SECTION 2

ELEMENTS OF DESIGN

Horizontal Alignment and Superelevation

EPG Category: 200 Geometrics

230: Alignments of the Roadway

230.1: Horizontal Alignments

AASHTO Green Book Chapter 3

Elements of Design

EPG Category 230.1: Horizontal Alignment

A roadway design should provide safe, continuous operation at a speed at which most of the traffic travels under normal conditions while being economically practical.

Geometric elements allow the designer to provide such balanced design.

These geometric elements are known as horizontal and vertical alignments.

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

What is it?

Horizontal alignment is the physical location of a roadway baseline composed of geometric elements such as points, lines, and curves. This horizontal alignment is known as a "chain".

Users can create these elements using GEOPAK traditional Coordinate Geometry (cogo), graphical cogo or/and horizontal alignment tools.

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

Chains are expressed in terms of bearings, distances, curvature, transitions, stations, and offsets.

Typically, the alignment dimensions and distances are tabulated in a manner that facilitates construction staking as conducted by a field surveying crew. *EPG Table 237.1.1*

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

Coordinate Geometry Definitions:

Curves – are a segment of a circular arc.

Types of curves – simple, spirals, reversed, and compound curves

Simple Curves – Most commonly used in highway design. MoDOT uses simple curves unless project parameters meet the requirements for a spiral curve combination.

Reverse Curves – are only suitable for low speed roads such as a temporary bypass.

Compound Curves – Typically used for low-speed turning roadways at intersections.

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

Spiral Curves – Provide a gradual change from the tangent section to the circular curve and vice versa.

Advantages:

1. A properly designed transition curve will provide a natural and smooth path, and will minimize encroachment on adjoining traffic.
2. Transition curve length provide a suitable location for Superelevation runoff length.
3. Spirals facilitate the transition in width where widening of the pavement is needed.
4. Appearance of highway is enhanced, a transition curve can avoid noticeable breaks in alignments or “kinks”.

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

Coordinate Geometry Definitions:

Simple Curves – are defined by degree of curvature in the traditional U.S. unit system and by radius in the metric system.

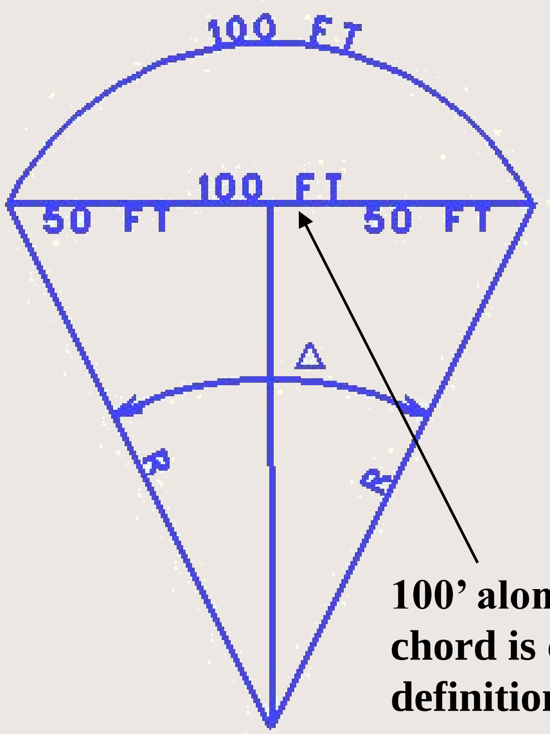
Degree of Curvature – Arc definition or Chord definition.

Arc definition* – central angle subtended by an arc of 100 ft.

Chord definition – central angle subtended by a chord of 100 ft.

* Arc definition is used for new alignments.

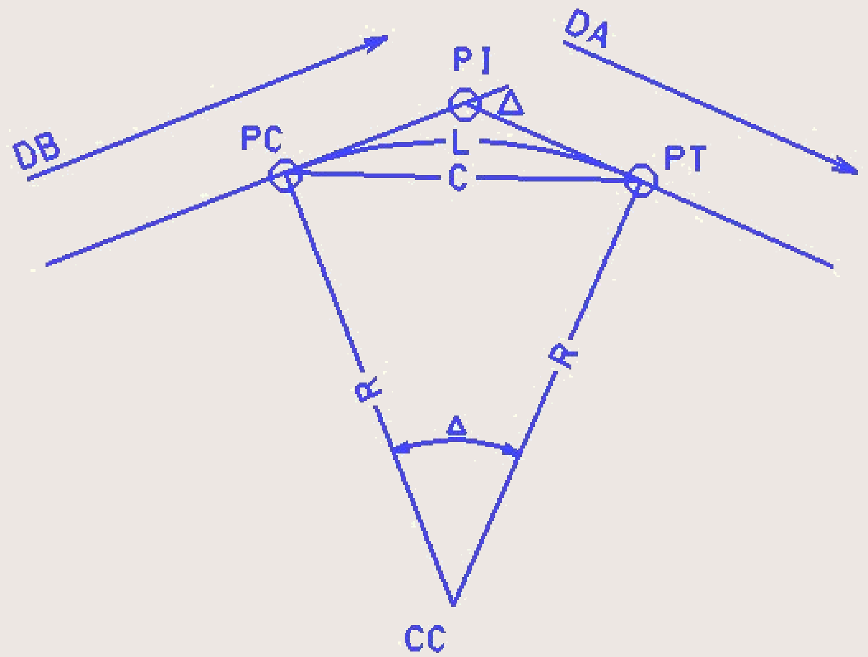
100’ along curve is arc definition



100’ along the chord is chord definition

Elements of Design: Horizontal Alignment

Simple Curve Geometry



PC=Point of curvature

PT=Point of tangency

PI=Point of intersection

Δ=Central angle

L=Length of curvature

D=Degree of curvature

R=Radius of curve

C=Chord length

T=Tangent length

$L = \frac{\pi R \Delta}{180}$

$T = R \tan(\Delta/2)$

$C = 2R \sin(\Delta/2)$

(Arc Def.) $\frac{2\pi R}{360} = \frac{100\ \text{ft}}{D}$ or $R = 5729.58/D$

(Chord Def.) $R = 50/\sin(\Delta/2)$

Elements of Design: Horizontal Alignment

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MoDOT Criteria for Curves:

- ✓Arc definition should be used for all new alignment
- ✓Chord definition ONLY used when an existing curve is utilized in the alignment

Approximate Length of curvature:

- ✓For design speeds < = 60 mph, L=15 x design speed
- ✓For design speeds > 60 mph, L=30 x design speed

For small deflection angles:

- ✓For roadways with less than 400 vehicles/day, no curves are required for central angles of 1 degree or less
- ✓L must be at least 500 ft for a central angle of 5 degrees
- ✓L must increase 100 ft for 1 decrease in the central angle

Elements of Design: Horizontal Alignment

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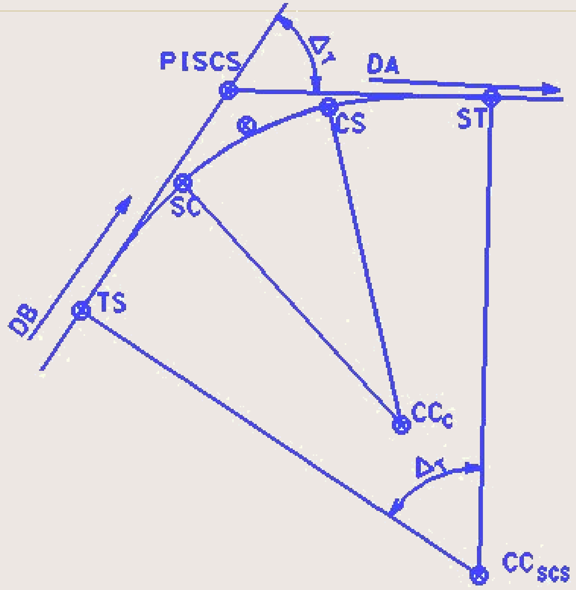
When do we use spiral curve combinations?

If project data meets all three of the following MoDOT guidelines:

1. ADT > 400
2. V > 50 mph
3. Radius < 2865 ft

Elements of Design: Horizontal Alignment

Spiral Curve Geometry



$L_{s,ft} = 1.6\ V^3_{mph}/R_{ft}$ (approximate value)

$\Delta_T = \Delta_c + \Delta_s$ $\Delta_s = L_s\ D/200$

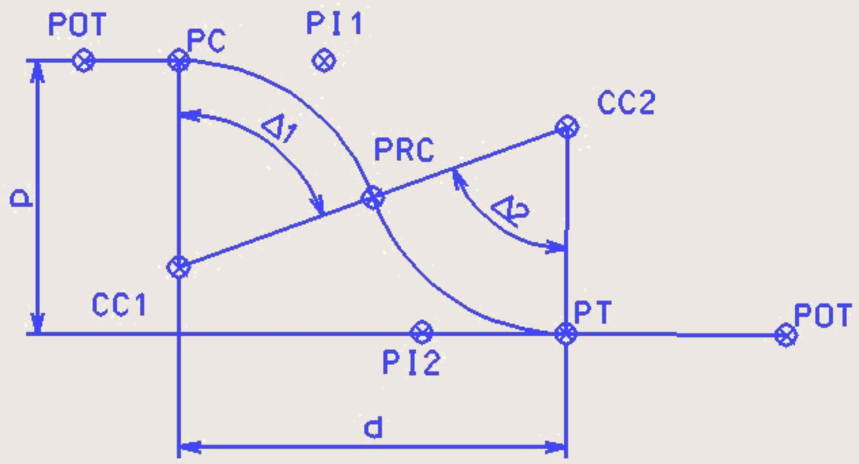
Ls = L in Standard Plans 203.20 & 203.21
Also see AASHTO Green Book Superelevation tables

TS=Tangent to Spiral Point
SC=Spiral to Curve Point
CS=Curve to Spiral Point
ST=Spiral to Tangent Point
PISCS=Overall PI
Δ_T=Total Central Angle (degrees)
Δ_c=Curve Central Angle (degrees)
Δ_s=Spiral Central Angle (degrees)
Ls=Length of Spiral (ft)
Lc=Length of Curve (ft)
D=Degree of Curvature (degrees)
Ts=Tangent Length of SCS (ft)
R=Radius (ft)

There are various ways of selecting the spiral length, Ls, including rules of thumb, tables, formulas & codes. In the DOT industry, we select the Ls either from the AASHTO tables or our own Standard Plans.

Elements of Design: Horizontal Alignment

Reverse Curve Geometry



POT=Point on a Tangent

PC=Point of Curvature

PI=Point of Intersection

PT=Point of Tangency

PRC=Point of Reverse Curve

R_1 , R_2 =Radius for C1 & C2 (ft)

Δ =Central angle (Same for both curves) units are degrees

p=Offset Distance (ft)

d=Tangent Distance (ft)

Equations:

$p=(R_1 + R_2)(1\text{-}\cos \Delta)$

$d =(R_1 + R_2)(\sin \Delta)$

If $R_1 = R_2$

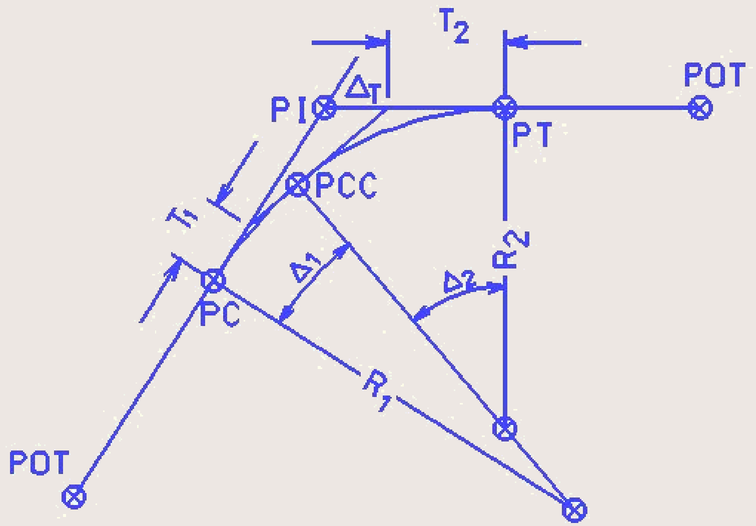
$p=2R(1\text{-}\cos \Delta)$

$d =2R\sin \Delta$

$p/d = \tan (\Delta/2)$

Elements of Design: Horizontal Alignment

Compound Curve Geometry



PC=Point of Curvature

PI=Point of Intersection

PT=Point of Tangency

PCC=Point of Compound Curve

R_1, R_2 =Radius for C1 & C2 (ft)

Δ_1, Δ_2 =Central Angle for C1 & C2 (degrees)

T_1, T_2 =Tangent for C1 & C2 (ft)

Δ_T=Total Central Angle (degrees)

Equations:

$\Delta_T = \Delta_1 + \Delta_2$

$T_1 = R_1 \tan \Delta_1/2$

$T_2 = R_2 \tan \Delta_2/2$

Elements of Design: Horizontal Alignment

Chains

Chains are a combination of other elements such as points, curves, spirals, or other chains.

Chains have stationing associated with them. Locations along a chain can be determined by the stationing. Sometimes stations equations are used.

What are Stations? Stations are points along a chain which describe a distance from a reference point, usually the beginning of the project.

Conventional stationing proceeds North-South or West-East

One station = 100 ft (English)

One station = 1 km (Metric)

Elements of Design: Horizontal Alignment

Finding stationing at critical points:

Simple Curves:

PI station = PC station + T

PT station = PC station + L

SCS Combinations:

SC station = TS station + Ls

CS station = SC station + Lc

ST station = CS station + Ls

Compound Curves:

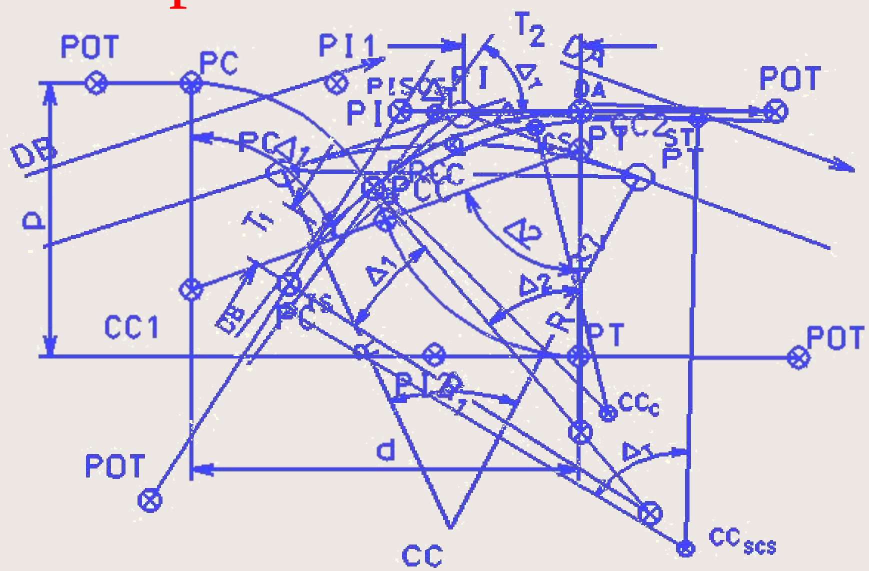
PCC station = PC station + Length of Curve 1

PT station = PCC station + Length of Curve 2

Reverse Curves:

PRC station = PC station + Length of Curve 1

PT station = PRC station + Length of Curve 2

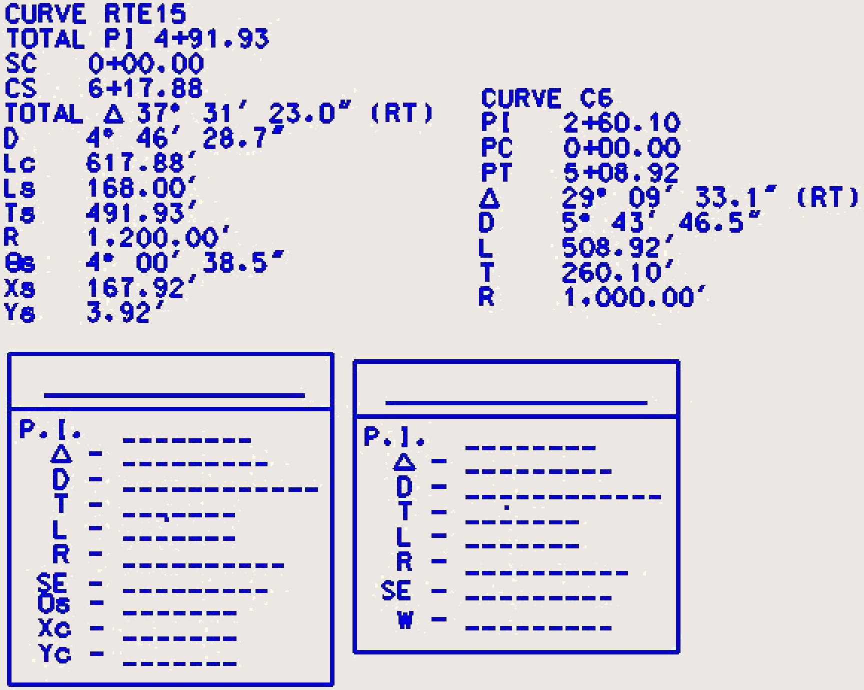


Elements of Design: Horizontal Alignment

Curve Data for Plans Preparation

- PI, PC, and PT Stations
- Central Angle, Δ
- Degree of Curvature, D
- Length of Curvature, L
- Tangent Length, T
- Radius of Curve, R
- Superelevation, SE
- Bearings
- Overall PI for SCS combinations

Geopak



Settings Manager

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

MoDOT Guidelines for stationing chains

- ✓ Centerline of median is generally used as the survey base line for divided pavement improvements
- ✓ If median > 100 ft or is not parallel, then consideration should be given to using the inside edge of traveled way of each lane for individual alignment
- ✓ For undivided pavements, the survey base line is at the "center" of the pavement
- ✓ Use existing centerlines when practical
- ✓ Conventional stationing proceeds from N-S or W-E
- ✓ Crossroad stationing of intersected roadways is based on the existing stationing, if it exists
- ✓ If there is no existing stationing on a crossroad, then stationing proceeds from the left side of the intersection to the right side.

Elements of Design: Horizontal Alignment

EPG Category 230.1: Horizontal Alignment

MoDOT Guidelines for stationing chains

- ✓ New stationing for intersections is chosen such that a five station increment occurs at the intersection with the main roadway
- ✓ For ramps, the base line is located along the right edge of the traveled way relative to the direction of traffic
- ✓ Stationing for ramps is carried in the direction of traffic, except for diamond interchange ramps
- ✓ Diamond interchange ramps are stationed in the same direction as the main line
- ✓ Ramp base lines are equated to the main roadway or cross road at the termini

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Regardless of the type of curve being designed, their design should be based on an appropriate relationship between design speed, curvature or radius, “superelevation”, and side friction or pavement friction.

What is SuperElevation (SE)?

Superelevation is simply when we “tilt” a curve towards its inner side in order to keep vehicles from slipping due to the centrifugal forces acting upon them.

A vehicle moving on a circular path experience a centripetal acceleration which acts towards the center of curvature.

This acceleration is prolonged either by the weight of the vehicle related to the SE, the side friction between the vehicle tires and pavement, or by a combination of the two.

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Design Considerations

Maximum SE rates are used to determine minimum curvature for the design speed chosen.

The 4 factors controlling maximum SE rates are:

1. Climate conditions (frequency and amounts of ice/snow)
2. Terrain conditions (flat, rolling, mountainous)
3. Type of area (rural vs. urban)
4. Frequency of very slow moving vehicles

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Certain limiting values for maximum SE rate e_{max} and side friction f_{max} have been determined through extensive research and are used to determine the minimum radius of curve for a particular design speed.

Limiting values for e_{max} and f_{max} are found in AASHTO Green Book.

The equation below shows the relationship between SE, friction and radius of curve.

$$R_{min} = \frac{V^2}{15(0.01e_{max} + f_{max})}$$

This equation is used to determine the values in the SE tables in Std. Plans 203.20 & 203.21 and AASHTO Green Book Superelevation tables.

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Transitioning Superelevation

Transitioning refers to going from normal crown to e_{max} as well as going from tangent section to curve and vice-versa.

SE Transition sections

- Superelevation transition runoff (L)– length of roadway needed to accomplish the change in outside lane cross slope from flat (zero) to full SE and vice-versa.
- Superelevation tangent runout (x) – length of roadway needed to accomplish the change in outside lane cross slope from normal crown to flat (zero) slope.

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Runoff Calculations

For MoDOT designs, the runoff length L_{runoff} is already calculated for specific lane widths and design SE rates. See Standard Drawings 203.20 & 203.21 or AASHTO Green Book Exhibits Superelevation tables and graphs.

Tangent Runout Calculations, x

Minimum Runout Length – determined by the amount of adverse cross slope to be removed and the rate at which it is removed.

$$x = \frac{NC(\%)}{e(\%)} \times L_{runoff}$$

x– runout (AASHTO Green Book calls this L_t)
L_{runoff} – runoff
e– max. SE rate*

* From Std Drawing 203.20 & 203.21 or AASHTO Green Book Superelevation tables.

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

AASHTO Recommendations on SE rates:

1. A maximum of 12% should be used for rural situations.
2. Any SE rates > 8% should only be used where no ice/snow conditions exist.
3. For urban design, 4%-6% SE rates are recommended.
4. SE can be omitted on low-speed urban design areas.

Because there is no single maximum SE rate that is universal, the transportation industry uses a range of SE rates for various criteria.

At MoDOT, these SE rates are listed in Standard Drawings 203.20 & 203.21. AASHTO Green Book Superelevation tables and graphs can also be used.

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

MoDOT Guidelines:

MoDOT's maximum SE rates tables are found in Standard Drawings 203.20 & 203.21

1. Maximum of 8% SE rate for rural design (203.20 Pg. 2/5; 203.21 Pg. 3/5).
2. Maximum of 4% SE rate for urban design (203.20 Pg. 2/5; 203.21 Pg. 3/5).

Look up design speed column and find the corresponding e% for the appropriate radius of curve. Use the nearest value if not found in table.

L_{runoff} = Length of Superelevation Runoff

NC – Normal Cross Slope

RC – Remove Adverse Cross Slope

w= Amount of widening required

Elements of Design: Superelevation

EPG Category 230.1: Horizontal Alignment

Methods of attaining SE for undivided highways (Std. Plan 203.20)

Case 1: Rotating about the centerline (Page 3/5).

Case 2: Rotating about the inside edge (Page 4/5).

Case 3: Rotating about the outside edge (Page 5/5).

Methods of attaining SE for divided highways (Std. Plan 203.21)

SE for divided highways is attained by rotating about the inside edge of pavement.

How SE should be shown on plans

When using SE rates specified in the guidelines; only SE max. rate and widening are required on plans. However, construction likes to see the station and SE transition slopes on the cross sections.

If *not using SE rates specified in the guidelines*, complete details of all transitions are required on plans.

Elements of Design: Widening

EPG Category 230.1: Horizontal Alignment

Application of Widening on Curves

With the introduction of Practical Design, narrower traveled ways are being designed. Some curves may not provide adequate width to fit the paths of the vehicles entering or leaving the curve.

Guidelines on widening (AASHTO)

- On unspiraled curves, apply the widening to the inside edge of traveled way only.
- On spiraled curves, you may apply the widening to the inside edge of traveled way OR divided equally on either side of the centerline.
- Widening should transition over the superelevation runoff length when practical, but shorter lengths are sometimes used.
- Widening transition should be a smooth, graceful curve. A tangent transition should be avoided.

Elements of Design: Widening

EPG Category 230.1: Horizontal Alignment

How much widening to apply?

The amount of widening is based on the curve radius, speed, design vehicle and width of lane width.

Amount of widening is tabulated on MoDOT Std. Plans 203.20 and 203.21 These values are for a WB-50 AASHTO designation design vehicle (intermediate semi-trailer) and 2-lane roadways.

Designers can always refer to the AASHTO Green Book widening tables.