GUIDELINES FOR USE OF RUMBLE STRIPS

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16. Abstract:

The study collected information on rumble strip design, installation, and maintenance practices and experiences in Texas DOT Districts and 34 other state DOT's. Evaluation of other state DOT experiences and the technical literature resulted in recommended designs for rumble strips on the shoulder and in the travel lane. The treatments recommended for the shoulder to alert weary drivers are, in order of preference, a milled groove on 305 mm (12 in.) centers, a rolled-in groove on 200 to 230 mm (8 to 9 in.) centers, and 100 mm (4 in.) traffic buttons parallel to the travel lane on 1500 mm (5 ft) centers. It is recommended that rumble strips in the travel lane only be considered at locations where all other traffic control or warning devices have been employed and found to be insufficiently effective at reducing accidents. The design recommended consists of 3 approach rumble strip pads separated at specified distances, each pad consisting of 24 grooves. Four alternative installation standards are recommended which present different methods for extending the groove across the lane(s) and shoulder. These alternatives are presented as options that may be tried in an effort to accommodate 2-wheel vehicles and familiar drivers by allowing them to avoid traversing the rumble strips. Traffic observations and speed data were collected from 3 field test installations prior to, immediately following, and 4 to 6 months after construction. Comparison of before and after speeds showed a numerical reduction in approach However, analysis of the data revealed no statistically significant reduction in speed approaching intersections as a result of installing the rumble strip pads. speeds. Measurements of noise created by vehicles traversing rumble strips made adjacent to the pads and at various distances away from the installation revealed that a minimum of 60 m is necessary for noise level to return to level comparable to that made by vehicles not traversing rumble strips.

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IMPLEMENTATION STATEMENT

The application of the findings of this proposed study is in design guidelines and standards for state-wide TxDOT installation and maintenance of rumble strips. The form of the findings of the study includes standard drawings and specifications. TxDOT will be responsible for the application of the results of this study.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

AUTHOR'S DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was Warren K. Wray, P.E., Texas 51199.

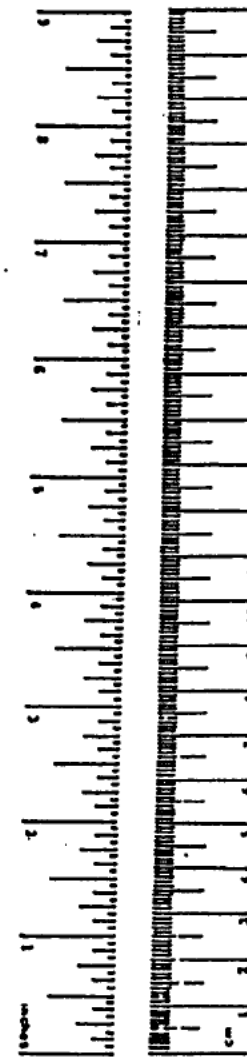
TRADE NAMES AND MANUFACTURERS' NAMES

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

METRIC CONVERSION FACTORS

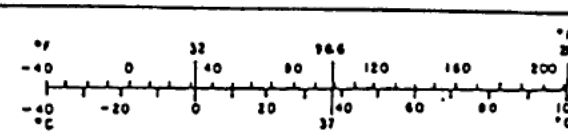
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

The principle objectives of this study were to (1) consider installation factors, operational problems, and maintenance concerns of rumble strips in the travel lane; (2) develop design guidelines and standards for installing and maintaining rumble strips on the shoulder as well as in the travel lane; and (3) verify the proper functioning of rumble strips in the travel lane by installing selected designs at carefully chosen locations and making observations on drivers' reactions and assessing the effect on reduction in speed. The study also collected information on rumble strip design, installation, and maintenance practices and experiences in other Texas DOT Districts and 34 other state DOT's. Evaluation of other state DOT experiences and the technical literature resulted in recommended designs for rumble strips on the shoulder and in the travel lane. The treatments recommended for the shoulder to alert weary drivers are, in order of preference, a milled groove on 305 mm (12 in.) centers, a rolled-in groove on 200 to 230 mm (8 to 9 in.) centers, and 100 mm (4 in.) traffic buttons parallel to the travel lane on 1500 mm (5 ft) centers. Standards, specifications and guidelines were developed for the use of rumble strips on the shoulder (referred to as shoulder texturing). It is recommended that rumble strips in the travel lane only be considered at locations where all other traffic control or warning devices have been employed and fund to be insufficiently effective at reducing accidents. The design recommended consists of 3 approach rumble strip pads separated at specified distances, each pad consisting of 24 grooves. Four alternative installation standards are recommended which present different methods for extending the groove across the lane(s) and shoulder. These alternatives are presented as options that may be tried in an effort to accommodate 2-wheel vehicles and familiar drivers from having the traverse the rumble strips. Traffic observations and speed data were collected from 3 field test installations prior to construction, immediately following construction, and 4 to 6 months after construction. Comparison of speeds showed a numerical reduction in approach speeds. However, analysis of the data revealed no statistically significant reduction in speed approaching the intersections as a result of installing the rumble strip pads. Noise created by vehicles traversing the rumble strips was also a principal concern of the study. Noise measurements made adjacent to the rumble strips and at various distances away from the installation revealed that a minimum of 60 m is necessary for the noise level to return to a level comparable to that made by vehicles not traversing rumble strips.

CHAPTER I
INTRODUCTION

1.1 Background

This study was done for the Texas Department of Transportation (TxDOT) to assess design standards and guidelines for the use of rumble strips in the travel lane and on paved shoulders. Rumble strips are raised or depressed patterns used to provide auditory or tactile sensations to the driver to call attention to an upcoming change or hazard in the roadway. Rumble strips are used for shoulder treatment and in-lane treatment. Research in rumble strips and their use and effectiveness is documented as far back as the 1940s with the "singing shoulders" and the early 1950s with rumble strips in the travel lane in use in several different states.

Reasons cited for using rumble strips include warning drivers of the need to stop, slow down, change lanes, warning of changes in roadway alignment, warning that they are leaving or have left the traveled way, and to warn of other potentially unexpected situations. Rumble strips on the roadway are therefore used on approaches to intersections, toll plazas, horizontal curves, work zones, and in lanes to be closed. Specific concerns generated in relationship to the use of rumble strips include noise created by the installations, motorist use of opposing lanes to avoid rumble strips, maintenance problems, motorist concerns, bicyclist concerns, and motorcyclist concerns.

It has been well established through other studies that rumble strips on the shoulder (often referred to as shoulder texturing) are effective at reducing run-off-the-road accidents in monotonous rural locations. One study reported a reduction in run-off-the-road accidents as high as 70 percent using the latest rumble strip design of milled grooves (Wood, 1994). Rumble strips in the travel lane have been credited with accident reduction rates of 50 percent for certain types of accidents determined to be treatable by the strips. In most cases, accident reduction is considered to fall into the 20 to 30 percent reduction range after treatment with the rumble strips (NCHRP, 1993).

Common types of rumble strips in use today include raised bars, raised buttons, grooved bars, corrugated Portland cement concrete, and overlays with exposed coarse aggregate. Several terms are used with respect to the rumble strip applications. The rumble strip depression is the individual indentation or groove. The rumble strip pad is the set of depressions that are grouped or constructed together in a continuous pattern. A typical rumble strip installation is shown in Fig. 1.1. Within these classifications there are multiple designs and parameters for each type of strip and its intended use. New designs and construction methods are also being developed currently to help in the accident prevention effect for which these strips are designed and to provide for easier construction and maintenance.

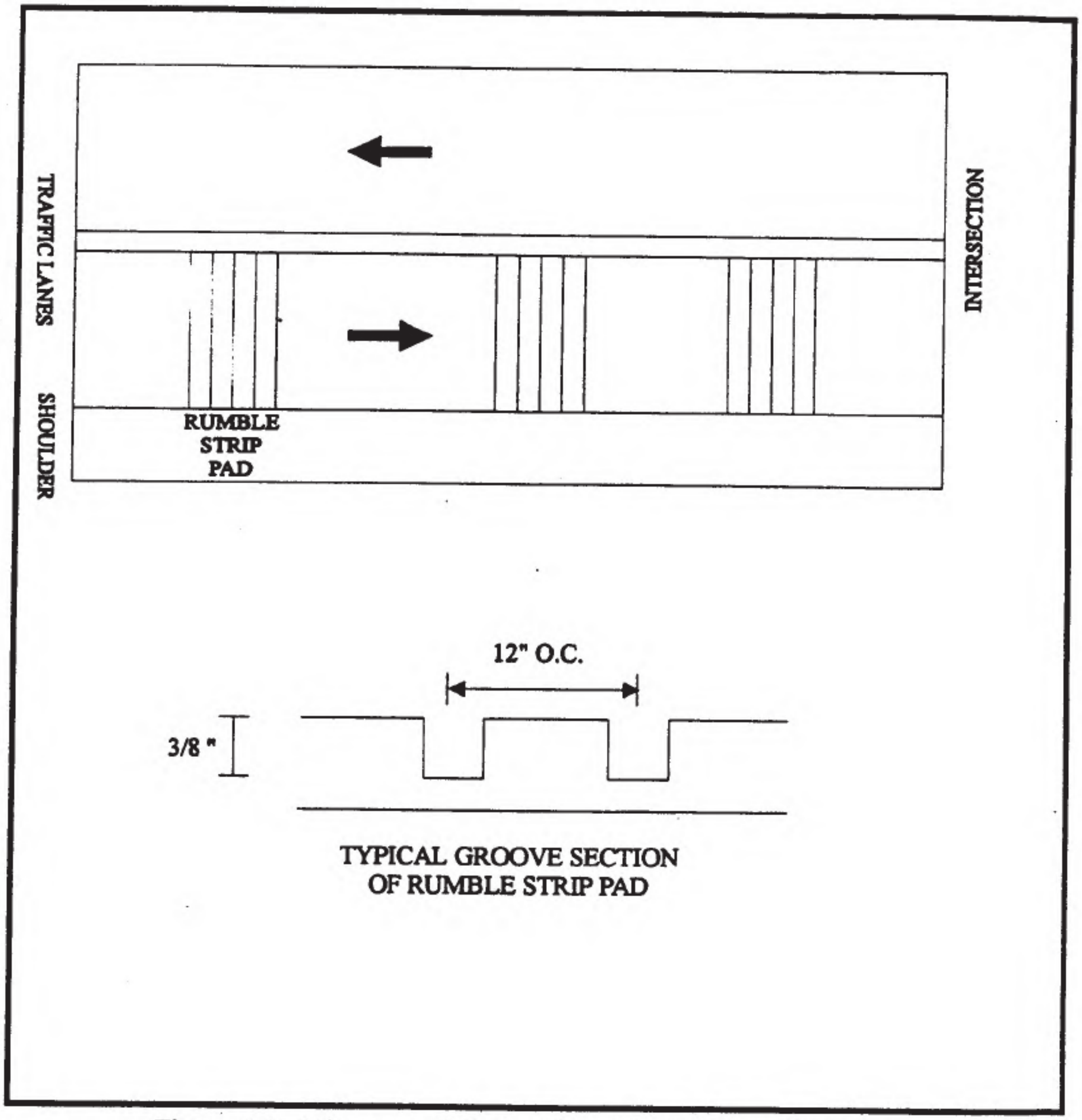

Figure 1.1. Diagram of Typical Rumble Strip Installation

1.2 Study Objectives

The principal objective of this study is to produce guidelines, specifications, and standards for state-wide use of rumble strips in the travel lane as well as on the shoulders. Specifically, the study has four subobjectives.

1. Review information from TxDOT, other transportation agencies and research studies published in the technical literature on the use and design of rumble strips in shoulders and in the travel lane.

2. Consider installation factors, operational problems, and maintenance concerns and develop guidelines, specifications, and standards for installing and maintaining rumble strips in the travel lane.

3. Consider installation factors, operational problems, maintenance concerns, and information gained from shoulder treatment effectiveness studies and performance monitoring studies and develop guidelines, specifications, and standards for installing and maintaining rumble strips installed on highway shoulders.

4. Verify the proper functioning of rumble strips in the travel lane by installing selected designs at carefully chosen field test locations and making observations on drivers' reactions and assessing the effect of the rumble strip installations on reduction in vehicle speed.

CHAPTER II
REVIEW OF TECHNICAL LITERATURE

2.1 Rumble Strip Pattern Development

Bellis (1969) gave insights into effective rumble strip patterns. Bellis reported that Texas had the greatest use of rumble strips since 1956, known for their ceramic tiles and "jiggle bars" attached with an epoxy resin. Maryland at this time had constructed 238 rumble strip installations. Maryland design consisted of strips made of slag or stone on top of a bed of bitumen. Bellis noted that Nebraska had constructed 20 sets of bonded aggregate strips attached with an epoxy. Illinois had similar sections to those of Nebraska, and North Carolina was experimenting with strips from sand asphalt. Colorado and Indiana were performing their own tests on rumble strips. As early as 1947 New Jersey was experimenting with "singing lanes" on Route 46 to warn drivers that they were approaching an adjacent lane (Bellis, 1969).

2.2 Overview of Rumble Strip Studies

A 1962 Contra Costa County, California study (Kermit and Hein) consisted of 4 stop-controlled intersections. Each site had rumble strip installations of 8 to 11 rumble strip pads that were between 7.6 and 9.1 m in length. The pads were spaced at 50 to 100 ft intervals. The 4 rumble strip installations were credited with reducing accidents by 59 percent, 76 percent, 84 percent, and 100 percent, respectively. The cases from the California study were noted as having very small accident sample sizes, considering that only accidents pertinent to rumble strip construction were considered in the study.

Kermit (1968) investigated the effects of rumble strips on a stop-controlled T-intersection in California. The initial accident reduction was 50 percent. Three years after the rumble strips had been constructed there was an 18-month period without any accidents attributed to running the stop sign. The conclusion drawn was that the rumble strips were effective in the reduction of accidents and that the rumble strips' benefits increased with time.

Owens (1967) examined the effectiveness of rumble strips on 2 rural stop-controlled approaches in Minnesota. There was a 50 percent reduction in the number of accidents between the two-year period before the installation and the two-year period after the installation. The Minnesota sites had few accidents and could not be deemed significant with the analysis.

The Transport and Road Research Laboratory (TRRL) (1977) performed a study including 10 sites on main rural highways in the United Kingdom. The number of accidents reduced from 56 to 34 after installation of the strips. The frequency of accidents that were attributed to assistance by the rumble strips was cut almost in half.

The Illinois Division of Highways (1970) performed a study at 5 different intersections with 3 different rumble strip designs and formats that had been installed in 1962. From the field analysis, a design was generated consisting of 2 rumble strip pads placed 7.6 m apart and 300 m in advance of the intersection with an additional pad at the section 90 m in front of the stop sign. Two intersections showed a reduction in the number of accidents and 2 others showed an increase in the number of accidents. The fifth site showed a 40 percent increase in accidents over the next 3 years with a reduction in accidents the following year after a flashing beacon was installed. It was determined from this study that rumble strips were more effective at four-way and one-way stops than at two-way stops. Although the report noted that rumble strips should never be used as a permanent solution, three situations were listed for permanent installations. The first situation was an intersection hidden by a horizontal or vertical curve. The second situation was an area where motorists were found to have trouble observing a traffic control device. The final location was where a control device followed a long tangent.

Moore (1987) conducted a study for the Louisiana Department of Transportation using 24 stop-controlled intersection approaches. The installations consisted of 13 raised rumble strips for each intersection. The accident data was analyzed in 2-year "before" and "after" periods. The total accident frequency showed a reduction of 29 percent over the study period. The fatal and injury accident frequency showed a reduction of 14 percent. Accidents occurring at night showed a reduction of 50 percent.

The Pennsylvania Department of Transportation conducted a study on 8 stop-controlled approaches to intersections (1974). The results showed that total accidents decreased 40 percent, and that run-stop-sign accidents showed a 59 percent decrease.

The Virginia Department of Highways and Transportation (1981) performed a study that involved 9 intersections with stop-controlled approaches. The design usually was composed of two patterns of transverse strips on the intersection approach at varying distances in front of the stop sign. The total accident frequency dropped by 37 percent. The fatal accidents were reduced by 93 percent. The total accident rates were reduced by 44 percent. With respect to those types of accidents that were deemed correctable by rumble strip installation, the accident rate was reduced by 89 percent. The measurements were made over a two-year period before and after installation of the rumble strips.

Carstens (1982) participated in a study for the Iowa DOT (Department of Transportation) with rumble strip installations on primary and secondary highway approaches. The design used 3 patterns of 4 transverse rumble strips. The primary highway approaches consisted of 10 four-way intersections and 11 T-intersections. "Before" and "after" data were taken at each of the sites and analysis showed a 51 percent decrease for total accidents and a 38 percent decrease for run-stop-sign accidents. Data gathered for 88 intersections on secondary highways did not show any significance. Carstens determined from the study that rumble strips are more effective at primary highway intersections than at secondary intersections for the following reasons:

1. Primary highways serve a higher proportion of drivers who are unfamiliar with the highway.

2. Trips tend to be longer on primary highways so that fatigue and the monotony of driving may play a more important role than on secondary roads.

3. Traffic volumes are higher on primary roads, so the number of potential conflicts is greater.

4. The geometric layout of primary highway intersections is often more complex than that of secondary road intersections. (p. 13)

Carstens also analyzed the effects of rumble strips on daytime and nighttime driving. The analysis suggested that rumble strips may be more effective for reducing nighttime accidents at unlighted intersections than at lighted intersections.

2.3 Rumble Strip Effects on Vehicle Speeds

Kermit (1968) reported that rumble strip installations have been shown to produce a small reduction in vehicle speeds. They are not recommended as any kind of speed control device. Some studies (e.g., Owens, 1967, Kothari, 1992) have also shown that the rumble strips may increase speed variance.

Kermit and Hein (1962) reported from the Contra Costa County study that installation of rumble strips led to increased gradual deceleration. Owens measured speeds in a Minnesota study at 457 m, 305 m, 152 m, and 90 m from the intersections before and after rumble strips were installed. The speeds after the rumble strip installations showed decreases of 3 to 5 km/h at each section. This study also showed an increase in speed variances for all of the sections farther than 90 m from the end. This was cited as a possible problem causing increased rear-end accidents.

A TRRL study (1977) of 10 sites where rumble strips were installed in advance of traffic circles, four-way intersections, T-intersections, horizontal curves, and small towns did not give consistent data. The speeds were measured 400 m in front of the hazard and 50 m in front of the hazard. The combined data for all of the 10 sites showed a small speed reduction. These reductions were found to not be statistically significant. A study at the University of Toledo (1992) measured speed reduction at a point 90 m downstream of the first rumble strip pattern at 7 intersections in Ohio. Six of the 7 sites showed a reduction in speed, but only 5 were statistically significant at the 95 percent confidence level. From this study there seems to be reductions in speed early in the deceleration process.

2.4 Ohio Study

A study by Gupta (1994) for the Ohio DOT and the US DOT/Federal Highway Administration (FHWA) dealt with the development of criteria for design, placement, and spacing of rumble strip patterns. Gupta introduced different types of rumble strips and gave results of a survey sent out to gain information from other states DOTs concerning design, use, and effectiveness of rumble strips from various states. Analysis of accident rates was made on existing rumble strip sites in Ohio. It was determined that no conclusions could be drawn with respect to rumble strip performance from this data.

Gupta developed four different grooved rumble strip patterns from the research for the study. These patterns included one with a 100 mm- (4 in.) wide depressed groove, vertically straight edges, and 300 mm (12 in.) spacing center-to-center. The second design consisted of a 100 mm (4 inch) wide depressed groove with a tapered edge and a bottom groove width of 90 mm (3.5 in.) The third and fourth patterns were similar to the first two except that they had a 75 mm (3 in.) wide groove. All of the grooves had a 13 mm (1/2 in.) depth. It was evaluated that mean response time for the average driver would be approximately 0.15 seconds. This was used to determine the 3.7 m (12.12 ft) length of the pads. Based on the surveys, a 3.0 to 4.6 m range was used for possible rumble strip pad length for the study. A series of pads 2 to 4 seconds apart was another design standard for the study. It was also determined that 3 to 5 pad installations would be used. From human factors research and calculations it was determined that the last pad should be at least 90 m from the point of reference. Gupta found use of a "Rumble Strips Ahead" warning sign and at least 450 mm (18 in.) of clean pavement for bicyclists' use in the design for the installations.

Speed measurements for the study were done using automated data recording equipment. Seven sites were chosen for new installations of the rumble strips. Accident history, sharp curves, rolling terrain, visibility, speed, number of lanes, environment, and stop sign controls were all cited as being important factors in choosing the sites. Four of the sites were approaches to stop-controlled intersections and three were approaches to sharp curves. "Before" and "after" studies were done at each of the sites. At five locations the studies were done four weeks after installation. At two locations the studies were done two to three weeks after installation. There were complaints of increased noise levels at these latter sites, and they were removed.

Noise measurements,were made at several different locations. The first measurement location was 90 m in front of the first pad, as it was being approached by the vehicles. The second location was at the rumble strip pad. The noise stations were each 3.05 m from the edge of the pavement. Noise levels were measured for different sizes and classifications of vehicles. The measurements showed a mean base traffic noise level with vehicles on the road between 68.5 and 74.5 decibels (dB) for cars and between 77.7 and 83.2 dB for trucks. After installation of the rumble strips, the noise levels were between 73.6 and 80.3 dB for cars and between 82.0 and 90.2 dB for trucks when traveling over the pads.

The speed data showed a reduction in speed when examining the data after the rumble strips were installed. At the second station 90 m downstream of the first pad encountered by vehicles, there was an average drop of 6.4 km/h for all 7 locations. At the third station there was a reduction of only 1.6 km/h after the rumble strip installation. This reduction in speed was determined to not be significant to the presence of the rumble strips.

The data was analyzed separately for those sections in advance of a stop sign and in advance of a curve. The 4 locations with approaches to stop signs showed mean speeds before installation of the strips of 77.4 km/h (first pad), 71.0 km/h (second pad), and 57.0 km/h (last pad). The mean speeds after the installations were 80.8, 66.3, and 58.1 km/h, respectively. The speed reduction for this data occurred only at the second pad. The 3 locations in advance of a curve showed mean speeds before installation of the strips of 88.4, 84.3, and 77.2 km/h, respectively, for the 3 pads. The mean speeds after the installations were 83.8, 77.9, and 71.5 km/h, respectively. There was a reduction at each pad for this data.

The following conclusions were drawn from the Gupta (1994) study.

- Straight-edge rumble strips were more effective than tapered-edge strips.
- Rumble strips with dimensions of four in. width and one-half in. depth were most suitable for installation.
- Three or four pad installations were preferred over five pad installations.
- The greatest deceleration rate occurred over the first rumble strip pad.
- An approximately seven to eight decibel increase in noise levels resulted from the installations, which caused opposition from residents living within a few hundred feet of the installations.

Recommendations for rumble strip installations gathered from Gupta's study include points on design and installation. The design recommendations included use of a 100 mm (4 in.) wide, 13 mm (1/2 in.) deep, vertical straight-edge grooved or depressed strip. The maximum number of pads per installation should be four. The pads should be at least two seconds apart but not more than four seconds apart. The last rumble strip should be positioned 300 ft in front of the intersection, stop line, or beginning of curve. The rumble strip pad should consist of 15 strips that are 300 mm (12 in.) center-to-center. Also the installations should not be near any residential or business areas.

CHAPTER III
STUDY MODEL

3.1 Surveys

At the start of the project, a survey was devised and sent out to all TxDOT District Offices asking for information concerning the locations of any current rumble strip installations, dimensions and descriptions of the installations, and any complaints received concerning the installations. Possible test site locations were also requested at this time from each District.

A second survey was developed and sent to each DOT office in each state requesting similar information with respect to rumble strip applications, complaints, and any design standards that were available. The design standards developed in this study were derived from this data and the survey information from each of the TxDOT offices. An initial test site list for in-lane rumble strips was also prepared and evaluated from the TxDOT survey.

3.2 Test Sites

From the initial requests, several proposed field test sites were evaluated for the study. Accident data for many of these sites was inadequate. Several other sites were determined to be more adequate for the study. Some of the initial proposed test sites were too close to residential areas and business districts and were subsequently eliminated from further consideration. Three test sites were selected for construction and field evaluation of proposed rumble strip designs and are shown in Fig. 3.1. The test method was performed over three different test days. Construction of the rumble strip test sites was accomplished by each of the participating TxDOT Districts immediately after the first set of vehicle speed data was taken. The first site selected was on FM 153 at the intersection of US 277 in Taylor County; this site was called the "Abilene Site" and is shown in Fig. 3.2. The second site selected was a T-intersection of FM 1061 at US 385 in Oldham County; this site was termed the "Amarillo Site" and is shown in Fig. 3.4. The third site was a T-intersection in Ellis County of FM 1183 at US 287, called the "Ennis Site" and is shown in Fig. 3.7. Rumble strip installations at each site are shown in Figs. 3.3, 3.5, 3.7, and 3.8.

3.3 Design Standards

In developing a design standard for rumble strips in the travel lane, several aspects of the in-lane rumble strips were analyzed:

- Actual dimensions of each strip,
- Dimensions of the rumble strip pad,
- Spacing of the strips,
- Number of pads to be used,
- Spacing of the pads.

Construction methods were also analyzed.

At two different times during the project, a meeting was held with the TxDOT Study Technical Committee to evaluate proposed designs and receive suggestions and recommendations. Different aspects were discussed at each meeting such as concerns for bicyclists, vehicle safety aspects, noise aspects, construction concerns, and proper signing for warning drivers approaching the rumble strips. The design standards are presented in Chapter IV.

3.4 Field Test Method

After the design of the rumble strips was developed, and the test locations were established, the test method was developed. The test method consisted of a vehicle speed study, noise (decibel) measurement, and site analysis. The test method consisted of three separate measurements at each test site location. The first vehicle speed measurements were taken prior to the rumble strips being installed. The second speed measurements were taken immediately after the strips were constructed. The third speed measurements were taken several months after the strips were constructed.

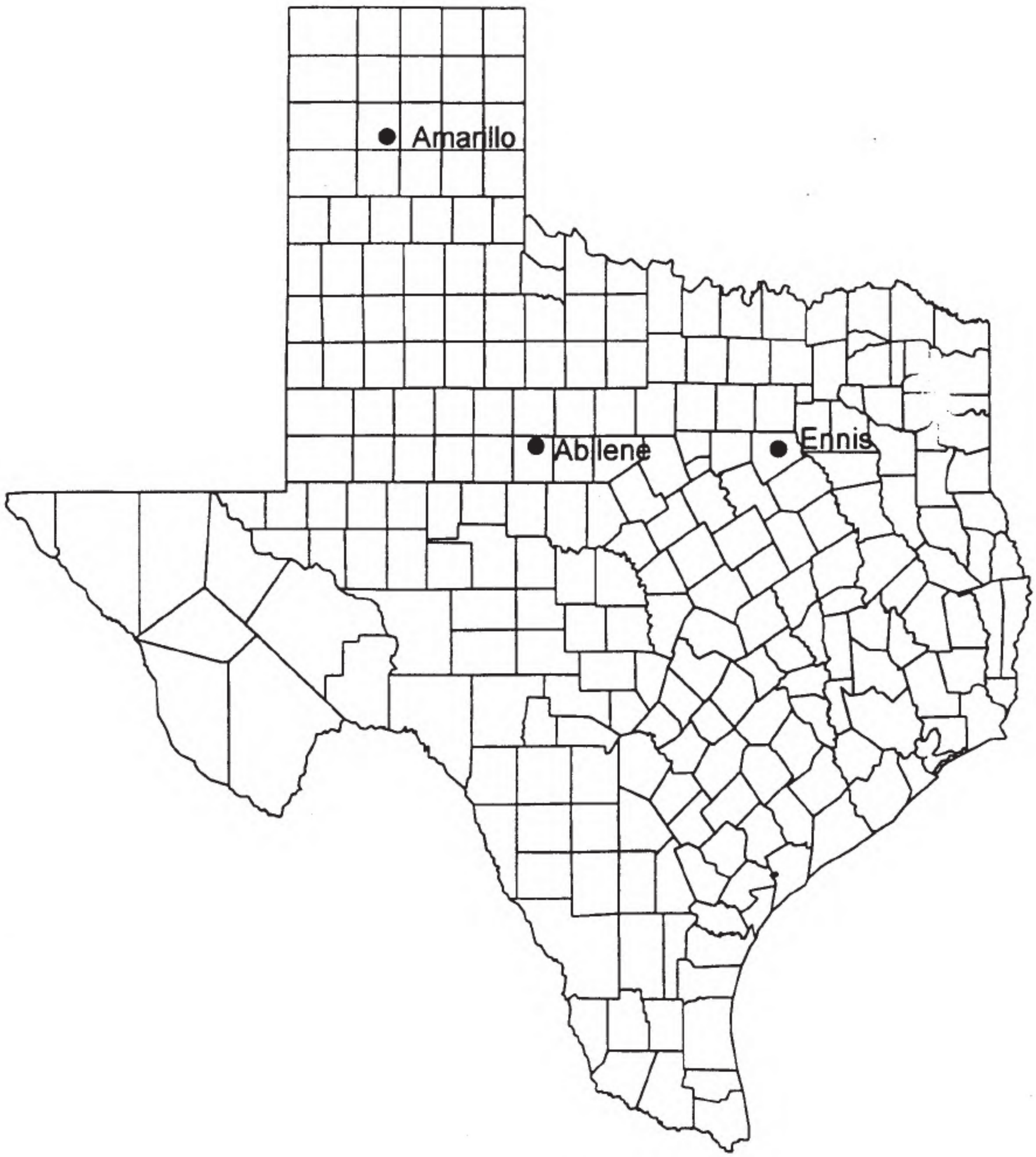

Fig. 3.1. Rumble Strip Field Test Site Locations

Abilene 3.2. Abilene Site - intersection on FM 153 at US 277 (looking along FM 153 toward intersection with US 277)

Figure 3.3. Rumble Strip Applications - Abilene Site

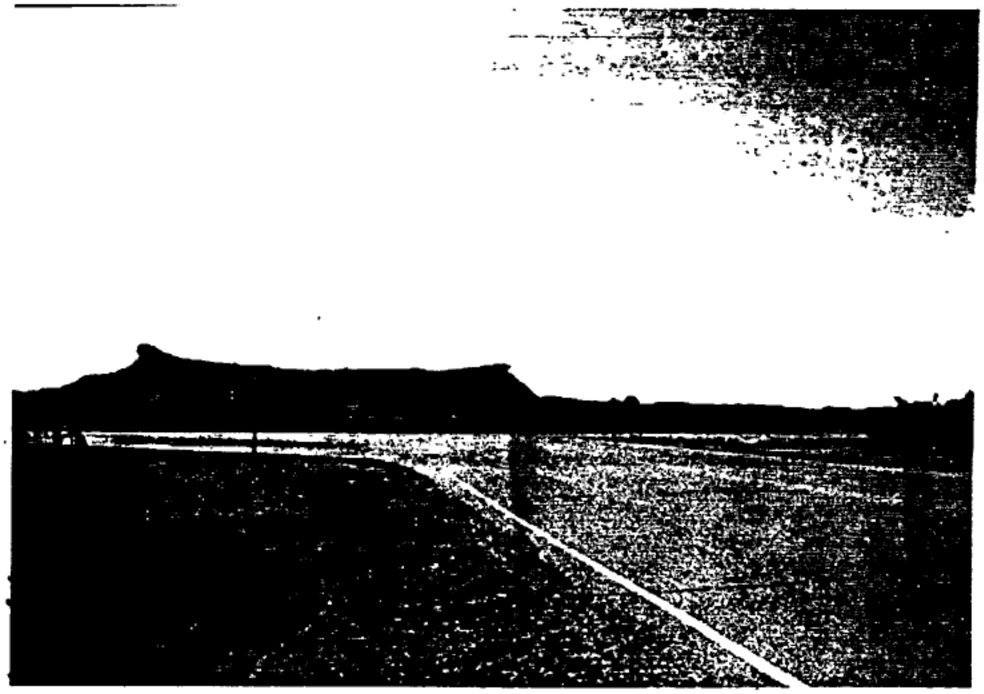

Figure 3.4. Amarillo Site - Intersection on FM 1061 at US 385 (looking toward FM 1061 intersection with US 385)

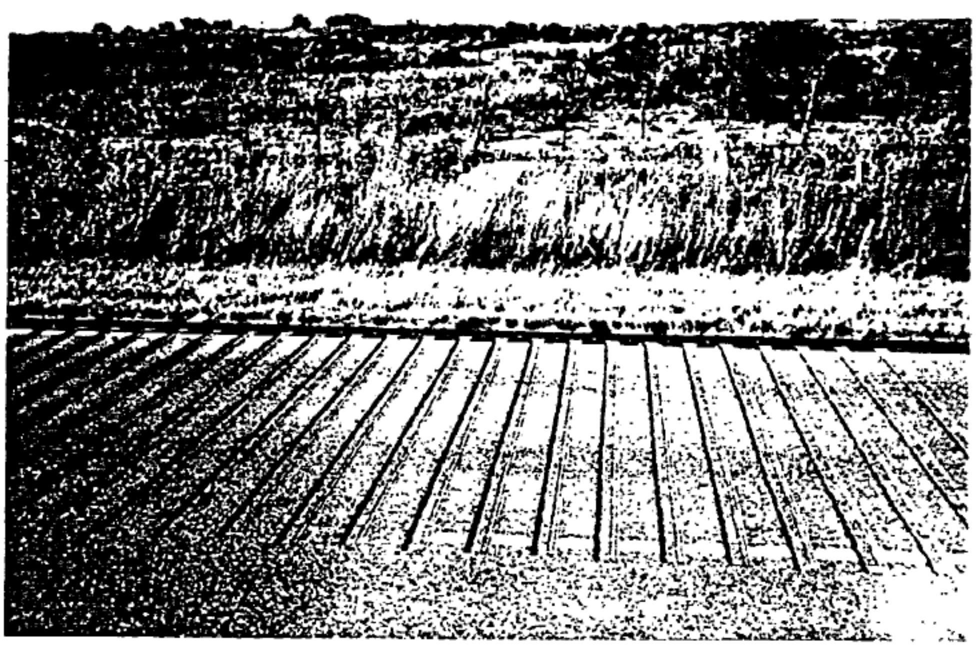

Figure 3.5. Rumble Strip Applications - Amarillo Site

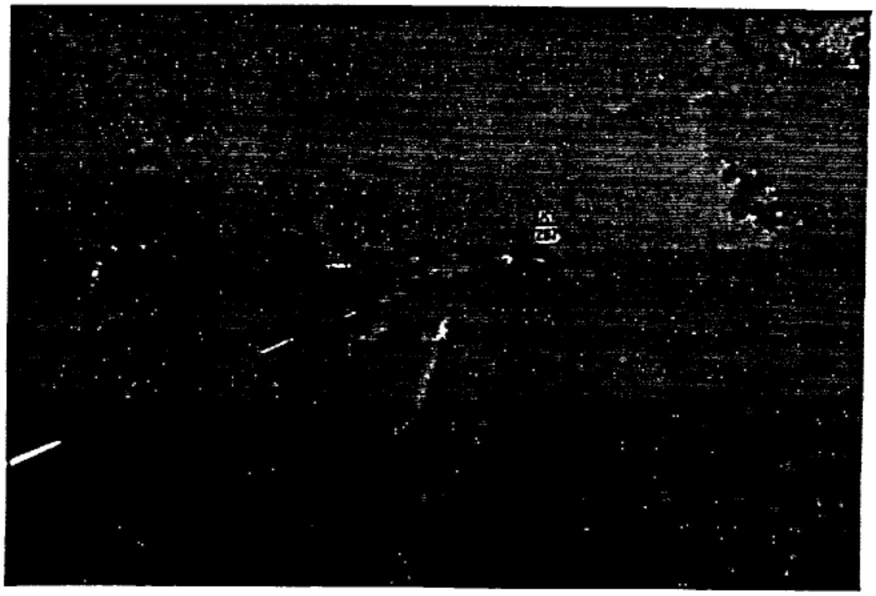

Figure 3.6. Ennis Site - Intersection on FM 1183 at US 287 (looking along FM 1183 toward intersection with US 287)

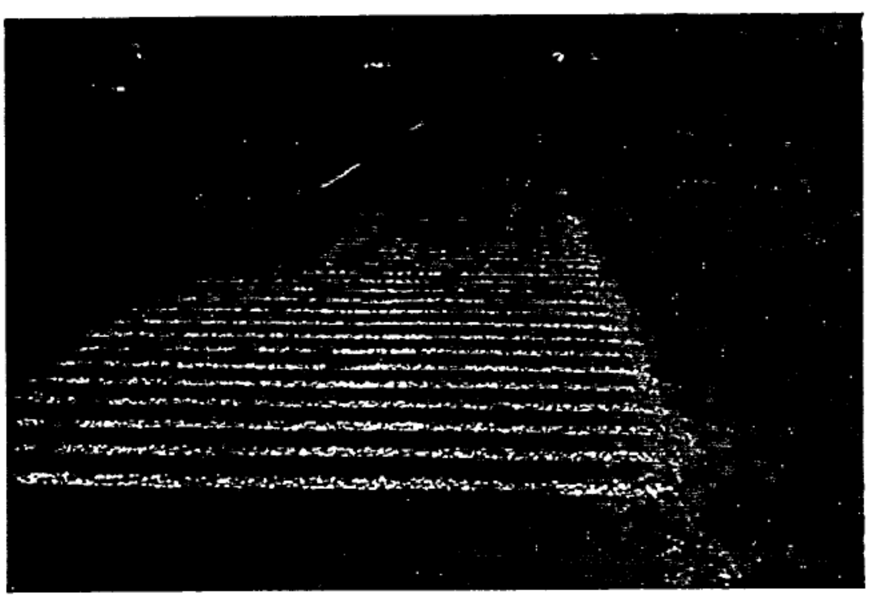

Figure 3.7. rumble Strip Applications - Ennis Site

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CHAPTER IV
RESULTS

4.1 Survey of TxDOT Districts

The survey sent out to each of the TxDOT District Offices was to inventory current rumble strip installations and uses in the travel lane. From the responses, six districts reported locations of rumble strips already installed. These districts were Atlanta, Bryan, Corpus Christi, Lubbock, Paris, and Tyler. All of the installations were described as raised rumble strips except for those in the Bryan District. All rumble strips were reported as having been installed between 1988 and 1994. Various designs were used within the different Districts. The designs differed with respect to the number, width, spacing, depth or height, and the length of the rumble strips used. Problems reported in the survey with the rumble strips included aggregate settling into the roadway, snow plows breaking the buttons, and trouble with seal coats and adhesives. Results from the survey are shown in Table 4.1. Special points of deficiencies or effectiveness were requested in the survey. Favorable comments included effectiveness of the strips in reducing accidents and positive comments from the Department of Public Safety.

4.2 National Survey of Transportation Agencies and State DOTs

The national survey of transportation agencies and state DOTs also assessed current rumble strip installations and uses in each state. Fifty-one surveys were mailed out with 37 responses received. Only two of the states which responded did not use any kind of rumble strip installation. The survey showed a large percentage of use of rumble strips for road shoulders and intersection approaches. The most complaints received concerning the rumble strips, that were noted in the survey results, were from nearby residents with respect to increased noise levels.

Principal deficiencies that had been identified were also requested in the survey. Several comments consisted of concerns with noise and people avoiding the strips by using the opposing lane or the shoulder. Several maintenance concerns addressed difficulty in removing raised strips from the pavement without damaging the pavement after the strips were no longer needed. Some responses indicated a difficulty in maintaining the rumble strips installed or constructed in asphalt concrete pavements. One response indicated a design with a deficiency where crack sealing had been used. A problem with "wear-down" and dislodging by larger trucks was also cited. Some of the strips had the effect of catching and holding debris. There was also a problem with accommodation of bicyclists on narrow rural roads with narrow shoulders.

Tables listing current design criteria for in-lane and shoulder rumble strips from the NCHRP 191 (1993) report were included with the survey so that respondents could compare their earlier design criteria with their current criteria. Almost every state was still using at least a portion of the NCHRP 191 criteria. Many states had made additions

District	Rumble Strip Location	Strip Type	Year Installed	Number of Pads	Width of Pads		Spacing of Pads		Depth/ Height		Length of Pad	
					ft	m	ft	m	in.	mm	ft	m
Amarillo	No Applications											
Atlanta	FM 899 & Edwards St.	Raised	1994	2	10	3.1	2	0.6			10	3.1
	SH 43 & SH 49	Raised	1994	2	10	3.1	2	0.6			10	3.1
Austin	No Applications											
Beaumont	No Applications											
Brownwood	No Applications											
Bryan	FM 60 & FM 158	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	OSR & FM 1687	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 1179 & Jones Rd.	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 3058 & FM 60	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 3058 & FM 166	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 937 & SH 7	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 979 & FM 2293	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
	FM 1696 & SH 75	Grooved	1988-1990	2	Var.	Var.	Var.	Var.	0.5	13	17	5.2
Childress	No Applications											
Corpus Christi	SH 119 & SH 80	Raised	1994	6	12	3.7	2	0.6	1/4	6	10	31
	FM 743	Raised	1994	6	12	3.7	2	0.6	1/4	6	10	3.1
	SH 123 & BI 181	Raised	1994	6	12	3.7	2	0.6	1/4	6	10	3.1
Dallas	No Applications											
Fort Worth	No Applications											
Houston	No Applications											

(continued on next page)

Var. = Variable
Width of Pad = Distance Transverse to Travel Lane
Length of Pad = Distance Parallel to Travel Lane

Table 4.1 TxDOT District Survey Results

Table 4.1 Cont.

District	Rumble Strip Location	Strip Type	Year Installed	Number of Pads	Width of Pads		Spacing of Pads		Depth/ Height		Length of Pad	
					ft	m	ft	m	in.	mm	ft	m
Lubbock	FM 300 & FM 303	Raised	1990	2	12	3.7	Var.	Var.	3/8	10	7.75	2.4
	IH 27 Frontage Rd. (45)	Raised	1990	3	11.5	3.5	Var.	Var.	5/8	16	3.8	1.2
	IH 27 Frontage Rd. (89)	Raised	1990	3	9	2.7	Var.	Var.	5/8	16	2.3	0.7
	IH 27 Frontage Rd. (61)	Raised	1990	3	11.5	3.5	Var.	Var.	5/8	16	2.3	0.7
Lufkin	No Applications											
Paris	FM 195 & FM 2118	Raised	1992	2			Var.	Var.	5/8	16	20	6.1
Pharr	No Applications											
Tyler	US 69 & IH 20	Raised	1992	2	24	7.3	2	0.6	1/5	5	12	3.7
Waco	No Applications											
Wichita Falls	No Applications											
Yoakum	No Applications											

Var. = Variable
Width of Pad = Distance Transverse to Travel Lane
Length of Pad = Distance Parallel to Travel Lane

to their designs since publication of the NCHRP 191 report, but were also still using the older designs in some areas. Several design specifications, standards, and reports were included with the completed surveys. Results from the national survey are reported in Table 4.2.

4.3 Design Standards and Specifications

4.3.1 Rumble Strips in the Travel Lane. The design standards were developed for the rumble strips through the combined use of the technical literature material and the information from the TxDOT District and the DOT/Agency survey. Grooved, indented, or depressed applications were determined to be more feasible and provide less maintenance concerns. The use of depressed strips has become more popular nation-wide, mainly because of better durability and reduced snow plowing conflicts. The dimensions were determined through examining effective strip designs and installations reported in the technical literature, from other states, and through other studies. Considerations were also given to strips designed for areas with the same type of climate, as that of Texas.

The desirable pad length was based on the average reaction time for an individual, which is reported at the greatest to be 0.25 second (Gupta, 1994). The average reaction time in relationship to the average speeds of vehicles of 72.4, 88.5, and 104.6 kilometers per hour was used to determine the pad length needed. The calculated lengths for these speeds were 5.18, 6.10, and 7.11 m, respectively. The greater pad length of 7.11 m (23 ft-4 in.) was selected to accommodate the faster speeds because many rumble strip applications are to warn fast-moving drivers of approaching hazards. The groove spacing of 300 mm center-to-center was common to several state designs. Several test sites reported in the technical literature as being successful employed 300 mm (12 in.) on-center groove spacing. The 10 mm (3/8-in.) depth was also adopted from use in other successful designs. The specifications included with the drawings were determined from previous experience, TxDOT design standards, and concerns generated through the meetings with the TxDOT Study Technical Committee.

Four different rumble strip design patterns are recommended for use by TxDOT. The final rumble strip design patterns that are recommended were developed through experiences cited in the technical literature, discussions held with DOT engineers in other states, previous TxDOT experience, and extensive discussions with the members of the TxDOT Study Technical Committee. The four patterns include:

1. Strips covering the full traffic lane (or lanes) from centerline to edge line, but not extending onto the shoulder (Fig. 4.1).

2. Strips covering the full traffic lane (or lanes) width and half of the paved shoulder (Fig. 4.2).

State DOT or Agency	Rumble Strip Applications: Intersection Approach	Construction Zone	Curve Approach	Toll Booth	Bridge	Road Shoulder	Lane Number: Two-Lane	Multi-Lane	Width of Strips: CL to EL	CL to EPS	EL to EL	EEIPS to EEOPS	Discontinuous Strips
Alabama	X	X				X	X	X	X		X		
Alaska						X							
Arkansas	X		X				X		X				
California	X	X		X		X	X	X	X		X		X
Colorado	X	X	X		X	X	X	X					X
Delaware													
Hawaii	X			X		X	X	X	X				
Idaho	X		X			X	X	X	X	X	X	X	X
Indiana	X					X	X		X				
Iowa	X	X		X		X	X	X	X		X		
Kansas	X			X		X	X	X	X		X		
Kentucky	X	X	X	X		X	X	X	X				
Maryland	X	X		X		X	X	X		X		X	
Massachusetts	X	X		X			X	X	X		X		
Michigan			X			X		X			X		
Minnesota	X	X				X	X	X	X		X	X	
Missouri	X					X	X						X
Montana						X							
Nebraska	X					X	X		X	X			
New Hampshire	X	X					X						X
New York		X					X	X	X		X		
NYSTA						X		X					
North Dakota	X					X	X	X	X	X			X
Ohio	X	X	X	X		X	X	X		X			
Oregon		X				X							
Pennsylvania	X	X				X	X	X	X		X		
South Carolina	X		X			X	X		X				
South Dakota	X					X	X	X					X
Utah	X					X							X
Virginia	X					X	X		X				
Washington	X					X	X		X				X
West Virginia	X		X			X	X						
Wisconsin	X					X	X		X				
Wyoming	X					X							

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CL - Center Line *EL - Edge Line* *EPS - Edge of Paved Shoulder*

EEIPS - Extreme Edge of Inside Paved Shoulder

EEOPS - Extreme Edge of Outside Paved Shoulder

Note: Table only includes those DOTs or agencies that responded to the survey

Table 4.2 National Survey Results

Table 4.2 Cont.

State DOT or Agency	Complaints By: Car Drivers	Truck Drivers	Motor-Cyclists	Bicyclists	Nearby Residents	Nearby Businesses	Still Using Design from NCHRP 191 Report	Design Changes Since NCHRP 191 Report	Designs/ Standards Provided
Alabama	X		X		X		X		
Alaska									
Arkansas					X				
California			X	X			X	X	X
Colorado		X		X				X	X
Delaware					X		X	X	
Hawaii	X				X		X		X
Idaho					X				
Indiana							X		X
Iowa			X		X	X	X		X
Kansas					X		X	X	X
Kentucky				X			X		X
Maryland									
Massachusetts									X
Michigan					X		X		
Minnesota									X
Missouri							X		
Montana	X								
Nebraska							X	X	
New Hampshire							X		
New York									
NYSTA									X
North Dakota	X		X						
Ohio			X	X	X		X		X
Oregon									X
Pennsylvania							X		X
South Carolina			X		X				X
South Dakota	X	X							
Utah							X		X
Virginia									X
Washington	X			X	X		X		X
West Virginia	X		X	X	X		X	X	
Wisconsin							X	X	X
Wyoming							X	X	X

CL - Center Line EL - Edge Line EPS - Edge of Paved Shoulder
EEIPS - Extreme Edge of Inside Paved Shoulder
EEOPS - Extreme Edge of Outside Paved Shoulder
Note: Table only includes those DOTs or agencies that responded to the survey

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3. Strips covering the traffic lane (or lanes) with a 400 mm (16-in.) cutout in the center of the travel lane, but not extending onto the shoulder (Fig. 4.3).

4. Strips covering the full traffic lane (or lanes) width and half of the paved shoulder with two cutouts each 400 mm (16 in.) wide and 1.2 m (4 ft) apart (Fig. 4.4).

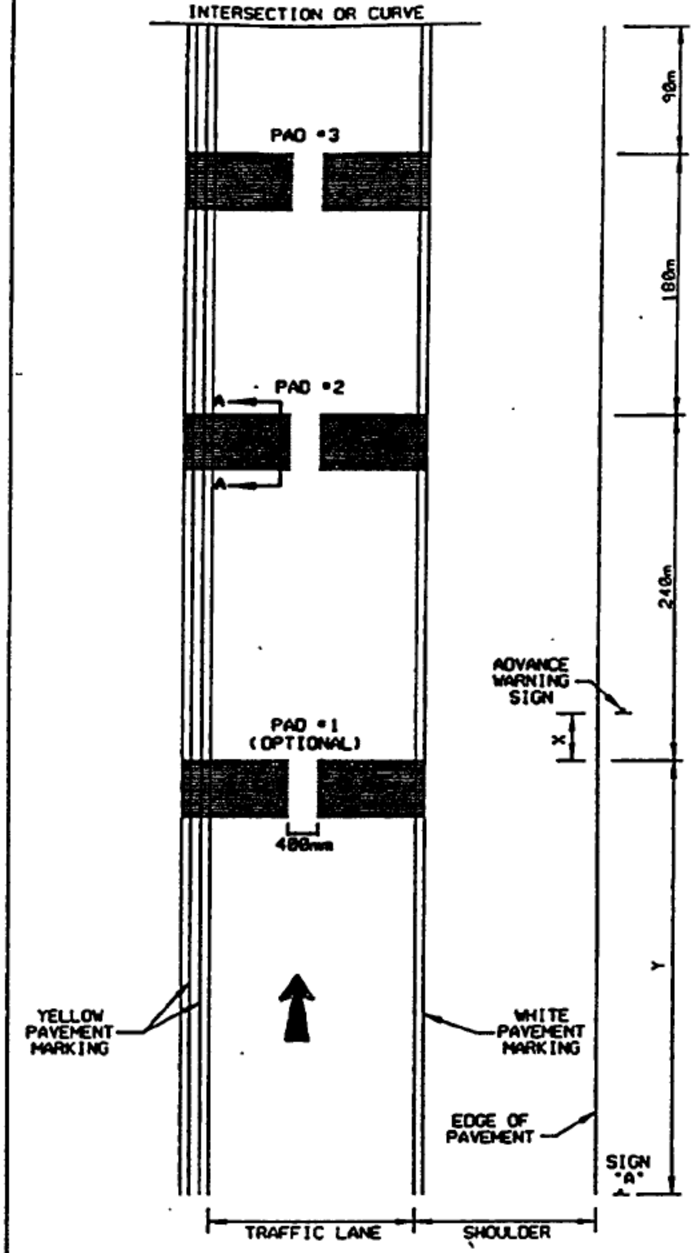
The designs that include part of the paved shoulder were designed for shoulder widths of at least 1.8 m (6 ft) and which are wide enough to accommodate bicyclists on the outer edge. The design with a single center cutout was to accommodate bicyclists and motorcyclists in the travel lane. The design with the wheelpath cutouts was to accommodate local drivers who travel the area often, are aware of the rumble strips and their purpose, and wish to avoid the nuisance factor of frequently encountering known rumble strip installations. However, despite the intention of field-testing most or all of the four designs, the only design used at the three test sites was the full width travel lane design. The reason that only one design was tested was that none of the acceptable test sites had paved shoulders, and the full width travel lane design was the best design for construction with the current equipment. Specifications were also devised as to what type of roadway each design is appropriate for and for what type of situations. The four different rumble strip designs are shown in English units in Figs. C1 - C4 in Appendix C.

4.3.2 Shoulder-Only Texturing. The purpose of the study was to evaluate if shoulder treatments were effective in reducing the number of single vehicle run-off-the-road (SVROR) accidents and, if found to be successful, which types of treatment were found to be the most successful.

The study found that some treatments were successful in reducing SVROR accidents. The study also recommended three types of treatments as being better than others when construction, maintenance, and safety considerations were also included in the evaluation (Table 4.3). The method considered to be the most effective was "milled-in" grooves. Milled-in grooves consist of 175 mm wide x 400 mm long x 13 mm deep grooves 300 mm on center (7 in. wide x 16 in. long x 0.5 in. deep grooves 12 in. on center) that are milled into either Portland cement concrete (PCC) or hot mix asphalt concrete (HMAC) shoulders by specially configured milling equipment. This method produced both loud noise and internal vibrations that alerted drivers that they had departed the travel lane and had driven onto the paved shoulder of the highway. This method has been found by other researchers to be equally successful with both automobiles and large trucks (which employ larger-diameter wheels). "Rolled-in" grooves is an alternate method that was found to be successful from the standpoint of creating noise to arouse and alert a driver that the vehicle was operating on the paved shoulder. Rolled-in grooves are only applicable to HMAC shoulders and can be installed only during new construction or overlay operations. The installation is accomplished by impressing the approximately 25 mm (1 in.) deep grooves into the newly-placed and still hot HMAC using 50 mm (2 in.) diameter cut-in-half steel pipes

TABLE 4.3 RECOMMENDED SHOULDER TREATMENT TECHNIQUES (After Wray and Nicodemus, 1996)

METHOD OR TECHNIQUE	RECOMMENDED APPLICATION	APPLICABLE PAVEMENTS	COMMENTS
Milled Grooves	7 in. wide x 16 in. long x 0.5 in. deep grooves on 12 in. centers (175 x 400 x 13 x 300 mm); grooves perpendicular to direction of vehicle travel; grooves installed within the 3 ft (or 1 m) nearest the outside driving lane edge line should be 2 ft.	Portland cement concrete or hot mix asphalt concrete	Line of grooves should be interrupted and not extend across entrance exit ramps. This is the most preferable shoulder treatment.
Traffic Buttons	4 in. (100 mm) diameter white (outside shoulder) or yellow (inside shoulder) ceramic traffic buttons installed with an appropriate adhesive on 5 ft (1.52 m) centers parallel to the edge line.	Portland cement concrete, hot mix asphalt concrete, or surface treatments.	Depressed techniques are recommended ahead of this technique unless it is shown that the other techniques are not applicable or appropriate for the specific situation.
Rolled-In Grooves	2 in. wide x 24 in. long x 1 in. deep on 8 to 9 in. centers (50 x 600 x 25 mm on 200 to 225 mm centers; approximate dimensions); grooves to be perpendicular to direction of vehicle travel; grooves installed within the 3 ft (or 1 m) nearest the outside driving lane edge line	Hot mix asphalt concrete	Line of grooves should be interrupted and not extend across entrance and exit ramps.



NOTES

1. THIS DESIGN SHOULD ONLY BE USED ON ROADWAYS WITH PAVED SHOULDERS MEETING FULL DESIGN STANDARDS AND IN GOOD CONDITION.
2. A WARNING SIGN GIVING NOTICE TO THE ADVANCE CONDITIONS IS REQUIRED BEYOND PAD #1 AS INDICATED.
3. WHEN A TWO PAD DESIGN IS TO BE USED PAD #1 SHOULD BE EXCLUDED AND THE SIGNS SHOULD BE PLACED AROUND PAD #2 AT THE DISTANCES GIVEN BELOW.
4. THIS DESIGN SHALL NOT BE PLACED ON FOUR OR MORE LANE-ROADWAYS.
5. AS DIRECTED BY THE ENGINEER THIS DESIGN MAY BE MODIFIED SUCH THAT THE RUMBLE STRIPS EXTEND ACROSS ½ OF THE SHOULDER WIDTH.
6. IF USED IN ADVANCE OF A CURVE, THE RUMBLE STRIPS SHOULD BE EXTENDED ACROSS ½ OF THE PAVED SHOULDER WIDTH AND A TWO PAD DESIGN SHOULD BE USED.

85TH % OR POSTED SPEED (kph)	MINIMUM DISTANCE X(m)	MINIMUM DISTANCE Y(m)
50	32	104
60	38	132
70	44	161
80	50	189
90	57	217
100	63	245
110	69	273

X SHOULD NOT EXCEED 76m. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 305m.

SIGN "A"

SECTION A-A

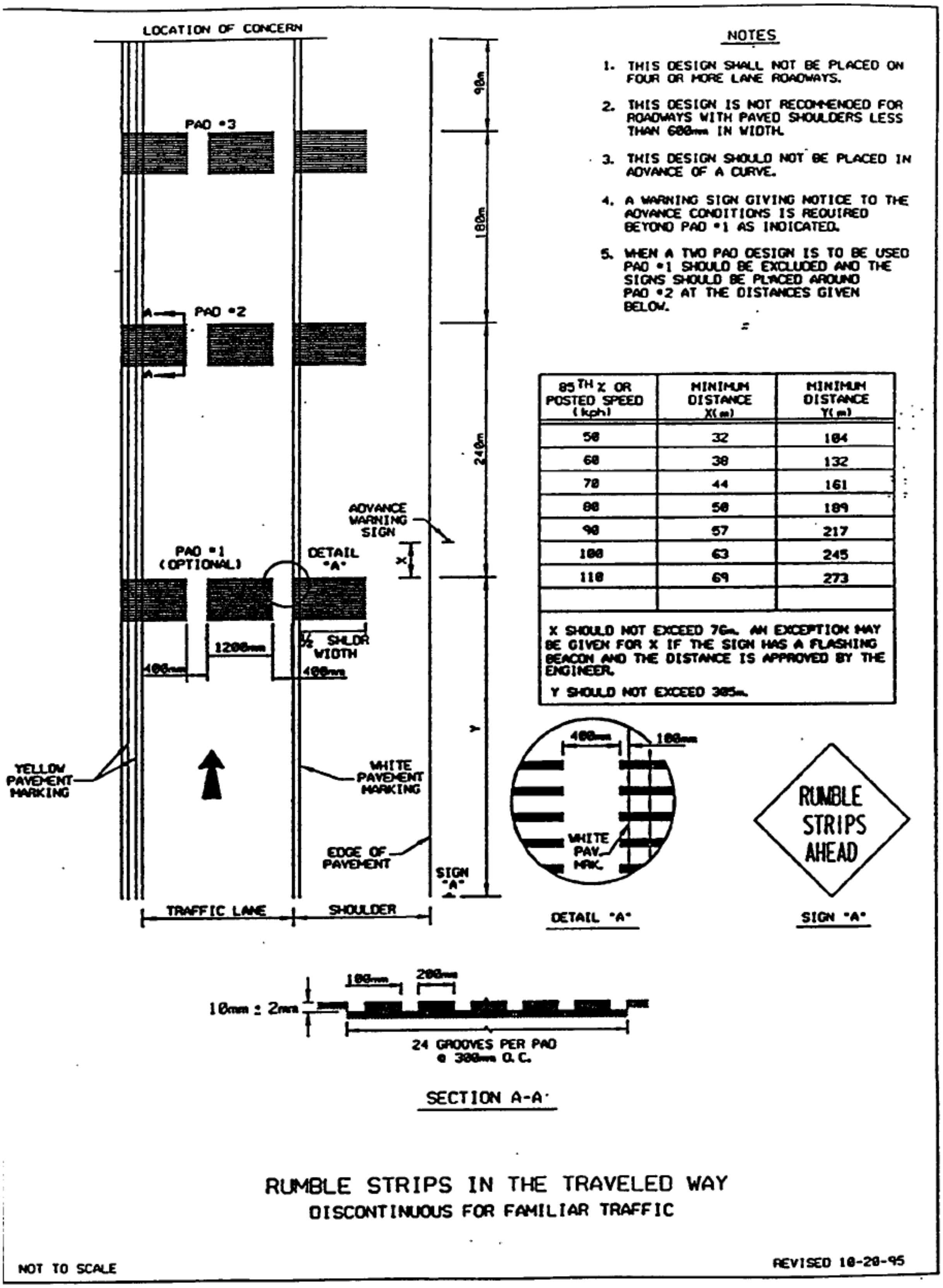
RUMBLE STRIPS IN THE TRAVELED WAY

DISCONTINUOUS FOR CYCLISTS

NOT TO SCALE

REVISED 10-20-95

Fig. 4.3. Recommended design standard for rumble strips interrupted at mid-width of the travel lane to accommodate cyclists.



85TH % OR POSTED SPEED (kph)	MINIMUM DISTANCE X(m)	MINIMUM DISTANCE Y(m)
50	32	104
60	38	132
70	44	161
80	50	189
90	57	217
100	63	245
110	69	273

X SHOULD NOT EXCEED 76m. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 305m.

Fig. 4.4. Recommended design standard for rumble strips extending over half of the paved shoulder but interrupted in the travel lane(s) to accommodate local drivers familiar with the rumble strips and the hazard with which they are associated)

installed on a steel wheel roller. The grooves are 50 mm wide x 25 mm deep x 600 mm long with 75 mm tapers on each end (2 in. wide x 1 in. deep x 24 in. long with 3 in. tapers); the grooves are 200 to 225 mm (8 to 9 in.) on center.

The third treatment recommended in Study 187 (Task 12) was that of installing 100 mm (4 in.) diameter traffic buttons on 1.5m (5-ft) centers on the shoulder parallel to but 150 mm (6 in.) from the edge line. The traffic button treatment was noted as being applicable for those types of shoulders where milled-in grooves could not be installed; for example, on shoulders constructed of single or double bituminous surface layer treatments. The principal deficiency associated with traffic buttons was maintenance: the buttons were easily removed during snow removal operations and had to be reapplied after every seal coat application.

The results from Study 187 (Task 12) can be used either in conjunction with rumble strips or as a substitute for rumble strips when the application is restricted only to paved shoulder installations. Standard drawings and construction specifications which resulted from Study 187 (Task 12) have been prepared and submitted to the TxDOT Design Division for review and adoption. The drawings and specifications as submitted are included in Appendices D (metric units) and E (English units).

4.4 Field Test Sites

The data at each field test site was collected by taking vehicle speed measurements before the rumble strips were installed, immediately after the strips were installed, and several months after the rumble strips were installed. Each of the test measurements was taken on weekdays other than Monday or Friday to generate the most typical traffic data. As described in Section 3.5, the tests were performed by recording timings for each vehicle between four locations. These locations were 580, 520, 275, and 90 m (1900, 1700, 900, and 300 ft) preceding the intersection. One person would make all four timing measurements for the same vehicle. The times were taken as each vehicle passed a measured line on the pavement at each of the four locations. The elapsed times were taken and recorded for each vehicle with the type (classification) of vehicle also being recorded. The speeds for each vehicle were then calculated from the times and distances covered.

The vehicles were categorized as passenger car (P), cars with trailers (P/B), single unit trucks (SU), and combination trucks (WB). These classifications are consistent with those established in AASHTO (1994). The passenger car classification includes all types of cars, pick-up trucks, vans, blazers, and station wagons. The single unit truck category is for the trucks in which the cab and freight area are connected as a single vehicle, and the WB combination trucks include all types of semi-trailers. Mean values of vehicle speeds were calculated for each classification of vehicle as well as the whole data set (all vehicles). This same procedure was followed for the pre-construction, immediate post-construction, and final post-construction measurements. Individual results and data for each site are reported below.

During the second or immediate post-construction speed measurement trip, noise readings were made using a decibel meter. Measurements were made for vehicles traveling over the rumble strips, and not traveling over the rumble strips. There was concern over the increase in noise level generated as a result of the installation of the strips. Noise was a major area of complaint by adjacent or nearby residents and businesses in surveys by others. It was a study objective to determine how close a building or residence could be to the strips without having any adverse noise effects.

Measurements were also made on predetermined sections of the rumble strip grooves and pads to determine their dimensions soon after construction. Selected locations of the pads were measured and marked with paint for future reference shortly after the strips were completed.

During the final measurement trip, measurements were taken again at the selected sections of the pads. The paint markings and the original recorded location areas were used for reference of the initial sections. The groove measurements were taken to help assess durability of the installations over time. These measurements are reported in Section 4.8.

4.4.1 Abilene Site. The site on FM 153 at US 277 is a two-way stop intersection. Earlier efforts had been made to warn drivers on FM 153 of the upcoming intersection. Warning signs at 450 m and 300 m preceding the intersection are installed on both US 277 and FM 153. Flashing warning beacons were installed on the approaches of FM 153. Warning signs were also hung over FM 153 on both approaches to the intersection.

The pre-construction traffic and speed data was taken over the period 7:30 a.m. to 6:00 p.m., Thursday, March 2. A total of 118 vehicles were recorded during this period. The vehicles were divided into the four categories, P, P/B, SU, and WB. The distribution of vehicles was 74 P vehicles, 13 P/B vehicles, 25 SU vehicles, and 6 WB vehicles. The distribution of the mean speeds for the different categories is reported in Fig. 4.5. The greatest reduction in speed occurred before the last rumble strip pad, located 90 m prior to the intersection. At this last pad the average speeds were in the low-30 km/h range. It was noted by TxDOT employees that there was a highway patrolman parked close to the intersection the previous day, and that this could have affected speeds for the testing. The speed data is shown in Table 4.4.

Table 4.4 Abilene Pre-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type[a]	Distance From Intersection (m)			
	580	520	275	90
P	109	98	87	43
P/B	92	77	69	39
SU	119	105	92	42
WB	97	84	74	35
All Vehicles	109	95	84	40

[a]P = Passenger Car; P/B = Car and Trailer;
WB = Semi-Trailer Truck; SU = Single Unit Truck
(AASHTO, 1994)

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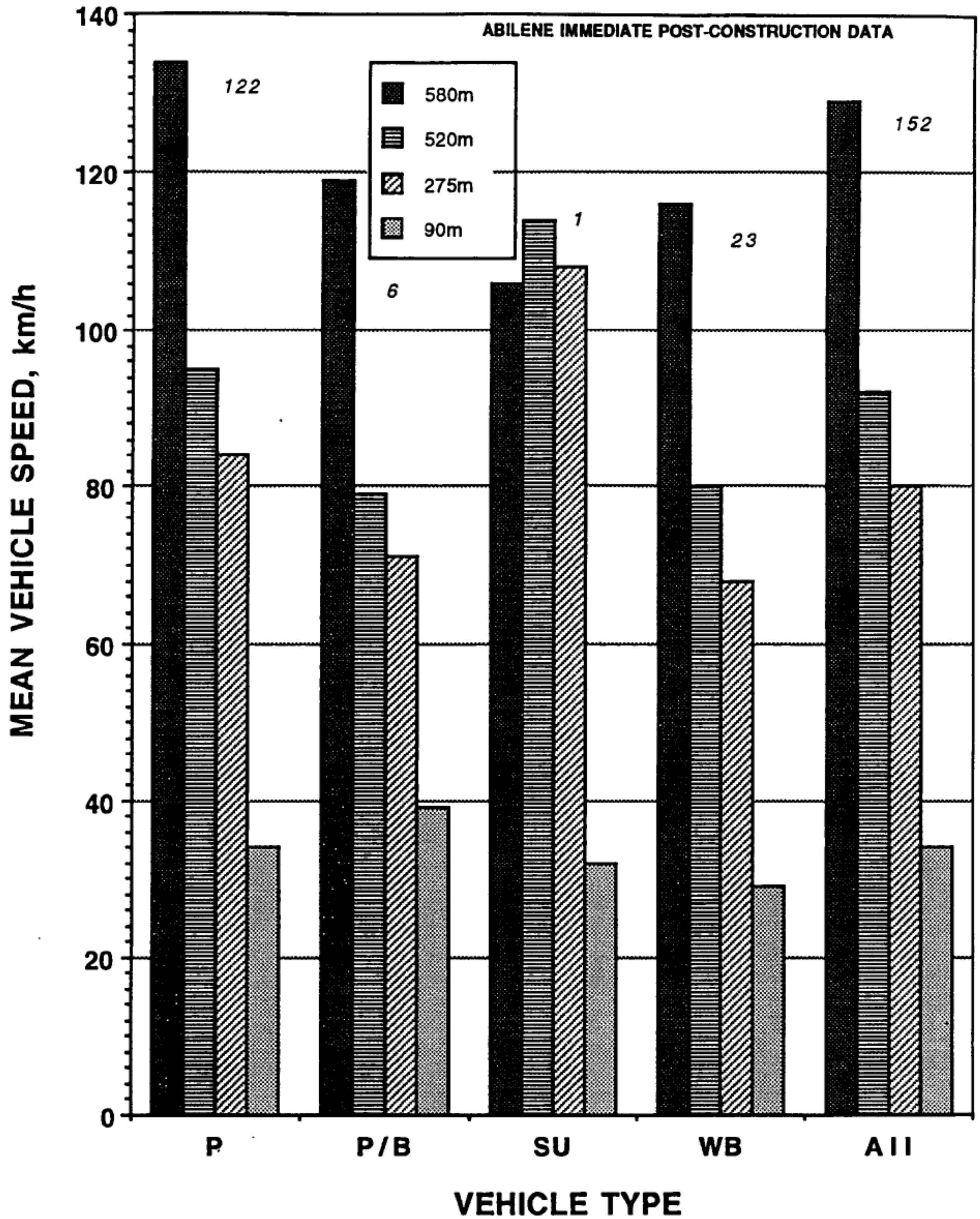

Fig. 4.6. Mean speeds observed by type of vehicle at four locations on SH 153 in advance of the intersection with US 277 immediately following installation of approach rumble strips on SH 153 in the Abilene District

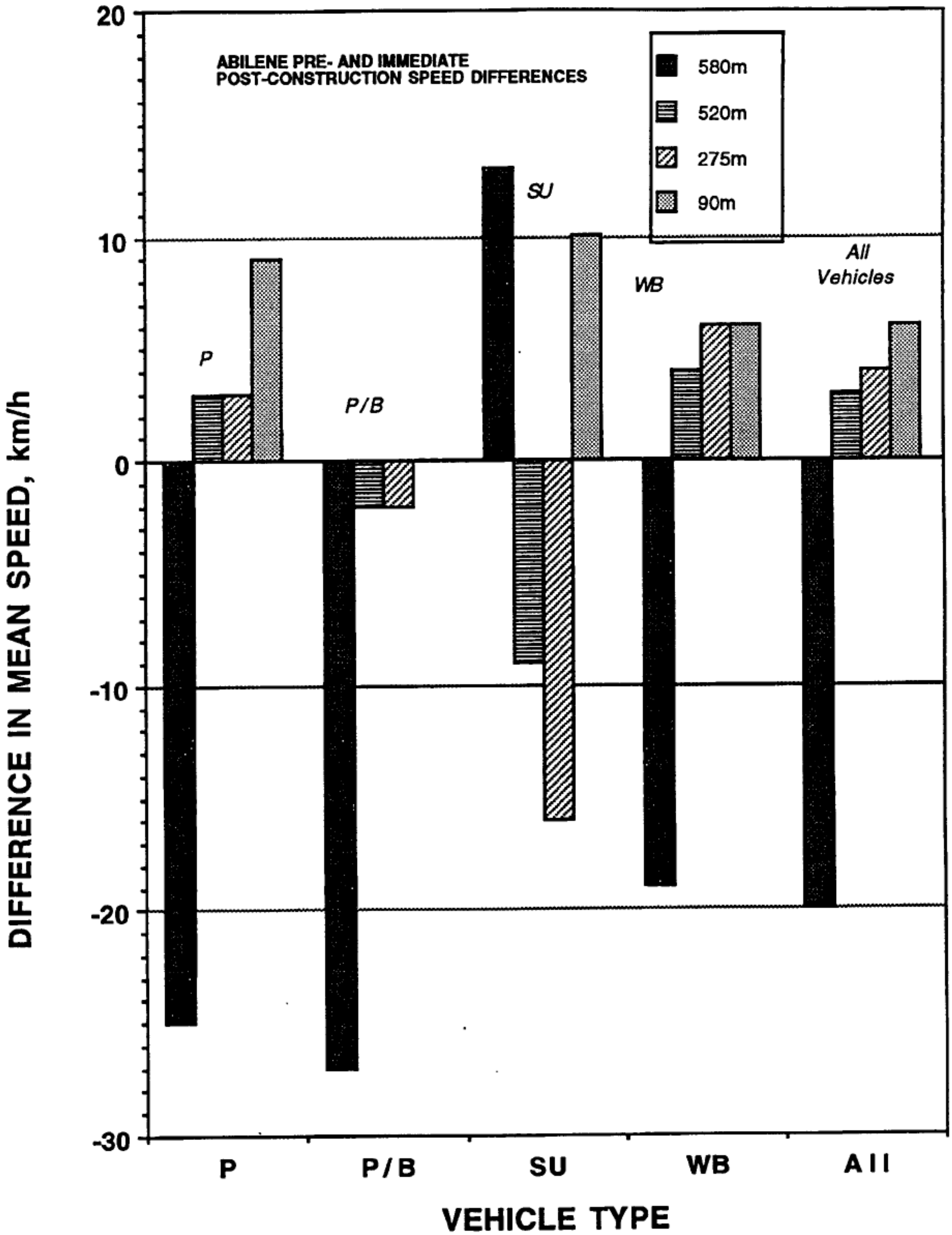

Fig. 4.7. A comparison of changes in approach speeds before and immediately after installation of rumble strips on SH 153 in the Abilene District

4.4.2 Amarillo Site. The site on FM 1061 at US 385 in Oldham County is a T-intersection with the stop sign for FM 1061. Some of the accidents at this intersection involve vehicles running through the intersection of FM 1061 and hitting the fence after crossing US 385.

The pre-construction vehicle speed data was recorded during the period 7:30 a.m. to 6:00 p.m., Thursday, April 13. A total of 204 vehicles were recorded for this site during this measurement. The distribution of vehicles was 162 P vehicles, 6 P/B vehicles, 9 SU vehicles, and 27 WB vehicles. The distribution of the mean speeds for the different categories can be seen in Fig. 4.10. The speed data is shown in Table 4.7. The greatest reduction in speed occurred before the last rumble strip pad at 90 m from the intersection. At this last pad the average speeds were in the low 30-km/h range.

Table 4.7 Amarillo Pre-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	580	520	275	90
P	106	101	100	39
P/B	93	76	90	35
SU	103	103	101	37
WB	97	89	90	34
All Vehicles	105	100	98	39

The immediate post-construction data was recorded during the period 7:30 a.m. to 5:30 p.m., Thursday, April 27. A total of 145 vehicles were recorded during this measurement. The distribution of vehicles was 95 P vehicles, 7 P/B vehicles, 29 SU vehicles, and 14 WB vehicles. The speed data is shown in Table 4.8. The greatest reduction in speed was seen after the third pad at 90 m from the intersection. The distributions for the immediate post-construction data can be seen in Fig. 4.11. One vehicle was observed trying to avoid the rumble strips by driving in the opposing lane. Pre-construction and immediate post-construction data differences were determined for the site. The positive values show a reduction in speed. As seen in Fig. 4.12, all of the final rumble strip pads show a reduction in speed. The greatest reductions in speed occur at the second rumble strip pad at 275 m from the intersection.

Table 4.8 Amarillo Immediate Post-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	580	520	275	90
P	105	100	89	35
P/B	93	90	89	31
SU	95	87	79	31
WB	93	80	74	32
All Vehicles	101	95	85	34

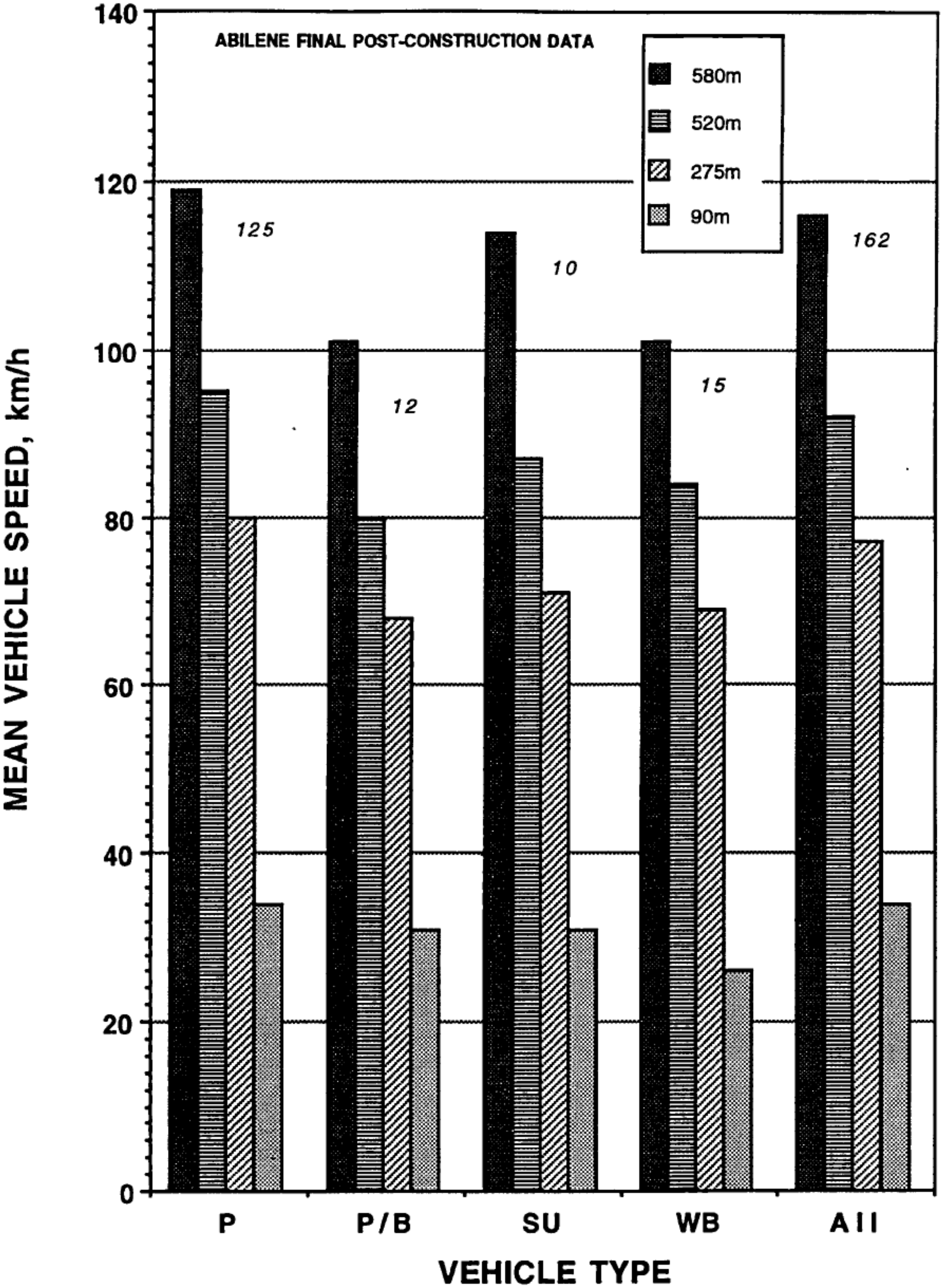

Fig. 4.8. Mean speeds observed by type of vehicle at four locations on SH 153 in advance of the intersection with US 277 several weeks after installation of approach rumble strips on SH 153 in the Abilene District

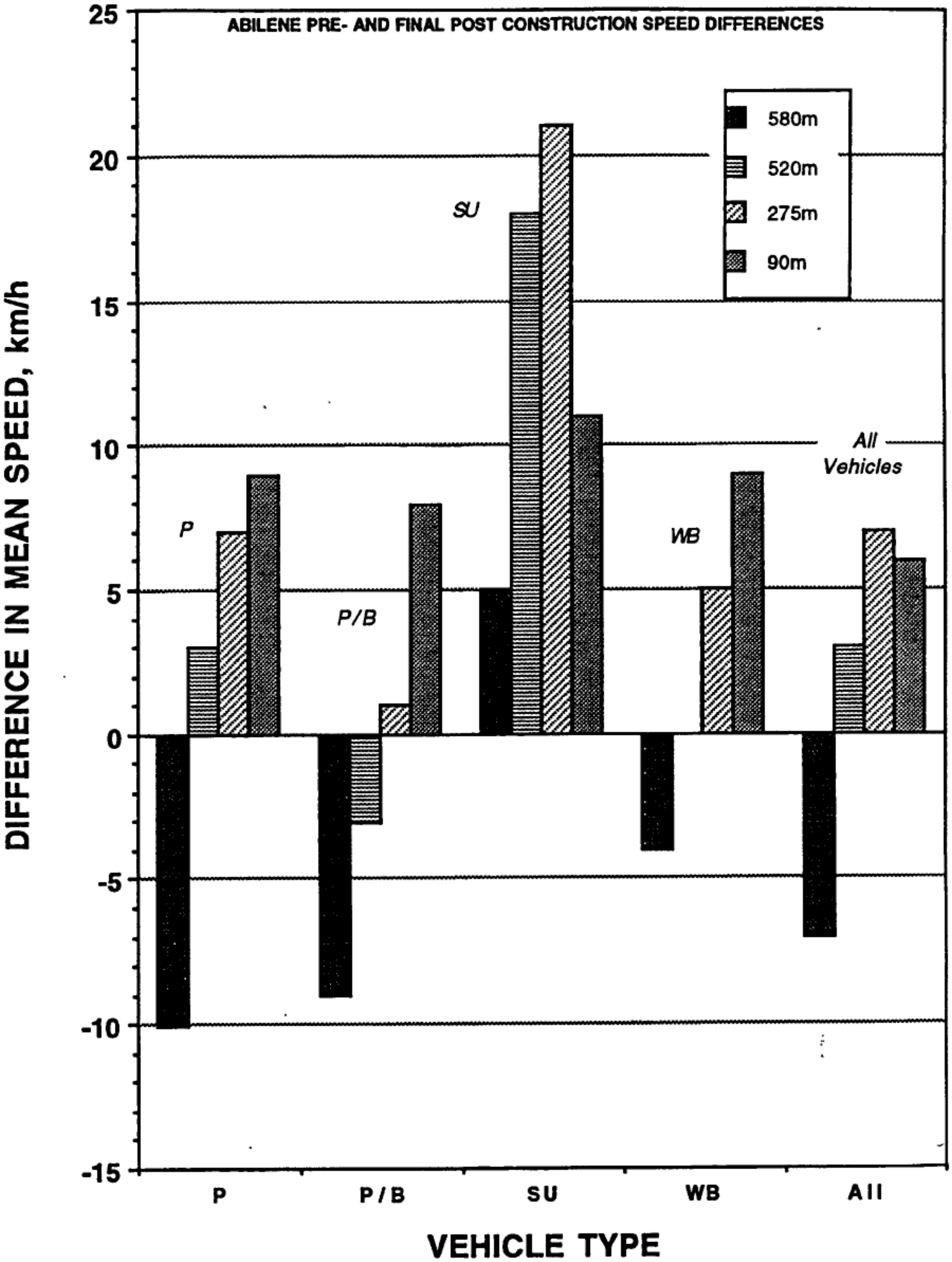

Fig. 4.9. A comparison of changes in approach speeds before and several weeks after installation of rumble strips on SH 153 in the Abilene District

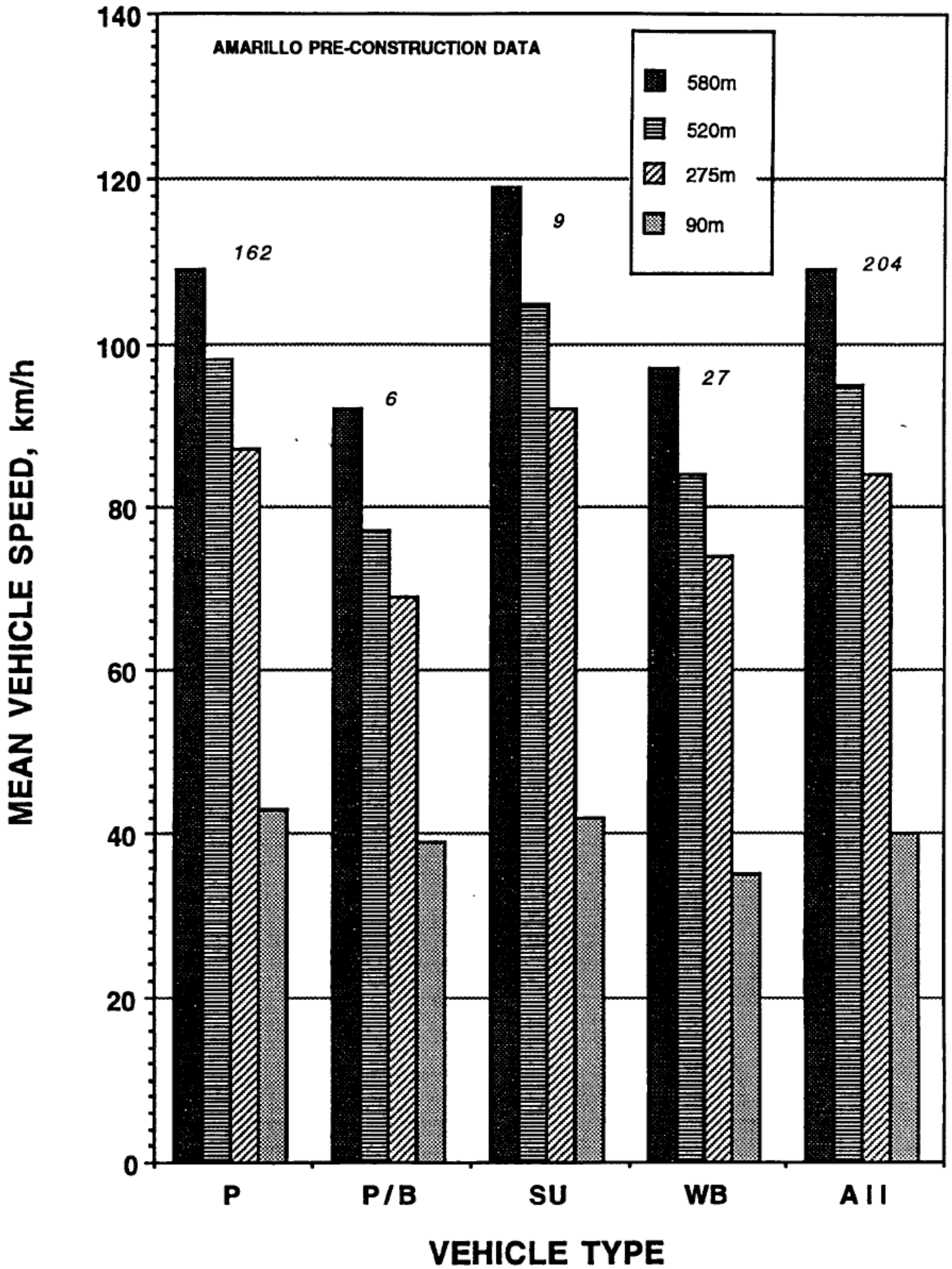

Fig. 4.10. Mean speeds observed by type of vehicle at four locations on FM 1061 in advance of the intersection with US 385 prior to installing approach rumble strips on FM 1061 in the Amarillo District

The final post-construction data was recorded during the period 7:30 a.m. to 5:30 p.m., Thursday, July 13, 3 months after construction. A total of 145 vehicles were recorded during this measurement. The distribution of vehicles was 111 P vehicles, 6 P/B vehicles, 8 SU vehicles, and 20 WB vehicles. The speed data is shown in Table 4.9. The greatest reduction in speed was seen after the third pad at 90 m in front of the intersection. The distributions for the final post-construction data can be seen in Fig. 4.13. Two vehicles were observed trying to avoid the rumble strips by driving in the opposing lane. Pre-construction and final post-construction data differences were determined for the site. The positive values show a reduction in speed. As seen in Fig. 4.14, all of the final rumble strip pads show a reduction in speed. The greatest reductions in speed occur at the second rumble strip pad at 275 m from the intersection.

Table 4.9. Amarillo Final Post-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	580	520	275	90
P	108	100	90	37
P/B	100	85	77	27
SU	98	87	84	32
WB	98	85	82	32
All Vehicles	106	97	89	35

4.4.3 Ennis Site. The site on FM 1183 at US 287 in Ellis County is a skewed intersection at the edge of town. The accidents at this intersection involved disregarding the stop sign on FM 1183. The pre-construction data was recorded during the period 7:30 a.m. to 6:00 p.m., Thursday, March 30. A total of 157 vehicles were recorded during this measurement. The distribution of vehicles was 147 P vehicles, 2 P/B vehicles, 6 SU vehicles, and 2 WB vehicles. The distribution of these mean speeds for the different categories can be seen in Fig. 4.15. The speed data is shown in Table 4.10. The greatest reduction in speed occurred before the last rumble strip section location (i.e., 90 m from the intersection). At this last pad the average speeds were, in general, in the low-30 km/h range.

Table 4.10. Ennis Pre-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	580	520	275	90
P	93	84	79	35
P/B	90	76	77	29
SU	71	69	69	39
WB	103	82	72	37
All Vehicles	93	84	79	35

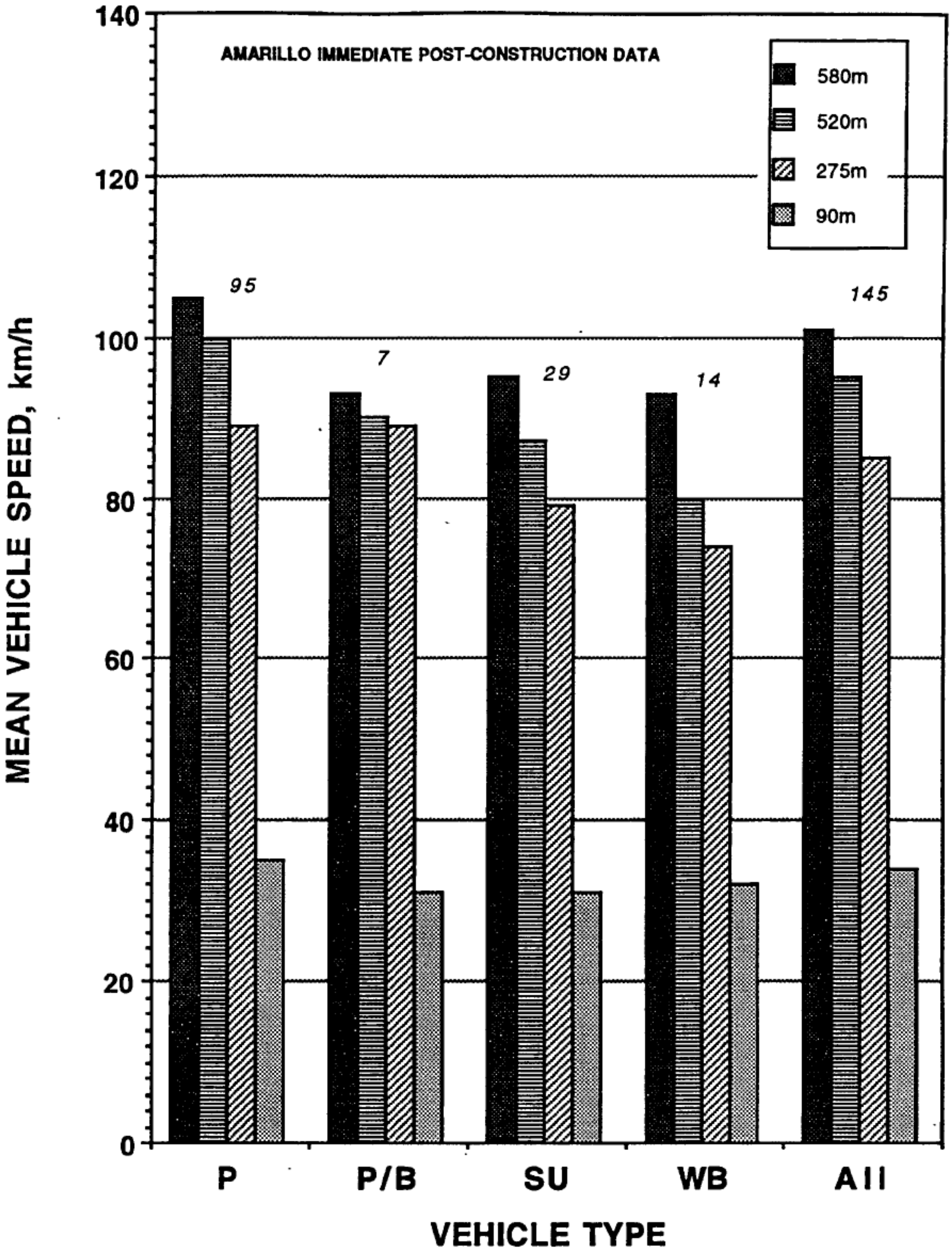

Fig. 4.11. Mean speeds observed by type of vehicle at four locations on FM 1061 in advance of the intersection with US 385 immediately following installation of approach rumble strips on FM 1061 in the Amarillo District

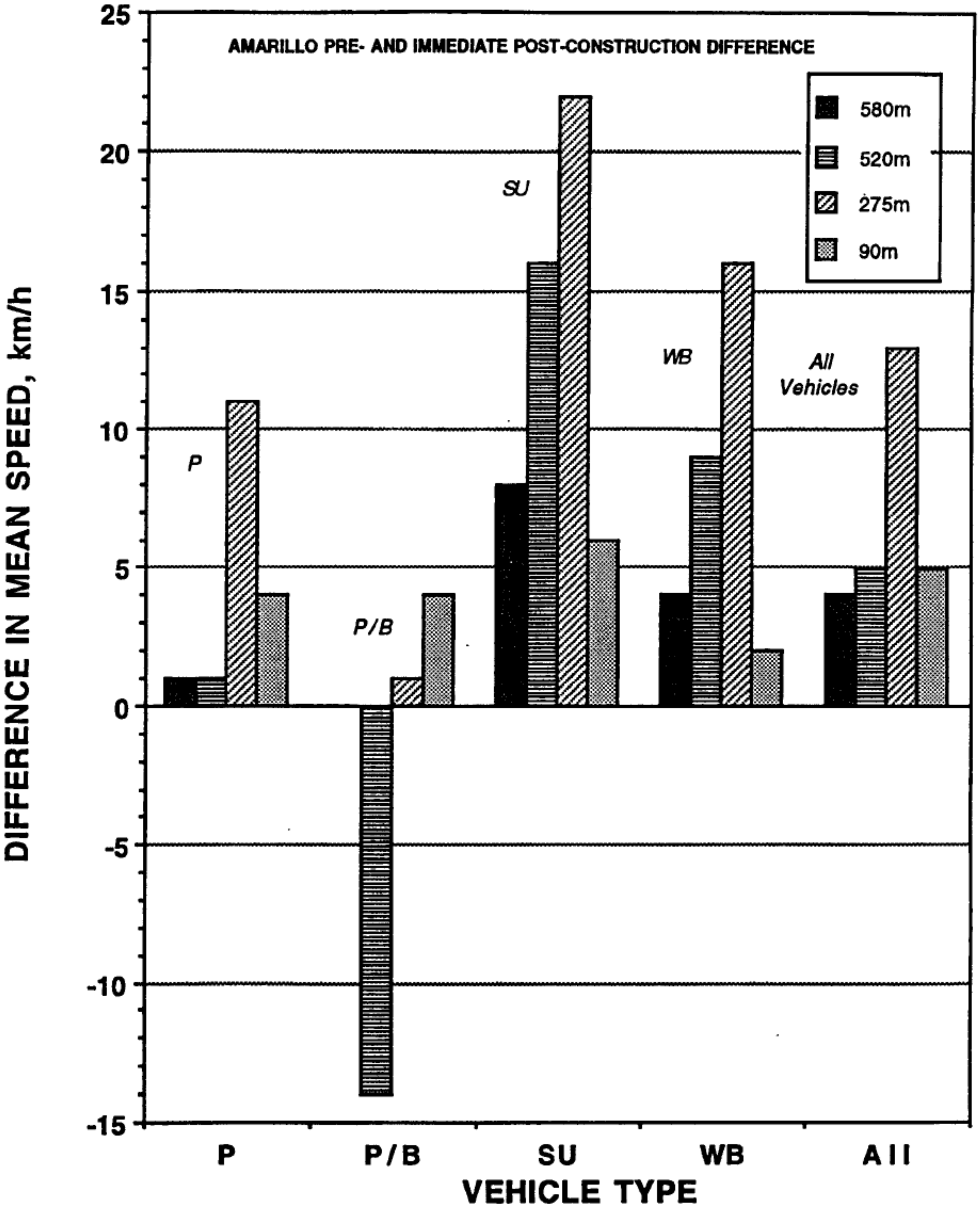

Fig. 4.12: A comparison of changes in approach speeds before and immediately after installation of rumble strips on FM 1061 in the Amarillo District

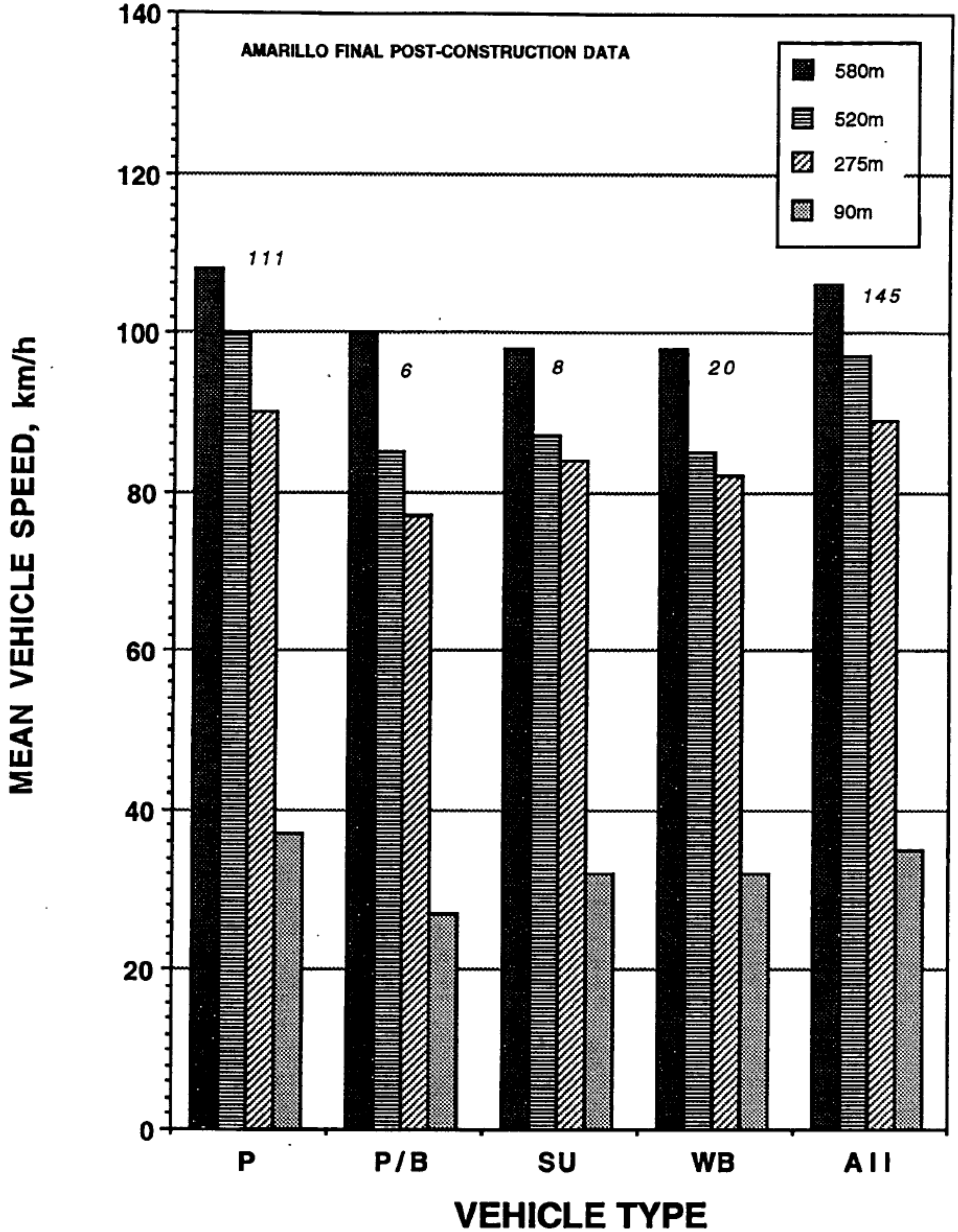

Fig. 4.13. Mean speeds observed by type of vehicle at four locations on FM 1061 in advance of the intersection with US 385 several weeks after installation of approach rumble strips on FM 1061 in the Amarillo District

Subsequent to the pre-construction speed observations, maintenance personnel from the Ennis Area Engineer's office constructed in-lane rumble strips on both approaches to the intersection. However, the maintenance personnel misinterpreted the plan and instead of constructing the first rumble strip pad 90 m (300 ft) from the intersection, the second pad 185 m (600 ft from the first pad or 275 m from the intersection), and the third pad 240 m (800 ft) from the second pad (or 515m from the intersection), the three pads were actually constructed 90, 185, and 240 m (300, 600, and 800 ft) from the intersection. Thus, direct comparison between pre-construction and post-construction speed differences could be made only at the last rumble strip pad (90 m from the intersection). An inferred comparison could be made between the 275 m (from the intersection) pre-construction observations and the 240 m (from the intersection) post-construction observations. Comparison of the pre-construction speed data for all vehicle types with the two post-construction measurement data at the 90 m location shows the pre-and post-construction data to be essentially the same: the mean approach speed immediately following construction had reduced by 3 km/h but had increased to the same speed as the pre-construction observations 4 months later at the end of the study. Comparing the speed observations at the pre-construction 275 m location to the 240 m post-construction speed data, shows the approach speeds to have actually increased after crossing the first rumble strip pad: 79 km/h before construction and 82 and 84 km/h, respectively, immediately following construction and at the end of the study.

The immediate post-construction data was recorded during the period 7:30 a.m. to 3:00 p.m., Thursday, April 20. The number of vehicles observed was fewer than for the pre- and final post-construction dates due to bad weather conditions on April 20 and due to a reduced observation period. A total of 47 vehicles were recorded during this period. The distribution of vehicles was 46 P vehicles and 1 WB vehicle. The average approach speeds were measured at the location of each rumble strip pad and 60 m in advance of the first pad. The speed data is shown in Table 4.11. The greatest reduction in speed was seen after the third pad located 90 m in front of the intersection. The distributions for the immediate post-construction data can be seen in Fig. 4.16. One driver was observed to drive around the rumble strips on the grass shoulder (narrowly missing a culvert) and another driver was observed to move into the on-coming traffic lane in order to avoid traversing the rumble strips. Pre-construction and post-construction data differences were determined for the site. The positive values show a reduction in speed.

Table 4.11. Ennis Immediate Post-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	300	240	185	90
P	80	80	72	32
P/B	0	0	0	0
SU	0	0	0	0
WB	63	58	50	27
All Vehicles	80	82	72	32

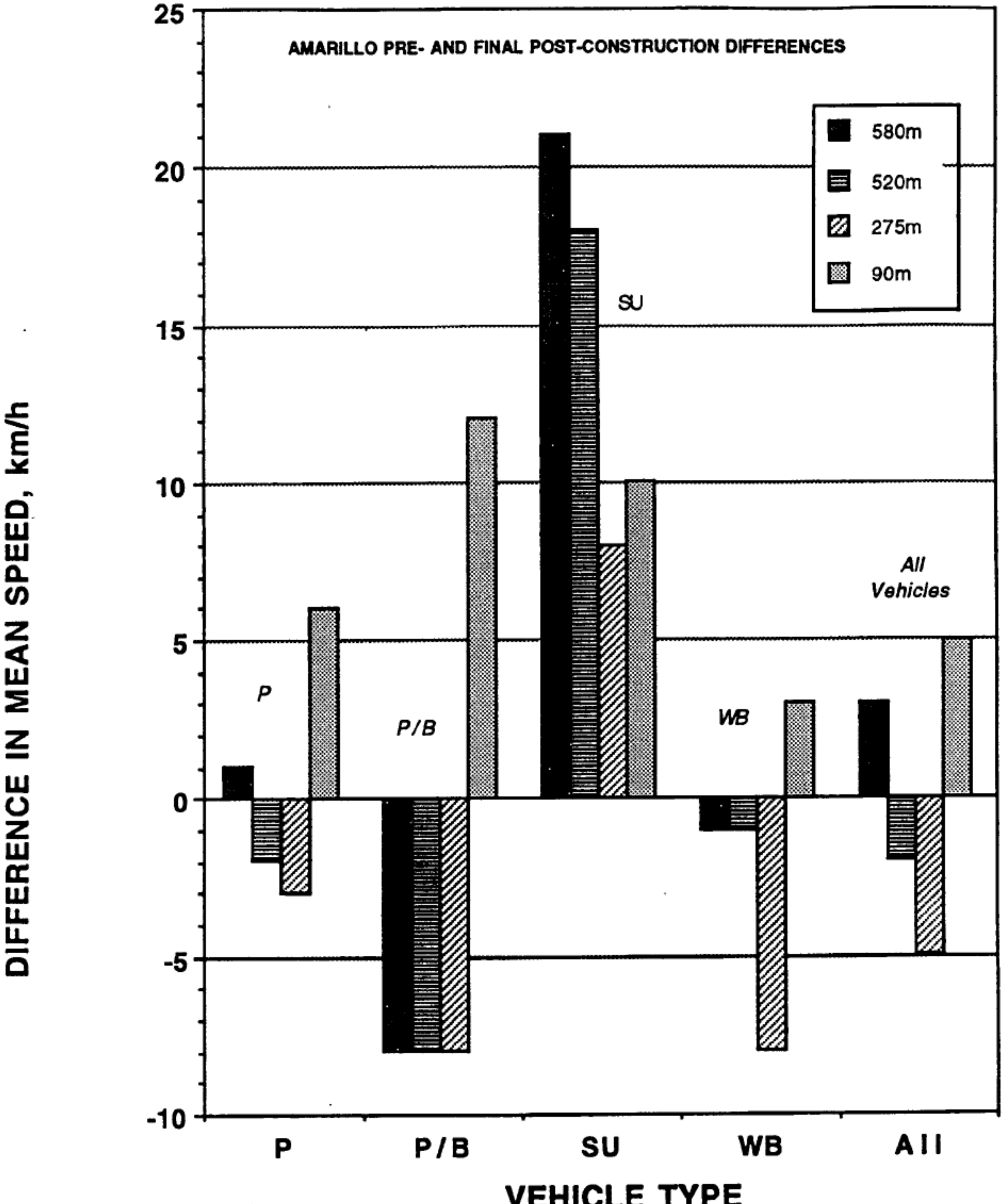

Fig. 4.14 A comparison of changes in approach speeds before and several weeks after installation of fumble strips on FM 1061 in the Amarillo district.

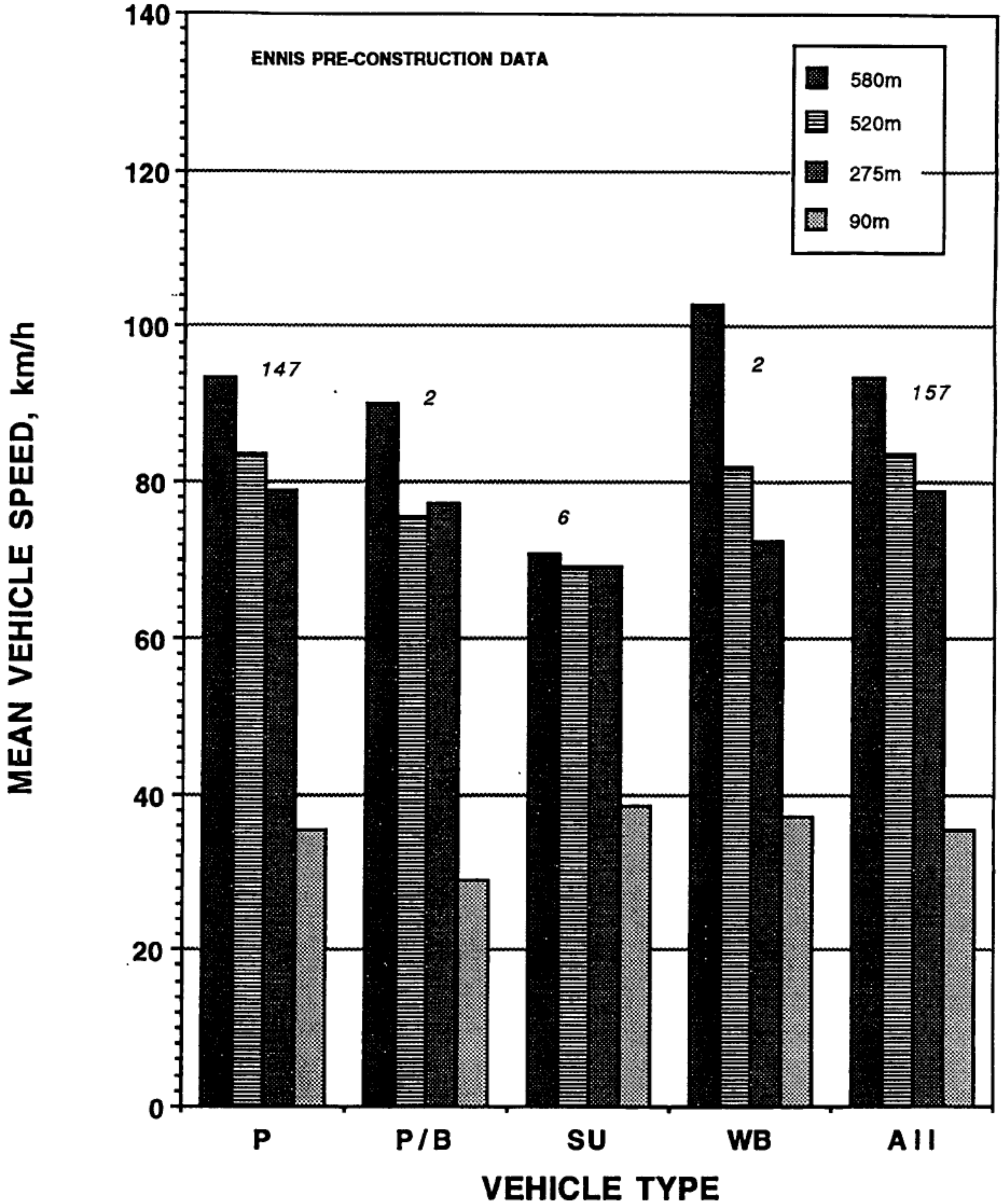

Fig. 4.15. Mean speeds observed by type of vehicle at four locations on FM 1183 in advance of the intersection with US 287 prior to installing approach rumble strips on FM 1183 near Ennis in the Dallas District

The final post-construction data was recorded during the period 7:30 a.m. to 3:00 p.m., Wednesday, July 26, 3 months after construction. A total of 130 vehicles were recorded during this period. The distribution of vehicles was 112 P vehicles, 4 P/B vehicles, 11 SU vehicles, and 3 WB vehicles. The speed data is shown in Table 4.12. The greatest reduction in speed was seen after the third pad, 90 m prior to the intersection. The distributions for the immediate post-construction data are shown in Fig. 4.17. Pre-construction and final post-construction differences were not determined for the site except for the 90 m from the intersection location, which showed no change in approach speed.

Table 4.12. Ennis Final Post-Construction Mean Vehicle Speed Data (km/h)

Vehicle Type	Distance From Intersection (m)			
	300	240	185	90
P	100	84	80	37
P/B	98	79	69	35
SU	101	93	79	34
WB	85	89	76	31
All Vehicles	100	84	80	35

4.5. Discussion of Observed Approach Speed Data

Because of the error in constructing the location of the rumble strip pads at the Ennis site, only the Abilene and Amarillo sites (with the exception of the Ennis rumble strip pad located 300 ft from the intersection, which was a location common at all three test locations) can provide any definitive insight into the effectiveness of the pads in reducing intersection approach speeds.

4.5.1. "All" Speed Data. The "all" speed data, which is the mean speed of all vehicles at each point (i.e., approach, 1st pad, 2nd pad, and 3rd pad) provides a larger number of vehicles to evaluate and allows an "overall" perspective of the impact of the installed rumble strip pads on reducing the speed of vehicles approaching the intersection.

A major difference can be detected in the approach speeds of the vehicles measured at the Abilene test site (Table 4.3) and those observed at the Amarillo test site (Table 4.6). In general, those approaching the Abilene site were traveling at speeds of 31-45[a] km/h above the posted speed limit of 89 km/h (then the legal highway speed), while those

[a] During midway of the field observation period, TxDOT maintenance personnel informed the study team that a highway patrolman had been parked in his marked vehicle at the approach to the intersection the day prior to the approach speed data collection, and that vehicles had been approaching the intersection the previous day, as well as the current day, in a more cautious (slower) manner than typical. Thus, the 68 mph mean approach speed measured by the field observation team during the pre-construction observation field visit was obviously lower than the mean approach speed measured on subsequent days, even after construction of the rumble strip pads.

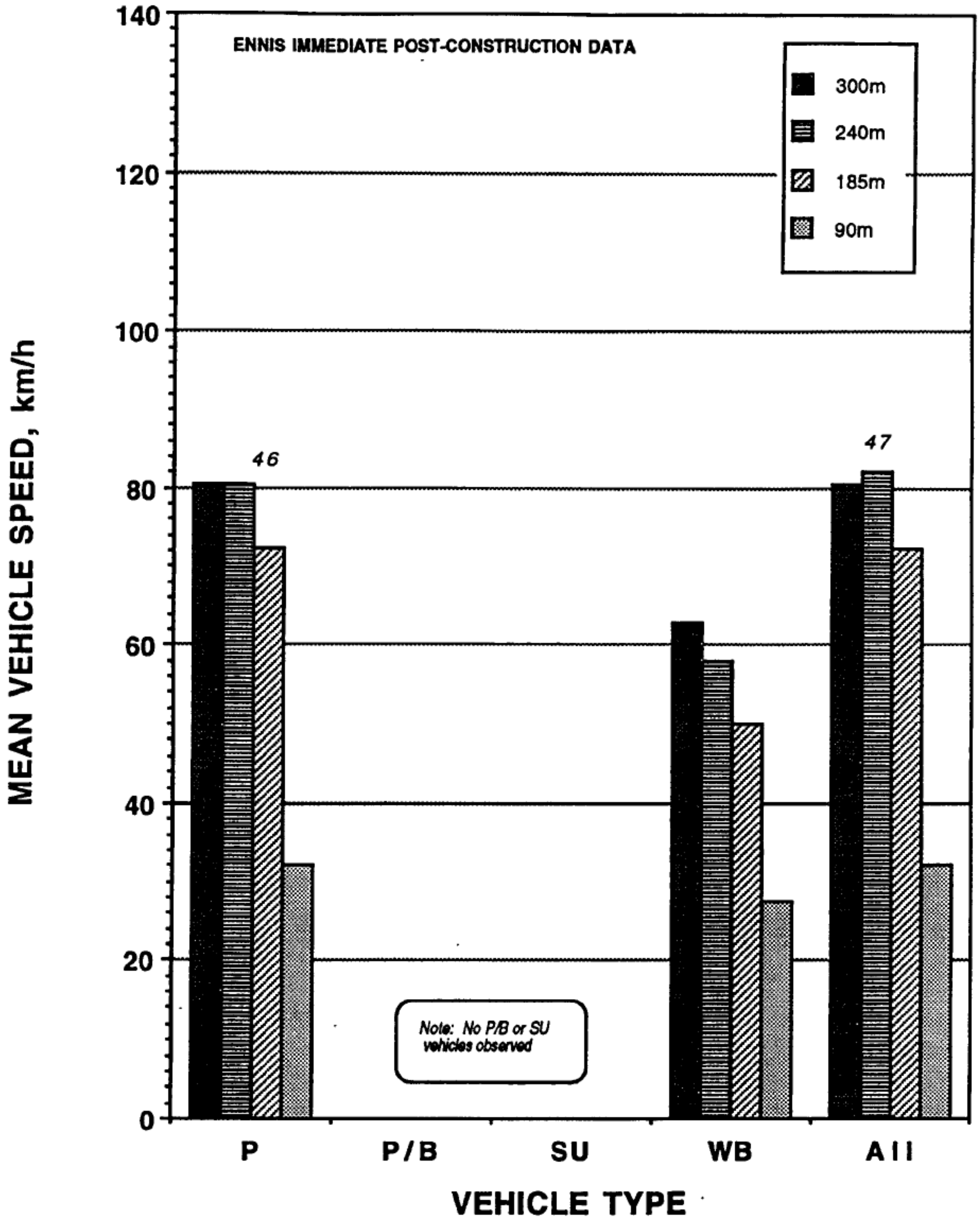

Fig. 4.16. Mean speeds observed by type of vehicle at four locations on FM 1183 in advance of the intersection with US 287 immediately following installation of approach rumble strips on FM 1183 near Ennis in the Dallas District

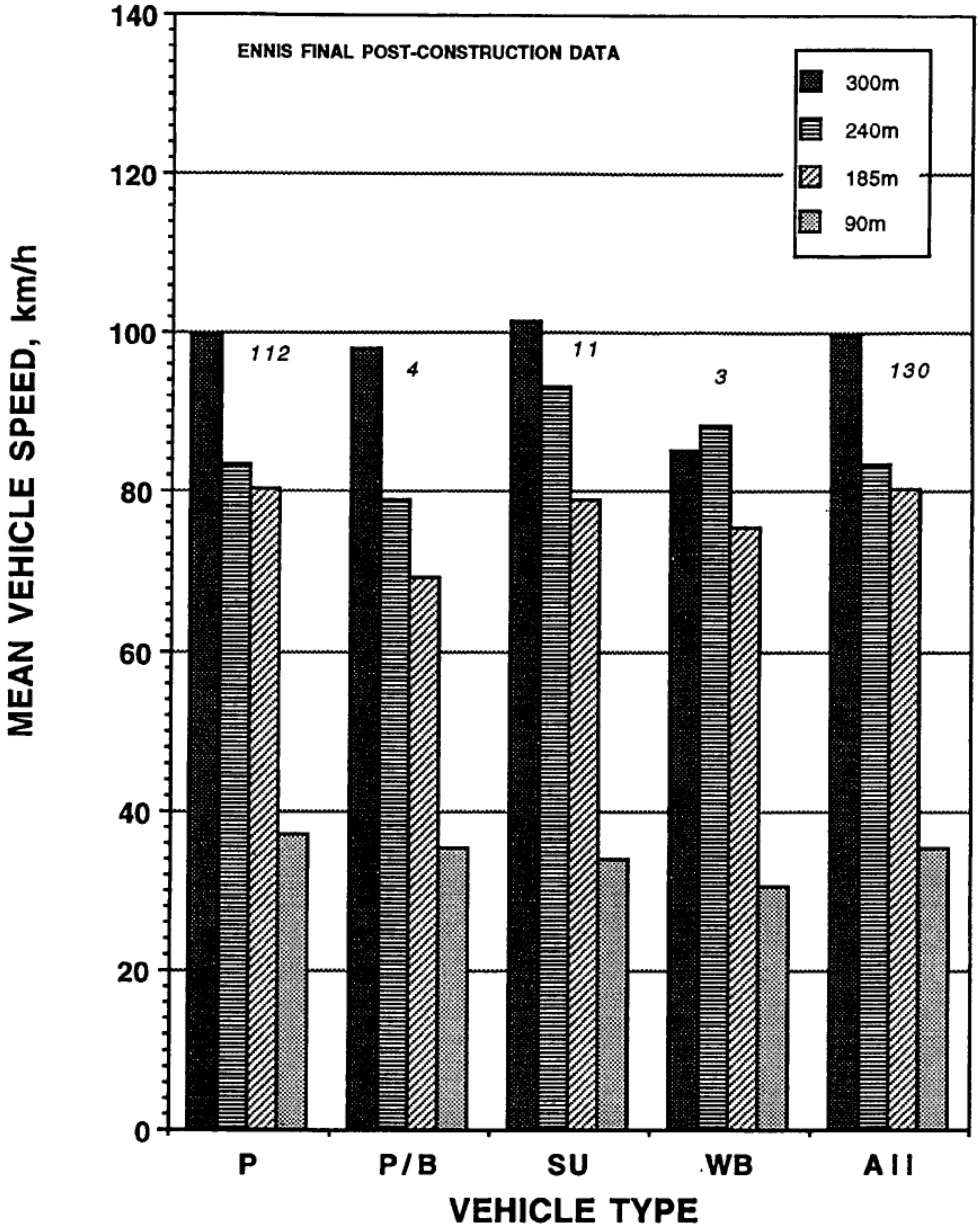

Fig. 4.17 Mean speeds observed by type of vehicle at four locations on FM 1183 in advance of the intersecion with US 287 prior to instaling approach rumble strips on FM 1183 near Ennis in the Dallas District

approaching at the Amarillo test site were still well above the legal speed limit of 89 km/h, but only 16-19 km/h in excess. Because of the unknown impact or influence of the parked highway patrolman noted in the footnote, the typical before-construction mean approach speed cannot be correctly stated and the resulting mean speed data comparisons shown in Table 4.13 cannot be directly compared.

At first glance, the reader may be inclined to conclude that the installation of the rumble strip pads resulted in a significant reduction in approach speeds, e.g., a 37 km/h reduction immediately after installation at the Abilene site. However, when the changes in observed speeds following rumble strip installation is compared to the measured speeds at the same measurement point before construction of the rumble strips, it is noted that only a nominal decrease in speed occurred at each site, i.e., 3 km/h for Abilene and 5 km/h for Amarillo at the first pad. The Abilene site experienced only a 3 km/h reduction in speed at the second pad, however, the Amarillo drivers had slowed an average of 13 km/h compared to the pre-construction measurement by the time they had encountered the second pad. Even by the time the drivers had reached the third and last rumble strip pad--only 90m from the intersection, the speed reductions compared to the pre-construction observations were still not appreciable: 6 km/h at the Abilene site, 5 km/h at the Amarillo site, and 3 km/h at the Ennis site.

Table 4.13. Comparison of Average All-Vehicle Speeds (in km/h) at Common Locations at Each Field Test Site

Site	Observation Period	1900 Ft	1700 Ft	900 Ft	300 Ft
Abilene	Pre-Construction	109	95	84	40
	Immediate Post-Construction	129	92	80	34
	Post-Construction	116	92	77	34
Amarillo	Pre-Construction	105	100	98	39
	Immediate Post-Construction	101	95	85	34
	Post-Construction	106	97	89	35
Ennis	Pre-Construction	-	-	-	35
	Immediate Post-Construction	-	-	-	32
	Post-Construction	-	-	-	35

Field measurements of speed reductions at each location were made a third time at each site to determine if familiarity with the rumble strips had resulted in any change in approach speeds or if the familiarity had resulted in altered driving habits (e.g., driving around the pads on either the shoulder or in the opposing lane). What was termed the "post-construction" measurements were made at each site between 4 and 6 months after construction. Compared to the pre-construction measurements, the Abilene site revealed 3, 3, and 6 km/h speed reductions at each rumble strip pad. The approaching vehicles at the Amarillo site exhibited 3, 10, and 3 km/h speed reductions at each pad location, and the Ennis site showed no change in the approach speed at the only directly comparable pad location (i.e., 90m from the intersection).

Two other factors may have had a part in the approach speeds. It had been reported by TxDOT maintenance personnel that vehicles approaching the intersection at the Abilene site could see a long distance in either direction on the intersection highway and, consequently, many drivers would make no attempt to stop at the intersection if no oncoming traffic was observed. Thus, drivers approaching the Abilene test site were accustomed to driving well above the legal 89 km/h speed limit (which was borne out by the field studies, discounting the impact of the parked highway patrolman) and many likely approached the intersection with no intent of appreciably slowing (i.e., performing a "rolling stop" maneuver), let alone coming to a complete stop, if no approaching cross traffic was observed. The Amarillo test site intersection terrain, like the Abilene site, allowed drivers to see a great distance and observe on-coming cross traffic. However, the approach to the intersection ended in a T-intersection which forced the drivers to at least slow to a speed that would permit them to make the 90 degree turn onto the intersecting highway even if they didn't stop. The difference in intersection geometry may have partly accounted for the lower speeds of vehicles approaching the intersection at the Amarillo site.

Because of the apparently small changes in approach speed at each of the rumble strip pad locations (i.e., pre-construction speed versus post-construction speed), rather than the difference between the vehicle speed approaching the first set of rumble strips and its speed after encountering the first rumble strip, a definitive conclusion regarding the success of the installed rumble strips in reducing approach speeds based solely on average speed reduction could not be made. Thus, a statistical approach to analyzing the data to determine whether or not the noted speed reductions were significant was employed.

4.5.2. <u>Driver Behavior</u>. One of the objectives of making observations of approaching traffic near the end of the study period was to evaluate the impact the rumble strips had on long-term behavior of "local" drivers, i.e., drivers that encountered the rumble strips daily or frequently. Some technical literature had cited attempts by drivers to avoid the rumble strips by driving on the shoulder or even moving into the opposing traffic lane.

There were several incidences observed in which drivers took "evasive" action to avoid traversing the rumble strips. At Amarillo three vehicles were observed trying to avoid the rumble strips by driving in the opposing lane during the two days of post construction observation. At Ennis, which did not have paved shoulders, one driver was observed to drive around the rumble strips on the grass shoulder (narrowly missing a culvert) and another driver was observed to move into the opposing traffic lane in order to avoid traversing the rumble strips. Tracks were also observed on the grass shoulder where at least one other vehicle had previously moved onto the grass shoulder to avoid encountering the rumble strips. None of the vehicles observed at the Abilene site attempted to avoid the rumble strips by driving around them.

4.6 Statistical Analysis

Analysis of Variance (ANOVA) is a method used to test for differences of the means of data samples over several groups. ANOVA can be used as a measure for one factor or can be extended to handle data samples where more than one factor needs to be studied. ANOVA deals with the analysis of total variation by dividing it into its significant parts. ANOVA starts with the assumption that there are two types of variability in the analysis. The first type of variability is linked with systematic differences among the treatments. The second type of variability includes all other forms of variability, assumed to operate randomly throughout the samples and contribute equally to all the treatments (Frank, 1994).

The results in the ANOVA tables give values for the sets corresponding to the mean values of the sets and the variance determined between the sets. The terms on the tables refer to the sum of the squares of the values (SS), degrees of freedom (df), the mean square value (MS), F distribution, p-value, and the F-critical value. The degrees of freedom are in relationship to the mean value and the number of sample values of the data that are "free" to vary. The F distribution is the relationship between the mean square values between the groups of data and the variation of the sample mean of each group. The F-critical value is the F distribution value determined for a predetermined number of samples and degrees of freedom. The p-value is commonly known as the "observed level of significance." The p-value is another measure as to how well the data sets fit the expected outcome (Frank, 1994). ANOVA computations were used to examine the relationship of the data that was taken for each of the sites. Single factor analysis was done in comparing the "before" treatment and the "after" treatment data. Analysis was also done with the different locations in each data set to determine the variability of each set. The analysis shows that the F-values in relationship to the critical F-value determine the outcome of the analysis. The F-value must exceed the F-critical value for a relationship to exist between the variables in the test. These values are shown in Table 4.14. For each of the before and after tests at each of the three sites there was no relationship shown that would be attributable to installation of the rumble strips. The variance in the data sets occurs at the third strip location only because of the increased reductions in speed in comparison to the two other locations.

Frequency distribution is used in determining the percentile rankings. The 85th percentile results give an idea of what type of variables are represented and how they are arranged in the data sets. The 85th percentile speeds for each of the sites were calculated for the pre-construction and immediate post-construction data. These values give an idea of the different distributions of speeds at each of the sites in relationship to the number of vehicles measured at each site. These values are shown for each of the sites in Figs. 4.18-4.20. (Because of the error in constructing the Ennis test site, only the observations from immediately following the construction and the observations from the end of the study period are compared in Fig. 4.20.)

4.7 Construction

Construction methods were examined for installing rumble strips. At each of the three test sites, the rumble strips had to be cut into the existing pavement. DOT offices in Oklahoma, Colorado, and Utah were consulted, and for this type of installation it was determined that there was no standard or typical method of after-the-fact construction. In most cases, some type of grinder was used to grind the grooves into the pavement. The machinery that each DOT reported being used was unique for each site and design of rumble strip pad.

ABILENE

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	202	50.5	341.667
Column 2	4	196	49	365.333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.5	1	4.5	0.013	0.914	5.987
Within Groups	2121	6	353.5			
Total	2125.5	7				

AMARILLO

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	204	51	343.333
Column 2	4	202	50.5	321.667

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.5	1	0.5	0.002	0.970	5.987
Within Groups	1995	6	332.5			
Total	1995.5	7				

ENNIS

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	4	181	45.25	254.25
Column 2	4	166	41.5	212.333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	28.125	1	28.125	0.121	0.740	5.987
Within Groups	1399.75	6	233.292			
Total	1427.88	7				

Table 4.14 ANOVA Test Site Results

The construction at each test site was done by the TxDOT maintenance section in that District. The Abilene site was the initial site for installation. Their research revealed a concrete pavement planer that was adequate to grind the desired 4-in. wide groove to a 13 mm depth. The Enco™ planer was rented from Prime Equipment Co. in El Paso, TX and tested before taking it to the test location. The three-pad installation was cut in three days by a five-man crew using the Enco™ planer. Different consistencies of grooves were tried with the Enco™ planer. Difficulty was experienced in keeping the grooves straight and consistent because of the bulkiness of the machinery.

The Amarillo site was constructed using the same Enco™ grinder used at the Abilene site. There were problems early in the construction process with the steel grinder blades breaking. The blades were replaced with carbide-tipped blades and no more broken blades occurred. Using the carbide-tipped blades, the 13 mm deep grooves were cut in one pass. This same equipment was used again at the Ennis site. The construction process was long, and multiple passes had to be made for the grooves at this site using the non-carbide-tipped steel blades. Construction time was noted as being approximately one pad per day for all three sites. Amarillo and Ennis both had problems with the non-carbide-tipped steel blades and the construction time was extended because of having to replace the blades and to make multiple passes. The sites listed use of a five-man crew, including traffic control, for construction. Approximate construction costs for rental of equipment, crews, and the cutter wheels was $2,500 for one week's construction time.

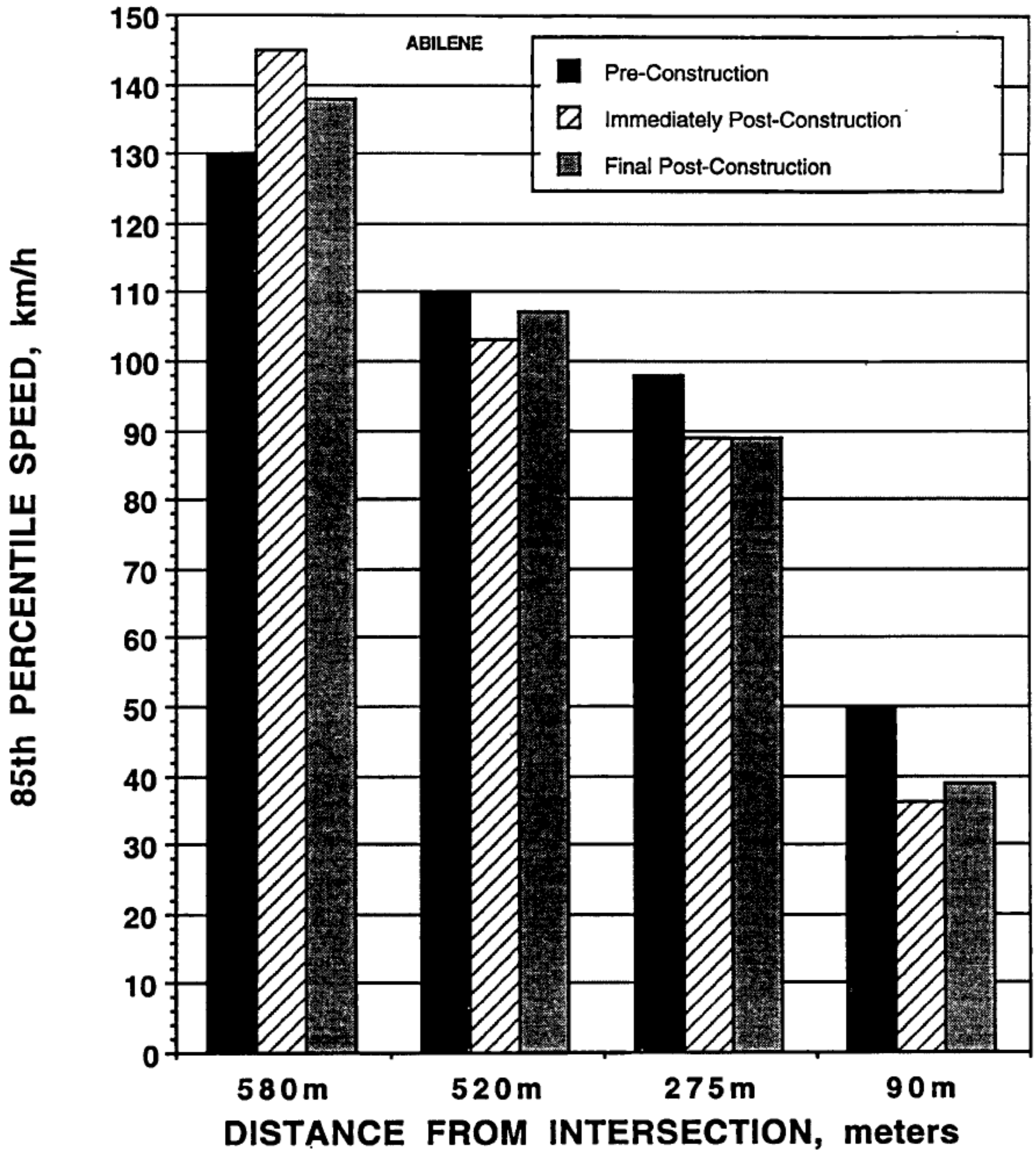

Fig. 4.18. 85th percentile speeds observed prior to, immediately following, and several weeks after installation of approach rumble strips at each of four measurement locations on SH 153 in the Abilene District

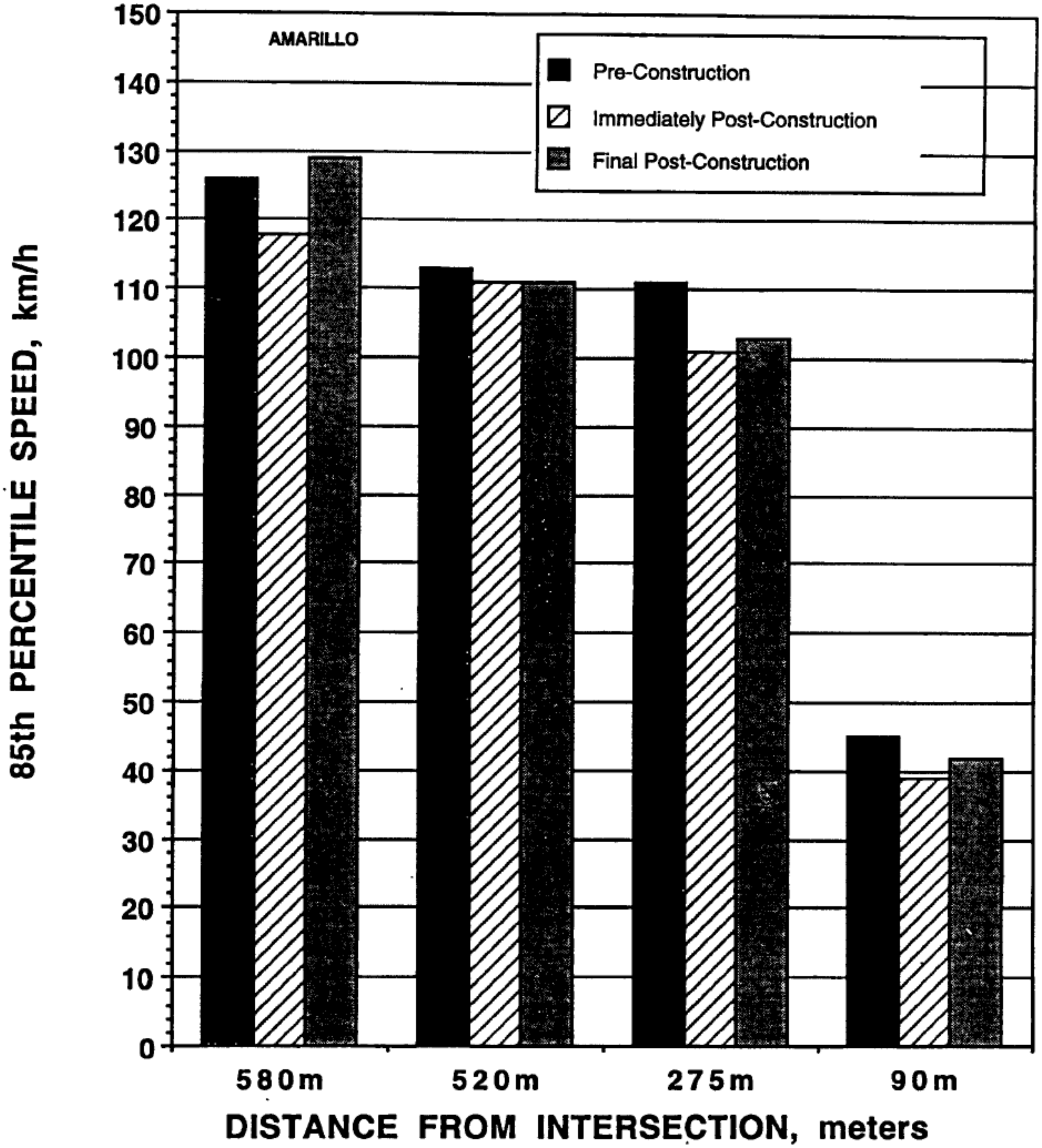

Fig. 4.19. 85th percentile speeds observed prior to, immediately following, and several weeks after installation of approach rumble strips at each of four measurement locations on FM 1061 in the Amarillo District

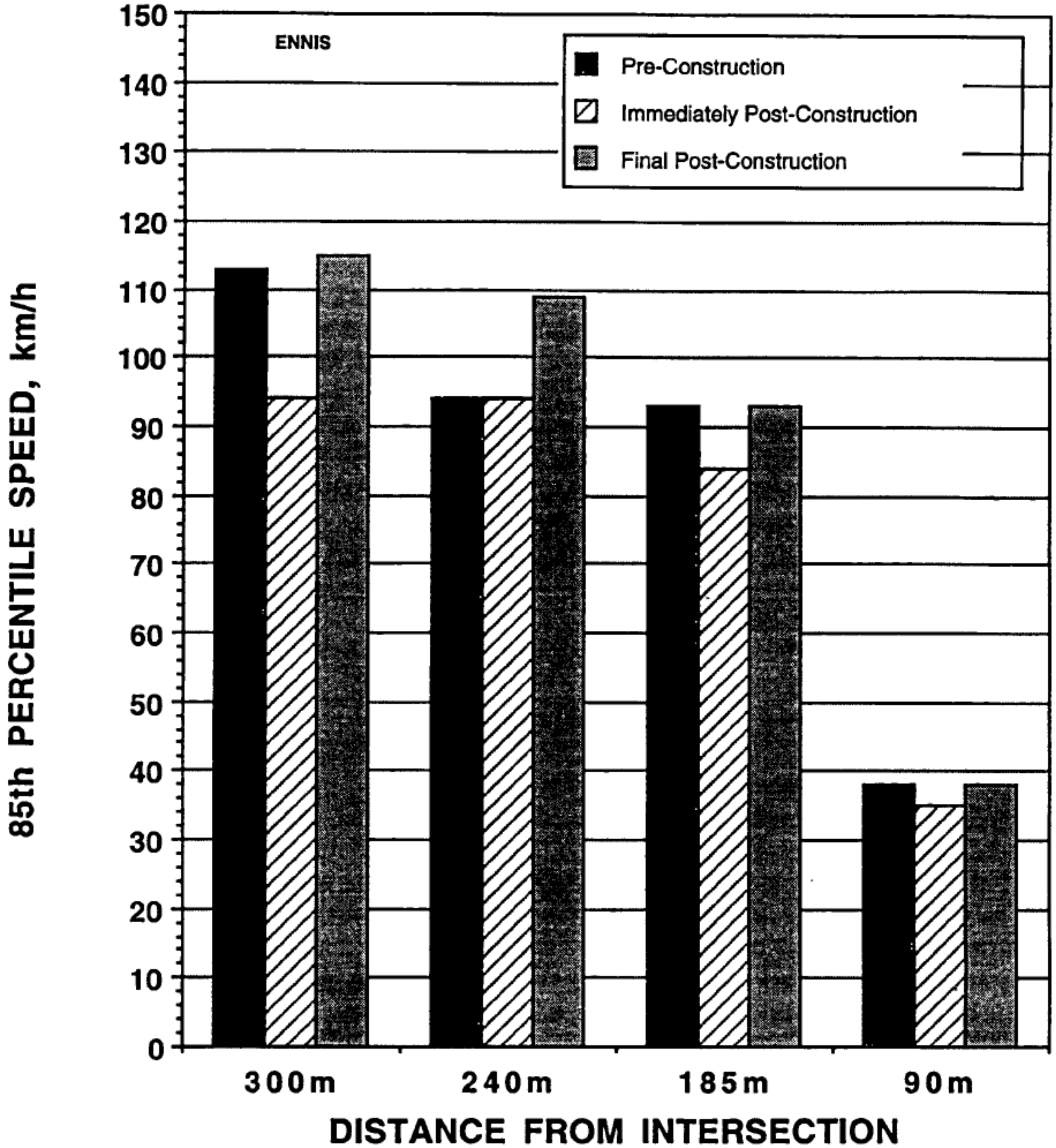

Fig. 4.20. 85th percentile speeds observed immediately following and several weeks after installation of approach rumble strips at each of four measurement locations on FM 1183 near Ennis in the Dallas District

4.8 Noise Levels

Sound level measurements were taken at the sites to evaluate changes in noise level due to the rumble strip installation. The readings were taken with a decibel meter; the *A* scale was used since it is the one that closely resembles sound for an industrial setting. The *A*-weighted network measures frequency responses that are similar to ones of the human ear at relatively low sound pressure levels (Grimaldi, 1989). Nelson (1978) gives the noise level equation in relationship to distance from the source as $L = 20 \log(D/50)$, where L is the sound level in decibels, and D is the distance in feet from the sound source. The "50" in the equation is taken as a reference distance of 50 ft (15.2 m). Using this equation (no metric version of the equation is known), it was determined that the increase in decibel level would drop by approximately three decibels (dB) for every 50 ft (15.2 m) increase in distance from the noise source. The increased levels measured at the sites indicated a 10 to 12 db increase immediately at the edge of the pavement, with typical readings of 80 to 85 dB. Measurements taken at 6.1 to 7.6 m from the pavement edge revealed that the sound level decreased approximately 3 dB, i.e., the sound level increase at 6.1 to 7.6 m from the pavement edge due to the rumble strips was increased 7 to 8 dB. At 15.2 m from the pavement edge, the increased sound level was 6 to 7 dB greater than the average initial reading of 85 dB. These measurements were taken at various locations and distances from the rumble strips where it was possible to obtain the readings. The distance needed to sustain the noise level (i.e., to attenuate the increased noise magnitude to pre-construction level) was found to be a minimum of 60 m for any businesses or residences in that immediate area.

4.9 Rumble Strip Pad Deformation Measurements

Measurements of groove depths were taken first during the immediate post-construction testing and then again during the final post-construction testing. Measurement sections were determined, locations and measurements recorded for easy future reference, and then also marked with paint for easy future reference. The two sites with the measurements taken at both times were Amarillo and Ennis. Initial depth measurements at the Abilene site were failed to be taken during the immediate post-construction measurements, but a full set of measurements was taken at the Abilene site during the final post-construction measurements.

Depth measurements were taken at each site using the measuring tip of a caliper. Measurements were taken for each pad of the installations. Four different measurements were taken at four different areas for each pad. Two measurements were taken for areas that were determined to be in the normal wheelpath and two were taken for areas that were not in the normal wheelpath. The Abilene and Ennis sites both had northbound and southbound approaches. The T-intersection at the Amarillo site only had one approach. The measurements for each of the sites are shown below in Tables 4.15 - 4.20.

Table 4.15. Abilene - FM 153 Final Post-Construction Groove Dept Measurements

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1 North	8.0	2.0	4.5	12.0
Pad 2 North	10.4	6.8	8.1	11.5
Pad 3 North	6.2	4.9	6.5	10.4
Pad 1 South	3.1	4.2	1.1	5.0
Pad 2 South	9.0	4.1	2.9	5.0
Pad 3 South	12.1	10.9	7.2	10.0

Table 4.16. Amarillo - FM 1061 Immediate Post-Construction Groove Depth Measurements

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1	13.0	11.5	8.2	10.5
Pad 2	10.0	8.0	10.5	10.8
Pad 3	10.1	9.2	12.5	10.5

Table 4.17. Amarillo - FM 1061 Final Post-Construction Groove Depth Measurements

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1	11.0	9.6	8.0	9.0
Pad 2	9.2	8.0	10.0	10.0
Pad 3	10.0	8.0	11.2	10.1

Table 4.18. Amarillo - Deformation Differences Between Immediate and Final Post-Construction Measurements[a]

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1	2.0	1.9	0.2	1.5
Pad 2	0.8	0.0	0.5	0.8
Pad 3	0.1	1.2	1.3	0.4

[a] Positive value indicates a reduction in height

Table 4.19. Ennis - FM 1183 Immediate Post-Construction Groove Depth Measurements

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1 North	9.5	12.6	11.2	8.7
Pad 2 North	11.3	10.7	7.6	9.8
Pad 3 North	14	19.1	16.3	7.6
Pad 1 South	14.0	7.7	15.6	4.7
Pad 2 South	11.7	12.1	10.9	9.8
Pad 3 South	8.2	7.8	12.8	6.7

Table 4.20. Ennis - FM 1183 Final Post-Construction Groove Depth Measurements

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1 North	7.0	11.0	8.2	8.5
Pad 2 North	8.2	7.0	4.0	8.5
Pad 3 North	14.0	0.0	9.8	4.0
Pad 1 South	5.0	4.0	5.0	4.0
Pad 2 South	10.0	11.2	8.9	6.5
Pad 3 South	0.0	3.0	2.0	0.0

Table 4.21. Ennis - Deformation Differences Between Immediate and Final Post-Construction Measurements[a]

Location	Area 1 (mm)	Area 2 (mm)	Area 3 (mm)	Area 4 (mm)
Pad 1 North	2.5	1.6	3.0	0.2
Pad 2 North	3.1	3.7	3.6	1.3
Pad 3 North	0.0	19.1	6.5	3.6
Pad 1 South	9.0	3.7	10.6	0.7
Pad 2 South	1.7	0.9	2.0	3.3
Pad 3 South	8.2	4.8	10.8	6.7

[a] Positive value indicates a reduction in height

The Amarillo site showed a 0.8 mm mean reduction in groove depth with a range from 0 to 2.0 mm over all three pads on FM 1061 over the 4 month observation period. The measured range of depth for the depressions for FM 1061 was between 18 and 13 mm. The Ennis site showed greater pad deformation. The mean reduction for the FM 1183 northbound pads was 4.6 mm with a range between 1 and 7 mm over the 4 month observation period. The initial measured range of depth for depressions on northbound FM 1183 was between 10 and 20 mm. The reduction range for the FM 1183 southbound pads was between 1 and 11 mm. The initial measured range of depth for depressions on southbound FM 1183 was between 5 and 16 mm. The final measurement on the Abilene site gave measurements of the depth of depressions to be between 2 and 12 mm for northbound FM 153 and between 1 and 10 mm for southbound FM 153.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1. Limitations of Study and Results.

In accomplishing the study, several limitations were experienced that constrained the scope of what could be accomplished.

5.1.1. Number and Type of Field Test Sites. The first limitation was the number and type of field test sites. At the outset of the study, it was hoped that six to eight sites could be studied. The limitation on site selection was the willingness of TxDOT Districts or Areas to volunteer locations and to invest time and money in the construction of the rumble strip pads at those locations. Initially, it was also hoped that a variety of test locations could be studied: rural and suburban locations; long tangent sections, sharp curves, blind intersections, etc. As it developed, very few sites were volunteered that were not long tangent approaches to intersections.

5.1.2. Accident History. A limitation that was placed on the selection of the test locations was that each site should exhibit some degree of accident frequency, i.e., it was considered that rumble strip installation effectiveness could be better evaluated at a future time if installed at locations that had a history of accidents rather than placing rumble strips at locations that had experienced few or no accidents. Since the scope of the study was to be limited to only one year in length, it should be noted that evaluation of reduction in accidents due to installation of rumble strips was not an objective of the study.

5.1.3. Nearness of Adjacent Occupied Buildings. Another constraint on site selection was nearness of adjacent houses or businesses. A number of studies found in the technical literature had reported that noise from vehicles passing over the rumble strips had created a nuisance--in some cases the noise was perceived to be a very great nuisance--for people who lived or worked near the rumble strip installations. Thus, locations that had too many houses or business near where the rumble strips would be installed or had houses or business immediately adjacent to the rumble strip locations were eliminated as potential study locations.

5.1.4. Weather and Construction of Test Sites. An uncontrolled constraint on the study involved weather and construction schedules. The combination of the availability of TxDOT maintenance personnel to construct the rumble strips and periods of inclement weather, which impacted other scheduled major or priority maintenance, resulted in some otherwise acceptable locations not able to be constructed.

5.1.5. Type of Rumble Strip Installation. Based on reports of other investigations from the technical literature and from the responses received from the nationwide survey conducted at the beginning of the study, it was apparent that a single rumble strip installation design in the driving lane would not be satisfactory. Consequently, four separate rumble strip designs were devised, each to meet a specific need. At the initiation of the study, it was anticipated that most or all of the four different types of rumble strip designs would be tested. However, for specific reasons, all three field test sites were constructed using the same design.

Thus, only three sites were ultimately constructed. Each site was located on a long tangent approach to an intersection. Each site was in a rural location. Each site was a on a low volume 2-lane highway. No site had paved shoulders. Each site was constructed using the same rumble strip design: continuous transverse rumble strips across only the travel lane. One of the three test sites was incorrectly constructed, reducing the data available for comparability evaluation to that from only two sites. Neither of the two sites were on high traffic volume routes; thus, neither the number of vehicles nor observed data available for evaluation at either site was appreciably large. Consequently, this also limited some of the analyses that could be applied to the data.

5.2 Conclusions

The study consisted initially of research and surveys to obtain information on current rumble strip installation designs, uses, and problems. The question as to whether or not rumble strips in the travel lane would reduce accidents was not considered; sufficient numbers of studies reported in the technical literature showed rumble strips in the travel lane to be effective in reducing accidents. The intent of this study was to develop acceptable designs of rumble strips on the shoulders and in the travel lanes based on other studies and the experience of other DOTs. The study also intended to determine if the adopted in-lane rumble strip designs produced any adverse effects to vehicle operations or caused aberrant driving behavior by vehicle operators. From this information, recommended design standards and specifications were developed for use by TxDOT.

Test sites were chosen for the proposed in-lane rumble strip designs, and construction methods were established for the pads. Speed studies were conducted at each test site. One set of traffic type and approach speed data was gathered before the strips were constructed, and one set of data was taken immediately after the strips were installed. A third set of data was obtained near the end of the study to assess changes in direct behavior. Noise measurements were also made to determine what type of adverse noise effects rumble strips would generate. Observations were made at each site to determine the actions of the vehicle operators, such as trying to avoid the rumble strips. Measurements were also taken of the depth of strips so as to be able to determine their durability over an extended period of time.

Noise measurements taken show as much as a 10 to 12 dB increase in noise level immediately at the pavement edge after rumble strip installation. This increase in noise would require at least 60 m between the rumble strip pads and any adjacent residence or business to reduce the noise levels to that caused by traffic prior to the rumble strip installation. Five of the 782 vehicles observed in this study were noted driving around the rumble strips; four drove into the opposing traffic's lane and one drove onto the sod shoulder narrowly missing a culvert. Deformation measurements taken show a 0.8 mm mean reduction in groove depth for the Amarillo site and a 4.6 mm mean reduction for the Ennis site. Further study would be needed to determine the effect of deformation on the rumble strips over a longer period.

The speed data was taken for each of the sites and an analysis was performed. Three to five km/h average speed reductions were observed at each of the sites after installation of the rumble strips. Analysis failed to yield any statistical significance at the 95 percent confidence level of this effect being wholly attributable to the rumble strips. Thus, the results of this study show that, at least in the two field sites analyzed, no statistically significant reduction in approach speed can be expected to occur as a result of construction rumble strips in the travel lane on the approach to a stop-intersection. However, the purpose or intent of rumble strips in advance of an intersection is to alert the few errant drivers every year that might otherwise not have been cognizant of the intersection and, as a result, prevent a potential accident. Although it appears that the rumble strips in the travel lane were effective in slowing vehicles down to some extent at the Abilene and Amarillo locations, their effectiveness in alerting the few errant drivers, and thus reducing accidents, could not be determined through the scope of this study.

Some questions that were not addressed in this study and, consequently, no conclusions drawn but which might require further study include the following:

1. There is nothing in the technical literature that definitively addresses whether or not rumble strips are effective--or more/less effective--on low traffic volume roadways than on higher volume routes. None of the test sites were installed on high volume routes.

2. Should in-lane rumble strip installations be limited to locations consisting of intersections preceded by long tangents sections? All three test sites included in this study involved this particular situation. The effectiveness of installing in-travel-lane rumble strips in advance of sharp or blind curves preceded by long tangent sections, unfortunately, was not addressed via a test site in this study.

3. The study was limited to a 12-month period. Because of construction constraints, less than half the study period was able to be devoted to observing driving behavior and monitoring approach speeds. Thus, it is not known what the long-term behavior of drivers operating over the test section routes was (or will be). Although no origin-destination studies were conducted in association with this study, it is likely that the greatest majority of the drivers were "local," i.e., regularly traveled the routes that included the test sites. Experiences cited by other DOTs suggested that drivers who frequently travel a route with in-travel-lane rumble strips eventually consider the strips to be a nuisance and try to avoid the rumble strips by driving around them. The short duration of this study prevented the observation of such changes in driving habits. However, in consideration of these potential driving habits, rumble strip design alternatives were recommended which were intended to allow drivers familiar with the rumble strips to avoid the noise and vibration nuisances by guiding their vehicles through provided gaps in the otherwise continuous strips.

5.3 Recommendations

Recommendations include use of the design standards and specifications developed. Certain details would include observing the specifications of not constructing the full strips on the shoulder unless there is at least 1.5 m of shoulder width. This would allow 1 m of free width for any bicyclists using the roadway. Designs generated for the study have allowed some width of roadway for bicyclists in the designs. It is also recommended that at least 2 rumble strip pads and not more than 5 pads be used at each installation in the travel lane with 3 pads the recommended optimum number. It is also recommended that the final pad before the intersection be at least 90 m in advance of the intersection. To construct the pads, the equipment used to construct the test rumble strip installations described in this study is adequate, but use of carbide-tipped blades is recommended for easier and quicker construction. At least 60 m between the rumble strip pads and any adjacent business or residence should be observed in placing the pads.

Recommendations for employing rumble strips in the driving lane and rumble strips on the shoulder (or shoulder texturing) should be considered separately.

1. <u>Shoulder Rumble Strips or Shoulder Texturing</u>. Shoulder texturing should be employed primarily to alert drivers that they have left the travel lane. The function of shoulder treatments are to produce auditory and tactile sensations that arouse and alert the driver of the vehicle's direction so that the driver may re-direct the vehicle back into the travel lane. Because it cannot be pre-determined where shoulder treatment

installations are needed or required, shoulder treatments should be installed continuously. The three recommended shoulder treatment methods or techniques and their recommended usage are described in Table 4.3. Recommended design drawings and construction specifications are included in Appendices D and E. The following recommendations also apply to shoulder treatment installations:

- Roadways carrying many long-destination trips and having few visual or physical interruptions are of primary concern with respect to single vehicle run-off-the-road accidents. Thus, it is recommended that the majority of rural interstate highways receive shoulder treatment and should be given priority followed by non-interstate divided highways with controlled access.

- Divided highways with partial or limited control of access should be evaluated on an individual basis for the potential need for treated shoulders. [A recommended method for evaluating the potential need is described in the Study Number 187 (Task 12) report: "Monitoring Prevention of Single Vehicle Run-Off-The Road Accidents." (Wray and Nicodemus, 1996)]

- Other roadways, 2-lane highways in particular, should be treated only if an unacceptably high number of single vehicle run-off-the-road accidents occur. [A recommended method for evaluating the potential need is described in the Study Number 187 (Task 12) report: "Monitoring Prevention of Single Vehicle Run-Off-The Road Accidents." (Wray and Nicodemus, 1996)]

- Milled-In texturing is the method recommended for first consideration. This method produces the best auditory and tactile stimuli, accommodates cyclists better than rolled-in texturing, does not require other construction in order to be accomplished, is not impacted by snow removal operations, is applicable to both asphaltic and concrete pavements, and the quality is easier to control than the rolled-in treatment.

- Either milled-in or rolled-in treatments are preferred over button treatments.

- Treatments should be installed such that the greatest possible width of the paved shoulder is available for use by cyclists. A minimum of 1m of untreated paved width is required for cyclists.

- It is recommended that adjacent TxDOT Districts coordinate or even combine shoulder treatment projects to ensure uniform treatments (as well as to benefit from probable reduced costs resulting from larger project size).

2. Rumble Strips in the Travel Lane. Rumble strips installed in the travel lane typically have a different purpose than rumble strips or surface treatments installed on the paved shoulder. Typically, the purpose of in-travel-lane rumble strips are to alert the driver to an approaching or impending hazard or danger that is likely not apparent to the driver unfamiliar with the roadway (or a hazard that does not become apparent sufficiently quickly such that an unalert driver can take a more measured response).

The usual objective in constructing rumble strips in the travel lane is to induce the driver to reduce speed. Rumble strips in the travel lane are discontinuous (i.e. no rumble strips are installed between pads) and the pads are spaced progressively closer approaching the hazard or danger. Rumble strips in the travel lane are also discontinuous and more closely spaced nearer to the hazard or danger. The result is a different sensation being delivered to the driver than that from shoulder installations. The following points are recommended when rumble strips are being considered for installation in the travel lane:

- Rumble strips have a shock effect to drivers who encounter them for the first time. Thus, rumble strips will eventually lose their effectiveness and later become nuisances to drivers who travel over the route regularly. Consequently, rumble strip installations should not be widespread or used indiscriminately.

- Rumble strips should be employed only after all other traffic control or warning devices have been employed and found to be insufficiently effective.

- Rumble strip installations may be effective at rural intersections, including T-intersections, where the intersection has often been overlooked by unfamiliar drivers. Installations may also be used prior to curves that are commonly overshot due to driver inattention and installations may also be effective to warn drivers of blind entrances or where slow-moving vehicles enter the highway.

- More than five rumble strip pads should not be used, but an installation must include at least two pads. Three properly spaced pads have been found to be effective.

- If insufficient length preceding the hazard or danger prevents the installation of three rumble strip pads, two pads may be used but at a reduced effectiveness.

- The final rumble strip pad should be no closer than 90m from the hazard or danger if approaching vehicles are initially traveling at highway speeds.

- Rumble strip pads should be at least 60m from the nearest business or residence to allow increased noise resulting from traffic traversing the pad to be attenuated to a level approximately equal to the "highway noise" present prior to the rumble strip installation.

- Rumble strip installations should allow for cyclists to use the paved shoulder. Thus, it is recommended that rumble strips not be extended onto the paved shoulder unless the paved shoulder is at least 1.5 m wide, and then at least the outer 1m should be uncorrugated and reserved for cyclist use.

Additional recommendations include additional observations at the test sites made well after installation of the rumble strips. One recommendation would be an analysis of accident data for an adequate period before and after installation to assess accident-reduction characteristics. Another recommendation is to continue to measure the depth of the grooves to assess their durability.

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APPENDIX A

Speed Data for Three Field Test Sites

Table A.1. Abilene Pre-Construction Vehicle Speeds (mph)

Vehicle	Distance from Intersection			
Number	1900 ft	1700 ft	900 ft	300 ft
1	64	59	59	45
2	63	55	52	30
3	60	50	49	34
4	69	56	50	25
5	67	59	56	30
6	80	62	54	22
7	60	53	48	24
8	90	65	59	27
9	45	35	32	22
10	43	33	38	22
11	41	53	58	14
12	58	51	50	23
13	64	54	53	25
14	78	61	49	34
15	54	59	53	30
16	46	50	42	29
17	69	56	46	29
18	71	55	58	36
19	80	61	54	26
20	72	63	56	25
21	86	71	67	28
22	61	63	58	33
23	71	59	59	33
24	79	49	43	21
25	50	51	43	19
26	55	55	47	21
27	62	58	51	24
28	62	60	48	19
29	68	62	58	28
30	68	63	52	24
31	84	57	52	32
32	52	52	48	27
33	46	38	54	21
34	59	46	42	18
35	80	56	52	25
36	85	56	51	31
37	68	49	47	23

Table A.1. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
38	85	62	55	25
39	72	59	57	31
40	89	72	57	41
41	72	59	54	26
42	55	43	42	25
43	53	55	57	26
44	62	55	53	27
45	62	53	47	23
46	97	65	59	32
47	81	68	64	21
48	90	66	60	40
49	71	82	72	27
50	67	69	57	24
51	52	45	36	20
52	98	66	60	35
53	51	58	50	17
54	61	48	45	25
55	69	59	54	20
56	97	52	46	26
57	42	43	36	15
58	53	68	48	24
59	65	65	46	18
60	68	43	37	22
61	80	68	60	22
62	65	57	48	21
63	75	73	67	34
64	71	65	48	32
65	67	59	49	26
66	79	62	51	19
67	65	66	51	25
68	75	81	66	22
69	68	58	52	22
70	57	55	50	23
71	72	72	51	18
72	66	81	66	25
73	64	53	47	19
74	80	70	65	30

Table A.1. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
75	50	46	36	15
76	65	53	67	21
77	67	61	58	23
78	58	50	49	21
79	63	55	52	20
80	66	78	62	41
81	79	75	65	27
82	58	51	42	25
83	65	46	45	26
84	60	47	47	20
85	65	60	53	34
86	56	53	49	21
87	59	47	41	18
88	86	74	64	26
89	65	55	46	22
90	67	65	53	26
91	79	77	66	27
92	64	52	41	22
93	82	60	53	28
94	85	89	79	32
95	34	34	32	20
96	72	55	46	23
97	71	67	64	22
98	84	72	57	31
99	65	60	57	25
100	75	63	52	28
101	55	53	51	25
102	60	50	27	16
103	85	64	57	27
104	60	55	47	22
105	62	56	48	28
106	63	50	37	23
107	54	53	45	29
108	75	60	54	26
109	59	57	50	32
110	54	52	45	27
111	80	70	63	24

Table A.1. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
112	64	64	53	22
113	85	65	59	27
114	64	52	43	19
115	68	57	51	20
116	60	71	57	24
117	61	66	54	28
118	70	66	56	24

Table A.2. Abilene Immediate Post-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
1	67	55	53	24
2	66	44	40	21
3	75	46	36	18
4	66	66	60	22
5	67	43	35	17
6	67	44	35	19
7	77	55	43	23
8	74	59	54	22
9	81	56	42	17
10	84	53	46	18
11	83	56	50	21
12	72	59	43	20
13	68	45	34	20
14	79	57	51	29
15	85	66	61	26
16	76	51	45	18
17	61	54	45	18
18	78	57	47	21
19	70	43	35	15
20	83	67	58	20
21	67	45	43	18
22	84	50	43	21
23	85	57	47	22
24	76	44	36	18
25	84	54	47	20
26	80	61	57	26
27	77	50	46	25
28	82	49	34	19
29	81	55	47	22
30	66	59	46	21
31	86	68	61	23
32	73	53	46	18
33	68	48	44	21
34	74	42	36	17
35	71	74	69	21
36	75	48	41	19
37	83	57	50	22

Table A.2. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
38	87	62	56	17
39	77	54	53	21
40	80	56	38	20
41	70	49	43	18
42	70	37	30	13
43	89	66	55	22
44	79	57	51	20
45	81	57	51	24
46	87	69	64	20
47	71	41	43	16
48	68	40	38	15
49	88	59	52	26
50	80	62	54	21
51	79	52	44	20
52	89	68	55	23
53	85	68	65	23
54	84	61	58	19
55	78	55	44	20
56	78	54	49	22
57	70	51	45	19
58	67	48	44	16
59	84	51	43	14
60	64	49	40	18
61	76	51	45	20
62	71	53	49	19
63	74	58	47	18
64	85	83	74	24
65	80	68	59	20
66	60	50	49	20
67	81	55	52	18
68	60	52	48	18
69	82	70	61	32
70	70	53	43	19
71	70	57	49	21
72	77	48	41	22
73	74	64	62	21
74	81	68	62	22

Table A.2. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
75	63	35	30	15
76	83	55	42	27
77	77	62	46	24
78	84	59	55	23
79	79	45	40	20
80	77	59	46	22
81	74	50	50	21
82	72	81	67	20
83	80	56	46	19
84	68	42	35	17
85	88	58	51	19
86	89	58	49	18
87	80	59	53	21
88	70	42	33	15
89	75	48	44	22
90	84	55	47	20
91	87	61	53	18
92	75	55	39	20
93	97	70	62	24
94	87	66	60	22
95	69	63	60	20
96	84	46	39	18
97	70	49	40	17
98	80	54	50	19
99	82	57	52	22
100	82	71	64	24
101	87	60	55	21
102	77	50	42	19
103	77	60	60	22
104	85	65	53	21
105	72	48	42	19
106	67	61	48	22
107	89	60	51	22
108	89	59	53	23
109	70	58	48	20
110	85	64	50	22
111	76	56	52	20

Table A.2. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
112	81	74	66	21
113	81	69	57	19
114	78	61	47	18
115	73	59	48	17
116	81	49	40	18
117	74	60	53	20
118	80	63	50	21
119	67	39	36	21
120	70	59	43	21
121	71	48	35	22
122	68	48	42	16
123	80	61	50	19
124	75	57	49	21
125	70	60	55	19
126	73	56	50	20
127	76	63	55	20
128	75	53	48	19
129	70	52	47	22
130	72	44	42	18
131	73	55	46	20
132	77	64	58	22
133	82	60	53	17
134	73	55	52	20
135	73	50	50	17
136	66	52	42	17
137	81	56	51	21
138	70	52	42	18
139	77	58	54	18
140	75	55	50	19
141	65	60	55	24
142	80	58	47	22
143	71	50	45	17
144	75	60	51	20
145	85	65	58	25
146	74	63	59	17
147	53	50	41	18
148	78	60	50	22

Table A.2. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
149	75	56	52	24
150	80	61	50	15
151	85	59	47	21
152	85	62	53	19

Table A.3. Abilene Final Post-Construction Data

Vehicle Number	Distance from Intersection 1900	1700	900	300
1	45	36	34	17
2	77	64	51	21
3	42	47	50	25
4	42	59	53	19
5	61	54	55	18
6	64	48	40	19
7	72	47	40	15
8	76	62	53	20
9	47	55	48	16
10	94	68	66	20
11	71	53	52	17
12	78	49	43	18
13	74	65	57	25
14	71	60	49	19
15	68	62	55	20
16	69	55	47	22
17	75	59	48	20
18	66	64	55	23
19	69	47	39	20
20	83	58	55	23
21	90	81	69	27
22	77	62	52	22
23	63	57	45	30
24	45	53	44	19
25	65	63	48	24
26	97	79	69	22
27	66	55	44	17
28	88	64	54	21
29	70	75	57	19
30	66	55	46	22
31	83	68	65	24
32	45	60	46	20
33	50	58	49	21
34	90	75	61	22
35	93	61	53	17
36	61	41	36	17
37	49	38	32	16

Table A.3. Cont.

Vehicle Number	Distance from Intersection 1900	1700	900	300
38	66	53	45	20
39	65	60	52	20
40	76	56	49	18
41	70	59	43	23
42	70	63	49	21
43	51	53	52	19
44	54	43	37	18
45	82	72	56	28
46	81	66	64	27
47	40	48	39	24
48	60	54	44	20
49	58	54	43	20
50	93	50	37	18
51	74	50	44	21
52	73	57	49	18
53	83	68	53	19
54	58	49	40	14
55	67	55	43	19
56	80	60	50	21
57	73	60	43	18
58	66	53	48	16
59	64	55	45	17
60	68	53	45	20
61	53	44	42	19
62	60	53	49	20
63	93	66	57	24
64	68	50	44	18
65	73	60	49	19
66	74	72	65	24
67	60	47	36	17
68	81	66	51	17
69	77	56	48	20
70	63	52	43	19
71	84	71	60	24
72	74	55	56	20
73	91	79	62	23
74	76	54	41	20

Table A.3. Cont.

Vehicle Number	Distance from Intersection 1900	1700	900	300
75	66	45	40	18
76	61	48	40	22
77	64	55	42	21
78	87	74	64	26
79	72	48	39	19
80	60	55	41	24
81	75	50	41	22
82	59	67	55	22
83	71	57	46	19
84	89	61	45	22
85	62	52	43	18
86	73	51	44	20
87	77	62	58	23
88	71	63	52	21
89	80	64	50	20
90	91	64	51	25
91	70	51	41	24
92	82	62	54	26
93	68	75	58	25
94	71	58	51	12
95	68	57	53	21
96	49	53	40	20
97	60	41	34	14
98	52	55	46	17
99	86	76	64	28
100	66	49	47	18
101	81	58	49	23
102	78	68	49	26
103	60	46	35	20
104	98	77	64	23
105	81	62	53	25
106	80	48	37	21
107	73	65	42	22
108	82	54	55	25
109	62	53	43	23
110	86	62	57	20
111	60	70	61	30

Table A.3. Cont.

Vehicle Number	Distance from Intersection 1900	1700	900	300
112	85	65	55	20
113	73	49	44	18
114	66	55	44	21
115	84	65	49	18
116	47	57	52	21
117	78	49	44	19
118	71	64	59	22
119	75	51	40	17
120	62	53	35	17
121	69	46	43	19
122	40	45	41	22
123	75	51	42	18
124	68	57	46	22
125	91	53	47	20
126	51	48	39	15
127	77	59	52	26
128	87	58	50	21
129	97	64	49	22
130	77	57	44	18
131	67	49	41	16
132	74	47	45	16
133	68	53	43	21
134	86	63	48	22
135	92	68	56	24
136	73	46	35	15
137	72	51	46	22
138	83	68	54	20
139	80	68	65	22
140	75	66	51	20
141	67	52	40	15
142	64	41	33	16
143	91	54	46	18
144	90	68	57	24
145	94	75	59	23
146	75	59	47	21
147	73	56	40	21
148	86	68	52	20

Table A.3. Cont.

Vehicle Number	Distance from Intersection			
	1900	1700	900	300
149	89	65	57	20
150	75	58	51	18
151	60	49	39	20
152	61	44	35	18
153	64	53	37	18
154	72	60	49	24
155	81	52	43	23
156	75	46	39	22
157	53	43	36	18
158	90	57	49	15
159	77	60	50	25
160	93	71	65	25
161	55	43	41	20
162	65	60	54	21

Table A.4. Amarillo Pre-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
1	70	64	65	36
2	72	55	56	22
3	91	69	59	21
4	45	55	50	22
5	74	61	64	22
6	64	59	48	22
7	73	75	66	27
8	63	60	62	23
9	67	67	69	21
10	77	64	56	18
11	75	70	66	21
12	57	53	55	26
13	74	67	63	23
14	69	65	69	25
15	68	64	57	24
16	80	69	50	21
17	74	70	69	28
18	52	59	55	17
19	84	66	60	23
20	76	72	70	21
21	68	67	71	23
22	71	65	59	33
23	55	55	58	20
24	62	61	64	28
25	58	59	59	22
26	70	66	62	20
27	84	63	57	20
28	81	77	68	28
29	70	65	64	20
30	64	59	66	22
31	85	70	67	22
32	51	61	66	23
33	80	73	65	32
34	75	70	75	22
35	67	65	60	24
36	79	65	67	23
37	73	74	74	22

Table A.4. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
38	64	53	57	26
39	65	61	62	22
40	87	62	61	22
41	62	61	63	22
42	70	66	63	20
43	74	65	66	22
44	69	66	65	22
45	63	55	52	21
46	62	66	68	26
47	56	55	52	20
48	72	70	74	23
49	53	54	57	23
50	73	63	72	21
51	65	65	63	26
52	57	59	53	21
53	63	57	52	23
54	65	64	66	27
55	76	72	78	28
56	70	69	69	25
57	61	72	73	22
58	68	60	53	20
59	40	43	41	14
60	48	53	61	23
61	60	62	59	21
62	47	53	51	17
63	58	60	54	19
64	73	75	66	24
65	64	60	68	20
66	38	42	41	27
67	77	71	69	26
68	67	68	72	22
69	68	73	72	24
70	77	76	79	22
71	65	49	60	20
72	61	58	58	27
73	97	61	58	25
74	67	47	47	21

Table A.4. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
75	58	57	55	24
76	63	60	55	21
77	71	62	66	24
78	79	66	75	24
79	70	64	54	25
80	60	66	65	23
81	53	57	54	24
82	51	52	57	21
83	64	66	65	29
84	63	60	54	27
85	64	59	55	25
86	58	56	60	26
87	58	60	65	19
88	77	67	70	27
89	61	74	69	25
90	59	58	55	24
91	60	61	58	24
92	62	61	56	21
93	66	67	69	26
94	63	58	64	22
95	46	48	53	20
96	60	61	64	24
97	89	76	66	26
98	53	48	53	21
99	34	34	33	17
100	66	65	66	27
101	66	62	67	22
102	84	76	73	30
103	65	62	62	28
104	58	61	54	24
105	79	78	65	26
106	58	61	61	21
107	54	49	47	20
108	60	64	62	26
109	60	52	48	19
110	57	63	64	24
111	79	72	63	26

Table A.4. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
112	65	63	60	28
113	73	65	58	10
114	63	70	65	19
115	57	61	65	26
116	87	80	76	24
117	65	68	64	27
118	63	60	65	20
119	68	68	63	23
120	62	56	55	20
121	59	50	47	22
122	71	65	50	21
123	55	53	50	21
124	79	73	62	25
125	63	61	58	22
126	78	75	68	25
127	56	49	49	17
128	56	61	63	29
129	64	63	61	23
130	67	63	59	23
131	61	58	62	21
132	61	58	58	26
133	62	63	73	20
134	55	49	49	19
135	68	63	56	20
136	37	37	37	17
137	41	48	41	30
138	52	71	66	31
139	50	47	43	18
140	71	64	50	25
141	56	50	51	25
142	52	57	52	27
143	50	57	45	27
144	55	51	57	31
145	61	58	62	23
146	77	76	78	26
147	68	55	46	21
148	59	63	59	19

Table A.4. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
149	68	63	57	18
150	81	77	70	38
151	76	69	59	26
152	65	76	52	20
153	86	83	84	24
154	82	72	67	32
155	63	56	47	20
156	66	68	64	22
157	78	75	71	27
158	66	70	63	22
159	49	47	49	18
160	58	56	39	21
161	61	51	60	22
162	52	60	59	25
163	51	54	51	30
164	60	64	61	24
165	63	66	70	26
166	49	68	66	22
167	56	56	58	22
168	77	59	52	27
169	59	57	59	22
170	73	60	51	19
171	61	68	60	22
172	72	81	65	27
173	84	66	70	26
174	59	60	62	27
175	53	54	60	23
176	70	64	65	31
177	65	68	64	22
178	58	56	58	26
179	78	61	57	22
180	65	68	67	24
181	77	72	62	21
182	57	62	63	24
183	62	61	60	26
184	62	67	60	24
185	63	64	67	23

Table A.4. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
186	83	60	52	21
187	77	69	61	29
188	45	40	48	18
189	83	75	62	27
190	78	78	63	23
191	65	60	56	30
192	70	66	71	26
193	67	65	65	30
194	60	65	61	28
195	55	53	49	20
196	76	62	68	24
197	71	59	61	23
198	60	61	57	19
199	72	65	67	26
200	74	69	76	26
201	63	53	62	24
202	75	72	74	33
203	66	61	59	29
204	71	66	55	28

Table A.5. Amarillo Immediate Post-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
1	49	54	47	20
2	65	48	46	21
3	68	56	55	20
4	67	74	68	23
5	73	76	58	25
6	36	48	57	24
7	85	65	63	21
8	52	60	49	21
9	56	51	48	19
10	63	67	59	20
11	53	57	50	25
12	57	54	53	18
13	96	62	51	23
14	69	65	50	22
15	62	61	58	21
16	56	50	51	19
17	57	62	55	24
18	68	94	60	26
19	48	43	30	19
20	51	46	41	19
21	58	53	46	18
22	51	63	61	21
23	70	46	43	21
24	71	66	54	17
25	56	58	54	29
26	48	42	39	17
27	71	67	56	24
28	52	47	32	20
29	66	63	51	19
30	72	64	65	22
31	67	58	62	21
32	56	56	51	21
33	57	58	54	19
34	52	58	56	19
35	44	57	48	17
36	77	80	68	28
37	46	47	42	22

Table A.5. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
38	57	57	51	20
39	83	77	56	21
40	73	60	53	21
41	59	62	56	20
42	75	69	57	25
43	66	68	67	20
44	57	44	38	21
45	66	66	53	25
46	57	52	44	21
47	63	51	47	19
48	71	65	54	23
49	68	62	59	21
50	69	52	56	23
51	58	56	53	19
52	70	65	58	21
53	57	59	50	20
54	62	57	49	20
55	70	64	64	24
56	62	51	53	22
57	68	71	65	27
58	51	49	49	19
59	64	58	53	19
60	51	48	37	14
61	66	65	59	24
62	53	49	46	22
63	81	59	57	20
64	58	60	67	20
65	88	71	60	21
66	73	71	64	19
67	55	49	43	19
68	62	59	55	16
69	73	57	52	21
70	55	69	68	21
71	57	57	55	20
72	55	63	58	19
73	48	61	51	18
74	75	78	67	21

Table A.5. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
75	60	69	53	23
76	53	54	48	26
77	59	57	55	20
78	63	56	54	20
79	50	49	46	16
80	51	63	56	23
81	58	69	68	22
82	60	59	58	22
83	71	52	47	20
84	61	65	54	16
85	61	56	50	18
86	58	59	58	20
87	58	56	44	18
88	65	48	40	18
89	58	71	62	20
90	64	65	63	21
91	76	64	65	25
92	52	45	43	19
93	73	55	46	22
94	43	53	53	21
95	67	48	44	17
96	63	58	60	23
97	57	54	53	22
98	61	64	62	24
99	55	54	53	21
100	71	69	55	24
101	68	57	60	24
102	55	45	39	21
103	55	31	31	18
104	58	62	54	19
105	65	52	53	17
106	81	74	71	28
107	76	69	52	22
108	48	42	41	17
109	57	50	46	17
110	64	68	61	23
111	94	77	69	24

Table A.5. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
112	41	49	41	22
113	47	57	58	18
114	53	51	46	18
115	53	56	53	23
116	66	58	47	21
117	56	50	47	20
118	61	55	52	17
119	72	62	56	25
120	64	63	49	21
121	66	57	51	19
122	79	66	58	26
123	77	66	54	20
124	54	47	38	16
125	59	57	47	24
126	75	78	65	20
127	80	74	71	32
128	73	60	57	23
129	61	44	39	20
130	82	75	69	27
131	75	57	49	24
132	65	66	65	24
133	57	55	49	21
134	60	50	47	16
135	62	57	55	19
136	80	72	61	24
137	60	51	48	25
138	62	48	34	14
139	70	63	55	25
140	85	68	61	24
141	51	50	40	16
142	65	51	37	14
143	70	59	53	21
144	80	70	53	21
145	65	60	50	25

Table A.6. Amarillo Final Post-Construction Vehicle Speeds (mph)

Vehicle	Distance from Intersection			
Number	1900 ft	1700 ft	900 ft	300 ft
1	65	58	49	20
2	70	62	50	25
3	80	64	64	22
4	67	60	37	24
5	75	68	60	21
6	63	61	68	18
7	49	61	62	23
8	56	58	51	21
9	52	53	57	17
10	57	77	64	23
11	58	55	54	17
12	58	75	61	23
13	68	61	60	20
14	58	62	59	21
15	70	57	37	26
16	50	83	67	28
17	63	62	57	19
18	65	58	52	21
19	67	50	50	20
20	51	48	53	28
21	83	78	73	24
22	80	74	58	23
23	84	73	69	19
24	81	61	58	21
25	77	71	73	21
26	76	62	61	26
27	71	65	65	16
28	42	45	46	16
29	62	59	60	22
30	73	63	62	26
31	64	62	56	20
32	45	46	53	18
33	60	62	61	16
34	61	63	63	24
35	73	64	51	15
36	66	63	54	20
37	78	55	60	20

Table A.6. Cont.

Vehicle	Distance from Intersection			
Number	1900 ft	1700 ft	900 ft	300 ft
38	87	73	68	20
39	87	64	66	16
40	50	57	47	16
41	42	47	43	19
42	51	47	48	19
43	71	50	46	16
44	60	65	58	21
45	59	55	60	20
46	65	61	60	22
47	78	59	55	17
48	64	58	55	23
49	80	57	57	20
50	68	64	55	24
51	43	51	45	20
52	64	62	54	17
53	65	67	66	26
54	81	70	65	21
55	63	56	58	18
56	75	47	50	21
57	60	39	33	13
58	73	65	59	24
59	79	62	52	24
60	56	49	50	23
61	39	58	55	23
62	63	72	70	22
63	93	68	64	21
64	72	65	68	22
65	70	48	42	18
66	65	53	54	18
67	59	52	57	17
68	75	69	62	20
69	60	53	51	17
70	57	59	60	24
71	96	71	63	21
72	72	79	62	22
73	95	59	62	21
74	73	65	49	27

Table A6. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
75	50	49	44	22
76	65	44	37	16
77	78	63	55	19
78	80	70	65	24
79	65	58	51	22
80	49	38	45	15
81	71	55	51	73
82	68	65	54	24
83	62	58	55	29
84	64	53	52	19
85	75	63	54	24
86	73	51	46	25
87	82	64	58	20
88	63	46	45	19
89	56	52	46	25
90	72	60	52	22
91	50	55	59	18
92	93	71	44	21
93	75	63	52	23
94	93	78	71	23
95	63	58	48	22
96	59	57	64	28
97	72	66	64	22
98	74	75	61	24
99	62	55	51	19
100	57	48	44	26
101	54	54	45	25
102	60	57	62	23
103	93	58	56	22
104	74	64	72	24
105	97	56	47	31
106	80	67	46	22
107	62	60	51	24
108	60	62	49	32
109	76	71	58	23
110	57	51	54	20
111	59	58	50	23

Table A.6. Cont.

Vehicle Number	Distance from Intersection			
	1900 ft	1700 ft	900 ft	300 ft
112	66	53	57	23
113	76	56	64	20
114	59	61	49	22
115	82	67	51	25
116	87	62	65	17
117	59	55	47	22
118	68	53	53	26
119	60	60	46	22
120	52	58	40	26
121	45	56	57	39
122	55	58	56	27
123	42	46	41	16
124	39	57	46	20
125	41	51	42	24
126	61	54	53	19
127	51	60	68	24
128	60	61	49	26
129	53	62	54	23
130	73	70	59	27
131	70	66	79	18
132	44	56	55	25
133	42	63	52	30
134	65	56	63	22
135	47	59	72	27
136	71	71	48	26
137	66	51	47	17
138	84	74	45	33
139	60	62	55	20
140	54	53	45	24
141	46	53	39	22
142	58	60	47	26
143	77	62	44	24
144	75	66	64	26
145	71	58	54	22
146	66	60	55	22

Table A.7. Ennis Pre-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
1	73	72	69	27
2	61	58	58	25
3	42	48	52	17
4	52	59	54	25
5	58	55	54	23
6	33	42	40	26
7	59	54	47	22
8	36	35	38	22
9	50	49	44	21
10	54	51	52	28
11	40	39-	38	29
12	49	51	43	24
13	62	49	57	18
14	43	35	31	22
15	60	56	50	23
16	58	50	48	26
17	49	48	41	22
18	57	58	60	21
19	47	46	39	21
20	57	52	52	19
21	60	55	53	23
22	84	68	65	28
23	46	46	48	17
24	62	51	51	26
25	50	54	54	23
26	65	48	49	22
27	52	48	48	23
28	74	56	51	21
219	80	49	45	21
30	68	58	54	24
31	66	49	51	22
32	63	61	59	23
33	41	46	46	23
34	46	38	35	20
35	57	46	44	28
36	46	42	39	23
37	68	59	55	21

Table A.7. Ennis Pre-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
38	68	52	48	19
39	65	51	46	25
40	57	53	50	20
41	55	51	52	22
42	39	42	40	23
43	42	52	61	26
44	53	55	47	21
45	36	45	45\	20
46	47	35	34	22
47	71	68	61	20
48	52	57	57	26
49	68	59	46	25
50	55	58	57	23
51	63	62	67	27
52	43	46	44	22
53	77	64	61	19
54	60	48	42	23
55	80	63	57	20
56	57	44	39	21
57	44	38	32	18
58	44	45	52	22
59	62	47	48	20
60	93	60	52	20
61	52	46	46	23
62	64	67	68	22
63	65	44	44	21
64	54	49	49	18
65	66	56	55	19
66	70	60	58	25
67	55	53	41	21
68	68	54	54	26
69	72	52	52	29
70	59	43	43	20
71	50	40	38	18
72	52	51	52	22
73	66	37	37	18
74	77	71	67	20

Table A.7. Ennis Pre-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
75	66	58	53	212
76	53	51	43	25
77	37	37	34	34
78	47	44	42	19
79	56	50	50	20
80	60	51	52	20
81	53	48	43	23
82	59	50	50	20
83	54	56	53	23
84	60	55	53	20
85	62	42	46	22
86	55	52	49	19
87	59	54	52	24
88	52	53	44	29
89	62	51	49	25
90	55	51	49	29
91	42	39	36	22
92	55	55	46	20
93	53	50	47	25
94	56	49	48	29
95	51	48	47	29
96	48	47	47	26
97	43	51	50	24
98	60	56	49	25
99	44	57	56	18
100	39	45	47	19
101	51	48	45	19
102	84	78	77	26
103	87	66	63	23
104	61	62	58	30
105	43	47	47	26
106	91	63	54	23
107	78	58	54	21\
108	72	63	55	24
109	42	36	35	21
110	68	57	47	19
111	54	54	50	24

Table A.7. Ennis Pre-Construction Vehicle Speeds (mph)

Vehicle	Distance from Intersection			
Number	1900 ft	1700 ft	900 ft	300 ft
112	53	47	47	19
113	63	52	50	25
114	68	48	40	20
115	71	47	45	22
116	63	52	45	19
117	53	48	46	28
118	44	40	43	24
119	43	41	43	20
120	42	42	43	20
121	68	61	61\	25
122	50	50	48	24
123	60	49	45	21
124	63	47	43	21
125	49	44	39	17
126	67	59	53	24
127	49	51	57	20
128	53	62	41	24
129	67	56	57	22
130	51	44	42	19
131	53	59	59	23
132	55	48	42	27
133	63	51	52	20
134	64	61	54	22
135	63	58	57	24
136	63	62	56	21
137	65	52	53	28
138	44	52	53	19
139	73	58	60	24
140	45	47	49	19
141	74	54\	53	23
142	61	55	57	22
143	55	53	54	18
144	45	49	51	20
145	50	51	48	23
146	52	53	53	22
147	44	44	42	23
148	45	45	44	19

Table A.7. Ennis Pre-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
149	76	54	51	22
150	73	57	53	21
151	59	47	50	23
152	48	56	53\	20
153	70	56	48	23
154	47	44	37	28
155	43	48	41	25
156	49	43	34\	23
157	97	66	60	26

Table A.8. Ennis Immediate Post-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
1	43	41	38	19
2	59	63	49	22
3	49	48	44	18
4	51	46	38	18
5	53	55	50	19
6	57	46	42	20
7	48	44	38	25
8	56	52	42	23
9	58	56	52	22
10	37	35	36	16
11	56	58	55	22
12	51	63	60	24
13	53	57	49	23
14	51	53	46	18
15	45	47	45	22
16	60	54	51	20
17	41	49	45	20
18	45	43	42	18
19	46	46	40	18
20	34	35	30	18
21	68	71	64	21
22	71	71	57	25
23	37	37	34	20
24	34	36	35	22
25	59	54	48	18
26	43	39	39	16
27	52	53	48	19
28	58	59	49	23
219	42	47	43	22
30	67	52	46	22
31	56	56	50	20
32	53	48	47	27
33	47	48	45	17
34	71	75	48	27
35	59	59	47	19
36	60	69	64	26
37	56	55	46	20

Table A.8. Cont.

Vehicle Number	Distance from Intersection 1900 ft	1700 ft	900 ft	300 ft
38	46	46	45	21
39	61	58	55	23
40	39	36	31	17
41	46	52	52	23
42	52	65	57	21
43	37	33	29	20
44	36	38	38	20
45	49	57	44	26
46	42	49	47	20
47	37	42	28	18

Table A.9. Ennis Final Post-Construction Vehicle Speeds (mph)

Vehicle Number	Distance from Intersection 1900	1700	900	300
1	51	53	44	22
2	64	59	52	25
3	46	44	34	20
4	48	51	39	20
5	95	86	74	20
6	55	56	57	19
7	77	68	51	19
8	61	65	60	23
9	72	68	57	25
10	73	74	65	24
11	45	49	42	21
12	70	61	49	22
13	61	56	44	20
14	61	52	35	15
15	54	50	40	20
16	84	78	54	20
17	46	45	37	20
18	46	45	38	17
19	69	60	46	23
20	49	49	32	16
21	66	67	65	22
22	44	48	39	21
23	51	50	45	29
24	55	47	30	25
25	57	53	38	22
26	62	65	52	23
27	59	54	44	24
28	61	56	47	19
29	81	53	48	25
30	57	53	49	24
31	50	51	42	22
32	52	54	52	23
33	70	67	51	31
34	84	75	59	16
35	66	82	65	28
36	60	64	52	19
37	55	56	45	23

Table A.9. Cont.

Vehicle Number	Distance from Intersection 1900	1700	900	300
38	71	63	52	25
39	62	60	58	21
40	71	66	55	30
41	70	64	55	32
42	61	84	57	25
43	60	55	45	20
44	62	59	44	23
45	75	71	58	26
46	55	58	49	22
47	55	48	44	22
48	66	63	49	20
49	53	61	47	20
50	62	59	46	23
51	54	55	50	22
52	67	64	55	22
53	61	52	52	21
54	55	58	45	27
55	48	51	48	23
56	72	65	52	29
57	55	49	36	22
58	53	51	43	22
59	62	61	53	24
60	62	60	48	23
61	60	60	50	23
62	55	56	40	20
63	83	81	70	25
64	47	55	38	21
65	73	68	62	22
66	55	54	43	26
67	60	55	51	17
68	64	64	49	23
69	75	74	56	25
70	51	45	41	23
71	44	47	44	22
72	72	67	57	19
73	62	61	54	24
74	45	46	39	22

Table A.9. Cont.

Vehicle	Distance from Intersection			
Number	1900	1700	900	300
75	53	50	46	16
76	57	57	47	21
77	63	58	48	27
78	68	65	52	23
79	52	54	42	23
80	60	59	51	22
81	78	72	62	24
82	72	61	55	22
83	64	68	63	23
84	70	61	57	28
85	57	55	52	20
86	59	49	68	19
87	65	65	53	27
88	70	61	57	22
89	55	61	53	22
90	61	59	50	28
91	70	61	48	31
92	70	58	51	25
93	77	74	68	18
94	51	49	40	21
95	55	56	49	28
96	71	61	53	22
97	73	63	49	21
98	54	54	46	17
99	57	51	42	21
100	61	63	52	22
101	40	57	64	19
102	57	56	48	24
103	65	61	56	27
104	51	55	48	20
105	55	56	45	21
106	67	62	49	23
107	61	51	47	21
108	73	64	55	25
109	61	53	48	24
110	38	45	42	14
111	70	48	46	24

Table A.9. Cont.

Vehicle Number	Distance from Intersection			
	1900	1700	900	300
112	65	57	46	26
113	79	67	60	19
114	84	54	50	20
115	65	56	47	22
116	74	59	52	20
117	58	45	38	26
118	53	45	39	14
119	67	60	55	16
120	60	58	51	19
121	56	54	49	16
122	65	61	53	22
123	67	63	52	32
124	51	41	42	19
125	71	76	57	23
126	65	64	54	25
127	91	53	44	21
128	73	70	53	25
129	57	49	45	22
130	51	41	42	17

APPENDIX B

Analysis of Variance for Locations Within Each Test Site

Table B.1. Abilene Pre-Construction

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	327	65.4	46.8		
Column 2	5	285	57	47.5		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	176.4	1	176.4	3.741251	0.089137	5.317645
Within Groups	377.2	8	47.15			
Total	553.6	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	285	57	47.5		
Column 2	5	252	50.4	33.3		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	108.9	1	108.9	2.695545	0.139256	5.317645
Within Groups	323.2	8	40.4			
Total	432.1	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	252	50.4	33.3		
Column 2	5	124	24.8	3.7		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1638.4	1	1638.4	88.56216	1.33E-05	5.317645
Within Groups	148	8	18.5			
Total	1786.4	9				

Table B.2. Abilene Immediate Post-Construction

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	361	72.2	49.2		
Column 2	5	288	57.6	78.8		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	532.9	1	532.9	8.326563	0.020337	5.317645
Within Groups	512	8	64			
Total	1044.9	9				

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	288	57.6	78.8		
Column 2	5	257	51.4	96.8		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	96.1	1	96.1	1.094533	0.326047	5.317645
Within Groups	702.4	8	87.8			
Total	798.5	9				

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	257	51.4	96.8		
Column 2	5	108	21.6	8.3		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2220.1	1	2220.1	42.24738	0.000188	5.317645
Within Groups	420.4	8	52.55			
Total	2640.5	9				

Table B.3. Amarillo Pre-Construction

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	313	62.6	11.8		
Column 2	5	301	60.2	15.7		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.4	1	14.4	1.047273	0.336082	5.317645
Within Groups	110	8	13.75			
Total	124.4	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	301	60.2	15.7		
Column 2	5	298	59.6	11.3		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.9	1	0.9	0.066667	0.802772	5.317645
Within Groups	108	8	13.5			
Total	108.9	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	298	59.6	11.3		
Column 2	5	114	22.8	1.7		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3385.6	1	3385.6	520.8615	1.44E-08	5.317645
Within Groups	52	8	6.5			
Total	3437.6	9				

Table B.4. Amarillo Immediate Post-Construction

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	303	60.6	10.3
Column 2	5	281	56.2	21.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	48.4	1	48.4	3.073016	0.117694	5.317645
Within Groups	126	8	15.75			
Total	174.4	9				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	281	56.2	21.2
Column 2	5	258	51.6	15.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	52.9	1	52.9	2.859459	0.129303	5.317645
Within Groups	148	8	18.5			
Total	200.9	9				

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	258	51.6	15.8
Column 2	5	101	20.2	1.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2464.9	1	2464.9	281.7029	1.61E-07	5.317645
Within Groups	70	8	8.75			
Total	2534.9	9				

Table B.5. Ennis Pre-Construction

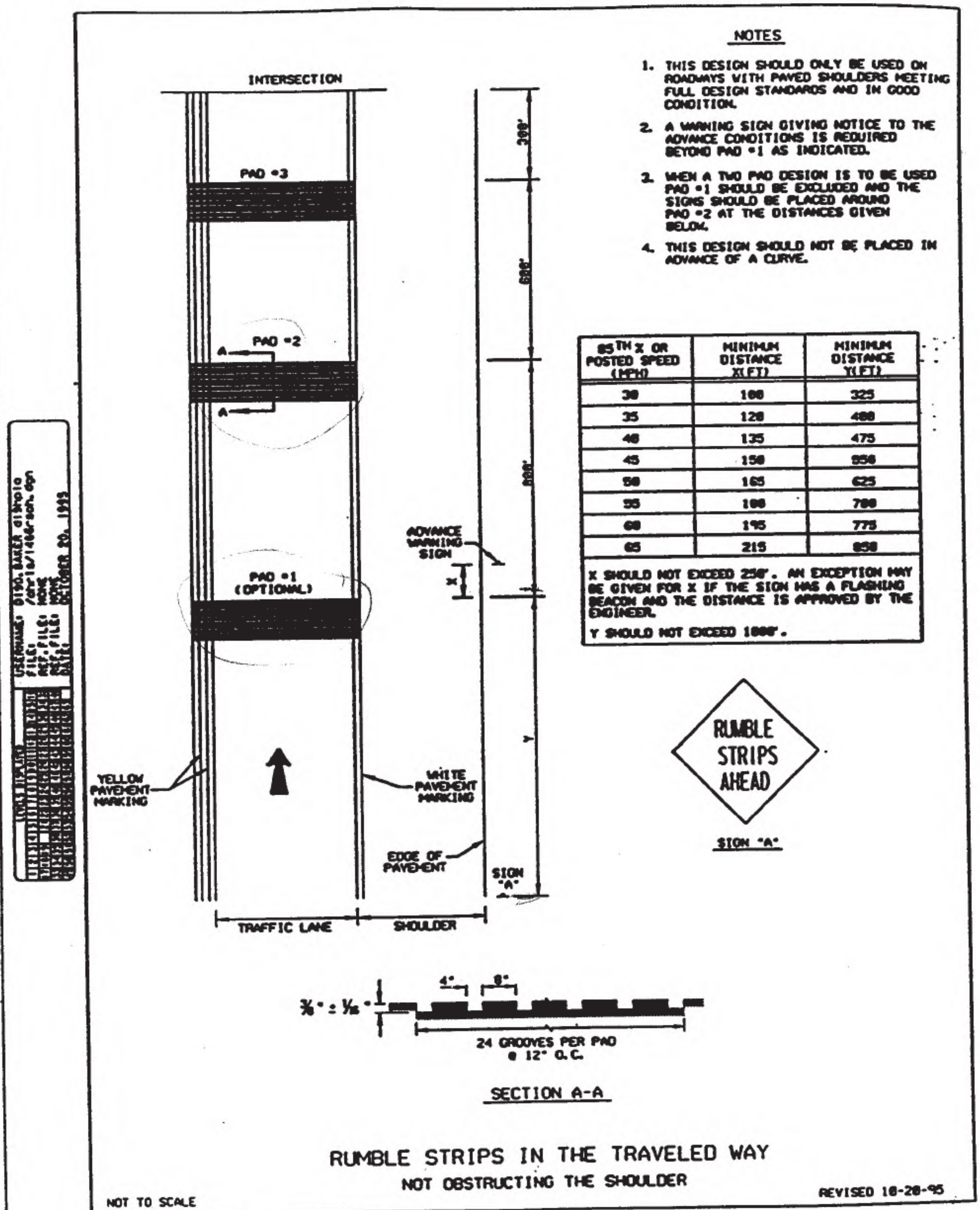
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	280	56	54		
Column 2	5	245	49	15.5		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	122.5	1	122.5	3.52518	0.097272	5.317645
Within Groups	278	8	34.75			
Total	400.5	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	245	49	15.5		
Column 2	5	234	46.8	7.2		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.1	1	12.1	1.066079	0.332034	5.317645
Within Groups	90.8	8	11.35			
Total	102.9	9				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	5	234	46.8	7.2		
Column 2	5	109	21.8	5.2		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1562.5	1	1562.5	252.0161	2.48E-07	5.317645
Within Groups	49.6	8	6.2			
Total	1612.1	9				

Table B.6. Ennis Immediate Post-Construction

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	3	139	46.33333	40.33333		
Column 2	3	137	45.66667	70.33333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.666667	1	0.666667	0.012048	0.917883	7.70865
Within Groups	221.3333	4	55.33333			
Total	222	5				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	3	137	45.66667	70.33333		
Column 2	3	121	40.33333	65.33333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	42.66667	1	42.66667	0.628993	0.472113	7.70865
Within Groups	271.3333	4	67.83333			
Total	314	5				
Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	3	121	40.33333	65.33333		
Column 2	3	57	19	3		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	682.6667	1	682.6667	19.98049	0.011075	7.70865
Within Groups	136.6667	4	34.16667			
Total	819.3333	5				

APPENDIX C

Design Standards for Rumble Strips
(English Units)



85TH % OR POSTED SPEED (MPH)	MINIMUM DISTANCE X(FT)	MINIMUM DISTANCE Y(FT)
30	100	325
35	120	400
40	135	475
45	150	550
50	165	625
55	180	700
60	195	775
65	215	850

X SHOULD NOT EXCEED 250'. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 1000'.

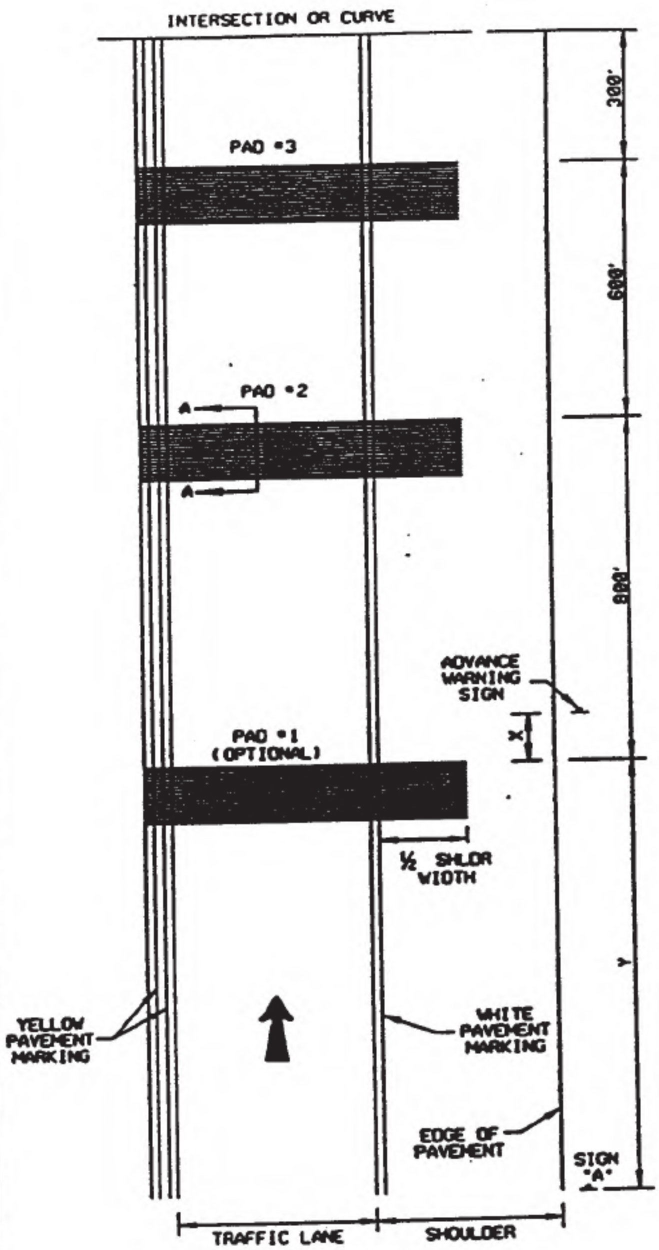
Fig. C.1. Recommended design standard for rumble strips extending continuously across only the travel lane(s)

NOTES

1. A WARNING SIGN GIVING NOTICE TO THE ADVANCE CONDITIONS IS REQUIRED BEYOND PAD #1 AS INDICATED.

2. WHEN A TWO PAD DESIGN IS TO BE USED PAD #1 SHOULD BE EXCLUDED AND THE SIGNS SHOULD BE PLACED AROUND PAD #2 AT THE DISTANCES GIVEN BELOW.

3. IF USED IN ADVANCE OF A CURVE, A TWO PAD DESIGN SHOULD BE USED.



85TH % OR POSTED SPEED (MPH)	MINIMUM DISTANCE X(FT)	MINIMUM DISTANCE Y(FT)
30	100	325
35	120	400
40	135	475
45	150	550
50	165	625
55	180	700
60	195	775
65	215	850

X SHOULD NOT EXCEED 250'. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 1000'.

SIGN "A"

SECTION A-A

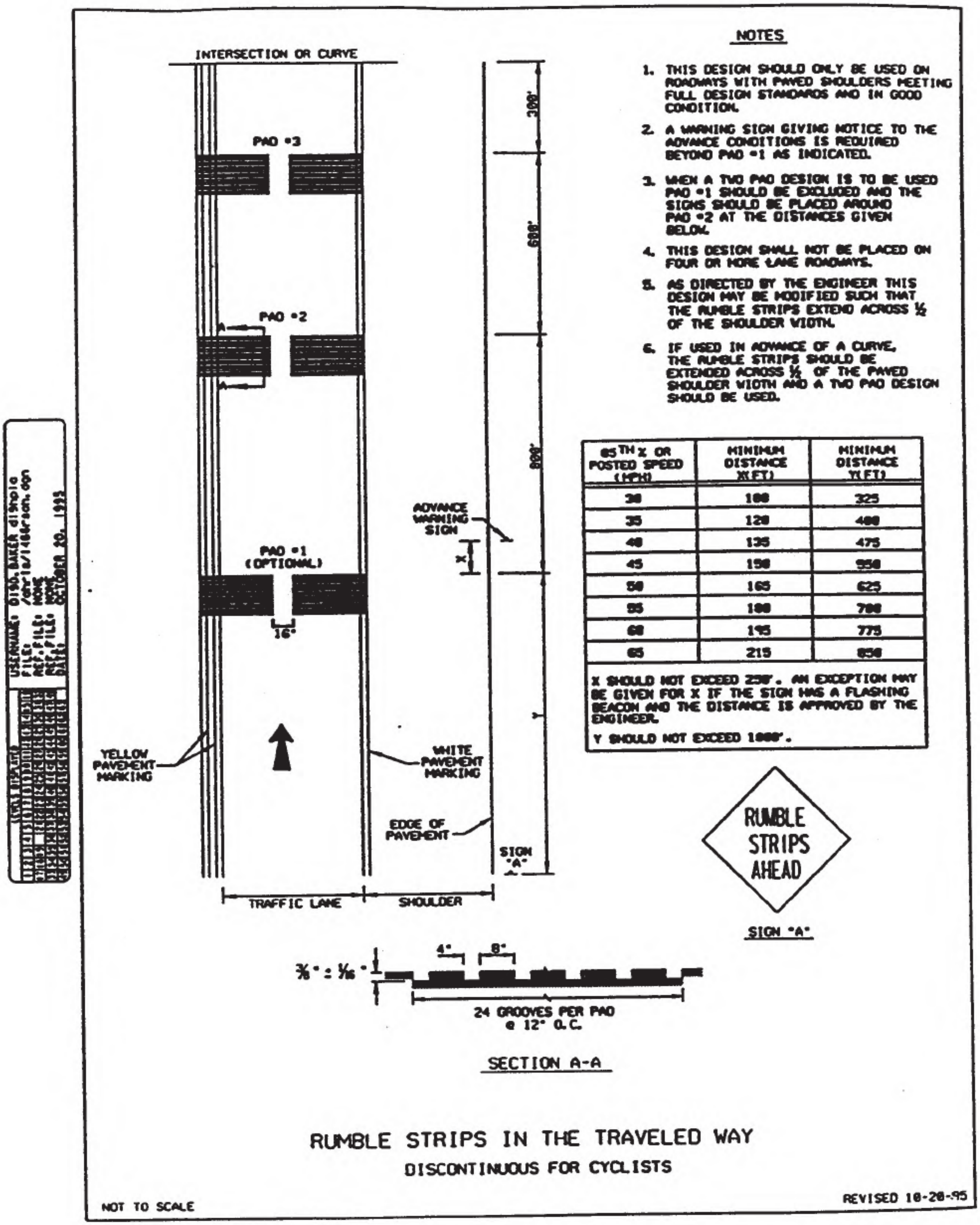
RUMBLE STRIPS IN THE TRAVELED WAY

PARTIALLY OBSTRUCTING THE SHOULDER

REVISED 10-20-95

NOT TO SCALE

Fig. C.2. Recommended design standard for rumble strips extending continuously across only the travel lane(s) and half of the paved shoulder

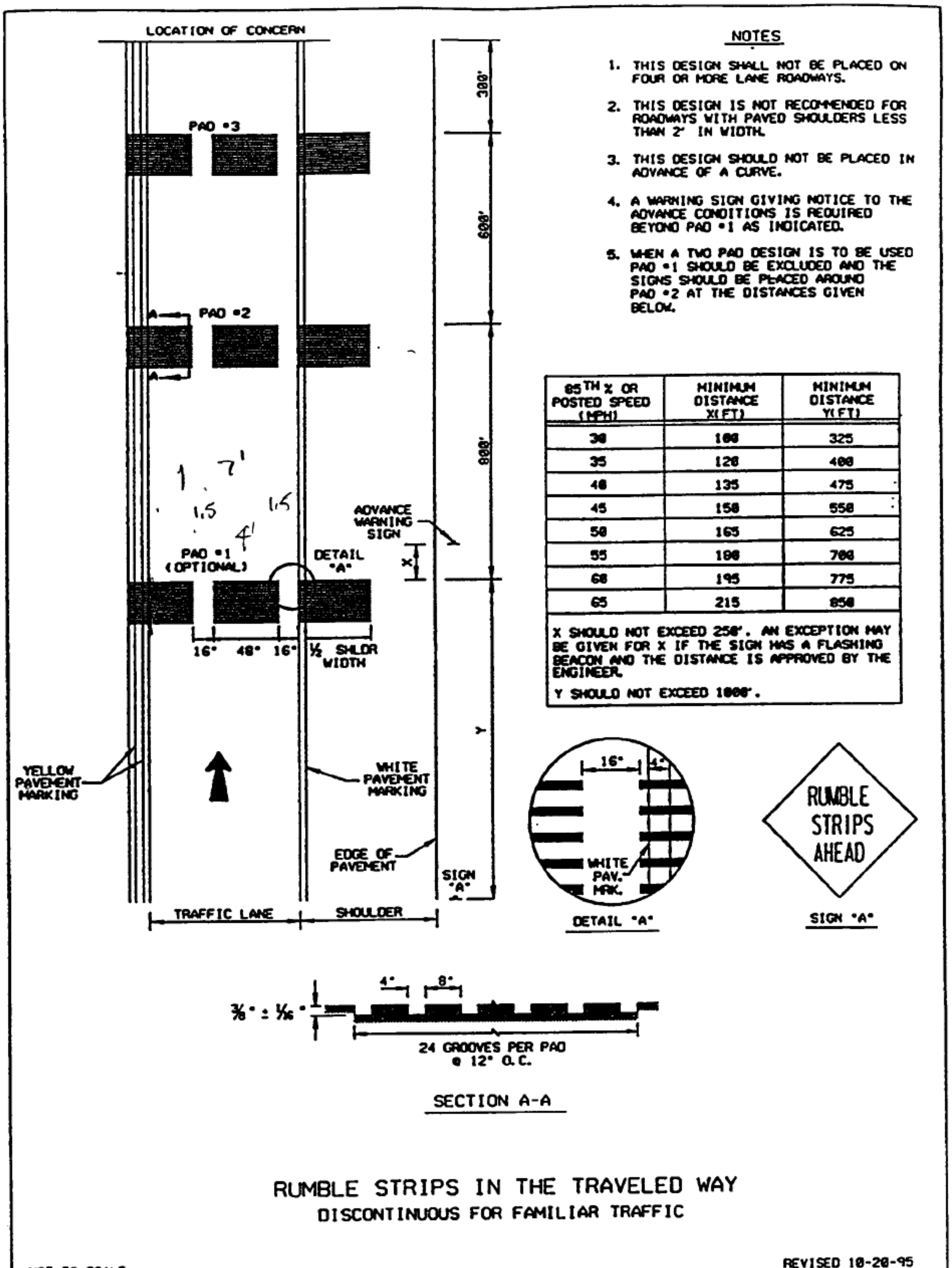


85TH % OR POSTED SPEED (MPH)	MINIMUM DISTANCE X (FT)	MINIMUM DISTANCE Y (FT)
30	100	325
35	120	400
40	135	475
45	150	550
50	165	625
55	180	700
60	195	775
65	215	850

X SHOULD NOT EXCEED 250'. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 1000'.

Fig. C.3. Recommended design standard for rumble strips interrupted at mid-width of the travel lane to accommodate cyclists.



85TH % OR POSTED SPEED (MPH)	MINIMUM DISTANCE X(FT)	MINIMUM DISTANCE Y(FT)
30	100	325
35	120	400
40	135	475
45	150	550
50	165	625
55	180	700
60	195	775
65	215	850

X SHOULD NOT EXCEED 250'. AN EXCEPTION MAY BE GIVEN FOR X IF THE SIGN HAS A FLASHING BEACON AND THE DISTANCE IS APPROVED BY THE ENGINEER.

Y SHOULD NOT EXCEED 1000'.

Fig. C.4. Recommended design standard for rumble strips extending over half of the paved shoulder but interrupted in the travel lane(s) to accommodate local drivers familiar with the rumble strips and the hazard with which they are associated

APPENDIX D

Design Drawings for Recommended Shoulder Treatment Methods (Metric Units)

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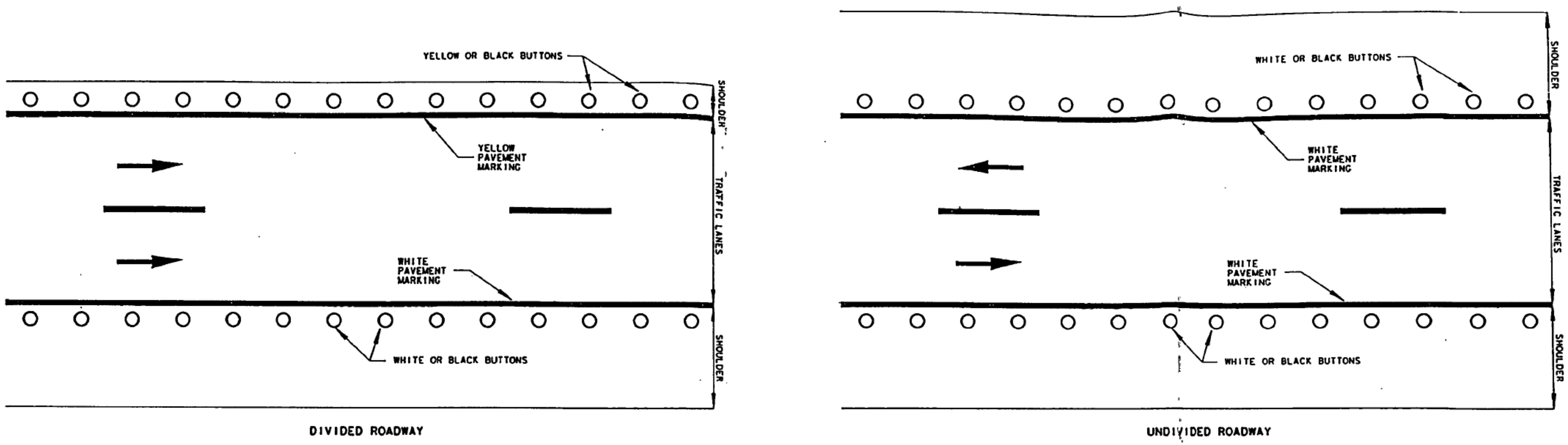
--CTR Library Digitization Team



PLAN VIEW

GENERAL NOTES

① Buttons shall not be placed across intersecting streets, ramps, acceleration and deceleration lanes, crossovers or gore areas.

② Specifications for traffic buttons shall be as detailed on RPM(1)-92

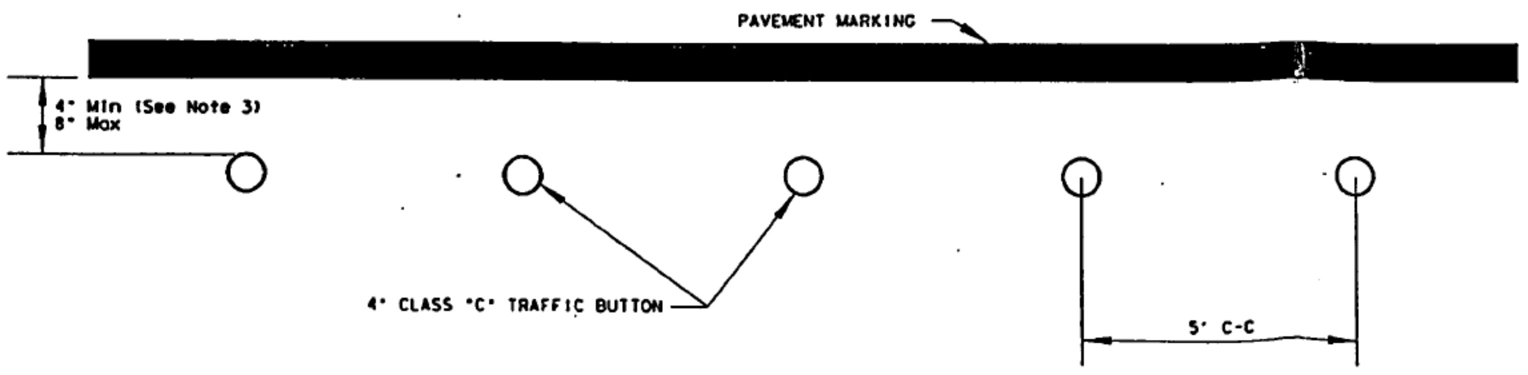
③ The minimum distance between the edgeline and the buttons should be used if the shoulder is 6 feet or less in width.

PLACEMENT RECOMMENDATIONS

④ The use of buttons as texturing should be limited to stretches of roadways with shoulders that have insufficient pavement depth or width to accommodate depressed texturing and where a significant single vehicle run-off-the-road accident history exists.

⑤ In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane.

⑥ Consideration should be given to cyclists when considering the appropriate placement of texturing. The maximum width allowable should be left untextured on the outside of the shoulder.



TYPICAL PLACEMENT

PRELIMINARY SUBJECT TO CHANGE

Texas Department of Transportation
Design Division (Roadway Section)

SHOULDER TEXTURING USING BUTTONS
ST(2)-95

JANUARY 1994

PRELIMINARY

SUBJECT TO CHANGE

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FILE: CHRISTSTI.DGN
REF.FILE: NONE
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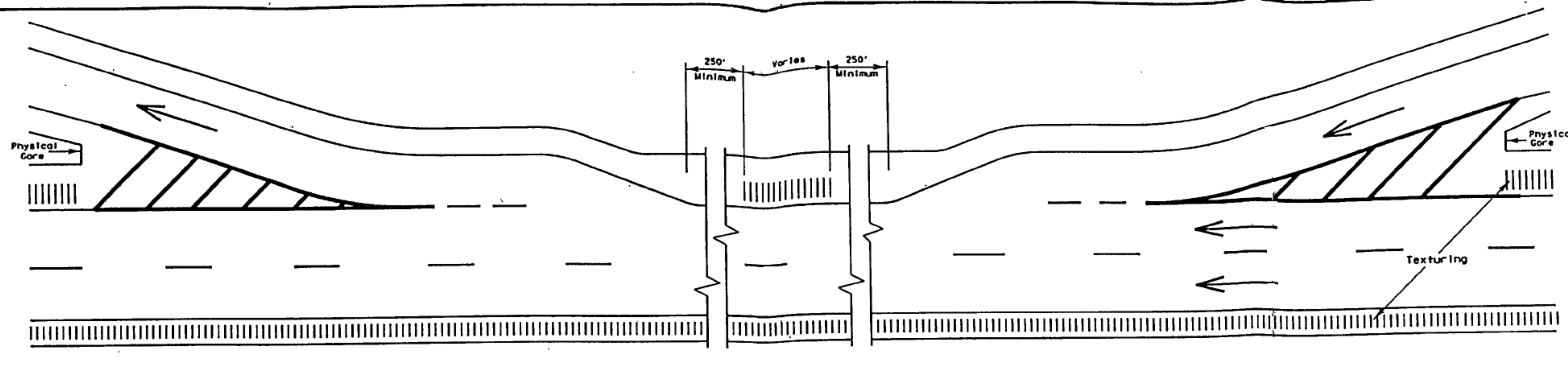
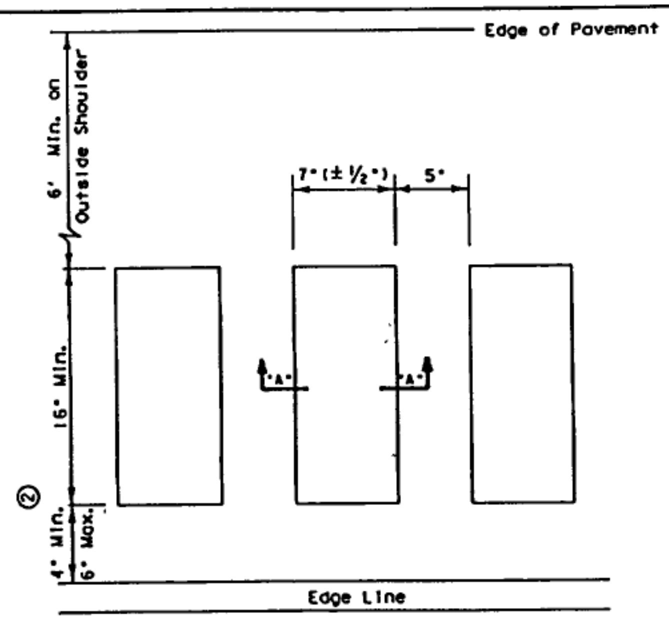
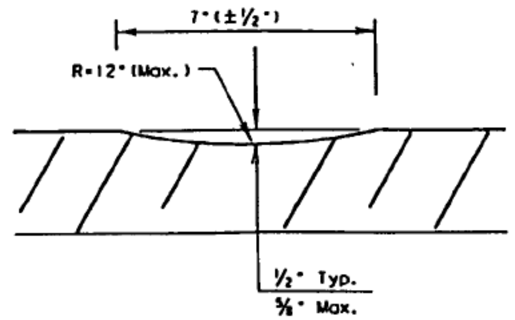
DATE: OCTOBER 20, 1995



TYPICAL TEXTURING PLACEMENT AT EXIT AND ENTRANCE RAMPS

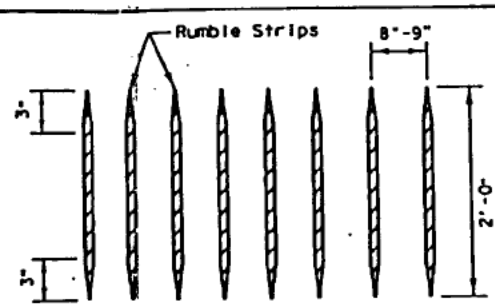


PLAN VIEW

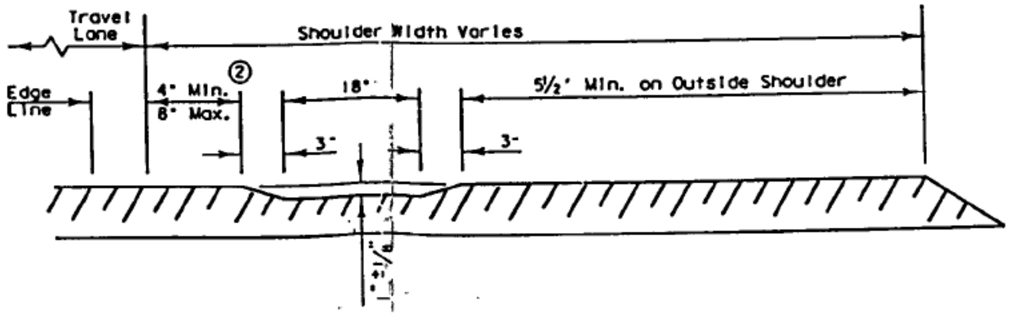


SECTION "A-A"

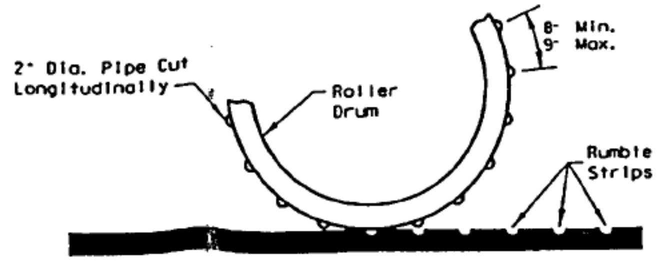
OPTION 1: CONTINUOUS MILLED DEPRESSIONS



PLAN VIEW



TYPICAL SECTION



ROLLER DRUM DETAIL

OPTION 2: CONTINUOUS ROLLED DEPRESSIONS

GENERAL NOTES

① Extreme caution shall be taken at all times to avoid texturing at locations other than those designated on the plans. Texturing shall not be placed across intersecting streets, ramps, acceleration and deceleration lanes, crossovers, or gore areas.

② The minimum distance between the edgeline and the texturing should be used if the shoulder is 6 feet or less in width.

PLACEMENT RECOMMENDATIONS

③ Depressed textured shoulder treatments should only be placed on four lane or more rural highways with 8 feet or wider shoulders. They may be placed on the inside shoulder of divided roadways.

④ Other rural highways are not recommended for treatment except in special cases. These special cases should be discussed with the Design Division prior to implementation.

⑤ In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane on four lane or more divided highways.

⑥ Consideration should be given to cyclists when considering the appropriate placement of texturing. A minimum of 5½ feet shall be left untextured on the outside of the outside shoulder.

⑦ Consideration should be given to mail routes such that a sufficient untextured width is provided for the postal carriers.

Texas Department of Transportation
Design Division (Roadway Section)

DEPRESSED SHOULDER TEXTURING

ST(1)-95

JANUARY 1994

A. INTRODUCTION

Rumble strips are raised or depressed patterns used to provide auditory and tactile sensations to the driver to call attention to an upcoming change or potential hazard in the roadway. Shoulder texturing is the use of rumble strips along the shoulder as a warning device to alert drivers that they are leaving the roadway. In particular, they are used to alert weary drivers. Rumble strips used in the travel lane are intended to alert drivers that some action is necessary concerning an impending feature that is often overlooked.

B. SHOULDER TEXTURING

1. Types of Texturing

Milled-in rumble strips are the most effective type of shoulder texturing at reducing the number of single vehicle run-off-the-road accidents. Milled rumble strips are shallow depressions perpendicular to the edgeline typically no longer than 16 in. (400 mm) across the shoulder, 7 in. (178 mm) wide, and spaced about 12 in. (305 mm) on center continuously along the shoulder. Machinery specifically adapted for this type of work is required. Milled-in texturing produces sufficient stimuli to alert semi-truck drivers but yet does not effect the maneuverability capabilities of motorcycles or small vehicles.

Rolled-in rumble strips produce less noise and vibration, and therefore are less effective, than milled-in rumble strips. However, they do reduce a significant number of single vehicle run-off-the-road accidents. Rolled-in rumble strips are produced by half sections of pipe welded on a steel wheel roller at the appropriate spacing. Concerns associated with rolled-in texturing include: 1) They can only be placed in coordination with other asphalt concrete pavement construction. 2) The temperature of the asphalt concrete pavement is critical for achieving the proper depth without damaging the surface. 3) The required width across the shoulder takes unobstructed area away from bicyclists and mail carriers. 4) They may not produce sufficient stimuli to alert most semi-trucks.

Traffic buttons placed along the edgeline spaced approximately 5 ft. (1500 mm) on center may also be used as shoulder texturing when rolled-in or milled-in texturing is not feasible. Buttons should be limited to roadways where there is insufficient pavement structure or shoulder width to accommodate either of the depressed texturing treatments and where the accident experience justifies the cost for placing and maintaining buttons. Also, buttons may not be suitable where snow plows are used.

Raised profile pavement markings, primarily used to provide delineation during adverse driving conditions, do provide a rumble noise when traversed. However, due to the relatively low noise level and small time of exposure, raised profile pavement markings should not be used exclusively as a rumble strip unless texturing is desired where no shoulders exist. If shoulders exist on roadways that exhibit the need for texturing, other types of texturing, as described above, should be used in conjunction with the raised profile pavement markings.

Neither raised asphaltic strips nor jiggle bar tiles should be used as shoulder texturing since both applications have a short life span and the jiggle bars present a hazard after becoming dislodged.

If bicyclists, mail carriers and/or farm equipment use the shoulder, a type of texturing that will accommodate them needs to be chosen.

2. Roadway Eligibility for Shoulder Texturing

The highest priority roadways for texturing treatment are rural divided freeways with full control of access, monotonous surroundings, and carrying traffic on long destination trips where a significant number of single vehicle run-off-the-road type accidents are occurring. These characteristics necessitate that the majority of the Interstate system requires textured shoulders and should be given priority over other roadways. Other four-lane or more rural divided highways with full control of access would then take precedent for treatment.

Divided facilities with partial or limited control of access should be evaluated on an individual basis for the need of textured shoulders based on accident history.

Non-divided four-lane or more rural highways should only be treated with textured shoulders when accident history warrants installation and the location is not within close proximity to urban areas. Other rural highways should not be treated except in special cases where a significant number of the accidents, by frequency and by percentage of fatal accidents, is attributed to weary drivers running off of the road and the installation of rumble strips is determined to be cost beneficial.

Continuity across district boundaries should be achieved when possible (i.e. coordinating the time of installation and type of texturing).

In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane on four lane or more divided highways.

In addition, textured shoulders should not be used where the shoulders are commonly used by slow traffic to allow faster traffic to pass unless it is the intent to prohibit this practice.

C. RUMBLE STRIPS IN THE TRAVEL LANE

Rumble strips should be used in the travel lane only when all other methods of traffic control have been implemented and have failed to reduce the accidents significantly or, from previous experience, other traffic control measures are know to be insufficient.

Engineering judgment should be exercised in deciding to use rumble strips in the travel lane such that overuse, which breeds driver complacency, is avoided.

Rumble strips in the travel lane shall not be placed within 200 ft (60 meters) of a residence or business due to the noise created. No rumble strips shall be placed within the area where braking occurs.

The rumble strips shall be installed such that, upon traversing the first rumble strip pad, the drivers' attention is directed to a traffic control device indicating the approaching condition. a "RUMBLE STRIPS AHEAD" warning sign shall be placed prior to the rumble strips.

1. Temporary Installations

   Temporary installations of rumble strips in the travel lane may be used in advance of intersections where the "STOP" condition has changed or in work zones with high traffic volumes where a lane is being dropped. Other special conditions where a change in the drivers' routine environment has been made that is not anticipated or is not readily apparent to the driver may also warrant temporary rumble strips as approved by the Engineer.

   Temporary rumble strips are typically raised (e.g. buttons, multiple layers of pavement markings, or prefabricated rumble strips) and should be from 1/2 in. (13 mm) to 3/4 in. (19 mm) in height. At least six rows per rumble strip pad should be used, spaced at 8 in. (203 mm) to 12 in. (305 mm) on center, which at least two pads approaching the condition.

   Temporary rumble strips should be removed as soon as the hazard no longer exists or compliance with the condition is well established.

2. Permanent Installations

   Rumble strips may be permanently installed in the travel lane when an accident history exists at a location where the accidents are related to features in the roadway that are being disregard.

   Rumble strips in the travel lane may be effective at rural intersections (particularly T-intersections) where the driver has been unencumbered for a considerable distance. They may also be used prior to curves that are commonly overshot.

At least two pads, but preferably three pads, with no less than 24 depressions per pad, should be used on each applicable approach. The depressions should be milled or formed into the pavement approximately 3/8 in. (10 mm) deep, 4 in. (100 mm) wide, and on 12 in. (300 mm) centers.

Accommodations for cyclists shall be a consideration where applicable. The rumble strips may be placed with gaps such that motorcyclists, bicyclists and familiar drivers may avoid them.

SPECIAL SPECIFICATION

ITEM

MILLED SHOULDER TEXTURING

1. Description. This Item shall govern for constructing textured shoulders on the finished surface of asphaltic concrete pavement or portland cement concrete by use of a milling machinge as specificed in this Item and as shown on the plans.

2. Equipment. The equipment shall consist of a rotary type cutting head with a maximum outside diameter of 24 inches and a minimum length of 16 inches. The cutting head shall have the cutting tips arranged in such a pattern as to provide a relatively smooth cut (approximately 1/16 of an inch between peaks and valleys). The cutting head(s) shall be on their own independent suspension from that of the power unit to allow the tool to self align with the slope of the shoulder and/or any irregularities in the shoulder surface.

   The cutting tool shall be equipped with guides to provide consistent alignment of each cut in relation to the roadway and to provide uniformity and consistency throughout the project.

3. Construction. The rumble strips shall have finished dimensions of seven (7) inches wide (+/- 1/2 inch) in the direction of travel and shall be a minimum of 16 inches long measured perpendicular to the direction of travel. The depressions shall have a concave circular arc shape with a minimum depth of one-half inch and a maximum depth of 5/8 inch at the center of the cut.

   The rumble strips shall be placed at a distance from the travel lane as shown on the plans or as directed by the Engineer and this distance shall be consistent for the entire limits of texturing. A minimum of 6 feet shall be left on the outside of the outside shoulder.

   At the end of each working day, all equipment shall be removed to a location where it does not present an obstacle to traffic, the pavement shall be cleaned by sweeping or flushing, unless otherwise shown on the plans, and the work area shall be opened to traffic.

   The Contractor shall demonstrate to the Engineer the ability to achieve the desired surface inside each depression without tearing or snagging the asphalt prior to beginning the work.

   Rumble strips shall not be placed across exit or entrance ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

Extreme caution shall be taken at all times to avoid texturing at locations other than those specified in this Item and as shown on the plans. Any misplaced texturing must be corrected at the expense of the Contractor.

4. Measurement. Milled shoulder texturing will be measured longitudinally by the linear foot along the shoulder on which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

5. Payment. The work performed in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Milled Shoulder Texturing". This price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM

ROLLED-IN SHOULDER TEXTURING

1. Description. This Item shall govern for constructing textured shoulders on the surface of asphaltic concrete pavement by use of a roller as specificed in this Item and as shown on the plans.

2. Construction. A steel-wheel or a combination steel-wheel rubber-tire roller shall be provided and used for texturing shoulders. Rubber tires shall only be permitted that have a smooth or "slick" tread design. The roller used to score the pavement shall weigh a minimum of six (6) tons or apply a force equivalent to a six-ton roller. The roller shall have a steering wheel and shall be equipped with a water system to moisten the drums and tires sufficiently to prevent picking up bituminous material. A method to guide the roller shall be used enabling the operator to maintain the desired alignment.

   The rollers, used in the construction of textured shoulders, shall produce texturing as shown on the plans by securely fastening sections of a nominal 2-inch I.D. schedule 40 steel pipe to the roller drum. The pipe shall be cut such that the depth of the indention made by the pipe is one (1) inch with a variability of 1/8 inch. The pipes are to be cut in two-foot segments which are to include three-inch tapers on each end. The center to center spacing of the indentions shall be eight (8) inches minimum and nine (9) inches maximum.

   Longitudinal alignment of texturing shall be four (4) inches to six (6) inches from the outside edge of the edgeline. This distance shall be as shown on the plans or as directed by the Engineer and shall be consistent for the entire limits of texturing. A minimum of 5-1/2 feet shall be left untextured on the outside of the outside shoulder.

   The pipe shall be placed on the non-steering drum of the roller and the roller shall be shimmed tight so the drum may rotate but cannot move from side to side.

   Texturing of the shoulders shall be performed immediately behind the breakdown rolling operation and as closely behind the paver as possible as approved by the Engineer, and shall be accomplished in one (1) pass of the roller. No additional construction vehicles or equipment shall be permitted on the scored pavement for a period of 24 hours after scoring.

Rollers used to construct textured shoulders shall be positioned by using planking or other methods approved by the Engineer and extreme caution shall be taken at all times to avoid texturing at locations other than those shown on the plans.

Any additional texturing at locations other than those shown on the plans must be corrected at the expense of the contractor.

3. Measurement. The rolled-in shoulder texturing will be measured longitudinally by the linear foot along the shoulder which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas or intersections with other roadways.

4. Payment. The work performed in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Rolled-In Shoulder Texturing". This price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM

TEXTURED SHOULDERS USING TRAFFIC BUTTONS

1. Description. This Item shall govern for constructing textured shoulders on the finished shoulder surface using standard 4-inch diameter traffic buttons in accordance with these specifications and as shown on the plans.

2. Materials. Traffic buttons, bituminous adhesive, and epoxy, and the construction methods used for the placement thereof, shall conform to the pertinent requirements of Item 672, "Raised Pavement Markers".

   Non-reflectorized traffic buttons shall be Class C and Type W, Type Y or black as specified in the plans.

   Black buttons shall have a black body and no reflective faces.

3. Construction. Buttons shall be placed parallel to the edgeline, spaced five (5) feet center to center, and the edge of the buttons shall be placed four (4) to eight (8) inches from the outside edge of the edgeline. This distance shall be as shown on the plans or as directed by the Engineer and shall be consistent for the entire limits of texturing. The buttons shall not be misaligned more than +/- 1/4 inches.

   Placement of buttons shall be aligned by using a placement template approved in advance by the Engineer. Templates placed on the roadway for alignment purposes shall not establish a permanent marking on the roadway.

   Buttons shall not be placed across entrance and exit ramps, acceleration and deceleration lances, crossovers, gore areas, or intersecting roadways.

   Buttons placed that are not in alignment or sequence, as shown on the plans or as stated in this specification, shall be removed by the Contractor at the Contractor's expense. Removal shall be in accordance with Item 677, "Eliminating Existing Pavement Markings and Markers", except for measurement and payment.

4. Measurement. Textured shoulders using traffic buttons will be measured longitudinally by the linear foot along the shoulder on which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas or intersections with other roadways.

5. <u>Payment</u>. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Textured Shoulders Using Traffic Buttons" of the types specified. This price shall be full compensation for furnishing all materials, surface preparation, installation, labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM 0000

FORMED-IN TEXTURING

1. **Description.** This Item shall govern for constructing textured shoulders in portland cement concrete pavement by forming patterns of depressions into freshly placed concrete shoulders at the locations indicated in the plans and to the dimensions specified in this item.

2. **Construction Methods.** The rumble strips shall have finished dimensions of 165 to 190 millimeters wide in the direction of travel and shall be 400 millimeters long measured perpendicular to the direction of travel unless otherwise specified in the plans. The depressions shall have a concave circular arc shape with a minimum depth of 13 millimeters and a maximum depth of 19 millimeters. The center to center spacing of the depressions shall be 610 millimeters, unless otherwise specified in the plans.

Where the shoulder joint is at the edge of traveled way, the impressions shall normally be formed-in starting 200 millimeters beyond the shoulder joint. Where the shoulder joint is placed 610 millimeters beyond the edge of traveled way, the impressions shall be formed between the edge of traveled way and the joint with a minimum clearance of 100 millimeters from each. A minimum of 1700 millimeters shall be left on the outside of the outside shoulder.

The forming and/or floating operations shall be done in such a manner as to minimize the formation of raised areas or ridges that will project up. The maximum allowable projection above the general plane of the shoulder shall be 10 millimeters.

Prior to beginning full production work on the shoulders, the Contractor shall demonstrate to the Engineer the ability to achieve the desired indentations by constructing a 30 meter representative length of the shoulder and forming in the required impressions.

Rumble strips shall not be placed across exit or entrance ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

Extreme caution shall be taken at all times to avoid texturing at locations other than those specified in this item and as designated on the plans. Any misplaced texturing must be corrected at the expense of the contractor.

3. **Measurement.** Formed-in Texturing will be measured longitudinally by the meter or by the 100 meters along the shoulder on which the rumble strips are constructed. Measurement shall not include interruptions across ramps, acceleration and

deceleration lanes, crossovers, gore areas, or intersections with other roadways.

4. Payment. The work performed in accordance with this item and measured as provided under "Measurement" will be paid for at the unit price bid for "Formed-in Texturing." This Price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.

APPENDIX E

Design Drawings for Recommended Shoulder Treatment Methods (English Units)

The original report did not include pages 145–8 for scanning.

--CTR Library Digitization Team

A. INTRODUCTION

Rumble strips are raised or depressed patterns used to provide auditory and tactile sensations to the driver to call attention to an upcoming change or potential hazard in the roadway. Shoulder texturing is the use of rumble strips along the shoulder as a warning device to alert drivers that they are leaving the roadway. In particular, they are used to alert weary drivers. Rumble strips used in the travel lane are intended to alert drivers that some action is necessary concerning an impending feature that is often overlooked.

B. SHOULDER TEXTURING

1. Types of Texturing

Milled-in rumble strips are the most effective type of shoulder texturing at reducing the number of single vehicle run-off-the-road accidents. Milled rumble strips are shallow depressions perpendicular to the edgeline typically no longer than 16 in. (400 mm) across the shoulder, 7 in. (178 mm) wide, and spaced about 12 in. (305 mm) on center continuously along the shoulder. Machinery specifically adapted for this type of work is required. Milled-in texturing produces sufficient stimuli to alert semi-truck drivers but yet does not effect the maneuverability capabilities of motorcycles or small vehicles.

Rolled-in rumble strips produce less noise and vibration, and therefore are less effective, than milled-in rumble strips. However, they do reduce a significant number of single vehicle run-off-the-road accidents. Rolled-in rumble strips are produced by half sections of pipe welded on a steel wheel roller at the appropriate spacing. Concerns associated with rolled-in texturing include: 1) They can only be placed in coordination with other asphalt concrete pavement construction. 2) The temperature of the asphalt concrete pavement is critical for achieving the proper depth without damaging the surface. 3) The required width across the shoulder takes unobstructed area away from bicyclists and mail carriers. 4) They may not produce sufficient stimuli to alert most semi-trucks.

Traffic buttons placed along the edgeline spaced approximately 5 ft. (1500 mm) on center may also be used as shoulder texturing when rolled-in or milled-in texturing is not feasible. Buttons should be limited to roadways where there is insufficient pavement structure or shoulder width to accommodate either of the depressed texturing treatments and where the accident experience justifies the cost for placing and maintaining buttons. Also, buttons may not be suitable where snow plows are used.

Raised profile pavement markings, primarily used to provide delineation during adverse driving conditions, do provide a rumble noise when traversed. However, due to the relatively low noise level and small time of exposure, raised profile pavement markings should not be used exclusively as a rumble strip unless texturing is desired where no shoulders exist. If shoulders exist on roadways that exhibit the need for texturing, other types of texturing, as described above, should be used in conjunction with the raised profile pavement markings.

Neither raised asphaltic strips nor jiggle bar tiles should be used as shoulder texturing since both applications have a short life span and the jiggle bars present a hazard after becoming dislodged.

If bicyclists, mail carriers and/or farm equipment use the shoulder, a type of texturing that will accommodate them needs to be chosen.

2. Roadway Eligibility for Shoulder Texturing

The highest priority roadways for texturing treatment are rural divided freeways with full control of access, monotonous surroundings, and carrying traffic on long destination trips where a significant number of single vehicle run-off-the-road type accidents are occurring. These characteristics necessitate that the majority of the Interstate system requires textured shoulders and should be given priority over other roadways. Other four-lane or more rural divided highways with full control of access would then take precedent for treatment.

Divided facilities with partial or limited control of access should be evaluated on an individual basis for the need of textured shoulders based on accident history.

Non-divided four-lane or more rural highways should only be treated with textured shoulders when accident history warrants installation and the location is not within close proximity to urban areas. Other rural highways should not be treated except in special cases where a significant number of the accidents, by frequency and by percentage of fatal accidents, is attributed to weary drivers running off of the road and the installation of rumble strips is determined to be cost beneficial.

Continuity across district boundaries should be achieved when possible (i.e. coordinating the time of installation and type of texturing).

In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane on four lane or more divided highways.

In addition, textured shoulders should not be used where the shoulders are commonly used by slow traffic to allow faster traffic to pass unless it is the intent to prohibit this practice.

C. RUMBLE STRIPS IN THE TRAVEL LANE

Rumble strips should be used in the travel lane only when all other methods of traffic control have been implemented and have failed to reduce the accidents significantly or, from previous experience, other traffic control measures are know to be insufficient.

Engineering judgment should be exercised in deciding to use rumble strips in the travel lane such that overuse, which breeds driver complacency, is avoided.

Rumble strips in the travel lane shall not be placed within 200 ft (60 meters) of a residence or business due to the noise created. No rumble strips shall be placed within the area where braking occurs.

The rumble strips shall be installed such that, upon traversing the first rumble strip pad, the drivers' attention is directed to a traffic control device indicating the approaching condition. a "RUMBLE STRIPS AHEAD" warning sign shall be placed prior to the rumble strips.

1. Temporary Installations

Temporary installations of rumble strips in the travel lane may be used in advance of intersections where the "STOP" condition has changed or in work zones with high traffic volumes where a lane is being dropped. Other special conditions where a change in the drivers' routine environment has been made that is not anticipated or is not readily apparent to the driver may also warrant temporary rumble strips as approved by the Engineer.

Temporary rumble strips are typically raised (e.g. buttons, multiple layers of pavement markings, or prefabricated rumble strips) and should be from 1/2 in. (13 mm) to 3/4 in. (19 mm) in height. At least six rows per rumble strip pad should be used, spaced at 8 in. (203 mm) to 12 in. (305 mm) on center, which at least two pads approaching the condition.

Temporary rumble strips should be removed as soon as the hazard no longer exists or compliance with the condition is well established.

2. Permanent Installations

Rumble strips may be permanently installed in the travel lane when an accident history exists at a location where the accidents are related to features in the roadway that are being disregard.

Rumble strips in the travel lane may be effective at rural intersections (particularly T-intersections) where the driver has been unencumbered for a considerable distance. They may also be used prior to curves that are commonly overshot.

At least two pads, but preferably three pads, with no less than 24 depressions per pad, should be used on each applicable approach. The depressions should be milled or formed into the pavement approximately 3/8 in. (10 mm) deep, 4 in. (100 mm) wide, and on 12 in. (300 mm) centers.

Accommodations for cyclists shall be a consideration where applicable. The rumble strips may be placed with gaps such that motorcyclists, bicyclists and familiar drivers may avoid them.

SPECIAL SPECIFICATION

ITEM

MILLED SHOULDER TEXTURING

1. Description. This Item shall govern for constructing textured shoulders on the finished surface of asphaltic concrete pavement or portland cement concrete by use of a milling machinge as specificed in this Item and as shown on the plans.

2. Equipment. The equipment shall consist of a rotary type cutting head with a maximum outside diameter of 600 millimeters and a minimum length of 400 millimeters. The cutting head shall have the cutting tips arranged in such a pattern as to provide a relatively smooth cut (approximately one (1) to two (2) millimeters between peaks and valleys). The cutting head(s) shall be on their own independent suspension from that of the power unit to allow the tool to self align with the slope of the shoulder and/or any irregularities in the shoulder surface.

   The cutting tool shall be equipped with guides to provide consistent alignment of each cut in relation to the roadway and to provide uniformity and consistency throughout the project.

3. Construction. The rumble strips shall have finished dimensions of 175 millimeters wide (+/- 15 millimeters) in the direction of travel and shall be a minimum of 400 millimeters long measured perpendicular to the direction of travel. The depressions shall have a concave circular arc shape with a minimum depth of 13 millimeters and a maximum depth of 16 millimeters at the center of the cut.

   The rumble strips shall be placed at a distance from the travel lane as shown on the plans or as directed by the Engineer and this distance shall be consistent for the entire limits of texturing. A minimum of 1800 millimeters shall be left on the outside of the outside shoulder.

   At the end of each working day, all equipment shall be removed to a location where it does not present an obstacle to traffic, the pavement shall be cleaned by sweeping or flushing, unless otherwise shown on the plans, and the work area shall be opened to traffic.

   The Contractor shall demonstrate to the Engineer the ability to achieve the desired surface inside each depression without tearing or snagging the asphalt prior to beginning the work.

   Rumble strips shall not be placed across exit or entrance ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

Extreme caution shall be taken at all times to avoid texturing at locations other than those specified in this Item and as shown on the plans. Any misplaced texturing must be corrected at the expense of the Contractor.

4. Measurement. Milled shoulder texturing will be measured longitudinally by the meter along the shoulder on which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

5. Payment. The work performed in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Milled Shoulder Texturing". This price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM

ROLLED-IN SHOULDER TEXTURING

1. Description. This Item shall govern for constructing textured shoulders on the surface of asphaltic concrete pavement by use of a roller as specificed in this Item and as shown on the plans.

2. Construction. A steel-wheel or a combination steel-wheel rubber-tire roller shall be provided and used for texturing shoulders. Rubber tires shall only be permitted that have a smooth or "slick" tread design. The roller used to score the pavement shall weigh a minimum of 5.4 megagrams or apply a force equivalent to a 5.4-megagram roller. The roller shall have a steering wheel and shall be equipped with a water system to moisten the drums and tires sufficiently to prevent picking up bituminous material. A method to guide the roller shall be used enabling the operator to maintain the desired alignment.

   The rollers, used in the construction of textured shoulders, shall produce texturing as shown on the plans by securely fastening sections of a nominal 50-millimeter I.D. schedule 40 steel pipe to the roller drum. The pipe shall be cut such that the depth of the indention made by the pipe is 25 millimeters with a variability of three (3) millimeters. The pipes are to be cut in 600-millimeter segments which are to include 75 millimeter tapers on each end. The center to center spacing of the indentions shall be 200 millimeters minimum and 225 millimeters maximum.

   Longitudinal alignment of texturing shall be 100 to 200 millimeters from the outside edge of the edgeline. This distance shall be as shown on the plans or as directed by the Engineer and shall be consistent for the entire limits of texturing. A minimum of 1700 millimeters shall be left untextured on the outside of the outside shoulder.

   The pipe shall be placed on the non-steering drum of the roller and the roller shall be shimmed tight so the drum may rotate but cannot move from side to side.

   Texturing of the shoulders shall be performed immediately behind the breakdown rolling operation and as closely behind the paver as possible as approved by the Engineer, and shall be accomplished in one (1) pass of the roller. No additional construction vehicles or equipment shall be permitted on the scored pavement for a period of 24 hours after scoring.

Rollers used to construct textured shoulders shall be positioned by using planking or other methods approved by the Engineer and extreme caution shall be taken at all times to avoid texturing at locations other than those shown on the plans.

Any additional texturing at locations other than those shown on the plans must be corrected at the expense of the contractor.

3. Measurement. The rolled-in shoulder texturing will be measured longitudinally by the meter along the shoulder which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

4. Payment. The work performed in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Rolled-In Shoulder Texturing". This price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM

TEXTURED SHOULDERS USING TRAFFIC BUTTONS

1. Description. This Item shall govern for constructing textured shoulders on the finished shoulder surface using standard 100 millimeter diameter traffic buttons in accordance with these specifications and as shown on the plans.

2. Materials. Traffic buttons, bituminous adhesive, and epoxy, and the construction methods used for the placement thereof, shall conform to the pertinent requirements of Item 672, "Raised Pavement Markers".

   Non-reflectorized traffic buttons shall be Class C and Type W, Type Y or black as specified in the plans.

   Black buttons shall have a black body and no reflective faces.

3. Construction. Buttons shall be placed parallel to the edgeline, spaced 1500 millimeters center to center, and the edge of the buttons shall be placed 100 to 200 millimeters from the outside edge of the edgeline. This distance shall be as shown on the plans or as directed by the Engineer and shall be consistent for the entire limits of texturing. The buttons shall not be misaligned more than +/- 7 millimeters.

   Placement of buttons shall be aligned by using a placement template approved in advance by the Engineer. Templates placed on the roadway for alignment purposes shall not establish a permanent marking on the roadway.

   Buttons shall not be placed across entrance and exit ramps, acceleration and deceleration lances, crossovers, gore areas, or intersecting roadways.

   Buttons placed that are not in alignment or sequence, as shown on the plans or as stated in this specification, shall be removed by the Contractor at the Contractor's expense. Removal shall be in accordance with Item 677, "Eliminating Existing Pavement Markings and Markers", except for measurement and payment.

4. Measurement. Textured shoulders using traffic buttons will be measured longitudinally by the meter along the shoulder on which the texturing is constructed. Measurement shall not include interruptions across ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

5. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Textured Shoulders Using Traffic Buttons" of the types specified. This price shall be full compensation for furnishing all materials, surface preparation, installation, labor, equipment, tools and incidentals necessary to complete the work.

SPECIAL SPECIFICATION

ITEM 0000

FORMED-IN TEXTURING

1. **Description.** This Item shall govern for constructing textured shoulders in portland cement concrete pavement by forming patterns of depressions into freshly placed concrete shoulders at the locations indicated in the plans and to the dimensions specified in this item.

2. **Construction Methods.** The rumble strips shall have finished dimensions of 6 1/2 to 7 1/2 inches wide in the direction of travel and shall be 16 inches long measured perpendicular to the direction of travel unless otherwise specified in the plans. The depressions shall have a concave circular arc shape with a minimum depth of 1/2 inch and a maximum depth of 3/4 inch. The center to center spacing of the depressions shall be 2 feet, unless otherwise specified in the plans.

Where the shoulder joint is at the edge of traveled way, the impressions shall normally be formed-in starting 8 inches beyond the shoulder joint. Where the shoulder joint is placed 2 feet beyond the edge of traveled way, the impressions shall be formed between the edge of traveled way and the joint with a minimum clearance of 4 inches from each. A minimum of 5 1/2 feet shall be left on the outside of the outside shoulder.

The forming and/or floating operations shall be done in such a manner as to minimize the formation of raised areas or ridges that will project up. The maximum allowable projection above the general plane of the shoulder shall be 3/8 inch.

Prior to beginning full production work on the shoulders, the Contractor shall demonstrate to the Engineer the ability to achieve the desired indentations by constructing a 100 foot representative length of the shoulder and forming in the required impressions.

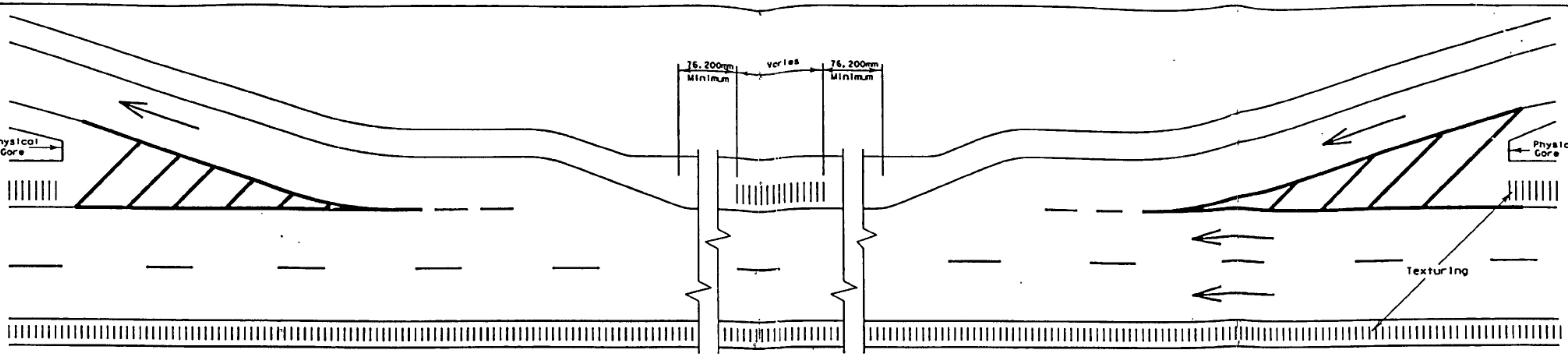
Rumble strips shall not be placed across exit or entrance ramps, acceleration and deceleration lanes, crossovers, gore areas, or intersections with other roadways.

Extreme caution shall be taken at all times to avoid texturing at locations other than those specified in this item and as designated on the plans. Any misplaced texturing must be corrected at the expense of the contractor.

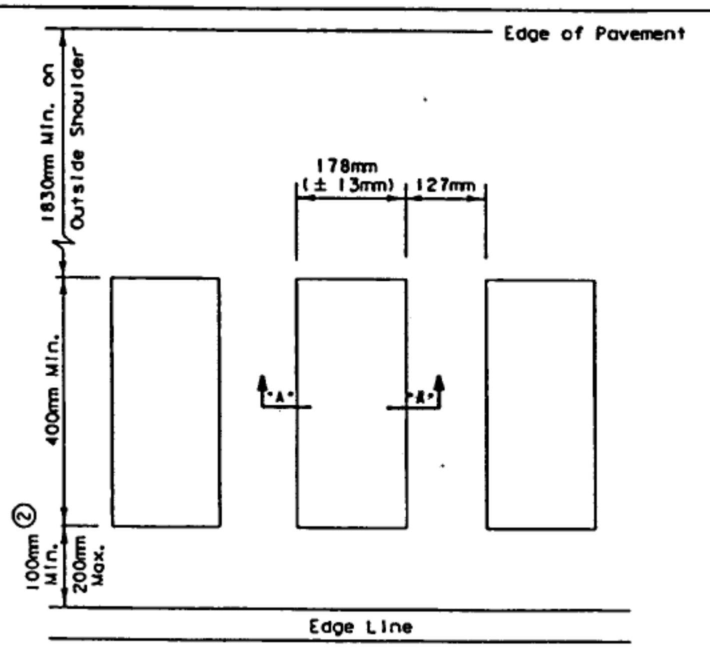
3. **Measurement.** Formed-in Texturing will be measured longitudinally by the linear foot or by the 100-foot station along the shoulder on which the rumble strips are constructed. Measurement shall not include interruptions across ramps, acceleration and

deceleration lanes, crossovers, gore areas, or intersections with other roadways.

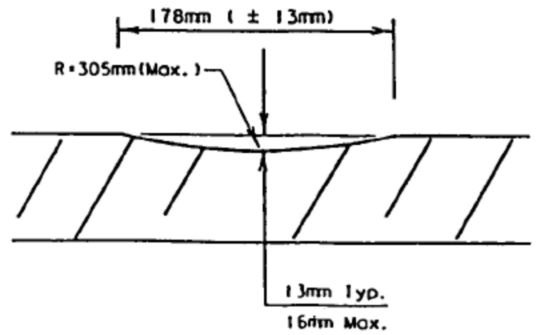
4. Payment. The work performed in accordance with this item and measured as provided under "Measurement" will be paid for at the unit price bid for "Formed-in Texturing." This Price shall be full compensation for all labor, equipment, tools and incidentals necessary to complete the work.



TYPICAL TEXTURING PLACEMENT AT EXIT AND ENTRANCE RAMPS

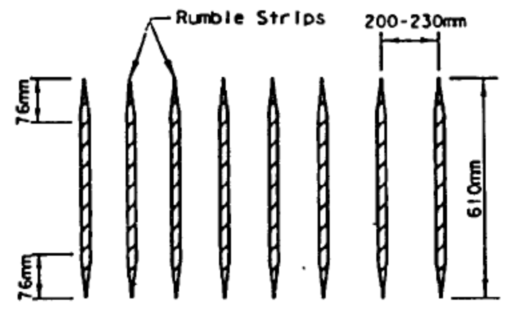


PLAN VIEW

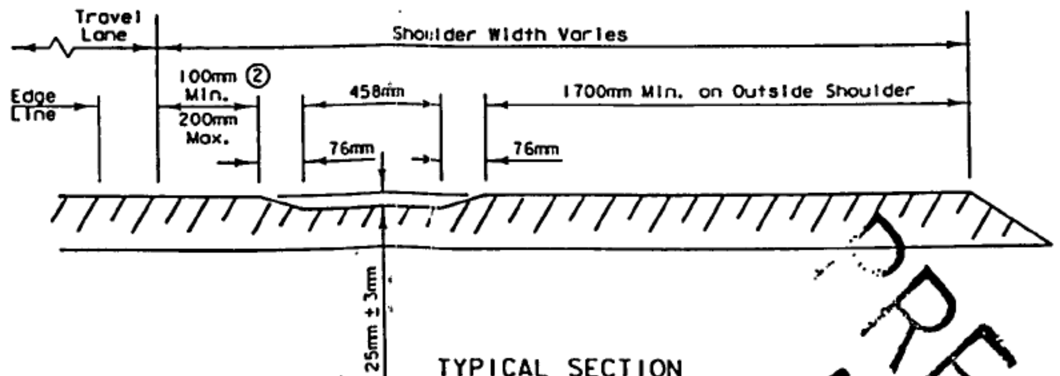


SECTION "A-A"

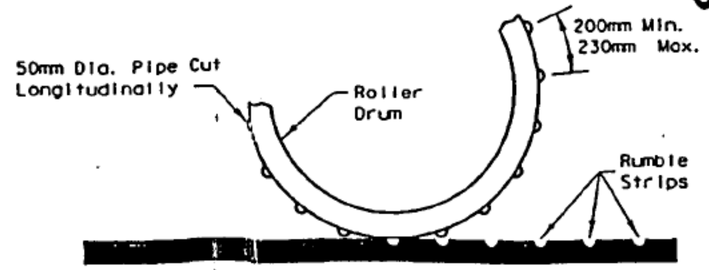
OPTION 1: CONTINUOUS MILLED DEPRESSIONS



PLAN VIEW



TYPICAL SECTION



ROLLER DRUM DETAIL

OPTION 2: CONTINUOUS ROLLED DEPRESSIONS

PRELIMINARY SUBJECT TO CHANGE

GENERAL NOTES

① Extreme caution shall be taken at all times to avoid texturing at locations other than those designated on the plans. Texturing shall not be placed across intersecting streets, ramps, acceleration and deceleration lanes, crossovers, or gore areas.

② The minimum distance between the edgeline and the texturing should be used if the shoulder is 1800mm or less in width.

PLACEMENT RECOMMENDATIONS

③ Depressed textured shoulder treatments should only be placed on four lane or more rural highways with 2440mm or wider shoulders. They may be placed on the inside shoulder of divided roadways.

④ Other rural highways are not recommended for treatment except in special cases. These special cases should be discussed with the Design Division prior to implementation.

⑤ In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane on four lane or more divided highways.

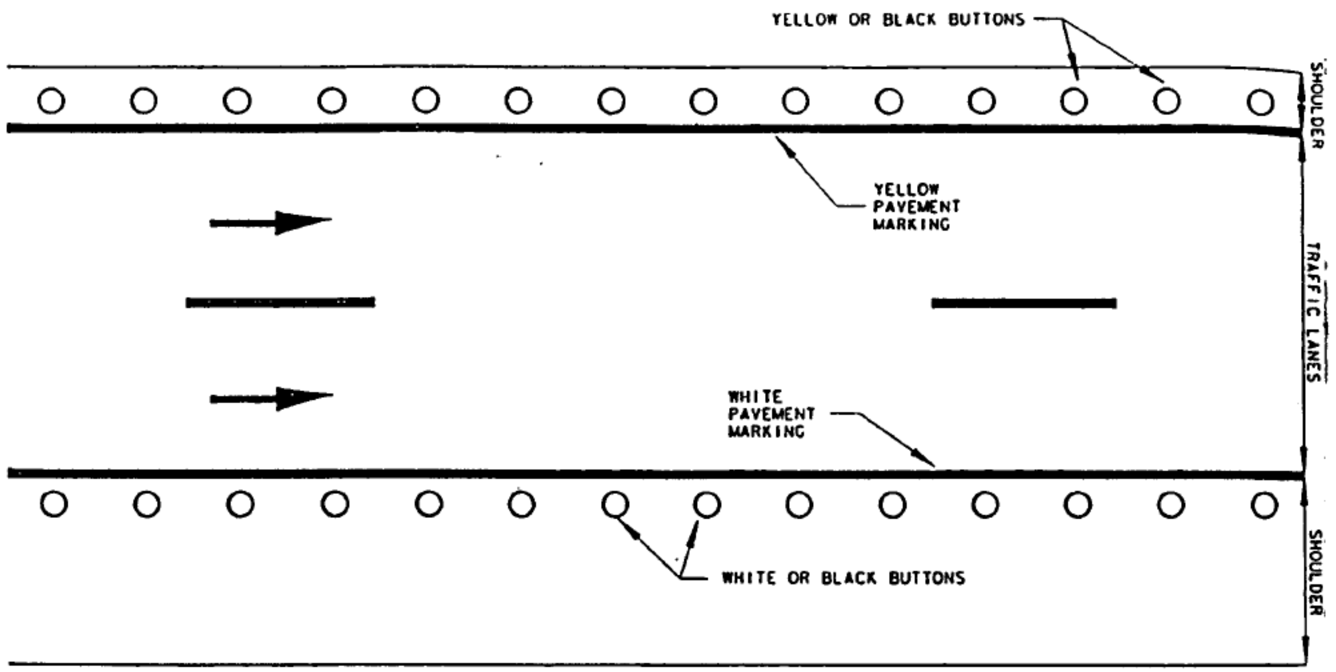
⑥ Consideration should be given to cyclists when considering the appropriate placement of texturing. A minimum of 1700mm shall be left untextured on the outside of the outside shoulder.

⑦ Consideration should be given to mail routes such that a sufficient untextured width is provided for the postal carriers.

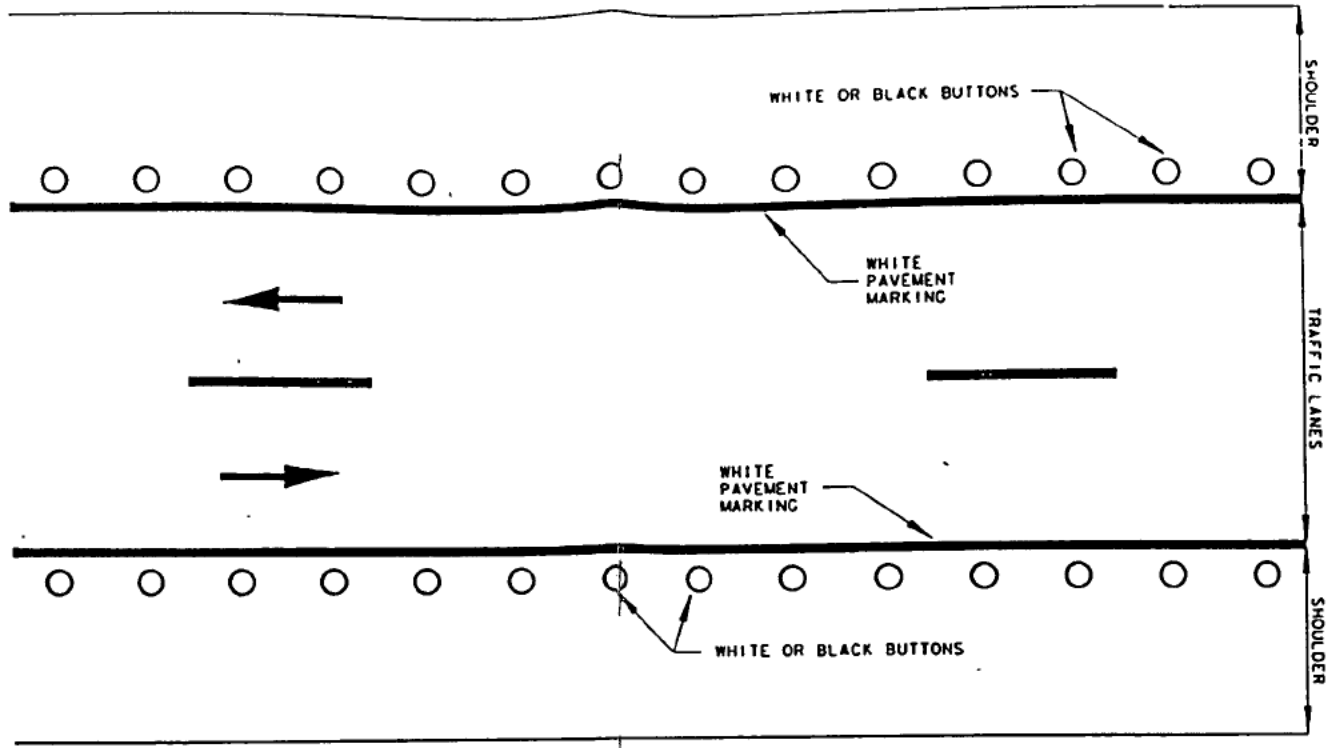
Texas Department of Transportation
Design Division (Roadway Section)

DEPRESSED SHOULDER TEXTURING
ST(1)-95(M)

JANUARY, 1994 CCH RD JHD JCM
1-27-95 Shldr widths for cyclists
All 6

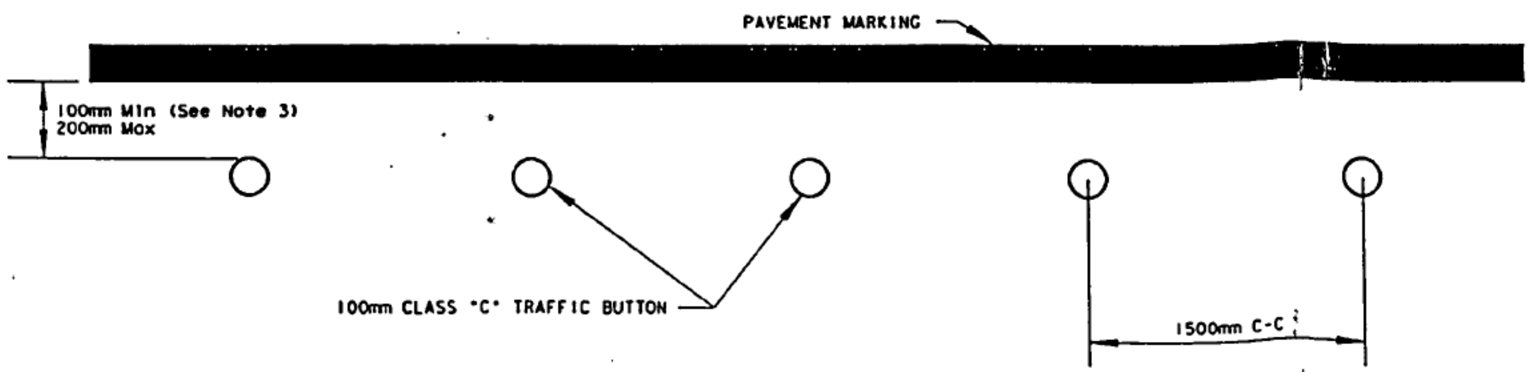


DIVIDED ROADWAY



UNDIVIDED ROADWAY

PLAN VIEW



TYPICAL PLACEMENT

PRELIMINARY
SUBJECT TO CHANGE

GENERAL NOTES

① Buttons shall not be placed across intersecting streets, ramps, acceleration and deceleration lanes, crossovers or gore areas.

② Specifications for traffic buttons shall be as detailed on RPM(1)-92

③ The minimum distance between the edgeline and the buttons should be used if the shoulder is 1800mm or less in width.

PLACEMENT RECOMMENDATIONS

④ The use of buttons as texturing should be limited to stretches of roadways with shoulders that have insufficient pavement depth or width to accommodate depressed texturing and where a significant single vehicle run-off-the-road accident history exists.

⑤ In urban areas textured shoulder treatments are not usually needed for the purpose of reducing the number of run-off-the-road accidents. High traffic volumes may necessitate using the shoulder as a travel lane during construction or maintenance or for additional capacity. However, a textured shoulder treatment in spot locations is acceptable in urban areas when the intent is to discourage the use of the shoulder as a travel lane.

⑥ Consideration should be given to cyclists when considering the appropriate placement of texturing. The maximum width allowable should be left untextured on the outside of the shoulder.

Texas Department of Transportation
Design Division (Roadway Section)

SHOULDER TEXTURING USING BUTTONS ST(2)-95(M)

JANUARY 1994 | CCH | BCD | TCM | A27A
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USERNAME: D19D.BAKER d19nplo
FILE: CHRISTS2.DGN
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DATE: OCTOBER 20, 1995