EVALUATION OF INNOVATIVE SAFETY TREATMENTS

Volume 3: A Study of the Effectiveness of Tyregrip High Friction Surface Treatment

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16. Abstract

The Florida Department of Transportation (FDOT) District 4 Traffic Operations office in consultation with the Federal Highway Administration (FHWA) has installed the Tyregrip high friction surfacing system to help reduce the potential for run-off-road crashes along the on-ramp to northbound I-75 from eastbound Royal Palm Boulevard located in the City of Weston, Broward County, Florida. The Tyregrip system was installed on a 300-foot section of the ramp, just upstream of the gore area between I-75 and the ramp, where the majority of the crashes occurred. This particular ramp was chosen as a candidate for this field test based on its crash history with 12 run-off-road crashes in the three-year period from 2002 to 2004. Eighty-three percent of these crashes occurred under wet road surface conditions. The effectiveness of the Tyregrip surface was evaluated from a materials perspective and from a safety perspective by using various types of data as discussed below.

Crash data were obtained from the Florida Department of Transportation Crash Analysis Reporting System (CARS). Over the four-year period prior to the installation of the Tyregrip, the treated section experienced an average of 2.54 crashes per year. In the 12 month period immediately following the installation of Tyregrip surface, the section experienced two crashes. Since the Tyregrip was installed in May 2006, sufficient crash data was not available to determine a statistically significant difference in crash frequency or rate. Due to the crash data limitations, surrogate measures of safety were evaluated to obtain a better understanding of the effects of the Tyregrip treatment as discussed below.

Skid tests were performed by the FDOT Materials Testing office for the study section of the ramp before and after the treatment on April 11, 2006 and May 23, 2006, respectively. The results of these tests indicate that the friction number was much higher after application of the Tyregrip treatment, as expected.

Speed studies performed within the treated section before and after the installation of the Tyregrip at different times of the day. The results of these studies indicate that the mean speeds were decreased by an average of 3.72 miles per hour under dry pavement conditions. Under wet conditions, the mean speeds also decreased, by an average of 2.62 miles per hour after the application of the Tyregrip treatment.

The proportion of vehicles encroaching either the outer or inner shoulders was examined prior to and after the application of the Tyregrip using the Z-test. The results indicate that the proportion of drivers encroaching the shoulder decreased significantly after the installation of the Tyregrip under wet pavement conditions while no significant difference was found under dry conditions.

Overall, the Tyregrip treatment was effective in increasing the friction between the roadway and vehicle tires. The treatment was found to assist motorists in maintaining their lane position under wet pavement conditions. In addition, drivers tended to slow down when traveling over the treated section of the ramp. It appears that the use of Tyregrip may be a practical countermeasure for improving safety at locations that are prone to run-off-road crashes, particularly sharp curves and entry/exit ramps.

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Executive Summary

The Florida Department of Transportation (FDOT) District 4 Traffic Operations Office in consultation with the FDOT District 4 Maintenance office, the FDOT Central office, and the Federal Highway Administration (FHWA) has installed the Tyregrip high friction surfacing system to help reduce the potential for run-off-road crashes along the on-ramp to northbound I-75 from eastbound Royal Palm Boulevard located in the City of Weston, Broward County, Florida.

The Tyregrip system was installed on a 300-foot section of the ramp, just upstream of the gore area between I-75 and the ramp, where the majority of the crashes occurred. The subject ramp is a one-lane loop ramp with an advisory speed of 25 miles per hour. Curve warning signs and chevron signs exist in advance of the study section of the ramp. This particular ramp was chosen as a candidate for this field test based on its crash history with 12 run-off-road crashes in the three-year period from 2002 to 2004. Eighty-three percent of these crashes occurred under wet road surface conditions.

In order to evaluate the effectiveness of the Tyregrip treatment, a before and after methodology was utilized. The after condition refers to the location and time where the Tyregrip has been applied and the before condition refers to the location and time prior to the installation of the Tyregrip. The Tyregrip treatment was applied on May 15, 2006. The effectiveness of the Tyregrip surface was evaluated from a materials perspective and from a safety perspective by using various types of data as discussed below.

Friction Factor

A before and after comparison of friction numbers was conducted to determine if skid numbers for the study section of the ramp after the treatment are significantly higher than the skid numbers before the treatment. Skid numbers are a measure of the amount of friction between the roadway and a standardized tire under wet road conditions. Skid tests were performed by the FDOT Materials Testing office for the study section of the ramp before and after the treatment on April 11, 2006 and May 23, 2006, respectively. The results of these tests indicate that the friction number was much higher (104 after the treatment as compared to 35 before the treatment) after application of the Tyregrip treatment, as expected.

Crash Frequency

Crash data were obtained from the Florida Department of Transportation Crash Analysis Reporting System (CARS). Over the four-year and four-moth period (from January 2002 to April 2006) prior to the installation of the Tyregrip, the treated section experienced an average of 2.54 crashes per year. In the 12 month period (June 2006 to June 2007) immediately following the installation of the Tyregrip surface, the section experienced two crashes. Since the Tyregrip was installed in May 2006, sufficient crash data were not available to determine a statistically significant difference in crash frequency or rate. Due to the crash data limitations, surrogate measures of safety were evaluated to obtain a better understanding of the effects of the Tyregrip treatment. Explanations of these surrogate measures are presented in the following paragraphs.

Vehicle Speeds

Vehicle speed is one of the factors that affect the amount of friction needed to keep a vehicle on the roadway. Since the study intentionally varies the amount of friction available while the other two factors (radius of curvature and superelevation) are held constant, it is important to know if there are any changes in vehicle speeds after the installation of the Tyregrip surface.

Spot speed studies were performed using a radar gun within the treated section before and after the installation of the Tyregrip at different times of the day (morning, mid-day and evening peak hours). Researchers collected speed data during rainy and dry conditions, so that the impact of Tyregrip on travel speeds can be evaluated for both wet and dry conditions. A total of five speed studies were conducted in early May of 2006, prior to the application of the Tyregrip treatment. The researchers began data collection activities for the after period in July 2006 and concluded in September 2007. Once again, speed data were collected at different times of the day and for various days of the week during this period, resulting in a total of nine speed studies for the after period.

The mean speeds were found to decrease by an average of 3.72 miles per hour under dry pavement conditions after the application of the Tyregrip treatment. Under wet conditions, the mean speeds also decreased, by an average of 2.62 miles per hour after the application of the Tyregrip treatment. The increased frictional forces created by the Tyregrip treatment make it possible for drivers to travel at higher speeds while maintaining their lane position. However, it appears that drivers are reducing their speeds, possibly due to texture difference in pavement and potential additional noise created by the Tyregrip surface.

The proportion of speeding drivers was found to decrease after the Tyregrip surface treatment had been applied under both wet and dry pavement conditions. The variance of the travel speeds also decreased following the Tyregrip treatment. These findings indicate that there were fewer drivers traveling over the speed limit.

Shoulder Encroachments

The proportion of vehicles encroaching either the outer or inner shoulder was examined prior to and following the application of the Tyregrip surface. The number of vehicles whose wheels crossed the edge lines on the ramp were collected at the same spot before and after the treatment was applied. Observers recorded the date and time of day, the total number of vehicles and the number of vehicles that crossed the pavement edge lines. Data were collected during dry and wet conditions to determine if there are any changes in shoulder encroachments under dry and wet conditions.

Encroachment data were collected for the before condition (without Tyregrip) in May 2006, during which time researchers conducted six studies at different times of the day and for various days of the week. The researchers began data collection activities for the after condition (with Tyregrip) in July 2006 and completed in September 2007. A total of 10 studies were conducted during the after period.

The proportion of drivers encroaching the shoulder decreased significantly after the installation of the Tyregrip under wet pavement conditions while no significant difference was found under dry conditions.

Overall, the Tyregrip treatment was effective in increasing the friction between the roadway and vehicle tires. The treatment was also effective in assisting motorists in maintaining their lane position under wet pavement conditions. In addition, drivers tended to slow down when traveling over the treated section of the ramp. It appears that the use of Tyregrip may be a practical countermeasure for improving safety at locations that are prone to run-off-road crashes, particularly sharp curves and entry/exit ramps.

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1.0 INTRODUCTION

There are several factors that go into the design of a turning roadway that affect the ability of a vehicle to stay within the traveled way: the radius of curvature (R), the anticipated speed of the vehicle (V), the superelevation of the roadway (e), and the side friction factor (f). The simplified formula for the design of horizontal alignment of roadways relates these four factors as follows:

$$f = \frac{V^2}{15R} - 0.01e$$

On existing horizontal curves with a crash history of run-off-road crashes, changing the radius of curvature or the super elevation of the roadway in an attempt to improve safety is frequently not a viable option. In addition, measures aimed at reducing vehicle speed (such as enforcement or the posting of advance curve warning signs with advisory speeds) may not always be effective. In these situations, a surface treatment that increases the side friction factor may be another option to reduce the potential for run-off-road crashes.

The Florida Department of Transportation (FDOT) District 4 Traffic Operations office in consultation with the FDOT District 4 Maintenance office, the FDOT Central office, and the Federal Highway Administration (FHWA) has installed the Tyregrip high friction surfacing system to help reduce the potential for run-off-road crashes along the on-ramp to northbound I-75 from eastbound Royal Palm Boulevard (Arvida Parkway) located in the City of Weston, Broward County, Florida (see Figure 1, Project Location Map). Based on the information received from the manufacturer, "the Tyregrip high friction surfacing system consists of a highly modified exothermic epoxy resin two-part binder usually top dressed with a calcined bauxite with a PSV (Polished Stone Value) of 70%+. This gives the system long lasting durability and skid resistance properties on both wet and dry pavement conditions."

The Tyregrip system was installed on a 300-foot section of the ramp, just upstream of the gore area on I-75, where the majority of the crashes occurred (see Appendix). The subject ramp is a one-lane loop ramp with an advisory speed of 25 mph. Curve warning signs and chevron signs exist in advance of the study section of the ramp. This particular ramp was chosen as a candidate for this field test based on its crash history with12 run-off-road crashes in the three-year period from 2002 to 2004. Eighty-three percent (83%) of these crashes occurred under wet road surface conditions.

The purpose of this study was to determine if this surface treatment reduces the potential for run-off-road crashes.

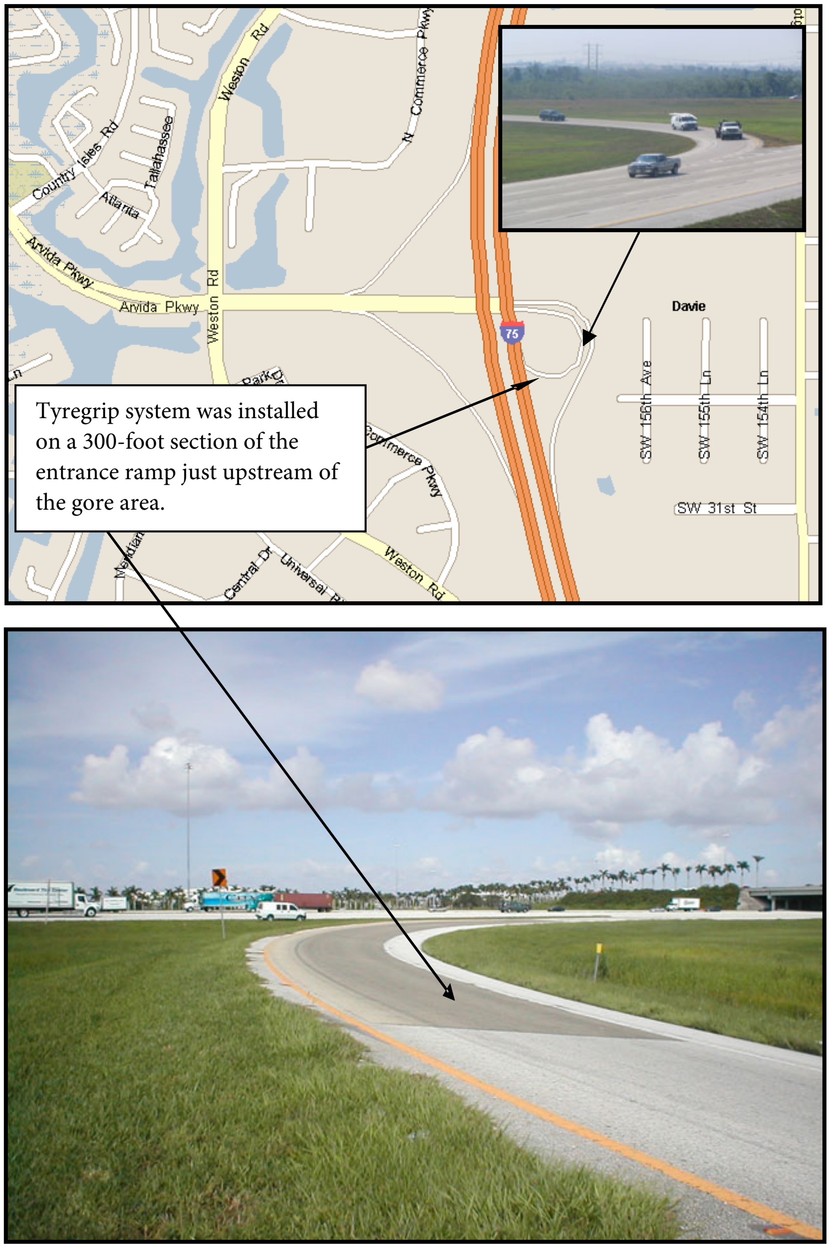


Figure 1. Project Location Map

2.0 STUDY METHODOLOGY

In order to evaluate the effectiveness of the Tyregrip treatment, a before and after methodology was utilized. In the before and after evaluation, as shown in Figure 2, data are compared for conditions before and after the installation of the Tyregrip treatment [1]. The after condition refers to the location and time where the Tyregrip has been applied and the before condition refers to the location and time prior to the installation of the Tyregrip. Various measures of effectiveness (MOEs) for the before and after conditions were compared to determine the impact of the pavement surface treatment on safety. The following sections provide a description of the MOEs that were used as part of this study.

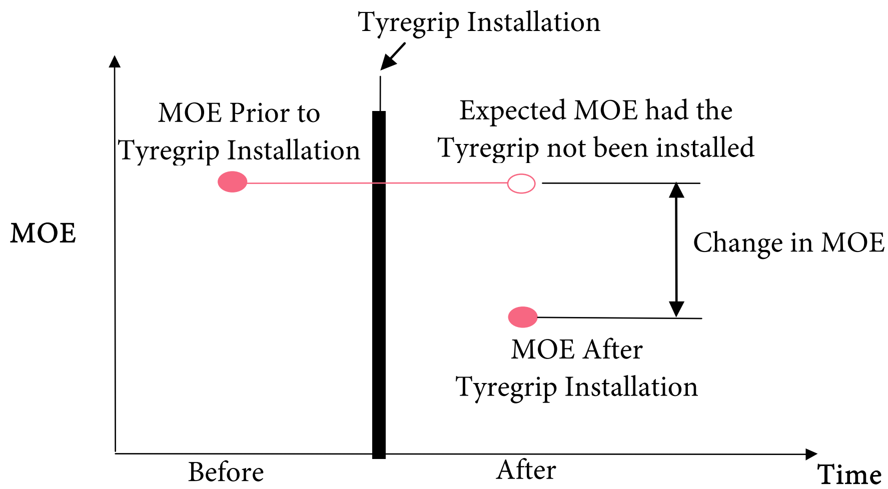


Figure 2. Before and After Evaluation Plan

Crash Frequency

The most direct measures of traffic safety are the crash frequency or crash rate for a given location or a group of locations. A comparison between the number of crashes before and after the installation of the Tyregrip treatment would provide such a direct measure. Table 1 provides before/after crash statistics for the section of the ramp where the Tyregrip was applied. Crash data were obtained from the Florida Department of Transportation Crash Analysis Reporting System (CARS). Over the four-year and four-moth period prior to the installation of the Tyregrip, the treated section experienced an average of 2.54 crashes per year. In the 12 month period immediately following the installation (June 2006 to June 2007), the section has experienced two crashes. Since the Tyregrip was installed in May 2006, sufficient crash data was not available to determine a statistically significant difference in crash frequency or rate. Due to the crash data limitations, surrogate measures of safety were evaluated to obtain a better understanding of the effects of the Tyregrip treatment. Explanations of these surrogate measures are presented in the following paragraphs.

Table 1. Before/After Crash Statistics

Year	Before Treatment (January 2002- April 2006)	After Treatment (June 2006 – June 2007)
2002	3	N/A
2003	1	N/A
2004	5	N/A
2005	2	N/A
2006	0	2
Total	11	2

Vehicle Speeds

As mentioned earlier in this report, vehicle speed is one of the factors that affect the amount of friction needed to keep a vehicle on the roadway. Since the study intentionally varies the amount of friction available while the other two factors (radius of curvature and superelevation) are held constant, it is important to know if there are any changes in vehicle speeds after the installation of the Tyregrip surface. Consequently, spot speed studies were performed and vehicle speeds prior to and after the installation of the treatment were compared. Specific MOEs for the speed comparison were the shape of the speed distributions (variability), the mean of the speed distributions, and the proportion of vehicles traveling over the advisory speed limit.

Shoulder Encroachments

Another surrogate measure is to compare the number of vehicles whose wheels crossed the edge lines on the ramp, which would indicate if Tyregrip was able to reduce the potential for encroachments onto the shoulder. This data were collected at the same spot before and after the treatment was applied. The proposed MOE for this comparison is the percentage of vehicles whose wheels crossed the yellow or white edge line on the ramp.

Statistical tests were conducted to better understand whether the changes observed in the measures of effectiveness are attributable to the use of the Tyregrip or simply due to chance. Statistical analyses that were performed to test the effectiveness of the Tyregrip include:

- One-Sample Kolmogorov-Smirnov (K-S) Test – to determine if the speed distributions obtained from the spot speed studies are normally distributed
- F-Test – to determine if the variances of the speed distributions are equal between the before and after periods

- Mann-Whitney U Test – to determine differences between the mean speeds in the before and after periods are statistically significant
- Z-Test – to determine if statistically significant differences exist between the proportion of vehicles speeding and the proportion of vehicles encroaching on the ramp shoulders between the before and after periods

3.0 DATA COLLECTION

The Tyregrip treatment was applied on May 15, 2006. Speed and shoulder encroachment data were collected before and after the installation of the Tyregrip surface. The effectiveness of the Tyregrip surface was evaluated from a materials perspective and from a safety perspective by using various types of data as discussed below.

Friction Factor

A before and after comparison of friction numbers was conducted to determine if skid numbers for the study section of the ramp after the treatment are significantly higher than the skid numbers before the treatment. Skid numbers are a measure of the amount of friction between the roadway and a standardized tire under wet road conditions. Skid tests were performed by the FDOT Materials Testing office for the study section of the ramp before and after the treatment on April 11, 2006 and May 23, 2006, respectively. A locked wheel tester under designation ASTM E-274 was used to evaluate the surface in terms of friction. As can be seen from Table 2, the friction number was much higher after application of the Tyregrip treatment, as expected. Further testing was scheduled, but the trailer being used to conduct the testing has not been able to consistently lock up the tires due to the horizontal forces created by the Tyregrip surface. Additional testing may be conducted at a later date after the Tyregrip surface has experienced further usage.

Table 2. Friction (FN_{40R}) Test Results

Friction Number at 40 MPH (FN_{40R})	Test Date	Pavement Surface Treatment	Time Period
35	04/11/06	FC-5	Before
104	05/23/06	Tyregrip	After

Spot Speed Studies

Spot speed studies were performed using a radar gun within the treated section before and after the installation of the Tyregrip at different times of the day (morning, mid-day and evening peak hours).

Researchers collected speed data during rainy and dry conditions, so that the impact of Tyregrip on travel speeds can be evaluated for both wet and dry conditions. A total of five speed studies were conducted in early May of 2006 prior to the application of the Tyregrip treatment. The researchers began data collection activities for the after period in July 2006 and concluded in September 2007. Once again, speed data were collected at different times of the day and for various days of the week during this period, resulting in a total of 9 speed studies for the after period. Summary statistics for each of the aforementioned speed studies are provided in Table 3.

Table 3. Summary Statistics for Speed Studies

	Date	Day	Time	Number of Vehicles	Mean Speed (mph)	Standard Deviation (mph)	85th Percentile Speed (mph)	Pavement Condition
Before	5/11/2006	Thu	17:35 - 18:21	92	29.90	4.55	34.24	Dry
	5/16/2006	Tue	8:23 - 9:37	100	26.60	4.40	30.44	Wet
	5/16/2006	Tue	15:50 - 16:34	99	22.20	3.59	25.29	Wet
	5/17/2006	Wed	15:09 - 15:53	100	27.20	4.04	30.54	Dry
	5/17/2006	Wed	16:00 - 16:46	99	27.40	3.36	30.19	Dry
After	7/6/2006	Thu	15:09 - 15:58	102	22.10	3.33	25.21	Dry
	7/6/2006	Thu	16:05 - 16:50	100	22.50	3.45	25.58	Dry
	7/10/2006	Mon	15:50 - 16:29	100	22.70	2.75	25.23	Dry
	7/10/2006	Mon	17:25 - 18:20	100	22.20	2.77	25.00	Dry
	7/11/2006	Tue	8:23 - 9:17	100	21.80	2.87	25.00	Wet
	9/13/2007	Thu	14:27 - 15:00	97	24.95	2.90	27.40	Dry
	9/19/2007	Wed	15:00 - 16:00	96	22.71	3.29	25.70	Dry
	9/19/2007	Wed	16:00 - 17:00	91	21.33	3.61	25.20	Dry
	9/19/2007	Wed	11:30 - 12:30	100	22.62	3.61	26.30	Dry

Since all of the speed studies were conducted at the same location, it is possible to combine the speed data, thus increasing the sample size. All speed studies conducted under dry conditions were combined into a single sample and all studies conducted under wet conditions were combined into a single sample for both the before and after periods. Summary statistics for each of these samples are shown in Table 4.

Table 4. Combined Summary Statistics for Speed Studies

Period	Pavement Condition	Number of Vehicles	Mean	Standard Deviation
Before	Dry	291	28.13	4.16
	Wet	199	24.41	4.57
After	Dry	786	22.64	3.35
	Wet	100	21.79	2.87

Shoulder Encroachment Studies

Shoulder encroachment studies were conducted, prior to the installation of treatment, in May 2006. Observers recorded the date and time of day, the total number of vehicles and the number of vehicles that crossed the pavement edge lines. Data were collected during dry and wet conditions to determine if there are any changes in shoulder encroachments under dry and wet conditions.

Encroachment data were collected for the before condition (without Tyregrip) in May 2006, during which time researchers conducted 6 studies at different times of the day and for various days of the week. The researchers began data collection activities for the after condition (with Tyregrip) in July 2006 and completed in September 2007. A total of 10 studies were conducted during the after period. Summary statistics for the encroachment studies are provided in Table 5.

Table 5. Summary Statistics for Encroachment Studies

	Date	Day	Time Period of Observation	Total No. of Vehicles Observed	Number of Encroachments (Vehicles)	Percentage of Vehicles Encroaching Shoulder	Pavement Condition
Before	5/10/2006	Wed	12:30 - 13:30	809	109	13.47	Dry
	5/10/2006	Wed	17:52 - 18:52	1179	129	10.94	Dry
	5/11/2006	Thu	10:22 - 11:22	936	151	16.13	Dry
	5/16/2006	Tue	8:47 - 9:47	945	195	20.63	Wet
	5/16/2006	Tue	14:45 - 15:45	531	193	36.35	Wet
	5/16/2006	Tue	18:12 – 18:49	485	176	36.29	Wet
After	7/7/2006	Fri	10:22 – 11:22	729	124	17.01	Wet
	7/7/2006	Fri	12:30 – 13:30	800	109	13.63	Dry
	7/7/2006	Fri	14:45 - 15:45	993	108	10.88	Wet
	7/7/2006	Fri	17:52 – 19:02	955	126	13.19	Dry
	9/13/2007	Thu	13:15 - 14:15	810	102	12.59	Dry
	9/13/2007	Thu	15:00 – 16:00	464	65	14.01	Dry
	9/19/2007	Wed	10:30-11:30	759	114	15.02	Dry
	9/19/2007	Wed	12:30 – 13:30	563	115	20.43	Dry
	9/19/2007	Wed	17:30 – 18:30	1025	154	15.02	Dry
	9/20/2007	Thu	8:45 - 9: 45	892	136	15.25	Dry

4.0 STATISTICAL ANALYSIS

It is customary to use statistical analysis in the effectiveness evaluation process. Such analyses ensure that the observed differences in MOEs for before and after periods are in fact due to the treatment and not due to chance. All statistical analyses require certain assumptions. Validity of the assumptions is critical to the appropriateness of the statistical analyses; therefore, several tests were performed.

Tests for Variability

The F Max test was performed to test the homogeneity of the variance in before and after data. The F Max value is the ratio of the two variances of samples where the larger of the two variances is used in the numerator. The null hypothesis for this test states that the population variance during the before period equals the population variance during the after period. The alternative hypothesis states that the population variances are not equal. The test statistic for the F Max test is as follows [1]:

$$F = \frac{s_1^2}{s_2^2}$$

where:

s_1^2 is the value of the larger sample variance of the two groups

s_2^2 is the value of the smaller sample variance of the two groups

The critical values for the F Max test are based on the F distribution and they are determined by the number of degrees of freedom of the before condition and the after condition, as well as the assumed confidence level, in this case 95%. If the calculated F Max value exceeds the critical F value, the null hypothesis must be rejected and the assumption of homogeneity fails.

The F-Max test was conducted to determine whether Student's t-Test is appropriate for testing the differences in mean speeds as opposed to a nonparametric alternative test. If the p-value resulting from the F-test is less than the critical value of $\alpha=0.05$, the differences in the sample variances are unlikely to have occurred based on random variation. Thus, the null hypothesis is rejected and it can be concluded that there is a difference between the variances in the populations of the two groups from which the samples were drawn.

Tests for Differences in the Mean Speeds

Student's t-test requires data to be normally distributed and have equal variances. The F-Test was used to test homogeneity of variance while the One Sample Kolmogorov-Smirnov Test was used to determine whether the data were normally distributed [2]. If both of these conditions are satisfied, Student's t-test can be used to compare speed differences between the two groups. The analysis revealed that neither of these conditions were satisfied, so the Mann-Whitney U Test was utilized instead to determine if differences in the mean speeds before and after the application of the Tyregrip treatment are statistically significant.

The Mann-Whitney U test is a non-parametric test for assessing whether two nonparametric samples are equal. The test involves the calculation of a statistic, U, whose distribution under the null hypothesis is known. To calculate the test statistic, all observations from both groups are arranged in a single ranked series. Summing up the overall ranks for the first group provides the variable R1. "U" is then given by the following formula:

$$U = R_1 - \frac{n_1(n_1 + 1)}{2}$$

Where n1 is equal to the sample size of the first group. For sufficiently large samples, a normal approximation is used to calculate the z-statistic as follows:

$$z = \frac{U - \mu_U}{\sigma_U}$$

Where z is a standard normal deviate whose significance can be checked using the standard tables of the normal distribution. The variables μU and σU are the mean and standard deviation of U if the null hypothesis is true, and are given by the following equations:

$$\mu_u = \frac{n_1 n_2}{2}$$

$$\sigma_U = \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}$$

Where n1 is the sample size of the first group and n2 is the sample size of the second group.

A two-tailed test was used in which the null hypothesis stated that there was no difference between the speeds in the before and after periods. A one-tailed test requires the direction of the difference to be known/specified prior to the analysis. The two-tailed test was used for this analysis, as the effectiveness of the Tyregrip was not known. The two-tailed test is more stringent than the one-tailed test and requires a larger difference between the means in order to be statistically significant.

Z-Test for Differences in Proportions of Advisory Speed Limit Violations and Encroachments

The z-test was used to determine if the differences in the proportion of speeding vehicles before and after the Tyregrip treatment were different. For the z-test, a two-tailed analysis was performed with a null hypothesis that states there are no differences between the two proportions. As with the test of mean speeds, a two-tailed test was used for this analysis as the effectiveness of the Tyregrip was not known beforehand. Also, the level of confidence was 0.05 and the power was selected as 0.8.

The following are the equations used to calculate the z-statistic. If the calculated z-value is greater than the critical z-value obtained from the standard statistical tables, the difference in proportions is statistically significant. The calculated z-value was determined using the following equation [2]:

$$z = \frac{(p_1 - p_2) - (P_1 - P_2)}{s_{p1-p2}}$$

where:

p_1 = the sample proportion associated with the before period

p_2 = the sample proportion associated with the after period

P_1 = the population proportion of the before period

P_2 = the population proportion of the after period

s_{p1-p2} = the standard error of the difference between two independent proportions

If the two proportion distributions are approximately normal and the mean is equal to the difference between the population proportions (P1-P2), the standard deviation can be estimated as the standard error of the difference between two independent proportions and is calculated as follows [2]:

$$s_{p1-p2} = \sqrt{pq\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

where:

$$p = \frac{f_1 + f_2}{n_1 + n_2}$$

$q = 1 - p$

f_1 = the frequency of occurrence in the before period

f_2 = the frequency of occurrence in the after period

5.0 RESULTS

This section presents the results of the statistical tests conducted to examine the effects of the Tyregrip surface on travel speeds and shoulder encroachments.

Tests for Speed Variability

Table 6 presents the results of the F-test used to determine whether the variances of the speed distributions are equal before and after the application of the Tyregrip treatment. In both cases, the variance was found to decrease significantly after the Tyregrip was applied, which indicates a positive impact on safety. As the variability of travel speeds at a particular location decreases, so does the likelihood of a crash.

Table 6. F-test Results for Variance of Speed Distributions

			Sample Size	Variance	F-Statistic	F-Critical	Conclusion
Treated	Dry	Before	291	17.31	1.21	1.1694	Unequal Variances
		After	786	20.88			
	Wet	Before	199	11.22	1.36	1.3210	Unequal Variances
		After	100	8.24			

Tests for Normality of Speed Distributions

Table 7 presents the results of the One-Sample Kolmogorov-Smirnov test used to determine whether the speed distributions were normal. Normality is a critical assumption for the traditional parametric procedures used to test whether the speeds are significantly different between the two samples. In order for the parametric tests to be valid, both the before and after speed distributions must be approximately normal. However, the normality assumption was not met for the after period speed distributions under either wet or dry pavement conditions. Consequently, the nonparametric Mann-Whitney U Test was utilized to compare the mean speeds for the before and after periods.

Table 7. One Sample Kolmogorov-Smirnov Test Results

Pavement Condition	Period	Sample Size	Mean Speed (mph)	Std. Dev. (mph)	Z-statistic	Z-critical	Conclusion
Dry	Before	291	28.13	4.158	1.201	+/- 1.36	Approximately Normal
	After	786	22.64	3.352	2.538	+/- 1.36	Not Normal
Wet	Before	199	24.41	4.574	0.971	+/- 1.36	Approximately Normal
	After	100	21.79	2.872	1.384	+/- 1.36	Not Normal

Tests for Differences in the Mean Speeds

The results of the Mann-Whitney U Tests are shown in Table 8. The mean speeds were found to decrease by an average of 3.72 miles per hour under dry pavement conditions after the application of the Tyregrip treatment. Under wet conditions, the mean speeds also decreased, by an average of 2.62 miles per hour after the application of the Tyregrip treatment. The increased frictional forces created by the Tyregrip treatment make it possible for drivers to travel at higher speeds while maintaining their lane position. However, it appears that drivers are reducing their speeds, possibly due to texture difference in pavement and potential additional noise created by the Tyregrip surface.

Table 8. Mann-Whitney U Test Results for Mean Vehicle Speeds

Pavement Condition	Period	Sample Size	Mean Speed (mph)	Mean Rank	Mann-Whitney U	Z-statistic	Z-critical	Conclusion
Dry	Before	291	28.13	814.23	33981.5	-17.769	+/- 1.96	Speeds Lower After Treatment
	After	786	24.41	436.29				
Wet	Before	199	24.41	167.77	6414.5	-5.027	+/- 1.96	Speeds Lower After Treatment
	After	100	21.79	114.65				

Z-Test for Differences in Proportions of Speed Limit Violations

The posted advisory speed for the ramp under study is 25 miles per hour. Z-test was conducted to determine if the proportion of vehicles traveling over the advisory speed was significantly different after the application of the Tyregrip treatment. The results in Table 9 show that the proportion of speeding drivers on the treated section of the ramp decreased significantly under both wet and dry pavement conditions. These findings are consistent with the results of the mean speed analysis discussed earlier. In general, after the Tyregrip has been applied, drivers tended to decrease their speed as they progressed along the ramp. This was particularly true of the faster drivers because both the proportion of speeding vehicles and the variance of the speed distribution were found to decrease after the treatment had been applied.

Table 9. Z-test Results for Proportion of Vehicles Exceeding Posted Advisory Speed

Pavement Condition	Period	Sample Size	Cars Speeding	Proportion Speeding	Group Proportion	Z-statistic	Z-critical	Conclusion
Dry	Before	291	218	0.75	0.36	-16.02	+/- 1.96	Fewer Speeding Vehicles After Treatment
	After	786	173	0.22				
Wet	Before	199	79	0.40	0.31	-4.34	+/- 1.96	Fewer Speeding Vehicles After Treatment
	After	100	15	0.15				

Z-Test for Differences in Proportions of Vehicles Encroaching the Shoulder

The proportion of vehicles encroaching either the outer or inner shoulder was examined prior to and following the application of the Tyregrip using the Z-test. Table 10 shows that the proportion of drivers encroaching the shoulder decreased after the installation of the Tyregrip under wet pavement conditions while no significant difference was found under dry conditions.

Table 10. Z-test Results for Proportion of Encroaching Vehicles

Pavement Condition	Period	Sample Size	Vehicles Encroaching	Proportion	Group Proportion	Z-statistic	Z-critical	Conclusion
Dry	Before	2924	389	0.13	0.14	-1.07	+/- 1.96	No Statistically Significant Difference
	After	6268	921	0.15				
Wet	Before	1961	564	0.29	0.22	12.34	+/- 1.96	Encroachments Decreased After Treatment
	After	1722	232	0.13				

6.0 CONCLUSIONS

The objective of this study was to determine the effectiveness of the Tyregrip system in improving safety through increased pavement friction. A field experiment was conducted on the on-ramp to northbound I-75 from eastbound Royal Palm Boulevard. Crash, speed and encroachment data were collected before and after the application of the Tyregrip treatment at various times of the day and week. Statistical tests were conducted in order to better understand whether the changes observed in the measures of effectiveness (mean speed, speed distribution, proportion of speeding vehicles and proportion of vehicles encroaching the shoulder) are attributable to the utilization of the Tyregrip treatment. A summary of the findings is as follows:

- Over the four-year period prior to the installation of the Tyregrip, the treated section experienced an average of 2.54 crashes per year. In the 12-month period immediately following the installation (June 2006 to June 2007), the treated section of the ramp has experienced two crashes. Since sufficient crash data was not available to determine a statistically significant difference in crash frequency or rate, surrogate measures of safety were evaluated as discussed below.
- Travel speeds were found to decrease after the application of the Tyregrip by an average of 3.72 miles per hour under dry pavement conditions and 2.62 miles per hour under wet pavement conditions. While the increased frictional forces created by the Tyregrip treatment make it possible for drivers to travel at higher speeds while maintaining their lane position, the speed studies indicate that motorist are reducing their speed, possibly due to texture difference in pavement and potential additional noise created by the Tyregrip surface.
- The proportion of speeding drivers was found to decrease after the Tyregrip surface treatment had been applied under both wet and dry pavement conditions. The variance of the travel speeds

also decreased following the Tyregrip treatment. These findings indicate that there were fewer drivers traveling substantially over the speed limit.

- The proportion of vehicles encroaching onto the shoulder was found to decrease substantially under wet pavement conditions after the installation of the Tyregrip treatment. No significant difference was found in the proportion of encroachments under dry conditions.

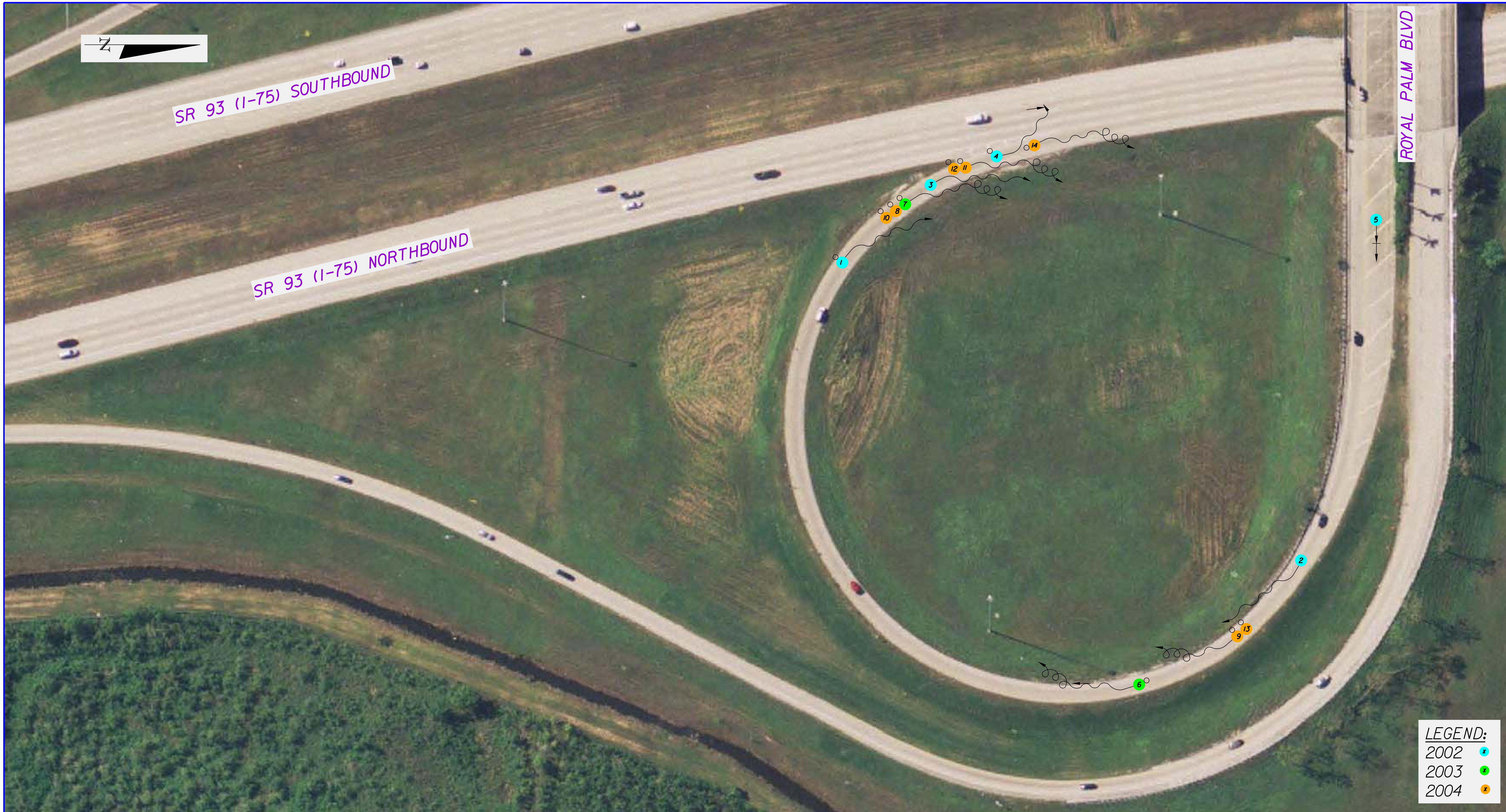
Overall, the Tyregrip treatment was effective in increasing the friction between the roadway and vehicle tires. The treatment was also effective in assisting motorists in maintaining their lane position under wet pavement conditions. In addition, drivers tended to slow down when traveling over the treated section of the ramp. It appears that the use of Tyregrip may be a practical countermeasure for improving safety at locations that are prone to run-off-road crashes, particularly sharp curves and entry/exit ramps.

7.0 REFERENCES

1. *Highway Safety Evaluation Procedural Guide,* Federal Highway Administration, March 1981.
2. Montgomery, D.C. and G.C. Runger. *Applied Statistics and Probability for Engineers, Fourth Edition*. John Wiley and Sons, Inc., Hoboken, NJ, 2007.

APPENDIX A

Collision Diagram for the Before Period (2002 to 2004)



REAR-END COLLISION
SIDESWIPE
ANGLE COLLISION
COLLISION W/ PEDESTRIAN
COLLISION W/ BICYCLE

SYMBOLS:

HIT FIXED OBJECT
OUT OF CONTROL
LEFT TURN COLLISION
RIGHT TURN COLLISION
DISREGARDED TRAFFIC SIGNAL
PERSONAL INJURY
FATALITY

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2002 TO 2004 COLLISION DIAGRAM
SR 93 (I-75) NB ON-RAMP
FROM ROYAL PALM BLVD (EB)

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