ALIGNMENT and CROSS SECTION

NCHRP Report 500, Vol. 7

Objectives

• Reduces likelihood of vehicle crossing centerline or leaving roadway
• Minimize consequences of leaving roadway
Most Prevalent Crash Types

- “Run Off the Road” (ROR) crashes
- Head-on crashes

Problem Description

- 25% of all fatalities occurred along horizontal curves
- Average accident rate on horizontal curves
EXHIBIT III-1
Percentage of Fatalities by Roadway Alignment

- Tangent: 74%
- Curve: 25%
- Unidentified: 1%

EXHIBIT III-2
Severity Distribution
*All crashes on curved-roadway segments*

- Fatal: 1.8%
- Incapacitating: 10.0%
- Non-Incapacitating: 15.9%
- Possible Injury: 13.7%
- No Injury: 58.5%

Source: GES 1999
EXHIBIT III-3
Location of Fatal Crashes on Horizontal Curves

Urban
27%

Rural
73%

EXHIBIT III-4
Location of Fatal Crashes on Horizontal Curves by Roadway Classification

Local Road or Street
23%

Collector
31%

Minor Arterial
17%

Principal Arterial - Interstate
10%

Principal Arterial - Freeway or Expressway
3%

Principal Arterial - Other
16%
EXHIBIT III-5
Fatal Crashes on Horizontal Curves
By Number of Lanes and Rural vs. Urban

EXHIBIT III-6
Position of Crash Relative to Roadway
All crashes on curved-roadway segments

Source: GES, 1999
Objective I

Reduce likelihood of leaving lane
Advance Warning of Unexpected Horizontal Alignment Changes

- Roadway signing – ‘curve’ sign
  - Low cost ‘tried’ option
  - With advisory speed plates
    - Increases effectiveness slightly
  - With flashing beacon
    - Significant speed reduction
Advance Warning of Unexpected Horizontal Alignment Changes

• Pavement markings
  – Transverse stripes of decreasing width and spacing
  – Narrowing edge lines
  – Low cost options
  – Under experimentation
Advisory Speed Plates

- Low compliance with advisory speeds
- Criteria to set advisory speeds, 50+ yrs old
- Drivers drive faster with more lateral acceleration than curve sign and advisory speed plate recommend
Enhance Delineators Along Curve

- Methods
  - Chevrons
  - Post-mounted delineators
  - Delineators on guardrail
  - Lane lines
  - Edge lines
  - Raised pavement markers
  - Non-traditional LED in pavement (light emitting diode)
  - LED barrier mounted
Post-Mounted Delineators and Chevrons

- Warns driver of approaching curve
- Provides tracking information
  - Post-mounted delineator and chevrons lower accident rates
  - Chevrons influence speeds and encroachments more than delineators
  - Drivers react to chevrons most favorably on sharp curves (−7°)
  - Support post design must minimize hazard
Pavement Markings

(Treated in more depth in “Run-Off Road” section)

• Effective pavement markings are;
  – More durable
  – All-weather
  – Higher reflectivity
  – Wider edge lines

• Raised pavement markers
  – Low cost option
  – Provide increased delineation
  – Provide tactile and auditory warnings
  – Effectiveness not proven

Provide Adequate Sight Distance

• Sight obstruction may be
  – Vertical alignment
  – Horizontal alignment
  – Cross-section; cut sections, barriers, obstructions

• Design
  – Stopping sight distance must be provided for 100% of roadway

• Possible problems
  – Seasonal vegetation
  – Temporary parked vehicles
  – Roadside signs
Install Shoulder Rumble Strip

- Primarily reduce run-off road crashes, but can reduce head-ons
- Most run-off road crashes depart at 3-8°
- Crashes reduced by 20-50%
- Potential problems
  - Snow removal; damage to plows and rumble strips
  - Drainage
  - Maintenance
  - Noise
  - Motorcycle
Install Centerline Rumble Strip

- Reduce head-on and side-swipe crashes
- 0.5m (1.5 ft.) wide
  - Continuously along centerline
  - Either side of centerline
- Significant reduction in crashes
  - 4-5 crashes/mo reduced to 1.9 crashed/mo, California
  - 13 crashes/yr reduced to 9 crashes/yr, Delaware
Prevent Edge Drop Offs

Covered in Run-off Road crashes section

Provide Skid-Resistant Pavement

- Design side friction values provide adequate safety margin over skidding, normally
- NY low-skid resistance maintenance program reduced wet road crashes by 800 annually
- Improving skid resistance reduced
  - Wet road accidents, 50%
  - Total accidents, 20%
  - Resurface short roadway segments, i.e., horizontal curves
Horizontal Curve Design
Based on Comfort

<table>
<thead>
<tr>
<th>Horizontal Curve Design</th>
<th>Speed</th>
<th>Side Friction</th>
<th>Skid Factor</th>
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<tbody>
<tr>
<td></td>
<td>20</td>
<td>.26</td>
<td>.40</td>
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<td>50</td>
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<tr>
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<td>60</td>
<td>.12</td>
<td>.29</td>
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</table>

\[ R = \frac{V^2}{15(e+f)}; R = \frac{V^2}{127(e+f)} \]

Provide Grooved Pavement

- Longitudinal and transverse cuts to
  - Increase skid resistance
  - Reduce wet weather crashes
  - Reduce hydroplaning potential
- California study showed
  - 72% reduction in wet pavement accidents
  - 7% reduction in dry pavement accidents
- Los Angeles study results
  - 69% reduction in wet weather pavement accidents
  - Side swipe and roadside object accident reduced
- Longitudinal grooves – increase directional control
- Transverse grooves – effective where vehicles stop
Provide Lighting on Curve

- ~51% of 9,791 fatal crashes occurred on curves at night
- Lighting enhanced delineation and attracts attention
- Potential problems
  - High cost
  - Supports are added roadside obstacles

Provide Dynamic Curve Warning System

- Typical system, radar device with variable message sign
- Used to reduce truck rollover crashes
- One installation – reduced rollover crashes from 10 to 0
Widen Roadway

- Needed to accommodate off-tracking and to provide added area for steering
- Effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Accident Reduction</th>
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<tbody>
<tr>
<td>Widening lane</td>
<td>5-21%</td>
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<tr>
<td>Widening paved shoulder</td>
<td>4-23%</td>
</tr>
<tr>
<td>Widening unpaved shoulder</td>
<td>3-29%</td>
</tr>
</tbody>
</table>
Improve or Restore Superelevation

- Superelevation deficiency, difference between AASHTO superelevation and actual superelevation
- Example AMFs for superelevation deficiency
- Superelevation run-off, use
  - 70% on tangent, 30% on curve
  - Spiral

<table>
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<tr>
<th>Super Deficiency</th>
<th>AMF</th>
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<tr>
<td>0.009</td>
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<td>1.09</td>
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<tr>
<td>0.0399</td>
<td>1.12</td>
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</table>
Modify Horizontal Alignments

- Alternatives
  - Increase curve radius
  - Use spiral transition curves
  - Eliminate compound curves

<table>
<thead>
<tr>
<th>Degree of Curve</th>
<th>Radius</th>
<th>AMFs w/ spiral</th>
<th>AMFs w/o spiral</th>
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<tbody>
<tr>
<td>38</td>
<td>150</td>
<td>5.5</td>
<td>5.6</td>
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<td>11</td>
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<tr>
<td>6</td>
<td>1000</td>
<td>1.7</td>
<td>1.8</td>
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<tr>
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<td>2000</td>
<td>1.1</td>
<td>1.2</td>
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<tr>
<td>2</td>
<td>3000</td>
<td>1.0</td>
<td>1.1</td>
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</table>
Other Non-Traditional Methods

• Install automated anti-icing systems
  – 17 states have at selected locations
  – Prohibit/restrict trucks where off-tracking exceeds pavement width
  • Distance from king pin to rear axle criteria

EXHIBIT V-19
California Truck Advisory Sign
(http://www.dot.ca.gov/hq/trafops/trucks/trucksize/fs-trkruts.htm)
Objective II

Strategies to minimize consequences of leaving roadway on horizontal curve covered in “Run-off Road” section
Strategies

- Design safer slopes and ditches to prevent rollovers
- Remove/relocate objects in hazardous areas
- Delineate roadside objects
- Add or improve roadside hardware
- Improve barrier/attenuation system
Side Slopes

- Recoverable slopes
  - 4:1 or flatter
- Non-recoverable slopes
  - 3:1 to 4:1
- Critical slopes
  - Greater than 3:1
  - Vehicles likely overturn
Clear Zone / Recovery Area

Source: 2002 AASHTO Roadside Design Guide

TABLE 3.2 Horizontal Curve Adjustments

<table>
<thead>
<tr>
<th>RADIUS (m)</th>
<th>DESIGN SPEED (km/h)</th>
</tr>
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<tbody>
<tr>
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</tr>
<tr>
<td>150</td>
<td>1.4</td>
</tr>
<tr>
<td>100</td>
<td>1.5</td>
</tr>
</tbody>
</table>

$C_{Z} = 60K_{CZ}$

Where: $C_{Z}$ = clear zone on outside of curve, meter

$K_{CZ}$ = clear zone distance factor. Figure 3.1 or Table 3.1

$K_{CZ}$ = curve correction factor

Notes: Clear zone correction factor is applied to outside of curves only. Curves faster than 900 m do not require an adjusted clear zone.

Source: 1996 AASHTO
Preferred Ditch Section

- V ditch
- Trapezoidal ditch

*This chart is applicable to all Vee ditches, rounded channels with a bottom width less than 2.4 m [8 ft] and trapezoidal channels with bottom width less than 1.2 m [4 ft].

Source: 2002 AASHTO Roadside Design Guide
Guardrail and Roadside Barriers

- 2002 AASHTO Roadside Design Guide