Enhanced Horizontal Curve Safety Treatments

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PDH: 3

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INTRODUCTION

AASHTO's **Strategic Highway Safety Plan** set a goal of reducing annual highway fatalities by 5000 to 7000. Various guides are available to identify methods for reducing injuries and fatalities in targeted areas – one such area is the issue of vehicle crashes at horizontal curves.

The average crash rate for horizontal curves in the U.S. is roughly three times that for other highway sections. **A Guide for Reducing Collisions on Horizontal Curves** reports that nearly 25% of U.S. traffic fatalities are killed in vehicle crashes at curves annually with:

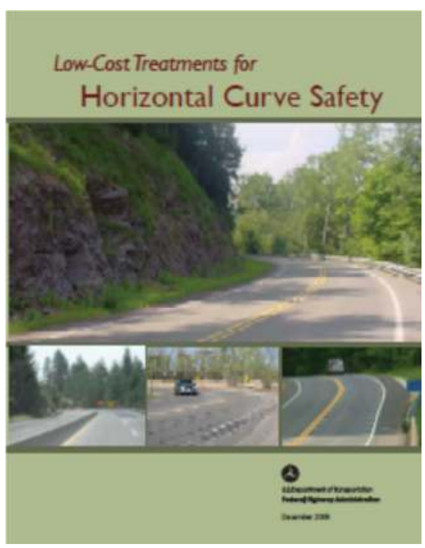
76% - *single vehicles leaving the roadway*

75% - *rural roads*

70% - *two-lane secondary (local) road crashes*

11% - *head-on crashes.*

Due to these statistics, the Federal Highway Administration (FHWA) identified Roadway Departure as one of its program emphasis areas and developed practical information publications for local agencies. The main reference for this course, **Low-Cost Treatments for Horizontal Curve Safety*** is a result of these Roadway Departure program goals.



http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/fhwasa07002.pdf

* This reference may also be referred to as "LCTHCS" throughout this document and includes only those engineering treatments that are low cost strategies.

COURSE CONTENTS

This course summarizes practical information on where, when, or how to apply safety treatments for horizontal curves or winding sections. These treatments are relatively low cost versus geometric design improvements (degree of curve, shoulders, superelevation, curve length, cross-section, etc.). Information for each treatment will generally include:

Description

Application guidelines – installation practices

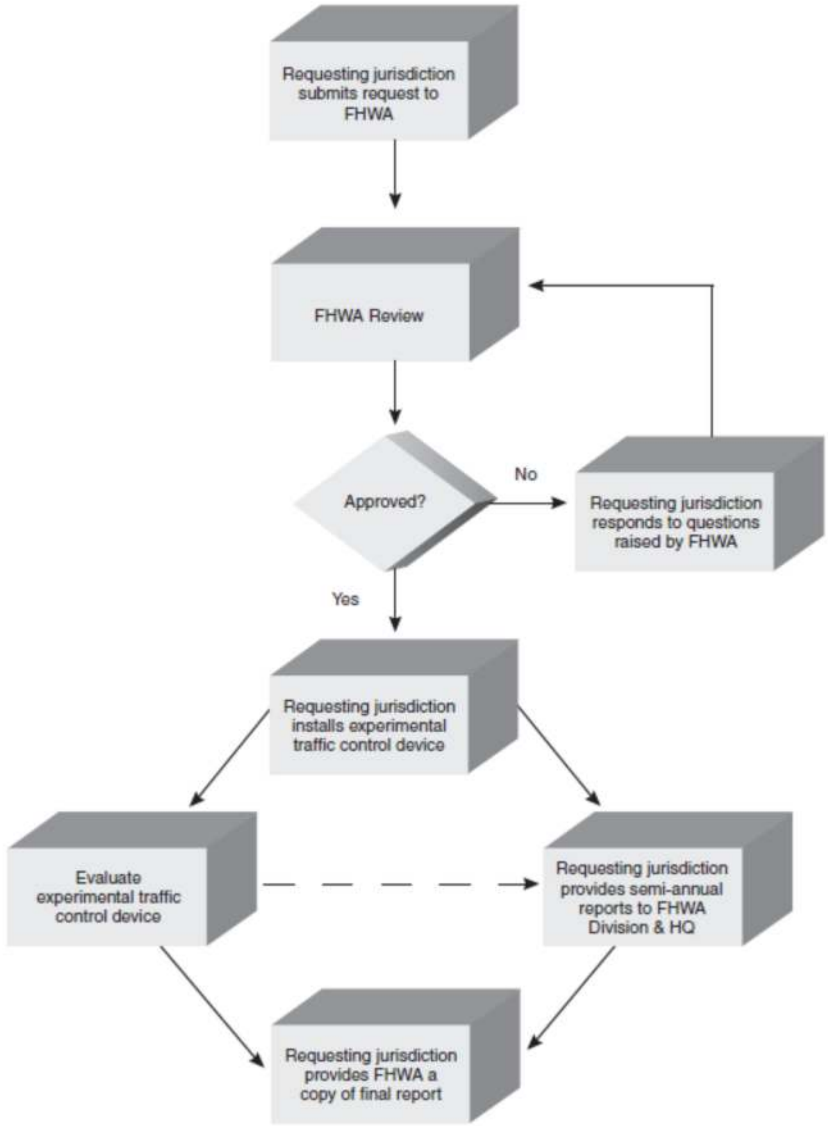
Design elements and materials

Effectiveness – safety improvements

Cost

Some of these traffic control devices or treatments may be considered to be “experimental” and may not comply with the MUTCD. Anyone wanting to use noncompliant devices on a public road must get FHWA approval for testing.

Figure 1A-1. Process for Requesting and Conducting Experimentations for New Traffic Control Devices



Estimates for treatment effectiveness in reducing crashes are included if available. Actual observed effectiveness values of a treatment may vary depending on its location.

Topics covered in this course include:

Enhanced Basic Treatments

Treatments considered to be enhancements to basic devices

Larger devices

Doubling-up

Retroreflective and fluorescent sheeting

Flashing beacons

Profile thermoplastic markings

Raised Pavement Markers

Other Traffic Control Device Treatments

Treatments not in the MUTCD which are used by State and local agencies

Reflective barrier delineation

Roadside object delineation

Dynamic Curve Warning System

Speed Limit Advisory Marking

Rumble Strips

Overview of applications

Centerline

Shoulder

Roadway

Minor Roadway Improvements

Low-cost treatments requiring minor roadway or shoulder improvements

Paved Shoulder Treatment

Shoulder drop-off elimination

Widen shoulder

Skid-resistive pavement surface

Innovative and Experimental Treatments

New treatments that have not been applied extensively

The purpose of this course is to encourage readers to use this information to evaluate problems and implement appropriate treatments for problem curve locations. These treatments should help reduce roadway departure crashes, injuries, and fatalities.

ENHANCED BASIC TREATMENTS

Many basic safety treatments for horizontal curves can be improved in various ways to increase visibility. The key is to provide the driver with adequate perception-response time to see the device, determine its meaning, and negotiate the section. The following treatments have proved effective in attracting 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

For typical roadway locations, the MUTCD requires using "conventional road" (not "minimum") sign sizes. However, it does allow "minimum" sizes for low-speed road where the reduced letter size is sufficient or where larger sizes are not practical. Oversized and larger signs may be used for safety problems such as horizontal curves where speed, volume, or other factors require increased emphasis, improved recognition, or increased legibility.

Table 2C-2. Warning Sign and Plaque Sizes (Sheet 1 of 3)

Sign or Plaque	Sign Designation	Section	Conventional Road		Expressway	Freeway	Minimum	Oversized
			Single Lane	Multi-Lane				
Horizontal Alignment	W1-1,2,3,4,5	2C.07	30 x 30*	36 x 36	36 x 36	36 x 36	—	48 x 48
Combination Horizontal Alignment/Advisory Speed	W1-1a,2a	2C.10	36 x 36	36 x 36	48 x 48	48 x 48	—	48 x 48
One-Direction Large Arrow	W1-6	2C.12	48 x 24	48 x 24	60 x 30	60 x 30	—	60 x 30
Two-Direction Large Arrow	W1-7	2C.47	48 x 24	48 x 24	—	—	—	60 x 30
Chevron Alignment	W1-8	2C.09	18 x 24	18 x 24	30 x 36	36 x 48	—	24 x 30
Combination Horizontal Alignment/Intersection	W1-10,10a, 10b,10c,10d, 10e	2C.11	36 x 36	36 x 36	36 x 36	48 x 48	—	—
Hairpin Curve	W1-11	2C.07	30 x 30	30 x 30	36 x 36	48 x 48	—	48 x 48
Truck Rollover	W1-13	2C.13	36 x 36	36 x 36	36 x 36	48 x 48	—	36 x 36
270-degree Loop	W1-15	2C.07	30 x 30	30 x 30	36 x 36	48 x 48	—	48 x 48
Intersection Warning	W2-1, 2,3,4,5,6,7,8	2C.46	30 x 30	30 x 30	36 x 36	—	24 x 24	48 x 48
Advanced Traffic Control	W3-1,2,3	2C.36	30 x 30	30 x 30	48 x 48	48 x 48	30 x 30	—

DOUBLING-UP OF DEVICES

"Doubling-up" is the practice of installing a second, identical sign on the left side of the roadway. This increases the opportunity for sign visibility and driver perception-response time. Doubling-up may be helpful at locations where visibility or obstruction problems (vegetation, sight distance, etc.) exist for the single right-hand side sign.

HIGH RETROREFLECTIVE INTENSITY & FLUORESCENT YELLOW SHEETING

Traffic sign retroreflective sheeting typically consists of either glass beads or microprisms. Some older types of sign sheeting use tiny spherical reflector glass beads to reflect light. Light enters the bead and reflects off the rear surface back along its original path to the source. Engineering grade sheeting uses glass bead reflector technology.

The retroreflective properties of glass beads depend on:

- **Chemical makeup of the beads**
- **Size**
- **Depth in binder**
- **Color, other properties of binder**

Microprismatic sheeting uses hundreds of small prisms per square inch (like bicycle reflectors) to reflect more of the light back to the driver. These types of signs appear much brighter than engineering grade or high intensity signs due to their efficiency. Using microprismatic sheeting for key warning and regulatory signs gives the signs a greater target value at night and meets the need for commanding user attention.

Table 2A-3. Minimum Maintained Retroreflectivity Levels[1]

Sign Color	Sheeting Type (ASTM D4956-04)				Additional Criteria
	Beaded Sheeting			Prismatic Sheeting	
	I	II	III	III, IV, VI, VII, VIII, IX, X	
White on Green	W*; G ≥ 7	W*; G ≥ 15	W*; G ≥ 25	W ≥ 250; G ≥ 25	Overhead
White on Green	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			[2]
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 75; O ≥ 75			[3]
White on Red	W ≥ 35; R ≥ 7				[4]
Black on White	W ≥ 50				–

[1] The minimum maintained retroreflectivity levels shown in this table are in units of $cd/lx/m^2$ measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Bold Symbol Signs

- W1-1,2 – Turn and Curve
- W1-3,4 – Reverse Turn and Curve
- W1-5 – Winding Road
- W1-6,7 – Large Arrow
- W1-8 – Chevron
- W1-10 – Intersection in Curve
- W1-11 – Hairpin Curve
- W1-15 – 270 Degree Loop
- W2-1 – Cross Road
- W2-2,3 – Side Road
- W2-4,5 – T and Y Intersection
- W2-6 – Circular Intersection
- W2-7,8 – Double Side Roads
- W3-1 – Stop Ahead
- W3-2 – Yield Ahead
- W3-3 – Signal Ahead
- W4-1 – Merge
- W4-2 – Lane Ends
- W4-3 – Added Lane
- W4-5 – Entering Roadway Merge
- W4-6 – Entering Roadway Added Lane
- W6-1,2 – Divided Highway Begins and Ends
- W6-3 – Two-Way Traffic
- W10-1,2,3,4,11,12 – Grade Crossing Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3,4,16-22 – Large Animals
- W11-5 – Farm Equipment
- W11-6 – Snowmobile Crossing
- W11-7 – Equestrian Crossing
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow
- W16-5P,6P,7P – Pointing Arrow Plaques
- W20-7 – Flagger
- W21-1 – Worker

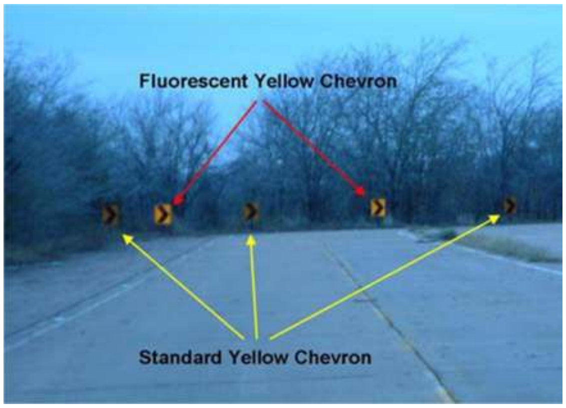
Fine Symbol Signs (symbol signs not listed as bold symbol signs)

Special Cases

- W3-1 – Stop Ahead: Red retroreflectivity ≥ 7
- W3-2 – Yield Ahead: Red retroreflectivity ≥ 7; White retroreflectivity ≥ 35
- W3-3 – Signal Ahead: Red retroreflectivity ≥ 7; Green retroreflectivity ≥ 7
- W3-5 – Speed Reduction: White retroreflectivity ≥ 50
- For non-diamond shaped signs, such as W14-3 (No Passing Zone), W4-4P (Cross Traffic Does Not Stop), or W13-1P,2,3,6,7 (Speed Advisory Plaques), use the largest sign dimension to determine the proper minimum retroreflectivity level.

High-intensity retroreflective sheeting and **fluorescent-yellow** sheeting make signs more visible or noticeable. Retroreflective sheeting is available in different intensity grades. High-intensity sheeting can help increase visibility at night.

Fluorescent yellow increases sign visibility - both day and night. Higher intensity sheeting make signs more visible for earlier driver recognition and response. Fluorescent materials appear brighter than ordinary colors during daytime due to their efficient utilization of light/energy. These signs are more visible during inclimate weather since they re-emit short-wave light/energy as longer, visible light waves which better penetrate clouds or fog.



(Source: LCTHCS)

Research data has shown that upgrading conventional yellow signs to fluorescent yellow improves driver perception and suggests a potential safety benefits.

Typical Costs

Sheeting	Unit Costs
Type III	\$1.20/ft²
Fluorescent Microprismatic	\$4.00/ft²

FLASHING BEACONS

Flashing Beacons are roadway traffic signals with one or more signal sections typically used for intersection control or other warning applications. Using flashing beacons with an advance Horizontal Alignment sign is another way to attract driver attention to curve locations where other treatments have not solved a safety problem. The availability of accessible power is a limiting factor to their use. Reliable solar power panel are a viable option as a possible power supply.

These beacons are standard traffic signal circular yellow sections. One or more beacons that can be flashed either alternately or simultaneously. Locating the beacon signal housing at least 12 inches outside of the nearest edge of the sign will prevent any visibility problems regarding the sign's message.

The beacons flash at a rate of 50 to 60 times per minute. The illuminated period of each flash should range from ½ to 2/3 of the total cycle. Automatic dimming devices may be used to control signal brightness during nighttime operations.

(Source: LCTHCS)

FLASHING BEACON APPLICATIONS

Intersection Control - one or more signal faces directed toward each approach
- used only at intersections to control multiple directions of travel

Warning - used for roadway obstructions, warning sign supplement, midblock crosswalks, regulatory sign supplement, in conjunction with signs to indicate conditional time periods

Speed Limit - used to supplement Speed Limit signs
- signal indicators have a minimum nominal diameter of 8 inches

Stop - used to supplement *Stop, Do Not Enter,* or *Wrong Way* signs
- beacon signal housing should be from 12 to 24 inches above the top of the sign

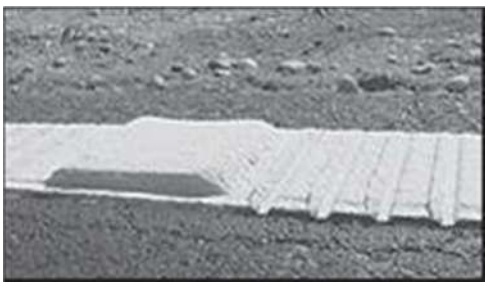
A 1970s study evaluated the effects of signing to warn drivers of wet weather skidding hazards at horizontal curves and concluded that vehicle speed could be significantly reduced by adding flashing beacons to the curve warning sign.

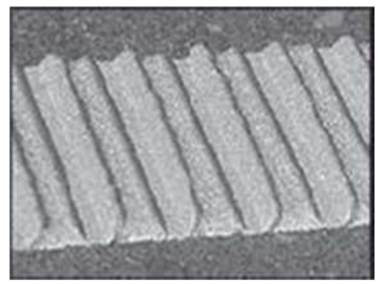
Currently, there are no specific guidelines for when flashing beacons are appropriate, but it is reasonable to limit these to areas where other methods have failed to solve any safety issues.

PROFILE THERMOPLASTIC MARKINGS

Profile thermoplastic markings are a specific form of raised strips that are used to produce a rumble effect and enhance marking visibility. These are created by fusing thermoplastic to the pavement surface and construct furrow or ridge patterns. *Inverted-profile* markings are produced by using a cog to corrugate the wet markings. *Raised-profile* (convex traffic lines) markings are made by allowing extra thermoplastic thickness at specific distances to create bumps or ridges.

Currently, there is no firm evaluation of profile thermoplastic markings due to their limited use. These markings are usually used in warmer climates since snow plows can destroy them.





(Source: LCTHCS)

The California Department of Transportation (Caltrans) has used both raised and inverted profile patterns (shown above).

RAISED PAVEMENT MARKERS

Raised pavement markers can supplement or substitute for roadway pavement markings. These may be either *retroreflective* or *non-retroreflective* with prismatic cube-corner reflectors used for necessary retroreflective properties.

(Source: LCTHCS)

Markers are typically applied to long roadway sections to provide a longer visible delineation. RPMs also work well when at single curved roadway sections by providing an auditory warning to anyone who travels on them.

Advantages of Raised Pavement Markers

Increased visibility under adverse weather conditions

Better durability than markings

Tactile and audible warnings

Use as transverse rumble strips

The color of RPMs under both daylight and nighttime conditions needs to conform to the color of the marking for which they serve, supplement or substitute. Retroreflective or internally illuminated raised pavement markers can be used in the roadway bordering curbed approach ends or on top of raised medians and island curbs. These markers are available in *mono-directional* and *bidirectional* (capable of displaying the applicable color for each direction of travel). All internally illuminated markers must be steadily illuminated and not flash when used.

Red – used to alert wrong-way traffic

Blue – used to assist emergency personnel in locating fire hydrants

Non-retroreflective raised pavement markers should never be used alone as a substitute for other types of pavement markings without supplemental retroreflective or internally illuminated markers.

Directional configurations should maximize correct information and minimize confusing information from visibility of markers that do not apply to the road user.

The spacing of retroreflective RPMs should correspond with the pattern of broken lines (40-ft for normal rural roadways) for which the markers serve, supplement or substitute. Nonreflective markers for broken-line segments should be used in groups of three to five – depending on the normal lane marking length. For additional emphasis, retroreflective raised pavement markers may be spaced closer than described in the MUTCD if determined by engineering judgment.

The *"Traffic Control Devices Handbook"* contains further details pertaining to the spacing of raised pavement markers for longitudinal markings.

Disadvantages of RPMs

High installation costs

Susceptible to damage or removal

Raised pavement markers must be protected from snowplow blades in locations susceptible to snowy conditions. Snowplowable markers are encased in durable castings designed to guide blades over the marker – while standard markers can be recessed below the roadway surface to prevent damage.

Studies of operational effects have shown that RPMs reduce the variation in lane placement and move vehicles away from the centerline.

Safety Benefits

Roadway curvature	< 3.5 degrees
High traffic volume	> 5000 vehicles/day

Safety Challenges

Roadway curvature	> 3.5 degrees (under all traffic volumes)

OTHER TRAFFIC CONTROL DEVICE TREATMENTS

REFLECTIVE BARRIER DELINEATION

Retroreflective material (reflectors, panels, etc.) is a highly effective treatment for delineating curves - especially at night. Reflective strips can be applied to either guardrail or concrete barriers to alert drivers of approaching curves. The delineation should always match the color of the adjacent edge lines. Delineation for a two-lane, two-way road would be white on both sides of the road.

Reflective sheeting panels should be spaced 18 to 36 inches apart running parallel to traffic. These panels can be anchored to concrete barriers with drilled holes and caulking compound. Adhesive can be used to attach the panels to metal guardrail.

Spacing for individual reflectors should follow the same criteria as post delineators. Individual reflectors should be aligned perpendicular to the angle of oncoming headlights for curved sections of guardrail.

(Source: LCTHCS)

Oregon DOT (ODOT) tested 3M Linear Delineation System as an application of reflective barrier treatments. Test results showed that retroreflective panels provide a good alternative to traditional concrete barrier delineation methods. The panels could be removed and reused for future projects. The data led ODOT to consider future usage where crash histories show the need for additional safety measures. Challenges included a panel installation process that proved to be time-intensive, and maintenance concerns about road materials preventing optimal retroreflectivity levels.

COSTS

Individual reflectors	$3.00 each
Linear Delineation System (reflective sheeting)	$2.33 per linear foot – 4 inch wide white

Presently, there are no published guidelines for using reflective barrier delineation. An existing barrier (either guardrail or concrete) must be in place for applying any material – but if frequently hit, new or supplemental reflectorization may be needed.

ROADSIDE OBJECT DELINEATION

Low-cost treatments such as object markers, reflectorized tape, or other simple delineation devices can help reduce the associated crash potential for trees, utility poles, and other obstructions located close to travel lanes (within the designated clear zone).

Depending on the location and the severity of the hazard, the following strategies are recommended for objects with crash histories:

- **Removal**
  It may be challenging to overcome public resistance to removing specific objects (trees, historical or environmental items).
- **Shielding**
  Options include roadside modifications to shield the object, flattening or grading sideslopes, improving shoulders, or regrading ditch sections.
- **Delineation**
  Preferred option if cost rules out other alternatives. Adequate delineation should be installed on curves regardless of the option selected.

(Source: LCTHCS)

Object Marker Installation Guidelines

(Type 2 or 3)

Objects 8’ or less from shoulder/curb	Marker bottom a min. of 4’ above roadway surface
Objects over 8’ from shoulder/curb	Marker bottom a min. of 4’ above ground

Use reflective tape (6” min.) as a supplement or substitute

Yellow is most commonly used color for retroreflective tape. Brown retroreflective tape can be used at locations with a history of daytime crashes, or in aesthetically sensitive areas.

The Pennsylvania Department of Transportation (PennDOT) has an experimental program for delineating hazards on road segments with high crash frequencies where it is not feasible to remove an object (budget constraints or private property). Each tree or utility pole is marked with one round of reflective tape - with two rounds for poles at intersections. Results from this program are still pending.

DYNAMIC CURVE WARNING SYSTEM

Dynamic curve warning systems typically use a speed measuring device (such as loop detectors or radar) combined with a flashing beacon and a variable message sign that activate when speeding vehicles approach horizontal curves. The system is designed to slow approaching motorists by measuring their speeds and providing messages to any who are speeding. These systems can be produced using off-the-shelf technology and have a much greater impact than typical static curve warning signs.

(Source: LCTHCS)

Based on their expense, dynamic curve warning systems should be limited to sites with high crash rates (fatalities and injuries) where other devices have failed.

DYNAMIC CURVE WARNING SYSTEM SITE RECOMMENDATIONS

	10 or more reported accidents*	Within 24 months
or		
	7 or more reported accidents*	Within 12 months

*Occurring within curve limits and 1000-ft downstream

A simple application (without major reconstruction) may consist of a radar speed detection device with warning signs and activated flashing beacons. Speeds can be measured with a radar gun and displayed using a speed display sign stating: “YOUR SPEED IS . . .”.

TYPICAL DYNAMIC SYSTEM LAYOUT

Turn Sign (W1-1)	625’ in advance of the curve
Overhead Sign	Point of curvature
Radar Detector	300’ before overhead sign

Costs of dynamic curve warning systems depend on their specific design. The equipment and installation costs of a typical system consisting of radar speed detection and associated flashing beacon, is approximately $18,000. The total system cost for a California interstate system was $61,000 (including traffic control). Caltrans reported a 44% reduction in crashes for the first year and 39% in the second year. Although accident effectiveness may vary by location, research has shown that dynamic curve warning systems can significantly reduce vehicle speeds for horizontal curves.

Several State DOT's (including Missouri, Texas, Washington, Wisconsin, and Colorado) have used Sequential Dynamic Curve Warning Systems to help reduce vehicle speeds and the frequency and/or the severity of curve-related crashes. This system consists of a series of solar-powered, LED-enhanced BlinkerSigns (a Curve Warning BlinkerSign and an array of Chevron BlinkerSigns) that are installed throughout a curve. Approaching vehicles are detected by radar or other ITS device, and trigger a controller that wirelessly activates the LED signs to flash sequentially through the curve to warn speeding vehicles to reduce their speed.

<u>Sequential Dynamic Curve Warning System Benefits</u>

Reduces frequency of lane departures

Solar system that can be installed anywhere

Economical – no power costs

Quick, simple installation

SPEED LIMIT ADVISORY MARKING IN LANE

The installation of advance pavement markings prior to curves is a highly visible, supplemental warning treatment with potential safety benefits. These markings provide essential information directly related to safe transit through curves and have been successful for speed reduction where signs have failed.

While the MUTCD and Standard Highway Signs (SHS) manual present specifications for the design and placement of speed limit advisory markings – presently, there are no established guidelines for when to use them. These appear to be more suited for high speed roadways or those with excessive speeding. The MUTCD shows examples of elongated pavement markings (letters and words). The SHS provides various layouts for these markings.

(Source: LCTHCS)

The advance placement distance for these pavement markings is dependent on the curve's approach and design speeds - which should be the same as advance distances for warning signs.

Findings from a Texas evaluation of advisory speed pavement markings regarding speed reductions at curves showed inconsistent results but concluded that the markings were "worthy of further exploration."

RUMBLE STRIPS

The MUTCD defines a rumble strip as “a series of intermittent, narrow, transverse areas of rough-textured, slightly raised, or depressed road surface that extend across the travel lane to alert road users to unusual traffic conditions or are located along the shoulder, along the roadway centerline, or within islands formed by pavement markings to alert road users that they are leaving the travel lanes”. By using noise and vibration, these strips alert drivers to unexpected roadway changes and stopping conditions.

<u>Types of Rumble Strips</u>

Milled

Formed by cutting a smooth groove in new/existing asphalt or cement concrete

Rolled

Pressed into freshly laid asphalt by a roller with steel pipes

Formed

Added to fresh concrete shoulders by a pressed corrugated form

Raised

Formed by applying asphalt as raised bars (1/4 to ½ inch) on the surface

Milled rumble strips are preferred for centerlines and shoulders due to their higher levels of noise and vibration. Raised rumble strips can be used for transverse applications with noise and vibration produced from their raised asphalt bars.

<u>Possible Rumble Strip Locations for Horizontal Curves</u>

Longitudinally with roadway centerline

With edge line or shoulder

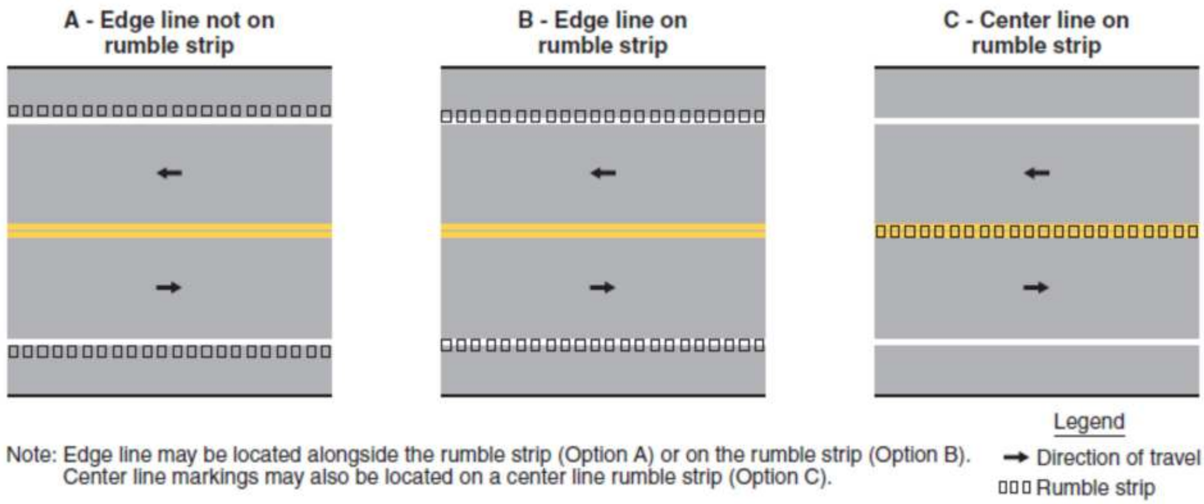
Transversally across road in advance of curve

Each of these has different objectives and alert motorists to different hazards.

Longitudinal Rumble Strip Markings

Longitudinal rumble strips are either a series of rough-textured, slightly raised or depressed road surfaces that warn drivers through vibration and sound of the limits of the travel lane – to prevent roadway departure.

Figure 3J-1. Examples of Longitudinal Rumble Strip Markings



Note: Edge line may be located alongside the rumble strip (Option A) or on the rumble strip (Option B). Center line markings may also be located on a center line rumble strip (Option C).

Transverse Rumble Strip Markings

Transverse rumble strips are intermittent narrow, transverse areas of roughly textured, slightly raised or depressed road surface that extend across the travel lanes. The resulting noise and vibration warns the driver about unusual vehicular traffic conditions (i.e. unexpected changes in road alignment, stopping conditions, speed reduction).

For locations where the color of a transverse rumble strip within a travel lane does not match the color of the pavement, the strip will be either **black or white**. To avoid confusion, white transverse rumble strips should not be placed in locations with other transverse markings (stop lines, crosswalks, etc.).

CENTERLINE RUMBLE STRIP

The centerline rumble strip (CLRS) is a treatment used to alert drivers who cross over the centerline at horizontal curves and to avoid head-on or opposite direction crashes. The use of CLRS just along curves has not been identified as an actual practice since the installation costs would not justify their use for a relatively short section. CLRS should be used on roadway sections of considerable lengths.

Guidelines for Applying CLRS

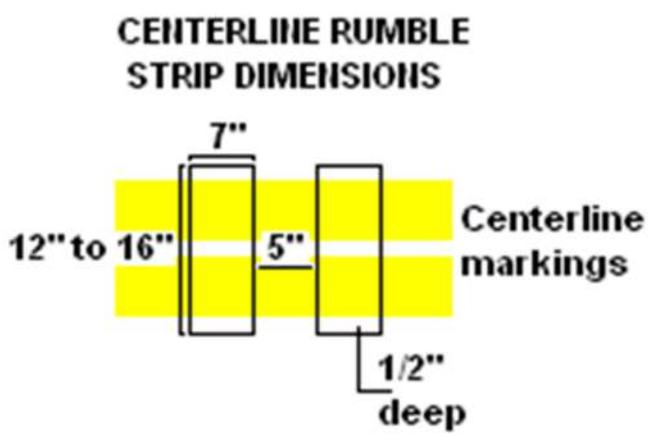
Large number of head-on or sideswipe crashes

Posted speed limit - 50 mph or greater

Minimum ADT – 1500 vehicles/day

Minimum pavement width - 20 ft

Asphalt surface in good condition (minimum depth of 2.5 in)



(Source: Gregory J. Taylor)

(Source: LCTHCS)

Although there are various design patterns, the most common types of milled centerline rumble strips are:

Continuous 12” to 24” apart

Alternating Paired 12” to 24” apart alternated with paired 24” or 48” apart

Positive effects far outweigh the negative ones for centerline rumble strips. The greatest benefit from using CLRS is the reduction in vehicular crashes (overall, cross over, injury, and fatal). Delaware DOT reported a reduction of 90% for head-on collisions for a two-lane rural highway after installing centerline rumble strips. Research results have shown that drivers stay farther away from CLRS while the strips help to delineate the centerline during adverse conditions.

Do not use centerline rumble strips for the following locations:

Bridge decks

Intersections with local roads or short distances between access points

Existing concrete pavements (overlay depth less than 2.5 in)

Roadways with residences in close proximity (noise complaints)

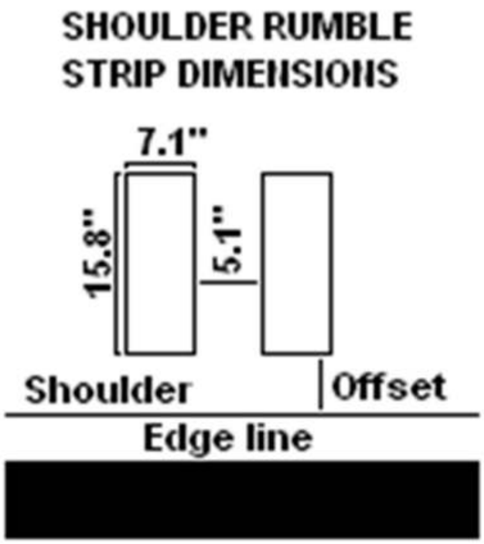
The potential negative effects from installing CLRS or any other rumble strips include: disruption to motorcycles and bicycles; roadside noise; and pavement deterioration.

Centerline rumble strips cost approximately $0.40 per linear foot, depending on the length of roadway, paving, pattern, location, etc. – this cost may be higher for single curves.

SHOULDER RUMBLE STRIP

Edge lines or center lines may be installed over a longitudinal rumble strip to create a **rumble stripe.** However, edge lines should not be used in addition to rumble stripes on shoulders. Colors for longitudinal rumble stripes have to conform to standard highway colors.

Rumble strips can be used with the edge line or on the roadway shoulder – if paved width is adequate. Although there are no specific guidelines when to use shoulder rumble strips, it should be considered for locations with a high number of run-off-road (ROR) crashes. SRS can alert drivers who veer onto the shoulder and thus avoid crashes. These rumble strips would likely not be used for a single curve due to high installation costs. Many of the guidelines for centerline rumble strips can be applied to those for shoulders as well.



(Source: Gregory J. Taylor)

(Source: LCTHCS)

Municipalities can change the SRS design to allow gaps in the pattern where bicycles can travel in order to reduce its potential negative effect on cyclists.

Shoulder rumble strips have proven safety benefits for large volume, high speed roads. Their effectiveness for lower volume roads may still prove to be cost efficient for high ROR crash sites. SRS on the New York State Thruway resulted in an 88% reduction in ROR crashes, and a 95% reduction in fatalities.

ROADWAY RUMBLE STRIP

Roadway (transverse) rumble strips (RRS) consist of intermittent narrow raised bars (maximum of ½ inch) or depressed grooves that extend across the travel lanes. These strips attract driver attention by noise and vibration in order to reduce speed or pay attention as they negotiate the horizontal curve.

(Source: LCTHCS)

For situations where the color of a transverse rumble strip within a travel lane does not match the color of the pavement - the color of the strip will be either black or white. White transverse rumble strips should not be placed where they may be confused with other transverse markings (stop lines, crosswalks, etc.).

<u>Guidelines for Using RRS on Horizontal Curves</u>

Locations with documented crash problem where conventional treatments have failed

Road segment with differences between roadway speed limit and curve advisory speed of 20 mph

Proximity of another geometric feature
(side street with limited sight distance, second, sharper curve, downgrade leading into the curve, etc.)

Long tangent section ending with a curve.

Municipalities can prevent drivers who are tempted to go around the rumble strip by driving onto the shoulder or into an adjacent lane by extending the rumble strip over part of the shoulder in addition to the traveled way or by using a discontinuous rumble strip configuration.

<u>Concerns With Roadway Rumble Strips</u>

•Noise complaints — avoid use in residential areas.

•Motorist use opposing lanes to avoid rumble strips — use a discontinuous pattern design

•Maintenance problems — grooved RRS is more durable and longer lasting

•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 — install a discontinuous patter design and warning sign RUMBLE STRIPS AHEAD.

•Overuse of rumble strips—leads to "crying wolf" attitude and therefore should be used sparingly.

Roadway rumble strips have proven to reduce roadway speeds but not to a practical level. Presently, there is no evidence of RRS effectiveness in reducing crashes at horizontal curves.

MINOR ROADWAY IMPROVEMENTS

The low-cost curve treatments shown below involve physical changes to the roadway.

PAVED SHOULDER TREATMENT

Paved shoulder treatments can replace unstable or narrow shoulders to increase safety and usable width. Different surface colorations can also prove beneficial. Cost benefits from upgrading to paved shoulders, as well as lower crash rates, should convince agencies with tight budgets of their advantages.

Roadway shoulder reconstruction involves removing and recompacting the shoulder base (commonly 6-in.). Asphalt roadway surfaces can be textured (visual, audible, and tactile clues) to warn drivers leaving the traveled way. Using a larger, uncoated seal coat on shoulders and a smaller aggregate seal coat on travel lanes is one method of texturizing.

Texas DOT (TxDOT) considers paved shoulder treatment to be operationally effective based on reported reductions in single ROR crashes - due to cues alerting drivers straying onto the shoulder. The traveling public also responded positively to the strong visual effect which should prove beneficial for night travel.

Seal-coating a gravel shoulder typically costs approximately \$1.00/yd^2 (for non-resurfacing projects).

SHOULDER DROP-OFF ELIMINATION

Pavement shoulder drop-off is defined as “the vertical height difference between the paved surface and the unpaved shoulder”. It is the result of unstabilized pavement edge erosion and occurs regularly for horizontal curves where motorists stray on the pavement edges. Small drop-offs (i.e. 3 inches) can prove dangerous when combined with vertical angles (90 degrees).

Drivers straying from a paved travel lane onto an unpaved shoulder often overcorrect to return to the road which can cause the rear tire to catch on the pavement edge, spin the vehicle, and lead to crashes (sideswipe, head-on, or opposite lane).

The shapes (vertical, rounded or tapered edge), pavement depths, vertical angle, and/or operational speed of pavement shoulder drop-offs can affect its hazard potential.

Compacted shoulder material can be provided to reduce drop-off depth and create a safe shoulder. A simple and cost-effective solution is the use of a 45-degree angle asphalt fillet for roadway edges on resurfacing projects. It provides a safe roadway edge and a strong interface between the roadway and the shoulder.

The 45-degree wedge can be created by using a steel wedge or the Safety Edge Maker™. The device's leading edge provides a smooth finished compaction and can be adjusted vertically for varying drop-off heights.

(Source: LCTHCS)

Drop-off shapes have been shown to reduce the rate of driver overcorrection, head-on, and run-off- road crashes.

<u>Benefits of Shoulder Drop-off Elimination</u>

- Fewer crashes
- Fewer injuries
- Reduced tort liability

Results from a Georgia DOT (GDOT) evaluation of the Safety Edge showed that it can be used on any type of roadway facility as part of asphalt preventative maintenance. Its use neither affects finished pavement smoothness or increases shoulder erosion.

Using the Safety Edge as part of the asphalt paving process can cost approximately less than one percent (1%) of hot-mix asphalt material.

WIDEN SHOULDER

Shoulders are roadway components adjacent to the travel lanes that are available for drivers to get off the roadway and avoid crashes. This is a particularly important safety feature at horizontal curves where vehicles may use more of the travel lane than other roadway sections.

(Source: LCTHCS)

Paved or stabilized roadway shoulders may have widths ranging from 2 feet (minor roads) to 12 feet (major roads). Any shoulder stabilization or roadside slope development must comply with AASHTO guidelines.

The table shown below displays estimated reductions in related crashes (single vehicle run-off-road, multiple vehicle head-on, sideswipe) resulting from widening paved or unpaved roadway shoulders. These estimated reductions apply only when roadside characteristics (side slope and clear zone) are rebuilt to conditions prior to any shoulder widening. The results are not limited to rural two-lane roads - it is reasonable to expect major benefits to horizontal curves as well.

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

(Source: LCTHCS)

SKID-RESISTIVE PAVEMENT SURFACE TREATMENT

Pavement maintenance is essential to ensure adequate friction for maneuvering and braking under both dry and wet conditions. Vehicle skidding occurs when friction demand exceeds friction force – between tires and the roadway surface. Crashes are extremely likely at horizontal curves under wet conditions. Pavement overlays and grooving have proven successful for roadway locations with histories of skidding crashes under wet conditions.

Remedial Skidding Treatments

Specific asphalt mixtures (aggregate type & gradation)

Pavement overlays (both concrete or asphalt)

Pavement grooving

Pavements with surface voids improve skid resistance and better drainage. A 1-inch open-graded asphalt concrete can help reduce wet pavement crashes since it has an increased number of surface voids than the maximum open-graded asphalt concrete standard mix.

Pavement Surface Overlay Procedure

- Repair major surface defects
- Apply dense-graded asphalt concrete
- Add tack coat to existing surface

or

apply a slurry seal

(Source: LCTHCS)

Pavement grooves are longitudinal or transverse cuts on rigid concrete surfaces to increase skid resistance and reduce the number of wet-weather crashes. Grooved pavement is intended for rigid concrete since asphalt's uniform structure is not drainage-friendly. Transverse grooves are most effective at locations with frequent stops. Longitudinal grooving is most effective for improving safety on horizontal curves by increasing directional control.

Research has shown greater accident reductions for 50 mph curves than at lower speed curves due to reduced hydroplaning (the major benefit of grooving).

TYPICAL PAVEMENT GROOVING DIMENSIONS

Depth	5/32" to 5/16"
Width	3/16" to 3/8"
Spacing	8 grooves/foot (random)

The New York State DOT (NYSDOT) implemented a statewide program to treat low skid resistance sites with overlays. NYSDOT treated 36 sites during a two-year period which resulted in reducing annually recurring wet road crashes by over 800 incidents. Their results showed that using this treatment helped reduce this type of crash by 50% and total crashes by 20%.

The Florida DOT (FDOT) tested Tyregrip® on a curved ramp. This treatment is a high-friction material consisting of a highly modified exothermic epoxy resin top with calcinated bauxite (Polish Stone Value of 70 percent plus). Tyregrip® effectively increased the skid resistance value from 35 to 104. This material may be applicable to a higher volume curve with a history of wet pavement crashes.

A California grooved pavement study showed a 72% reduction for wet pavement crashes and a 7% reduction for dry pavement crashes on a two-lane road with sharp curves. While pavement grooving is thought to accelerate roadway surface wear, it has does not affect ride quality nor drainage.

Skid-resistant overlay costs are relatively moderate - a typical Caltrans 2-mile section cost $200,000 in 1996.

INNOVATIVE TREATMENTS

The following treatments presented in this section do not have FHWA approval for general use. Municipalities need to get FHWA approval before installing any experimental treatments.

OPTICAL SPEED BARS

Optical Speed Bars are transverse stripes gradually spaced with decreasing distances in order to increase drivers' perception of speed and causing them to slow down (4-bar/sec spacing). The term "Optical Speed Bar" comes from its intended visual effect to the spacing of the treatment's painted white lines (18 in long and 12 in wide). Thermoplastic is the preferred marking material due to its durability.

(Source: LCTHCS)

Optical Speed Bars are designed to produce a gradual slowing from the initial approach speed to the reduced curve speed. As the bar spacing narrows – motorists sense an increase in speed and slow down to maintain the 4 bar/second spacing.

Optical Speed Bars are suitable for locations where traffic speeds need to be reduced. Currently, this treatment has been limited to known accident locations or sites requiring significant speed reduction. Overusing Optical Speed Bars (speed reduction only) can jeopardize the visual effect of this treatment.

The total length of the paving-marking segment is dependent on the desired speed difference (between approach and lower curve speed). The lengths listed in the table (shown below) are based on producing a comfortable speed reduction and providing a minimum of 4 seconds driving time within each marking segment.

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

Curve Speed, mi/h	Approach Speed, mi/h: 45	50	55	60	65	70
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

(Source: LCTHCS)

Research by New York, Mississippi, and Texas show transverse pavement markings can effectively reduce mean speeds, 85^{th} percentile speeds (initial reductions from 0 to 5 mph), and speed variance. Presently, their long term effects are not known.

A typical estimate (based on Virginia DOT data) to install Optical Speed Bars in two directions is approximately $2,000 (labor and materials).

PennDOT CURVE ADVANCE MARKING

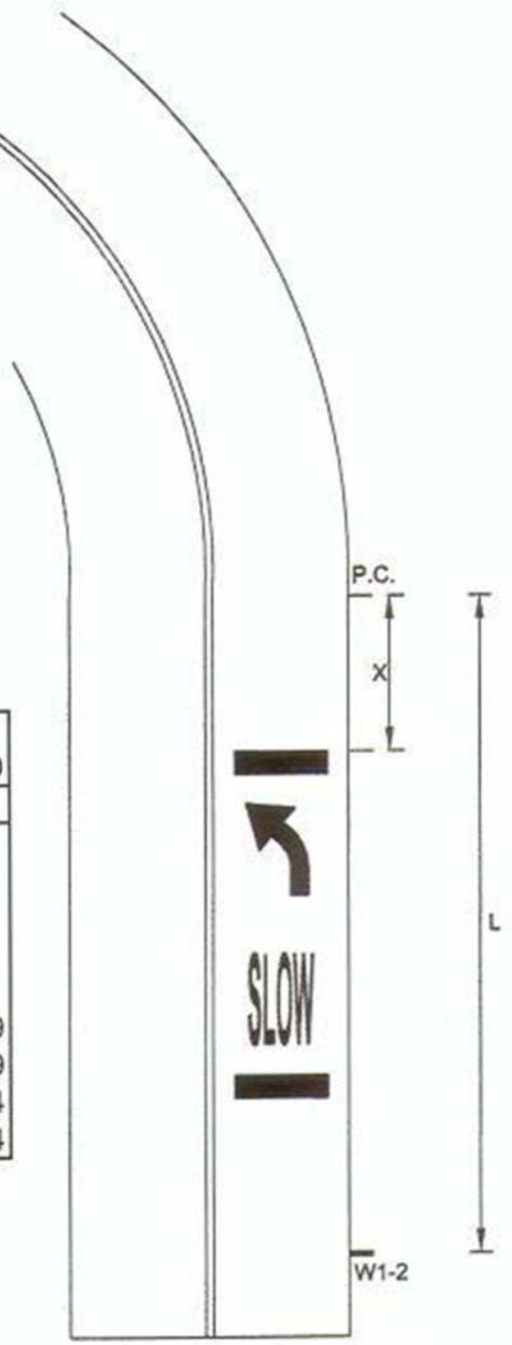
Pennsylvania DOT (PennDOT) developed their own type of innovative pavement marking for warning motorists of upcoming horizontal curves and alerting them to decrease their speed. The “PennDOT Curve Advance Marking” uses two transverse bars, a SLOW legend, and an arrow indicating the upcoming curve’s direction. PennDOT wanted a treatment to address two-lane locations with a high number of curve-related crashes. Their rationale was that you can reduce the number of run-off-road crashes by reducing the upper percentile speed.

(Source: LCTHCS)

The PennDOT Advanced Curve Warning marking should not be used where drivers may become confused due to intersecting roadways or driveways. Any existing signs, delineation, and pavement markings should be brought up to meet standards for locations with potential advanced curve warnings. Marking locations may be adjusted where sight distance is limited due to vertical geometry or other obstructions.

Using the PennDOT Advanced Curve Warning has been shown to reduce overall roadway speeds by 6 to 7 percent with slight reductions in high-speed traffic in curves. When using this treatment or any other device for horizontal curve safety, it is important to address the most hazardous curve first.

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



L is taken from Table II-1, pg 2C-3 of the MUTCD

(Source: LCTHCS)

MAINTENANCE TREATMENTS

Road agencies should properly maintain their roadways as well as any associated traffic control devices. It is important to plan and execute maintenance activities for continued user safety. The following maintenance treatments are highly recommended.

Restripe pavement markings as they lose their visibility.

Paint-based pavement markings have a typical service life of 1 to 2 years – which depends on material type, traffic volume, and climate. Thermoplastic markings have a much longer service life. Regular pavement marking inspection and restriping is crucial to provide adequate visibility.

Replace faded signs and those with low levels of retroreflectivity.

Retroreflective sheeting material for roadway signs is primarily responsible for night-time visibility. Although this material is being continuously improved to provide brighter and more durable signs, all signs still lose their color, retroreflectivity, and visibility over time. Responsible parties should have regularly scheduled inspections to ensure appropriate retroreflective levels for all signs. Any sign found to be ineffective should be replaced as soon as possible.

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

Safety at horizontal curve locations can be improved by providing the longest possible sight distance through curves or to traffic signs. Various types of vegetation can severely limit a motorist's view of the roadway or signs. Clearing any overgrowth can significantly improve sight distance through the curve and allow drivers to not only see the curve's length and sharpness – but also to see oncoming traffic. Annual roadway inspections can be used for identifying and correcting these issues.

Maintain the shoulders and smooth transitions between pavement and shoulder.

Roadway shoulders without any type of pavement or stabilization will usually erode over time and produce **pavement drop-offs**. Different types of delineation, markings, and warning systems can help correct this situation but periodic shoulder maintenance can *prevent* drop-offs from occurring.

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

Since run-off-road crashes occur more frequently at horizontal curves, it is important to minimize any roadside obstacles and install appropriate traffic barriers to shield them. Local authorities should be able to repair any barrier when needed.

Improve drainage around the curve.

Water flows on horizontal curves are caused by the roadway's superelevation. Improper or poor drainage on these curves may result in shoulder deterioration which in turn can cause pavement drop-off and shoulder loss. The use of curbs and improved drain maintenance may help resolve these issues.

SUMMARY

The purpose of this course was to encourage readers to use this information to evaluate problems and implement appropriate treatments for problem curve locations. These treatments should help reduce roadway departure crashes, injuries, and fatalities.

This course summarizes practical information on where, when, or how to apply safety treatments for horizontal curves or winding sections. These treatments are relatively low cost versus geometric design improvements (degree of curve, shoulders, superelevation, curve length, cross-section, etc.). Information for each treatment generally included *description, application guidelines, design elements and materials, effectiveness, and cost.*

Estimates for treatment effectiveness in reducing crashes were included if available. Actual observed effectiveness values of a treatment can vary depending on its location.

Some of the traffic control devices or treatments presented in this course may be considered to be “experimental” and not comply with the MUTCD.

Topics covered in this course include:

Enhanced Basic Treatments

Treatments considered to be enhancements to basic devices

Larger devices

Doubling-up

Retroreflective and fluorescent sheeting

Flashing beacons

Profile thermoplastic markings

Raised Pavement Markers

Other Traffic Control Device Treatments

Treatments not in the MUTCD which are used by State and local agencies

Reflective barrier delineation

Roadside object delineation

Dynamic Curve Warning System

Speed Limit Advisory Marking

Rumble Strips

Overview of applications

Centerline

Shoulder

Roadway

Minor Roadway Improvements

Low-cost treatments requiring minor roadway or shoulder improvements

Paved Shoulder Treatment

Shoulder drop-off elimination

Widen shoulder

Skid-resistive pavement surface

Innovative and Experimental Treatments

New treatments that have not been applied extensively

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