What is a Horizontal Curve?

- Provides a transition between two tangent lengths of roadway.

- PC (Point of Curvature at beginning of curve)
- PI (Point of Intersection of tangents)
- PT (Point of Tangency at end of curve)
Why are Horizontal Curves Needed?

- Necessary for gradual change in direction when a direct point of intersection is not feasible
- Ex. Highways, Interstates, high speed roads with constant flow of traffic
Types of Curves

- Simple Curve
- Compound Curve
- Reverse Curve
- Spiral Curve
Guidelines to Horizontal Curves

- **A Policy on Geometric Design of Highways and Streets (2001)**
  - Horizontal Alignment Considerations (pg. 131-234)
    - Radius
    - Design Speed
    - Side Friction Factor
    - Superelevation
      - Runoff
      - Runout
Design Considerations

- Safe
- Economically Practical

- For the most part, Design Speed is used as the overall design control
- Radius
Parameters

- Design of roadway curves should be based on an appropriate relationship between design speed and curvature and on their joint relationships with superelevation and side friction.
Superelevation

- Superelevation is tilting the roadway to help offset centrifugal forces developed as the vehicle goes around a curve.
- Along with friction, it is what keeps a vehicle from going off the road.
- Must be done gradually over a distance without noticeable reduction in speed or safety.
Superelevation force ($F_s$)

Transverse friction force ($F_t$)

Centrifugal force ($F_c$)
Superelevation

- Practical upper limits – 6% (NDDOT)
  - Climate
    - Water
    - Ice
  - Terrain conditions
    - Flat
    - Mountainous
  - Adjacent land use (rural or urban)
  - Frequency of slow moving vehicles
    - Tractors, Etc.
Methods of Distribution of Superelevation and Side Friction

- 5 methods
  - Methods #2 and #5 are the most common

Method #2: Side friction is such that a vehicle has all lateral acceleration sustained by side friction. Superelevation is used once $f$ is equal to $f_{\text{max}}$.

Method #5: Side friction and superelevation are in a curvilinear relation with the inverse of the radius of the curve.
Methods of Distribution of Superelevation and Side Friction

- **Method #2**
  - Used mostly for urban streets
    - Where speed is not uniform
    - Where constraints do not allow for superelevation
  - Superelevation is not needed on flatter curves that need less than maximum side friction for vehicles.
Methods of Distribution of Superelevation and Side Friction

- **Method #5**
  - Superelevation and side friction distributed concurrently
  - Most practical
Finding Minimum Radius

- Minimum Radius and Design Speeds are the common limiting values of curvature determined from max rate of superelevation and max side friction factor.
- Equation found on pg. 133* and pg. 143*
- Can use this equation to solve for \( R_{\text{min}} \)

\[
R_{\text{min}} = \frac{2V}{15(0.01e_{\text{max}} + f_{\text{max}})}
\]

Determine superelevation on a given horizontal curve:

- With curve radius, design speed, and maximum superelevation rate of 6% (as suggested by NDDOT)
  - Exhibit 3-22* has recommended values for superelevation

For example:

\[ R = 5000 \text{ ft}, \quad V = 75\text{mph}, \quad e_{\text{max}} = 6\% \]
\[ e = 4.2\% \]

Methods of Attaining Superelevation

- Rotate traveled way with normal cross slopes about the centerline profile
- Rotate traveled way with normal cross slope about the inside-edge profile
- Rotate traveled way with normal cross slope about the outside-edge profile
- Rotate traveled way with straight cross slope about the outside edge profile
The NDDOT recommends rotation about the centerline profile in all scenarios.

The few exceptions are where medians or ditches are left too shallow as a result of the centerline rotation.

- Inside-edge or outside-edge rotation may be appropriate in these situations.
Superelevation Transitions

- Consists of Tangent Runout and Superelevation Runoff Sections

- **Runout**: length of roadway needed to accomplish a change in outside lane cross slope from normal rate to zero

- **Runoff**: length of roadway needed to accomplish a change in outside lane cross slope from zero to full
Runoff

- For appearance and comfort, the length of superelevation runoff should be based on a maximum acceptable difference between the longitudinal grades of the axis of rotation and the edge of pavement.

- Proper runoff design can be attained through the exclusive use of the maximum relative gradient.
Runoff

- Maximum Relative Gradient:
  - Maximum grade of pavement edge slope relative to that of the axis of rotation
  - The Relative Gradient can be analyzed with the following equation

\[ \Delta = \frac{(\text{lane width}) \times (\# \text{ of lanes}) \times (e\%) \times \text{Runoff Length}}{\text{Runoff Length}} \]
Runoff

- NDDOT uses a Desired Relative Gradient as a percentage of the Maximum Relative Gradient.
  - **DRG = 83.3% of MRG**
    - This will increase the calculated length of runoff as 120% of the minimum runoff.
  
- Exhibit 3-27* has recommended values for Max Relative Gradient based on Design Speed.

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*A Policy on Geometric Design of Highways and Streets (2001)*
Runoff

- Locating a portion of the runoff on the tangent, in advance of the PC, is preferable, since this tends to minimize the peak lateral acceleration and resulting side friction demand.

- For non-spiral curves, the NDDOT places $2/3$ of the runoff on the tangent, and $1/3$ of the runoff on the curve.
Elements of a Superelevation Transition (Right Curve)
Runoff

- Placing a larger portion of the runoff length on the approach tangent is desired.
  - It decreases lateral velocity in an outward direction, which can lead to undesirable side friction due to corrective steer by the driver.
Equation for minimum length of superelevation runoff

where

- \( w \) = width of one traffic lane (ft)
- \( N \) = number of lanes rotated
- \( e \) = design superelevation rate (%)
- \( b \) = adjustment factor for \# of lanes
- \( G \) = max relative gradient (%)
Runout

- Determined by the amount of adverse cross slope to be removed and the rate at which it is removed.

- To create a smooth edge of pavement profile, the rate of removal should equal the relative gradient used to define the superelevation runoff length.
Spiral Curves

Spiral Transitions

http://www.nh.gov/dot/cadd/msv8/spiral.htm
Spiral Curves

- Spiral Transitions provide a gradual change in curvature from Tangent to Curve.
- Improves appearance and driver comfort.
- Provides location for Superelevation Runoff.
- Generally, NDDOT uses spirals on all curves greater than 1° on rural highways.
- Spirals should be a minimum length of 100 ft.
Superelevation Tables

- Incorporating Superelevations into Plan Sets

- Template on NDDOT website
    - http://www.ugpti.org/dotsc/prepguide/plansheets/displayps.php?catNum=100.1.2&infoType1=Plan Sheets&infoType2=Design
Superelevation Table

Note: Calculations based on AASHTO method five. A design speed of 75 mph and maximum superelevation on 6% were used.

PC or PT

Full Superelevation

Varies 2

Full Superelevation

Varies 2

Left

Normal

Right

Runout

0.0%

-2.1%

-2.1%

2/3 Full Superelevation

-2/3 Full Superelevation

Runout

-2.1%

0.0%

-2.1%
<table>
<thead>
<tr>
<th>Station</th>
<th>Left Slope</th>
<th>Right Slope</th>
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<td>PC - 166'</td>
<td>-2.1</td>
<td>-2.1</td>
</tr>
<tr>
<td>PC - 84'</td>
<td>-2.1</td>
<td>0.0</td>
</tr>
<tr>
<td>PC</td>
<td>-2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>PC + 42'</td>
<td>-3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>PT - 42'</td>
<td>-3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>PT</td>
<td>-2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>PT + 84'</td>
<td>-2.1</td>
<td>0.0</td>
</tr>
<tr>
<td>PT + 166'</td>
<td>-2.1</td>
<td>-2.1</td>
</tr>
</tbody>
</table>
Main Points

- Horizontal curves provide transitions between two tangent lengths of roadway

- Simple Curves have 4 variables
  - Radius
  - Design Speed
  - Side Friction Factor
  - Superelevation
Main Points

- Considerations for Horizontal Curves
  - Safety
  - Economic Practicality

- Other Considerations
  - Sight Distance
  - Traveled Way Widening
  - Offtracking
Main Points

- Superelevation Transitions
  - Runout
  - Runoff
    - Designed through use of Maximum Relative Gradient
    - 2/3 of length on tangent
    - 1/3 of length on curve
Sources

○ A Policy on Geometric Design of Highways and Streets, 2001

○ Cadd Standards
  http://www.dot.nd.gov/manuals/design/caddmanual/caddmanual.pdf

Thanks!