Safety Improvements for Horizontal Curves

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Safety Improvements for Horizontal Curves

• Presentation Overview
  • Case Study
  • MUTCD Signing Requirements (§2C.06 - §2C.14)
    o Table 2C-5 on Horizontal Alignment Sign Selection
    o Advisory Speed Changes
    o Exceptions
  • 2015 NCHRP Study with Traffic Control Device Guidelines for Curves
  • INDOT HFST Projects
  • Conclusion
Presentation Overview (Cont’d)

Additional Resources: https://safety.fhwa.dot.gov/provencountermeasures/
Case Study

- SR 159 at Louisville Rd, Vigo County
  - INDOT loses 2012 lawsuit about horizontal curve signing
  - Jury awarded $250,000 to plaintiff for injuries sustained due to inadequate road signage (Gulley v. INDOT).
Case Study (Cont’d)

• SR 159 at Louisville Rd, Vigo County (Aerial View)
Case Study (Cont’d)

• SR 159 at Louisville Rd, Vigo County (2005 Videolog Image 1)
Case Study (Cont’d)

- SR 159 at Louisville Rd, Vigo County (2005 Videolog Image 2)
Case Study (Cont’d)

Additional Resource

**Legal Research Digest 63**

**EFFECT OF MUTCD ON TORT LIABILITY OF GOVERNMENT TRANSPORTATION AGENCIES**

This report was prepared under NCHRP Project 20-6, “Legal Problems Arising Out of Highway Programs,” for which the Transportation Research Board is the agency coordinating the research. The report was prepared by Larry W. Thomas, The Thomas Law Firm, Washington, DC; James B. McDaniel, TRB Counsel for Legal Research Projects, was the principal investigator and content editor.

### The Problem and Its Solution

State highway departments and transportation agencies have a continuing need to balance efficient operations and legal protection of specific problems in highway design. This report examines MUTCD's guidance for highway departments in the use of signs that will affect their operations.

### Applications

The most recent version of the Annual Outdoor Traffic Control Devices (MUTCD) was adopted by the US Department of Transportation on December 11, 2001, to be effective January 11, 2003. The 2001 edition of the MUTCD includes new and revised requirements that will affect specific highway transportation agencies.

### Under the 2011 IMUTCD is the advance horizontal alignment warning sign correct for a combined curve/intersection?

### Is a single large arrow sign sufficient for the in-curve signing?

- Under the 2011 IMUTCD is the advance horizontal alignment warning sign correct for a combined curve/intersection?
- Is a single large arrow sign sufficient for the in-curve signing?
## 2011 IMUTCD Requirements (Cont’d)

### Table 2C-5. Horizontal Alignment Sign Selection

<table>
<thead>
<tr>
<th>Type of Horizontal Alignment Sign</th>
<th>Difference Between Speed Limit and Advisory Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 mph</td>
</tr>
<tr>
<td>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)</td>
<td>Recommended</td>
</tr>
<tr>
<td>Advisory Speed Plaque (W13-1P)</td>
<td>Recommended</td>
</tr>
<tr>
<td>Chevrons (W1-9) and/or One Direction Large Arrow (W1-6)</td>
<td>Optional</td>
</tr>
<tr>
<td>Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp</td>
<td>Optional</td>
</tr>
</tbody>
</table>

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.
## Table 2C-5. Horizontal Alignment Sign Usage

<table>
<thead>
<tr>
<th>Number of Alignment Changes</th>
<th>Advisory Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \leq 50 \text{ km/h} (\leq 30 \text{ MPH}) )</td>
</tr>
<tr>
<td></td>
<td>Turn (W1-1)&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>Reverse Turn&lt;sup&gt;2&lt;/sup&gt; (W1-3)</td>
</tr>
<tr>
<td>2&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Winding Road&lt;sup&gt;3&lt;/sup&gt; (W1-5)</td>
</tr>
<tr>
<td>3 or more&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1. Engineering judgment should be used to determine whether the Turn or Curve sign should be used.
2. Alignment changes are in opposite directions and are separated by a tangent distance of 180 m (600 ft) or less.
3. A Right Reverse Turn (W1-3R), Right Reverse Curve (W1-4R), or Right Winding Road (W1-5R) sign is used if the first change in alignment is to the right; a Left Reverse Turn (W1-3L), Left Reverse Curve (W1-4L), or Left Winding Road (W1-5L) sign is used if the first change in alignment is to the left.
§2C.11 Combination Horizontal Alignment/Intersection Signs (W1-10 Series)

- A turn (W1-1) or curve (W1-2) sign may be combined with a cross road (W2-1) sign or a side road (W2-2, W2-3) sign to create a combination horizontal alignment/intersection sign.
- No more than one cross road or two side roads should be used.
## Table 2C-6. Typical Spacing of Chevron Alignment Signs on Horizontal Curves

<table>
<thead>
<tr>
<th>Advisory Speed</th>
<th>Curve Radius</th>
<th>Sign Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 mph or less</td>
<td>Less than 200 feet</td>
<td>40 feet</td>
</tr>
<tr>
<td>20 to 30 mph</td>
<td>200 to 400 feet</td>
<td>80 feet</td>
</tr>
<tr>
<td>35 to 45 mph</td>
<td>401 to 700 feet</td>
<td>120 feet</td>
</tr>
<tr>
<td>50 to 60 mph</td>
<td>701 to 1,250 feet</td>
<td>160 feet</td>
</tr>
<tr>
<td>More than 60 mph</td>
<td>More than 1,250 feet</td>
<td>200 feet</td>
</tr>
</tbody>
</table>

Note: The relationship between the curve radius and the advisory speed shown in this table should not be used to determine the advisory speed.
Setting Advisory Speeds

• 2001 ITE Traffic Control Devices Handbook Ball Bank Procedures
  - 14 degrees of ball-bank for speeds of 20 mph or less
  - 12 degrees of ball-bank for speeds of 25 to 30 mph
  - 10 degrees of ball-bank for speeds of 35 mph and higher
Setting Advisory Speeds (Cont’d)

• 2011 IMUTCD Ball Bank Procedures in §2C.08
  ➢ 16 degrees of ball-bank for speeds of 20 mph or less
  ➢ 14 degrees of ball-bank for speeds of 25 to 30 mph
  ➢ 12 degrees of ball-bank for speeds of 35 mph and higher
  ➢ The 16, 14, and 12 degrees of ball-bank criteria are comparable to the current AASHTO horizontal curve design guidance.
Setting Advisory Speeds (Cont’d)

- Ball Bank Study Products and Services (No Endorsement)

**Rieker Products and Services**

- **MECHANICAL INCLINOMETERS**
  - 1023W1 Mechanical Inclinometer | Ball Bank Indicator
  - Price: $82.00

- **CARS: CURVE ADVISORY REPORTING SERVICE**

- **ELECTRONIC SENSORS**
  - RDS7-BB-09 Digital Ball Bank Indicator
  - Price: $704.44

**Vericom Product**

- V-SENSE RG
  - ROAD GEOMETRY / CURVE AUDIT SYSTEM
  - 1-PASS ROAD AUDIT
  - Price: $4,675.00
  - P/N: 530850-RG
  - Add to Cart
IMUTCD Target Compliance Date (from Table I-2)

December 31, 2019
(in 300 days)
Exceptions

- Low AADT (<1000); or
- Roadway functional classification status below collector

- Chevrons (W1-8) are not required if a One-Direction Large Arrow, also known as a night arrow sign (W1-6) is used.
Traffic Control Device Guidelines for Curves

• 2015 Study by Paul Carlson and Bradford Brimley with TTI (NCHRP 03-106)
  - Reviewed traffic control device applications for curves
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont’d)
  - Included Driver Behavior Study
  - 103 participants and 4,800 driver observations (3 states ID, OR, TX)

### Effects of TCDs on Curve Navigation Models

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Effect on Speed at PC (mph)</th>
<th>Effect on Deceleration Rate (ft/s²)</th>
<th>Effect on Lateral Acceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve sign</td>
<td>-0.88</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>Delineators</td>
<td>-2.3</td>
<td>-0.93</td>
<td>-0.018</td>
</tr>
<tr>
<td>Large Arrow</td>
<td>-2.7</td>
<td>-0.85</td>
<td>-0.0098</td>
</tr>
<tr>
<td>Chevrons</td>
<td>-2.5</td>
<td>-0.94</td>
<td>-0.026</td>
</tr>
<tr>
<td>RPMs</td>
<td>Not significant</td>
<td>-0.23</td>
<td>Not significant</td>
</tr>
</tbody>
</table>
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont’d)
  - Included Safety Analysis
  - 271 isolated curves and 270 curve series (4 states FL, OH, OR, TN)

Safety Performance at Curve Series
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont’d)
  - In-curve warning signs are chevrons and large arrow signs located in the curve (dashed line below represents aggregate of data)

Safety Performance at Isolated Curves
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont’d)
  
  - Advance warning signs are curve, turn, and winding road (dashed line below represents aggregate of data)
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont’d)
  - Turn signs are more effective than curve signs when the degree of curvature is greater than 10 degrees (radius less than ~600 ft).

Safety Performance of Curve and Turn Signs at Isolated Curves

![Graph showing the effectiveness of curve and turn warning signs vs. degree of curvature]
Traffic Control Device Guidelines for Curves

• NCHRP 03-106 Research (Cont’d)

<table>
<thead>
<tr>
<th>Speed Limit (mph)</th>
<th>Devices for Curve Advisory Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>25 20 25 30 35 40 45 50 55 60 65 70</td>
</tr>
<tr>
<td>25</td>
<td>M  M  M  M  M  M  M  M  M  M  M  M</td>
</tr>
<tr>
<td>30</td>
<td>W  W  W  W  M  M  M  M  M  M  M  M</td>
</tr>
<tr>
<td>35</td>
<td>D  D  D  D  D  D  D  D  D  D  D  D</td>
</tr>
<tr>
<td>40</td>
<td>D  D  D  D  D  D  D  D  D  D  D  D</td>
</tr>
<tr>
<td>45</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>50</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>55</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>60</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>65</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>70</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
<tr>
<td>75</td>
<td>C  C  C  C  C  C  C  C  C  C  C  C</td>
</tr>
</tbody>
</table>

Notes:

*The 85th percentile speed may be used in place of the speed limit (Section 2C.06a, Paragraph 06).
*An advance warning sign shall be used on roads without pavement markings as defined in Section 2C.06a, Paragraph 01.
AASHTO Request for Revision or Extension

• AASHTO has requested FHWA revise Chapter 2C based on these findings and issue an interim approval.
• The request also asked FHWA to consider extending the target compliance date by ten years to 12/31/2029.
• FHWA has not responded to the request as of 3/6/2019.
INDOT Curve Sign & Marking Visibility Projects

• District Contracts
  ➢ 8 contracts (to date)
    T-35109   T-36591
    RS-36046 (incl. resurfacing) T-39130
    T-39138   T-39140
    T-39148   T-39984
  ➢ $2 million spent (to date)
INDOT High Friction Surface Treatment Projects

• High Friction Surface Treatments (HFST)
  ➢ Consist of a high friction aggregate (primarily calcined bauxite) set in a polymer resin binder.
  ➢ HFST was first developed in Europe in the 1960’s and has now been installed in over 44 states.
  ➢ INDOT has let 2 contracts (T-40130 and R-40695) to apply HFST at 25 curves
INDOT HFST Projects (Cont’d)

• Expectations for HFST Projects
  • Service Life ~ 10 years
  • Cost ~ $17 /sys (weighted average from T-40130 and R-40695)
  • Crash Modification Factor ~ 0.52
    (Some locations have a higher level of crash reductions)

Additional Resources
### INDOT HFST Projects (Cont’d)

- INDOT HFST Pay Item Data (to date)

<table>
<thead>
<tr>
<th>High Friction Surface Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay Item 617-12128</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contract</th>
<th>Quantity (sys)</th>
<th>Unit Price (per sys)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-40130</td>
<td>51,168</td>
<td>$16.10</td>
<td>$823,804</td>
</tr>
<tr>
<td>R-40695</td>
<td>8,079</td>
<td>$19.50</td>
<td>$157,541</td>
</tr>
<tr>
<td>Totals:</td>
<td>59,247</td>
<td>$16.56</td>
<td>$981,345</td>
</tr>
</tbody>
</table>
Summary

• Takeaways

➢ Advisory speeds set prior to the 2011 IMUTCD need to be reviewed
➢ Review horizontal alignment signs and traffic control devices at horizontal curves.
➢ Current MUTCD Compliance Deadline of 12/31/2019
Conclusion

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