EVALUATION OF INNOVATIVE SAFETY TREATMENTS

Volume 2: A Study of the Effectiveness of Temporary Rumble Strips in Construction Work Zones

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16. Abstract

The Florida Department of Transportation (FDOT) District 1 office utilized temporary rumble strips on the approach to work zone areas on State Road 31 to alert motorists of lane closures associated with a milling/resurfacing project, from the Lee/Charlotte County line to the Charlotte/Desoto County line. The ability of rumble strips to alert drivers of unusual or hazardous conditions makes them ideal candidates for use on the approach to a highway work zone. In addition to ease-of-use, temporary rumble strips are brightly colored. Thus, temporary rumble strips provide three types of warnings to alert the motorist to the approaching work zone: a physical vibration, an auditory rumble sound, and a visual cue. In addition to making drivers more alert, it is anticipated that temporary rumble strips will impact travel speeds.

This report documents the findings and conclusions of a field experiment conducted on State Road 31 at various test (with temporary rumble strips) and control (without temporary rumble strips) locations to determine the effectiveness of temporary rumble strips in reducing travel speeds approaching highway work zones. The evaluation consisted of measuring travel speeds of motorists as they approached work zone areas with and without temporary rumble strips, and comparing changes in average speed, speed distribution, and the proportion of speeding vehicles. The results of this evaluation indicated that the use of temporary rumble strips in advance of construction work zones reduced vehicular speeds once motorists encountered the temporary rumble strips. Therefore, the use of temporary rumble strips prior to a construction work zone may be a practical countermeasure to reduce vehicular speeds through the work zone.

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Executive Summary

Speeding in highway work zones is one of the primary causes of injuries and fatalities. In 2003, a total of 3,509 crashes occurred in highway work zones in the State of Florida, resulting in 104 fatalities. Drivers need to be alert and travel at a slower speed to be able to safely travel through work zones. This is due to many factors including abrupt changes in horizontal or vertical alignment, lane closures, slow moving vehicles leaving/entering the traffic stream from the construction area, and less than the usual recovery areas.

The Florida Department of Transportation (FDOT) District 1 office utilized temporary rumble strips in addition to normally used warning signs/devices on the approach to work zone areas on State Road 31 (SR 31) to alert motorists of lane closures associated with a milling/resurfacing project (FM No. 193750), from the Lee/Charlotte County line to the Charlotte/Desoto County line. This segment of SR 31 is a two-lane rural highway with paved shoulders on both sides of the roadway. The speed limit along the entire study segment of SR 31 is 60 miles per hour.

Rumble strips are cuts or ridges formed in the pavement that cause vibrations and make a rumbling sound when driven over. Rumble strips are widely used across the United States to warn drivers of a change in traffic patterns or unusual roadway conditions. The ability of rumble strips to alert drivers of unusual or hazardous conditions makes them ideal candidates for use on the approach to a highway work zone. However, the traditional rumble strips are not easy to install or to remove, making them impractical for use in a temporary situation such as a highway work zone. Temporary rumble strips, made from a highly durable composite material with an adhesive backing that allows them to easily adhere to the roadway, can be installed and removed more easily than traditional rumble strips. In addition to being easy to use, temporary rumble strips are brightly colored. Thus, motorists experience three different types of warnings alerting them to the approaching work zone: a physical vibration, an auditory rumble sound, and a visual cue. In addition to making motorists more alert, it is anticipated that temporary rumble strips will also encourage drivers to slow down as they approach work zones.

The goal of this research was to determine the effectiveness of temporary rumble strips in reducing travel speeds approaching highway work zones. The effectiveness of the temporary rumble strips was determined through a field experiment conducted on SR 31 at various test (with temporary rumble strips) and control (without temporary rumble strips) locations.

Four sets of rumble strips were installed in advance of the work zone in each travel direction. The rumble strips were four inches wide and were installed in four sets of six strips per set. The first set was located 100 feet past the first (1500 feet) construction warning sign. The second, third, and fourth sets were installed at 500 feet, 250 feet, and 100 feet downstream of the previous sets, respectively. The rumble strips were installed perpendicular to the travel direction of northbound and southbound traffic.

The evaluation consisted of measuring travel speeds of motorists as they approached work zone areas with and without temporary rumble strips, and comparing differences in average speed, speed distribution, and the proportion of speeding vehicles. Statistical analyses were performed to test whether the observed differences were significant.

Speed data were collected for the control condition (without rumble strips) during the second week of June 2006 and the third week of July 2006 when researchers conducted 19 speed studies at different times of the day and for various days of the week. Similarly, speed data for the test condition (with rumble strips) were collected over a two-week period during the fourth week of July 2006 and the first week of August 2006. A total of 25 speed studies were conducted for the test condition.

Speed data were collected at two locations under each condition (with and without rumble strips): i) about 4,000 feet upstream from the first construction warning sign, and ii) just prior to the final warning sign or about 600 feet upstream from the flagging station. Based upon the data collected in the field and the requirements for sample size, the data for the test and control locations at the 4,000-foot and 600-foot locations were aggregated into two time periods, Noon and Evening. The Noon period includes data collected between 11 AM and before 2 PM and the Evening period includes data collected between 2 PM and 5 PM.

For both time periods at the 600-foot upstream location, the t-test for difference in mean speeds indicated that there was a statistically significant difference between the mean speeds for Noon and Evening time periods at the 95% confidence level. The mean speeds at test locations (with rumble strips) were approximately 9 miles per hour lower than those observed at control locations (without rumble strips). The tests also indicated that mean speeds for the Noon and Evening periods at the 4,000-foot upstream location were statistically similar.

The Mann-Whitney and the Kolmogorov-Smirnov tests were performed to determine if there were differences in the speed distributions between the test and control conditions. Both tests indicated statistically significant differences between the speed distributions for the Noon and Evening periods at

the 600-foot upstream location at the 95% confidence level. Based on the skew of the distribution, both the Noon and Evening time period distributions are positively skewed for the test condition (with rumble strips) indicating that there were a greater number of speed observations toward the lower end of the scale and fewer speed observations toward the upper end of the scale. The control (without rumble strips) condition's speed distribution exhibited a negative skew for both periods at the 600-foot location, indicating that there were a greater number of speed observations toward the upper end of the scale and fewer speed observations toward the lower end of the scale. This indicates that travel speeds were lower at the test (with rumble strips) locations than those observed at the control (without rumble strips) locations. In other words, the presence of rumble strips resulted in lower travel speeds approaching work zones.

The z-test was used to compare the proportions of vehicles speeding (traveling over the 60 mph speed limit) at the test locations, with those at the control locations. The results of the z-test indicate that the null hypothesis was accepted at the 95% confidence level indicating that the proportions of vehicles speeding at control and test locations for each of the analysis periods were statistically similar.

The results of this evaluation indicated that the use of temporary rumble strips in advance of construction work zones reduced vehicular speeds once motorists encountered temporary rumble strips. Therefore, the use of temporary rumble strips prior to a construction work zone may be a practical countermeasure to reduce vehicular speeds through the work zone.

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1.0 INTRODUCTION

Speeding is a common occurrence in highway construction and maintenance work zones. The hazards associated with maintaining traffic through highway work zones are elevated when drivers do not obey reduced speed limits associated with work zones. It is widely accepted by law enforcement and traffic safety professionals that excessive speeds and speed variance are contributing factors in traffic crashes.

Although highway work zones are marked for a reduced speed limit, the adherence to such reduced speed limit in work zones is sporadic at best. Driver perception of heightened risk is probably the most influential factor in achieving compliance with lowered speed limit regulations in work zones. Speeding in highway work zones is one of the primary causes of motorist and construction worker injuries and fatalities.

In 2003, a total of 3,509 crashes occurred in highway work zones in the State of Florida, resulting in 104 fatalities[1]. Nine out of ten fatalities in highway work zones in the State of Florida were either motorists or pedestrians, with only one out of ten involving construction workers. Drivers need to be alert and travel at a slower speed to be able to safely travel through work zones. This is due to many factors including abrupt changes in horizontal or vertical alignment, slow moving vehicles leaving/entering the traffic stream from the construction area, and less than the usual recovery areas.

In an effort to improve safety in work zones, the Florida Department of Transportation (FDOT) District 1 office utilized temporary rumble strips in addition to normally used warning signs/devices on the approach to work zone areas on State Road 31 to alert motorists of lane closures associated with a milling/resurfacing project (FM No. 193750), from the Lee/Charlotte County line to the Charlotte/Desoto County line (see Figure 1). This segment of SR 31 is a north/south, two-lane, rural highway with paved shoulders on both sides of the roadway (see Photograph 1). The speed limit along the entire study segment of SR 31 is 60 miles per hour.

Rumble strips are cuts or ridges formed in the pavement that cause vibrations and make a rumbling sound when driven over. Rumble strips are widely used across the United States to warn drivers of a change in traffic pattern or unusual roadway conditions. For instance, they are frequently used on the shoulder of high-speed roadways to alert potentially errant drivers that they are leaving the traveled way. Rumble strips are also frequently used on the approach to an unusual roadway condition, such as a sharp curve or an unexpected stop condition.

Figure 1. Project location map

Temporary rumble strips installed in advance of work zones on SR 31 in Charlotte County from Lee County line to Desoto County line.

Photograph 1. SR 31 typical cross section in the vicinity of the work zone

The ability of rumble strips to alert drivers of unusual or hazardous conditions makes them ideal candidates for use on the approach to a highway work zone. However, the traditional rumble strips are not easy to install or to remove, making them impractical for use in a temporary situation like a highway work zone. In recent years, however, manufacturers have developed temporary rumble strips, made from a highly durable composite material with an adhesive backing that allows them to easily adhere to the roadway (see Photographs 2 and 3). Temporary rumble strips can be installed and removed more easily than traditional rumble strips. In addition to ease-of-use, temporary rumble strips are brightly colored, which is another advantage over traditional rumble strips. Thus, temporary rumble strips provide motorists with three different types of warnings alerting them to the approaching work zone: a physical vibration, an auditory rumble sound, and a visual cue. In addition to making drivers more alert, it is anticipated that temporary rumble strips will also encourage drivers to slow down as they approach work zones.

The goal of this research was to determine the effectiveness of temporary rumble strips in reducing travel speeds approaching highway work zones. The effectiveness of the temporary rumble strips was determined through a field experiment conducted on SR 31 at various test (with temporary rumble strips) and control (without temporary rumble strips) locations.

2.0 STUDY OBJECTIVES

A variety of traffic control devices and special countermeasures are employed in varying degrees in work zones to warn approaching drivers of a change in traffic pattern, lane closures, reduced speed limits or unusual roadway conditions. In addition to normally used warning signs/devices, the Florida Department of Transportation District 1 office utilized temporary rumble strips on the approach to work zone areas on State Road 31 to alert motorists of lane closures associated with a milling and resurfacing project (Project No. 193750). This research was designed to evaluate the effectiveness of work zones with temporary rumble strips, in comparison to work zones without rumble strips.

The objective of this study was to determine the effectiveness of the use of temporary rumble strips through the examination of vehicular speeds measured along SR 31 at various locations with and without temporary rumble strips.

Photograph 2. Sectional view of temporary rumble strip
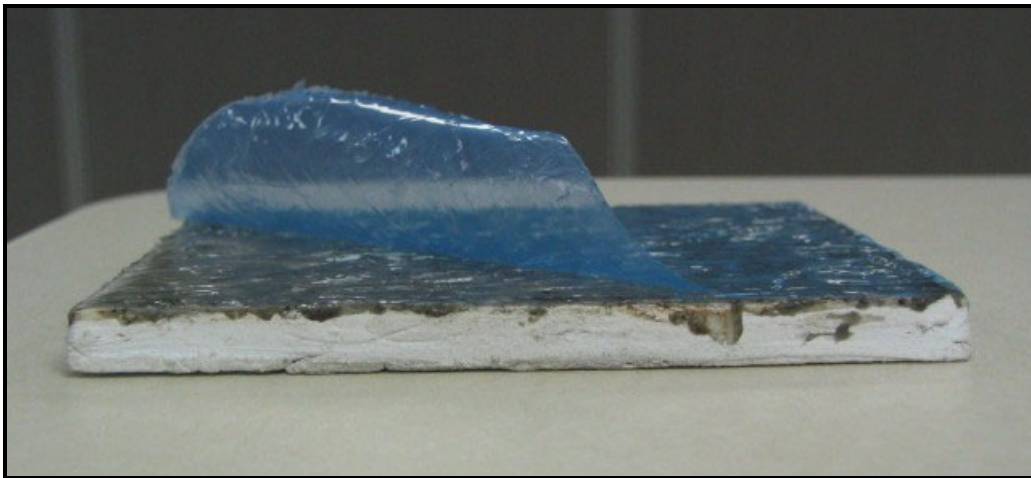
Photograph 3. Adhesive backing on temporary rumble strip

3.0 STUDY METHODOLOGY

In order to determine the effectiveness of the temporary rumble strips, a comparative parallel evaluation methodology was utilized. In the comparative parallel evaluation study, data are compared for test and control conditions. In this case, a test condition refers to a work zone that utilized temporary rumble strips and a control condition refers to a work zone that did not utilize temporary rumble strips (see Figures 2 and 3).

Four sets of rumble strips were installed in advance of the work zone, in each travel direction. The rumble strips were four inches wide and were installed in four sets of six strips per set (see Photograph 4). The first set was located 100 feet past the first (1500 feet) construction warning sign. The second, third, and fourth sets were installed at 500 feet, 250 feet, and 100 feet downstream of the previous sets, respectively (see Figure 3). The rumble strips were installed perpendicular to the travel direction of northbound and southbound traffic.

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The Maintenance of Traffic (MOT) plan remained the same in each condition (control and test), except for the use of temporary rumble strips. The MOT plans for the control and test conditions are shown in Figures 2 and 3, respectively. The MOT plans shown in these figures are derived from Index 603 of the 2004 FDOT Design Standards for Design, Construction, Maintenance and Operations on the State Highway System.

Photograph 4: Typical installation of temporary rumble strips (6 strips per set)

Measures of Effectiveness

A comparison was made between the speeds of vehicles traveling through construction work zones with and without temporary rumble strips. Changes in travel speed were evaluated in several ways, such as changes in mean speed, speed distribution and the proportion of speeding motorists (the percentage of motorists driving above the 60 mph speed limit). Thus, the proposed measures of effectiveness (MOEs) for this evaluation study were as follows:

- Change in average speed
- Change in speed distribution
- Change in the proportion of speeding vehicles

The statistical significance of the effectiveness of temporary rumble strips was tested to determine whether the changes observed in the measures of effectiveness are attributable to the use of temporary rumble strips or simply due to chance. Statistical analyses that were performed to test the effectiveness of temporary rumble strips were as follows:

- Kolmogorov-Smirnov and Shapiro-Wilk Tests – to determine if the data are normally distributed
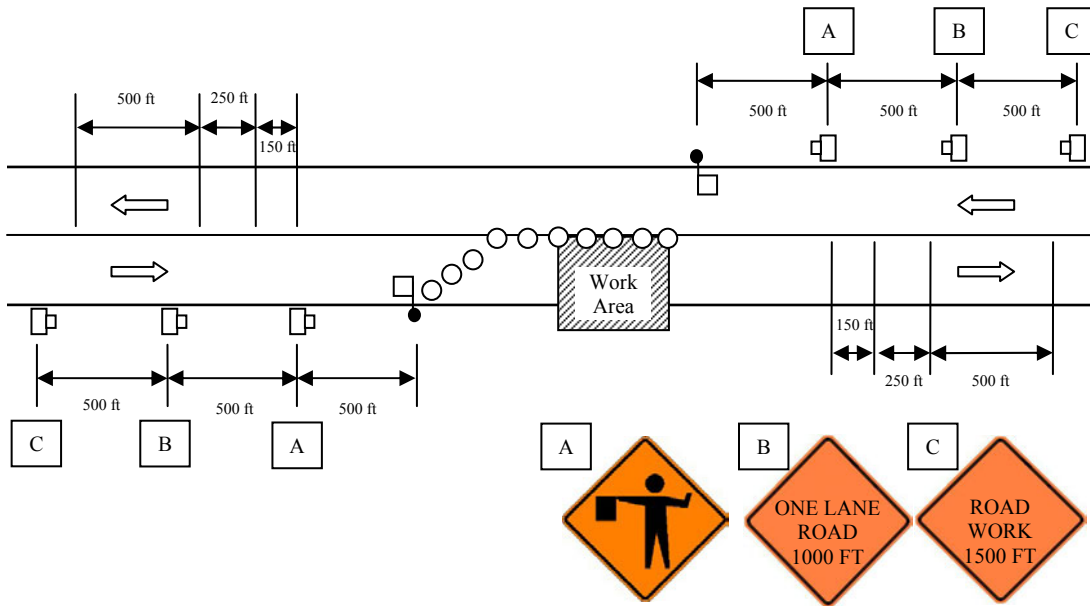
5

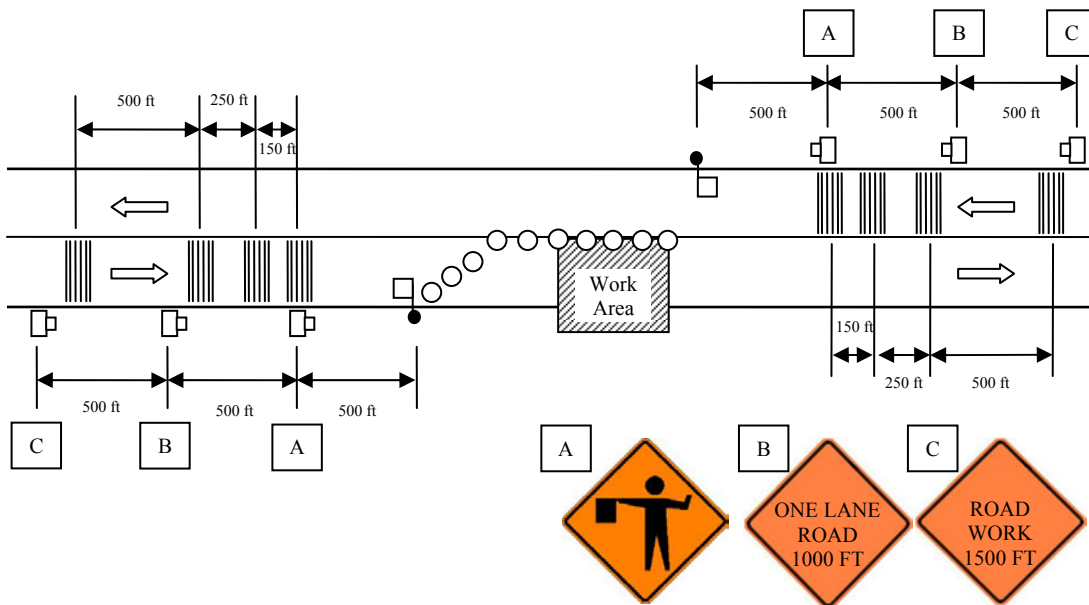Figure 2. MOT Plan for Control Condition

Figure 3. MOT Plan for Test Condition

- Z-scores for skewness and kurtosis with the Kolmogorov-Smirnov Test – to determine if there are significant changes in the shape of the speed distribution
- Student's t-Test – to determine if the differences between the mean speeds are statistically significant
- z-Test – to determine if the differences between the proportions of vehicles traveling over the speed limit are statistically significant

Limitations/Assumptions

The variables that could not be controlled and the assumptions that were made in the design of this experiment are as follows:

- The work zone was dynamic and changed location every day. Thus, researchers were able to collect data at similar locations with and without rumble strips, though not necessarily at the identical location. Because SR 31 is a two-lane rural roadway with a 60 mph speed limit along the entire 19-mile study segment, it was assumed that conditions are materially the same at each location, making it possible to compare the test and control data.
- It is likely that some factors such as the weather, the time of day, and the approach sight distance for the work zone varied from one data collection period to another. Each time data were collected, however, researchers recorded general observations so that these factors could be taken into account as necessary.

4.0 DATA COLLECTION

Observers collected speed data using a radar gun, and the speed of individual vehicles was recorded. Observers also recorded the date and time of day, the direction of travel (northbound or southbound), and any other information that could affect the speed or behavior of motorists entering the work zone area, such as the weather or the approach sight distance for the work zone.

Speed data were collected for the control condition (without rumble strips) during the second week of June 2006 and the third week of July 2006, during which time researchers conducted 19 speed studies at different times of the day and for various days of the week. The contractor began to apply the temporary rumble strips as a part of setting up the Maintenance of Traffic (MOT) each day starting the fourth week of July 2006. Once again, speed data for the test (with rumble strips) condition were collected

at different times of the day and for various days of the week over a two-week period, during the fourth week of July 2006 and the first week of August 2006. A total of 25 speed studies were conducted for the test condition. Speed data were collected at the following two locations with and without rumble strips:

- About 4,000 feet upstream from the first warning sign. This location was selected to obtain travel speeds that are not influenced by signs/devices associated with the work zone or the slow moving/stopped traffic associated with lane closures.

- Just prior to the final warning sign or about 600 feet upstream from the flagging station. Since this location is in the midst of a series of rumble strips, the travel speeds measured at this location reflect speeds of vehicles that encountered three of the four sets of rumble strips.

The data collected at each of the locations are summarized in Table 1 for the 4,000-foot upstream location and Table 2 for the 600-foot upstream location.

Table 1. Summary of the Speed Studies Conducted 4,000 feet Prior to the First Warning Sign

Site Type	Date	Time	No. of Vehicles Observed	Mean Speed (MPH)	85th Percentile Speed (MPH)	Standard Deviation (MPH)
Control Condition (Without Rumble Strips)	6/6/2006	1:50 - 2:40 PM	100	58.6	61.91	3.94
	6/6/2006	3:22 - 4:00 PM	103	57.2	62.78	5.74
	6/7/2006	11:05 - 11:53 AM	100	56.4	60.7	4.8
	6/7/2006	4:08 - 4:57 PM	100	57.9	63.17	5.05
	6/8/2006	11:00 - 11:52 AM	100	58.8	61.33	3.71
	6/9/2006	11:42 - 12:17 PM	100	57.3	63.0	6.73
	7/17/2006	11:00 - 11:43 AM	100	56.9	62.0	5.51
	7/17/2006	4:06 - 4:52 PM	100	59.2	64.75	6.08
	7/18/2006	11:00 - 11:47 AM	100	55.7	60.75	4.99
	7/18/2006	3:50 - 4:34 PM	104	56.1	60.88	5.79
Test Condition (With Rumble Strips)	7/24/2006	4:00 - 4:48 PM	100	58.1	62.86	5.12
	7/25/2006	11:00 - 11:43 AM	100	57.2	62.4	6.18
	7/25/2006	3:40 - 4:20 PM	100	56.6	62.67	5.76
	7/26/2006	11:00 - 12:15 PM	100	55.8	61.0	6.23
	7/26/2006	3:56 - 4:33 PM	100	56.9	62.4	5.8
	7/27/2006	11:09 - 12:21 PM	100	56.8	62.33	6.25
	7/28/2006	11:00 - 12:03 PM	100	59.0	65.0	6.02
	8/3/2006	2:25 - 4:45 PM	101	59.1	65.14	5.95

Table 2. Summary of the Speed Studies Conducted 600 feet Upstream from the Flagging Station

Site Type	Date	Time	No. of Vehicles Observed	Mean Speed (MPH)	85th Percentile Speed (MPH)	Standard Deviation (MPH)
Control Condition (Without Rumble Strips)	6/7/2006	12:00 - 1:38 PM	100	49.8	54.2	4.53
	6/7/2006	2:10 - 4:03 PM	100	49.8	53.75	4.5
	6/8/2006	12:02 - 1:16 PM	50	45.6	49.93	5.24
	6/9/2006	12:26 - 1:52 PM	99	46.7	53.58	6.6
	6/9/2006	2:00 - 3:19 PM	68	46.7	51.7	5.76
	7/17/2006	12:00 - 1:47 PM	100	41.0	45.8	4.94
	7/17/2006	2:00 - 3:52 PM	100	39.9	45.2	5.43
	7/18/2006	12:00 - 1:48 PM	100	42.9	50.33	7.05
	7/18/2006	1:55 - 3:36 PM	104	41.8	48.8	6.33
Test Condition (With Rumble Strips)	7/24/2006	12:15 - 2:21 PM	96	29.7	34.87	5.36
	7/24/2006	2:25 - 3:53 PM	100	30.5	36.0	5.68
	7/25/2006	12:00 - 1:41 PM	100	35.9	42.33	6.38
	7/25/2006	1:50 - 3:27 PM	100	35.9	43.0	6.38
	7/26/2006	12:00 - 1:51 PM	100	37.8	42.6	5.57
	7/26/2006	1:55 - 3:48 PM	100	35.9	40.71	5.49
	7/27/2006	12:30 - 2:10 PM	67	37.4	43.48	5.92
	7/28/2006	12:10 - 1:55 PM	100	37.4	42.5	5.39
	7/28/2006	2:00 - 3:17 PM	56	36.8	41.6	5.64
	8/1/2006	2:44 - 5:15 PM	37	43.0	52.45	7.65
	8/2/2006	8:30 - 11:30 AM	89	39.6	47.83	7.76
	8/2/2006	12:00 - 2:00 PM	28	38.6	45.9	6.9
	8/2/2006	2:00 - 5:00 PM	69	36.3	41.88	7.5
	8/3/2006	8:00 - 11:30 AM	87	44.8	51.49	8.08
	8/3/2006	12:00 - 2:00 PM	70	43.7	52.17	8.45
	8/3/2006	2:00 - 5:00 PM	44	39.3	47.4	7.34
	8/4/2006	10:45 - 12:47 PM	63	32.5	36.55	5.52

Because the work zone required a lane closure, only one direction of traffic was allowed to traverse the work zone at a time using a flagging operation (see Photograph 5). The flagger stopped northbound traffic while southbound traffic traversed the work zone. Similarly, southbound traffic was halted while northbound traffic traversed the work zone. While each direction of travel was halted, a traffic queue continued to build, as shown in Photograph 6. Because these queues are likely to impact the speed of approaching vehicles, observers did not collect speed data until the stopped vehicles were allowed to move through the work zone and reached a free-flow condition. It was necessary for observers to coordinate with the flaggers, since the flaggers would not normally wait for free-flow speeds before halting traffic to let the traffic move in the other direction.

The number of observations, or sample size, collected at each location was reviewed to assure that Type I and Type II errors were minimized. For a detailed discussion of Type I and Type II errors, please refer to the Statistical Evaluation section of this report.   In order to determine the sample that was required to assure a statistically valid study, the following formula was used to estimate sample size:

$$n = \frac{Z^2 * \sigma^2}{\varepsilon^2}$$

Where:

        n = estimated sample size

        Z = 1.96, the two-tailed value of the standardized normal deviate associated with the desired level of confidence, 95%

        σ = standard deviation of the population

        ε = acceptable error, or half of the maximum acceptable confidence interval

The method listed above only requires the knowledge of the standard deviation of the population and the level of confidence or alpha level, which corresponds to the Type I error. However, the power of the test, $1-\beta$, is not specified nor controlled, which may result in a severe problem associated with Type II errors. Another formula for sample size, provided by Hinkle, et al [2], allows protection for both Type I and Type II errors.

Photograph 5. Typical One-Lane Operation with Flaggers

Photograph 6. Typical Queue Buildup due to One-Lane Operation

The formula is as follows [2]:

$$n = \frac{(Z_\beta - Z_\alpha)^2 * \sigma^2}{\varepsilon^2}$$

Where:

Z_β = distance from the critical value to mean in H_a (in standard deviation units);

for $\beta = 0.2$, $Z = -0.842$

Z_α = distance from the critical value to mean in H_o (in standard deviation units); for a

two-tailed test and $\alpha = 0.05$, $Z = 1.96$

Table 3 summarizes the sample size requirements based upon various beta and error levels. The final sample size required was selected using a beta of 0.20 and an error level of two miles per hour (MPH) for a minimum sample size of 130 speed observations for each condition, control and test.

Table 3. Sample Size Requirements

Beta Level	Minimum Sample Size Required	
	2 mph Error Level	5 mph Error Level
0.20	130	21
0.30	102	17

In order to achieve a power of 80 % (beta equal to 0.20), the sample size requirements of 130 observations must be met. However, the actual number of observations collected at each location was slightly less than 130. Based upon the data collected in the field and the requirements for sample size, the data for the test and control conditions at the 4,000-foot and 600-foot locations were aggregated for analysis purposes. The data were aggregated into two time periods, Noon and Evening. The Noon period includes data collected between 11 AM and before 2 PM and the Evening period includes data collected between 2 PM and 5 PM. The data collected prior to 11 AM during the test condition was not included in the analysis due to lack of data during a similar time period under the control condition. The statistical tests were then conducted for the following comparison groups between test and control locations:

- Noon (11 AM to before 2 PM) at the 600-foot upstream location
- Evening (2 PM to 5 PM) at the 600-foot upstream location
- Noon (11 AM to before 2 PM) at the 4,000-foot upstream location
- Evening (2 PM to 5 PM) at the 4,000-foot upstream location

5.0 STATISTICAL EVALUATION

It is customary to use statistical analysis in the effectiveness evaluation process. Such analysis ensures that the observed differences in the test and control conditions are in fact due to the treatment/countermeasure, in this case temporary rumble strips, and not due to chance. All statistical analyses require certain assumptions. Validity of the assumptions is critical to the appropriateness of the statistical analysis; therefore, several tests were performed to test validity of the assumptions and are summarized below.

Tests for Normality

In order to determine if the speed data utilized for the Student's t-test are normally distributed, the skewness and kurtosis of the speed distribution were examined. The skewness and kurtosis can be tested by dividing the variable by the standard error of the variable to determine a calculated z-score [3]. The calculated z-score is compared to a z-critical value of 1.96. If the calculated value is greater than z-critical, then the data are considered to have deviated from the normal distribution. Two other tests that determine the normality of the data are the Kolmogorov-Smirnov and the Shapiro-Wilk tests which compare the observations in the sample to a normally distributed set of samples with the same mean and standard deviation [3].

Tests for Speed Distribution

Both the Mann-Whitney and Kolmorogov-Smirnov tests examine the distributions of two independent groups to determine if the distributions are similar [4].

Student's t-Test for Mean Speed Differences

In order to test the effectiveness of the rumble strips in reducing vehicular speeds, the Student's t-test was used to determine if the differences in the mean speeds were statistically significant. There are two underlying assumptions of the data before the Student's t-test can be applied. The data must exhibit a distribution that is approximately normal with variances that are equal between the two groups being tested. For the Student's t-test, a two-tailed analysis was used in which the null hypothesis states that there was no difference between the two means. The alternative hypothesis states that the means are not similar. A one-tailed test requires the direction of the difference to be specified prior to the analysis. The two-tailed test was used for this research because the effectiveness of temporary rumble strips was not known.

There are two potential errors involved in any statistical analysis, a Type I error or a Type II error. A Type I error indicates that a particular treatment has an impact on dependent variables, when in fact there is none [2]. A Type II error would indicate that the treatment does not have an impact on the dependant variables, when in fact there is an impact [2]. The Type I error can be reduced by selecting a small alpha level; however, this increases the possibility of a Type II error. Therefore, the selection of the level of confidence is critical. Traffic engineering professionals have consistently used a level of confidence of 95% for evaluations of various treatments.

The Student's t-test was used when comparing the mean speed for the test condition with the mean speed of the control condition. The following equations were utilized to calculate the t-statistic and the degrees of freedom (k'), assuming unequal sample sizes. If the calculated t-value was greater than the critical t-value obtained in available statistical tables, then the difference in mean speeds was considered to be statistically significant. The t-value was calculated with the following equation for [NB + NA − 2] degrees of freedom [2]:

$$t_{calc} = \frac{\overline{X}_B - \overline{X}_A}{\sigma^2 \, (1/N_B + 1/N_A)}$$

Where:

$\overline{X}_B$ = sample mean of data collected at control locations

$\overline{X}_A$ = sample mean of data collected at test locations

N_B = number of control locations

N_A = number of test locations

σ = common standard deviation

In case where the assumptions of normality and equal variances were not met, other statistical tests such as the F Max test were utilized to test the homogeneity of the variance.

If the data follow a normal distribution, but the variances are not equal, the Welch's test, or modified Student's t-test, can be utilized to test the differences in the mean speeds of the test and control conditions. The Welch's test statistic is as follows [4]:

$$W = \frac{\overline{X}_B - \overline{X}_A}{\sqrt{\dfrac{\hat{\sigma}^2_B}{N_B} + \dfrac{\hat{\sigma}^2_A}{N_A}}}$$

$$k' = \frac{\left[\hat{\sigma}^2_B / N_B + \hat{\sigma}^2_A / N_A \right]^2}{\dfrac{\left(\hat{\sigma}^2_B / N_B \right)^2}{N_B} + \dfrac{\left(\hat{\sigma}^2_A / N_A \right)^2}{N_A}}$$

Where:

X_B	=	sample mean of data collected at control locations
$\overline{X_A}$	=	sample mean of data collected at test locations
N_B	=	number of control locations
N_A	=	number of test locations
σ_B	=	standard deviation of data for control locations
σ_A	=	standard deviation of data for test locations
k'	=	degrees of freedom

Z-test for Differences in Proportions of Speed Limit Violations

The z-test was used to determine if the differences in the proportion of speeding vehicles with and without rumble strips were different. For the z-test, a two-tailed analysis was used with a null hypothesis that states there are no differences between the two proportions. The alternative hypothesis states that the proportions are not similar.

The following are the equations utilized to calculate the z-statistic. If the calculated z-value is greater than the critical z-value obtained in available statistical tables, then it can be stated that 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 test locations

p_2 = the sample proportion associated with the control locations

P_1 = the population proportion of the test locations

P_2 = the population proportion of the control locations

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]:

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

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

Where: q = 1 – p

f_1 = the frequency of occurrence in the test condition

f_2 = the frequency of occurrence in the control condition

The results of the statistical analysis are described in the following section.

6.0   RESULTS OF THE STATISTICAL TESTING

Tests for Normality

Aggregating the data into four groups (Noon at 600 feet, Evening at 600 feet, Noon at 4,000 feet and Evening at 4,000 feet) resulted in large sample sizes. The descriptive statistics for each of the four groups are shown in Table 4. The Kolmogorov-Smirnov and Shapiro-Wilk tests were performed to determine if each of the aggregated data sets were normally distributed. For each of the groups, the data were determined to significantly differ from the normal distribution at a level of confidence of 95%. Therefore, the data for each individual site was examined for normality.

Each data set was subdivided by the date of data collection and analyzed for normality. Each data set was plotted using a normal probability plot with the expected normal distribution values on the y-axis and the observed values on the x-axis. Data that are normally distributed should fall along the normal probability line. Each of the data sets probability plots are shown in Figures 4 through 11. It can be observed that each data set has small deviations from normality, but not sufficient to introduce a bias into the statistical testing. It was determined that the vast majority of the individual data sets were normally distributed.   Therefore, it may be assumed that the entire data set could be sufficiently normally distributed for further statistical testing without introducing a bias.

Table 4. Descriptive Statistics for the Analysis Periods

Various Speed Statistics	Time Period and Location of Speed Data							
	Noon at 600 feet WRS	Noon at 600 feet WORS	Noon at 4,000 feet WRS	Noon at 4,000 feet WORS	Evening at 600 feet WRS	Evening at 600 feet WORS	Evening at 4,000 feet WRS	Evening at 4,000 feet WORS
Sample Size	624	449	400	500	506	372	401	507
Mean (mph)	36.28	45.17	57.19	57.02	35.79	44.34	57.70	57.79
Median (mph)	36.0	46.0	57.0	57.0	35.0	45.0	58.0	58.0
Standard Deviation	7.24	6.61	6.26	5.32	7.11	6.82	5.74	5.47
Variance	52.36	43.73	39.17	28.28	50.62	46.50	32.95	29.90
Skewness	0.39	-0.19	0.60	0.08	0.40	-0.13	0.03	-0.17
Standard Error of Skewness	0.10	0.12	0.12	0.11	0.11	0.13	0.12	0.11
Kurtosis	0.05	-0.42	1.28	-0.04	0.19	-0.44	-0.35	0.02
Standard Error of Kurtosis	0.20	0.23	0.24	0.22	0.22	0.25	0.24	0.22
85th Percentile Speed (mph)	43.0	52.0	63.0	62.0	43.0	51.0	64.0	63.0

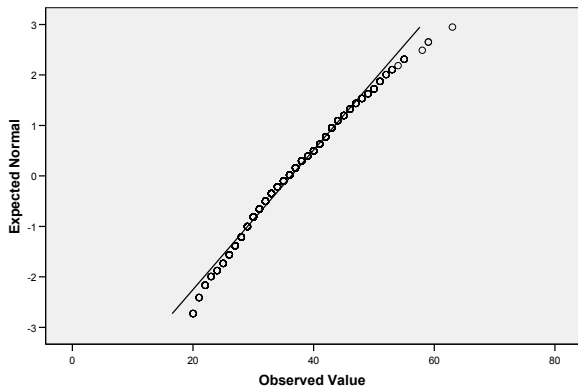WRS: With Rumble Strips; WORS: Without Rumble Strips

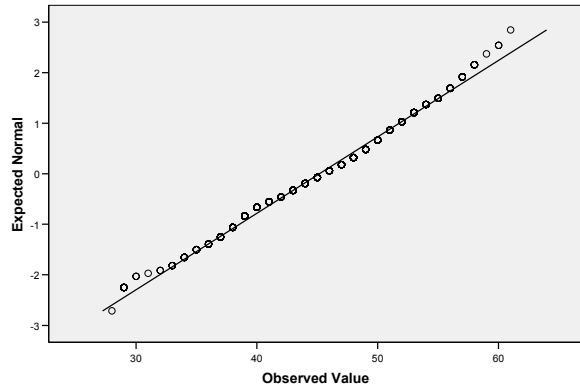Figure 4. Normal Probability Plot for Noon Period at 600-foot Upstream Location With Rumble Strips

Figure 5. Normal Probability Plot for Noon Period at 600-foot Upstream Location Without Rumble Strips
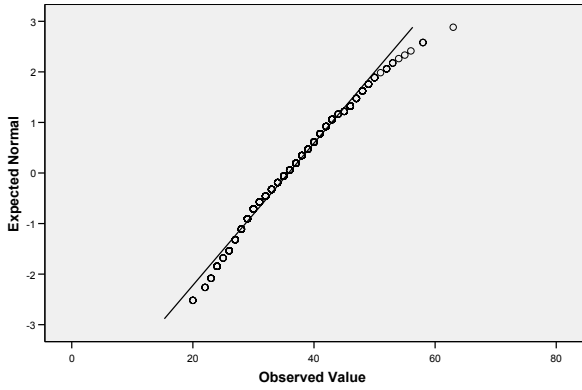
Figure 6. Normal Probability Plot for PM
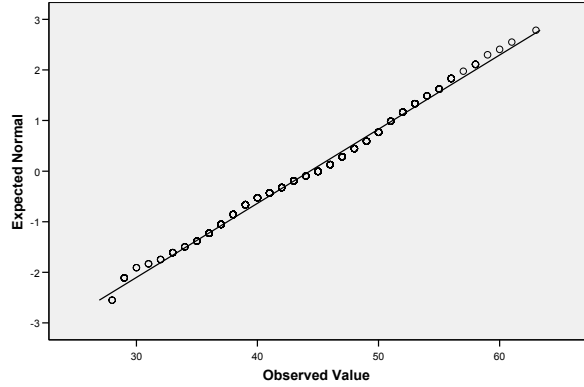Period at 600-foot Upstream Location
With Rumble Strips

Figure 7. Normal Probability Plot for PM
Period at 600-foot Upstream Location
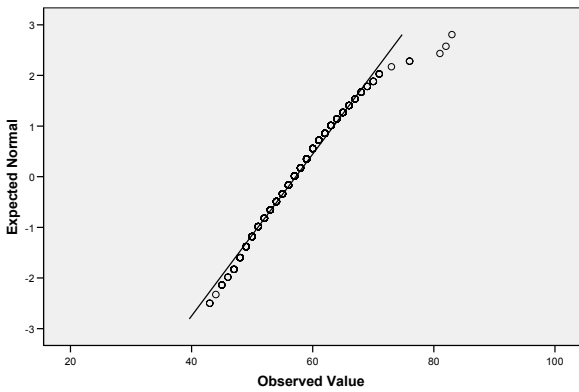Without Rumble Strips

Figure 8. Normal Probability Plot for Noon
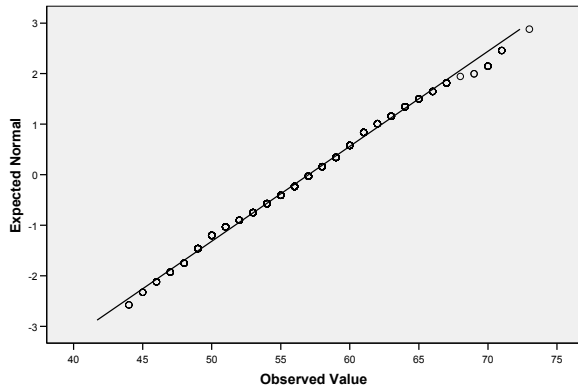Period at 4,000-foot Upstream Location
With Rumble Strips

Figure 9. Normal Probability Plot for Noon
Period at 4,000-foot Upstream Location
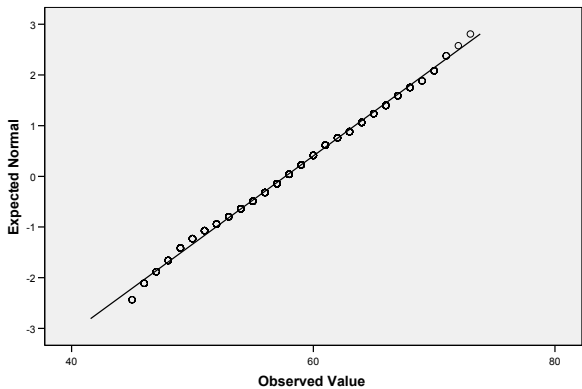Without Rumble Strips

Figure 10. Normal Probability Plot for PM
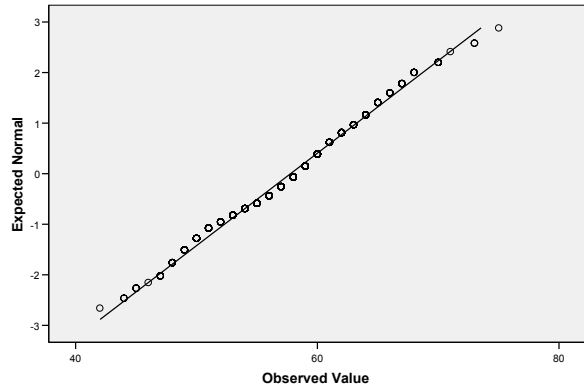Period at 4,000-foot Upstream Location
With Rumble Strips

Figure 11. Normal Probability Plot for PM
Period at 4,000-foot Upstream Location
 Without Rumble Strips

Tests for Speed Distribution

The Mann-Whitney and the Kolmogorov-Smirnov tests were performed to determine if there were differences in the speed distribution between the four analysis groups. Both tests indicated statistically significant differences between the speed distributions for the Noon and Evening periods at the 600-foot upstream location at the 95% confidence level. The tests also indicated that the speed distributions for the Noon and Evening periods at the 4,000-foot upstream location were statistically similar.

Based on the data collected at the 600-foot upstream locations, the speed distribution at the locations with rumble strips was significantly different than those at the locations without rumble strips. Based on the skewness of the distribution, both the Noon and Evening time period distributions for the test condition (with rumble strips) are positively skewed indicating that there were a greater number of speed observations toward the lower end of the scale and fewer speed observations toward the upper end of the scale. The control (without rumble strips) condition's speed distribution exhibited a negative skew for both periods at the 600-foot location, indicating that there were a greater number of speed observations toward the upper end of the scale and fewer speed observations toward the lower end of the scale. This indicates that travel speeds were lower at the test (with rumble strips) locations than those observed at the control (without rumble strips) locations.

Student's t-Test for Mean Speed Differences

Prior to conducting statistical analyses using the Student t-test, the assumption of equal variances was tested with the F Max test. Through the F Max test, it was found that only one of the groups, the Noon Period at the 4,000-foot upstream location, had dissimilar variances with a calculated F Max value of 1.39, which was greater than the critical value of 1.23. Therefore, the modified Student's t-test, or the Welch's procedure, was utilized as the test statistic for the Noon Period at the 4,000-foot upstream location and the Student's t-test was used for the other three analysis groups.

For both time periods at the 600-foot upstream location, the null hypothesis (the mean speed of the test condition was similar to the mean speed of the control condition) was not accepted. This indicates that there was a statistically significant difference between the mean speeds of Noon and Evening groups at the 95% confidence level. The mean speeds at test locations (with rumble strips) were significantly lower than those observed at control locations (without rumble strips). Table 5 summarizes the results of the Student's t-test.

Table 5. Student's t-test Results

Analysis Period	C_calculated	C_critical	Degrees of Freedom	Effect Size	Power of the Test	Test Results
Noon Period at 600-foot upstream	20.57	±1.96	1071	-1.27	95.25%	Reject Null
PM Period at 600-foot upstream	-17.91	±1.96	876	-1.22	95.25%	Reject Null
Noon Period at 4,000-foot upstream	0.432	±1.96	786	Not Calculated	99.91%	Accept Null
PM Period at 4,000-foot upstream	-0.24	±1.96	906	Not Calculated	89.77%	Accept Null

The extent of the effect size describes the practical significance between the two speeds [2]. Effect size is valuable in statistical analysis, as any difference between two means can be found to be significantly different when the sample sizes are large. A very small difference in mean speed, such as 0.1 mph, may be statistically different; however, there is practically no difference between the mean speeds. To circumvent this issue, effect size is utilized to provide a measure of the magnitude of the difference between the two mean speeds in terms of the number of standard deviation units from zero [2]. Therefore, a large effect size of 1.0 or greater would indicate an apparent practical difference in mean speeds [2]. For both time periods, at the 600-foot upstream location, the effect size can be considered large indicating a practical, as well as statistical significant difference.

Z-Test for Differences in Speed Limit Violation Proportions

The z-test was used to compare the proportions of vehicles speeding (traveling over the 60 mph speed limit) at the test locations, with those at the control locations. The data used in the statistical analysis are based on the individual observations from the data taken in the field for the same four time periods of analysis, as previously described. The null hypothesis for each of the z-tests conducted stated that there was no difference in the proportion of vehicles traveling in excess of the 60 mph speed limit with and without rumble strips. For the four time periods analyzed, the null hypothesis was accepted at the 95% confidence level indicating that the proportions of vehicles speeding at control and test locations for each of the analysis periods were statistically similar, as shown in Table 6.

7.0 CONCLUSIONS

The objective of this study was to determine the effectiveness of temporary rumble strips in reducing travel speeds approaching highway work zones. A field experiment was conducted along State Road 31 in Charlotte County, Florida to evaluate the effectiveness of the rumble strips. Speed data were

collected for the control condition (without rumble strips) in June and July 2006 at different times of the day and for various days of the week. Speed data were also collected during the test condition (with rumble strips) for a two-week period in July and August 2006 at different times of the day and for various days of the week.

Table 6. z-Test Results

Analysis Period	Proportion of Speeding Vehicles WRS	Proportion of Speeding Vehicles WORS	$z_{calculated}$	$z_{critical}$	Test Results
Noon Period at 600-foot upstream	0.16%	0.22%	-0.225	± 2.575	Accept Null
PM Period at 600-foot upstream	0.20%	0.538%	-0.68	± 2.575	Accept Null
Noon Period at 4,000-foot upstream	25.25%	23.40%	0.062	± 2.575	Accept Null
PM Period at 4,000-foot upstream	30.17%	30.37%	0.68	± 2.575	Accept Null

WRS: With Rumble Strips; WORS: Without Rumble Strips

The statistical significance of the effectiveness of the rumble strips was tested to determine whether the changes observed in the measures of effectiveness (mean speed, speed distribution and proportion of speeding vehicles) are attributable to the installation of the rumble strips. Findings are as follows:

- For the Noon and Evening periods at the 600-foot upstream location, the speed distributions for the test condition (with rumble strips) were significantly different than those for the control condition (without rumble strips). The speed distributions for each of the periods indicated a greater proportion of higher speeds at the control locations (without rumble strips) as compared to the test locations (with rumble strips) where a greater proportion of lower speeds were found.

- For the Noon and Evening periods at the 600-foot upstream location, the mean speeds at test locations (with rumble strips) were significantly different at the 95% confidence level than those observed at control locations (without rumble strips). During the Noon period, the mean travel speed at the test locations with rumble strips was 36.28 miles per hour (mph) as compared to 45.17 mph at the control locations without rumble strips. During the evening period, the mean speed for the test locations with rumble strips was 35.79 mph as compared to 44.34 mph for the

control locations without rumble strips. This indicates that the installation of rumble strips reduced the mean speed by approximately 9 mph.

- For the Noon and Evening periods at the 4,000-foot upstream location, the mean speeds and the speed distributions were not different at the 95% confidence level. This indicates that motorists maintained similar speeds at an upstream location when they did not encounter rumble strips. This observation also indicates that travel speeds approaching work zones, at a 4,000-foot upstream location, were similar under both the test and control conditions.

- In general, a majority of motorists slowed their vehicles in response to construction warning signs, flagmen and rumble strips.

In summary, the use of temporary rumble strips in advance of construction work zones reduced vehicular speeds once motorists encountered the temporary rumble strips. Therefore, the use of temporary rumble strips prior to a construction work zone may be a practical countermeasure to reduce vehicular speeds through the work zone, thereby improving safety for both the motorist and the construction worker.

8.0 REFERENCES

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