Indiana Design Manual
Chapter 43: Horizontal Alignment
Proposed Revisions

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Horizontal Curves Studies

In crash studies it has been estimated that nation wide nearly 25% of all fatal crashes occur in or near a horizontal curve. Horizontal curves makeup about 5% of the nation total roadway system.

Research conducted on behalf of MnDOT and the Minnesota Local Road Research Board (LRRB) determined that about 2/3 of the rural crashes in Minnesota resulted from road departures and half of those occurred on horizontal curves.

Crash rates were found to increase as the radius decreased. In the study's data set the following:

1. Curve related crashes with a radius greater than equal to 2000-ft had a crash rate equal to the statewide average for all two-lane highways.
2. Curves with a 1500-ft radius had a crash rate approximately twice the statewide average.

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Horizontal Curves Studies-Continued

3. Curves with a 1000-ft radius had a crash rate 5 times the statewide average.
4. Curves with a 500-ft radius had a crash rate 11 times the statewide average.
5. Approximately 90% of the fatal crashes and 75% of injuries occurred on curves with a radius less than 1500-ft.
6. 46% of severe lane departure crashes occurred on 36% of curves with radii between 500 and 1800-ft.
7. In urban and suburban areas, road crashes were generally lower in curves than in tangent sections, while the frequency of off-road crashes are higher in the curves.

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Roadway Curvature vs Crash Rate

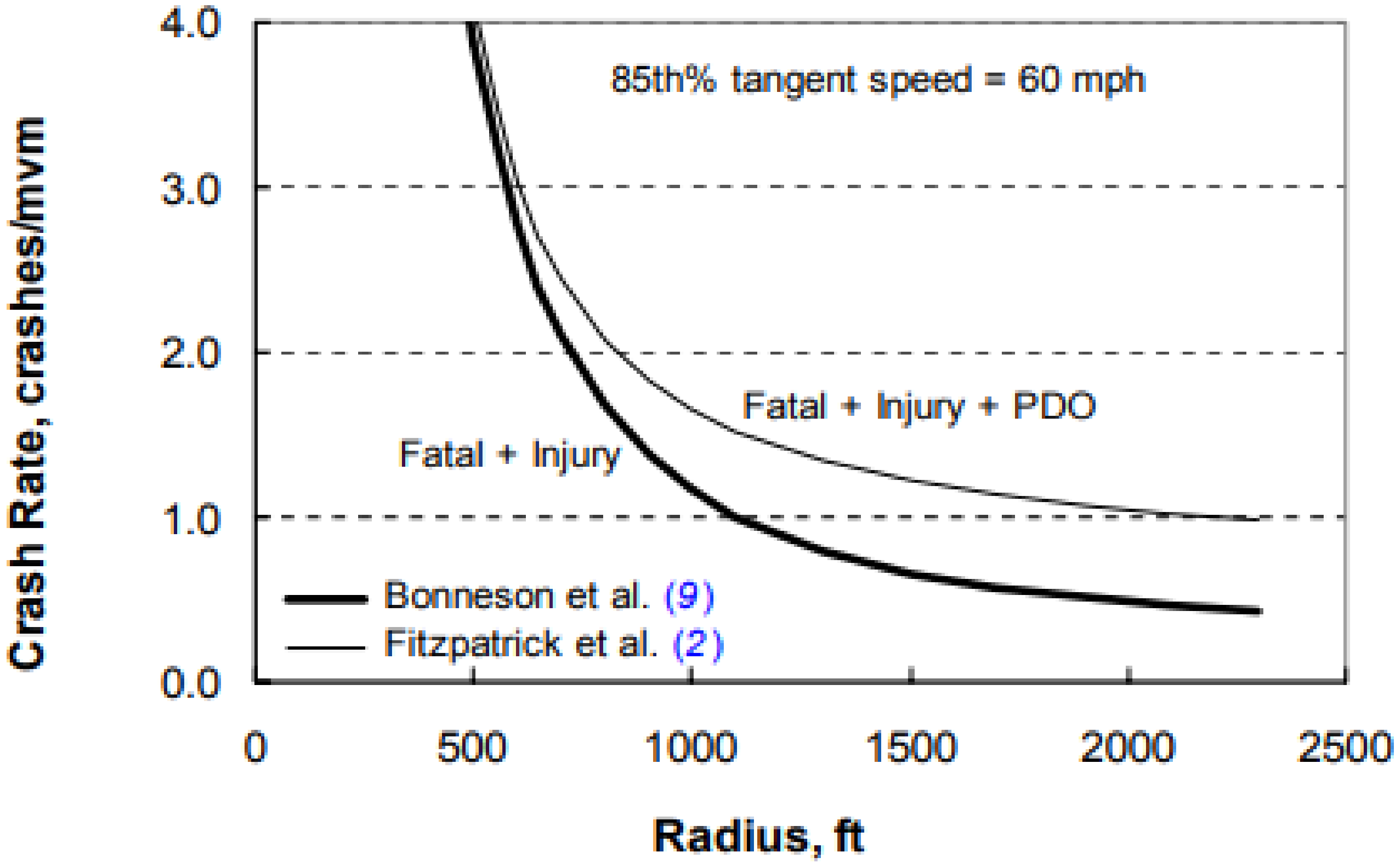

Figure 2-4. Curve Crash Rate as a Function of Radius.

The figure is from *Development of Guidelines for Establishing Effective Curve Advisory Speeds,* Bonneson etal. 2007, basically mirrors finding from the MnDOT study. Data from this curve is from Texas which stated that they have approximately 3200 fatalities a year where 44% of those occur on horizontal curves. The sharp increase occurs at radii less than 1000-ft.

Chapter 43 -Summary of Revisions

- Horizontal Alignment Practices
  - Minimum Length of Curve
  - Broken-Back Curves
  - Compound Curves
  - Reverse Curves

- Superelevation Runoff Changes
  - Figures no longer incorporated 2018 AASHTO GB
  - Revisions to the distribution of the transition.
  - New range for maximum gradient
  - New Policy for using minimum superelevation runoff length

Section 43-2.05 Minimum Length of Curve

Δ (deg)	Minimum Curve Length (ft)
≤ 1	100
1 < Δ ≤ 2	200
2 < Δ ≤ 3	300
3 < Δ ≤ 4	400
4 < Δ ≤ 5	500
> 5	Calculated Length

AASHTO (*AASHO*) since 1954 has stated the following:

"For small deflections angles, curves should be sufficiently long to avoid the appearance of a kink. Curves should be at least 500-ft long for a central angle of 5 degrees, and the minimum length should be increased 100-ft for each 1-degree decrease in the central angle."- 2018 GDHS, Section 3.3.13

Section 43-2.05 Minimum Length of Curve

Freeway or Rural Highway. The minimum length of curve should be *15V* for esthetics.

A Policy on Geometric Design of Highways and Streets, 2018, 7th Edition, Section 3.3.13 states: *"The minimum length for horizontal curves on main highways, $L_{c\,min}$, should be 15 times the speed(V) expressed in mph. On high-speed controlled access facilities that use flat curvature for esthetic reasons, the desirable minimum length of curves should be double the minimum length (30V) described above."*

This language first showed up in the 1984, GDHS….the original *"GreenBook"*.

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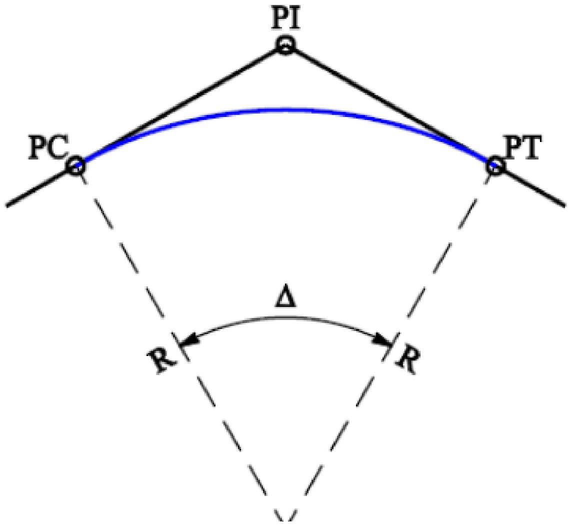
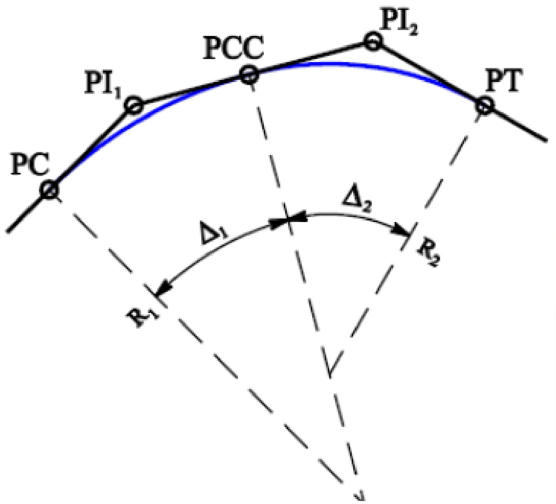
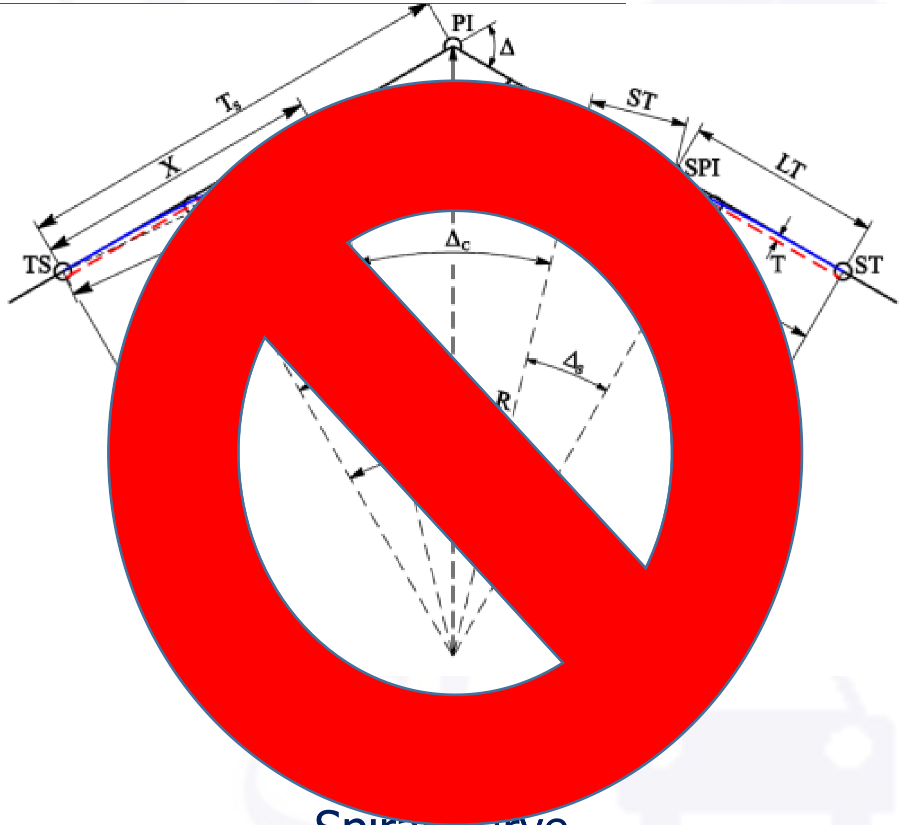
Horizontal Curve Types



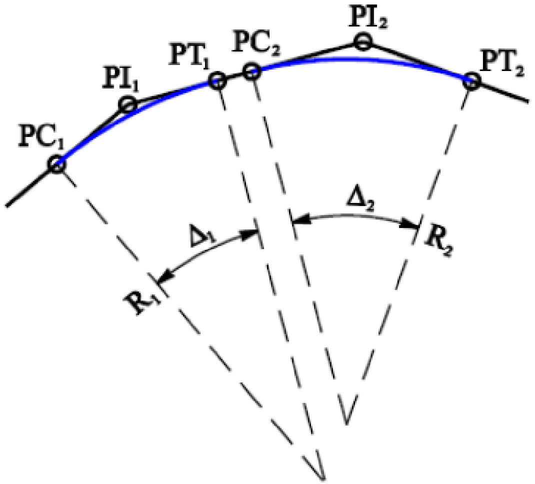
Simple Curve



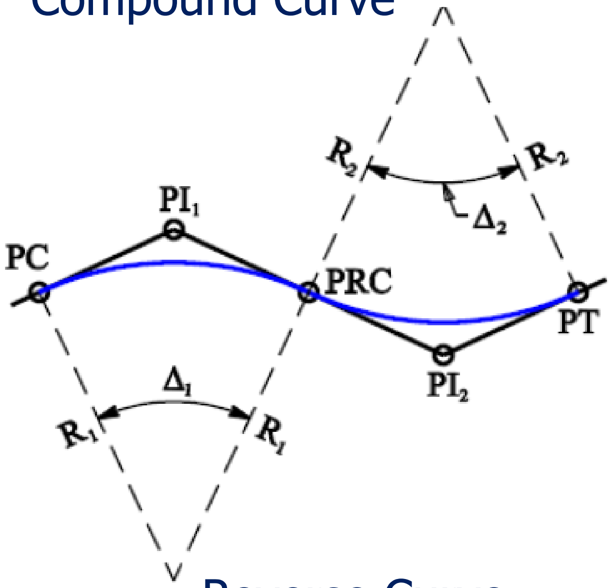
Compound Curve



Spiral Curve



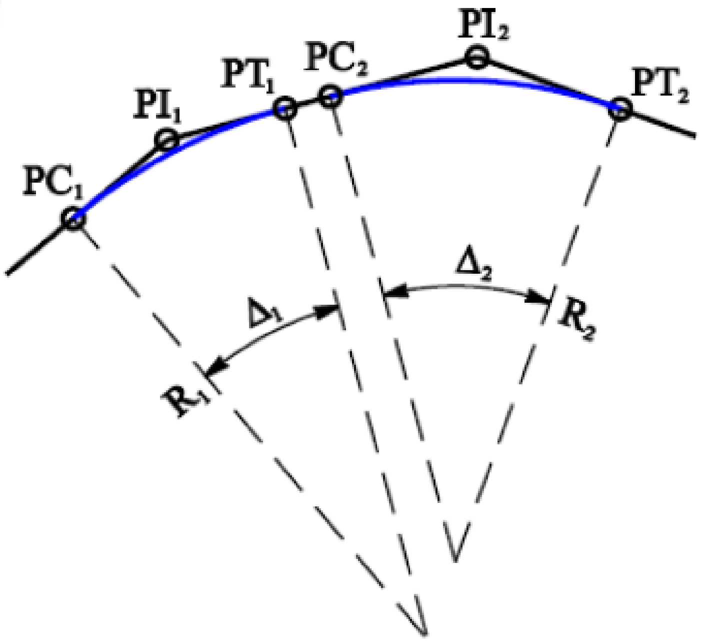
Broken-Back Curve



Reverse Curve

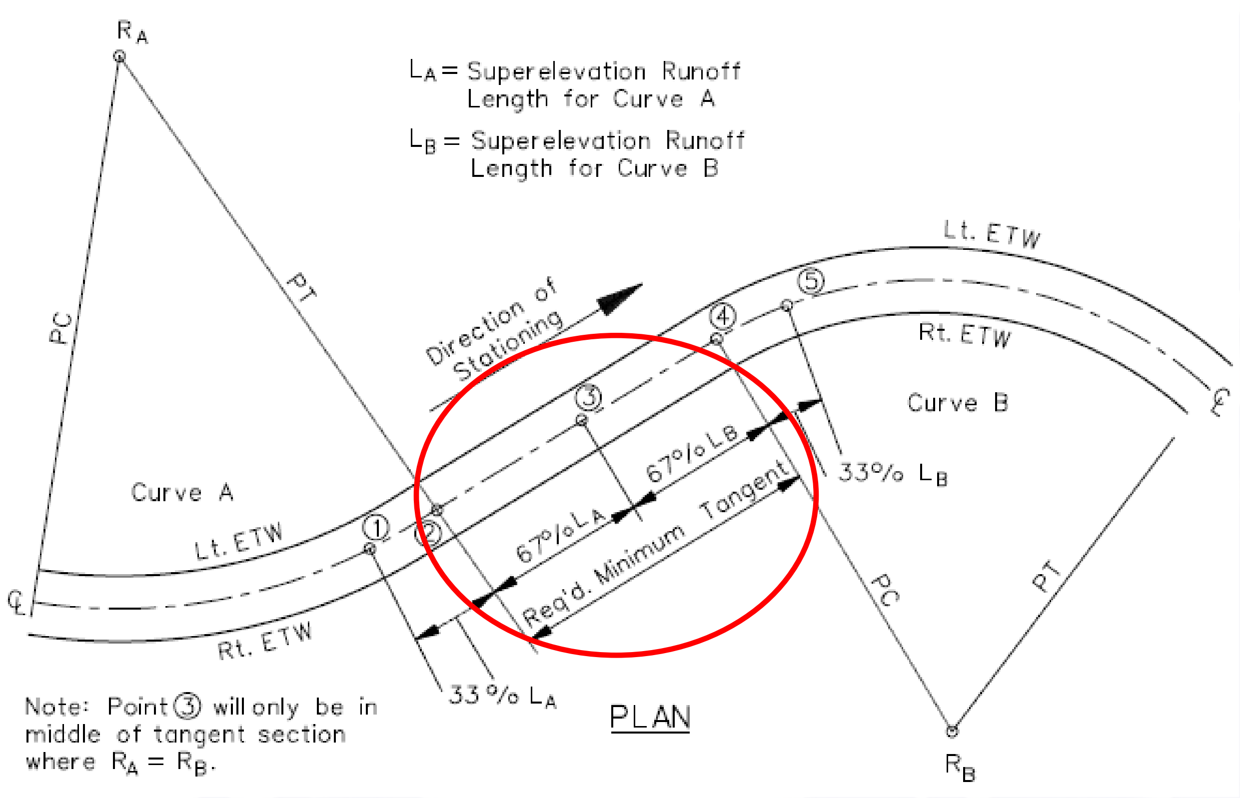
Broken-Back Curves

- Definition: A broken-back curve are successive curves turning in the same direction separated by short tangent. The AASHO publications, *A Policy on Geometric Design of Rural Highways*, 1954 & 1965 and *A Policy on Design of Urban Highways and Arterial Streets*, 1973 defined a broken-back curve as having the tangent being less than 1500-ft.
- *Avoid* using. The alignment violates the driver's expectancy.
- Most DOT design manuals either don't mention them in their manual or state they are *"unsightly"* or *"not esthetically pleasing"* in appearance or should be used with caution.
- Minnesota, Illinois and Louisiana use different criteria for minimum tangent between the curves. Illinois uses 1500-ft, Louisiana uses *15V* and Minnesota uses 1000-ft.
- INDOT's position is to require a minimum tangent length of **1000-ft** between the curves and the usage should be avoided.
- The length of curve criteria applies to each curve…not the combination of the lengths of both curves and tangent.



Broken-back Curve

Reverse Curves – Revisions to IDM Section 43-3.07



IDM Section 43-1.0 defines a reverse curve as "…two simple curves with deflections in opposite directions which are joined with an intervening ***short tangent*** section."

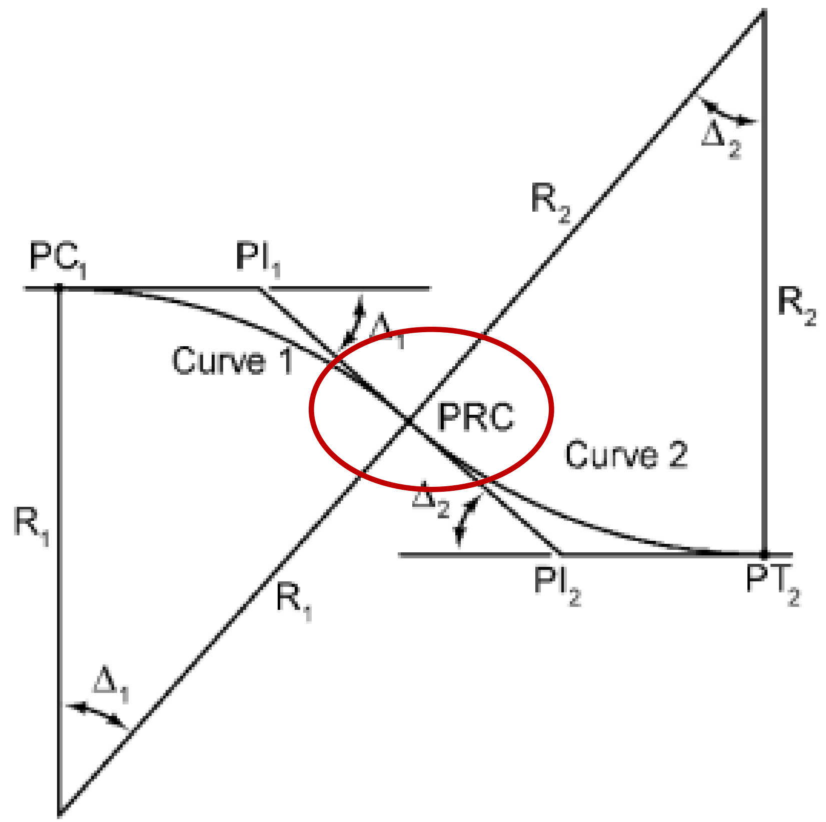
Returning to a tangent section between the reversed curves will require a minimum of 2 seconds of travel time and the superelevation transition requirements for both curves. This includes desirably the sum of the respective 2/3 of superelevation runoff and tangent runout lengths for each curve plus 2 seconds of travel time.

On superelevated curves using a continuously rotating plane the distance between the PT and PC should be desirably the sum of the respective 2/3 of superelevation runoff lengths.

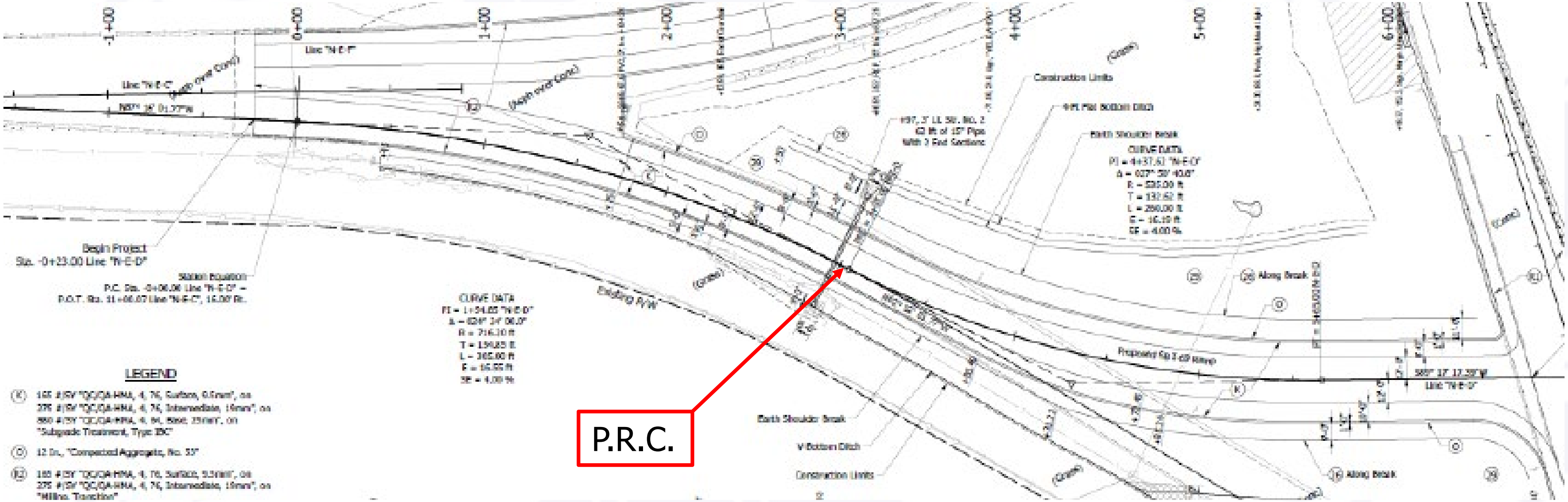
The minimum tangent length on non-superelevated sections should be 200-feet.

Point of Reverse Curvature (P.R.C.)

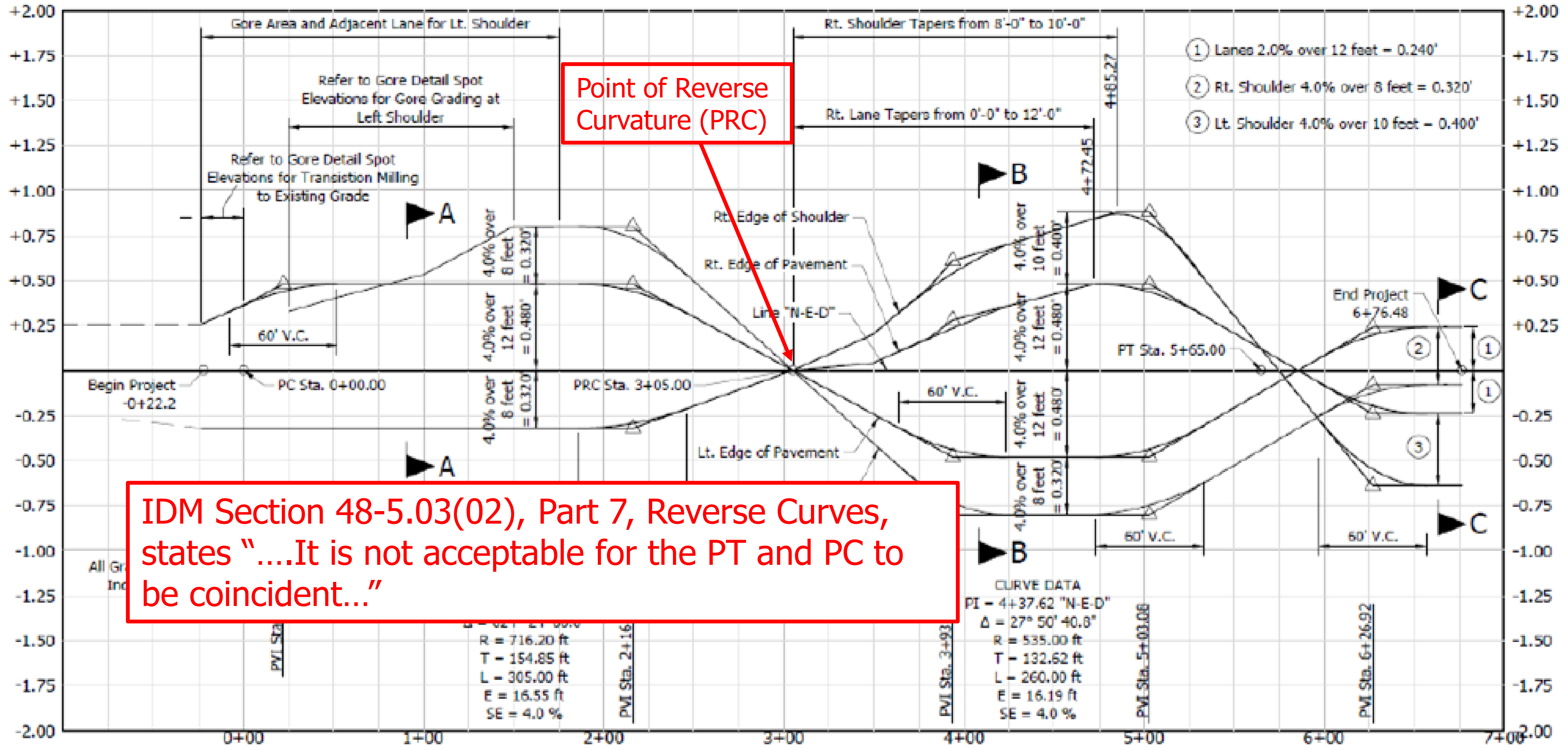
- Point of Reverse Curvature is where two reverse curves are joined at a common point, the Point of Reverse Curvature (PRC).
- These have been showing up way too frequently on major projects involving high-speed roadways, interstates and interchange ramps. Not allowed on ramps or mainline roadways.
- When two curves are superelevated in the opposite direction and connected at the PRC, one of the following two scenarios happen in which neither is good:
    1. The PRC is not super elevated going in or out of a curve.
    2. The PRC will have super elevation in the wrong direction going in or out of one of the curves.



Point of Reverse Curvature (P.R.C.)



Point of Reverse Curvature (P.R.C.)



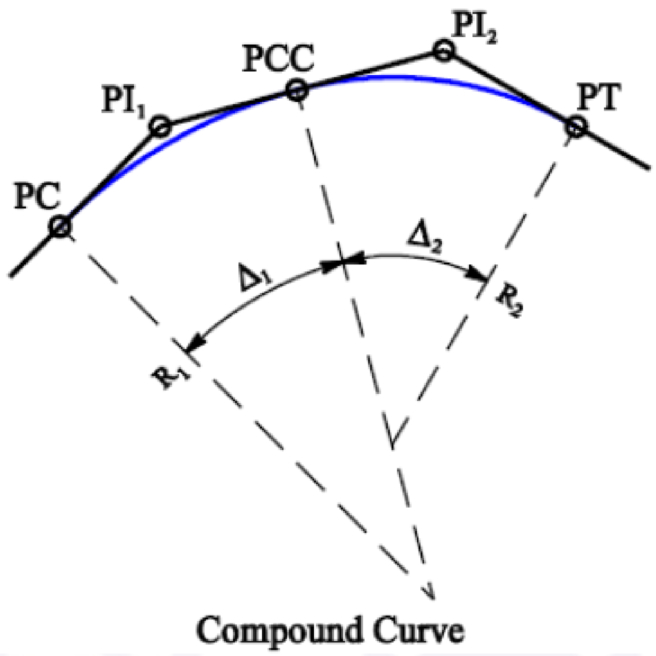
Point of Reverse Curvature (PRC)

IDM Section 48-5.03(02), Part 7, Reverse Curves, states "….It is not acceptable for the PT and PC to be coincident…"

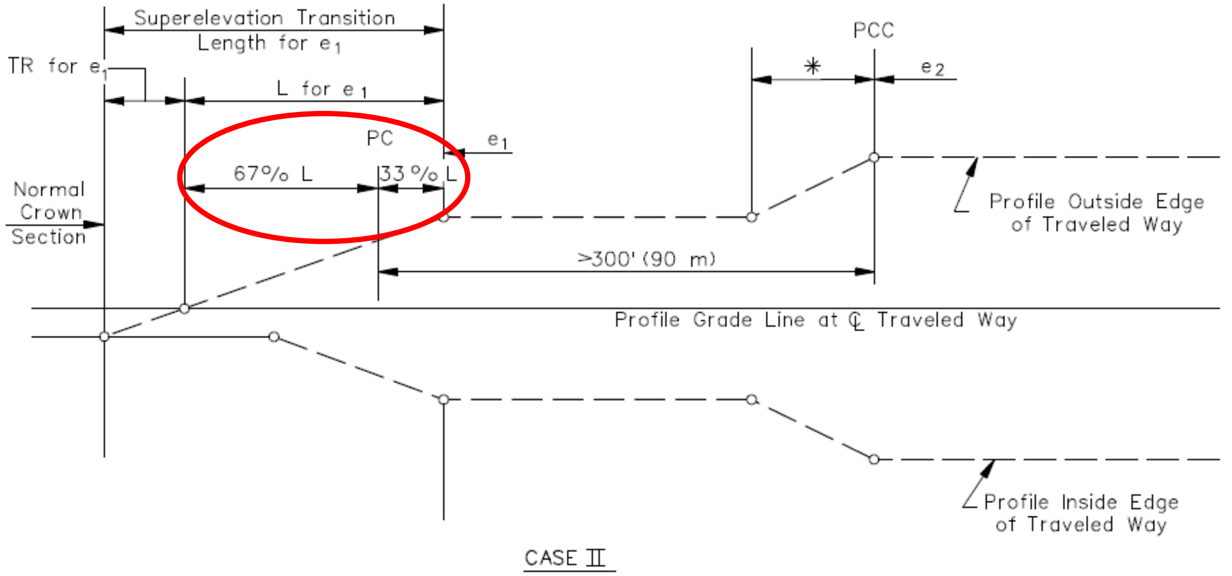
Compound Curves

The IDM Chapter 43 does not address the design of compound curves. The following is the proposed design criteria using 2018 GDHS Sections 3.3.7.3 and 3.3.8.12 and has been in the AASHO/AASHTO publications since 1954:

- The use of compound curves should be ***avoided***.
- For a compound curves used on open highways, and system interchange ramps, the larger radius should not desirable be 25% (1.25:1) greater than the smaller radius. However, the ratio should not exceed 1.5:1.
- For approaches at intersections, turning and low speed roadways including service interchange ramps, the desirable maximum ratio of the larger radius to the smaller radius is *1.75:1*. However the ratio should not exceed 2:1.
- For directional roadways and ramps, compound curves with a radius ratio larger than 2:1 for traveling from the smaller to a larger radius is not an issue.
- The criteria for *minimum lengths of a horizontal curve* presented earlier in this presentation are applicable to the total arc length of the compound curves.

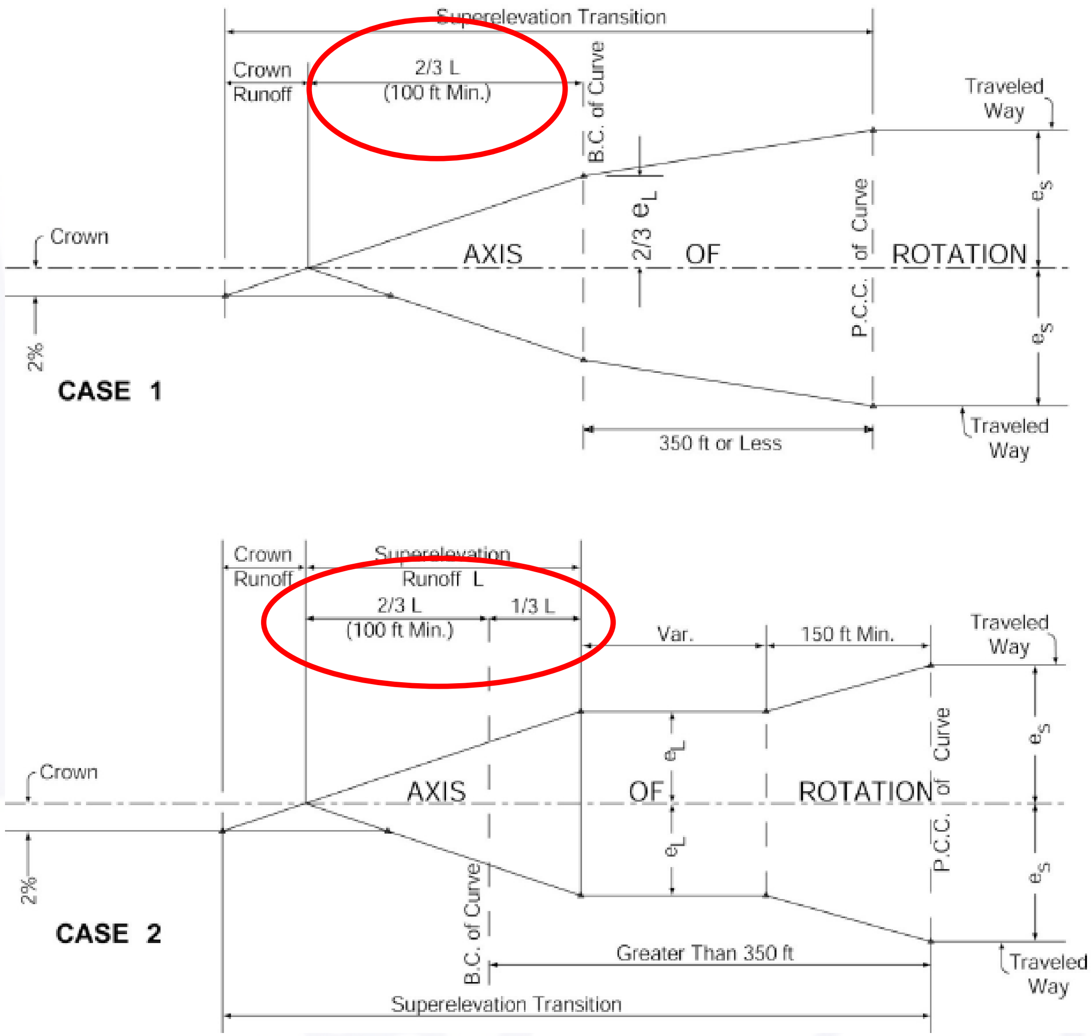


Compound Curves - Superelevation Diagrams



∗ *This distance may be determined by application of RS for the first curve to the increase in superelevation for the second curve (i.e., $e_2 - e_1$).*

Illinois DOT – Figure 32-3M



Caltrans – Figure 202.6

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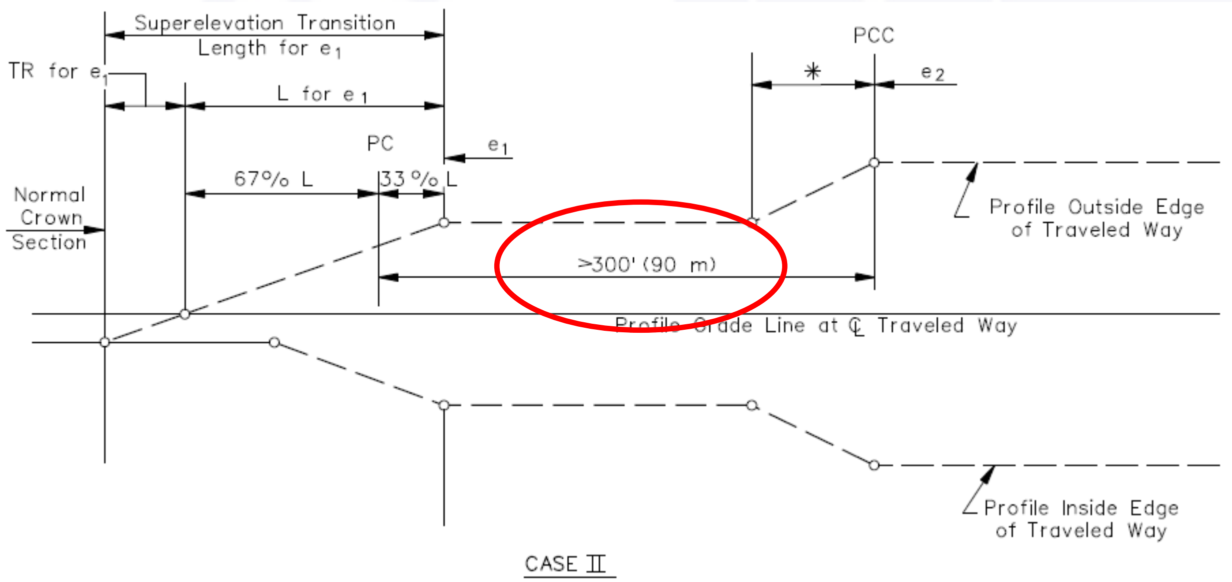
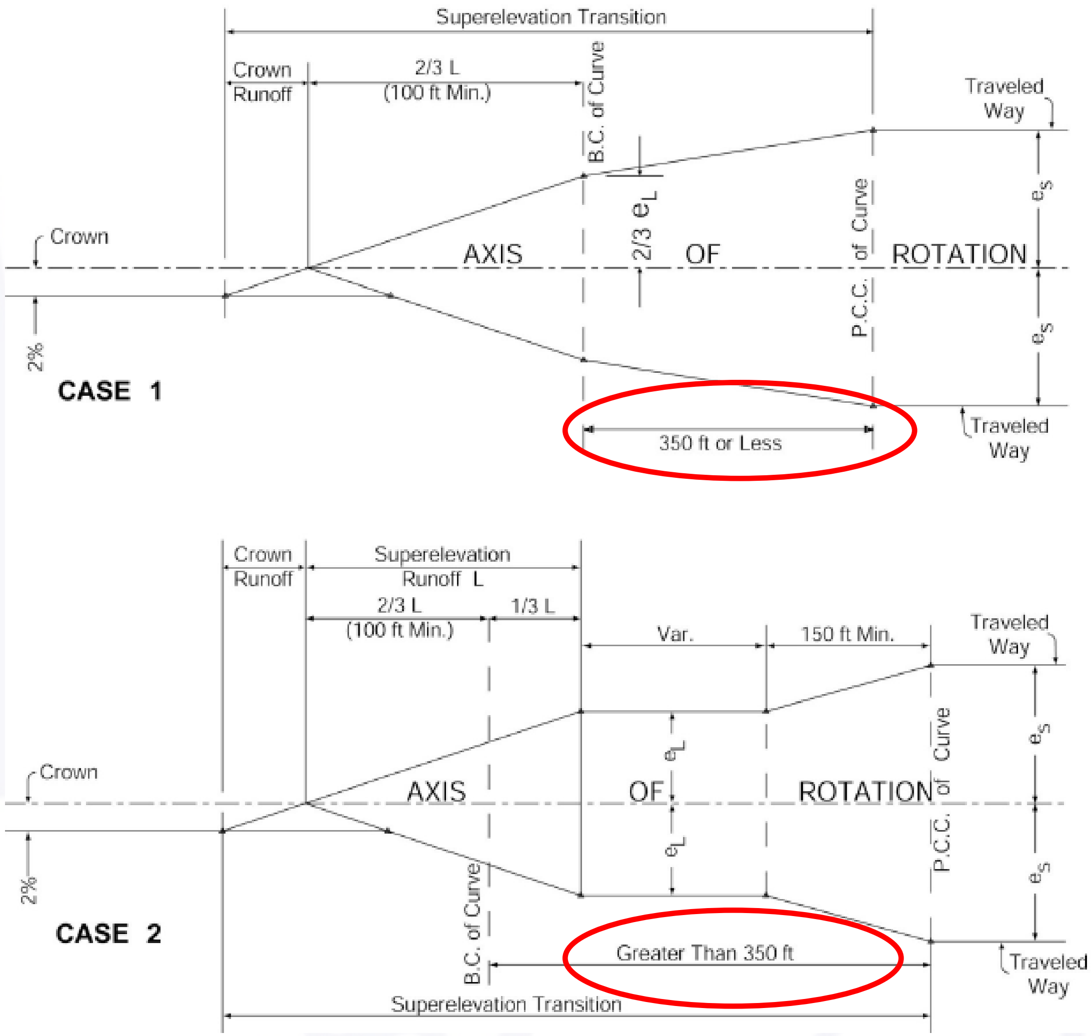
Compound Curves – Superelevation Diagrams



* *This distance may be determined by application of RS for the first curve to the increase in superelevation for the second curve (i.e., $e_2 - e_1$).*

Illinois DOT – Figure 32-3M



Caltrans – Figure 202.6

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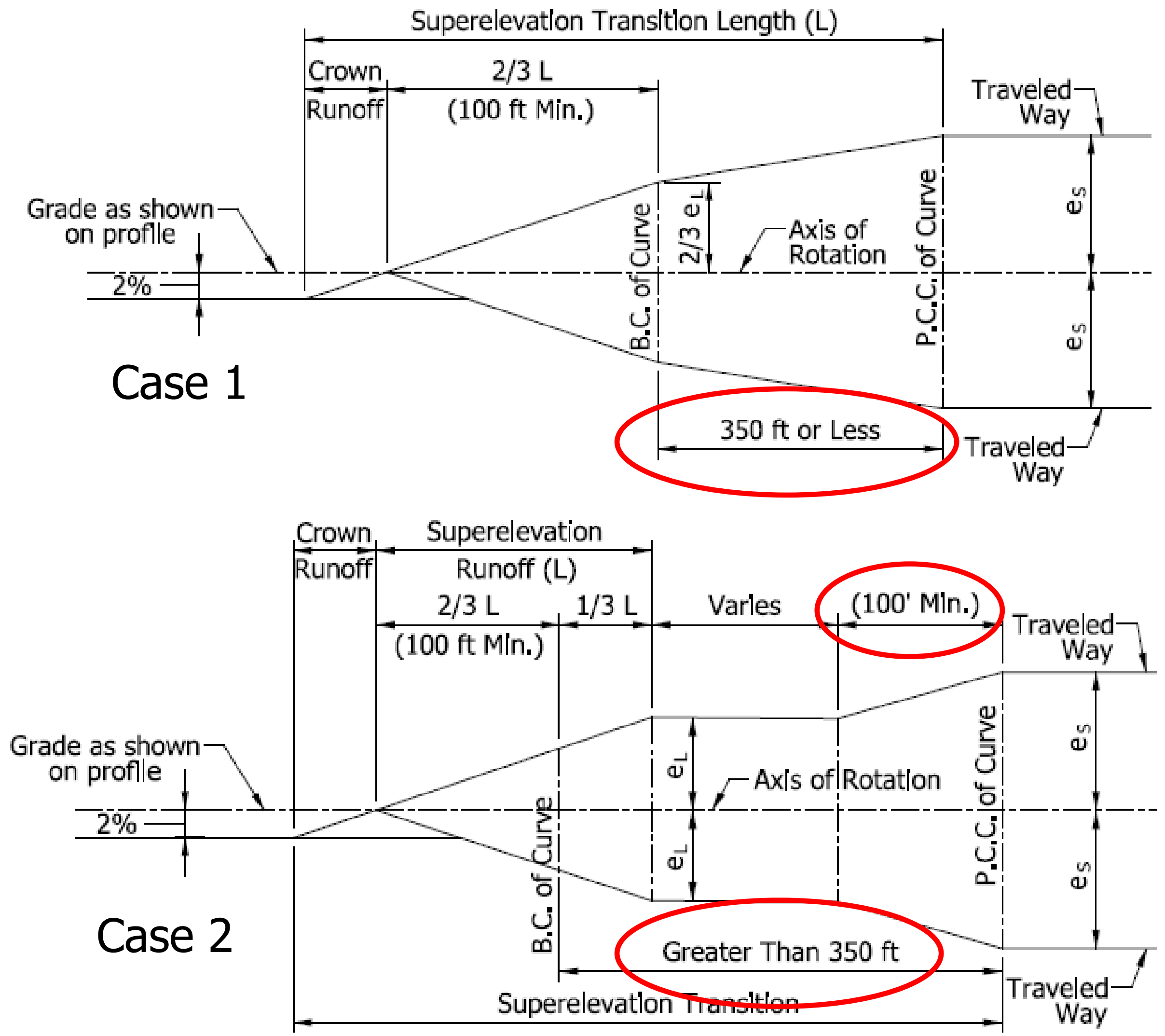
Compound Curve Superelevation Diagram



Case 1: The distance between the PC of larger radius curve to the PCC is 350-ft or less.

Case 2: The distance between the PC of larger radius curve to the PCC is greater than 350-ft.

L= Length of Super Elevation Transition Length

e_S = Super elevation rate for small radius curve

e_L = Super elevation for large radius curve

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Superelevation Runoff

Superelevation Runoff

The 2001 AASHTO revised the methodology for superelevation based on the NCHRP Report 439, *Superelevation Distribution Methods and Transition Designs,* 2000:

In summary:

- Stated theoretically "that values for the proportion of runoff length on the tangent in the range of 70 to 90 percent offer the best operating conditions". This was to reduce the effects lateral acceleration.
- Added table (Figure 43-3F) to determine the portion of runoff length on tangent based on speed and number of lanes.
- Introduced the b_w factor to determine *minimum* runoff lengths…which significantly reduce runoff lengths depending on the number of rotated lanes. See Figure 43-3G.

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Superelevation Runoff

Number of Lanes Being Rotated*	b_w
1	1.0
1½	0.83
2	0.75
2½	0.70
3	0.67
3½	0.64

bw VALUES
(Superelevation Runoff Lengths, Multilane Highways)

Figure 43-3G

V (mph)	Number of Lanes Rotated			
	1	1.5	2 or 2.5	3 or 3.5
15 - 45	80%	85%	90%	90%
50 - 70	70%	75%	80%	85%

PORTION OF SUPERELEVATION RUNOFF ON TANGENT, %

Figure 43-3F

Superelevation Runoff

In the 2018 AASHTO GB, based on NCHRP Report No. 774, *Superelevation Criteria for Sharp Horizontal Curves on Steep Grades*, 2013, the superelevation transition runoff distribution was revised again.

- It was found that *"placing too great a proportion of the runoff length on the approach tangent develops excessive superelevation prior to the PC and results in negative side friction through much of the transition. With negative side friction, drivers are required to correctively steer uphill against the developing superelevation in order to maintain position in their lane."*
- To achieve a balance between the lateral acceleration and negative side friction, it was proposed to place 50 to 80 percent of the runoff on the tangent. Most agencies are using 67%.

Superelevation Runoff: The b_w Factor

- IDM Section 43-3.03(02), ***Highway with 4 or More Lanes***, discusses superelevation runoff distance for multilane highways. It directs the designer to use Equation 43-3-3:

$$L_r = \frac{wne_d(b_w)}{G}$$

- There is no discussion on when or why to use b_w. The manual does not state that the formula is for the *minimum length* of SE Runoff. The Section refers to Figure 43-3G to determine the appropriate factor.
- There is no discussion on the impact of the Gradient of the superelevated edges of pavement. The gradients depending on the number of lanes rotated can increase the Gradient by 50 % and decrease the design speed by over 3.5 times.

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The Effects of b_w on the *Gradient*

Design Speed	Required G_{max}	Number of Lanes Rotated (b_w factor)							
		1.5(0.83)		2(0.75)		2.5(0.70)		3(0.67)	
MPH	%	G_r	V_r	G_r	V_r	G_r	V_r	G_r	V_r
40	0.58	0.70	25	0.77	16	0.83	<15	0.87	<15
45	0.54	0.65	31	0.72	23	0.77	16	0.81	<15
>50	0.50	0.60	37	0.67	29	0.71	24	0.75	19

G_r = Resultant Gradient
V_r = Equivalent Speed (mph)

Design Speed (mph)	Equivalent Max. *RS*	Edge-of-Travelway Slope Relative to Centerline G_{max} (%)
15	128	0.78
20	135	0.74
25	143	0.70
30	152	0.66
35	161	0.62
40	172	0.58
45	185	0.54
50	200	0.50
55	213	0.47
60	222	0.45
65	233	0.43
70	250	0.40

$$G_{max} = \frac{100}{RS}$$

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Superelevation Runoff: The b_w Factor

- The 2001 GDHS and all subsequent publications of the GDHS have stated that using the above referenced formula is for the "***minimum length of runoff***". It also states that for *"higher type alignments, runoff lengths longer than those shown …may be desirable."* Florida, and California do not use the b_w factor. Ohio does not allow the use on their interstate system and primary highways. Texas does not use but will yield if existing facilities are impacted.

Superelevation Runoff

INDOT Proposed Policy:

- The 2018 AASHTO eliminated the table for maximum gradients that had been in previous Green Books and defers to the text in the Chapter which mirrors the values from 50 mph and lower, however it capped the maximum gradient at 0.50% for 50 mph and greater.
- INDOT is proposing that 67% of the SE runoff length is to be on the tangent regardless of the number lanes rotated.
- INDOT facilities are consider a higher type facilities, the current formula for determining the desired superelevation runoff lengths for multilane facilities, would limit the adjustment factor to $b_w = 1$. However, strict adherence to the desirable length may not be possible at all times, a reduced length can be calculated using the adjustment factors but *not always* to the minimum.

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Superelevation Runoff - Revised Tables

Adjustment Factor, b_w		
Number of Lanes, Rotated	INDOT Highways, Interstates, Freeways and Ramps	Others
1	1.00	1.00
1.5	1.00	0.83
2	1.00	0.75
2.5	1.00	0.70
3	1.00	0.67
3.5	1.00	0.64

Adjustment Factor for Number of Lanes Rotated

Design Speed (mph)	Equivalent Maximum Relative Slope (*RS*)	Maximum Relative Gradient *G = RS x 100%*
15	1:128	0.78
20	1:135	0.74
25	1:143	0.70
30	1:152	0.66
35	1:161	0.62
40	1:172	0.58
45	1:185	0.54
≥ 50	1:200	0.50

Maximum Relative Slopes and Gradients

Summary

- Minimum of 500-ft length of curves for non-high-speed facilities and the ramp proper of service ramps where practical.
- Minimum *15V* length of curve for high-speed rural and urban facilities where practical. *30V* length of curve desirable for interstates.
- Broken-back curves are discouraged to be used, however the use of a minimum 1000-ft tangent length between curves is acceptable.
- Reverse Curves – tangent sections to accommodate required SE transitions. Minimum tangent length of 200-ft between curves. **No PRCs**.
- Compound Curves-avoid using. High speed roadway, desirable ratio 1.25 of large to small radius, maximum ratio should not exceed 1.5. For low-speed facilities, the desirable ratio is 1.75:1, maximum ratio should not exceed 2:1.
- Superelevation criteria, adopt 2018 AASHTO guidance, use b_w =1 for all of INDOT facilities. Use 2/3 superelevation runoff length on the tangent regardless of the number of lanes rotated.

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Questions?

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