National Committee on Uniform Traffic Control Devices

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TECHNICAL COMMITTEE : Joint Task Force on Optional Applications of Pavement Markings and Delineators and Rumble Strip Markings in Combination with Horizontal Curve Warning Signing - June 2012

TOPIC: Optional Applications of Pavement Markings and Delineators and Rumble Strip Markings in Combination with Horizontal Curve Warning Signing

STATUS/DATE OF ACTION:

RWSTC Drafts	**01/03/13;01/09/13**
RWSTC Approval:	**1-10-13 (APPROVED BY RWSTC AND MARKINGS TECHNICAL COMMITTEES)**
Transmitted to Sponsors:	Submitted to sponsors Spring 2013
RWSTC Approval:	**June 26, 2013**
Markings Tech Comm Approval:	**June 26, 2013**
Council Approval:	**June 27, 2013**

ORIGIN OF REQUEST: **Task Force: Paul Carlson (Chair), Tom Heydel, Lee Roadifer, Stacey Glass, Richard Porter, Mark Nahra, Tom Grant, Dave Woodin, and Fred Ranck**

AFFECTED SECTIONS OF MUTCD: **Section 2C.06 Horizontal Alignment Warning Signs and Chapter 3B**

SUMMARY:

Current Text of 2009 MUTCD:

Section 2C.06 Horizontal Alignment Warning Signs

Support:

01 A variety of horizontal alignment warning signs (see Figure 2C-1), pavement markings (see Chapter 3B), and delineation (see Chapter 3F) can be used to advise motorists of a change in the roadway alignment. Uniform application of these traffic control devices with respect to the amount of change in the roadway alignment conveys a consistent message establishing driver expectancy and promoting effective roadway operations. The design and application of horizontal alignment warning signs to meet those requirements are addressed in Sections 2C.06 through 2C.15.

Standard:

02 **In advance of horizontal curves on freeways, on expressways, and on roadways with more than 1,000 AADT that are functionally classified as arterials or collectors, horizontal alignment warning signs shall be used in accordance with Table 2C-5 based on the speed differential between the roadway's posted or statutory speed limit or 85th-percentile speed, whichever is higher, or the prevailing speed on the approach to the curve, and the horizontal curve's advisory speed.**

Option:

03 Horizontal Alignment Warning signs may also be used on other roadways or on arterial and collector roadways with less than 1,000 AADT based on engineering judgment.

Table 2C-5. Horizontal Alignment Sign Selection

Type of Horizontal Alignment Sign	Difference Between Speed Limit and Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W10-1) (see Section 2C.07 to determine which sign to use)	Recommended	Required	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Recommended	Required	Required	Required	Required
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Optional	Recommended	Required	Required	Required
Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp	Optional	Optional	Recommended	Required	Required

Note: Required means that the sign and/or plaque shall be used, recommended means that the sign and/or plaque should be used, and optional means that the sign and/or plaque may be used.

See Section 2C.06 for roadways with less than 1,000 ADT.

1. RWSTC and Council approved the following prior to to the 2009 MUTCD:

Table 2C-5. Horizontal Alignment Sign Selection

Type of Horizontal Alignment Sign	Difference Between Speed Limit and Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W1-10) (see Section 2C.07 to determine which sign to use)	Option ~~Recommended~~	Recommended ~~Required~~	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Option ~~Recommended~~	Recommended ~~Required~~	Required	Required	Required
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Optional	Option ~~Recommended~~	Recommended ~~Required~~	Required	Required

Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp	Optional	Optional	Recommended	Recommended ~~Required~~	Required

Note: Required means that the sign and/or plaque shall be used, recommended means that the sign and/or plaque should be used, and
optional means that the sign and/or plaque may be used.
See Section 2C.06 for roadways with less than 1,000 AADT.

2. RWSTC and Council January 2011 previously approved the following changes to the 2009 MUTCD:

Section 2C.06 Horizontal Alignment Warning Signs, page 110

Standard:

In advance of horizontal curves on freeways, on expressways, and on roadways with more than 1,000 AADT that are functionally classified as arterials or collectors, horizontal alignment warning signs shall be used in accordance with Table 2C-5 based on the speed differential between the roadway's posted or statutory speed limit ~~or 85th percentile speed, whichever is higher, or the prevailing speed on the approach to the curve,~~ and the horizontal curve's advisory speed.

RESEARCH:

Statistics from the Fatality Analysis Reporting System (FARS) for 2008 were 34,017 fatal crashes with 17,818 of these being roadway departure crashes. Approximately 28 percent of these fatal crashes occurred along horizontal curves.

FHWA Summary of Horizontal Curve Fatalities from FARS:

2007 Fatalities in Horizontal Curves

fhwa

	Blank	Straight	Curve	Unknown	total	% of fatalities that occur in curves
Vermont	0	39	48	0	87	55.17%
Montana	0	139	124	0	263	47.15%
West Virginia	0	223	185	2	410	45.12%
Maine	0	104	84	0	188	44.68%
New Hampshire	0	73	54	0	127	42.52%
Kentucky	0	535	378	0	913	41.40%
Oregon	0	279	194	4	477	40.67%
Virginia	0	570	389	4	963	40.39%
Wyoming	0	116	78	1	195	40.00%
Arkansas	0	407	256	2	665	38.50%
Washington	0	396	234	0	630	37.14%
Tennessee	1	821	465	0	1287	36.13%
Colorado	0	344	191	0	535	35.70%
Connecticut	1	190	106	4	301	35.22%

Pennsylvania	0	993	532	0	1525	34.89%
Idaho	0	175	92	0	267	34.46%
North Carolina	0	1023	536	0	1559	34.38%
Missouri	0	721	375	0	1096	34.22%
Georgia	0	1110	575	8	1693	33.96%
Alaska	0	49	25	0	74	33.78%
Rhode Island	0	55	26	0	81	32.10%
Alabama	0	843	364	1	1208	30.13%
Wisconsin	0	502	217	5	724	29.97%
New York	0	1042	413	1	1456	28.37%
Louisiana	0	704	278	0	982	28.31%
Minnesota	0	355	138	1	494	27.94%
Maryland	0	472	176	3	651	27.04%
Delaware	0	109	39	0	148	26.35%
Hawaii	0	118	42	1	161	26.09%
South Carolina	0	776	261	0	1037	25.17%
Ohio	0	922	311	5	1238	25.12%
Utah	0	217	70	0	287	24.39%
North Dakota	0	86	25	0	111	22.52%
South Dakota	0	148	43	0	191	22.51%
California	0	3263	953	20	4236	22.50%
Nevada	0	335	97	0	432	22.45%
New Mexico	0	379	104	1	484	21.49%
Indiana	0	701	188	10	899	20.91%
Oklahoma	0	606	158	1	765	20.65%
Mississippi	0	735	176	0	911	19.32%
Texas	0	2791	669	15	3475	19.25%
Illinois	0	1018	235	1	1254	18.74%
Arizona	0	940	241	107	1288	18.71%
Massachusetts	0	338	80	12	430	18.60%
Florida	0	2759	609	6	3374	18.05%
New Jersey	157	480	135	0	772	17.49%
Michigan	0	882	183	20	1085	16.87%
Kansas	0	394	74	0	468	15.81%
Iowa	0	375	64	0	439	14.58%
Nebraska	0	230	39	0	269	14.50%
District of Columbia	0	32	5	0	37	13.51%
Total	159	30914	11334	235	42642	26.58%

These crashes occurred predominantly on two-lane rural highways that are often not part of the state DOT system. Considering these statistics and that the average accident rate for horizontal curves is about three times the average accident rate for highway tangents (Glennon et al., 1983), implementing strategies designed to improve the safety at horizontal curves will help achieve the overall goal of the AASHTO Strategic Highway Safety Plan.

Approximately 76 percent of curve-related fatal crashes were single-vehicle crashes in which the vehicle left the roadway and struck a fixed object or overturned, whereas 11 percent of curve-related fatal crashes were head-on crashes. Thus, ROR and head-on crashes accounted for 87 percent of the fatal crashes at horizontal curves, and the strategies for improving safety at horizontal curves focus on reducing the frequency and severity of these types of crashes. These strategies may not eliminate crashes with other vehicles, pedestrians, bicyclists, and trains that may be directly in the path of the vehicle, but crash statistics do not indicate that these types of collisions are prevalent on curves.

2. NCHRP 500 Volume 7: A Guide for Reducing Collisions on Horizontal Curves

Effectiveness of Traditional Advance Warning Treatments at Horizontal Curves

"Research suggests that the proliferation of curve warning signs, especially those supplemented with advisory speed plates, may have lessened the average motorist's respect for the messages that they convey (Lyles, 1980). However, because of tort liability concerns, many highway agencies prefer to use traditional advance warning and curve signs even if research indicates that these signs may be ineffective. The findings from studies that investigated the effectiveness of traditional advance warning signs are summarized in the following paragraphs.

Lyles (1980) examined the effectiveness of five sign treatments for controlling driver speeds in the vicinity of hazardous horizontal curves on rural two-lane highways. Sign treatments ranged from the standard curve warning sign to a regulatory speed zone sign in conjunction with a curve warning sign. The effectiveness of the signs was evaluated based on speeds of motorists as they approached and negotiated the horizontal curves and whether vehicles crossed over center and edgeline markings. Lyles found that no sign, or group of signs, was consistently more effective than another in decreasing the potential hazard at horizontal curves.

Zwahlen (1983) examined the effectiveness of advisory speed plates in causing drivers to reduce their speeds through curves. He concluded that advisory speed signs are not more effective in causing drivers to reduce their speeds through curves than the curve signs alone are, at least not in dry weather, and that further research was needed to determine the effectiveness of advisory speed signs in adverse weather conditions. Zwahlen recommended that advisory speed sign maintenance, especially new installations, be given a low priority.

Ritchie (1972) examined the choice of speed in driving through curves as a function of advisory speed and curve signs. He found that motorists drove faster and produced more lateral acceleration when (a) a curve sign was present, and (b) an advisory speed sign was present, than under the opposite conditions. In addition, motorists exceeded advisory speed signs of 24 to 56 km/h (15 to 35 mph), but motorists did not exceed advisory speed signs of 72 to 80 km/h (45 to 50 mph). Ritchie concluded that advance warning signs serve to reduce uncertainty and allow drivers to proceed with greater confidence.

One of the reasons for the low percentage of compliance with posted advisory speeds on curves may be that the criteria for setting advisory speeds on curves are outdated due to advances in vehicle characteristics. The current criteria for setting advisory speeds on curves have remained essentially unchanged for more than 50 years. Chowdhury et al. (1998) evaluated the validity of current criteria for determining advisory speeds on horizontal curves and concluded that the criteria are not valid for modern vehicles. At most curves, posted advisory speeds were well below the prevailing traffic speed and below the recommended values suggested by the two methods for determining advisory speeds, namely the ball-bank indicator and the *Traffic Control Devices Handbook* (TCDH) (Institute of Transportation Engineers, 2001). (1978 FHWA Traffic Control Devices Handbook +2001 ITE Traffic Control Devices Handbook use 14, 12, 10 degrees of bank for recommended curve speeds with 14 degrees for speeds below 20 mph, 12 degrees for 20-30 mph and 10 degrees for 35 mph or higher speeds)."

(Toward addressing the underlying issue of appropriate side friction values for design of horizontal curves and appropriate later acceleration values and their associated ball bank values, the Regulatory and Warning Signs Technical Committee of the National Committee on Uniform Traffic Control Devices undertook a comprehensive review of available research and technical knowledge applicable to horizontal curves in 2005 and 2006. Their recommendation in January of 2007 which was subsequently approved by the full National Committee was to revise the ball bank criteria to 16/14/12 degrees based upon published research by TTI. This change will increase recommended curve speeds by 8 to 10 mph).

"While the previously mentioned studies suggest that traditional advance warning treatments are not effective in decreasing the potential hazard at horizontal curves, several studies suggest otherwise. Hammer (1968) evaluated the effectiveness of various types of minor improvements in reducing accidents. Two of the minor improvements included in the evaluation were the installation of curve warning signs and advisory speed signs at horizontal curves. Hammer found that curve warning signs reduced accidents by 18 percent at horizontal curves and that installation of both curve warning and advisory speed signs reduced accidents by 22 percent. Leisch (1971) also reported advisory speed signs to be effective in reducing accidents at horizontal curves.

Hanscom (1976) evaluated a slightly different scenario. He evaluated the effects of signing to warn drivers of wet weather skidding hazards at horizontal curves. Three curved highway sections were treated using five experimental sign treatments. The primary measure of effectiveness was mean speed at the critical curve locations. In particular, the target sample was the highest quartile speed group of vehicles arriving in advance of the curve. Significant speed reductions were observed at critical curve locations during conditions of wet pavements when warning signs were supplemented with flashing beacons. Therefore, Hanscom recommended that activated warning signs be used at critical curve locations as a skidding accident countermeasure. Several other types of traditional advance warning treatments that have not necessarily been evaluated for their safety effectiveness at horizontal curves include oversized warning signs and double-posted signs. The MUTCD (USDOT, 2003) indicates that oversized warning signs may be used where speed, volume, and other factors result in conditions where greater visibility or emphasis would be desired, such as at unexpected or sharp horizontal curves. Agencies have also double-posted warning signs to draw greater attention to warning signs.

In summary, none of the studies designed to evaluate the effectiveness of traditional advance warning treatments at horizontal curves question the importance of providing a curve warning sign in advance of unexpected or sharp curves, but conflicting results have been obtained on the effectiveness of advisory speed signs. The most recent studies suggest that advisory speed signs do not garner respect from the average motorist. These studies conclude that advisory speed signs do not effectively reduce speeds at horizontal curves. Before drawing conclusions regarding the effectiveness of advisory speed signs on improving safety at horizontal curves, two issues should be considered. First, of the studies cited above, only Hammer evaluated the effectiveness of advisory speed signs using accident data. The other studies used speed as the measure for evaluating the effectiveness for advisory speed signs. Second, Hanscom is the only reference cited above that recommends targeting the highest quartile speed group of vehicles when evaluating the effectiveness of advance warning treatments based upon speed. He suggests that these vehicles are the vehicles most likely to be involved in accidents at horizontal curves.

Post-Mounted Delineators and Chevrons

Post-mounted delineators and chevrons are two types of delineation treatments that are installed outside of the roadway. They are intended to warn drivers of an approaching curve and provide tracking information and guidance to the drivers. While they are intended to act as a warning, it should also be remembered that the posts, placed along the roadside, represent a possible object with which an errant vehicle can crash. Design of posts to minimize damage and injury is an important part of the considerations to be made when selecting these treatments.

In *NCHRP Report 440*, Fitzpatrick et al. (2000a) report the results of several studies on postmounted delineators. They report that post-mounted delineators reduce the accident rate only on relatively sharp curves during periods of darkness. In addition, highways with postmounted delineators have lower accident rates than highways without post-mounted delineators, and the cost of post-mounted delineators are justified for highways with average daily traffic (ADT) exceeding 1,000 vehicles per day. Fitzpatrick et al. do not quantify the effectiveness of post-mounted delineators in reducing curve-related crashes. Bali et al. (1978) provide similar results.

Krammes and Tyer (1991) evaluated the operational effectiveness of raised pavement markers as an alternative to post-mounted delineators at horizontal curves on two-lane rural highways. They evaluated nighttime speed and lateral placement data from five sites. For both short-term and intermediate-term analyses, vehicle operations with raised pavement markers compared favorably with operations when post-mounted delineators were present. Vehicle operations were not significantly affected on the inside lane of the curve, but significant differences were observed on the outside lane of the curve. Speeds at the midpoint of the curve were consistently 1.6 to 4.8 km/h (1 to 3 mph) higher with the raised pavement markers, and the mean lateral placement of vehicles was consistently 0.3 to 0.6 m (1 to 2 ft) further from the centerline at the midpoint of the curve with the raised pavement markers than with the post-mounted delineators.

In addition, the variability in lateral placement of vehicles at the midpoint of the curve was less with raised pavement markers than with post-mounted delineators.

Zador et al. (1987) examined the short- and long-term effects of chevrons, post-mounted delineators, and raised pavement markers on the speed and placement of vehicles traveling on curves on rural two-lane highways. In general, all three delineation treatments affected driver behavior at night. Vehicle paths were shifted away from the centerline on horizontal curves where raised pavement markers and chevrons were installed and toward the centerline on curves where post-mounted delineators were used. Vehicle speed and placement variability were also slightly reduced with the use of chevrons and raised pavement markers. Zador et al. did not conclude that one delineation treatment was superior to the others and indicated that the primary benefit of any of these delineation treatments may simply be that they help drivers better recognize that they are approaching a curve.

Agent and Creasey (1986) investigated the ability of various traffic control devices to delineate horizontal curves so drivers would perceive the curve and slow to an appropriate speed and so drivers would have improved guidance through the curve. The investigation consisted of both laboratory tests and field data collection. The laboratory tests suggested that increasing the height of the post-mounted delineator while maintaining the distance from the post to the pavement edge, and keeping the post spacing constant, made a curve appear sharper than other delineator devices. From speed data, encroachment data, and some accident data, Agent and Creasey found that pavement markings had a greater effect on drivers than post-mounted delineators installed on the roadside did. In addition, chevrons had slightly more influence on speeds and encroachments than other post-mounted delineators did.

Jennings and Demetsky (1985) evaluated the effectiveness of three post-mounted delineator systems in controlling ROR crashes. The post-mounted delineator systems were evaluated based upon changes in speed and lateral placement of vehicles within the travel lane. Jennings and Demetsky found that drivers reacted most favorably to chevron signs on sharp curves greater than or equal to 7 degrees (radius of 250 m [820 ft]) and to standard postmounted delineators on curves less than 7 degrees."

Park, Carlson, Porter and Andersen (2011) reported consistent findings supporting the positive safety effects of wider edge lines installed on rural, two-lane highways. Results of empirical Bayes before-after evaluation of 1,626 segments (1,178 miles) of rural two-lane roadways in Kansas found a 17.5% reduction in total crashes and a 36.5% reduction in fatal plus injury crashes.

The findings from 253 segments (851.5 miles) in Michigan with 3 years of before and 3 years of after crash data were a 27.4% reduction in total crashes and 15.4% reduction in fatal plus injury crashes and a 19.4% reduction in total crashes and 16.1% reduction in fatal plus injury crashes from a 2^{nd} set of highway segments. The findings from Illinois crash data without animal collisions were a 30.l% reduction in total crashes and a 37.7% reduction in fatal plus injury crashes.

Table 8
Percent crash reduction estimates for wider edge lines on rural, two-lane highways based on the crash data from three states.

Crash type	Percent crash reduction			
	KS	MI (analysis 1)	MI (analysis 2)	IL (without
Total	**17.5**	**27.4**	**19.4**	**30.1**
Fatal plus injury	**36.5**	15.4	16.1	**37.7**
PDO	**12.3**	**30.5**	**19.6**	**23.9**
Day	**28.6**	**20.3**	12.0	**29.1**
Night	3.7	**30.7**	**18.8**	**29.9**
Daytime fatal plus injury	**41.5**	8.2	23.0	**36.0**
Nighttime fatal plus injury	12.7	22.6	−5.8	**34.2**
Wet	**22.9**	**67.2**	**62.6**	**34.7**
Wet night	24.3	**76.9**	**79.2**	35.7
Single vehicle	**27.0**	**30.0**	**18.7**	**37.0**
Single vehicle wet		**73.8**	**65.9**	**32.8**
Single vehicle night	**18.4**	**29.4**	**18.0**	**29.5**
Single vehicle fatal plus injury	**36.8**	10.0	−1.9	**42.2**
Single vehicle night fatal plus injury	18.7	9.7		**36.3**
Older driver				**24.1**
Fixed object	**19.0**			**29.5**

Note: Estimates in bold are significant at 95% confidence level.

2. More recent research as provided by the Crash Modification Clearinghouse (www.cmfclearinghouse.org) lists the following values for various warning signs, pavement markings, delineator, and rumble strip measures:
   a. Install edgelines and centerlines

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.76[B]	24	★★★★☆	All	Serious injury,Minor injury	All	Rural	Elvik, R. and Vaa, T., 2004

   b. Install edgelines, centerlines, and delineators

− Countermeasure: Install edgelines, centerlines, and post-mounted delineators

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.55 [B]	45	★★★★☆	All	Serious Injury,Minor Injury	Not Specified	All	Elvik, R. and Vaa, T., 2004

c. Install Edgelines on Curves

− Countermeasure: Install edgelines (curves)

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.741	25.9	★★★☆☆	All	All	Not Specified	Rural	Tsyganov et al., 2009
0.671	32.9	★★★☆☆	All	All	Not Specified	Rural	Tsyganov et al., 2009
0.89	11	★★★☆☆	Run off road	All	Not Specified	Urban	Tsyganov et al., 2009
0.873	12.7	★★☆☆☆	Run off road	All	Not Specified	Rural	Tsyganov et al., 2009
0.963	3.7	★★☆☆☆	Speed related	All	Not Specified	Rural	Tsyganov et al., 2009

d. Install wider edgelines (4” to 6”)

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.929	7.1	★★★★☆	All	All	All	Rural	Miles et al., 2010
0.829	17.1	★★★★☆	All	Fatal,Serious injury,Minor injury	All	Rural	Miles et al., 2010

e. Install wider markings and either edgeline or shoulder rumble strips with resurfacing

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.903	9.7	★★★★☆	All	Fatal,Serious injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.816	18.4	★★★★☆	All	Fatal,Serious injury,Minor injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010

f. Install wider markings without resurfacing

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.567	43.3	★★★★☆	All	Fatal,Serious injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010

g. Install Chevrons on Horizontal Curves

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.75	25	★★★★☆	Nighttime,Non-intersection	All	All	Rural	Srinivasan et al., 2009
0.78	22	★★★★☆	Head on,Nighttime,Non-intersection,Run off road,Sideswipe	All	All	Rural	Srinivasan et al., 2009

h. Install new or upgrade to fluorescent sheeting curve signs

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.82	18	★★★★☆	Non-intersection	All	All	Rural	Srinivasan et al., 2009
0.82	18	★★★★☆	Head on,Non-intersection,Run off road,Sideswipe	All	All	Rural	Srinivasan et al., 2009
0.75	25	★★★★☆	Non-intersection	Fatal,Serious injury,Minor injury	All	Rural	Srinivasan et al., 2009
0.66	34	★★★★☆	Head on,Nighttime,Non-intersection,Run off road,Sideswipe	All	All	Rural	Srinivasan et al., 2009

0.65	35	★★★☆☆	Nighttime,Non-intersection	All	All	Rural	Srinivasan et al., 2009

i. Install delineators

Countermeasure: Install post-mounted delineators

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
1.04 [B*]	-4	★★★☆☆	All	Serious Injury,Minor Injury	Not Specified	Rural	Elvik, R. and Vaa, T., 2004
1.05 [B*]	-5	★★★☆☆	All	Property Damage Only (PDO)	Not Specified	Rural	Elvik, R. and Vaa, T., 2004

j. Install static Horizontal Curve Warning Signs

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.7	30	Cannot Be Rated	Run off road	All	All	All	Agent et al., 1996

k. Install Raised Pavement Markers and Transverse Rumble Strips on Approaches to Horizontal Curves

Countermeasure: Install raised pavement markers and transverse rumble strips on approach to horizontal curves

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.94	6	★★☆☆☆	Run off road	Serious injury,Minor injury	Not specified	Rural	Elvik, R. and Vaa, T., 2004

l. Edgeline Shoulder Rumble Strips

− Countermeasure: Install edgeline rumble strips

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.67	33	★★★★☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.61	39	★★★★☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.71	29	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Principal Arterial Other Freeways and Expressways	Rural	Torbic et al., 2009
0.75	25	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Principal Arterial Other Freeways and Expressways	Rural	Torbic et al., 2009
0.75	25	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.7	30	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.58	42	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
1.31	-31	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009

m. Centerline Rumble Strip on Horizontal Curves

Countermeasure: Install centerline rumble strips on horizontal curves

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.53	47	★★★★★	Head on,Sideswipe	All	Not Specified	Rural	Torbic et al., 2009
0.83	17	★★★★☆	All	All	Not Specified	Rural	Torbic et al., 2009
1.16	-16	★★★★☆	All	All	Not Specified	Rural	Torbic et al., 2009
1.03	-3	★★★★☆	All	All	Not Specified	Rural	Torbic et al., 2009
1.04	-4	★★★★☆	All	All	Not Specified	Rural	Torbic et al., 2009
0.63	37	★★★★☆	All	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
1.1	-10	★★★★☆	All	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.94	6	★★★★☆	All	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009
0.53	47	★★★★☆	Head on,Sideswipe	All	Not Specified	Rural	Torbic et al., 2009
0.79	21	★★★☆☆	All	Fatal,Serious injury,Minor injury	Not Specified	Rural	Torbic et al., 2009

n. Shoulder and Centerline Strips

Countermeasure: Install centerline and shoulder rumble strips

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.82	18	★★★★☆	All	Fatal,Serious injury	Principal Arterial Other	Rural	Sayed et al., 2010
0.79	21.4	★★★★☆	Cross median,Frontal and opposing direction sideswipe,Head on,Run off road	All	Principal Arterial Other		Sayed et al., 2010

o. Install Wider Edgeline Markings with Resurfacing

− Countermeasure: Install wider markings and either edgeline or shoulder rumble strips with resurfacing

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.903	9.7	★★★★☆	All	Fatal,Serious injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.816	18.4	★★★★☆	All	Fatal,Serious injury,Minor injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.789	21.1	★★★★☆	All	Fatal,Serious injury	Principal Arterial Other Freeways and Expressways	Rural	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.787	21.3	★★★★☆	All	Fatal,Serious injury,Minor injury	Principal Arterial Other Freeways and Expressways	Rural	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.822	17.8	★★★★☆	All	Fatal,Serious injury,Minor injury	Principal Arterial Other Freeways and Expressways	Urban	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.794	20.6	★★★★☆	All	Fatal,Serious injury,Minor injury	Not Specified	Rural	Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.859	14.1	★★★★☆	All	Fatal,Serious injury,Minor injury	Not Specified	Urban	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010

p. Install wider edgelines without resurfacing

Countermeasure: Install wider markings WITHOUT resurfacing

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.567	43.3	★★★★☆	All	Fatal,Serious injury	All	All	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.38	62	★★★★☆	All	Fatal,Serious injury	Principal Arterial Other Freeways and Expressways	Rural	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010
0.441	55.9	★★★★☆	All	Fatal,Serious injury,Minor injury	Principal Arterial Other Freeways and Expressways	Urban	Potts, Hutton, Harwood, Bokenkroger, and Curtit, 2010

q. Increase Pavement Friction CMF=0.799

Countermeasure: Improve pavement friction (increase skid resistance)

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.799	20.1	★★★★☆	All	All	Not Specified	All	Lyon and Persaud, 2008

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Roadway Type	Area Type	Reference
0.76	24	★★★★★	All	All	All	All	Harkey et al., 2008
0.43	57	★★★★★	Wet road	All	All	All	Harkey et al., 2008
0.83	17	★★★★★	Rear end	All	All	All	Harkey et al., 2008
0.7	30	★★★★★	Single vehicle	All	All	All	Harkey et al., 2008
0.58	42	★★★★☆	Rear end	All	All	All	Harkey et al., 2008

3. The Highway Safety Manual (AASHTO 2009) provides methods to predict crashes for two lane rural highways and to quantify the effect of curvature for horizontal curves. For example for a typical 55 mph rural highway with 12 foot wide lanes and 6 foot wide paved shoulders,

For a Typical Rural 2-Lane Highway

Posted speed limit of 55 mph		
Total width (12 foot lane + 6 foot shoulders) =36 feet	36	
Degree of Curve	**9**	
Superelevation	**6**	
Length of curve in feet	1,000	0.189
Average Daily Traffic	5,000	

Curve Recommended Speed (mph)	Differential Speed (mph) of tangent to curve	Radius (feet) at **6%** superelevation	CMF without spiral transition	CMF with spiral transition
55	0	**1065**	1.257	1.216
50	5	835	1.327	1.286
45	10	660	1.414	1.373
40	15	510	1.536	1.495
35	20	380	1.719	1.678
30	25	275	1.993	1.953
25	30	185	2.477	2.436
20	35	115	3.376	3.335
15	40	65	5.203	5.162
10	45	15	19.213	19.172

From this analysis, for the typical horizontal curve without a spiral transition, annual crash frequency is 32.7% higher at 5 mph curve differential speed and 41.4% higher for 10 mph curve differential speed with even higher crash frequencies where the curve differential speeds are 15 mph or higher.

The overall safety effect of a horizontal curve on a two-lane rural highway is significant in that those horizontal curves with differential speeds of 15 mph to 25 mph have increased crash frequencies ranging from 50% to 99%

RECOMMENDED MUTCD PROVISIONS/ REVISIONS:

Note: Proposed changes to the MUTCD are shown in Underlined red and removed text are shown in ~~strike through Red.~~ ~~Blue strike through was adopted in 2011 by Council.~~ Items shown in blue in table 2C-5 previously approved by Council 2011

1. **Revise Table 2C-5 by relaxing certain thresholds if combined with pavement marking treatments as identified in a new section of Part 3.**

Section 2C.06 Horizontal Alignment Warning Signs

Standard:

02 **In advance of horizontal curves on freeways, on expressways, and on roadways with more than 1,000 AADT that are functionally classified as arterials or collectors, horizontal alignment warning signs shall be used in accordance with Table 2C-5 based on the speed differential between the roadway's posted or statutory speed limit ~~or 85th percentile speed, whichever is higher, or the prevailing speed on the approach to the curve,~~ and the horizontal curve's advisory speed.**

03 Horizontal Alignment Warning signs may also be used on other roadways or on arterial and collector roadways with less than 1,000 AADT based on engineering judgment.

Table 2C-5. Horizontal Alignment Sign Selection

Type of Horizontal Alignment Sign	Difference Between Speed Limit and Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W1-10) (see Section 2C.07 to determine which sign to use)	Optional ~~Recommended~~	Recommended ~~Required~~	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Optional ~~Recommended~~	Recommended ~~Required~~	Required	Required	Required
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Optional	Optional ~~Recommended~~	Recommended[1]	Required[2]	Required
Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp	Optional	Optional	Recommended	Recommended ~~Required~~	Required

Note: Required means that the sign and/or plaque shall be used, "recommended" means that the sign and/or plaque should be used, and
"optional" means that the sign and/or plaque may be used.
See Section 2C.06 for roadways with less than 1,000 AADT.

[1] Optional when one or more of the treatments listed in Section 3A.07 are used.
[2] Recommended when one or more of the treatments listed in Section 3A.07 are used.

Support:
The curve safety countermeasures identified below have been shown to be beneficial when applied in combination with horizontal alignment warning signs to enhance safety around curves:

1. Wide Edge lines,
2. Delineators,
3. Raised Retroreflective Pavement Markers
4. Longitudinal Rumble Strips or Stripes
5. Profiled Pavement Markings and/or
6. Other curve safety countermeasures with demonstrated safety benefits in reducing horizontal curve crashes.

Examples of curve safety countermeasures with demonstrated safety benefits include illumination, safety edge, and high friction surface treatments.

Section 3A.XX after Section 3A.07 as follows:

New Section following existing Section 3A.07

Section 3A.07 Application of Markings, Delineation, and Rumble Strips in Combination with Horizontal Alignment Warning Signs

Option:

The following curve safety countermeasures may be used ~~to relax~~ to modify selected curve signing requirements as indicated in Table 2C-5.

1. **Wide Edge lines**
2. **Delineators**
3. **Raised Retroreflective Pavement Markers**
4. **Longitudinal Rumble Strips or Stripes**
5. **Profiled Pavement Markings, and/or**
6. **Other treatments with demonstrated safety benefits in reducing horizontal curve crashes**

Support:

Examples of curve safety countermeasures with demonstrated safety benefits include illumination, safety edge, and high friction surface treatments.

Joint Task Force: VOTE FOR: Unanimous 1-9-13

Markings Technical Committee: 1-10-13 For: Unanimous
RWSTC 1-10-13 For: 24 Opposed: 0 Abstentions: 0
RWSTC 6-26-13 For: 26 Opposed: 0 Abstentions: 0
Markings Technical Committee: 6-26-13 For: Unanimous

COUNCIL VOTE: Motion passed 6-27-13
For: 33
Opposed: 1
Abstentions: 0

C:ncutcd/January 2013/Joint Task Force on optional markings measures approved RWSTC 1-10-13, revised by 6-26-13 following sponsor comments, as approved by Council 6-27-13