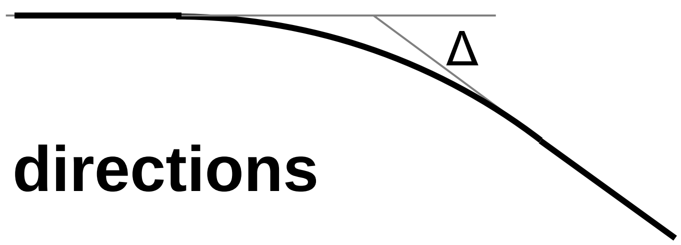

Horizontal
Alignment

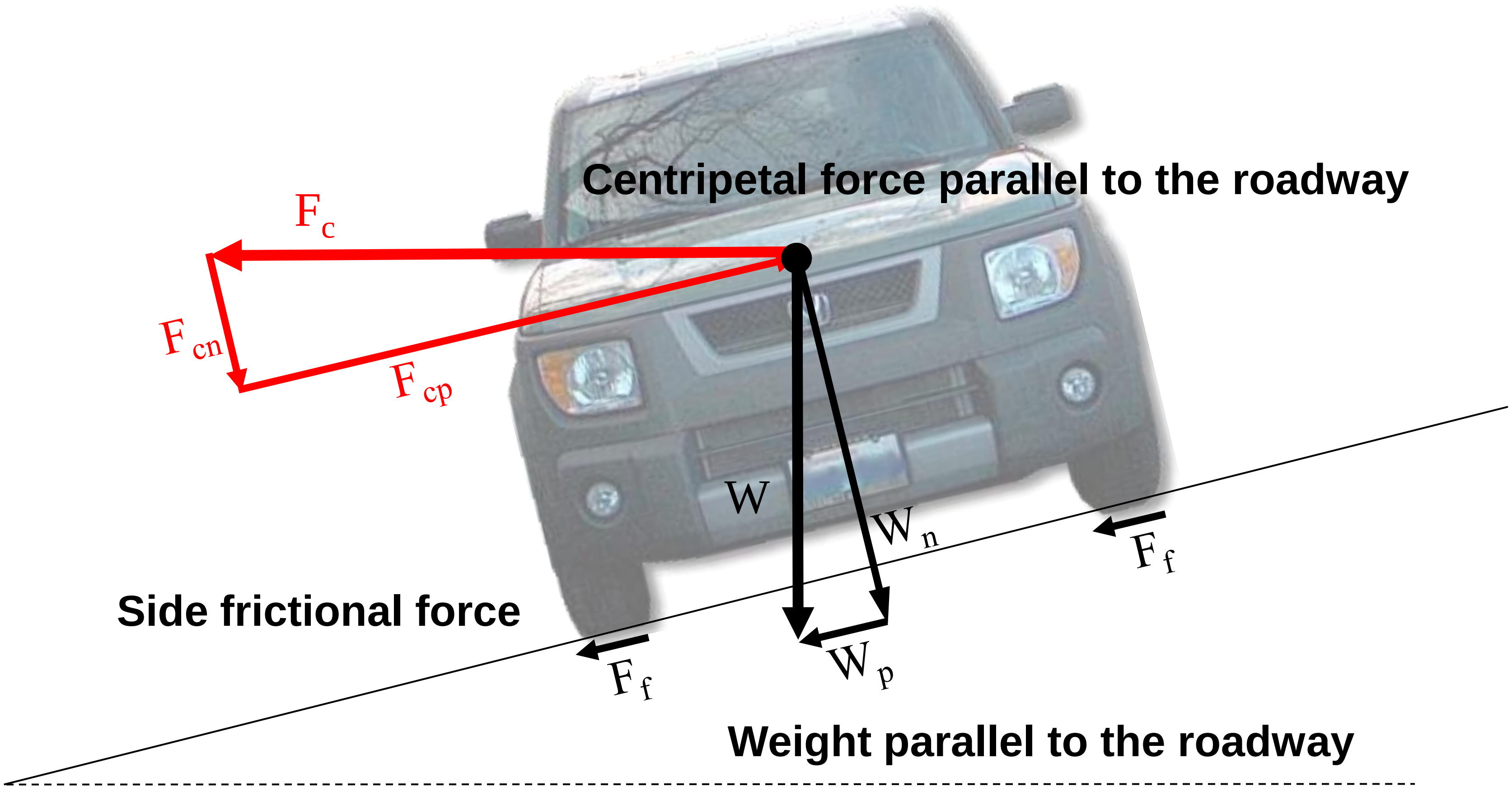
Horizontal Alignment

- **Objective:**
  - Geometry of directional transition to ensure:
    - Safety
    - Comfort



- **Primary challenge**
  - Transition between two directions
- **Fundamentals**
  - Circular curves
  - Superelevation or banking

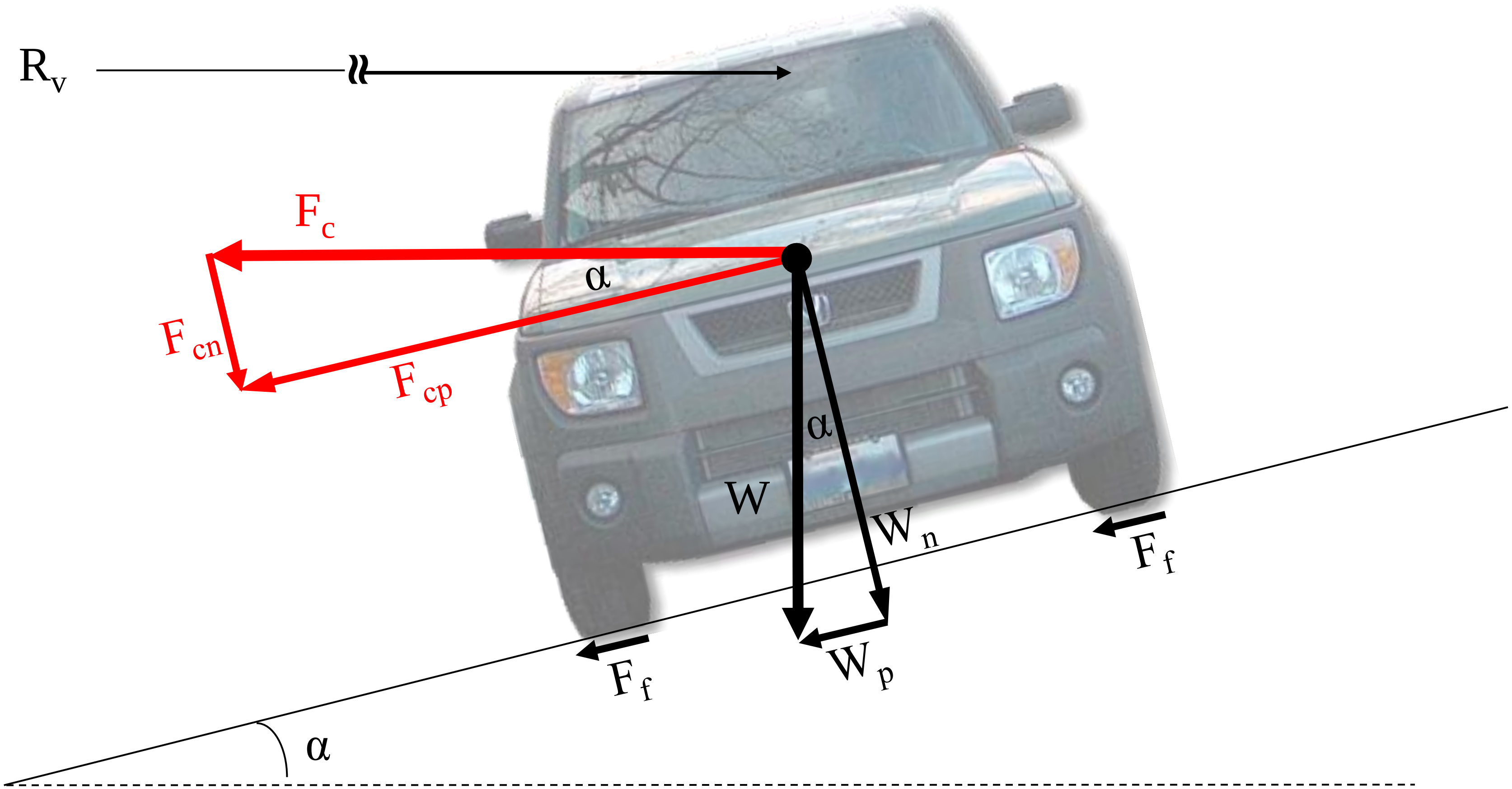
Vehicle Cornering



$$W_p + F_f = F_{cp}$$

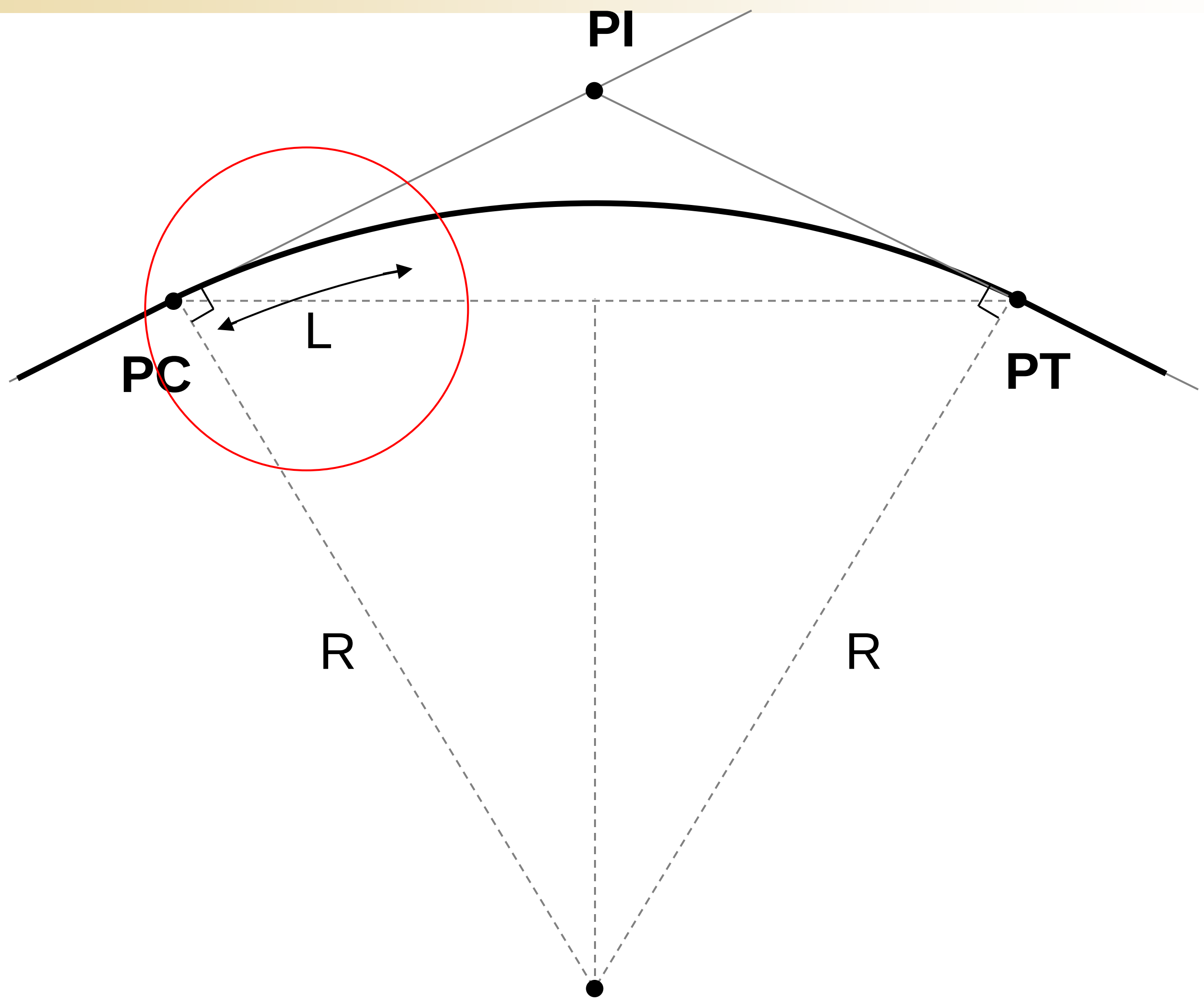
Vehicle Cornering

$$W_p + F_f = F_{cp}$$



$$W \sin\alpha + f_s\left(W\cos\alpha + \frac{WV^2}{gR_v}\sin\alpha\right) = \frac{WV^2}{gR_v}\cos\alpha$$

Horizontal Curve Fundamentals



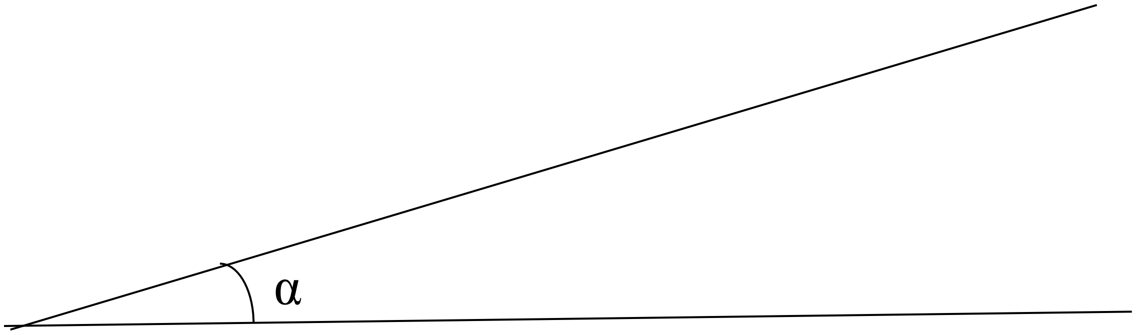
Curve is a circle, not a parabola

R versus R_v

- **R is used when introducing the basic physical properties that relate radius of curve to curve length**
- **With vehicle cornering we talked about a specific vehicle, so consider R_v, the radius to the center of the vehicle in question**

Superelevation

- Banking
- number of vertical feet of rise per 100 ft of horizontal distance
- $e = 100\tan\alpha$



Superelevation

$$W\sin\alpha + f_s\left(W\cos\alpha + \frac{WV^2}{gR_v}\sin\alpha\right) = \frac{WV^2}{gR_v}\cos\alpha$$

$$\tan\alpha + f_s = \frac{V^2}{gR_v}\left(1 - f_s\tan\alpha\right)$$

$$\frac{e}{100} + f_s = \frac{V^2}{gR_v}\left(1 - f_s\frac{e}{100}\right)$$

$$R_v = \frac{V^2}{g\left(f_s + \frac{e}{100}\right)}$$

Divide both sides by Wcos(α)

Superelevation

- Minimum radius that provides for safe vehicle operation
- Given vehicle speed, coefficient of side friction, gravity, and superelevation
- R_v because it is to the vehicle's path (as opposed to edge of roadway)

$$R_v = \frac{V^2}{g\left(f_s + \frac{e}{100}\right)}$$

Selection of e and f_s

- **Practical limits on superelevation (e)**
  - Climate
  - Constructability
  - Adjacent land use
- **Side friction factor (f_s) variations**
  - Vehicle speed
  - Pavement texture
  - Tire condition
  - Maximum side friction factor is the point at which tires begin to skid.
  - Design values are chosen below maximum.

Minimum Radius Tables

US Customary					
Design Speed (mph)	Maximum *e* (%)	Maximum *f*	Total (*e*/100 + *f*)	Calculated Radius (ft)	Rounded Radius (ft)
10	4.0	0.38	0.42	15.9	16
15	4.0	0.32	0.36	41.7	42
20	4.0	0.27	0.31	86.0	86
25	4.0	0.23	0.27	154.3	154
30	4.0	0.20	0.24	250.0	250
35	4.0	0.18	0.22	371.2	371
40	4.0	0.16	0.20	533.3	533
45	4.0	0.15	0.19	710.5	711
50	4.0	0.14	0.18	925.9	926
55	4.0	0.13	0.17	1186.3	1190
60	4.0	0.12	0.16	1500.0	1500
10	6.0	0.38	0.44	15.2	15
15	6.0	0.32	0.38	39.5	39
20	6.0	0.27	0.33	80.8	81

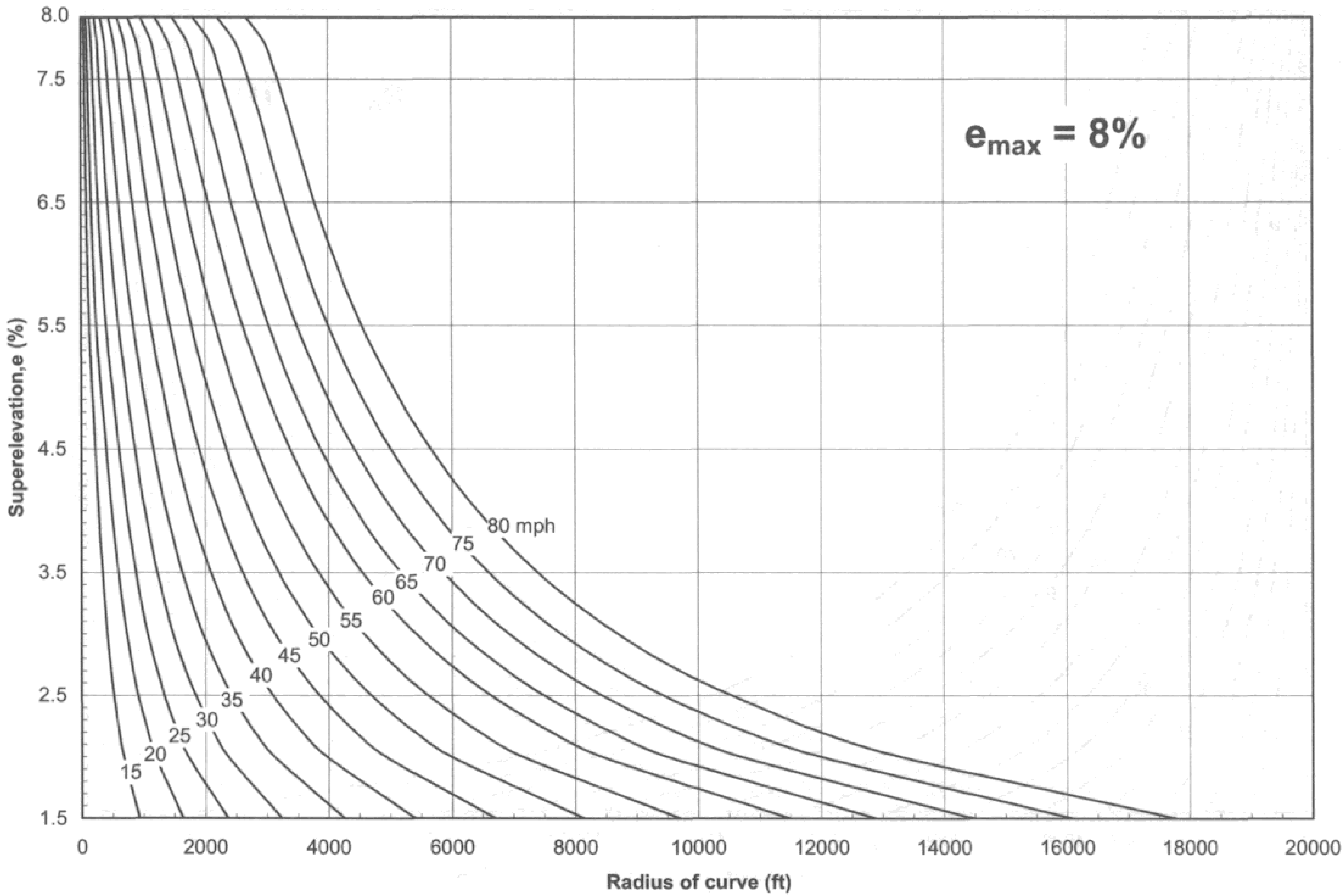
WSDOT Design Side Friction Factors

For Open Highways and Ramps

Design Speed (mph)	Side Friction Factor (f)
15	17.5
20	17
25	16.5
30	16
35	15.5
40	15
45	14.5
50	14
55	13
60	12
65	11
70	10
75	9
80	8

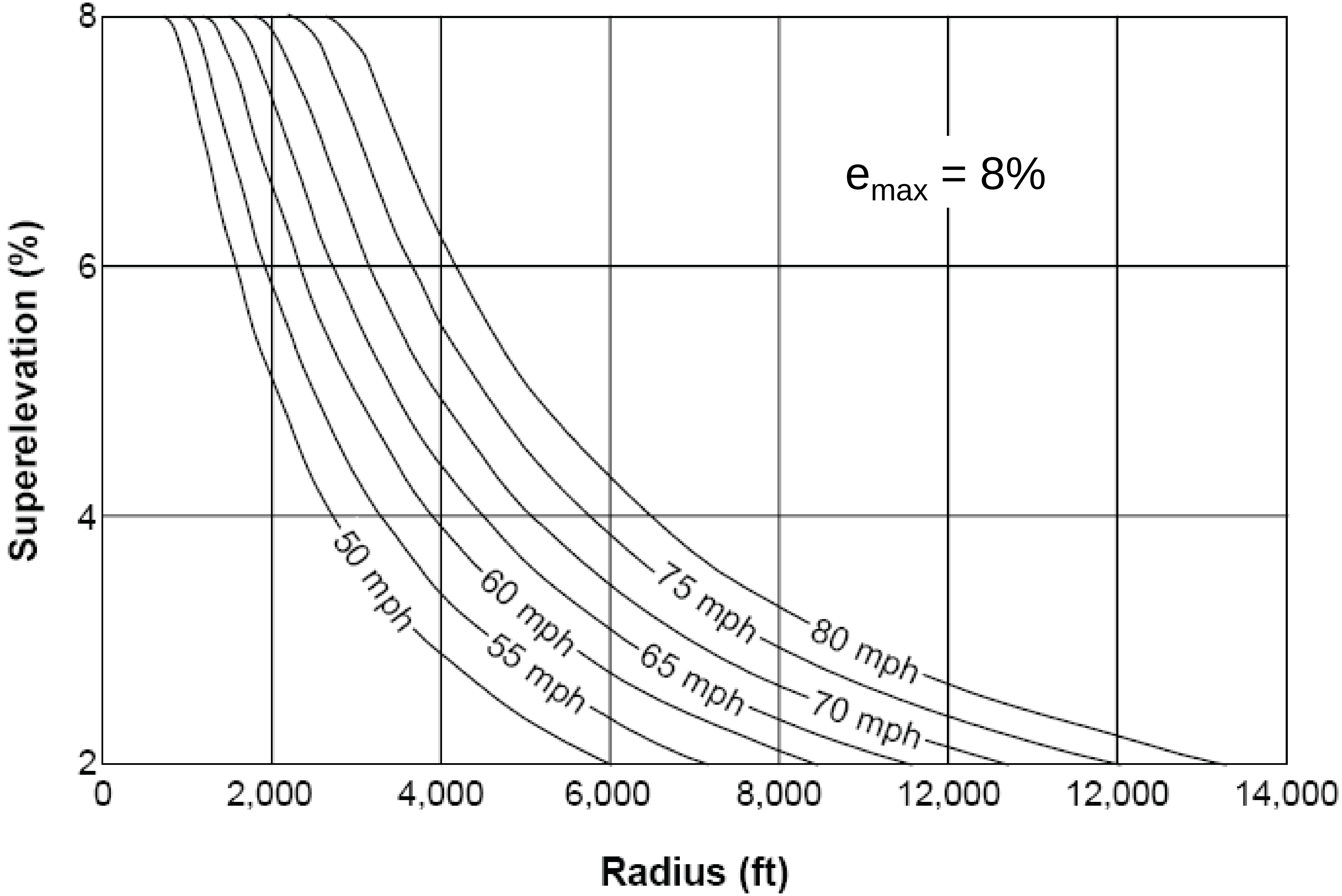
from the 2005 WSDOT *Design Manual*, M 22-01

Design Superelevation Rates - AASHTO



from AASHTO's *A Policy on Geometric Design of Highways and Streets 2004*

Design Superelevation Rates - WSDOT



from the 2005 WSDOT *Design Manual*, M 22-01

Example

A section of SR 522 is being designed as a high-speed divided highway. The design speed is 70 mph. Using WSDOT standards, what is the minimum curve radius (as measured to the traveled vehicle path) for safe vehicle operation?

Horizontal Curve Fundamentals

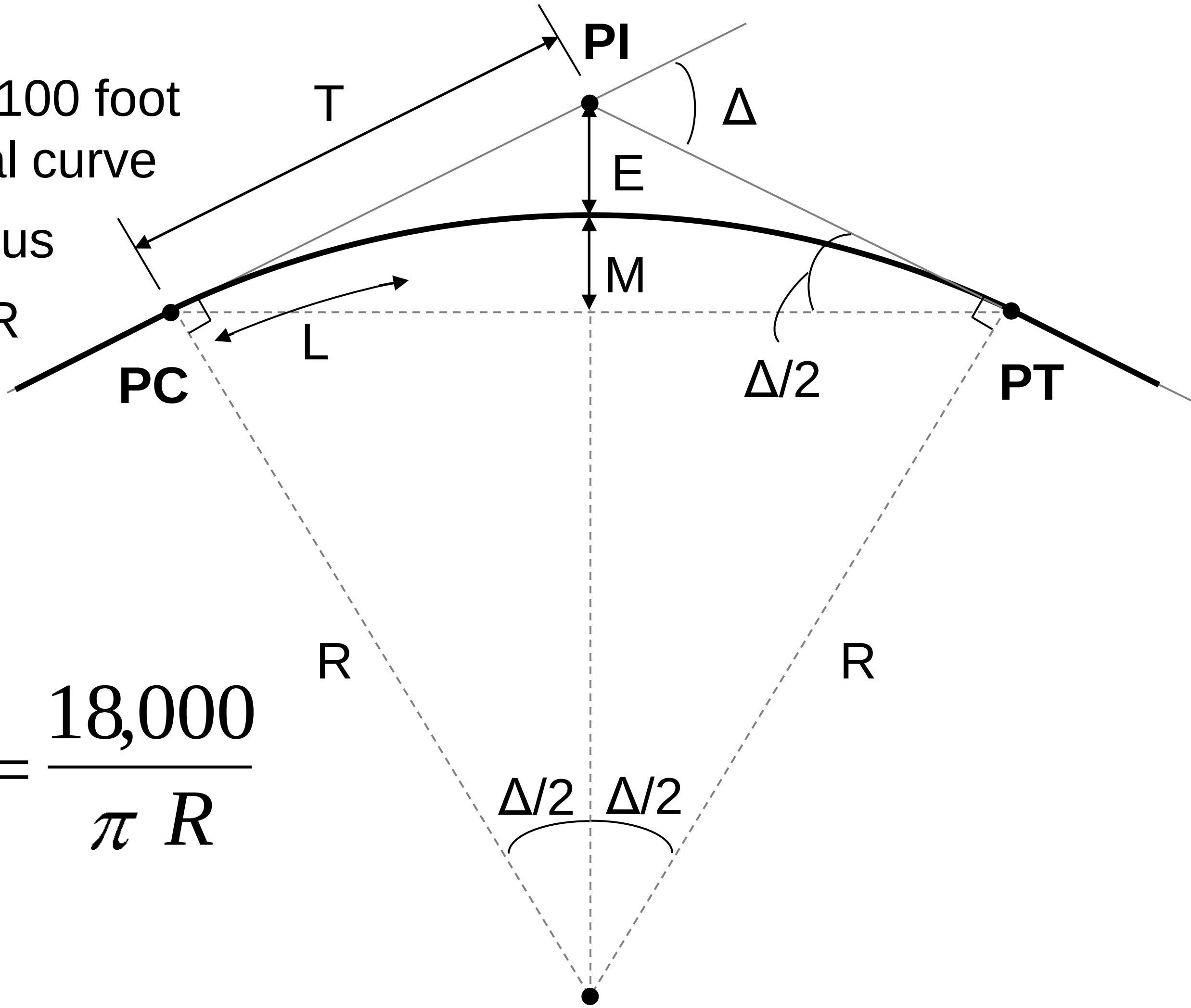
Degree of curvature:

Angle subtended by a 100 foot arc along the horizontal curve

A function of circle radius

Larger D with smaller R

Expressed in degrees

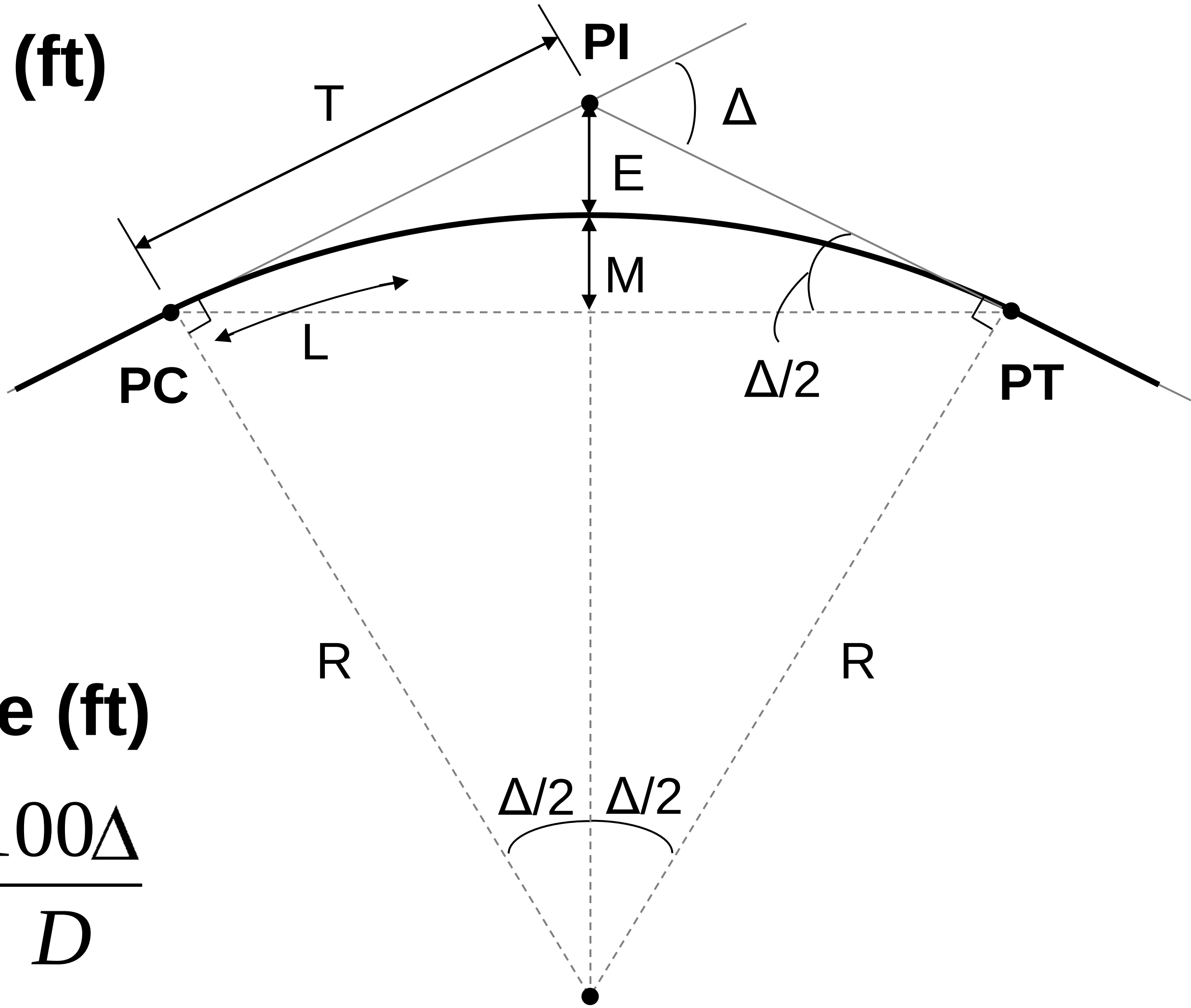


$$D = \frac{100\left(\frac{180}{\pi}\right)}{R} = \frac{18{,}000}{\pi\ R}$$

Horizontal Curve Fundamentals

Tangent length (ft)

$$T = R\tan\frac{\Delta}{2}$$



Length of curve (ft)

$$L = \frac{\pi}{180}R\Delta = \frac{100\Delta}{D}$$

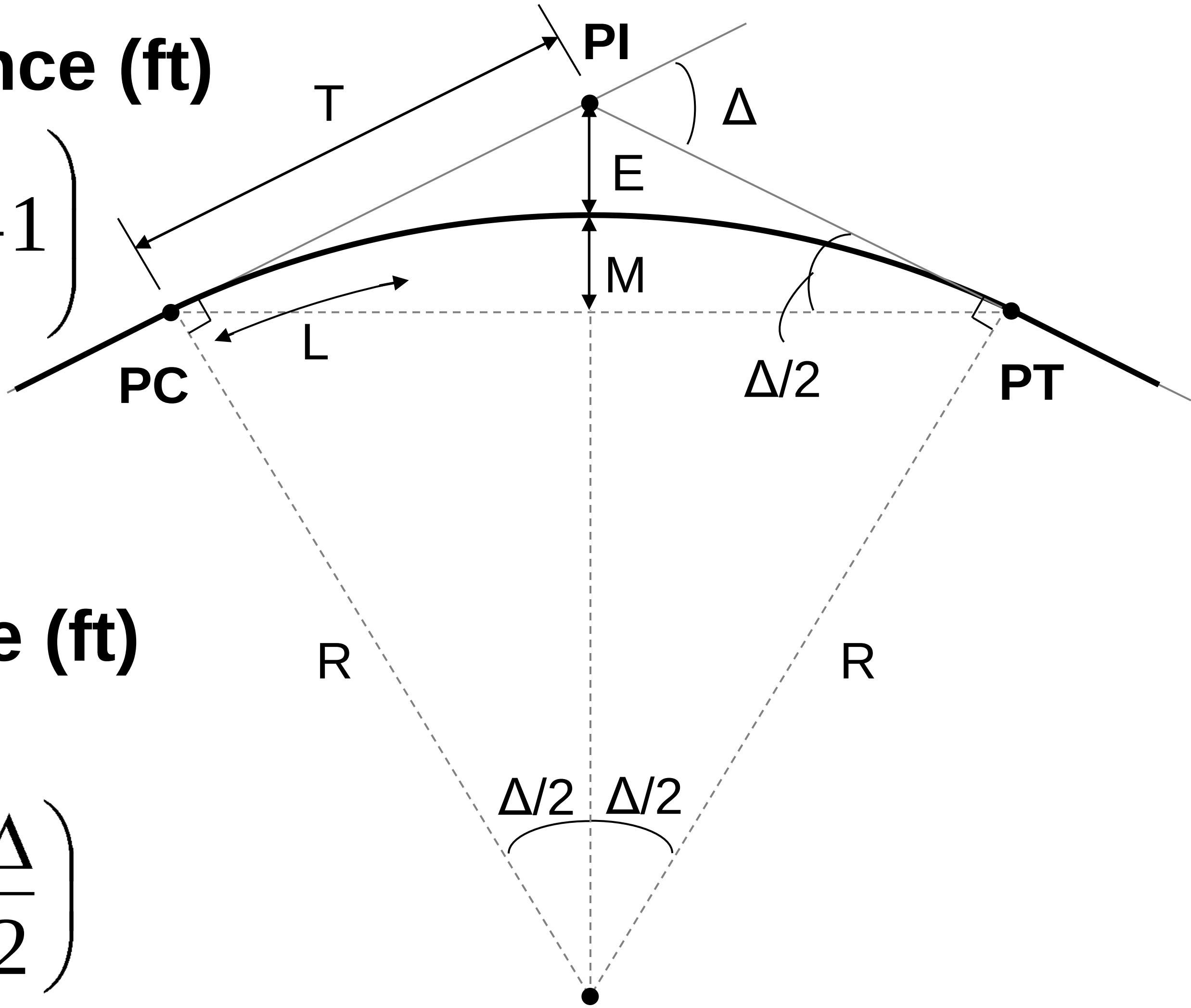
Horizontal Curve Fundamentals

External distance (ft)

$$E = R\left(\frac{1}{\cos\Delta/2} - 1\right)$$

Middle ordinate (ft)

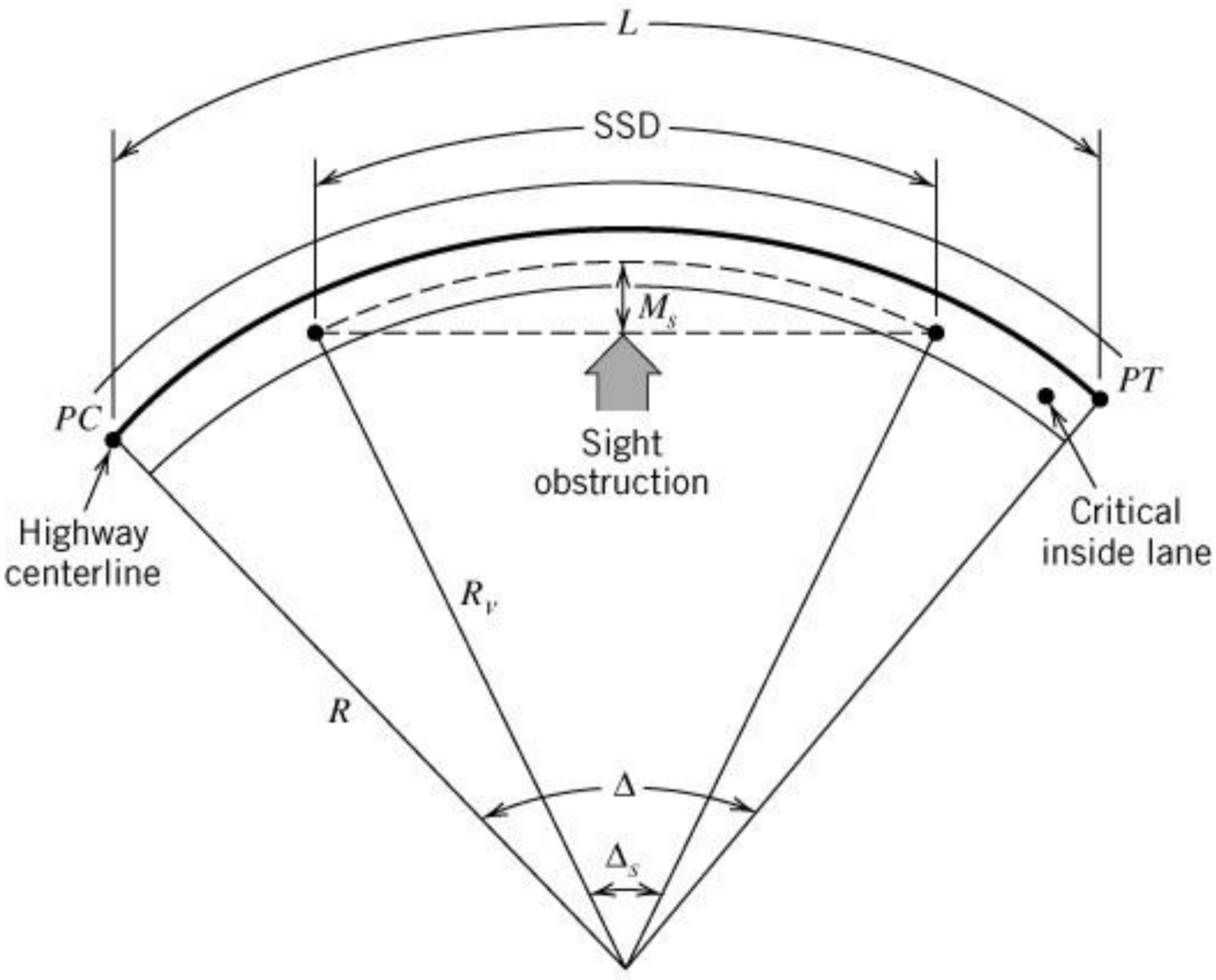
$$M = R\left(1 - \cos\frac{\Delta}{2}\right)$$



Example

A horizontal curve is designed with a 1500 ft. radius. The tangent length is 400 ft. and the PT station is 20+00. What is the PC station?

R versus R_v



L
SSD
M_s
PC
PT
Sight obstruction
Highway centerline
Critical inside lane
R_v
R
Δ
$Δ_s$

R versus R_v

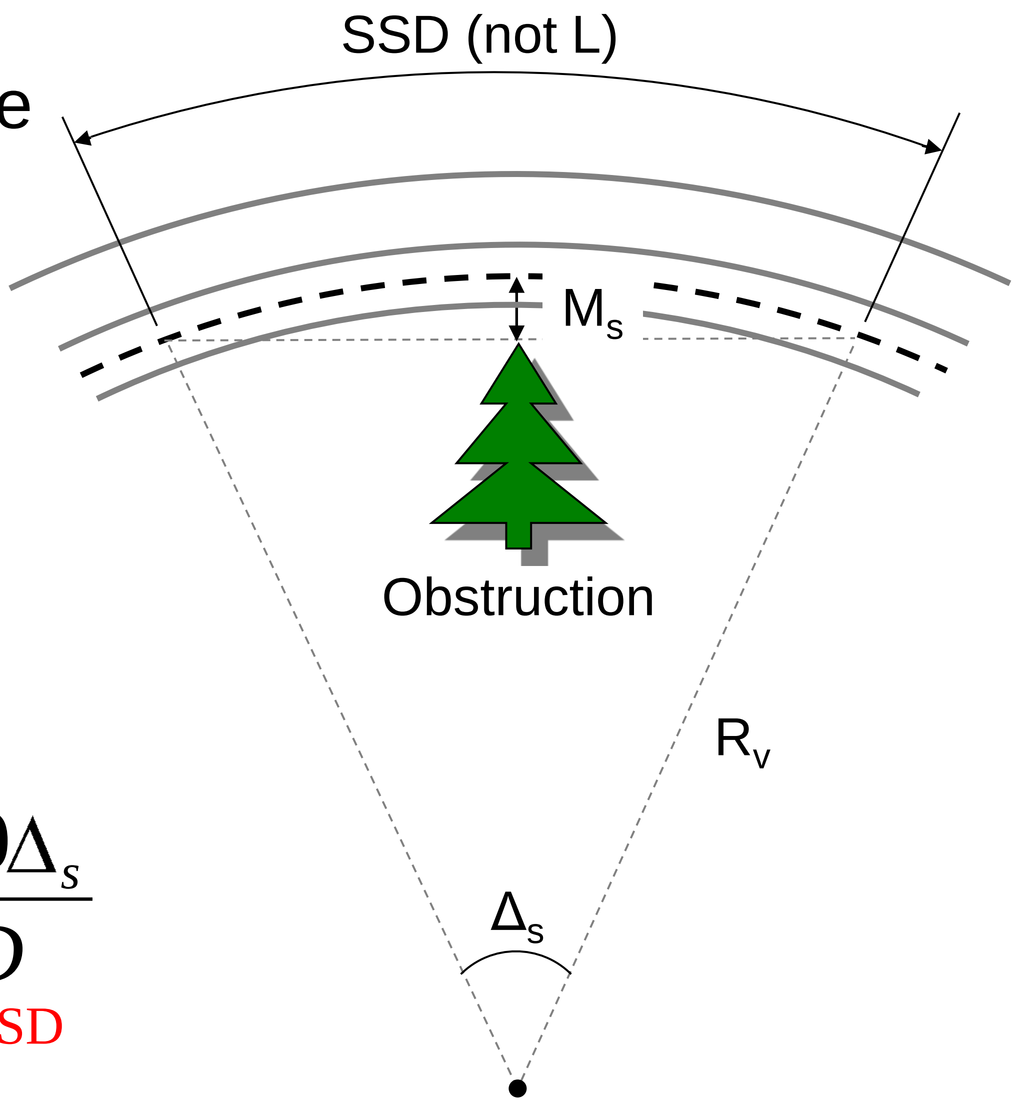
- A little more care is required when we move from thinking about a road as a line to a roadway with width.
  - R_v is the radius to the vehicle's traveled path (usually measured to the center of the innermost lane of the road)
  - R is measured to the centerline of the road
  - SSD is measured from center of inside lane

Stopping Sight Distance

- Looking around a curve
- Measured along horizontal curve from the center of the traveled lane
- Need to clear back to M_s (the middle of a line that has same arc length as SSD)

$$SSD = \frac{\pi}{180} R_v \Delta_s = \frac{100\Delta_s}{D}$$

Assumes curve exceeds required SSD

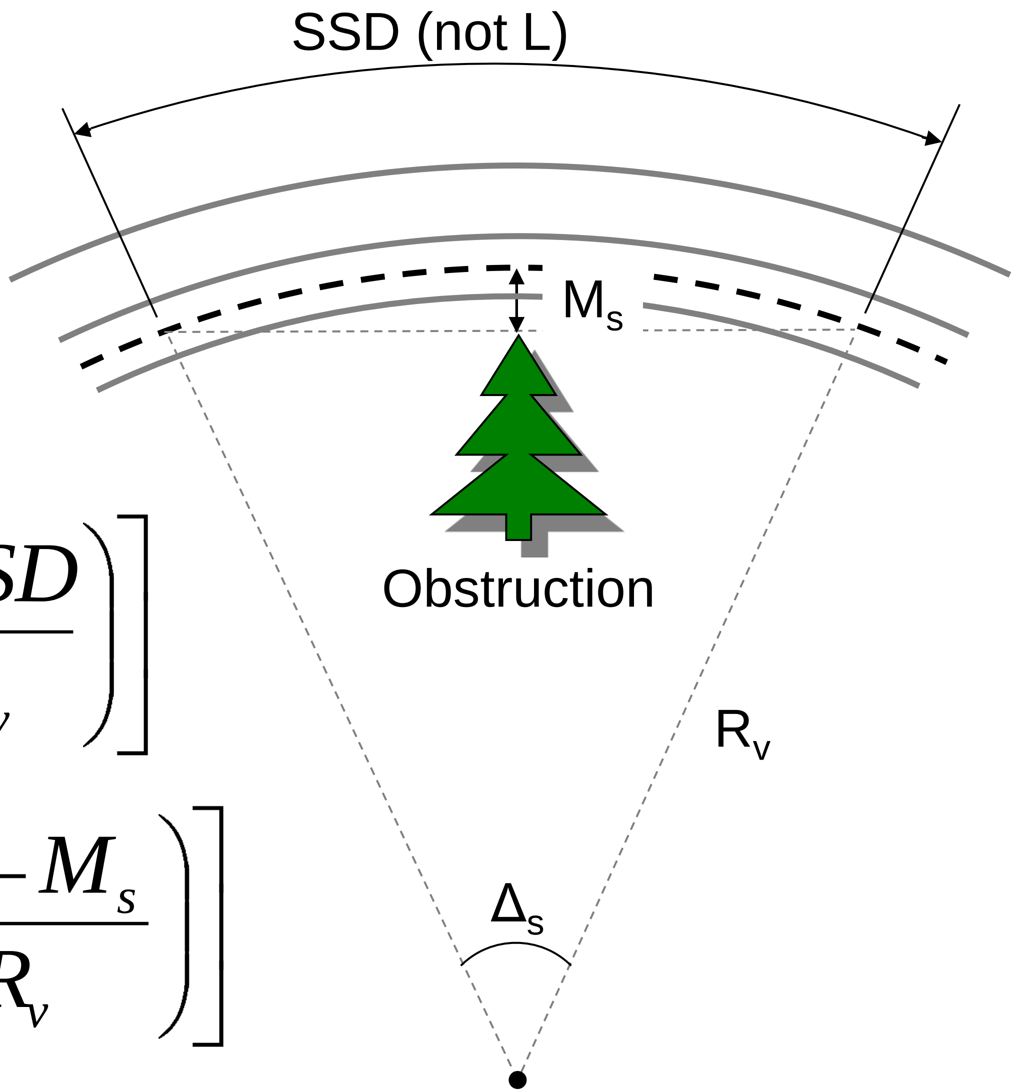


Stopping Sight Distance

$$\Delta_s = \frac{180(SSD)}{\pi R_v}$$

$$M_s = R_v\left[1-\cos\left(\frac{90SSD}{\pi R_v}\right)\right]$$

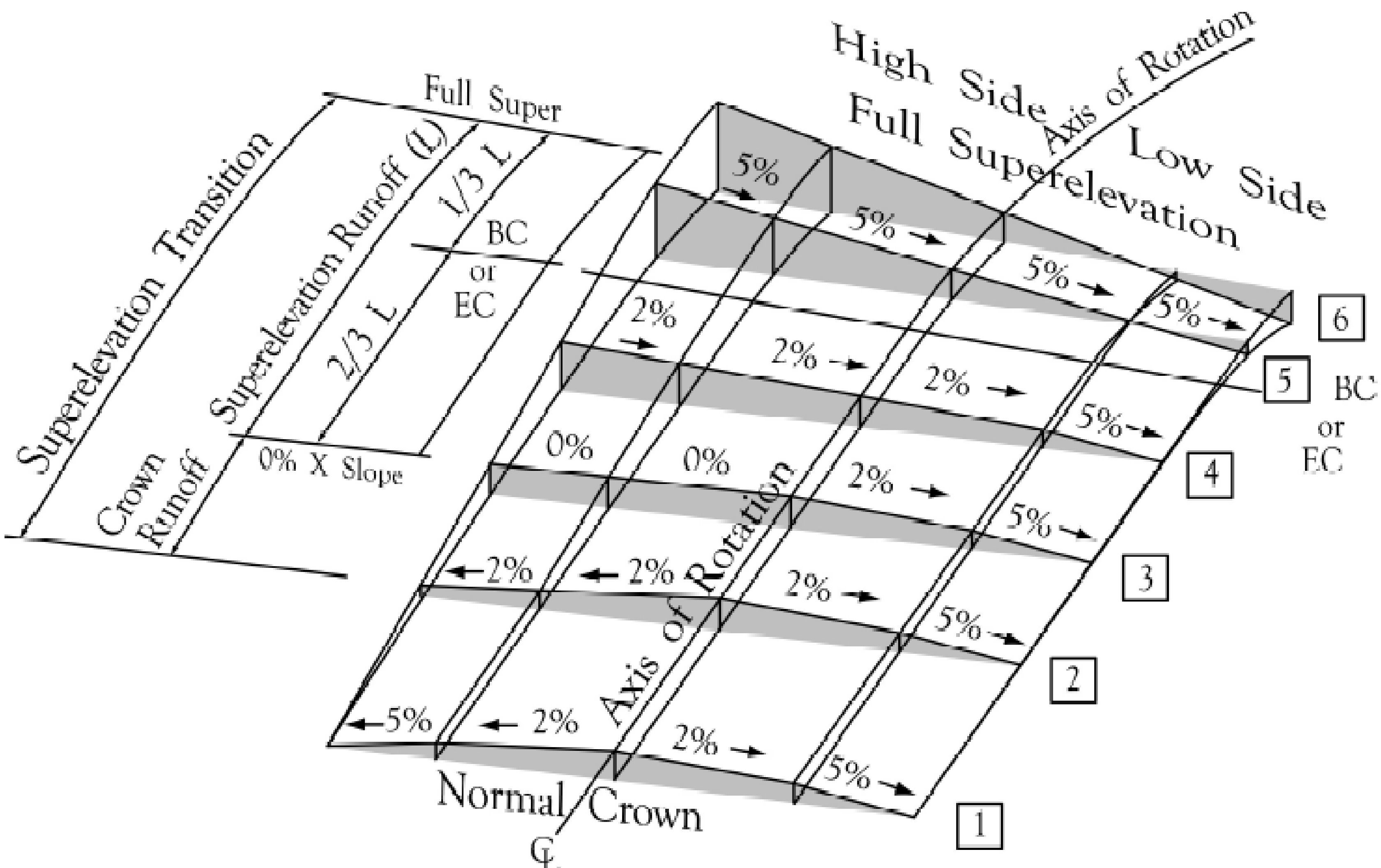
$$SSD = \frac{\pi R_v}{90}\left[\cos^{-1}\left(\frac{R_v - M_s}{R_v}\right)\right]$$



Example

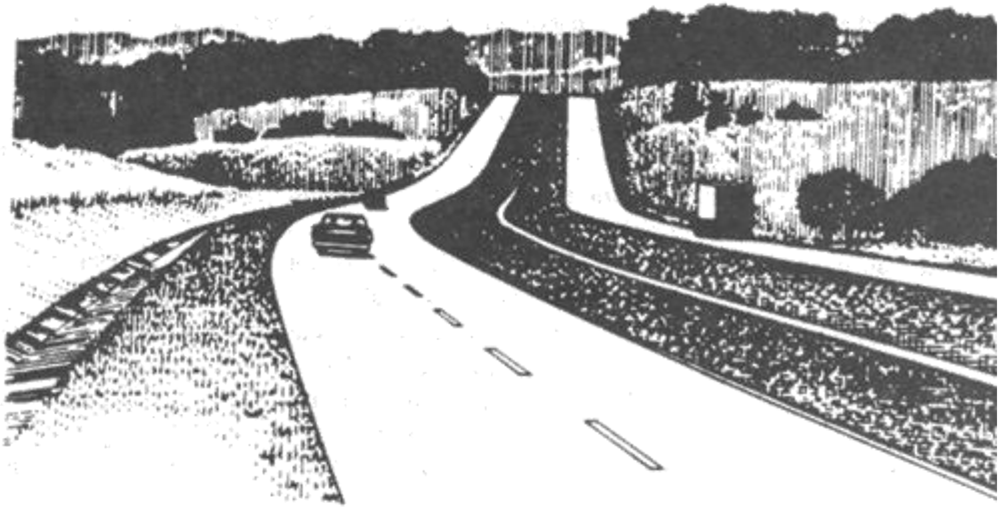
A horizontal curve with a radius to the vehicle’s path of 2000 ft and a 60 mph design speed. Determine the distance that must be cleared from the inside edge of the inside lane to provide sufficient stopping sight distance.

Superelevation Transition

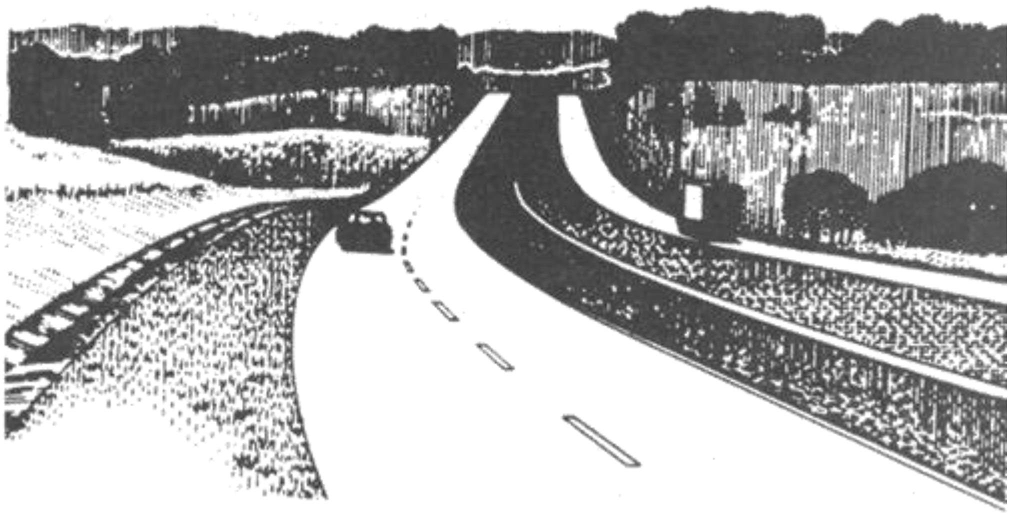


from the 2001 Caltrans *Highway Design Manual*

Spiral Curves



No Spiral



Spiral

from AASHTO's *A Policy on Geometric Design of Highways and Streets 2004*

Spiral Curves

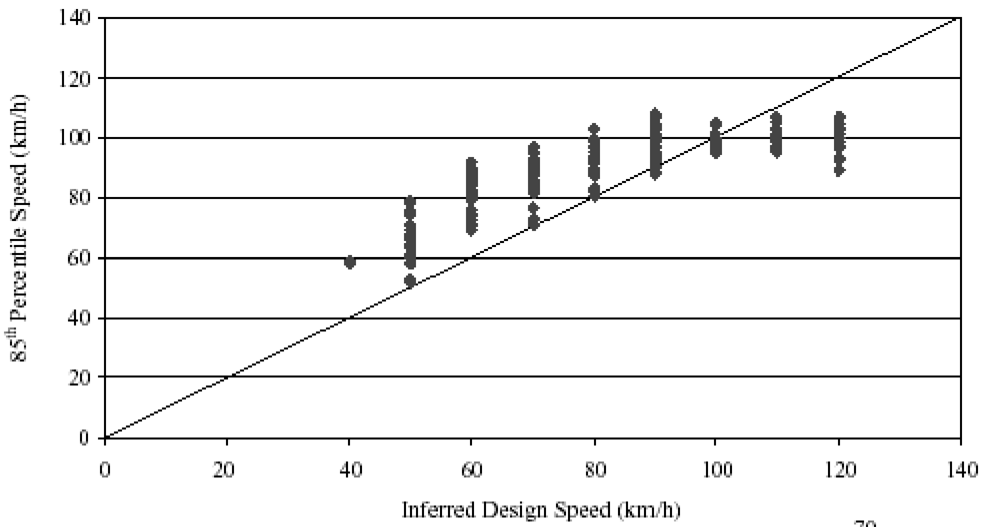
- Ease driver into the curve
- Think of how the steering wheel works, it's a change from zero angle to the angle of the turn in a finite amount of time
- This can result in lane wander
- Often make lanes bigger in turns to accommodate for this

No Spiral

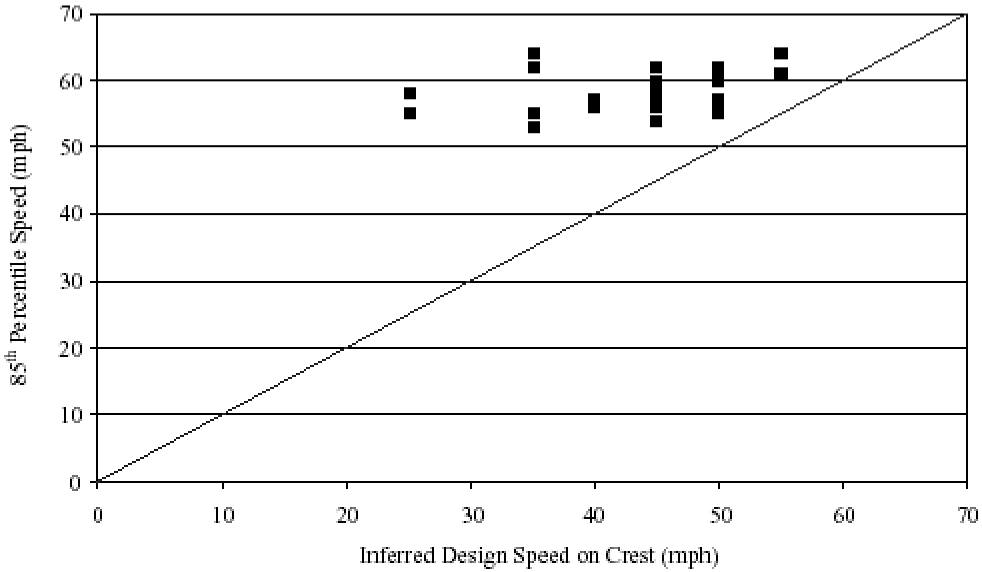
Spiral Curves

- WSDOT no longer uses spiral curves
- Involve complex geometry
- Require more surveying
- If used, superelevation transition should occur entirely within spiral

Operating vs. Design Speed



85th Percentile Speed vs. Inferred Design Speed for 138 Rural Two-Lane Highway Horizontal Curves



85th Percentile Speed vs. Inferred Design Speed for Rural Two-Lane Highway Limited Sight Distance Crest Vertical Curves

Example Problem

- A horizontal curve on a 2-lane highway (12 ft lanes) has a PC station 123+50 and a PT at station 129+34. The central angle is 34 degrees, the superelevation is .08, and 20.3 feet is cleared from the edge of the innermost lane.

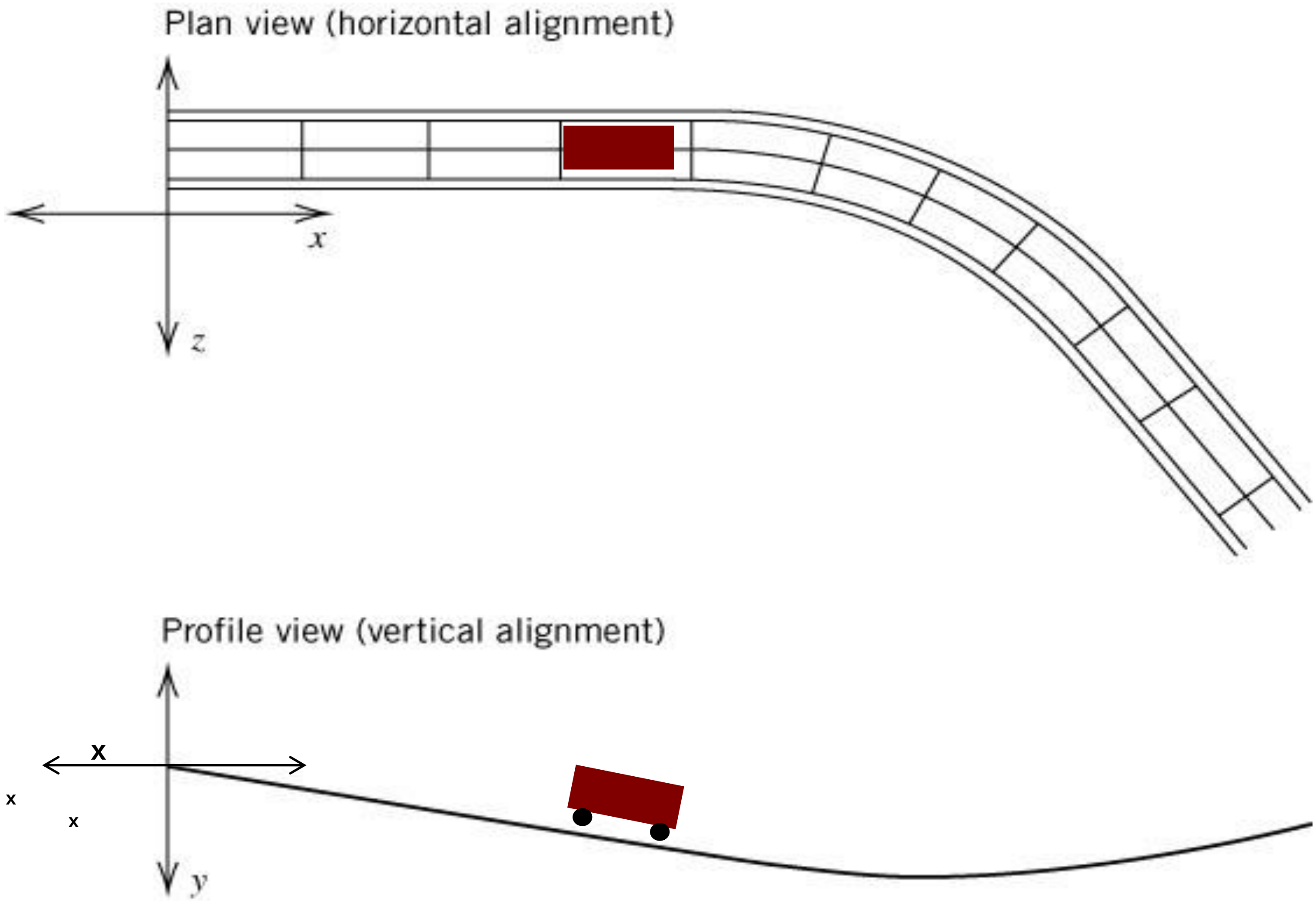
- Determine a maximum safe speed to the nearest 5 mi/hr.

Solution

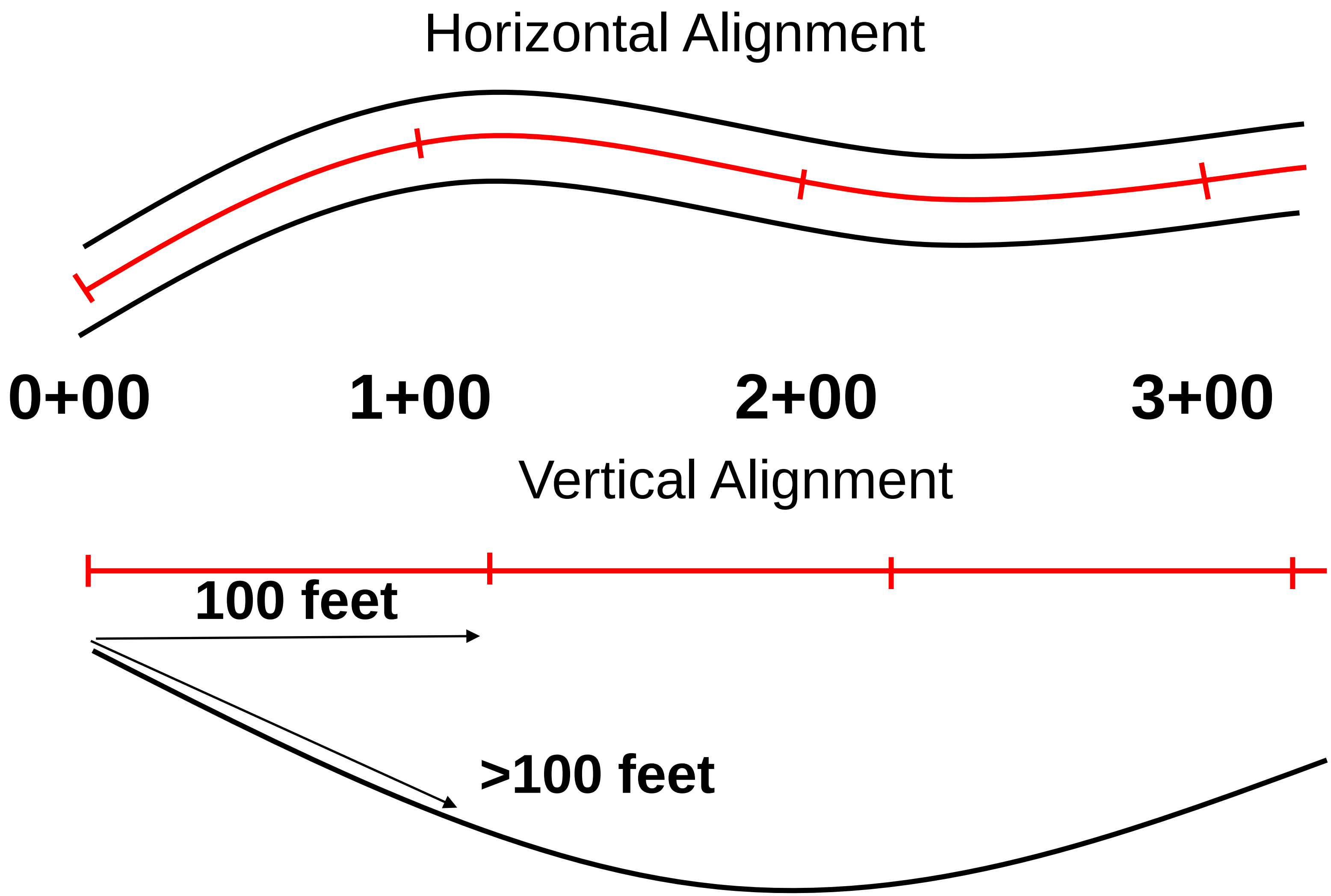
Solution

Solution

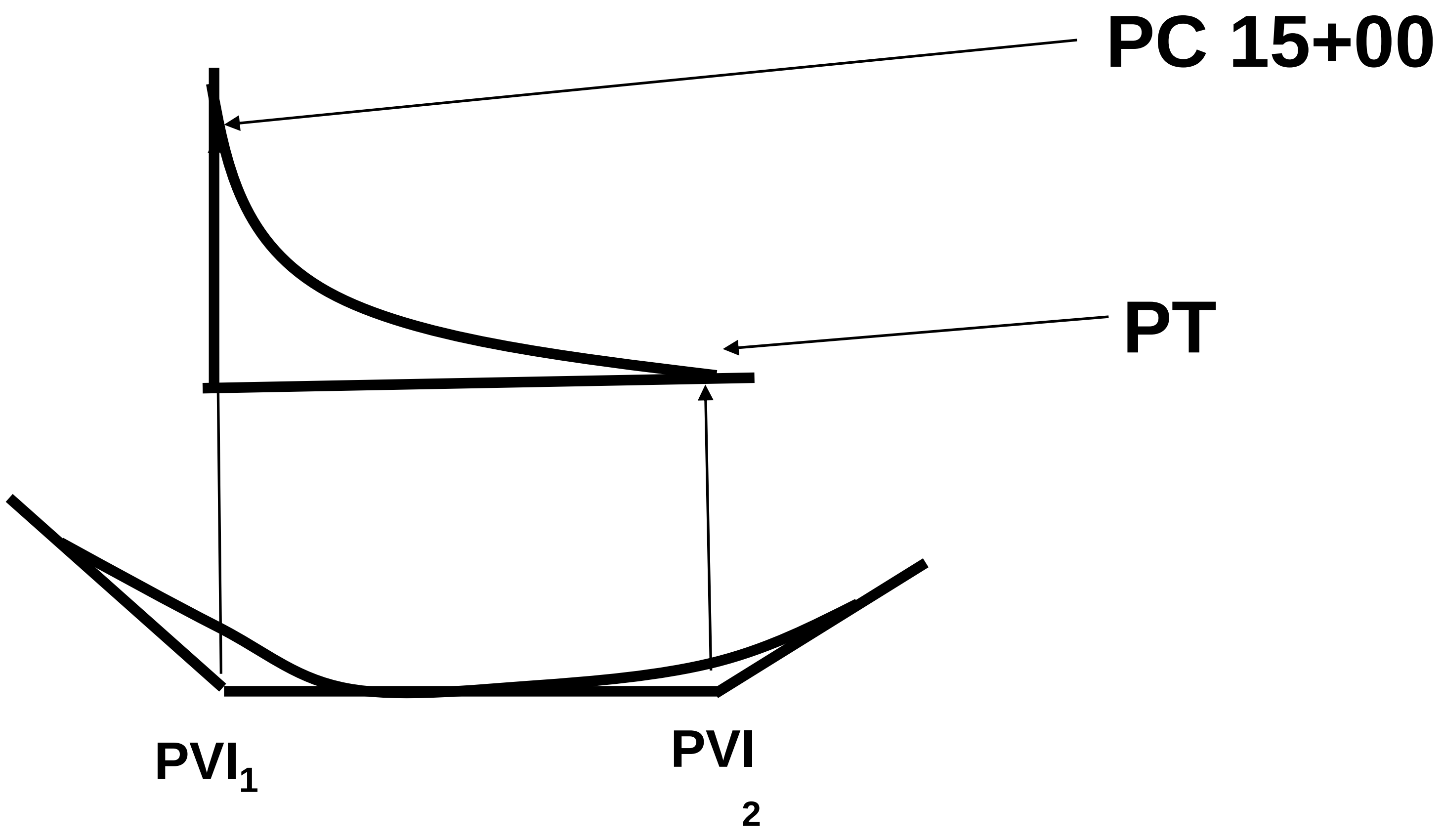
Combining Horizontal and Vertical Curves



Stationing – Linear Reference System



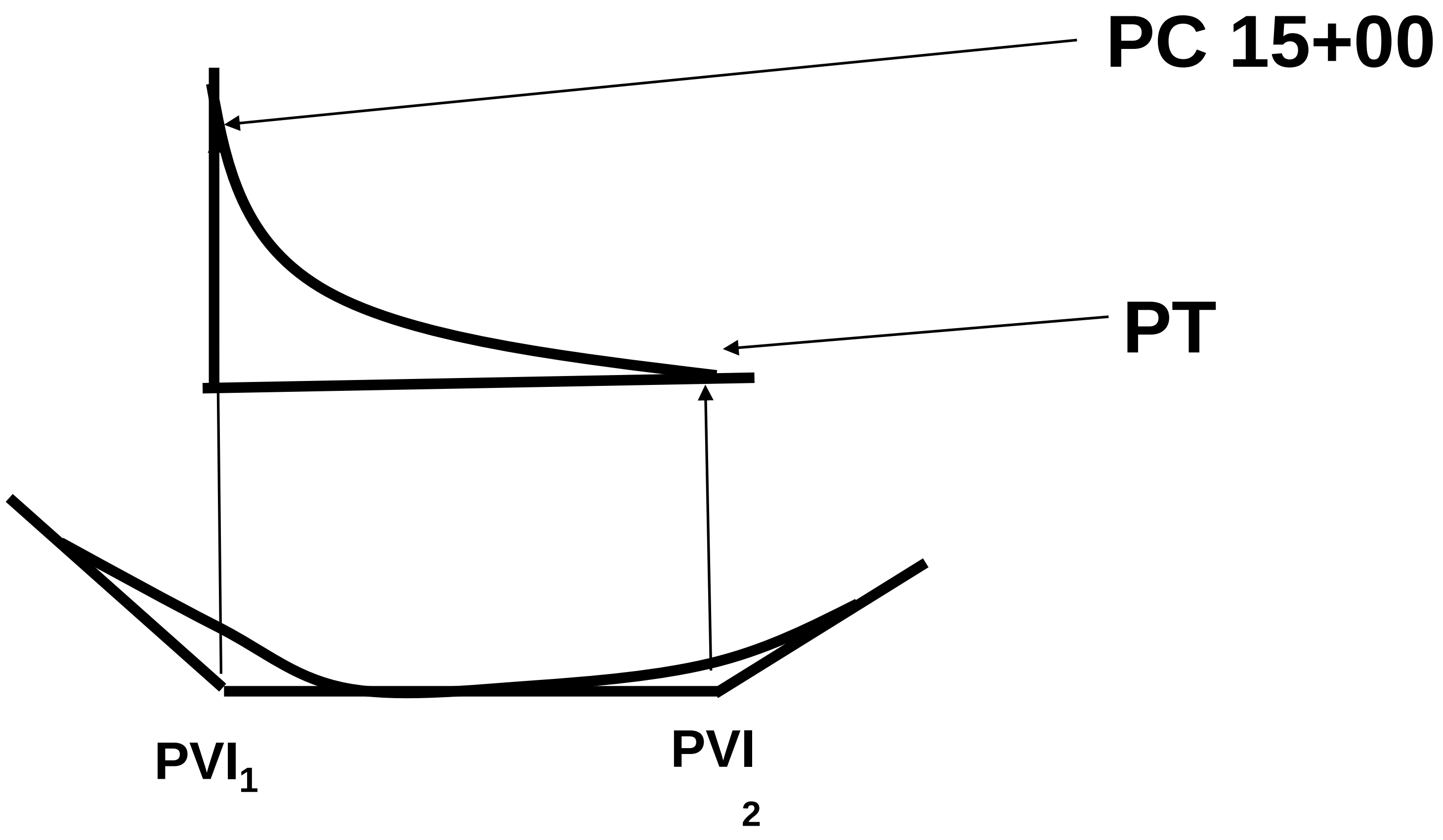
Want stationing for PC, PT, PVC, and PVT



solution

solution

Want stationing and elevation for PC, PT, PVC, and PVT



solution

solution