DESIGN OF HORIZONTAL CURVES

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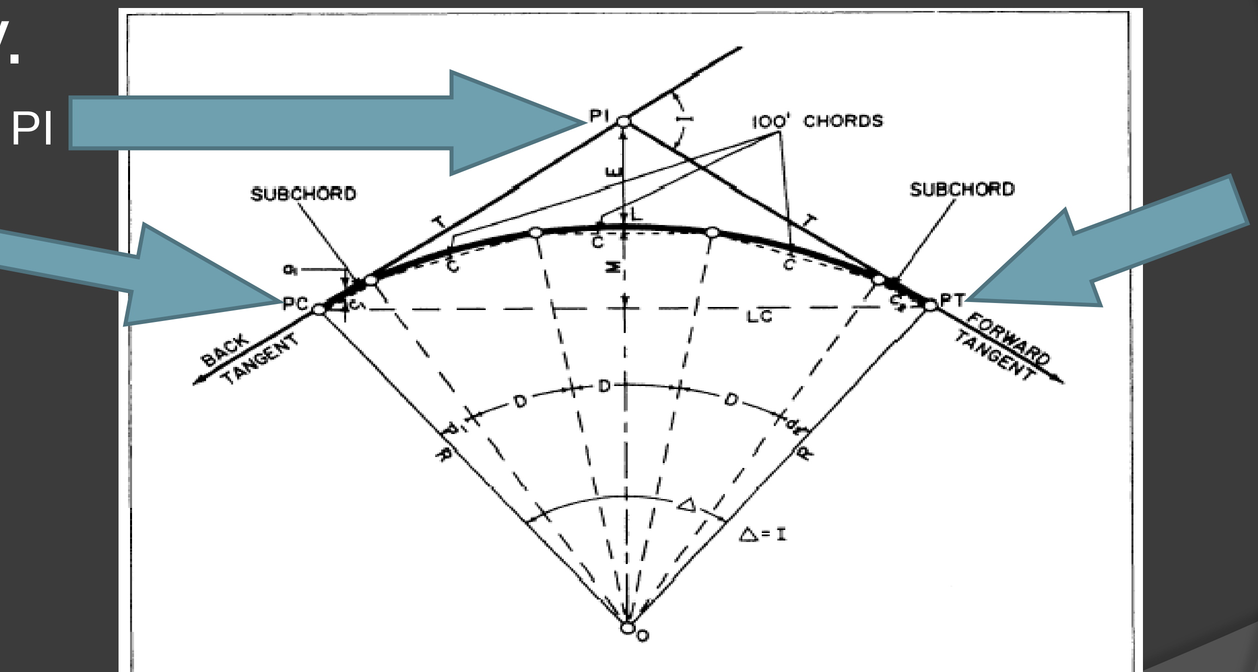
NDDOT Office of Project Development Conference

November 9, 2010

What is a Horizontal Curve?

- Provides a transition between two tangent lengths of roadway.



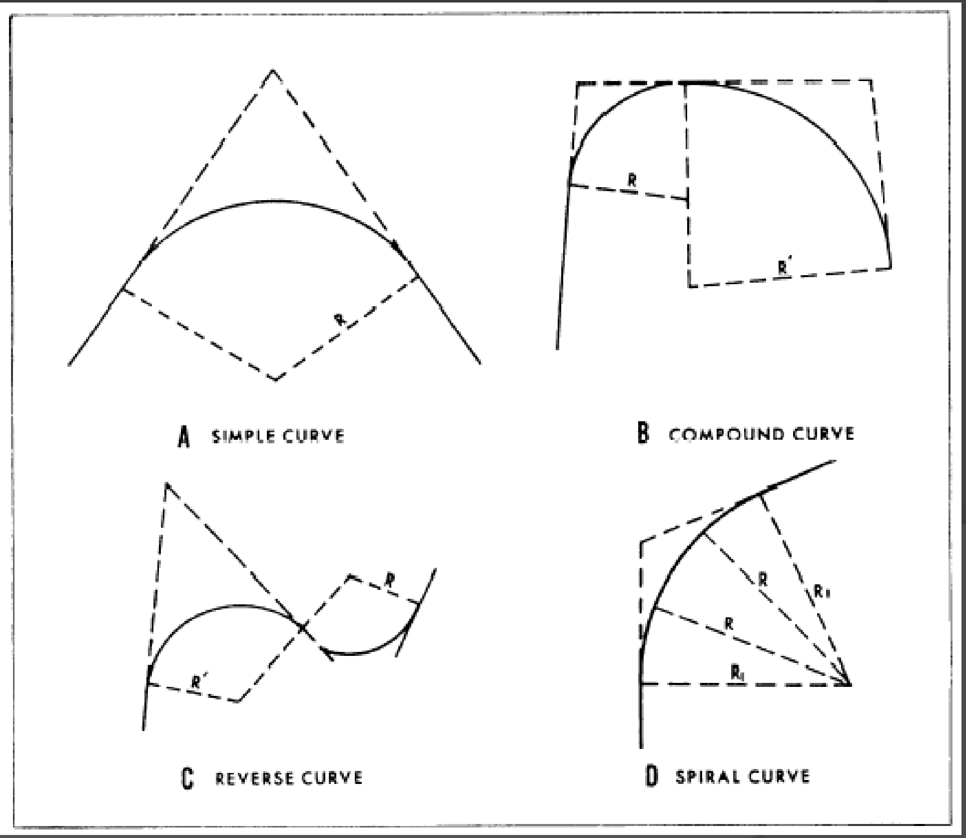
  - PC (Point of Curvature at beginning of curve)
  - PI (Point of Intersection of tangents)
  - PT (Point of Tangency at end of curve)

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

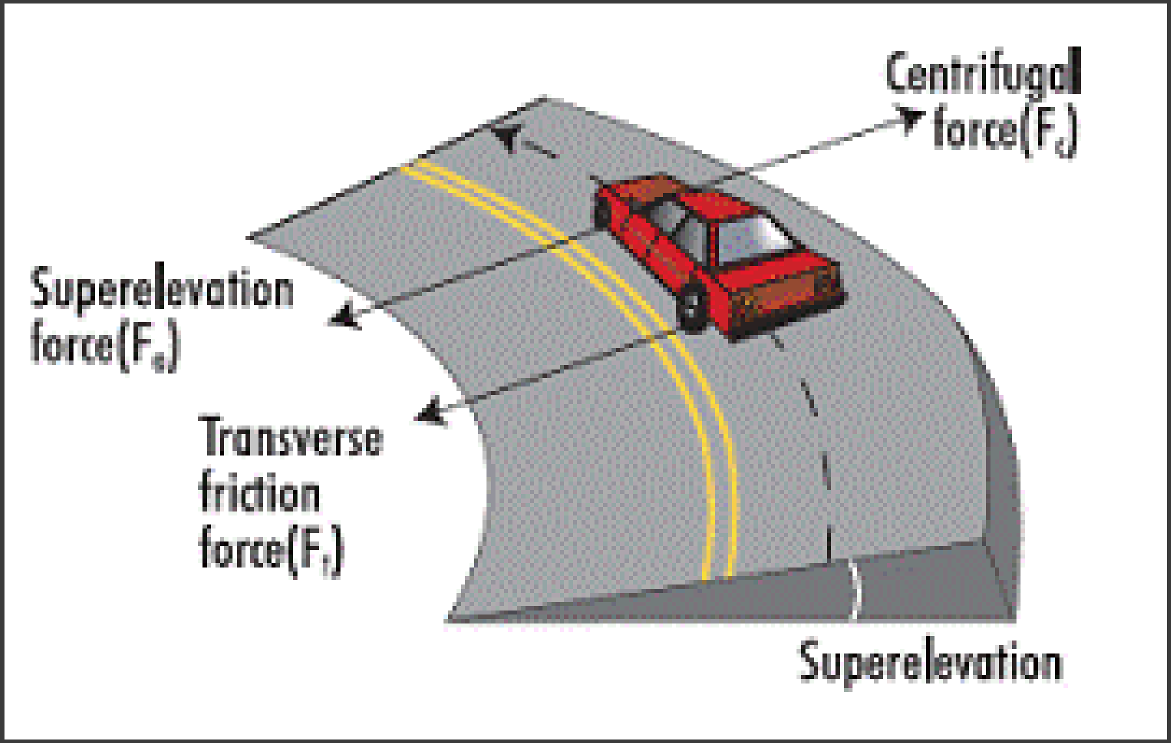
  - For the most part, Design Speed is used as the overall design control
  - Radius

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.


Centrifugal force(F_c)
Superelevation force(F_e)
Transverse friction force(F_f)
Superelevation

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_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_min

$$R_{min} = \frac{V^2}{15(.01e_{max} + f_{max})}$$

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

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 ft,   V = 75mph,   e_max = 6%

→ e = 4.2%

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

Methods of Attaining Superelevation

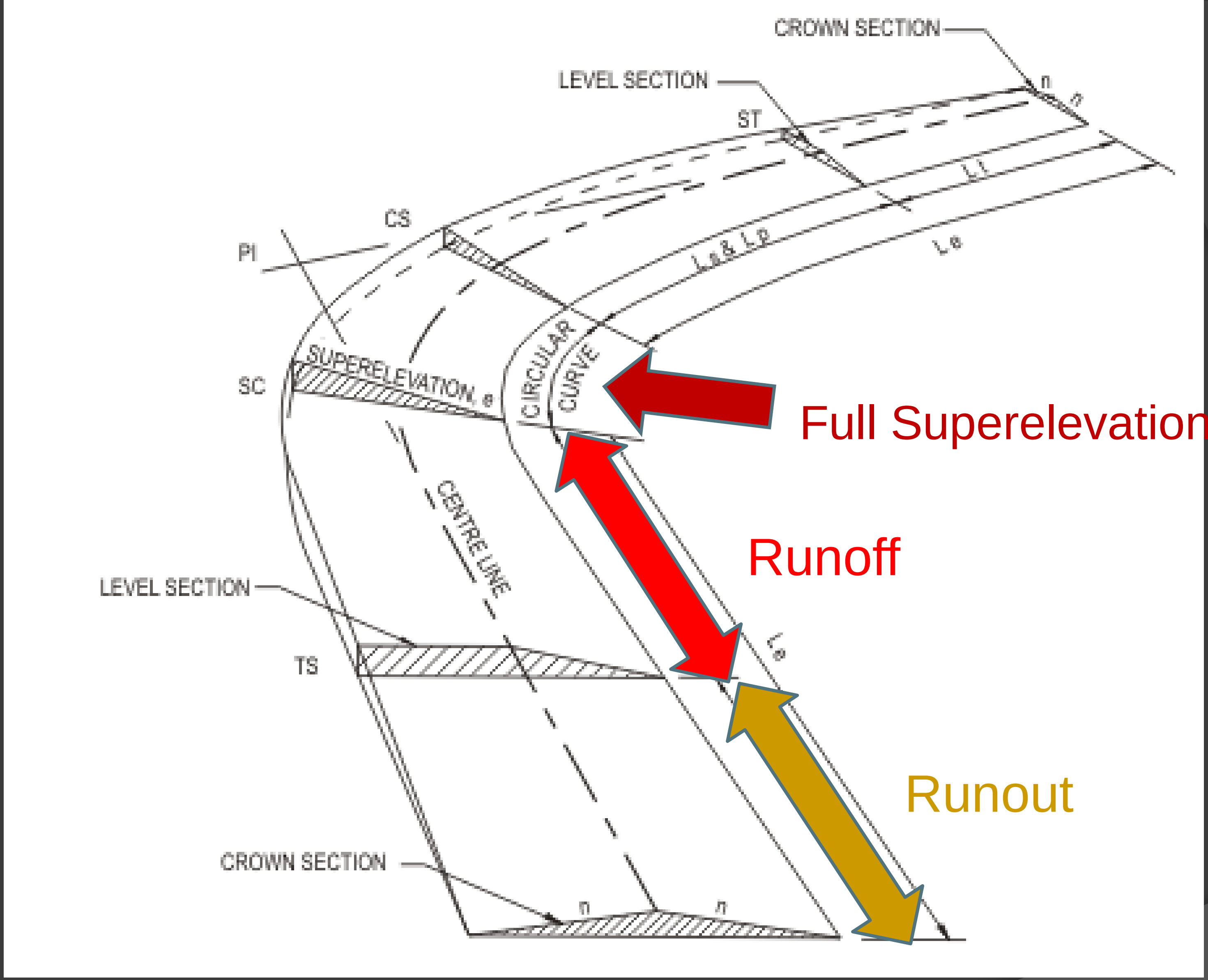
- Rotate traveled way with normal cross slopes about the centerline profile
- Rotate traveled way with normal cross slope about the inside-edge profile
- Rotate traveled way with normal cross slope about the outside-edge profile
- Rotate traveled way with straight cross slope about the outside edge profile

Methods of Rotation

- 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



http://techalive.mtu.edu/modules/module0003/Superelevation.htm

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

$$\Delta = \frac{(\text{lane width})*(\text{\# of lanes})*(e\%)}{\text{Runoff Length}}$$

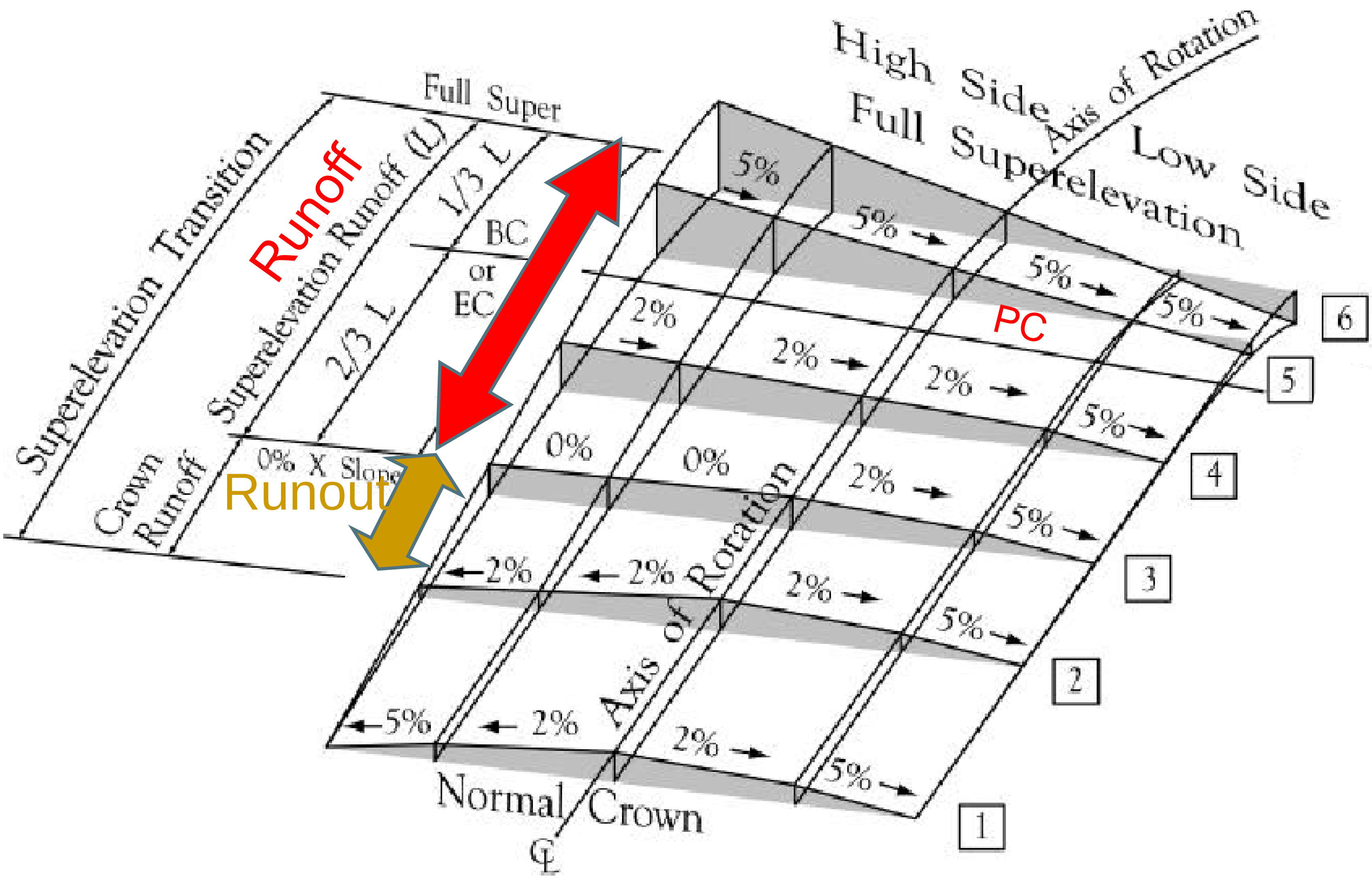
Runoff

- 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.

*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.

$$L = \frac{(wN_1)\,e_d}{G} * (b_w)$$

- 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

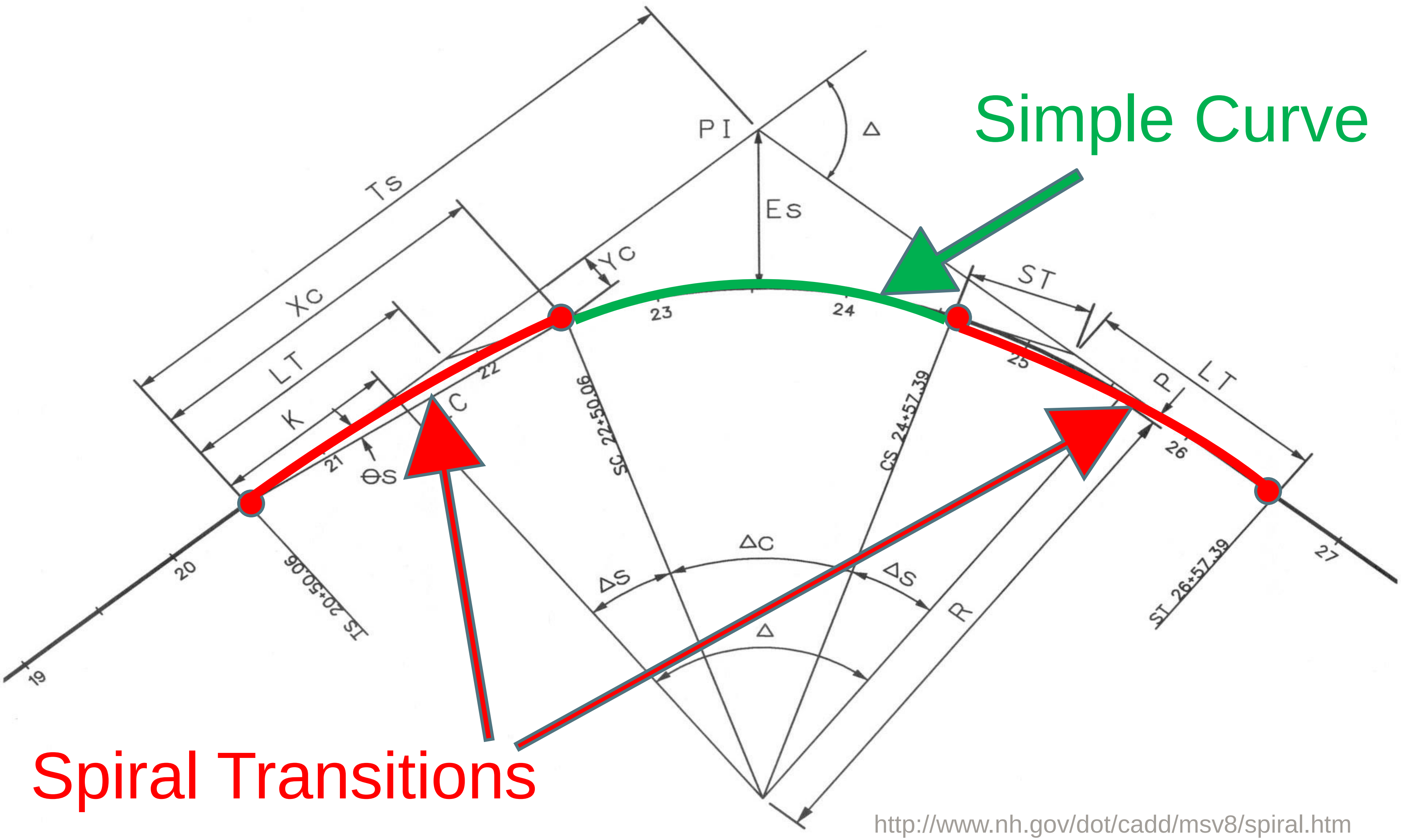
  G = max relative gradient (%)

Runout

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



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://mydot.nd.gov/ – Manuals – Design Manual-Prep Guide – Plan Sheets – Section 100
    - http://www.ugpti.org/dotsc/prepguide/plansheets/displayps.php?catNum=100.1.2&infoType1=Plan Sheets&infoType2=Design

STATE	PROJECT NO.	SECTION NO.	SHEET NO.
ND	project number	sec	page

T.S. Station	510+57.51
S.C. Station	514+57.51
P.C. Station	514+57.51
P.I. Station	519+07.22
Delta =	26° 30′ 00.00″ (RT)
Degree =	3° 00′ 00.00″
Tangent =	449.7122
Length =	883.2324
Radius =	1,909.8593
External =	52.2323
P.T. Station	523+40.74
C.S. Station	523+40.74
S.T. Station	527+40.74

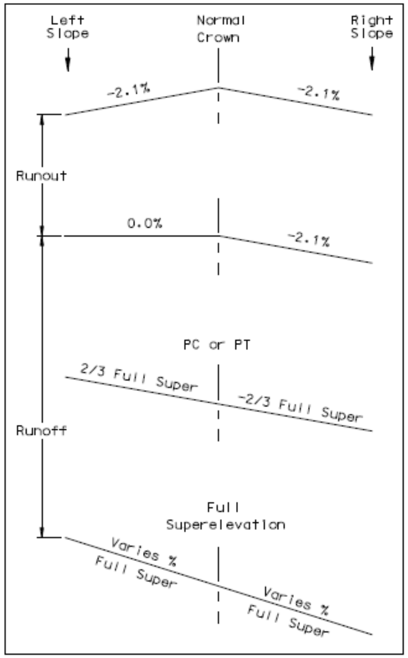
Station	Left Slope	Right Slope
TS − 142′	−2.1	−2.1
TS	0.0	−2.1
SC	5.91	−5.91
CS	5.91	−5.91
ST	0.0	−2.1
ST + 142′	−2.1	−2.1

P.C. Station	344+99.45
P.I. Station	358+52.12
Delta =	26° 34′ 00.00″ (LT)
Degree =	1° 00′ 00.00″
Tangent =	1,352.6722
Length =	2,656.6664
Radius =	5,729.6500
External =	157.5065
P.T. Station	371+56.11

Station	Left Slope	Right Slope
PC − 166′	−2.1	−2.1
PC − 84′	−2.1	0.0
PC	−2.2	2.2
PC + 42′	−3.3	3.3
PT − 42′	−3.3	3.3
PT	−2.2	2.2
PT + 84′	−2.1	0.0
PT + 166′	−2.1	−2.1

P.C. Station	446+20.20
P.I. Station	465+38.99
Delta =	90° 16′ 00.00″ (RT)
Degree =	3° 00′ 00.00″
Tangent =	1,918.7934
Length =	3,008.5835
Radius =	1,909.8837
External =	797.4072
P.T. Station	476+28.78

Station	Left Slope	Right Slope
PC − 169′	−2.1	−2.1
PC − 110′	0.0	−2.1
PC	3.9	−3.9
PC + 55′	5.9	−5.9
PT − 55′	5.9	−5.9
PT	3.9	−3.9
PT + 110′	0.0	−2.1
PT + 169′	−2.1	−2.1



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

Superelevation Table

P.C. Station		344+99.45
P.I. Station		358+52.12
Delta	=	26° 34′ 00.00″ (LT)
Degree	=	1° 00′ 00.00″
Tangent	=	1,352.6722
Length	=	2,656.6664
Radius	=	5,729.6500
External	=	157.5065
P.T. Station		371+56.11

Station	Left Slope	Right Slope
PC − 166′	−2.1	−2.1
PC − 84′	−2.1	0.0
PC	−2.2	2.2
PC + 42′	−3.3	3.3
PT − 42′	−3.3	3.3
PT	−2.2	2.2
PT + 84′	−2.1	0.0
PT + 166′	−2.1	−2.1

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!