Region Maintenance Areas Superintendent for correction.
4. Direct installation of “Slippery When Wet” signs, when needed, at sites with average skid numbers at or below 30.
5. Direct other immediate corrective action as needed.

I. Region Program Management

The Region Program Management Office is responsible to program suitable improvements at locations having a low skid number and a high collision rate, where maintenance has not yet made alterations.

V. Contact for More Information

For more information about this Policy Statement, please contact the Pavement Branch of the State Materials Laboratory at 360-709-5485

VI. Executive Review and Update Requirements

When changes are necessary to update this Policy Statement, please inform the Assistant Secretary for Engineering and Regional Operations.

The Assistant Secretary of Engineering and Regional Operations periodically reviews and updates this document.

Americans with Disabilities Act (ADA) Information

Materials can be provided in alternative formats by calling the ADA Compliance Manager at 360-705-7097. Persons who are deaf or hard of hearing may contact that number via the Washington Relay Service at 7-1-1.

Appendix B

Contract Execution Letter

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July 27, 2010

Total Highway Maintenance, LLC
930 KCK Way
Cedar Hill, TX 75104

RE: Agreement Number DD-353
SR 14 & 164th Avenue SB to WB On-Ramp
High Friction Surfacing
State Project
Clark County

Ladies & Gentlemen:

This is to inform you the contract for the above-referenced project was awarded to your firm at your bid price of \$43,800 before taxes. The Agreement was executed on July 27, 2010.

Per the Contract Provisions, the work shall commence no later than September 1, 2010.

Notify us about your planned work schedule in advance, so our traffic control crews can get ready.

If you have any questions, please contact Dave Burkey at (360)905-2262.

Sincerely,

Chad E. Hancock, P.E.
SW Region Traffic Engineer

CEH/js
Enclosure

cc: Roberta Funkhouser, SW Region Accounting

Appendix C

Experimental Feature Work Plan



Washington State Department of Transportation

WORK PLAN

Tyregrip® Evaluation

**State Route 14
SE 164th Ave Interchange
Milepost 7.93 to Milepost 8.90
014 S2 00793 Ramp
(SE 164th Ave Southbound to SR 14 Westbound)**

Mark A. Russell
Pavement Design Engineer
Washington State Department of Transportation

Experimental Feature Report

Introduction

The 014 S2 00793 ramp carries traffic merging onto westbound SR 14 from southbound SE 164th Ave. Traffic on the ramp must negotiate a curve to the right before merging onto SR 14. Twenty seven crashes in three years have been recorded on this curve making it a High Accident Location (HAL). To reduce crashes, WSDOT installed warning signs to alert motorists to the hazard but there is still a high occurrence of crashes. The majority of the crashes were single vehicle with 20 of the 27 occurring during wet weather. The ramp geometry and type of crashes indicate that increasing the pavement friction may reduce the number of crashes.

There are several methods to increase friction on an existing HMA pavement. These include replacing the pavement, placing a surface treatment such as a chip seal over the existing pavement or grooving the pavement by diamond grinding. These methods are costly and the existing HMA pavement on the ramp is not due for rehabilitation. A less costly solution is to install a thin high-friction laminate surface over the existing pavement.

One thin high-friction surface laminate material is ®. Tyregrip® is a thin polymer and aggregate surfacing material consisting of a highly modified two part epoxy resin. Tyregrip is usually top dressed with calcined bauxite, which is a durable aggregate that also has good friction characteristics. Other agencies have used Tyregrip® to improve friction but this will be the first use by WSDOT. This experimental feature will document the construction and performance of Tyregrip.

Scope

Tyregrip® will be installed on the 014 S2 00793 Ramp (SE 164th Ave Southbound to SR 14 Westbound) at the approximate limits shown in Figure 1. The length of the installation will be approximately 500 feet.

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Figure 1. Approximate limits of Tyregrip® installation on SR 14 S2 00793 ramp.

Staffing

This installation will be constructed as a Southwest Region Traffic Operations project. Therefore, the Region Traffic office will coordinate and manage all construction aspects. Representatives from and WSDOT Materials Laboratory (1 – 2 people) will also be involved with the process.

Contacts and Report Author

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Mark Russell
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Washington State DOT
(360) 709-5479
russelm@wsdot.wa.gov

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Testing

Pavement performance will be monitored by the following methods:

- Friction will be measured before and after construction then annually.
- Crash data will be gathered by the Southwest Region Traffic Office

Reporting

A “Post Construction Report” will be written following completion of the test section. This report will include construction details, cost of the treatment, construction test results, and other details concerning the overall process. Annual summaries will also be conducted over the next five years. At the end of the five-year period, a final report will be written which summarizes the performance characteristics, effectiveness at reducing crashes and future recommendations for use of this process.

Cost Estimate

CONSTRUCTION COSTS

No additional construction costs are required. This project will be constructed as a Region HAL enhancement (Q2 program) project.

TESTING COSTS

Pre-construction friction testing will be conducted as part of the Region Q program project (estimated cost \$2,500). Post construction testing will be conducted in conjunction with scheduled post construction testing of HMA preservation projects.

REPORT WRITING COSTS

Initial Report – 16 hours = \$1,600

Annual Report – 5 hours (1 hour each) = \$500

Final Report – 32 hours = \$3,200

TOTAL COST = \$10,300

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Schedule

Construction: June – July 2010

Date	Friction (Annual)	Post Construction Report	Annual Report	Final Report
Spring 2010	X			
Fall 2010	X	X		
Fall 2011	X		X	
Fall 2012	X		X	
Fall 2013	X		X	
Fall 2014	X		X	
Spring 2015				X

Americans with Disabilities Act (ADA) Information:

This material can be made available in an alternate format by emailing the Office of Equal Opportunity at wsdotada@wsdot.wa.gov or by calling toll free, 855-362-4ADA(4232). Persons who are deaf or hard of hearing may make a request by calling the Washington State Relay at 711.

Title VI Statement to Public:

It is the Washington State Department of Transportation's (WSDOT) policy to assure that no person shall, on the grounds of race, color, national origin or sex, as provided by Title VI of the Civil Rights Act of 1964, be excluded from participation in, be denied the benefits of, or be otherwise discriminated against under any of its federally funded programs and activities. Any person who believes his/her Title VI protection has been violated, may file a complaint with WSDOT's Office of Equal Opportunity (OEO). For additional information regarding Title VI complaint procedures and/or information regarding our non-discrimination obligations, please contact OEO's Title VI Coordinator at (360) 705-7082.
