REPORT NUMBER: WI-04-08

INVESTIGATIVE STUDY OF THE ITALGRIP™ SYSTEM

FINAL REPORT

SEPTEMBER 2008

Technical Report Documentation Page

1. Report No.
WI-04-08

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Investigative Study of the Italgrip™ System

5. Report Date
September 2008

6. Performing Organization Code
WisDOT Research Study # WI-99-01

7. Author(s)
Deb Bischoff, P.E.
WisDOT Pavement Policy & Design Engineer

8. Performing Organization Report No.
WisDOT Report # WI-04-08

9. Performing Organization Name and Address
Wisconsin Department of Transportation
Division of Transportation System Development
Bureau of Technical Services
Materials Management Section / Foundation & Pavements Unit
3502 Kinsman Blvd., Madison, WI 53704-2507

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
SPR #0092-00-20

12. Sponsoring Agency Name and Address
Wisconsin Department of Transportation
Division of Transportation System Development
Bureau of Technical Services
Materials Management Section / Foundation & Pavements Unit
3502 Kinsman Blvd., Madison, WI 53704-2507

13. Type of Report and Period Covered
Final Report, 1999-2005

14. Sponsoring Agency Code
WisDOT Research Study # WI-99-01

15. Supplementary Notes

16. Abstract

A research study was conducted by WisDOT to evaluate the performance of the Italgrip™ System, a pavement surface treatment designed to improve the frictional characteristics of a pavement. In 1999, Italgrip™ was installed at five locations in two different counties (La Crosse and Waukesha) in Wisconsin.

The overall performance of the Italgrip™ System was evaluated based on five main parameters: freeze-thaw durability, frictional charcteristics, accident statistics, noise characteristics, and visual inspections (in-situ performance).

The results of the research revealed that the Italgrip™ System showed good durability and held up well to the freeze-thaw testing. The friction number of the pavement surfaces improved considerably directly after placement of Italgrip™. After five years in service, the friction numbers decreased but were still considerably higher than before the Italgrip™ was placed. The Italgrip™ System also significantly reduced the number of accidents/incidents at all of the sites. Noise testing revealed that the Italgrip™ System reduced noise levels an additional one-decibel when compared to the ground concrete pavement. Annual visual inspections showed that there was progressive aggregate surface loss at the sites due to traffic and snowplow blades. The cost of the product was within the price range of comparable products in the market.

Based on the results of the study, the Italgrip™ System is recommended to be considered for short sections of roadways with high accident rates where pavement characteristics impacting friction, especially under wet or icy conditions, may be a factor.

17. Key Words
Italgrip, skid resistance, pavement surface treatment, epoxy overlay
chip seal, friction course, macro-texture, anti-skid treatment

18. Distribution Statement
Distribution Unlimited
Authorized for Public Release

19. Security Classification (of this report)
Unclassified

20. Security Classification (of this page)
Unclassified

21. No. of Pages

22. Price

INVESTIGATIVE STUDY OF THE ITALGRIP^{TM} SYSTEM

FINAL REPORT

WisDOT Research Study # WI-99-01
SPR # 0092-00-20

Final Report # WI-04-08

By:

Deb Bischoff, P.E.
WisDOT Pavement Policy & Design Engineer

Wisconsin Department of Transportation
Division of Transportation System Development
Bureau of Technical Services
Materials Management Section
Foundation and Pavements Unit
3502 Kinsman Blvd.
Madison, WI 53704

September 2008

This study was conducted by the Foundation & Pavements Unit of the Wisconsin Department of Transportation, Division of Transportation System Development, Bureau of Technical Services, Materials Management Section. The Federal Highway Administration provided financial and technical assistance for this research project. This publication does not endorse or approve any commercial product even though trade names may be cited, does not necessarily reflect official views or policies of the agency, and does not constitute a standard, specification or regulation.

TABLE OF CONTENTS

INTRODUCTION

The climatic conditions in Wisconsin present severe problems for pavements and motorists alike. The wet/freeze seasons, particularly, can cause slippery pavement surfaces and adverse driving conditions. Wet or icy road surfaces are quite common in Wisconsin and occur on both hot mix asphalt (HMA) and concrete pavements. These conditions are most prevalent in certain areas such as on bridge decks, curves, ramps, intersections, sag vertical curves, and through wetlands. Poor frictional characteristics of roadways can enhance these problems.

Adverse driving conditions are earnest concerns for Wisconsin Department of Transportation (WisDOT) engineers, and are currently addressed through design, construction and maintenance efforts. However, innovative improvement techniques are continuously sought after.

In 1999, WisDOT initiated a research study to evaluate the performance of Italgrip™, a pavement surface treatment with exceptional macro-texture designed to improve the frictional characteristics of a pavement surface.

BACKGROUND

The Italgrip™ System, manufactured by Italgrip USA, Inc., is a friction enhancing pavement surface treatment classified as an ultra-thin polymer concrete. It consists of a two-part polymer resin that is sprayed on the pavement surface and covered with a man-made aggregate of re-worked steel slag, three to four millimeters in size. The Italgrip™ System can be placed on either HMA and concrete pavements, or even metal surfaces.

Italgrip™ has been used on the Autostrade and other primary highways in North and Central Italy (including the Italian Alps) for over fifteen years. The installations are on both asphaltic and concrete surfaces and have shown very favorable results. As reported by the Highway Innovative Technology Evaluation Center (HITEC), an independent organization under the American Society of Civil Engineers' (ASCE's) Civil Engineering Research Foundation (CERF), Autostrade S.p.A., an Italian highway agency, confirmed a fifty percent reduction in the number of accidents at the Italgrip™ sites [1]. Further information on this topic is provided later in this report under "Accident Analysis."

The Italgrip™ System had never before been used in the United States, but is currently being evaluated by a HITEC panel [2]. In a cooperative effort with HITEC and the Federal Highway Administration (FHWA), three states (Wisconsin, Virginia, and New Jersey) agreed to test and evaluate the Italgrip™ System. As previously stated, WisDOT's specific evaluation of the Italgrip™ System began in 1999.

RESEARCH STUDY DESCRIPTION

The primary objective of this study was to determine if Italgrip™ is a suitable, durable, and cost-effective technique to enhance the safety and/or drainage characteristics of Wisconsin's roadways.

The potential benefits as reported in product literature [3] include:

- Enhanced friction (anti-skid) characteristics
- Reduction in accident rates
- Better performance and greater durability than current techniques
- Minimal traffic/construction delays
- Improved drainage capacity and reduced hydroplaning risks
- Waterproofing benefits
- Reduced braking distance
- Minimal layer thickness, thus requiring no road, curb, or shoulder grade adjustments
- Reduction in salt usage
- Noise reduction
- Improved night visibility/retroreflectivity
- Chemical resistance (e.g. salt, petroleum products)
- Low weight
- Recycling of steel slag (an industrial by-product)

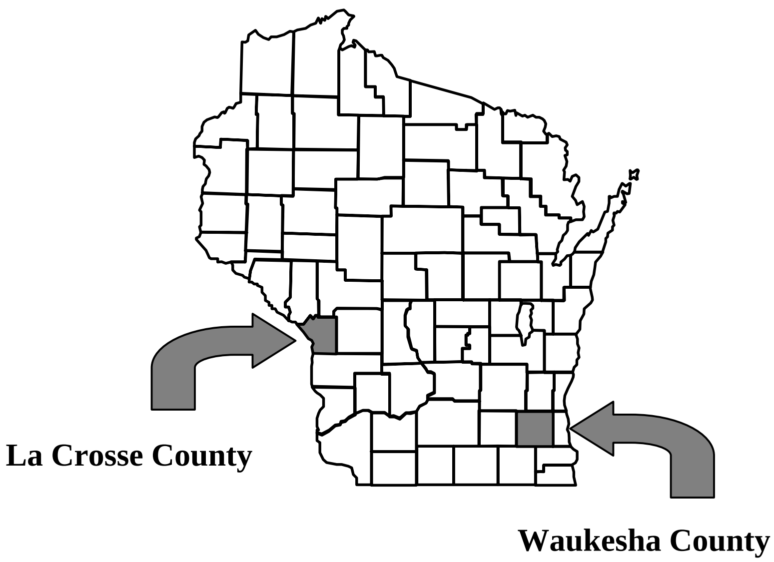
PERFORMANCE PARAMETERS

The overall performance of this product was evaluated based on five key parameters, including freeze-thaw durability, friction, accident statistics, noise characteristics, and surface integrity.

TEST SITES

Italgrip™ was installed at five different locations in Wisconsin. Although Italgrip™ can be applied to HMA or concrete pavements, all five test locations in Wisconsin consisted of concrete pavements. As illustrated in Figure 1, the five test sites were located in La Crosse and Waukesha counties.

Figure 1. Italgrip™ Test Sites



The first four test sites were all located on bridge decks in La Crosse County. All four structures had histories of high accident rates due to wet and/or icy pavement surfaces. See Figure A-1 in Appendix A for a map of the La Crosse County test sites. The fifth project site was located on State Trunk Highway (STH) 16 in Waukesha County, Wisconsin. This section of pavement is in a cut area and also had a history of accidents due to severe problems with black ice. See Figure A-2 in Appendix A for a map of the Waukesha County test site. The specifics of each test site are as follows:

Site 1: Structure B-32-0079 - Hunter's Bridge
USH 53 over the Black River
Concrete deck on pre-stressed concrete girders; built in 1982
Two-lane highway carrying two-way (NB & SB) traffic
Italgrip™ placed in both lanes and shoulders; 4 mm aggregate

Site 2: Structure B-32-0067 - Nutbush Bridge
STH 35 over the BNRR tracks
Concrete deck on steel girders; built in 1967; new concrete deck placed in 1992
Two NB traffic lanes
Italgrip™ placed in both lanes; 4 mm aggregate

Site 3: B-32-0111 - Medary Overhead (companion structure to B-32-0115)
WB on STH 16 over the CMSP & PRR tracks
Concrete deck on steel girders; built in 1986
Two WB traffic lanes
Italgrip™ placed in both lanes; 4 mm aggregate

Site 4: B-32-0115 - Medary Overhead (companion structure to B-32-0111)
EB on STH 16 over the CMSP & PRR tracks
Concrete deck on steel deck girder floor system; built in 1937
New concrete deck placed in 1986
Two EB traffic lanes
Italgrip™ placed in both lanes; 4 mm aggregate

Site 5: STH 16, under County JJ, in Waukesha County
Four-lane divided highway
Italgrip™ placed in all four lanes
Two EB lanes with 3 mm aggregate
Two WB lanes with 4 mm aggregate

CONSTRUCTION PROCESS

WisDOT became the first agency in the United States to install the Italgrip™ System. The Italgrip™ application process involved several steps. First, the existing pavement was swept to remove any existing debris from the surface. Secondly, the two-part polymer resin was sprayed onto the pavement surface with a special piece of equipment provided by Italgrip USA (see Photograph 1). The resin was applied in a side-to-side repetitive sweeping motion. The exact amount of resin applied varied based on pavement surface characteristics. The resin was green in color and can be seen in Photograph 2. Immediately after the resin was sprayed on the surface, the steel slag was applied

Photo 1: Italgrip™ resin applicator

using a typical chip spreader. Lastly, after the resin was completely dry and hard (Italgrip™ specifications stipulate an eight-hour curing period, or the minimum cure, which is temperature dependent and usually varies from three to ten hours), the excess aggregate was removed from the pavement surface with a vacuum sweeper. After sweeping was competed, the site was opened to traffic.

Photo 2: Italgrip® resin before and after aggregate application

The spray truck and the re-worked steel slag were shipped from Italy for the Wisconsin applications of the Italgrip™ System. The two-part polymer resin was made in Wisconsin by a local company. Italgrip USA personnel operated the spray truck and the on-board computer system that controlled the formulation of the resin. The vacuum sweeper and the chip spreader were provided by La Crosse and Walworth counties and were operated by county personnel.

Prior to the Italgrip™ installations, pull-off tests, in accordance with ASTM C 1583 [4], were conducted by Italgrip USA personnel on the prepared concrete surfaces to determine the near-surface tensile strengths of the existing pavement structures. The results at all sites were acceptable and showed concrete tensile strengths greater than 250 psi, meeting the minimum requirements per Italgrip™ specifications.

La Crosse County Application

The Italgrip™ application in La Crosse County began on September 22, 1999. The northbound lane of Hunter's Bridge (USH 53) and one of the northbound lanes of the Nutbush Bridge (STH 35) were completed that day. On September 23, 1999, the southbound lane of Hunter's Bridge and the other northbound lane of the Nutbush Bridge were completed. The work on the remaining two structures on STH 16 was completed in three additional workdays. On September 30th, Italgrip™ was applied to the shoulders of Hunter's Bridge, completing the work in La Crosse County. Thus, the Italgrip™ application process took a total of six workdays to complete all four structures.

Hunter's Bridge

The mean ambient temperature on September 22nd, the first day of the Italgrip™ application, was 57° F, with low and high temperatures for the day of 45° F and 77° F, respectively. The viscosity of the two-part epoxy resin was adjusted for the slightly cool temperature. The epoxy resin temperature was 131° F at the time of application. The epoxy was sprayed in a sweeping motion. Resin pooling in the tining of the pavement surface raised concerns that there was not enough resin on top of the tining for proper adhesion of the aggregate, so the speed of application was slowed. The application rate of the epoxy and the aggregate was approximately 10 feet per minute or 600 feet per hour. Any spot on the pavement surface was subjected to about eight passes of the epoxy (four passes in each direction). A total of 2,800 pounds of resin was used in the northbound lane. The northbound lane of Hunter's Bridge, which was 580 feet long, was completed in one hour with the exception of the final sweeping. The sweeping was completed 8½ hours after the application process began.

Average ambient temperatures during the six workdays of the La Crosse County Italgrip™ applications ranged between 53° F and 63° F, with lows ranging from 43° F to 52° F and highs between 63° F and 79° F. Four-millimeter re-worked steel slag was used on all four structures. The Italgrip™ System was applied to a total area of about 10,200 yd^2 for the four structures.

Waukesha County Application

Work on STH 16 began with repairing the deteriorated joints with full-depth doweled concrete patches. Afterwards, the pavement was diamond ground to restore the ride. The Italgrip™ was applied on STH 16 between the on and off ramps to County Trunk Highway (CTH) JJ. The Italgrip™ application began on October 11, 1999; two lanes (one lane in each direction) were completed that day. The other two lanes of STH 16 were completed the next day. Average ambient temperatures during the two days in Waukesha County were 52° F and 58° F. The lows over the two days ranged from 43° F to 46° F and the highs ranged from 64° F to 73° F. Four-millimeter aggregate was used on the westbound lanes, while three-millimeter aggregate was used on the eastbound lanes. The total area of the Italgrip™ applied at this site was 14,911 yd^2 (6,986 yd^2 in the westbound lanes and 7,925 yd^2 in the eastbound lanes).

CONSTRUCTION OBSERVATIONS

Construction operations went smoothly with just a couple minor setbacks. During the first application on Hunter's Bridge, there were problems with the spray nozzle getting clogged. This issue was related to the temperature of the polymer resin and was overcome by heating the polymer to a higher temperature. At the Waukesha County project site, complications were encountered on the first morning of the Italgrip™

application. The fuel pump and the epoxy heater were not working properly. The fuel pump's shaft was bent and was taken to the Waukesha County shop to straighten out. It was straightened adequately to complete the Waukesha application, but was replaced by another shaft (sent from Italy) at a later date. The fuel injector of the epoxy heater was also not working, and was replaced with a new one that was obtained from a local automotive parts store. Although these complications slightly delayed construction operations, due to the knowledgeable Italgrip USA technical representative who was operating the spray truck, they were overcome without too much difficulty.

ADDITIONAL ITALGRIP™ APPLICATIONS

In October 2002, three years after the original Wisconsin applications were completed, WisDOT used the Italgrip™ System at two additional locations in Waukesha County. The first location was on a STH 16 bridge that crosses over I-94. The second location consisted of four bridges (two eastbound structures and two westbound structures) on I-94 that span over the Fox River, the Wisconsin Central Railroad, and the Chicago, Milwaukee, St. Paul and Pacific Railroad. This section of I-94 is a six-lane divided highway, just east of CTH F.

The Italgrip™ was placed on the four I-94 bridges on October 11th through the 13th during temperatures that were forecast to be favorable for proper curing, but never materialized. The first day of application, October 11th, reached a high of 72º F, but the temperatures dropped from there, with a mean temperature of 56º F for the day and a low temperature of 45º F. The mean temperatures over the next two days were 58º F and 45º F, with lows ranging from 37º F to 54º F and the highs ranging from 52º F to 70º F.

This application was not part of this research study, so was not monitored accordingly. However, soon after application it became evident that the site was experiencing a significant loss of the Italgrip™ aggregate. The surface aggregate loss was determined to be due to the cooler average temperatures during application, coupled with the fact that the road could only be kept closed for twelve hours because of the high volume of traffic at this site. Thus, the epoxy resin had not sufficiently cured before allowing traffic back onto the pavement.

The Italgrip™ System specifications at that time indicated a minimum ambient air temperature of 55º F [5]. After the poor results of I-94 became apparent, an Italgrip™ representative acknowledged that a minimum pavement surface temperature and ambient air temperature of 60º F and rising during construction is imperative for proper curing; their specifications were later revised accordingly [6]. The representative affirmed that with enough lead-time, the characteristics of the Italgrip™ resin could be engineered to allow for a faster or slower cure time to account for the effects of temperature ranges. Thus, construction could occur during ambient temperatures as low as 50º F, but would require one or more of the following modifications to typical procedures: (1) road closure for a longer period of time, (2) adding accelerant to the epoxy resin, (3) heating the aggregate, and/or (4) heating the polymer to a higher temperature. In July 2004, Italgrip USA repaired the I-94 site by applying another course of Italgrip™ over the worst sections (100 percent of the middle lanes and about 80 percent of the inside lanes in both directions) at no cost to WisDOT.

PERFORMANCE RESULTS

The effectiveness and overall performance of the Italgrip™ System was evaluated based on five main parameters: (1) freeze-thaw testing, (2) friction testing, (3) accident analysis, (4) noise measurements, and (5) surface loss.

Freeze-Thaw Testing

Freeze-thaw testing, in accordance with ASTM C 666 [7], is typically performed on concrete samples to determine its resistance to rapid freezing and thawing cycles. Thus, unconfined freeze-thaw testing was conducted at the WisDOT Truax Center laboratory to determine the Italgrip™ System's resistance to freezing and thawing on concrete and HMA samples with and without the Italgrip™ System on the surface. Nine rectangular prisms were cast out of standard concrete and four out of HMA. After the samples were properly cured, the tops of six of the concrete samples and three of the HMA samples were sprayed with the Italgrip™ polymer resin and then covered with the reworked steel slag. All samples were weighed before and after the Italgrip™ surface application, and prior to any testing.

All thirteen samples were placed in metal containers with open tops and filled with a five percent sodium chloride solution. The metal containers were then placed in a freeze-thaw chamber and all samples were subjected to a total of 300 freezing and thawing cycles. The chamber was stopped after 175 cycles and at the completion of 300 cycles to weigh the specimens and determine their loss in mass. Any loss of concrete or HMA was separated from the Italgrip™ aggregate and weighed independently. The percentage of Italgrip™ loss was calculated by dividing the weight loss of the Italgrip™ coating by the average initial weight of the coating. The percentage of Italgrip™ loss for each individual sample after 300 freeze-thaw cycles, along with the average losses, are shown in Table 1. The complete freeze-thaw test data is located in Appendix B.

Table 1. Italgrip^{TM} Loss After 300 Freeze-Thaw Cycles

Sample	% Italgrip Loss
Italgrip on Concrete #1	2.5
Italgrip on Concrete #2	1.2
Italgrip on Concrete #3	0.9
Italgrip on Concrete #4	3.3
Italgrip on Concrete #5	0.7
Italgrip on Concrete #6	0.9
Italgrip on HMA #1	2.8
Italgrip on HMA #2	3.0
Italgrip on HMA #3	4.1
Average Italgrip Loss on Concrete	1.6%
Average Italgrip Loss on HMA	3.3%
Average Overall Italgrip Loss	2.1%

WisDOT defines failure of the freeze-thaw test as any concrete specimen that exceeds a ten percent loss in mass after 300 cycles. As shown in Table 1, the loss of Italgrip^{TM} on the individual concrete samples ranged from 0.7 to 3.3 percent, with an average loss of 1.6 percent. The loss of Italgrip^{TM} on the HMA samples ranged from 2.8 to 4.1 percent, with an average loss of 3.3 percent. The overall average Italgrip^{TM} loss on all the samples was 2.1 percent. All the results are within WisDOT acceptable limits for concrete, with mass losses less than ten percent. Thus, the Italgrip^{TM} System performed well in the testing and should hold up well to actual freeze-thaw conditions of Wisconsin pavements.

Friction Testing

Locked wheel friction tests were conducted by WisDOT's Pavement Data Unit, in accordance with ASTM E 274 [8], using a KJ Law 1290 pavement friction tester. Tests were conducted at both 40 and 50 miles per hour using both the E-501 ribbed tire and the E-524 smooth tire. The 40-mile per hour test with a ribbed tire is the ASTM standard. These tests result in a friction number (FN), which is determined from the force exerted on the locked wheel as it is dragged along the pavement surface at a particular test speed; higher FNs indicate better friction. The tests are conducted under simulated wet conditions by spraying water onto the pavement surface in front of the locked wheel. Speed gradients, or the frictional difference of the road between 40 mph and 50 mph, were also calculated. Speed gradients are unitless and are the difference of the frictional numbers at the two different travel speeds divided by the difference in the two speeds, which is 10 mph in this case (i.e. the slope of the line when plotting friction numbers versus speed). In general, values over 0.4 are undesirable because they indicate a big difference in the frictional characteristics of the road at those two travel speeds. Values less than 0.2, on the other hand, are preferable and indicate more uniform frictional characteristics for braking at the two different speeds.

Initial friction measurements were taken prior to the Italgrip™ installation at three of the test sites—USH 53 NB & SB (La Crosse County), STH 16 WB, (La Crosse County), and STH 16 EB & WB (Waukesha County). Friction tests were also performed within two weeks after the Italgrip™ applications at the same aforementioned sites to determine the baseline friction values, and subsequent measurements were taken annually through 2004. Friction testing was not conducted in 2000 because the friction tester was inoperable at that time. At least two runs, and in some cases up to eight runs, were made per lane at each of the variable conditions (40 and 50 mph with both ribbed and smooth tire) and the averages of those runs were calculated. A summary of the average friction numbers at 40 and 50 mph with ribbed and smooth tire is shown in Table 2. The graph in Figure 2 shows the annual average friction numbers at 40 mph with the ribbed tire over the life of the five-year study.

Table 2. Average Friction Numbers

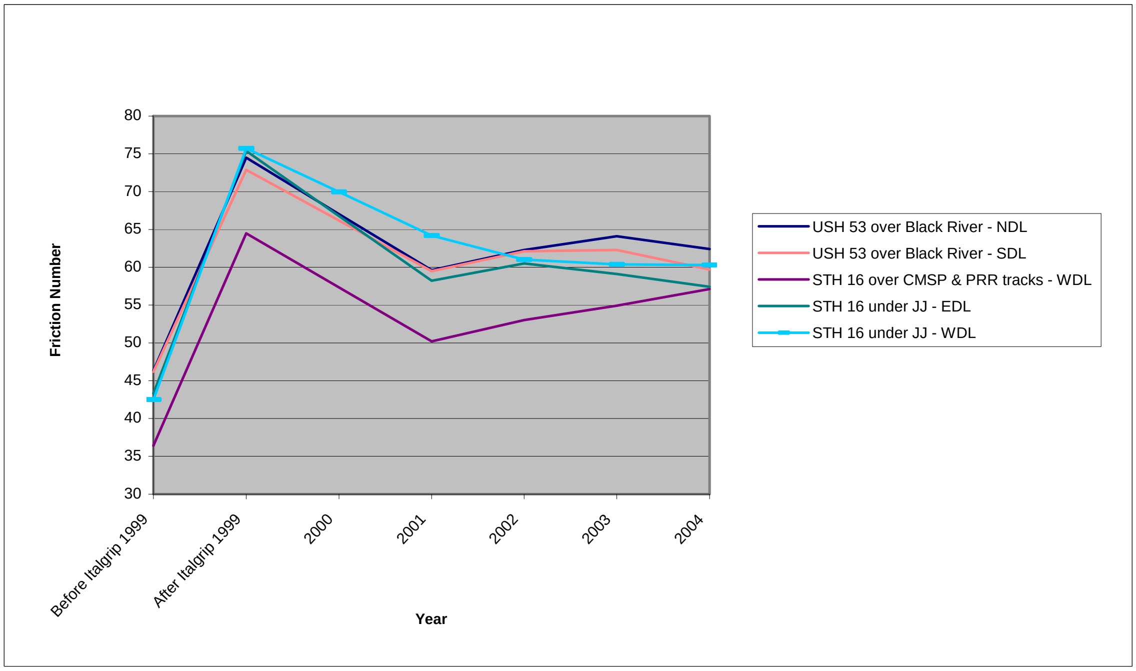
	Average Friction Numbers						Percent Increase in Friction Values from Aug '99 (Before Italgrip)	
LaCrosse County	Before Italgrip	After Italgrip						
	18-19 Aug 99	14-Oct-99	12-Jul-01	16-Jul-02	12-Aug-03	13-Jul-04	14-Oct-99	13-Jul-04
USH 53 over Black River - NDL								
Ribbed - 40 mph	46.3	74.5	59.6	62.3	64.1	62.4	60.9%	34.8%
Ribbed - 50 mph	42.6	72.7	57.5	60.1	58.9	57.4	70.7%	34.7%
Smooth - 40 mph	42.6	67.5	60.1	62.5	57.6	55.3	58.5%	29.8%
Smooth - 50 mph	38.3	68.9	53.9	57.6	53.6	49.4	79.9%	29.0%
USH 53 over Black River - SDL								
Ribbed - 40 mph	46.2	72.9	59.5	62.1	62.3	59.7	57.8%	29.2%
Ribbed - 50 mph	39.9	72.7	50.2	59.0	54.2	55.0	82.2%	37.8%
Smooth - 40 mph	43.2	74.8	57.8	64.3	54.5	53.8	73.1%	24.5%
Smooth - 50 mph	38.4	70.3	53.1	56.9	52.8	45.7	83.1%	19.0%
STH 35 over BNRR tracks *								
Ribbed - 40 mph						57.7		
Ribbed - 50 mph						53.1		
Smooth - 40 mph						48.8		
Smooth - 50 mph						43.0		
STH 16 over CMSP & PRR tracks - WDL **								
Ribbed - 40 mph	36.4	64.5	50.2	53.0	54.9	57.1	77.2%	56.9%
Smooth - 40 mph	28.8	60.9	46.9	49.8	52.2	53.1	111.5%	84.4%

	Average Friction Numbers						Percent Increase in Friction Values	
Waukesha County	Before Italgrip	After Italgrip						
	21-Sep-99	15-Oct-99	13-Jul-01	10-Jul-02	15-Aug-03	14-Jul-04	15-Oct-99	14-Jul-04
STH 16 under JJ - EDL								
Ribbed - 40 mph	43.3	75.4	58.2	60.5	59.1	57.4	74.1%	32.6%
Ribbed - 50 mph	38.3	72.7	56.4	56.4	51.3	55.6	89.8%	45.2%
Smooth - 40 mph	35.3		49.4	52.8	46.5	48.9		38.5%
Smooth - 50 mph	29.2		45.9	47.2	43.3	40.0		37.0%
STH 16 under JJ - WDL								
Ribbed - 40 mph	42.5	75.7	64.2	61.0	60.4	60.3	78.1%	41.9%
Ribbed - 50 mph	38.1	75.6	58.9	60.1	55.2	57.8	98.4%	51.7%
Smooth - 40 mph	33.4	***	56.8	57.4	52.6	55.4		65.9%
Smooth - 50 mph	28.2	***	55.1	50.7	50.0	51.3		81.9%

Average at 40 mph w/ ribbed tires (ASTM standard	42.94	72.6	58.34	59.78	60.16	59.38		
Average Increase in FN at 40 mph w/ ribbed tires		69.1%	35.9%	39.2%	40.1%	38.3%	69.1%	38.3%

* Friction data for STH 35 over BNRR was only collected in 2004, thus was excluded in calculation of above averages.
** Speed limit and traffic conditions resulted in the site not tested at a speed in excess of 40 mph.
*** The high FN at this site damaged the test system (in 1999) and smooth tire values were not obtained for post construction measurements.

Figure 2. Average Friction Numbers at 40 Miles Per Hour With Ribbed Tire



As Figure 2 shows, the trend over the five-year test span was similar for the different sites and lanes. Prior to the installation of Italgrip^{TM}, friction numbers ranged from 36.4 to 46.3 with an average friction number of 42.9. Immediately after Italgrip^{TM} was placed, the friction numbers increased significantly to a range of 64.5 to 75.7, with an average friction number of 72.6—a 69 percent increase in the average FN. After two years, in 2001 the average friction numbers decreased to 58.3, but that was still a 36 percent increase in friction compared to the values before Italgrip^{TM} was placed. After 2001, the average friction values at 40 mph with a ribbed tire are shown to have increased at most of the sites. This apparent increase could to attributed to several factors.

The friction number could be affected, to an extent, by the cleanliness and the temperature of the pavement. If the surface is very clean resulting from a heavy rain, the friction number could be slightly higher. Similarly, higher pavement surface temperatures could result in slightly higher friction numbers. Also, the values are not necessarily completely representative of the Italgrip^{TM} surface alone, since the friction numbers are a running average of measurements made for one second at the target test speed. At 40 miles per hour, the measurements are taken over a distance of 59 feet. Thus, the running average could include an area (say 30 feet) with a high friction number and an adjacent area (say 29 feet) with a great amount of aggregate loss and a low friction number. The determined friction number would be a running average of the measurements within that 59-foot segment. Furthermore, that 59-foot segment is not necessarily the exact segment for each consecutive run.

Nonetheless, the friction tests conducted in 2004, five years after Italgrip™ was placed, showed relatively stable friction numbers ranging from 57.1 to 62.4, with an average friction number of 59.4. Friction testing was also conduced on STH 35 in 2004. As shown in Table 2, the friction values at that site were comparable with the 2004 friction values of the other sites tested. Thus, after five years in service, the average friction number of all the sites at 40 mph with ribbed tire was 38 percent higher than before Italgrip™ was installed.

Additionally, the results in Table 2 show that the eastbound driving lane of STH 16 in Waukesha County had slightly higher friction numbers than the westbound driving lane prior to the Italgrip™ installation. However, after Italgrip™ was placed, the friction numbers were consistently higher in the westbound driving lane over the five-year span. That indicates that the four-millimeter aggregate that was used in the westbound lanes provides slightly better frictional characteristics than the three-millimeter aggregate that was used in the eastbound lanes. Although the friction numbers in the westbound driving lane are consistently higher across the board, the difference between the two directions is more pronounced with the smooth tire than with the ribbed tire. Thus, automobiles with bald tires or tires without much tread remaining would likely have a greater improvement in performance on the four millimeter aggregate surface as compared to the three-millimeter aggregate surface. However, bald tires are irrefutably unsafe on wet pavement surfaces, and more common than one might think. In fact, studies have shown that “every ninth car has at least one bald tire that offers little resistance to hydroplaning and almost no traction in the rain” [9]. More detailed friction test results from each year are included in Appendix C.

Table 3 shows the average annual speed gradients of the different sites. A speed gradient, as previously stated, is the difference in the frictional number at the two test speeds of 40 and 50 mph divided by the difference of the two speeds. Lower numbers are preferable and are representative of more uniform braking characteristics over the speed range.

Table 3. Average Speed Gradients

LaCrosse County	Before Italgrip	After Italgrip				
	18-19 Aug 99	14-Oct-99	12-Jul-01	16-Jul-02	12-Aug-03	13-Jul-04
USH 53 over Black River - NDL						
Ribbed	0.37	0.18	0.21	0.22	0.52	0.50
Smooth	0.43	0.13	0.62	0.49	0.40	0.59
USH 53 over Black River - SDL						
Ribbed	0.63	0.02	0.93	0.31	0.81	0.48
Smooth	0.49	0.45	0.46	0.74	0.17	0.81
STH 35 over BNRR tracks						
Ribbed						0.46
Smooth						0.58
STH 16 over CMSP & PRR tracks - WDL *						
Ribbed						
Smooth						

Average Speed Gradients						
Waukesha County	Before Italgrip	After Italgrip				
	21-Sep-99	15-Oct-99	13-Jul-01	10-Jul-02	15-Aug-03	14-Jul-04
STH 16 under JJ - EDL						
Ribbed	0.50	0.28	0.19	0.42	0.78	0.18
Smooth	0.62	**	0.35	0.56	0.32	0.89
STH 16 under JJ - WDL						
Ribbed	0.44	0.01	0.52	0.09	0.52	0.25
Smooth	0.52	**	0.16	0.67	0.26	0.41
Average Speed Gradient with Ribbed Tire	0.49	0.12	0.46	0.26	0.66	0.35
Average Speed Gradient with Smooth Tire	0.52	0.29	0.40	0.62	0.29	0.68

* Speed limit and traffic conditions resulted in the site not tested at a speed in excess of 40 mph, so speed gradients can not be determined.
** The high FN at this site damaged the test system and smooth tire friction values were not obtained for post-construction measurements

Prior to Italgrip™ installations the speed gradients ranged from 0.37 to 0.63, with an average gradient of 0.49 with a ribbed tire and 0.52 with a smooth tire. The average speed gradients decreased after the Italgrip™ was placed and ranged from 0.01 to 0.45, with ribbed and smooth tire averages of 0.12 and 0.29, respectively. In 2001, the speed gradients increased at most of the sites, but the values varied considerably. After 2001, there was no noticeable trend in the speed gradients and the values fluctuated from site to site and from one year to the next. That was likely due to some areas experiencing a greater amount of aggregate loss than others, thus resulting in inconsistent frictional characteristics relative to braking.

Accident Analysis

Accident reports for all Italgrip™ test sites were acquired for a period spanning from three years prior to the Italgrip™ installations to three years afterwards. All of the accident reports obtained were thoroughly reviewed to assure the incidents occurred within the limits of each test site. It is possible that some accidents or incidents may have been unintentionally overlooked in this analysis for one of several reasons, including:

1) missed by the database search, 2) vehicle left the scene, 3) accident not reported, or 4) exact location incorrectly documented on the accident report.

It is worth noting that all of the accidents/incidents at all of the locations, with the exception of one, occurred between November and February over the six-year time frame. Of those that occurred between November and February, all except one occurred when the weather and/or pavement condition was reported as snow, slush, sleet/hail, and/or ice. The accident that didn't occur between November and February took place in May, during rain and wet pavement conditions.

A tally of the number of incidents, the number of vehicles involved in the incidents, and number of injuries were recorded for each Italgrip™ site. These statistics are shown in Table 4. A total summary of all sites combined is shown in Table 5.

Table 4. Accident Statistics by Site

	LaCrosse County STH 53 NB & SB	LaCrosse County STH 35 NB	LaCrosse County STH 16 EB & WB	Waukesha County STH 16
Before Italgrip (Oct 96 - Sep 99)				
Incidents	9	3	11	5
Vehicles	10	16	30	7
Injuries	3	3	6	2
After Italgrip (Nov 99 - Oct 02)				
Incidents	1	0	1	0
Vehicles	3	0	4	0
Injuries	2	0	0	0

Table 5. Accident Statistic Summary

	3 Years Before Italgrip	3 Years After Italgrip	% Reduction
Incidents	28	2	93%
Vehicles	63	7	89%
Injuries	14	2	86%

As shown in Table 4, each individual statistic decreased at each site from the three-year period prior to the Italgrip™ installation to the three-year period after installation. Table 5 shows a 93 percent decrease in the number of accidents/incidents, an 89 percent decrease in the number of vehicles involved in the incidents, and an 86 percent reduction in the number of injuries from the three years before Italgrip™ to the three years after Italgrip™.

In comparison, at the beginning of this study, Italgrip USA had reported an average of 12.9 accidents per year over a three-year period before the installation of Italgrip™ at 16 locations in Italy. That number reduced to an average of 5.3 accidents per year for a three-year period after Italgrip™ was placed. Thus, Italy experienced an accident reduction rate of 59 percent for sixteen Italgrip™ sites over a similar 6-year time span [2].

Noise Measurements

Noise measurements were taken on STH 16 in Waukesha to identify and quantify exterior noise impacts of the Italgrip™ surface on concrete pavements. Marquette University and HNTB Corporation performed the noise testing and analysis for WisDOT using a controlled, single vehicle pass-by method. Two microphones positioned five feet high, 25 feet from the center of the traffic lane, and 200 feet apart were used to record the exterior noise levels. Noise characteristics were measured during construction on the existing transverse, random spaced tined concrete pavement, on the diamond-ground concrete pavement, and on the three millimeter and four millimeter Italgrip™ System that was applied to the diamond-ground concrete pavement.

Results showed that the diamond grinding operation decreased noise levels by three decibels. At 60 and 65 miles per hour, the Italgrip™ System reduced noise levels one additional decibel when compared to ground concrete. The Italgrip™ System showed a two to three decibel decrease in noise levels when compared to the diamond-ground pavement between 1550 and 2000 Hz frequency spectrums. The noise level difference between the three and four millimeter aggregate was insignificant [10].

Surface Loss

Progressive surface aggregate loss due to traffic and snowplow blades was identified during site surveys conducted annually. Thus, to estimate the total surface aggregate loss at each site, road videos collected by WisDOT's video profiler were used. Wisconsin's primary roads are videotaped every other year, the actual year of which is dependent on the individual county and region within the state. The total surface aggregate loss was calculated in 2005 from the latest videotapes that were available, which was 2005 for the La Crosse County test sites and 2004 for the Waukesha County test site. Personnel from WisDOT's Pavement Data Unit divided each lane of each site into roughly 50-foot equal length sections, and then estimated the surface loss of five segments of each lane (left edge of pavement, the left wheel path, the center of the lane, the right wheel path, and the right edge of pavement) over the 50-foot length of the section. The estimations were objective based on visual observations from perspective (long range) views as well as from camera views aimed downward onto the road surface. The values for each of the five lane segments were then summed up and averaged for the entire length of the site. Those values were then weighted, based on the width of the segments, and totaled to determine the total surface loss. The weighted rates are shown in Table 6. The total estimated surface loss of each site (by lane) and the average surface losses are shown in Tables 7 and 8, respectively. The complete worksheets that were developed to determine these values are provided in Appendix D.

Table 6. Weighted Rates

	Width	Weighted Rate
Left Edge	1'	0.0833
Left Wheelpath	3'	0.2500
Center of Lane	4'	0.3333
Right Wheelpath	3'	0.2500
Right Edge	1'	0.0833

Table 7. Total Surface Loss Per Lane Per Location

	% Loss by Lane		Total Loss
La Crosse County (2005)			
	NB Lane	SB Lane	
USH 53 over Black River	6.9	7.0	14%
	DL	PL	
STH 35 NB over the BNRR tracks	6.0	9.2	15%
	DL	PL	
STH 16 WB over the CMSP & PRR tracks	13.3	14.6	28%
	DL	PL	
STH 16 EB over the CMSP & PRR tracks	12.0	24.7	37%
Waukesha County (Driving Lanes Only) (2004)			
	EB DL	WB DL	
STH 16 under CTH JJ	2.4	3.5	6%

Table 8. Average Surface Loss

Average Surface Loss of Bridge Decks (After 6 Years in Service) =	23%
Average Surface Loss of Road (After 5 Years in Service) =	6%

Table 7 shows that in 2005, after six years in service, both STH 16 structures in La Crosse County were performing the worst in both directions. These structures are on a curve and could be experiencing more lateral stresses than the other sites. In addition, these structures had the highest average daily traffic of all the sites. Although the total loss of STH 16 in Waukesha County was performing the best, with a surface loss of only six percent, it should be reiterated that the estimate for that site was based on 2004 videotapes, thus represents results after five years in service. It can be assumed that six-year results for that site would be slightly higher. Overall, after six years in service, the average surface loss of the La Crosse County bridge sites was 23 percent.

Photo 3: WB on STH 16 in La Crosse County

It should be noted that additional wear and surface loss has occurred from 2005 until the time this report was written. However, estimating the amount of surface loss was a time consuming effort; therefore, up-to-date estimates were not recalculated. Photos 3 and 4 were taken from La Crosse County during a site review conducted in 2007, after Italgrip™ had eight years in service. Photo 3 was taken of the westbound lanes of STH 16 over the CMSP & PRR tracks and shows moderate surface loss of Italgrip™. Photo 4 was taken on

Photo 4: Area of extreme surface loss on STH 35

the northbound lane of STH 35 over the BNRR tracks and shows a close-up of an area with extreme surface loss.

COST

WisDOT was charged a reduced rate of \$13 per square yard for the initial Italgrip™ System installations in Wisconsin. This price included the materials, the epoxy sprayer with operator, and an Italgrip™ representative, but excluded traffic control, the sweeper with operator, and the aggregate spreader with operator. The current cost of Italgrip™ is about \$20 per square yard, but the price can fluctuate somewhat depending on the total amount needed and the transportation costs.

RESULTS AND CONCLUSIONS

The Italgrip™ System installations involved with this research study went relatively smoothly; only minor complications were encountered. The Italgrip USA technical representatives on site were able to resolve all issues with only minor construction delays. As stated earlier in this report, Italgrip™ was also installed at additional sites in Waukesha County outside the realm of this research study. Although not officially monitored, it became obvious that one of those sites was experiencing premature aggregate loss of the Italgrip™ surface due to cool temperatures during construction. The epoxy had not adequately cured prior to allowing traffic onto the surface. The Italgrip™ specifications have been revised accordingly since then. Thus, assuring that the climatic conditions during construction are in compliance with the specifications is vital for proper curing.

Results from the freeze/thaw testing showed that the Italgrip™ System held up well after 300 freeze-thaw cycles with an average loss of the Italgrip™ surface of only 2.1 percent. This indicates that the system should tolerate Wisconsin climates.

Locked-wheel friction testing showed that the Italgrip™ System increased the friction number of the test sites by an average of 69 percent at 40 miles per hour with ribbed tire, from an average of 42.9 prior to Italgrip™ to an average of 72.6 after application. After five years in service, the sites had an average friction number of 59.4. Although the friction had decreased after five years in service, the average friction number was still 38 percent higher than prior to the Italgrip™ installations. The friction testing also showed that the four-millimeter aggregate provides slightly better skid resistance than the three-millimeter surface. Although the average speed gradients decreased after the Italgrip™ installations, after two years in service the speed gradients varied considerably from site to site and from year to year. This indicates inconsistent braking characteristics on the Italgrip™ surface, possibly due to some areas experiencing greater aggregate surface loss than others.

Accident reports from all the test sites were reviewed for a three-year period prior to the Italgrip™ installations and for a three-year period after application. The results showed that the number of accidents at the sites decreased by 93 percent, the number of vehicles involved in the accidents decreased by 89 percent, and the number of injuries decreased by 86 percent during the three-year period after Italgrip™ was placed.

Noise measurements taken at the Waukesha County test site indicated that grinding the concrete surface decreased noise levels by three decibels. The Italgrip™ System reduced noise levels an additional decibel at 60 and 65 miles per hour. Although not verified, it can be assumed that the Italgrip™ System alone, placed directly on a pavement that was not diamond ground, could reduce the noise levels by four decibels. There was no difference in the noise level between the three-millimeter and four-millimeter aggregate surface.

Annual progressive aggregate surface loss due to traffic and snowplow blades was observed at the sites. The total amount of aggregate loss at the sites was estimated from the latest road videos collected with a video profiler. After five years in service, the average surface loss of the Waukesha County test site was six percent and the average surface loss of the La Crosse County test sites, after six years in service, was 23 percent. Additional surface loss has occurred since 2005 when the surface losses were estimated, the amount of which was not recalculated.

The current cost of Italgrip™ ranges from $16 to $20 per square yard. Other products that enhance the frictional characteristics of a pavement and have also shown positive results are available in the market today. The prices of those products vary significantly.

RECOMMENDATIONS

Based on the results of this study, it is recommended that the Italgrip™ System be approved for use in the state of Wisconsin. The Italgrip™ System should be considered for short sections of roadways (such as curves, intersections, bridge decks, etc.) with high accident rates where pavement characteristics impacting friction, especially under wet or icy conditions, may be a factor.

REFERENCES

1. Highway Innovative Technology Evaluation Center, Civil Engineering Research Foundation. (June 2000). *Evaluation of the Italgrip System*. Washington, D.C.

2. Highway Innovative Technology Evaluation Center, Civil Engineering Research Foundation. (October 1998). *Evaluation Plan for the Italgrip System.* Washington, D.C.

3. Italgrip USA. (n.d.). *Italgrip Antiskid and Waterproofing Systems*. Trieste, Italy.

4. ASTM International, Annual Book of ASTM Standards (Vol. 04.02). (2007). ASTM C 1583, *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)*. West Conshohocken, PA.

5. *Italgrip USA. (March 2000). Italgrip System Specifications – Thin Polymer Overlay.*

6. *Italgrip USA. (June 2006). Italgrip® - F System Specifications.*

7. ASTM International, Annual Book of ASTM Standards (Vol. 04.02). (2007). ASTM C 666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*. West Conshohocken, PA.

8. ASTM International, Annual Book of ASTM Standards (Vol. 04.03). (2007). ASTM E 274, *Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire*. West Conshohocken, P**A.**

9. PR Newswire. (April 2005). *Tire Experts: Don't Leave It To Chance, Take Safety Into Your Own Hands*. Available: http://www.automotive.com/auto-news/02/12009/index.html. Last accessed 21 August 2008.

10. Kuemmel, D., Jaeckel, J., & Satanovsky, A. (March 2000). *Investigative Study of the Italgrip System – Noise Analysis*. WisDOT Research Report Number WI/SPR-02-00.

APPENDIX A: LOCATION MAPS

Figure A-1. La Crosse County Test Sites

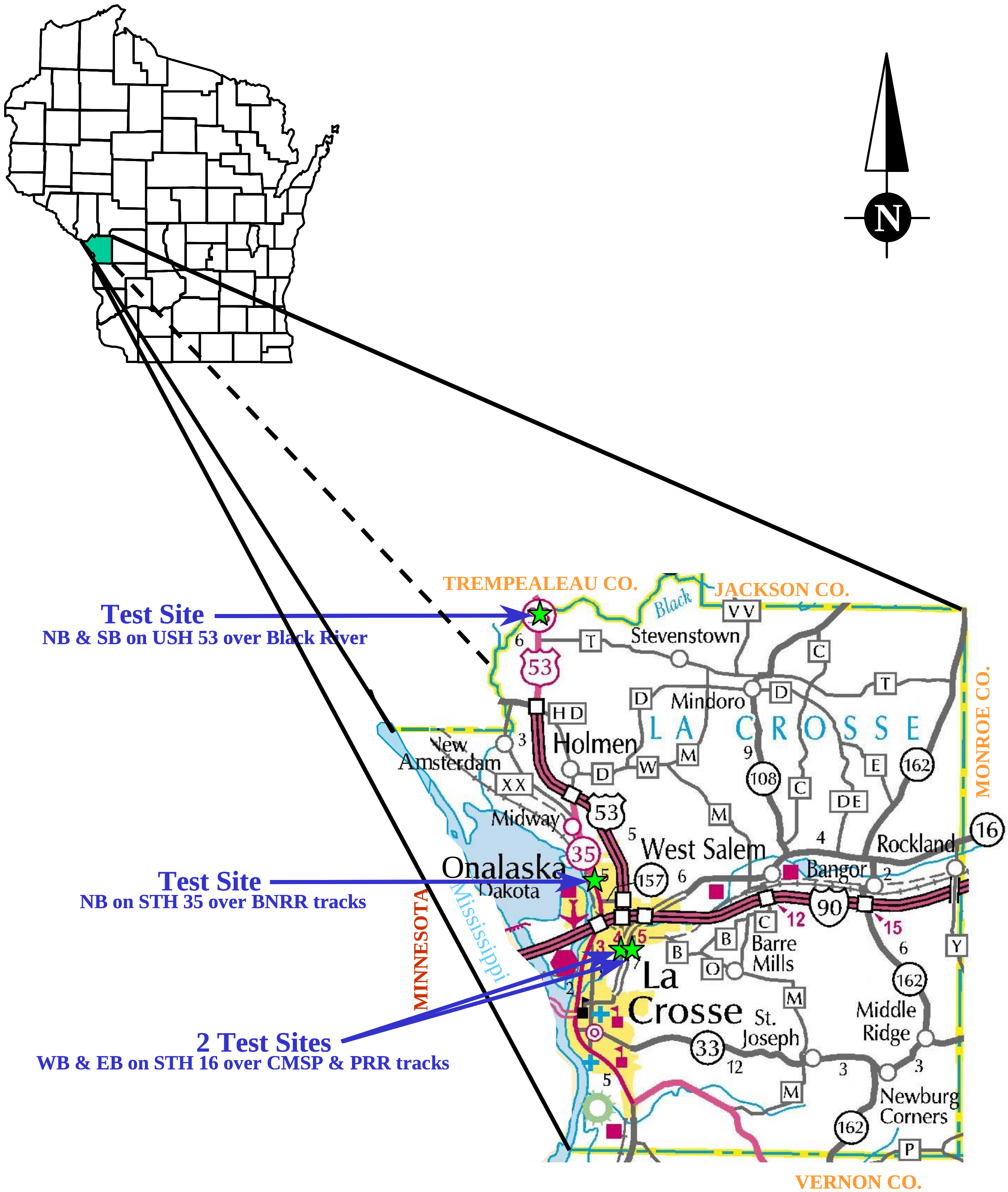
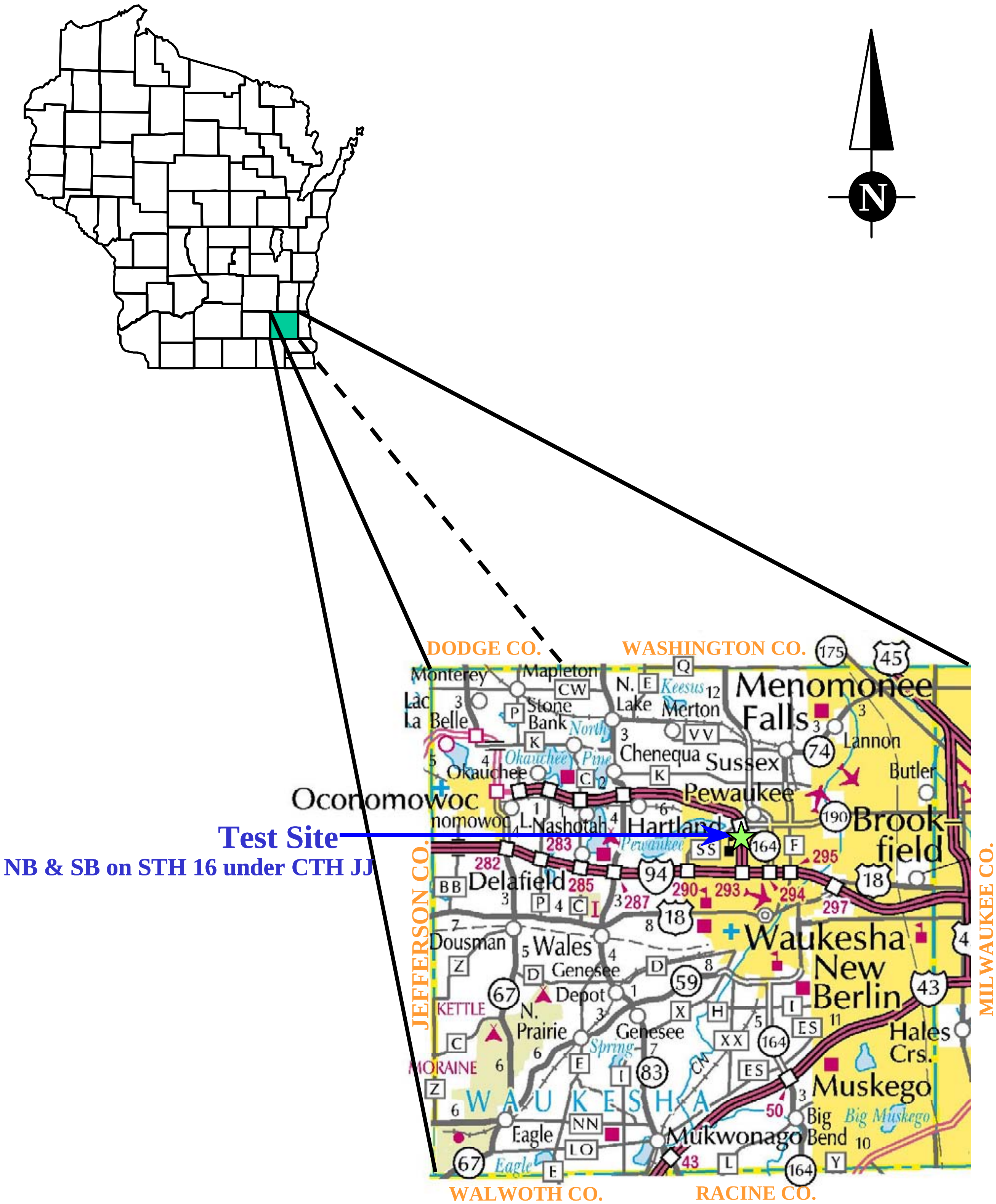


Figure A-2. Waukesha County Test Sites



APPENDIX B: FREEZE-THAW TEST DATA

Figure B-1. Freeze-Thaw Test Data

	Freeze-Thaw Cycles 0	175	300	Weight Change	Italgrip Loss 175 Cycles	Italgrip Loss 300 Cycles	Total Italgrip Loss
	Weight in Grams SSD*						
Standard Concrete #1	7228	7260	7240	12			
Standard Concrete #2	7288	7304	7275	-13			
Standard Concrete #3	7263	7285	7269	6			
Italgrip on Concrete #1	7499	7517	7487	-12	2.04	2.90	4.94
Italgrip on Concrete #2	7441	7471	7470	29	1.02	1.40	2.42
Italgrip on Concrete #3	7418	7454	7477	59	0.72	1.00	1.72
Italgrip on Concrete #4	7439	7476	7443	4	2.86	3.80	6.66
Italgrip on Concrete #5	7466	7498	7512	46	0.60	0.80	1.40
Italgrip on Concrete #6	7498	7532	7542	44	0.80	1.10	1.90
Standard HMA	3772	3798	3820	48			
Italgrip on HMA #1	3951	3976	4020	69	1.25	2.50	3.75
Italgrip on HMA #2	3870	3916	3954	84	1.37	2.70	4.07
Italgrip on HMA #3	3904	3915	3930	26	1.75	3.80	5.55

	Paste Loss 175 Cycles	Paste Loss 300 Cycles	Total Paste Loss	% Italgrip Loss**	% Paste Loss
Standard Concrete #1	8.00	24.00	32.00		0.4
Standard Concrete #2	7.40	19.10	26.50		0.4
Standard Concrete #3	11.30	22.70	34.00		0.5
Italgrip on Concrete #1	20.00	18.90	38.90	2.5	0.5
Italgrip on Concrete #2	28.90	26.80	55.70	1.2	0.8
Italgrip on Concrete #3	11.60	10.60	22.20	0.9	0.3
Italgrip on Concrete #4	48.00	38.20	86.20	3.3	1.2
Italgrip on Concrete #5	11.90	9.50	21.40	0.7	0.3
Italgrip on Concrete #6	17.60	12.10	29.70	0.9	0.4
Standard HMA					
Italgrip on HMA #1				2.8	
Italgrip on HMA #2				3.0	
Italgrip on HMA #3				4.1	

Average Initial Weights	
Standard Concrete	7260
Concrete with Italgrip	7460
Italgrip Coating***	201

Average Initial Weights	
Standard HMA	3772
HMA with Italgrip	3908
Italgrip Coating	136

Average Paste Loss	0.5%
Average Italgrip Loss on Concrete	1.6%
Average Italgrip Loss on HMA	3.3%
Overall Average Italgrip Loss	2.1%

A weight gain after 300 freeze-thaw cycles is due to bonding of the sodium chloride

* Surface Saturated Dry

** The percent of Italgrip loss is calculated by dividing the weight loss of Italgrip by the average weight of the Italgrip coating.

*** Average Italgrip coating is based on subtracting the average weight of the standard blocks from the average weight of the Italgrip blocks.

APPENDIX C: FRICTION TEST RESULTS

Figure C-1. 1999 Friction Testing: Pre- and Post- Italgrip™ Installations (Various Dates)

USH 53 - La Crosse County							
				Friction Number			
	Direction/Lane	Tire	Speed	High	Low	Average	S.G.
Pre - Construction	NDL	Ribbed	40	48.5	44.0	46.3	-0.37
18 August 1999	SDL	Ribbed	40	46.4	45.9	46.2	-0.63
	NDL	Ribbed	50	43.0	42.1	42.6	
	SDL	Ribbed	50	41.0	38.7	39.9	
	NDL	Smooth	40	45.1	40.1	42.6	-0.43
	SDL	Smooth	40	45.6	40.8	43.2	-0.49
	NDL	Smooth	50	40.0	36.6	38.3	
	SDL	Smooth	50	41.2	35.5	38.4	
Post - Construction	NDL	Ribbed	40	74.7	74.2	74.5	-0.18
14 October 1999	SDL	Ribbed	40	74.4	71.4	72.9	-0.02
	NDL	Ribbed	50	73.3	72.1	72.7	
	SDL	Ribbed	50	73.4	72.0	72.7	
	NDL	Smooth	40	67.5	67.5	67.5	0.13
	SDL	Smooth	40	74.9	74.7	74.8	-0.45
	NDL	Smooth	50	70.7	67.0	68.9	
	SDL	Smooth	50	70.4	70.2	70.3	

STH 16 - La Crosse County						
				Friction Number		
	Direction/Lane	Tire	Speed	High	Low	Average
Pre - Construction	WDL	Ribbed	40	38.9	33.1	36.4
18 August 1999	WDL	Smooth	40	30.1	27.3	28.8
Post - Construction	WDL	Ribbed	40	65.2	63.7	64.5
14 October 1999	WDL	Smooth	40	61.1	60.6	60.9
Note: Speed limit and traffic conditions resulted in this site not tested at a speed in excess of 40 mph.						

STH 16 - Waukesha County							
				Friction Number			
	Direction/Lane	Tire	Speed	High	Low	Average	S.G.
Pre - Construction	EDL	Ribbed	40	48.0	39.9	43.3	-0.50
21 September 1999	WDL	Ribbed	40	45.9	37.6	42.5	-0.44
	EDL	Ribbed	50	40.3	34.2	38.3	
	WDL	Ribbed	50	40.5	33.5	38.1	
	EDL	Smooth	40	44.5	23.8	35.3	-0.62
	WDL	Smooth	40	37.9	21.6	33.4	-0.52
	EDL	Smooth	50	32.4	23.3	29.2	
	WDL	Smooth	50	32.8	16.3	28.2	
Post - Construction	EDL	Ribbed	40	77.4	73.7	75.4	-0.28
15 October 1999	WDL	Ribbed	40	78.7	71.3	75.7	-0.01
	EDL	Ribbed	50	76.7	66.4	72.7	
	WDL	Ribbed	50	78.5	73.0	75.6	
Note: The high FN at this site damaged the test system and smooth tire friction values were not obtained for post-construction measurements.							

Figure C-2. 2001 Friction Testing, 12 & 13 July 2001

STH 53 - La Crosse County						
12 July 2001						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
NDL	Ribbed	40	61.9	57.9	59.6	-0.21
SDL	Ribbed	40	59.9	59.1	59.5	-0.93
NDL	Ribbed	50	57.5	57.5	57.5	
SDL	Ribbed	50	56.5	38.4	50.2	
NDL	Smooth	40	61.4	58.8	60.1	-0.62
SDL	Smooth	40	57.9	57.6	57.8	-0.46
NDL	Smooth	50	56.0	51.7	53.9	
SDL	Smooth	50	55.1	51.2	53.1	

STH 16 - La Crosse County					
12 July 2001					
			Friction Number		
Dir/Lane	Tire	Speed(mph)	High	Low	Average
WDL	Ribbed	40	50.9	49.4	50.2
WDL	Smooth	40	48.0	45.0	46.9

STH 16 - Waukesha County						
13 July 2001						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
EDL	Ribbed	40	63.0	51.5	58.2	-0.19
WDL	Ribbed	40	66.3	61.7	64.2	-0.52
EDL	Ribbed	50	58.4	53.3	56.4	
WDL	Ribbed	50	61.3	56.6	58.9	
EDL	Smooth	40	57.2	40.1	49.4	-0.35
WDL	Smooth	40	59.3	53.8	56.8	-0.16
EDL	Smooth	50	51.3	35.3	45.9	
WDL	Smooth	50	58.6	53.2	55.1	

Figure C-3. 2002 Friction Testing, 10 & 16 July 2002

STH 53 - La Crosse County						
16 July 2002						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
NDL	Ribbed	40	63.6	60.9	62.3	-0.22
SDL	Ribbed	40	62.2	62.0	62.1	-0.31
NDL	Ribbed	50	60.6	59.5	60.1	
SDL	Ribbed	50	59.2	58.7	59.0	
NDL	Smooth	40	66.0	58.9	62.5	-0.49
SDL	Smooth	40	64.8	63.7	64.3	-0.74
NDL	Smooth	50	58.4	56.7	57.6	
SDL	Smooth	50	58.1	55.7	56.9	

STH 16 - La Crosse County					
16 July 2002					
			Friction Number		
Dir/Lane	Tire	Speed(mph)	High	Low	Average
WDL	Ribbed	40	53.4	52.5	53.0
WDL	Smooth	40	51.1	48.0	49.8

STH 16 - Waukesha County						
10 July 2002						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
EDL	Ribbed	40	63.0	58.2	60.5	-0.42
WDL	Ribbed	40	63.7	53.9	61.0	-0.09
EDL	Ribbed	50	58.1	54.9	56.4	
WDL	Ribbed	50	61.6	57.5	60.1	
EDL	Smooth	40	55.3	50.9	52.8	-0.56
WDL	Smooth	40	60.0	54.6	57.4	-0.67
EDL	Smooth	50	49.8	43.5	47.2	
WDL	Smooth	50	54.2	45.8	50.7	

Figure C-4. 2003 Friction Testing, 12 & 15 August 2003

STH 53 - La Crosse County						
12 August 2003						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
NDL	Ribbed	40	64.8	63.4	64.1	-0.52
SDL	Ribbed	40	63.8	60.7	62.3	-0.81
NDL	Ribbed	50	59.8	58.0	58.9	
SDL	Ribbed	50	55.0	53.4	54.2	
NDL	Smooth	40	58.1	57.1	57.6	-0.40
SDL	Smooth	40	55.6	53.3	54.5	-0.17
NDL	Smooth	50	54.5	52.7	53.6	
SDL	Smooth	50	54.0	51.6	52.8	

STH 16 - La Crosse County					
12 August 2003					
			Friction Number		
Dir/Lane	Tire	Speed(mph)	High	Low	Average
WDL	Ribbed	40	56.5	52.7	54.9
WDL	Smooth	40	53.0	50.8	52.2

STH 16 - Waukesha County						
15 August 2003						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
EDL	Ribbed	40	61.4	54.4	59.1	-0.78
WDL	Ribbed	40	62.2	57.4	60.4	-0.52
EDL	Ribbed	50	53.8	49.2	51.3	
WDL	Ribbed	50	58.9	50.3	55.2	
EDL	Smooth	40	52.4	40.6	46.5	-0.32
WDL	Smooth	40	55.0	49.6	52.6	-0.26
EDL	Smooth	50	46.2	38.2	43.3	
WDL	Smooth	50	50.9	49.5	50.0	

Figure C-5. 2004 Friction Testing, 13 & 14 July 2004

STH 53 - La Crosse County						
13 July 2004						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
NDL	Ribbed	40	62.7	62.0	62.4	-0.50
SDL	Ribbed	40	59.8	59.6	59.7	-0.48
NDL	Ribbed	50	58.1	56.7	57.4	
SDL	Ribbed	50	55.1	54.8	55.0	
NDL	Smooth	40	55.7	54.8	55.3	-0.59
SDL	Smooth	40	56.0	51.6	53.8	-0.81
NDL	Smooth	50	49.7	49.0	49.4	
SDL	Smooth	50	46.7	44.7	45.7	

STH 35 - La Crosse County						
13 July 2004						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
NDL	Ribbed	40	58.9	56.4	57.7	-0.46
NDL	Ribbed	50	53.5	52.6	53.1	
NDL	Smooth	40	49.5	48.1	48.8	-0.58
NDL	Smooth	50	43.4	42.5	43.0	

STH 16 - La Crosse County					
13 July 2004					
			Friction Number		
Dir/Lane	Tire	Speed(mph)	High	Low	Average
WDL	Ribbed	40	57.5	56.5	57.1
WDL	Smooth	40	53.8	52.3	53.1

STH 16 - Waukesha County						
14 July 2004						
			Friction Number			
Dir/Lane	Tire	Speed(mph)	High	Low	Average	S.G.
EDL	Ribbed	40	60.4	52.6	57.4	-0.18
WDL	Ribbed	40	61.7	56.9	60.3	-0.25
EDL	Ribbed	50	56.2	54.5	55.6	
WDL	Ribbed	50	59.9	55.5	57.8	
EDL	Smooth	40	54.5	38.0	48.9	-0.89
WDL	Smooth	40	60.8	48.3	55.4	-0.41
EDL	Smooth	50	47.5	32.7	40.0	
WDL	Smooth	50	55.3	47.1	51.3	

APPENDIX D: SURFACE LOSS CALCULATIONS

Figure D-1. USH 53 & STH 35 Structures in La Crosse County

USH 53 over Black River (Hunter's Bridge) in La Crosse County B-32-0079

NB (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	5	15	12.5	12.5	10
	7.5	10	10	7.5	10
	7.5	12.5	10	10	12.5
	7.5	12.5	12.5	10	7.5
	5	12.5	12.5	7.5	7.5
	5	7.5	12.5	2.5	2.5
	2.5	5	5	7.5	2.5
	15	5	7.5	2.5	5
	25	15	15	12.5	10
	27.5	20	20	20	10
	27.5	30	30	22.5	15
	34	35.9	30.8	37.5	24
Average =	14.08	15.07	14.85	12.71	9.71
Weighted =	1.17	3.77	4.95	3.18	0.81
Surface Loss of NB Lane =					6.94%

SB (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	20	17.5	12.5	15	15
	20	15	15	17.5	7.5
	20	20	17.5	20	15
	20	15	10	12.5	5
	30	20	20	20	10
	35	20	20	20	15
	35	20	20	20	20
	25	8	10	12.5	8
	20	7.5	10	10	10
	20	10	5	8	8
	12	8	4	4	3
	8.9	10.4	6.7	10.4	8.2
Average =	22.15	14.28	12.56	14.16	10.39
Weighted =	1.85	3.57	4.19	3.54	0.87
Surface Loss of SB Lane =					7.00%

TOTAL LOSS = 14%

STH 35 NB over the BNRR tracks in La Crosse County B-32-0067

NB DL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	10	10	5	7.5	5
	15	7.5	7.5	10	7.5
	7.5	10	12.5	15	5
	12.5	15	10	15	5
	10	15	15	20	5
	2.5	2.5	5	7.5	2.5
	12.5	17.5	10	20	7.5
	40	20	12.5	40	2.5
Average =	13.75	12.19	9.69	16.88	5.00
Weighted =	1.15	3.05	3.23	4.22	0.42
Surface Loss of NB DL =					6.03%

NB PL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	7.5	12.5	12.5	25	32.5
	10	10	7.5	22.5	15
	5	7.5	7.5	20	35
	7.5	7.5	10	20	20
	5	12.5	12.5	20	20
	5	10	12.5	20	30
	15	22.5	20	35	50
	20	35	32.5	45	55
Average =	9.38	14.69	14.38	25.94	32.19
Weighted =	0.78	3.67	4.79	6.48	2.68
Surface Loss of NB PL =					9.21%

TOTAL LOSS = 15%

Figure D-2. STH 16 Structures in La Crosse County

STH 16 EB over the CMSP & PRR tracks in La Crosse County (Medary Overhead) B-32-0115

EB DL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	40	37.5	35	40	40
	50	35	30	37.5	20
	45	35	30	37.5	10
	50	42.5	37.5	42.5	15
	50	35	30	37.5	10
	20	30	25	30	10
	10	10	10	15	2.5
	20	30	25	30	10
	12.5	15	10	15	5
	15	25	20	15	2.5
	30	25	20	20	2.5
	5	15	7.5	12.5	2.5
	10	20	12.5	12.5	2.5
	7.5	17.5	12.5	12.5	2.5
	35	42.5	42.5	42.5	25
	35	42.5	37.5	37.5	25
	1	7.5	5	7.5	1.5
Average =	25.65	27.35	22.94	26.18	10.97
Weighted =	2.14	6.84	7.65	6.54	0.91
Surface Loss of NB DL =					12.04%

EB PL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	40	45	35	50	60
	35	42.5	30	50	57.5
	30	40	35	52.5	52.5
	35	45	35	52.5	70
	30	45	35	50	65
	25	45	37.5	50	60
	30	45	40	52.5	65
	40	45	45	62.5	70
	25	47.5	35	57.5	65
	30	40	35	50	60
	35	40	35	50	60
	40	50	40	50	65
	50	65	50	65	75
	50	65	50	65	75
	50	60	50	67.5	70
	50	65	60	75	75
	50	65	65	70	75
Average =	37.94	50.00	41.91	57.06	65.88
Weighted =	3.16	12.50	13.97	14.26	5.49
Surface Loss of NB PL =					24.69%

TOTAL LOSS = 37%

STH 16 WB over the CMSP & PRR tracks in La Crosse County (Medary Overhead) B-32-0111

WB DL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	65	70	65	67.5	80
	47.1	64.7	59.7	64.7	59.7
	25	30	25	30	25
	20	27.5	20	27.5	20
	20	25	20	25	20
	25	30	30	25	25
	15	37.5	35	37.5	25
	10	32.5	30	32.5	15
	10	25	20	25	20
	20	30	25	30	30
	12.5	22.5	15	20	20
	12.5	17.5	15	17.5	15
	15	20	10	20	20
	10	15	10	15	10
	5	15	10	15	10
	5	17.5	12.5	15	15
	10	25	17.5	22.5	20
	15	27.5	22.5	27.5	35
Average =	19.00	29.56	24.56	28.73	25.81
Weighted =	1.58	7.39	8.19	7.18	2.15
Surface Loss of SB DL =					13.25%

WB PL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	80	87.5	77.5	82.5	50
	26.8	71.8	66.8	68.5	34.3
	5	45	40	45	2.5
	2.5	45	40	40	2.5
	2.5	47.5	40	42.5	5
	5	50	45	50	5
	10	50	37.5	47.5	5
	1.3	47.5	37.5	42.5	2.5
	2.5	40	20	35	5
	1.3	40	20	37.5	1.5
	2.5	26	20	16	1.5
	1.5	17.5	10	5	1.5
	2.5	15	7.5	7.5	1.5
	5	22.5	12.5	10	1.5
	10	15	7.5	5	1
	17.5	32.5	17.5	10	5
	15	27.5	15	15	5
	15	25	20.6	10	2.5
Average =	11.43	39.18	29.72	31.64	7.38
Weighted =	0.95	9.80	9.91	7.91	0.61
Surface Loss of SB PL =					14.59%

TOTAL LOSS = 28%

Figure D-3. STH 16 in Waukesha County

STH 16 under CTH JJ in Waukesha County; DL only

EB DL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	7.5	7.5	7.5	7.5	5
	2.5	2.5	5	2.5	2.5
	2.5	2.5	2.5	2.5	2.5
	5	5	5	5	2.5
	2.5	5	2.5	5	2.5
	2.5	2.5	2.5	2.5	2.5
	10	5	5	5	5
	7.5	5	5	5	5
	7.5	5	5	5	5
	10	7.5	5	5	5
	7.5	5	5	5	5
	10	7.5	5	5	5
	7.5	7.5	7.5	5	5
	5	5	2.5	2.5	5
	10	5	2.5	5	5
	10	5	5	5	5
	7.5	7.5	7.5	7.5	7.5
	7.5	7.5	5	7.5	7.5
	5	5	5	5	5
	7.5	5	5	2.5	2.5
	7.5	5	5	2.5	2.5
	7.5	5	2.5	5	5
	7.5	7.5	2.5	2.5	2.5
	7.5	5	5	2.5	5
	7.5	5	5	5	5
	7.5	5	2.5	5	5
	7.5	5	2.5	2.5	2.5
	12.5	5	5	2.5	5
	5	2.5	2.5	2.5	2.5
	7.5	5	5	2.5	2.5
	7.5	5	2.5	5	5
	10	5	7.5	5	7.5
	7.5	5	2.5	7.5	5
	7.5	5	2.5	5	7.5
	10	5	5	5	5
	12.5	5	2.5	5	5
	10	5	2.5	5	5
Average =	7.50	5.20	4.26	4.46	4.53
Weighted =	0.63	1.30	1.42	1.11	0.38
Surface Loss of EB DL =					2.42%

WB DL (Max Loss Contribution to Total = 50%)

	LE	LWP	C	RWP	RE
	15	10	15	15	15
	15	10	7.5	12.5	15
	15	12.5	10	12.5	10
	10	10	7.5	5	7.5
	7.5	10	5	7.5	10
	5	7.5	5	7.5	12.5
	5	2.5	2.5	5	10
	7.5	5	5	5	15
	7.5	5	2.5	5	12.5
	7.5	7.5	5	7.5	12.5
	10	7.5	5	7.5	10
	7.5	5	2.5	5	5
	7.5	5	2.5	7.5	10
	7.5	5	5	7.5	10
	5	5	5	5	10
	5	5	5	5	10
	7.5	7.5	7.5	7.5	12.5
	5	5	2.5	12.5	10
	5	2.5	2.5	2.5	10
	5	2.5	2.5	2.5	10
	7.5	5	2.5	7.5	7.5
	7.5	5	2.5	5	7.5
	2.5	2.5	2.5	2.5	5
	2.5	2.5	2.5	2.5	2.5
	5	2.5	2.5	5	5
	15	7.5	5	7.5	7.5
	15	10	5	7.5	15
	10	7.5	5	7.5	10
	15	10	10	12.5	10
	15	12.5	7.5	10	15
	15	10	7.5	10	20
	10	10	7.5	10	20
	20	15	7.5	10	15
Average =	9.09	6.97	5.23	7.35	10.83
Weighted =	0.76	1.74	1.74	1.84	0.90
Surface Loss of WB DL =					3.49%

TOTAL LOSS = 6%