PDHonline Course C304 (4 PDH)

# Low Cost Treatments for Horizontal Curve Safety

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**2020**

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# *Low-Cost Treatments for*
# Horizontal Curve Safety

U.S.Department of Transportation
**Federal Highway Administration**

December 2006

# Technical Documentation Page

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<tr><td colspan="5">16. Abstract. Nearly 25 percent of fatal crashes occur at or near a horizontal curve. Hence, addressing the safety problem at horizontal curves is one of the 22 emphasis areas of the Strategic Highway Safety Plan prepared by AASHTO. Also, crashes at horizontal curves are a big component of the road departure crash problem, which is one of FHWA's three focus areas. This publication was prepared to provide practical information on low-cost treatments that can be applied at horizontal curves to address identified or potential safety problems. The publication concisely describes the treatment; shows examples; suggests when the treatment might be applicable; provides design features; and where available, provides information on the potential safety effectiveness and costs. The treatments include:<ul><li>Basic traffic signs and markings found in the MUTCD</li><li>Enhanced traffic control devices</li><li>Additional traffic control devices not found in the MUTCD</li><li>Rumble strips</li><li>Minor roadway improvements</li><li>Innovative and experimental treatments</li></ul>The publication concludes with a description of maintenance activities that should be conducted to keep the treatments effective.</td></tr>
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## SI* (MODERN METRIC) CONVERSION FACTORS

### APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

### APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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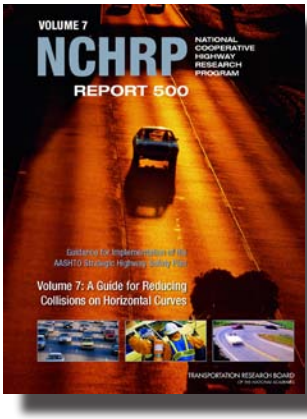
# CHAPTER 1. INTRODUCTION

## SAFETY PROBLEMS AT HORIZONTAL CURVES

In 1998, the American Association of State Highway and Transportation Officials (AASHTO) approved its *Strategic Highway Safety Plan*[1], which sets a goal of reducing annual highway fatalities by 5,000 to 7,000. To help implement the plan, the National Cooperative Highway Research Program (NCHRP) developed a series of guides State and local agencies can use to identify ways to reduce injuries and fatalities in targeted areas. One target or emphasis area is the problem of crashes at horizontal curves.

*A Guide for Reducing Collisions on Horizontal Curves*, which is referred to throughout this publication as the *Guide*, illustrates the problem. The *Guide* reports that nearly 25 percent of people who die each year on the Nation's roadways are killed in vehicle crashes at curves. About 75 percent of all fatal crashes occur in rural areas, and more than 70 percent are on two-lane secondary highways, many of which are local roads. Furthermore, the average crash rate for horizontal curves is about three times that of other highway segments. And, 76 percent of the curve-related fatal crashes involve single vehicles leaving the roadway and striking trees, utility poles, rocks, or other fixed objects or overturning. Another 11 percent are head-on crashes, the result of one vehicle drifting into the opposing lane when a driver tries to cut the curve or redirect the vehicle after having run onto the shoulder.




***One of several guides that provide strategies to address safety problems.***

It is because of these dramatic statistics that the Federal Highway Administration (FHWA) has identified Roadway Departure as one of its three program emphasis areas—the other two are Intersection Safety and Pedestrian Safety. One aspect of the Roadway Departure initiative is to develop a series of practical information publications designed for local road agencies. This publication is a result of, and supports Roadway Departure program goals.

## PUBLICATION PURPOSE AND SCOPE

The *Guide* identified 20 strategies as alternative countermeasures—or treatments—to address the specific safety problem at horizontal curves. These strategies share one of two objectives:

1. Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve.

1 Key references are italicized and listed at the end of the publication; an internet link to the reference is provided if known.

2. Minimize the damaging consequences of a vehicle leaving the roadway at a horizontal curve.

Although the *Guide* provides information about each strategy, transportation professionals felt that a document providing practical information on where, when, or how to apply a safety treatment or design feature—a resource that includes cost and examples—would be useful to local road agencies. This publication was prepared for this purpose.

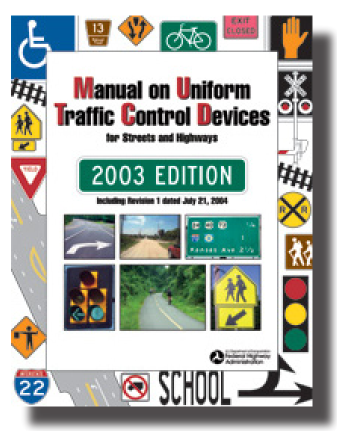
There are numerous strategies or treatments agencies can apply to a single horizontal curve or a winding road section to address a safety problem. This publication includes only those engineering treatments that are relatively low cost, as compared to reconstructing the curve or road section to improve the geometric design features, such as degree and length of curve, superelevation, cross section, and shoulders.

The information presented here is concise. To fully cover all the aspects of an individual treatment would require a much larger document that would likely be used less. Rather, this publication provides information specifically relating to local roads and the agencies that manage them. It will help transportation agencies and their crews understand the alternative treatments and how to select and apply them. Where appropriate, and when information was available, this publication provides the following for each treatment:

- Description—what it is.
- Application Guideline—when to install.
- Design—what design elements or materials to use.
- Effectiveness—how a treatment can improve safety.
- Cost—what it will cost.
- Additional sources and contacts.

## ABOUT THE MUTCD

Throughout this publication, you will see references to the *MUTCD*. Shorthand for the *Manual on Uniform Traffic Control Devices*, the *MUTCD* defines the standards for all traffic control devices (signs, signals, and pavement markings) road managers install and maintain to help regulate, warn, and guide drivers safely on the Nation’s roadways and streets. The *MUTCD* is published by the FHWA. All States are required to adopt either the Federal *MUTCD* or a State *MUTCD* that is in substantial conformance to the Federal *MUTCD*. Some States adopt the Federal *MUTCD* with a State Supplement. State laws regarding traffic control devices should be consulted.




***MUTCD* provides standards and guidance for application of traffic control devices.**

The *MUTCD* also defines conditions about what, where, and how a device is to be placed or installed. In different chapters of this publication you may see a treatment and the designation that the *MUTCD* states it *shall* be used. *Shall* means something is a standard—a practice or device that is specifically required or mandated—or explicitly prohibited. The *MUTCD* may designate other treatments as *guidance*, which tells the road manager that a practice or device is recommended and should be used in typical situations, with modifications allowed for a specific location if an engineering study or engineering judgment indicates the deviation to be appropriate. Finally, the *MUTCD* provides for options, which are presented as *may* statements.

To learn more about the *MUTCD*, visit http://mutcd.fhwa.dot.gov. The site is very easy to use and the Frequently Asked Questions (FAQ) section is very helpful.

## INFORMATION IN THIS PUBLICATION

First, a few comments about the publication's contents:

- The treatments discussed are intended to improve the safety of a single curve or a winding section. It is assumed that the agency has identified the location as an existing or potential safety problem. All transportation agencies should have a program for identifying such locations. If it does not, the *Guide* can help agencies develop such a program.
- Some traffic control devices or applications described in this publication do not comply with the *MUTCD* and are considered "experimental." Any road agency wanting to use a noncompliant device on a public road must request and receive FHWA approval for testing. The *MUTCD* refers to this as *experimentation*. *MUTCD* Section 1A.10 outlines the procedure for experimentation.
- Where evaluation information is available, the publication includes estimates of the effectiveness of the treatment in reducing crashes. However, agencies should not expect to obtain these crash reduction values at a specific location, as the actual observed effectiveness of a treatment will vary from site to site.
- Several treatments discussed in this publication are signs or other devices placed on supports or posts, which makes them a hazard. The *MUTCD* states that roadside sign supports in the clear zone shall be breakaway, yielding, or shielded with a longitudinal barrier or crash cushion. For information on breakaway sign supports and the definition of clear zone at http://safety.fhwa.dot.gov/roadway_dept/road_hardware/signsupports.htm.

## PUBLICATION ORGANIZATION

The balance of this publication organizes and presents information in the following chapters:

Chapter 2 - **Basic Treatments**—Devices found in the MUTCD.

Chapter 3 - **Enhanced Basic Treatments**—Devices considered enhancements to the basic treatments.

Chapter 4 - **Other Traffic Control Device Treatments**—Treatments not specifically mentioned in the MUTCD, but which are currently used by State and local agencies.

Chapter 5 - **Rumble Strips**—Overview of rumble strip applications with centerlines, edge lines, shoulders and transversely across the lane.

Chapter 6 - **Minor Roadway Improvements**—Relatively low-cost treatments that require minor improvements to the roadway or shoulder.

Chapter 7 - **Innovative and Experimental Devices**—New and innovative devices and other treatments that have not been applied extensively.

Chapter 8 - **Maintenance**—Simple, effective maintenance practices.

The FHWA encourages readers to use the information presented in this publication to evaluate problems and identify appropriate treatments for problem curve sections. Applying these treatments should help agencies reduce roadway departure crashes and resulting injuries and fatalities. The FHWA also welcomes feedback on experiences with these or other treatments agencies use to solve a safety problem at a horizontal curve. Send us comments and treatment results through the Office of Safety website at http://safety.fhwa.dot.gov.

# CHAPTER 2. BASIC TREATMENTS FOR HORIZONTAL CURVES

There are several traffic control devices road agencies can and, in many situations, should consider installing at a horizontal curve, especially curves that data or experience identify as a safety problem location. These devices are considered "basic" treatments that are found in the *MUTCD*. They include:

1. Centerline
2. Edge line
3. Horizontal Alignment signs: Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), Hairpin Curve (W1-11), or Loop (W1-15) as an advance warning sign depending on the geometry of the curve(s)
4. Advisory Speed Plaque (W13-1) (with any of the Horizontal Alignment signs)
5. One-Direction Large Arrow (W1-6) sign
6. Combination Horizontal Alignment/Advisory Speed (W1-1a or W1-2a) sign
7. Curve Speed (W13-5) sign
8. Chevron Alignment (W1-8) sign
9. Delineators

Agencies should base selection of one or more of the devices on an engineering study or engineering judgment. Factors to consider include:

- The difference in the posted speed limit and the 85th percentile speed (or a 16-degree ball-bank reading[2]).
- Geometric features of the curve to include its length, radius, shoulders and roadside features.
- Sight distance to and around the curve.
- Unexpected geometric features within the curve, such as an intersection or change in curve radius.
- Traffic volume.

Many curves require nothing more than the standard centerline and edge line (if paved) or one of the basic horizontal alignment warning signs. The decision to add one or more of the other devices listed will be influenced by the factors noted above. Additional consideration is necessary when the curve has been identified as a safety concern or recognized safety problem. The *Guide* mentioned in the previous chapter presents additional guidance on identifying safety problems.

The following discussion provides guidelines for using each device. All example signs and markings are from the *MUTCD*.

2 See *Traffic Control Devices Handbook* for use of a ball bank indicator.

## CENTERLINE

The centerline pavement marking is the minimal treatment to apply to a curve section, assuming the road is paved and has sufficient width and volume, as noted in the table below. A marked centerline helps drivers keep their vehicles on the correct side of the road and further delineates the roadway alignment. For any section of two-way, two-lane roadway, where passing is allowed in both directions, the basic centerline marking is a broken (dashed) yellow line. On some curves, the horizontal curvature, vertical curvature, or other conditions reduce the passing sight distance for one or both directions of travel below the minimum values given in Part 3 of the *MUTCD*. Use a solid yellow line to advise motorists of the no-passing regulation where the restriction exists for each direction of travel. For segments where passing is prohibited in both directions, use a solid yellow line for both directions, which provides a double yellow centerline. The *MUTCD* permits use of a centerline to specific locations, such as around a curve, so it need not be for the entire roadway section, unless a centerline is required for the entire roadway.

***Centerline for No Passing on horizontal curve.***

### Application Guideline

The table below summarizes *MUTCD* requirements for centerline marking of two-way roads.

**MUTCD Requirements for Centerline Markings on Paved Two-Way Streets.**

| | Area type | Road Class | | Lanes | ADT | Travel Width (ft) |
|---|---|---|---|---|---|---|
| REQUIRED | Urban | Collectors | Arterials | 2 | 6000 + | 20+ |
| | All | All | | 3+ | | |
| RECOMMENDED | Urban | Collectors | Arterials | 2 | 4000+ | 20+ |
| | Rural | Collectors | Arterials | 2 | 3000+ | 18+ |
| MAY CONSIDER | Any | Any | | 2 | Any | 16+ |

The *MUTCD* also states that “Engineering judgment should be used in determining whether to place centerline markings on travel ways less than 16 ft wide because of the potential for traffic encroaching on the pavement edges, traffic being affected by parked vehicles, and traffic encroaching into the opposing lane.” Therefore, when an agency identifies a curved section as a potential safety problem, and the road segment does not have a centerline, this should be the first, minimal treatment applied. When the curve carries a low traffic volume (fewer than 200 vehicles per day) and/or the pavement is less than 16 ft wide, consider using post delineators, chevrons, or curve warning signs, even though the centerline is not deemed appropriate.

### Centerline Materials

Road agencies commonly use a variety of paint-based materials and thermoplastic for the centerline markings. The specific material to be used depends on what an agency normally uses for its pavement marking applications. In general, thermoplastic markings are more cost-effective as they last much longer than paint materials. However, their higher initial costs may rule out their use on low-volume rural roads.

Other materials agencies can use for centerlines include a variety of raised pavement markers and "profile" thermoplastics. Chapter 3 discusses these supplemental devices. Also, chapter 5 discusses the use of rumble strips as a supplement to centerline pavement markings.

### Centerline Width

The standard width for each stripe of a centerline stripe is 4 in to 6 in, with the 4-in line more common. A wide line is simply twice the width of a standard line. There is no known safety benefit to having a wider centerline other than it provides a larger visual marking for motorists. When a double line is called for, such as when passing is not allowed, the normal practice in most jurisdictions is to separate the two lines by a measure approximately equal to the width of a single line—4 in to 6 in.

### Effectiveness

A 1996 Kentucky study estimated that including centerline markings reduced crashes by 35 percent. However, this study considered entire roadway sections, not individual curves. Other studies report much smaller benefits. These varying results suggest that agencies can expect safety benefits from installing centerline markings but that the magnitude of the benefits will vary based upon roadway and traffic characteristics.

### Cost

The cost to apply pavement markings varies, depending on several factors. For example, the material used—paint or thermoplastic; does the agency's own crew or an outside contractor perform the work; and is a single curve or several locations to be treated? Individual agencies are aware of their costs for applying pavement markings.

## EDGE LINE

Edge line pavement markings define or delineate the edge of a roadway. It provides a visual reference to guide motorists and helps prevent them from drifting onto the shoulder and roadside area. For horizontal curves, regardless of the road type, edge line markings are a solid white line at the right edge of the travel lane (i.e., not including any shoulder). With the centerline, or adjacent lane line for a multilane road, it defines the travel lane for the road user. As with the centerline, edge lines can be applied just prior to and within the curved section, although it typically is applied to an entire section of roadway when used.

***Centerline and edge line for two-lane road.***

### Application Guidelines

The *MUTCD requires* (STANDARD) edge lines only for "... rural arterials with a traveled way of 20 ft or more in width and an average daily traffic (ADT) of 6,000 vehicles per day or greater." They are *recommended* (GUIDANCE) for "... rural arterials and collectors with a traveled way of 20 ft or more in width and an ADT of 3,000 vehicles per day" or any other paved road where an engineering study identifies a need for edge line markings.

It is not necessary to have a centerline on the road to add an edge line, but be cautious. On a narrow two-way road, white lines applied on both edges, without a yellow centerline marking, may signal to the motorist that the road is one-way.

### Edge Line Materials

The same materials discussed for the centerlines apply to edge lines. The exception is raised pavement markers (RPMs), which the *MUTCD* prohibits either as a substitute or supplement to the edge line. The rationale is that under wet night conditions when only the RPMs are visible, edge line RPMs can confuse drivers who could misinterpret them as marking the lane line. Also, RPMs on an edge line can cause bicyclists using the shoulder to lose control. Some States have used the profile marking design, which is discussed in the next chapter.

### Edge Line Width

As with other longitudinal pavement markings, the standard edge line width is 4 in to 6 in, with the 4-in line used most. Six-inch edge lines are common on freeways and can be found on some lower class roads as well. Using a "wide" edge line (8 in to 12 in) on just the curved section, while not common, has been used to "emphasize" the curve section and provide a visually stronger guide for the motorist. However, do not use a wide edge line on roadways with a pavement width less than 20 ft, as it could cause motorists to move too far left into the opposing lane.

***Roadway with 4-in edge line***

***Roadway with 8-in edge line***

***A wide (8-in) edge line provides a stronger visual guide.***

**Effectiveness**

A New York study found that standard edge lines on curvy two-lane roads reduced total crashes by 5 percent and fixed object crashes by 17 percent. Also, the *Low Cost Local Road Safety Solutions* report documents the safety benefit of adding an edge line and provides additional information on low-cost strategies for curves and other roadway locations. While these evaluations were conducted on sections of roads, agencies should assume that a safety benefit would be realized for individual curves. As for wider edge lines, the same report cites several studies citing a safety benefit from wider edge lines. The report also cites motorists' preference, especially elderly drivers.

**Cost**

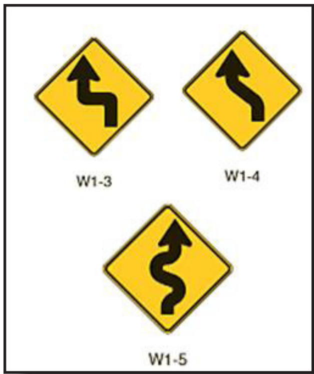
Comments regarding the cost of centerlines apply equally to edge line treatment.

## HORIZONTAL ALIGNMENT SIGNS

The *MUTCD* prescribes several Horizontal Alignment signs to give drivers advance warning of a horizontal curve. For a single curve section, there are four signs:

- Turn (W1-1)
- Curve (W1-2)
- Hairpin Curve (W1-11)
- 270-degree Loop (W1-15)


***The MUTCD prescribes Horizontal Alignment Signs for advanced warning of a single curve section.***




*Advance warning signs for sections with more than one curve in close proximity.*

For sections with a more than one curve in close proximity, there are three advance warning signs:

- Reverse Turn (W1-3)
- Reverse Curve (W1-4)
- Winding Road (W1-5)

**Application Guidelines**

Not all horizontal curves require a Horizontal Alignment sign. Curves that have: (1) gentle to moderate curvature for which a speed advisory is not necessary, (2) adequate sight distance through the curve, and (3) adequate pavement markings and/or raised pavement markings and delineators, likely do not require even the Curve (W1-2) sign. As the *MUTCD* states, use the Curve sign where there is an advisory speed of greater than 30 mi/h and the Turn sign when the advisory speed is 30 mi/h or less. However, this is subject to engineering judgment that considers the traffic volume, type of road, and other factors. Use the Hairpin Curve sign when the curve is 135 degrees or more. The Loop sign is usually limited to 270-degree loops found on cloverleaf interchange ramps; it is not addressed in this publication.


*Two options for two sequential curves.*

The two sequential curves signs (left turning followed by right turning or vice versa) are:

- Reverse Turn (W1-3)
- Reverse Curve (W1-4)


*Winding Road sign for three or more alignment changes in close proximity.*

The guidance is the same for selecting a Turn or Curve sign and agencies should base their decision on the advisory speed, as with the single Turn and Curve signs.

For road segments with three or more alignment changes in opposite directions in relatively close proximity, the Winding Road (W1-5) sign is appropriate.

**Design**

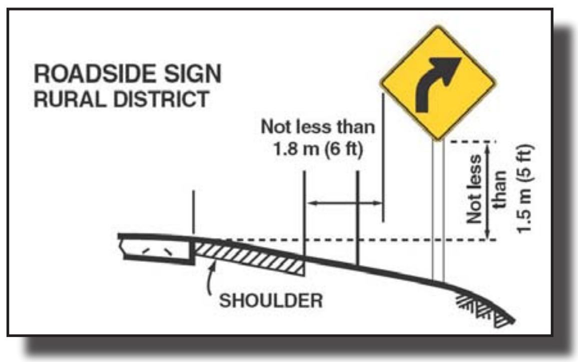
Depending on the geometry of the curve or sets of curves, place the appropriate sign the distance in advance of the point of curvature, as shown in the table that follows. This table is based on Table 2C-4 of the *MUTCD*. For example, if the posted speed of the road is 50 mi/h and the curve has a posted advisory speed of 30 mi/h, then agencies would place the sign 100 ft before the point of curvature.

**Guidelines for Advance Placement of Curve Warning Signs.**

| Posted or 85th-Percentile Speed (mi/h) | Advance Placement Distance (Feet) for Advisory speed of the curve (mi/h) of | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| 20 | n/a[1] | -- | -- | -- | -- | -- | -- |
| 25 | n/a[1] | n/a[1] | -- | -- | -- | -- | -- |
| 30 | n/a[1] | n/a[1] | -- | -- | -- | -- | -- |
| 35 | n/a[1] | n/a[1] | n/a[1] | -- | -- | -- | -- |
| 40 | n/a[1] | n/a[1] | n/a[1] | -- | -- | -- | -- |
| 45 | 125 | n/a[1] | n/a[1] | n/a[1] | -- | -- | -- |
| 50 | 200 | 150 | 100 | n/a[1] | -- | -- | -- |
| 55 | 275 | 225 | 175 | 100 | n/a[1] | -- | -- |
| 60 | 350 | 300 | 250 | 175 | n/a[1] | -- | -- |
| 65 | 425 | 400 | 350 | 275 | 175 | n/a[1] | -- |
| 70 | 525 | 500 | 425 | 350 | 250 | 150 | -- |
| 75 | 625 | 600 | 525 | 450 | 350 | 250 | 100 |

[1] No suggested distances are provided for these speeds, as the placement location depends on site conditions and other signing to provide an adequate advance warning for the driver.

This sign, and others discussed in this publication, should be placed in rural areas as illustrated at right.




*Offset and height placement for signs on rural roads.*

## Materials

Traffic signs of all types use retroreflective sheeting to ensure they are visible to drivers at night or in periods of low light. Over the last several years, agencies have transitioned from using engineering grade (Type I), to high-intensity grade (Type III), and even microprismatic sheeting (Type V). Each higher grade provides a brighter and longer lasting sign—but with increasing unit costs for each.

## Effectiveness

A 1968 evaluation of curve warning signs reported that installing warning signs can reduce crashes by 18 percent. No recent research identifies or evaluates this device, but a beneficial safety effect seems likely with their proper use.

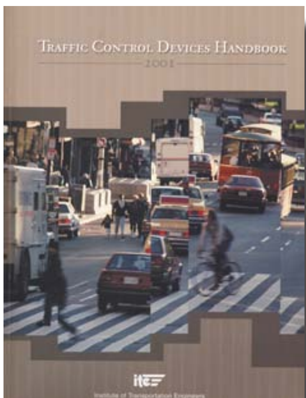

***MUTCD* Advisory Speed Plaque.**

## ADVISORY SPEED PLAQUE

An Advisory Speed plaque (W13-1) is simply a sign placed below a Horizontal Alignment sign (discussed above) to advise motorists of the safe speed through the curve(s). It is not the legal speed limit.

### Application Guideline

The *MUTCD* requires an engineering study to determine if an advisory speed is necessary for the condition. The *MUTCD* further states that ". . . the advisory speed may be the 85th-percentile speed of free-flowing traffic, the speed corresponding to a 16-degree ball bank indicator reading, or the speed otherwise determined by an engineering study because of unusual circumstances." The *Traffic Control Devices Handbook* provides further guidance on when to use an Advisory Speed Plaque. It also is suggests using the plaque whenever the difference between the advisory speed and the posted speed is 6 mi/h or greater.



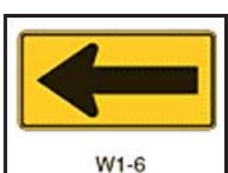

***The Traffic Control Devices Handbook* provides additional guidance on devices found in the *MUTCD.***

Photo source: Missouri DOT

***Curve Horizontal Alignment sign with an Advisory Speed Plaque warns the driver of an approaching curve over the crest of a hill.***

## ONE-DIRECTION LARGE ARROW SIGN

The One-Direction Large Arrow sign (W1-6) is used to define a change in horizontal alignment. Usually only one of these signs is used for a horizontal curve. It is typically placed on the outside of the curve directly in line with the approaching tangent section. Nothing in the *MUTCD* limits using multiple signs along the curve, but in this case, it would be more reasonable to use a series of Chevron (W1-8) signs. Install this Large Arrow sign only on the outside of a turn or curve in line with, and at approximately a right angle to approaching traffic.




***One-Direction Large Arrow Sign.***

**Application Guideline**

MUTCD guidance regarding the application of this sign is to install either the One-Direction Large Arrow sign or the Chevron Alignment sign when the Hairpin Curve sign or the Loop sign is installed. Based on standard practice, this sign is limited to sharper curves (turns). It should not be used when there is no advisory speed plaque.

***One direction Large Arrow Sign placed within curve.***

## COMBINATION HORIZONTAL ALIGNMENT / ADVISORY SPEED SIGN

Agencies can combine the Turn (W1-1) sign or the Curve (W1-2) sign with the Advisory Speed (W13-1) plaque to form a combination Turn/Advisory Speed (W1-1a) sign or a combination Curve/Advisory Speed (W1-2a) sign. Use it as a supplement to (not a replacement for) the advance Horizontal Alignment sign and Advisory Speed plaque, and place it at the beginning of the turn or curve. The sign is intended to remind motorists of the need to slow down as they begin to negotiate the alignment change.


***Combination Horizontal Alignment / Advisory Speed Signs.***

**Application Guideline**

The *MUTCD* contains no guidance as to when to use these signs, so it is up to an agency's "engineering judgment." It is probably best not use it when the distance from the advance horizontal alignment sign and the point of curvature is 200 ft or less because the two signs would be too close together. Where this situation occurs, use the Curve Speed sign, which is discussed next.

## CURVE SPEED SIGN

The Curve Speed (W13-5) sign, serves a similar function as the Combination Horizontal Alignment/Advisory Speed sign. It is used to remind motorists of the advisory speed and, if appropriate, where the recommended (advisory) speed changes with the road curvature, such as for a compound or spiral curve design. Place the sign within the curve either on the inside or outside of the curve to increase its visibility. Although a special situation may call for both the Curve Speed sign and the Combination Horizontal Alignment/Advisory Speed sign, use one or the other, not both.


***Curve Speed Sign.***

## CHEVRON ALIGNMENT SIGN

While designated as a warning sign in the *MUTCD*, the Chevron Alignment (W1-8) sign is intended to emphasize and guide drivers through a change in horizontal alignment. Because of their pattern and size and that several of the signs are in view of the motorist, they define the direction and sharpness of the curve the best of all the traffic control devices. When the chevron sign is used, agencies will also need one of the advance curve warning signs previously discussed.


***Chevron Alignment Sign***

***Before installation of Chevrons.***

***After installation of Chevrons.***

***The installation of Chevrons provides guidance for the approaching curve.***

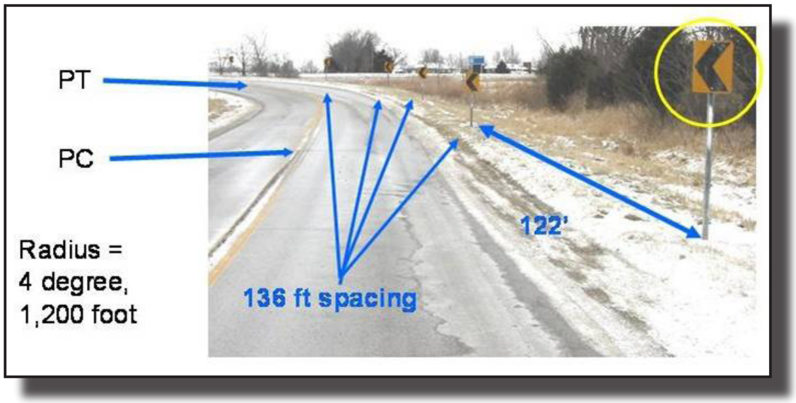
### Application Guidelines

Other than to state that the Chevron Alignment sign may be used as an alternative to supplement to standard delineators or to the One-Direction Large Arrow (W1-6) sign, the *MUTCD* provides no specific guidance as to when agencies should use the Chevron Alignment sign. The *Traffic Control Devices Handbook* suggests installing Chevrons when the difference between the advisory speed and posted speed is 25 mi/h or greater.

### Design

Install a series of these signs on the outside of turn or curve, positioned in line with approaching traffic at approximately a right angle to a driver's line of sight. On two-lane, two-way roads, use two-sided Chevron signs properly aimed to guide traffic traveling both directions.

The *MUTCD* does not specify spacing of the signs; however, it does recommend that spacing allow the motorist to view at least two signs until the change in alignment eliminates the need for the signs. The following figure illustrates a layout of these devices on a curve. Position Chevron signs 5 ft above the surface in rural areas, and 7 ft in urban areas. Additionally, the following pages provide examples of spacing charts developed by two State DOTs.




*Layout of Chevrons.*

**State recommended spacing charts for Chevrons**

| Advisory Speed Limit (mi/h) | Chevron Spacing (ft) |
|---|---|
| 15 | 40 |
| 20 | 80 |
| 25 | 80 |
| 30 | 80 |
| 35 | 120 |
| 40 | 120 |
| 45 | 160 |
| 50 | 160 |
| 55 | 160 |
| 60 | 200 |
| 65 | 200 |
| *NOTE:* The above spacing distances apply to points within the curve. Approach and departure spacing distances are twice those shown above. | |

| Recommended Chevron Spacing | | | | |
|---|---|---|---|---|
| Degree of Curve | Radius (ft) | Spacing (ft) | | |
| | | Curve | Turn | Tangent |
| | 10000 | 400 | 200 | 200 |
| 1 | | 304 | 152 | 200 |
| | 5000 | 282 | 141 | 200 |
| | 3000 | 218 | 109 | 196 |
| 2 | | 212 | 106 | 191 |
| | 2500 | 198 | 99 | 178 |
| | 2000 | 176 | 88 | 158 |
| 3 | | 172 | 86 | 155 |
| | 1800 | 168 | 84 | 151 |
| | 1600 | 156 | 78 | 140 |
| 4 | | 148 | 74 | 133 |
| | 1400 | 148 | 74 | 133 |
| | 1200 | 136 | 68 | 122 |
| 5 | | 132 | 66 | 119 |
| | 1000 | 124 | 62 | 112 |
| | 900 | 116 | 58 | 104 |
| 7 | | 110 | 55 | 99 |
| | 800 | 110 | 55 | 99 |
| | 700 | 102 | 51 | 92 |
| 9 | | 96 | 48 | 86 |
| | 600 | 94 | 47 | 85 |
| | 500 | 84 | 42 | 76 |
| 12 | | 82 | 41 | 74 |
| | 400 | 74 | 37 | 67 |
| 15 | | 72 | 36 | 65 |
| | 350 | 70 | 35 | 63 |
| 18 | | 66 | 33 | 59 |
| | 300 | 64 | 32 | 58 |
| 21 | | 60 | 30 | 54 |
| | 250 | 56 | 28 | 50 |
| 25 | | 56 | 28 | 50 |
| | 200 | 48 | 24 | 43 |
| 30 | | 48 | 24 | 43 |
| | 150 | 40 | 20 | 36 |
| 40 | | 38 | 19 | 34 |
| | 100 | 28 | 14 | 25 |

**Effectiveness**

Although the effectiveness of Chevron signs in reducing crashes has not been established, the signs have been shown to reduce vehicle encroachments onto the centerline in curves where the degree of curvature is more than 7 degrees.

**Cost**

The cost to apply Chevrons around a curve will vary with the number of signs installed. A typical installation of about 10 signs would cost approximately $500.

## DELINEATORS

A commonly used device for showing the curve alignment to the motorist is the delineator—a retroreflective device mounted above the roadway surface and along the side of the roadway in a series to show roadway alignment. A delineator is considered a guidance device rather than a warning device and is most effective at night and during adverse weather when pavement markings are not visible.

The delineator device is typically either circular or rectangular with a 3-in minimum dimension. They are usually mounted on posts (which can have retroreflective material as well) 4 ft above the pavement. They can be placed on barriers if they are present—if there are none, then delineators are placed on lightweight breakaway posts. As shown in the photo, the delineators are rectangular reflectors placed on a flexible post. The application shown is on a ramp, but they are also used for curved sections of roadways.

***Post delineators installed on a ramp.***

The *MUTCD* requires the color of the delineators to match the color of the adjacent edge line. For example on a curve on a two-way road, the edge lines on both sides of the road are white, so if delineators are used on the left side of the road they must be white. Delineators on the right side are also white.

### Application Guideline

The *MUTCD* does not provide any guidance as to when to install this device. However, given their relatively low cost, they should be considered for curves where any of the advance curve warning signs are used. For curves greater than 7-degree, the Chevron sign, discussed next, might be more cost-effective.

**Approximate Spacing for Delineators on Horizontal Curves.**

| Radius Of Curve (ft) | Approximate Spacing On Curve (ft) |
|---|---|
| 50 | 20 |
| 115 | 25 |
| 180 | 35 |
| 250 | 40 |
| 300 | 50 |
| 400 | 55 |
| 500 | 65 |
| 600 | 70 |
| 700 | 75 |
| 800 | 80 |
| 900 | 85 |
| 1000 | 90 |

### Design

Delineators are placed on the right shoulder and, therefore, the reflectors are white (clear) to match the white edge line. Adjust spacing of delineators on approaches to and throughout the horizontal curves so that several delineators are always visible to the motorist. Follow the approximate spacing shown in the table on the next page.

### Effectiveness

The *Low Cost Local Road Safety Solutions* publication cites a 1966 Ohio Department of Transportation Study which found that post-mounted delineators on rural two-lane curves reduced run-off-road crashes by 15 percent.

### Cost

The cost of post delineators applied to a single curve will vary depending upon the number used and the material for the post and retroreflector.

### Further Information

For further information on post delineators, see *Roadway Delineation Practices Handbook* (http://www.fhwa.dot.gov/tfhrc/safety/pubs/93001/intro.htm).

# CHAPTER 3. ENHANCED BASIC TREATMENTS

Most basic devices described in chapter 2 can be improved in different ways so that they can be seen farther away. The sooner a motorist is able to see a device and recognize its meaning, the more time there is to respond. This chapter discusses the following seven treatments have proved effective in getting motorists' attention:

- Larger devices
- Doubling up of devices
- High retroreflective intensity and fluorescent yellow sheeting
- Flashing beacons
- Profile Thermoplastic Markings
- Raised Pavement Markers

## LARGER DEVICES

The table below shows the sizes of the signs described in the previous chapter for conventional roads. The MUTCD prescribes the use of the "conventional road" sizes for typical situations. The minimum size is not recommended. However, the MUTCD allows their use on low-speed roadways where the reduced letter size remains adequate for the warning or where physical conditions prevent using a larger size. The MUTCD also states that ". . . oversized and larger signs may be used for those special applications where speed, volume, or other factors result in conditions where increased emphasis, improved recognition, or increased legibility would be desirable." A horizontal curve identified as a safety problem would likely meet this application guideline. Thus, consider larger sizes, typically in 6-in increments for both dimensions.

**Warning Sign Sizes (in).**

<table>
<tr><th colspan="2">Description</th><th rowspan="2">Minimum</th><th rowspan="2">Conventional Road</th><th rowspan="2">Expressway</th><th rowspan="2">Freeway</th></tr>
<tr><th>Shape</th><th>Sign Series</th></tr>
<tr><td>Diamond</td><td>W1-1, W1-2, W1-3, W1-4, W1-5, W1-11, W1-15, W1-1a, W1-2a</td><td>24 x 24</td><td>30 x 30</td><td>36 x 36</td><td>48 x 48</td></tr>
<tr><td rowspan="3">Rectangular</td><td>W1-6</td><td>36 x 18</td><td>48 x 24</td><td>--</td><td>--</td></tr>
<tr><td>W1-8</td><td>12 x 18</td><td>18 x 24</td><td>30 x 36</td><td>36 x 48</td></tr>
<tr><td>W13-5</td><td>24 x 30</td><td>24 x 30</td><td>36 x 48</td><td>48 x 60</td></tr>
</table>

Source: MUTCD, Table 2C-2.

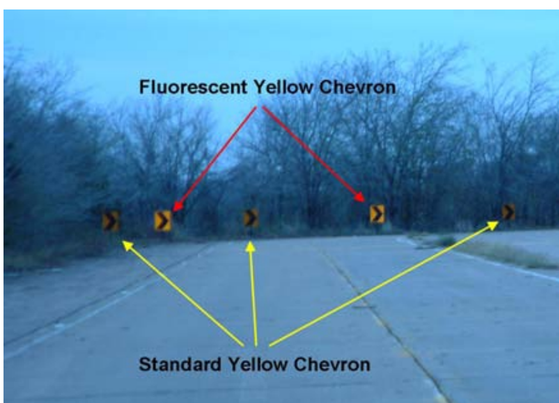
***Doubling-up of the sign proved effective at this site because tree limbs partially blocked the right side sign.***

### DOUBLING-UP OF DEVICES

"Doubling-up" simply refers to situations where agencies install a second, identical sign on the left side of the roadway. Agencies can do this for the basic signs discussed in the previous chapter. Doubling-up increases the opportunity for the motorist to see the sign, and more importantly, respond to the message. Doubling-up is a candidate treatment when visibility of the single right-hand side sign is less than desirable.

### HIGH RETROREFLECTIVE INTENSITY AND FLUORESCENT YELLOW SHEETING

Another way to make signs more visible or more noticeable to motorists is to use high-intensity retroreflective sheeting and fluorescent-yellow sheeting. As noted in chapter 2, the retroreflective sheeting for signs is available in different intensity grades. Signs made with high-intensity sheeting can help motorists see them from a longer distance at nighttime visibility. For more information on types of retroreflective sheeting, visit: http://safety.fhwa.dot.gov/roadway_dept/retro/index.htm




Source: Texas Transportation Institute

***Stimulus photo illustrating enhanced chevron visibility.***

Fluorescent yellow increases visibility of warning signs and certain other signs, such as the Chevron sign. Again, the higher intensity sheeting makes the sign more visible to motorists who can recognize and respond to it earlier. This visual advantage works day and night.

Initial research based on eye-tracking data indicates that upgrading conventional yellow chevrons to fluorescent yellow, while not affecting speed or lane placement, improves driver perception of the signs. This improved driver performance effect suggests a potential safety effect.

The estimated cost of an 18-in by 24-in Chevron sign with Type III sheeting is about \$335. This estimate was based on a unit price of \$1.20/ft$^2$ for sheeting. Applying an estimated cost of \$4.00/ft$^2$ of fluorescent color microprismatic sheeting brings the total sign cost to \$343, a cost increase of only 2.4 percent.

## FLASHING BEACONS

Using flashing beacons with a warning sign is another way to gain motorists' attention. The beacons are typically used with one of the advance Horizontal Alignment signs for a horizontal curve. There are no published guidelines for when they are appropriate, but reasonable guidelines are to limit them to locations where other treatments have not solved a safety problem. One factor limiting their use is the availability of an accessible power source, although agencies can use reliable solar power panel systems as well.


***Typical arrangement of signs and flashing beacons.***

The beacons used for this treatment are the circular yellow sections from a standard traffic signal. Agencies can install this with one or more beacons, but the photo on the right shows a typical arrangement. The beacons can be flashed either alternately or simultaneously. To prevent the flashing light from masking the sign message, locate the beacon signal housing at least 12 in outside of the nearest edge of the sign.

The safety effectiveness of this particular treatment is yet to be established, but a 1970s study evaluated the effects of signing to warn drivers of wet weather skidding hazards at horizontal curves. The study concluded that agencies could significantly reduce vehicle speed by adding flashing beacons on the curve warning sign.

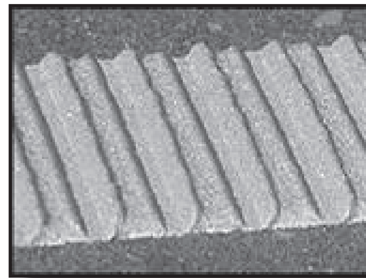
## PROFILE THERMOPLASTIC MARKINGS

Agencies apply thermoplastic markings to create a profile marking, which also produces a rumble effect and enhances visibility of the marking. A few agencies have used this treatment with good results, but there is no firm evaluation. As snow plowing can destroy this marking, its use is sometimes limited to warmer climate locations.

The California Department of Transportation (Caltrans) has used two types—raised and inverted profile patterns, as pictured on the next page and in the accompanying design specification.

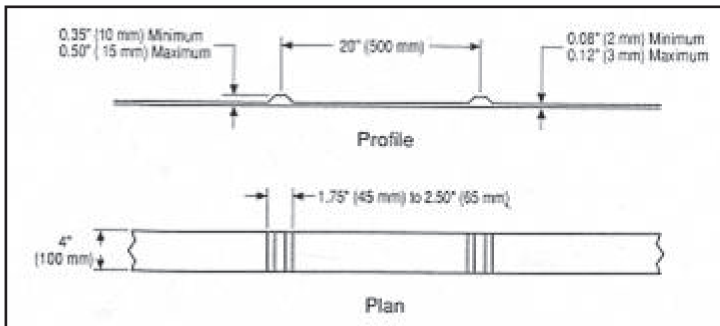
(Source: Caltrans)

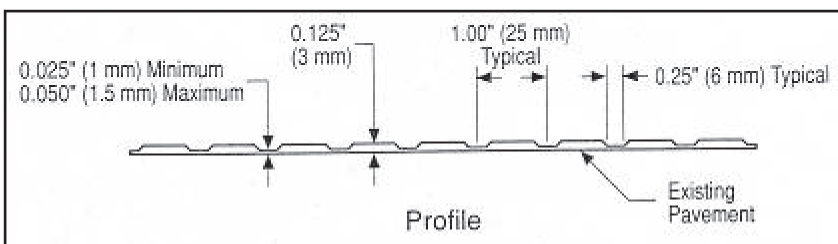
***Raised profile thermoplastic marker.***



(Source: Caltrans)

***Inverted profile thermoplastic marker.***



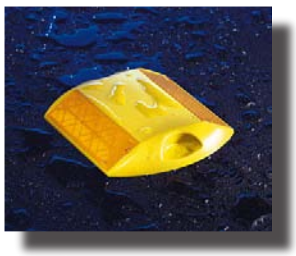

***A raised profile where a thicker layer of thermoplastic is applied on 20-in centers along the stripe.***

***An inverted profile where depressions are made every 1 in along the stripe.***

## RAISED PAVEMENT MARKERS

In many situations, agencies will install raised pavement markers (RPMs) to supplement or substitute for pavement markings. There are a variety of types and they can be reflective or nonreflective. For geographic areas where snow is common, the reflective device is encased in an iron casting or recessed below the pavement surface in a grooved section to prevent damage by snow plows. Agencies typically apply the markers within a long roadway section; the advantage is that they provide a longer visual range of delineation for motorists, especially at night (if reflective) and during wet conditions.  RPMs also work well when applied to a single curve or curvy section of roadway.  The RPMs also provide an auditory warning to the motorist who travels on them.

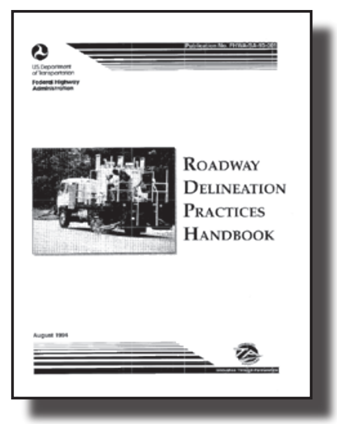
For more information about using raised pavement markers, visit the MUTCD (http://mutcd.fhwa.dot.gov/HTM/2003r1/part3/part3a.htm) and in the *Roadway Delineation Practices Handbook* (http://www.fhwa.dot.gov/tfhrc/safety/pubs/93001/intro.htm).



***Standard Raised Pavement Marker (yellow for centerline).***

***Snowplowable Raised Pavement Marker.***

While studies of the operational effects have shown RPMs can reduce the variation in lane placement and move vehicles away from the centerline, studies of crash changes have produced mixed results. They show a safety benefit on roadways with gentle curvature (less than 3.5 degrees) and relatively high volumes (greater than 5,000 veh/day), and safety disbenefits for roadways with sharper curvature (greater than 3.5 degrees) under all volume conditions.  It has been hypothesized that the disbenefit results from the higher speeds because motorists feel safer with the RPMs providing alignment information even under wet nighttime conditions.



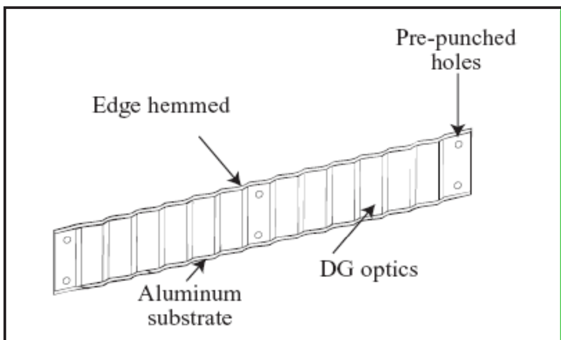

***A comprehensive guide on all types of delineation devices.***

# CHAPTER 4. OTHER TRAFFIC CONTROL DEVICE TREATMENTS

## REFLECTIVE BARRIER DELINEATION

### Description

Retroreflective material, such as reflectors or panels of retroreflective sheeting, can be a highly effective treatment for delineating curves, especially at nighttime. Strips of reflective sheeting shaped to provide linear reflectorization are applied to either concrete barriers or metal guardrail to alert drivers of approaching curves. The example shown below consists of 34-in-long, 4-in-wide to 6-in-wide panels. The color of the delineation should be the same as traditional delineation—the same color as the adjacent edge lines. On a two-lane, two-way road, this means that the delineation would be white on both sides of the road.




***Reflective sheeting shaped to provide linear reflectorization.***

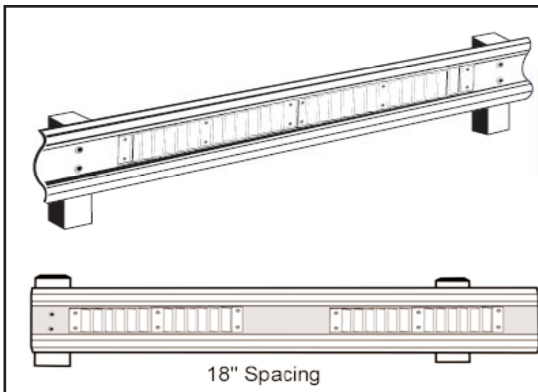
The photographs below show the resulting linear reflectorization effect on construction zone barriers. Agencies can achieve similar effective delineation on rural curves by applying the reflective panels to existing metal guardrails.

**Application Guideline**

There are no published guidelines for when this or similar treatments are appropriate. Obviously, an existing guardrail or concrete barrier must be in place before any material is applied. When the existing barrier is frequently hit consider adding new or supplemental reflectorization.

**Design**

Space reflective sheeting panels 18 to 36 in apart, running parallel to traffic. Attach the panels to concrete barriers by anchoring them into drilled holes supplemented with a caulking compound. To apply on metal guardrail, adhesive is used to attach the sheeting panels, housed in brackets, to the guardrail.




***Continuous and intermittent application of retroreflective sheeting on metal guardrail.***

The photos below illustrate reflector application on metal guardrail. Individual reflectors can be spaced according to the criteria noted for post delineators, discussed earlier. For curved sections of guardrail, it is important to adjust angles of individual reflectors (i.e., bend mounting brackets) to ensure their alignment is perpendicular to the angle of oncoming headlights.

***Installation of reflectors on W-beam guardrail.***

**Effectiveness**

Oregon DOT (ODOT) conducted an example application of reflective barrier treatments (shown above) known as the 3M Linear Delineation System. Results reveal that the retroreflective panels provide a good alternative to traditional concrete barrier delineation methods (such as reflective barrier markers). ODOT realized at the end of construction that the panels could be removed from the barrier for reuse on future projects. The success of the panels has led ODOT to consider future implementation when crash histories show the need for additional safety measures. However, installing the panels proved to be more challenging then envisioned, primarily because it is a time-intensive process. The evaluation also cited maintenance concerns about keeping the panels clean from dirt and road grime to maintain an optimal retroreflectivity level.

### Cost

Individual reflectors for guardrail application cost approximately $3.00 each. Strips of reflective sheeting, known as the guardrail Linear Delineation System, are available at approximately $2.33/lineal ft of 4-in-wide white material.

## ROADSIDE OBJECT DELINEATION

### Description

Trees, utility poles, and other obstructions located in the roadside area close to the nearest travel lane (such as within the designated clear zone) can be run-off-road road crash hazards. Installing an object marker, reflectorized tape, or other simple delineation device is a low-cost procedure to reduce the associated crash potential.

***Simply adding a reflective tape to a pole or tree that cannot be removed may prevent a crash.***

### Application Guideline

Depending on the roadside obstruction location and the severity of the hazard, agencies should first consider removing objects that have a history of being struck. Agencies will also discover the more difficult challenge of overcoming public resistance to removing trees. Other options to consider, such as modifying the roadside to shield the object from being struck, are flattening or grading sideslopes, regrading ditch sections, or improving shoulders. When cost rules out these alternatives, delineation is the preferred option. Regardless of the option selected, agencies must first install acceptable delineation on the curve, as previously discussed.

### Design

Once the decision is made to delineate a tree or other object, install a Type 2 or Type 3 object marker (see *MUTCD* Sections 3C.01 and 3C.04) according to the following principles:

- When marking objects 8 ft or less from the shoulder or curb, mount the object marker so the bottom of the marker is at least 4 ft above the surface of the nearest traffic lane.
- When marking objects more than 8 ft from the shoulder or curb, mount the reflective marker so that the bottom of the marker is at least 4 ft above the ground.
- Use a band of reflective tape to supplement or substitute for the object marker. The band should be at least 6 in wide.
- There is no required color for the retroreflective tape, but most agencies prefer yellow in most cases. However, in instances when there are few daytime crashes, and , especially in aesthetically sensitive areas, agencies can install brown retroreflective tape.

**Effectiveness**

The Pennsylvania Department of Transportation (PennDOT) has an experimental program targeting delineation to potentially hazardous objects on road segments with high run-off-road utility pole- and tree-related crash frequencies (particularly at night). The program is proving effective when it is not feasible to remove or relocate an object because of budget constraints or the object is on private property. PennDOT marks the tree or utility pole with a round of reflective tape. One round is used on each tree and each utility pole. Two rounds are used for poles at intersections. No evaluation has yet documented the effectiveness of this practice.

**Contact and Further Information**

A.J. Zeigler, *Guide to Management of Roadside Trees*, Report FHWA-IP-86-17, Michigan Department of Transportation, Lansing, MI 48909, December 1986.

Pennsylvania DOT Bureau of Highway Safety, Phone 717-705-1706.

*Highway Safety and Trees: The Delicate Balance* (FHWA-SA-06-13) is available as a DVD; email requests to Report.Center@dot.gov

## DYNAMIC CURVE WARNING SYSTEM

**Description**

Agencies can enhance curve warning systems by using supplemental beacons and/or messages that activate when a motorist approaches the curve at a high speed. A typical dynamic curve warning system combines a speed measuring device (such as loop detectors or radar) with flashing beacon and a variable message sign. The system is designed to slow high-speed vehicles as they approach and enter a horizontal curve. It works by measuring the speeds of approaching vehicles and providing messages to speeding drivers to slow down to an advisory speed. Agencies can develop these systems using off-the-shelf technology. The advantage of this treatment is that the device has a much greater effect on high-speed vehicles than a static curve warning sign. A variety of these systems are deployed in the U.S., as the three examples below demonstrate.


*Speed Actuated Sign – Augusta, ME.*


*Flashing Beacon on Warning Sign.*


(Courtesy of Caltrans)

*Dynamic Warning System on I-80 in California.*

**Application Guideline**

Because even the least expensive system is much more costly than static signs, agencies should limit their application to locations with high crash rates, especially those involving fatalities and injuries, and where other less expensive devices have failed to solve the problem. The only specific guideline found for when to use such a device is from a study of a similar device, which recommended that "... a vehicle-actuated curve speed control may be required if there have been 10 or more reported accidents in a 24-month period, or 7 or more reported accidents in a 12-month period. The accidents should occur along the section of road including the curve and a distance of 1000 ft downstream."

One dynamic system application that does not require major reconstruction involves a radar speed detection device coupled with warning signs and activated flashing beacons. The Texas system, illustrated in the photos below, advises drivers detected driving more than 5 mph over the 25-mph curve advisory speed limit to reduce their speed. A radar detector measures speeds and displays them using a speed display sign stating: "YOUR SPEED IS . . .". A W1-1 warning sign is located 625 ft in advance of the curve, and the overhead sign is located in the point of curvature. The radar is set to start processing the speed data about 300 ft before a vehicle reaches the overhead sign.



*Dynamic curve speed warning system in Camp County, Texas.*

**Cost**

The cost of these systems varies, depending upon the specific design. The cost of the Texas system presented above, which consists of radar speed detection and associated activation of flashing beacon, was approximately $18,000 for equipment and installation. The system deployed on a California interstate was $61,000 (in year 2001; the cost included traffic control).

**Effectiveness**

Dynamic curve warning systems can effectively reduce vehicle speeds in horizontal curves, especially during wet-pavement conditions. The accident effectiveness will likely vary by location. For the system displayed on a California interstate, Caltrans reported a 44 percent reduction in accidents in the first year and a 39 percent in the second year, compared to the year before installation.

### Contacts and Further Information

For the California installation—Robert Peterson, Chief Traffic Safety Branch, District 3, Caltrans, Robert_Peterson@dot.ca.gov

## SPEED LIMIT ADVISORY MARKING IN LANE

### Description

Pavement markings in advance of horizontal curves provide highly conspicuous, supplementary warning information and the potential to increase safety. In particular, advisory speed warnings provide essential information directly related to drivers' safe negotiation of curves. Pavement markings are especially important for reducing speeds at curve locations where signs have proved ineffective.

An example speed-limit advisory pavement marking is illustrated at right. In this example, the markings display is CURVE—55—MPH. PennDOT has also experimented with the use of the pavement arrow (such as *MUTCD* figure 3B-21), as discussed in chapter 7. That arrow is currently reserved for use in the designating lane-use at intersections, so other uses such as for curves requires FHWA experimentation approval.

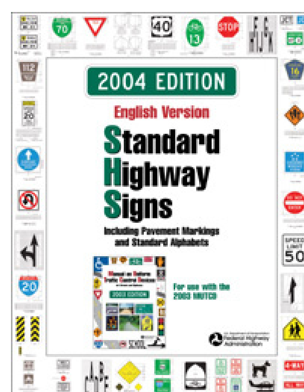

***Speed-limit advisory pavement marking.***

### Application Guideline

There is no established guideline for when to use this treatment. It is probably more appropriate for higher speed roads and those where speed studies indicate excessive speeding.

### Design

The *MUTCD* and the *Standard Highway Signs* (*SHS*) manual present specifications for designing and placing speed limit advisory pavement markings. *MUTCD* section 3B.19 has examples of elongated pavement marking letters and words suitable for reading by approaching motorists. Visit http://mutcd.fhwa.dot.gov/kno-2003r1.htm. The *SHS* includes layouts for applying these markings, including pavement markings. Visit http://mutcd.fhwa.dot.gov/ser-shs_millennium.htm.




***The SHS provides specifications for sign sizes and message layout.***

The advance distance at which such markings are applied depends on both the approach speed and design speed of the curve. Agencies should base advance placement distances on specific approach and curve speeds, which should be the same as advance distances prescribed for warning signs, as provided in chapter 3.

**Effectiveness**

A Texas evaluation of advisory speed pavement markings based its findings on speed reductions at curves compared with an upstream speed control point. While there were inconsistent results between data collection sites, the study concluded that the markings were "worthy of further exploration."

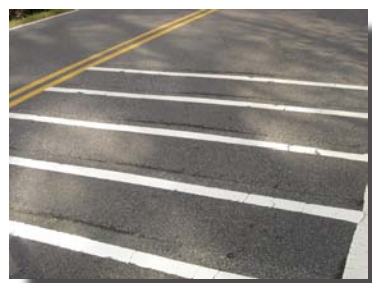
# CHAPTER 5. RUMBLE STRIPS

## DESCRIPTION

A rumble strip can be formed in the pavement surface by placing either grooves into the surface or strips of material above the surface according to a prescribed spacing pattern. A vehicle passing over the rumble strips produces noise and vibration and alerts the driver to a potentially hazardous situation. Agencies can install rumble strips on horizontal curves longitudinally with the centerline; with the edge line or on the shoulder; or transversally across the full lane in the advance of the curve.

Each of these three will alert drivers to different hazards and each achieves a different objective. Use the centerline rumble strip (CLRS) to alert drivers who drive into the opposing traffic lane and thereby avoid head-on or sideswipe-opposite direction crashes. Use the shoulder (or edge line) rumble strip (SRS) to alert motorists who drive onto the shoulder and beyond and thereby avoid run-off-road crashes. Use the roadway (transverse) rumble strip (RRS) to alert drivers approaching the curve of the potential need to reduce speed or at least be alert while driving through the curve. Because of the similarities in the applications, they are discussed together.





*Illustrations of rumble strip for centerline (left), shoulder (middle), and across roadway (right).*

There are four types of rumble strips:

1. Milled rumble strips are formed with a machine that cuts a smooth groove in a roadway of either new or existing asphalt or cement concrete.
2. Rolled rumble strips are pressed into freshly laid asphalt pavement by a roller with steel pipes welded to a drum.
3. Formed rumble strips are added to fresh concrete shoulder with a corrugated form that is pressed onto the surface just after concrete placement and finishing operations.
4. Raised rumble strips can be formed by applying asphalt material ( ¼ to ½ in high) as raised bars on the surface.

The milled or rolled strips are typically used for the centerline and shoulder application. The milled type is preferred because it produces a higher noise level and vibration stimuli than do rolled rumble strips. The raised types may be used for the across the pavement roadway application. The noise and vibration effect is created by the tires bouncing over the raised bars.

## CENTERLINE RUMBLE STRIP

### Application Guideline

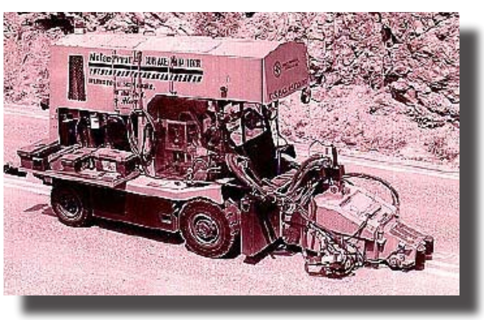
Because motorists frequently cross over the centerline through curved sections, the centerline rumble strip (CLRS) is a candidate treatment for horizontal curve sections. However, the application of CLRS just along a curve section has not been identified as an actual practice. This is likely because the installation cost of would not justify their use for a relatively short section. Therefore, when used, agencies should install CLRS on a considerable section of roadway.

Several State highway departments have guidelines for applying CLRS, including:

- Crash history indicates a large number of head-on or sideswipe crashes.
- Posted speed limit of 50 mi/h or greater.
- ADT threshold of at least 1500.
- Pavement width of at least 20 ft.
- Pavement type of asphalt in good condition with minimum depth of 2.5 in.

CLRS are not recommended for:

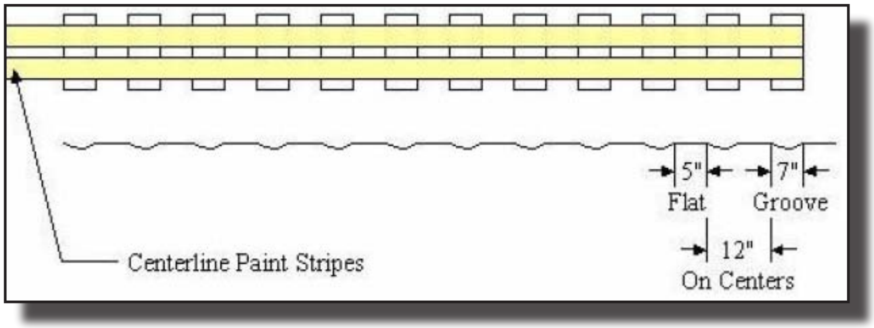
- Bridge decks.
- In area of intersections with public roads or short distances between access points.
- Existing concrete pavements with an overlay depth less than 2.5 in.
- Roadways where residences are close to the highway—because of noise complaints.



***Special machinery is needed to install milled rumble strips.***

### Design

There are variations in design patterns, but the most common types are milled, 12 in to 16 in long (perpendicular to the centerline), 7 in wide (along the centerline), ½ in deep. The two most common patterns are continuous rumble strips 12 in to 24 in apart, or alternating, with pairs of rumble strips 12 in or 24 in apart, with the pairs being 24 in or 48 in apart, respectively.




***Schematic for centerline rumble strips illustrates the applied pattern.***

**Effectiveness**

Based on a variety of information from States using CLRS, the positive effects far outweigh the potentially negative effects. The most significant positive effect is the reduction in overall, targeted (cross over), injury and/or fatal crashes reported by States that use them. For example, Delaware DOT reported a 90 percent reduction in the head-on collision rate after installing CLRS on a two-lane undivided rural highway with a high fatality rate. Also, studies show that motorists tend to position their vehicles farther away from the centerline, and that CLRS help drivers identify the centerline during adverse weather conditions, such as blowing snow.

The potential negative effects include:

- Disruption to motorcyclists and bicyclists.
- Roadside noise in residential areas.
- Pavement deterioration.

**Cost**

The installation cost will vary based on a number of factors including the length of section, pavement type, pattern, and highway location. Those agencies installing them report costs of about $0.40 per linear ft; however, when applied just to a single curve, expect a higher cost.

**SHOULDER RUMBLE STRIP**

**Application Guideline**

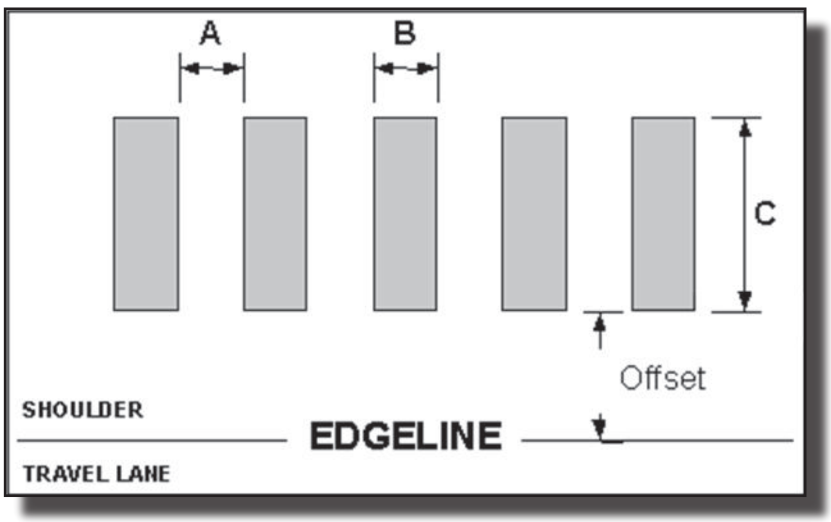
Rumble strips can be applied with the edge line or on the shoulder, if it is paved wide enough. There are no published guidelines for when to use this treatment, but it should be considered if there is a high number of run-off-road (ROR) crashes. As with the CLRS, the shoulder rumble strip (SRS) would likely not be used for a single curve because of high installation cost. The guidelines suggested for CLRS would be reasonable for SRS use as well.

**Design**

The layout design for the shoulder rumble strip (SRS) varies among those States using them. The following table and figure show the layout of a typical milled type SRS.

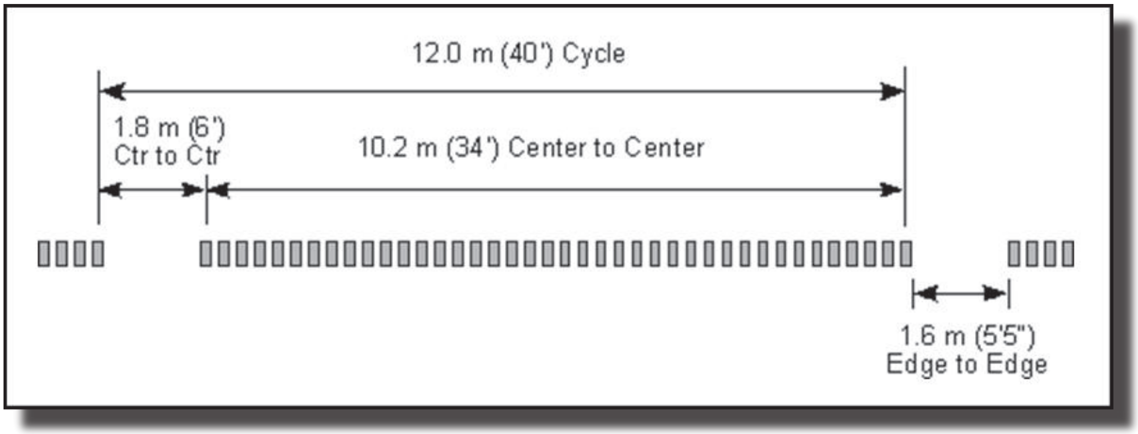
**Standard Dimensions of Milled and Rolled SRS.**

| Dimension | Measurement | Milled |
|---|---|---|
| A | Repeat Pattern | approx. 5.1 in |
| B | Longitudinal Width | 7.1 in |
| C | Transverse Width | 15.8 in |




***Standard SRS measurements.***

A concern for the SRS treatment is its effect on bicyclists. To reduce this potential negative effect, agencies can change the design to allow gaps in the pattern where bicyclist could travel to turn or change their position. The gap pattern adopted by Alaska is shown on the following page.




***Gap pattern adopted by Alaska DOT.***

**Effectiveness**

The safety benefit of SRS is well established, at least for large volume, high speed roads. For example, the application of SRS on the New York State Thruway resulted in an 88 percent reduction on ROR crashes, with a 95 percent reduction in fatalities. Their safety effectiveness for lower volume roads might be less dramatic, but may still be cost effective for roadway sections with high ROR crash rates.

**ROADWAY RUMBLE STRIP**

**Application Guideline**

Roadway (or Transverse) rumble strips (RRS) can be raised bars or grooves placed across the travel lane. For horizontal curve applications, RRSs are a warning device to supplement signing and alert drivers of the need to reduce speed or at least pay attention as they negotiate the curve.

Based on the available literature, the guidelines for their use on horizontal curves are:

- Documented crash problem where conventional treatments, discussed earlier, have failed to solve the safety problem.
- Road segment with distinct differences between the roadway speed limit and the curve advisory speed of at least 20 mi/h.
- Proximity of another geometric feature such as a side street with limited sight distance; a second, sharper curve a short distance beyond the first curve; or a downgrade leading into the curve.
- Long tangent section ends with a curve.

***For this RRS application a set of 5 grooves and painted lines were placed 200 ft before the curve.***

Some of the concerns with the use of RRS include:

- Noise complaints by nearby residents—avoid using them in residential areas.
- Motorist use opposing lanes to avoid rumble strips—a potential problem for local travelers that is reduced by using a discontinuous pattern design such as gaps in the bars or grooves across the pavement.
- Maintenance problems—grooved RRS is more durable, lasting longer than raised bars, especially in areas with snowplowing.
- Motorist worries—keep depth of groove or height of bar to ½ in or less and use a warning sign RUMBLE STRIPS AHEAD.
- Bicyclist and motorcyclist concerns—address by installing discontinuous pattern design—and warning sign RUMBLE STRIPS AHEAD.
- Overuse of rumble strips—leads to "crying wolf" attitude and therefore should be used sparingly.

**Design**

Generally, limit rumble strips to a maximum height or depth of ½ in to minimize the jarring action to vehicles. If thermoplastic materials are used to created raised bars for RRS, the material should be white.

Configure rumble strips so that most drivers are not tempted to go around the rumble strip by driving onto the shoulder or into an adjacent lane. Agencies can do this by extending the rumble strip over part of the shoulder as well as the full width of the traveled way or by using a discontinuous rumble strip design.

**Effectiveness**

There is currently no conclusive evidence of roadway rumble strip effectiveness in reducing crashes at curves. They do tend to reduce speed, in most cases, but not to a practical level.

### Agency Contacts and Further Information

More detailed information on rumble strips can be obtained from the following sources:

- NCHRP Synthesis Report 339, *Centerline Rumble Strips*, Transportation Research Board, 2005.
- NCHRP Synthesis Report 191, *Use of Rumble Strips to Enhance Safety,* Transportation Research Board, 1993.
- *Synthesis of Shoulder Rumble Strip Practices and Policies* obtained from http://safety.fhwa.dot.gov/roadway_dept/rumble/synthesis/exec_summary.htm
- Technical Advisory T 5040.35 *Roadway Shoulder Rumble Strips*, Federal Highway Administration, Washington, DC, December 20, 2001.
- *The Effectiveness and Use of Continuous Shoulder Rumble Strips*. Perrillo, K. Federal Highway Administration, August 1998. See http://safety.fhwa.dot.gov/roadway_dept/docs/continuousrumble.pdf.

# CHAPTER 6. MINOR ROADWAY IMPROVEMENTS

There are four treatments that involve physical changes to the roadway and are relatively minor in costs; they are discussed in this chapter.

## PAVED SHOULDER TREATMENT

### Description

Replace unstable or narrow shoulders with paved shoulders to increase usable width and driver safety. Variations in surface color also provide a beneficial safety effect.

### Application Guidelines

While tight budgets may influence an agency's decision to upgrade to paved shoulders on two-lane tangent sections, the resulting cost benefit from paved shoulders and fewer crashes on curves deserves consideration.

### Design

Reconstructing shoulders involve removing and recompacting a 6-in shoulder base. Agencies paving with asphalt can texturize the surface to provide visual, audible, and tactile clues to a driver leaving the travel lane. To texture the surface, apply a larger, uncoated seal coat on the shoulder while using a smaller aggregate seal coat on the driving lanes.

***In addition to paving the shoulder, color variation between the shoulder and travel lanes adds visual delineation.***

### Effectiveness

Texas DOT (TxDOT) considers application of this treatment as operationally effective because of the visual, audible, and tactile cues that alert a driver straying onto the shoulder. TxDOT believes the treatment reduced the number of single-vehicle ROR crashes. The agency also reports a positive public response to the strong visual effect, which it regards as useful for nighttime travel.

### Cost

The approximate cost of seal-coating a gravel shoulder is \$1.00/yd$^2$ (when not resurfacing the roadway).

### Agency Contacts and Further Information

TxDOT applied the treatment cited above in Cook County. The TxDOT Fort Worth District Engineer is Maribel Chavez, P.E. (817-370-6500).

## SHOULDER DROP-OFF ELIMINATION

### Description

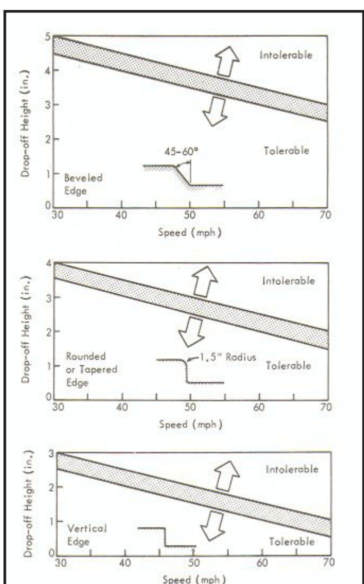
The vertical height difference between the paved surface and the unpaved shoulder is the pavement shoulder drop-off. Drop-offs happen when the unstabilized pavement edges erode, which creates the height difference. Horizontal curves are particularly prone to drop-offs, especially when vehicles stray on to the edge of the travel lane. The illustration at left shows how to measure height and depth of drop-offs.

*Technique for measuring height and depth of drop-offs.*

A drop-off as small as 3 in can create an unsafe condition when the vertical angle is 90 degrees. As an example, once a vehicle crosses from a paved surface onto an unimproved shoulder, the driver's reaction often is to overcorrect to get back on the road. The overreaction can cause the rear wheel to catch on the shoulder edge and spin the vehicle around. In many instances, drivers attempting to return to the road will veer into the adjacent lane, cross into opposing traffic, or leave on the opposite side of the roadway.

### Application Guidelines

Various shapes and depths of drop-offs can cause more or less of a hazard at various operational speeds. The shape of the drop-off (vertical, rounded, or tapered edges), or vertical angle, in combination with pavement depth can affect the hazard potential of drop-offs. The illustration on the left shows various pavement edge depths and associated operational speeds that research shows to be acceptable.




*Drop-off heights and depths in the 'Intolerable' range are unsafe.*

### Design

Applying filled and compacted shoulder material to reduce the drop-off depth has proved a viable method to create a safe condition. A simple, cost-effective solution for agencies is to adopt a standard contract specification requiring a 45-degree angle asphalt fillet along each side of the roadway in all resurfacing projects. The asphalt fillet provides a safer roadway edge and a stronger interface between the roadway and the shoulder.

One way to create a 45-degree wedge is to use a steel wedge or the Safety Edge Maker™, a commercial device being developed by TransTech Systems, Inc. A steel wedge device fabricated by the Georgia DOT (GDOT) Maintenance Division, shown at right, is mounted with a simple two-bolt connection onto the screed end gate. This device has a rounded leading edge that is crucial to providing a smooth finished compaction to the safety edge. The device can also adjust vertically to varying drop-off heights.


***Georgia DOT Safety Wedge Hardware.***

**Effectiveness**

Research has shown that drop-off shapes, such as those created by a safety wedge, are a safety device that can reduce the rate of driver overcorrection, head-on, and run-off-road crashes. Thus, the benefit of eliminating the drop-offs is fewer crashes and related injuries—and reduced tort liability.

GDOT evaluated the Safety Edge (see http://safety.fhwa.dot.gov/roadway_dept/docs/sa05003.htm) over a 13-mi roadway section. Results showed the Safety Edge Design can be placed on any type of roadway facility as part of the asphalt preventative maintenance paving process. Applying the treatment neither affects finished pavement smoothness, nor increases erosion of the shoulders.

**Cost**

Agencies can implement the safety edge on any type of roadway facility as part of the asphalt paving process. The Safety Edge implementation cost is approximately less than one percent of the hot-mix asphalt material cost. No specific cost information is available on the Safety Edge Maker™.

**Agency Contacts and Further Information**

For more detailed information, refer to the following sources:

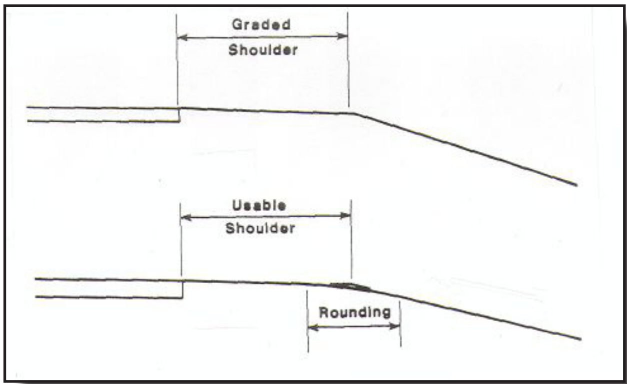
- The Safety Edge Pavement Treatment
  http://safety.fhwa.dot.gov/roadway_dept/docs/sa05003.htm
- *The Road Edge Drop Off: The Problem & Solution*
  http://www.transtechsys.com/rd/rd_proj_current.htm
- *Safety Impacts of Pavement Edge Drop-Offs*
  http://www.aaafoundation.org/pdf/PEDO_report.pdf

- **Frank Julian**
  FHWA, Resource Center, Atlanta
  (404) 562-3689
  Frank.Julian@fhwa.dot.gov


## WIDEN SHOULDER

### Description

The shoulder is the portion of the roadway next to the traveled way. This area is designed to accommodate stopped vehicles (when sufficiently wide) and to provide side support for the roadside in close proximity to the travel lane. Shoulders can be graded (level surface) or useable (rounding on outside edge), as illustrated at left.




*Cross sections of graded and useable shoulder widths.*

Shoulders are a safety feature because they provide space that allows drivers to get out of the travel lane and avoid crashes. This feature is particularly important in horizontal curves where vehicles typically use more of the travel lane than in straight sections.

### Application Guidelines

Shoulder widths can vary from approximately 2 ft on minor rural roads to 12 ft on major roads where the entire shoulder may be stabilized or paved. Agencies should stabilize widened shoulders and ensure roadside slopes comply with AASHTO guidelines. As the figures below illustrate, agencies can widen shoulders on both the inside or outside.

*Widening on inside of curve.*

*Widening on the outside of the curve.*

### Effectiveness

The table below lists estimated reductions in related crashes resulting from widening paved or unpaved shoulders. Related crashes, i.e., those affected by shoulder widenings, include single vehicle run-off-road and multiple vehicle head-on and sideswipe crashes. For example, widening an unpaved shoulder by 4ft (e.g., from 2 ft to 6 ft) would reduce related crashes by an estimated 25 percent. Adding 8-ft paved shoulders to a road with no shoulders would reduce related crashes by an estimated 49 percent. These estimated reductions in related crashes apply only when roadside characteristics (side slope and clear zone) are rebuilt to the condition existing before the shoulder was widened. Although the table below was developed for rural two-lane roads, and not limited to horizontal curves, it is reasonable to expect the major benefit from shoulder widening can also be realized for horizontal curves.

**Crash Reductions Related to Shoulder Widening.**

| Shoulder Widening per Side, (ft) | Reduction in Related Crash Types (%) | |
|---|---|---|
| | Paved | Unpaved |
| 2 | 16 | 13 |
| 4 | 29 | 25 |
| 6 | 40 | 35 |
| 8 | 49 | 43 |

## SKID-RESISTIVE PAVEMENT SURFACE TREATMENT

### Description

Agencies should maintain pavements to ensure adequate friction necessary for vehicle braking and maneuvering under both dry and wet conditions. A vehicle will skid during braking and maneuvering when frictional demand exceeds the friction force that can be developed between the tire and the road surface. Horizontal curves are particularly prone to these types of crashes, especially under wet conditions. On road segments where skidding crashes are known to occur, consider applying remedial treatments, including specific asphalt mixtures (type and gradation of aggregate as well as asphalt content), pavement overlays on both concrete or asphalt pavements, and pavement grooving.

*Application of skid-resistive pavement surface in curve.*

### Application Guidelines

Target locations where skidding is a recognized problem and apply either skid-resistive overlays or pavement grooving treatment. Specifically, select sites where vehicle crashes directly result from skidding during wet pavement conditions.

### Pavement Surface Overlay Design

Using aggregate that lacks specific particle gradations creates voids on the surface, which promotes better drainage and improves skid resistance. Engineers recommend applying a 1-in, open-graded asphalt concrete to reduce wet pavement crashes. The 1-in maximum gradation improves drainage and skid resistance because it has substantially more voids than the ⅜-in or ½-in maximum open-graded asphalt concrete standard mix.

An agency's first step is to repair major surface defects (cracks, ruts, etc.) and apply dense-graded asphalt concrete. Next, apply a tack coat to the existing surface before placing the open-graded material. Alternatively, apply a slurry seal using nonpolishing aggregate. A 0.15-ft-thick blanket of the 1-in maximum open-graded asphalt concrete should be sufficient to remove water, increase traction, and ultimately reduce the number of crashes.

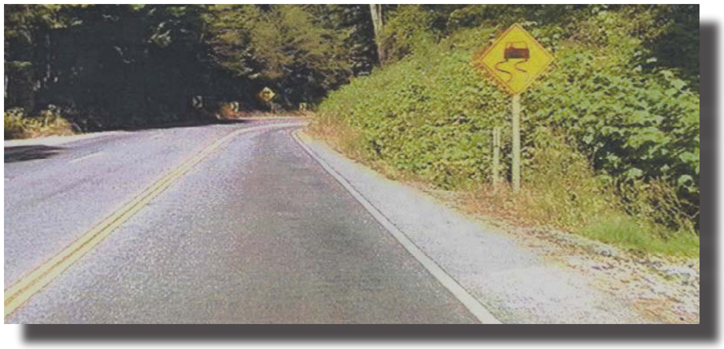
### Pavement Grooving Design

Pavement grooves increase skid resistance by improving drainage characteristics and creating a rougher pavement surface. Pavement grooving is a technique for installing longitudinal or transverse cuts on the surface to increase skid resistance and reduce the number of wet-weather crashes. Grooves cut in the longitudinal direction have proved most effective in increasing directional control of the vehicle, while transverse grooving is most effective at locations where vehicles make frequent stops. Therefore, applying longitudinal grooving is the commonsense choice for improving safety on horizontal curves.

Because asphalt concrete's uniform aggregate composition is not conducive to drainage, grooved pavement application is primarily intended for rigid concrete. Agencies can expect a greater accident-reduction result with application at 50 mi/h curves than at 30 or 40 mi/h curves because the major benefit of grooving is to reduce hydroplaning. An accepted application technique is to use a portable grooving machine equipped with carbide-tipped flails to install grooves 3/16 in to 3/8 in wide and 5/32 in to 5/16 in deep, with 8 grooves/ft on a random spacing.

### Skid-Resistive Overlay Effectiveness

The rural two-lane curve shown in the figure on the following page was treated with 1-in graded asphalt concrete to improve skid resistance. The appropriate warning sign also was installed. The result was an immediate reduced crash rate—from 16 wet pavement-related crashes in the 13-month period before treatment to two during the first six months following the treatment. Before treatment, 60 percent of crashes along a 2-mile section of treated pavement were wet-pavement related. After the treatment, wet-pavement accidents accounted for only 26 percent.



***Rural curve treated with skid-resistive graded asphalt concrete, warning signs, and chevrons.***

The New York State DOT (NYSDOT) implemented a program to identify sites statewide with a low skid resistance and treat them with overlays as part of the maintenance program. A site is eligible for treatment if its 2-year wet accident proportion is 50 percent higher than the average wet crash proportion for roads in the same county. Between 1995 and 1997, NYSDOT treated 36 sites on Long Island, which reduced the annually recurring wet road crashes by more than 800. These results, and others throughout the State, support earlier findings that treating wet-road crash locations can reduce this type of crash by 50 percent and reduce total crashes by 20 percent.

The Florida DOT (FDOT) treated a curved freeway ramp with Tyregrip®, a high-friction material illustrated below. This system consists of a highly modified exothermic epoxy resin two-part binder top dressed with a calcinated bauxite with a Polish Stone Value of 70 percent plus. The treatment proved effective at increasing the skid resistance value from 35 to 104. While the FDOT application was to a freeway ramp, the material may be applicable to a higher volume curve with a higher than normal number of wet pavement crashes.

***Application of Tyregrip® friction material on a curved ramp.***

**Pavement Grooving Effectiveness**

As indicated, grooved pavements can reduce wet-weather crashes. One study of a California two-lane road with sharp curves found a 72 percent reduction in wet-pavement accidents, but only 7 percent reduction in dry-pavement accidents. There is concern that grooving accelerates pavement wear, but it has not been shown to affect either ride quality or drainage performance.

**Cost**

Moderate costs are involved in the application of skid-resistive surface treatments. For example a 2-mi section of asphalt overlay cost the California DOT $200,000 in 1996.

**Further Information**

Technical Advisory T 5040.36 *Surface Texture for Asphalt and Concrete Pavements*, Federal Highway Administration, Washington, DC, June 17, 2005.

Florida DOT's experience with Tyregrip, high-friction material for Interstate ramp installation, Charles Holzschuher, phone (352) 955-6341.

# CHAPTER 7. INNOVATIVE AND EXPERIMENTAL TREATMENTS

The *MUTCD* considers the two treatments in this section as "experimental" and does not approve them for general use. Review the Introduction section of this publication (ABOUT THE *MUTCD*), which advises agencies to get FHWA approval before installing any experimental treatment. Agencies wishing to use either of these treatments, should visit http://mutcd.fhwa.dot.gov for information on how to submit a request for experimentation.

## OPTICAL SPEED BARS

### Description

As shown below, Optical Speed Bars are transverse stripes spaced at gradually decreasing distances. The rationale for using them is to increase drivers' perception of speed and cause them to reduce speed. The Optical Speed Bar name comes from this intended visual effect on drivers' speed as they react to the spacing of the painted lines. These white transverse stripes are 18 in long and 12 in wide. The preferred material is thermoplastic because of the exposure to traffic volume over time.

### Application Guideline

Optical Speed Bars are applied almost exclusively to road segments where vehicles traveling at highway speeds are required to slow for curves or other instances where traffic speeds should be reduced. To date, the treatment has been restricted to known accident locations or situations requiring traffic to significantly reduce speed. Agencies should avoid applying Optical Speed Bars just to reduce traffic speed because overuse could jeopardize the visual effect of the treatment.

Photo: Courtesy of Virginia Department of Transportation
***Optical Speed Bars used to reduce vehicle speed.***

### Design

Various Optical Speed Bars are designed and spaced to produce a gradual slowing from a vehicle's initial approach speed to the reduced curve speed. As spacing between bars gradually narrows, drivers sense they have increased speed and will slow down to keep the 4-bar/sec spacing. For example, think about an applied layout designed to slow a vehicle from 55 mi/h (81 ft/sec) into a 35-mi/h (51 ft/sec) curve. The initial bar separation distance is 81÷4 or 20 ft, and the final separation distance is 51÷4 or 13 ft. The table below shows New York Department of Transportation applied spacing between successive bars designed to cause drivers to reduce vehicle speed from 65 mi/h to 30 mi/h.

**Example Spacing Between Sequential Pairs of Optical Speed Bars.**

| Bars | Spacing (ft) | Bars | Spacing (ft) | Bars | Spacing (ft) |
|---|---|---|---|---|---|
| 1-2 | 24 | 11-12 | 19 | 21-22 | 15 |
| 2-3 | 23 | 12-13 | 19 | 22-23 | 15 |
| 3-4 | 23 | 13-14 | 19 | 23-24 | 15 |
| 4-5 | 23 | 14-15 | 18 | 24-25 | 14 |
| 5-6 | 22 | 16-17 | 18 | 26-27 | 13 |
| 6-7 | 22 | 16-17 | 18 | 26-27 | 13 |
| 7-8 | 21 | 17-18 | 17 | 27-28 | 13 |
| 8-9 | 21 | 18-19 | 16 | 28-29 | 12 |
| 9-10 | 21 | 19-20 | 16 | 29-30 | 12 |
| 10-11 | 20 | 20-21 | 16 | 30-31 | 12 |

The total length of the paving-marking segment depends upon the speed difference (from the approach and to the lower curve speed) the application is designed to produce. The following table suggests approximate lengths. Use these lengths as guidelines. The basis for the numbers is the need to produce a comfortable speed reduction and provide drivers with a minimum 4 seconds of driving time within the painted marking segment length.

**Guideline for Length (ft) of Speed Bar Segment in Advance of Curve.**

| | | Approach Speed, mi/h | | | | | |
|---|---|---|---|---|---|---|---|
| | | 45 | 50 | 55 | 60 | 65 | 70 |
| Curve Speed, mi/h | 15 | 300 | 385 | 470 | 565 | 670 | 785 |
| | 20 | 275 | 350 | 440 | 535 | 640 | 755 |
| | 25 | 235 | 315 | 405 | 500 | 600 | 720 |
| | 30 | | 270 | 360 | 450 | 560 | 670 |
| | 35 | | | 300 | 400 | 500 | 620 |
| | 40 | | | | 335 | 440 | 555 |
| | 45 | | | | | 370 | 480 |
| | 50 | | | | | | 405 |

**Effectiveness**

Studies by New York, Mississippi, and Texas show transverse pavement markings can effectively reduce mean speeds, 85th percentile speeds, and speed variance. Initial 85th percentile speed reductions varied from 0 to 5 mi/h. However, their long-term effectiveness is not known. The Virginia Department of Transportation (VDOT) was conducting a comprehensive study of Optical Speed Bars as this publication was being prepared; the results are expected early 2007.

**Cost**

Based on a VDOT 2006 estimate, cost to install the marking on two directions is approximately $2,000 (labor and materials).

**Contacts and Further Information**

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## PENNDOT CURVE ADVANCE MARKING

**Description**

PennDOT has experimented with an innovative pavement marking designed to alert motorists that they are approaching a curve and should slow down. Referred to as the "PennDOT Curve Advance Marking," this treatment involves two transverse bars, a SLOW legend, and an arrow indicating the direction of the upcoming curve. PennDOT developed the treatment to address driver behavior at locations identified as having a high number or rate of curve-related crashes. The device objective is that reducing the upper percentile speed will reduce the number of run-off-road crashes.


***PennDOT curve advance marking.***

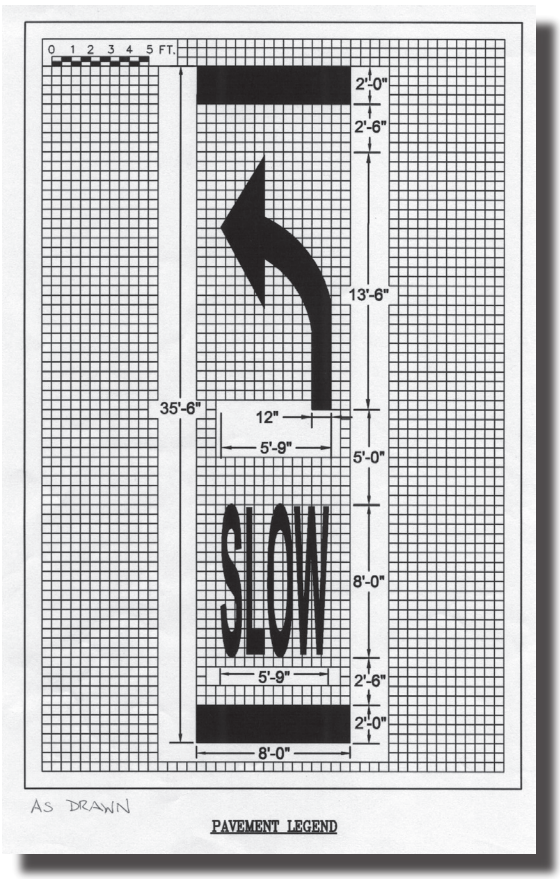
**Application Guideline**

The PennDOT Advanced Curve Warning marking is designed for two-lane locations having a high number of curve-related crashes. Agencies should avoid any location where there is any potential for driver confusion because of intersecting roadways or driveways. Agencies applying advanced curve warning at a location should also bring all existing signs, delineation, and pavement markings to standard, and consider posting an advisory speed limit.

As with any treatment used with multiple or compound curves, treat the most hazardous curve first.

**Design**

See the detailed design layout below. The chart on the following page indicates the distance of the marking from the point of curvature based on posted speed and posted warning speed. Designers used MUTCD Table 2C-4, Column B to calculate distance, L, to the advance warning sign.



Source: Pennsylvania Department of Transportation

Agencies can adjust the curve marking location when it is not plainly visible to the driver because of vertical geometry or other similar sight distance problems.

**Effectiveness**

This device has been shown to reduce overall speeds by 6 to 7 percent with slight reductions in the proportion of high-speed traffic in curves. Its effect on crash reduction is not yet established.

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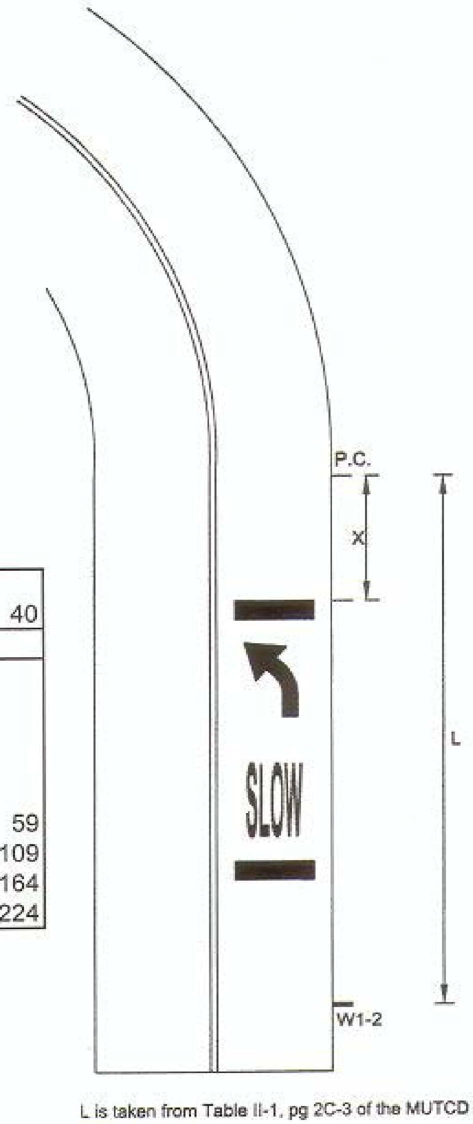
| Posted Speed | Warning Speed 10 | 20 | 30 | 40 |
|---|---|---|---|---|
| | Value of X (feet) | | | |
| 20 | 46 | | | |
| 25 | 70 | 39 | | |
| 30 | 99 | 67 | | |
| 35 | 133 | 101 | 49 | |
| 40 | 172 | 140 | 88 | |
| 45 | 216 | 185 | 133 | 59 |
| 50 | 266 | 234 | 182 | 109 |
| 55 | 321 | 289 | 237 | 164 |
| 60 | 381 | 349 | 297 | 224 |




***Distance from the point of curvature based on posted speed and posted warning speed*.**

# CHAPTER 8. MAINTENANCE TREATMENTS

The preceding chapters present specific treatments that road agencies can apply to a horizontal curve or series of curves to improve safety. The final word on this publication, however, relates to the importance of maintaining the roadway and the various traffic control devices installed. Regardless of the treatments used, road agencies should plan and carry out the following six maintenance activities to ensure continued safe travel.

1. **Restripe pavement markings as they lose their visibility.**

Pavement markings using paint-based materials have a relatively short service life—1 to 2 years. How long an agency's pavement markings last depends on material type, climate, and traffic volume. Markings of thermoplastic material have a substantially longer service life. To maintain their effectiveness, pavement markings must be visible, especially at nighttime and during conditions of limited visibility. An agency's regular inspection and restriping programs are critical to ensuring pavement markings provide needed visibility for motorists. For additional information on pavement marking visibility, visit http://safety.fhwa.dot.gov/roadway_dept/retro/pavement/pavement.htm.

2. **Replace faded signs and those with low levels of retroreflectivity.**

The various signs discussed in this report are visible at night because they are made with retroreflective sheeting material. Few, if any, are illuminated by external lighting. Even though the retroreflectivity of the sheeting material has improved to provide brighter and longer lasting signs, all signs deteriorate over time. Signs lose their color and retroreflectivity and eventually they are no longer visible to motorists from a distance. Therefore, it is good agency practice to schedule an annual inspection of all signs within its jurisdiction to ensure they are at or above the appropriate retroreflective level. For alternative methods for conducting this inspection, see *Maintaining Traffic Sign Retroreflectivity* (2005 Edition) (http://tcd.tamu.edu/Documents/MinRetro/MinRetro.htm). Replace any signs found to be ineffective as soon as possible. For additional information on sign retroreflectivity, visit http://safety.fhwa.dot.gov/roadway_dept/retro/index.htm.

3. **Cut back foliage to improve the sight distance through the curve and increase visibility of traffic control devices.**

Agencies can improve safety at a horizontal curve by maintaining the longest possible sight distance through the curve and to the various traffic signs. During the growing season, grass, weeds, brush, and tree limbs can limit a driver's view of the road and signs. This is why agencies should make an annual inspection of the roadway to identify and correct these situations.

More practical tips for controlling vegetation overgrowth are found in the FHWA report *Vegetation Control for Safety* (http://www.fhwa.dot.gov/tfhrc/safety/pubs/90003/intro.htm).

4. **Maintain the shoulders and smooth transitions between pavement and shoulder.**

***Clearing undergrowth on the right side would significantly improve sight distance through the curve and allow motorists to judge more accurately the length and sharpness of the curve—and more importantly see oncoming traffic.***

Unpaved or unstabilized shoulders can erode over time, especially on the inside curve shoulder. The result is pavement drop-offs. Chapter 4 focused on ways to correct this situation. Periodic maintenance of shoulders can prevent this situation.

5. **Eliminate roadside obstacles, such as culvert headwalls, or provide adequate shielding.**

Run-off-road crashes occur more frequently along horizontal curve sections. While implementing the treatments discussed in this publication should reduce the frequency of these type crashes, they will unfortunately still occur. It is important, therefore, to minimize roadside obstacles and shield them with an appropriate traffic barrier. Once a barrier is in place, road agencies must be ready to repair damage to it, as necessary. More complete information on treatment of roadside hazards is available in AASHTO's *Roadside Design Guide* and in the FHWA publication *Road Safety Fundamentals*.

6. **Improve drainage around the curve.**

Improper and poor drainage is particularly troublesome on horizontal curves because of water flows caused by the pavement superelevation. When water cannot drain properly, shoulder deterioration can cause pavement drop off and shoulder loss. Agencies should install curbing and improve drain maintenance. For tips on road drainage features important to safety, see the FHWA publication *Maintenance of Drainage Features for Safety.*

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