Horizontal Alignments and Horizontal-Vertical Coordination

The shortest distance between two points is:

- A straight line
- The circumference of a circle passing through both points and the center of the sphere
- Always under construction
Horizontal Curve Safety

Approximately 25% of all fatal crashes occur along horizontal curves.

Average crash rates for horizontal curve segments are about 3 times that of tangent segments.

AASHTO Curve Design Model

\[ e + f = \frac{V^2}{15} R \]

- \( e \) = superelevation
- \( f \) = side friction factor
- \( V \) = design speed (mph)
- \( R \) = radius of curve (ft)
**Side Friction Factor Assumptions**

- Maximum “f” based upon avoiding driver discomfort
- Provides ample margin of safety against skidding

2004 Greenbook Exhibit 3-12 for recommended side friction values in design

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**Side Friction Factor Assumptions**

- Assumed limit of skidding shown in upper part of graph
- “Maximum” friction factors are based on comfortable operation far short of losing traction around curves

2001 Greenbook Exhibit 3-11: Comparison of Side Friction Factors
Side Friction Factor Assumptions

- Shows how side friction is developed as degree of curvature increases
- Numbers in circles refer to “methods” of distribution

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

Method 2
- Maxes out side friction before introducing superelevation
- Used for low-speed urban streets

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction
**Method 3**
- Introduces no side friction at design speed until max super rate is achieved
- Not used for design

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

**Method 4**
- Same as Method 3 except that a running speed is assumed
- Avoids having to steer against super at less than design speed

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction
**Method 5**
- Used for rural and high-speed urban design
- Parabolic smoothing out of Method 4
- Little side friction on flat curves; more as curves sharpen

From 2004 Greenbook Exhibit 3-13: Methods of Distributing Superelevation and Side Friction

**Road Design Manual Criteria**
Mn/DOT uses three methods:

- **Low Speed**
- **High Speed (normal conditions)**
- **High Speed (restricted conditions)**
High Speed (normal conditions)

Table 3-3.02A (below) and Figure 3-3.02A (right)

• Method 5 distribution for rural and high-speed urban design

<table>
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<tr>
<th>Curve Radius (R)</th>
<th>V=20 mph</th>
<th>V=25 mph</th>
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<th>V=35 mph</th>
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Low Speed

Table 3-3.02B (below) and Figure 3-3.02B (right)

• Method 2 distribution for low-speed urban streets

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<th>V=20 mph</th>
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</tr>
</tbody>
</table>
Figure 3-3.03A

- Curvature / speed / superelevation chart using maximum side friction factors
- Useful tool for developing solutions in constrained or special circumstances

Examples:
- Curves approaching a stop condition
- Second curves on downstream portions of freeway ramps
- Reduced superelevation through intersections
- Flat curves where adverse super or minimal super would be advantageous
**HC Model Basis is Driver Comfort**

Although the model stems from the laws of mechanics, the values used in design are based on practical limits and empirically determined factors.

**Does Model Match Driver Behavior?**

- Do vehicles track a curve as designed?
- At what speeds do drivers track curves?
- What are the operations dynamics of trucks vs. passenger cars?
Off-Tracking on Horizontal Curves
Actual Vehicle Path Does Not Follow a Perfect Circle

- Drivers ‘Overshoot’ (track a path sharper than the radius)
- Driver path is spiral
- Overshoot behavior is independent of speed

Spiral Curve Transitions

- Provides a more natural turning path
- Minimizes encroachment into adjacent lane
- Provides a suitable location for superelevation runoff
Horizontal Curve Safety

Approximately 25% of all fatal crashes occur along horizontal curves.

Do Drivers skid off the road or drive off the road on a curve?

Average crash rates for horizontal curve segments are about 3 times that of tangent segments.

Risk Assessment for Horizontal Alignment

The speed of vehicles entering a curve is influenced by the horizontal and vertical alignment on the approaches. Risk varies as a function of the approach speed distribution.

- Avoid sharp curves at ends of long tangents
- Introduce sharp curvature through series of successively sharper curves
- Eliminate/minimize access near horizontal curves

Guide for Achieving Flexibility in Highway Design - AASHTO
Truck Operations on Curves

- Trucks with high centers of gravity may overturn before losing control due to skidding
- Trucks on downgrade curves generate greater lateral friction
- Margin of safety for ‘f’ is lower for trucks

Managing the Risk

Will two horizontal curves of the same radius with similar cross sections and traffic volumes always have a similar safety performance?

Hwy 411
Apple County

Hwy 21
Orange County
Risk Assessment for Horizontal Alignment

Risk of serious crashes within horizontal curves is a function not only of the curve geometry, but also of:

- The cross section
- Sight distance
- Presence of intersections and driveways
- Roadside features and clear zone
- Driver Expectancy

Case Study: CR 202

State Wildlife Management Area

Three Rivers Regional Park

Looking North

Goose Lake

Where does the road go?

Looking South
Session 8
Horizontal Alignments and Horizontal-Vertical Coordination

Case Study: CR 202

Reinforced Soil Slopes

Case Study: CR 202

Unknown Unknown!
Trees lost due to contaminated soil removal.

Looking North
Case Study: CR 202

Looking South

What does the driver see?
Session 8

Horizontal Alignments and Horizontal-Vertical Coordination

Nominally Safe but Substantive Safety Problem

A History of Safety Problems

I-494

R=260'

No Transition

Standard Exit

Lake Road

Standard Taper

2.3%

Basis for Standards

Driver Comfort

Minnesota Department of Transportation

University of Minnesota Center for Transportation Studies

Advanced Design Flexibility Workshop

May 2010