Iowa Department of Transportation
Office of Design

2A-2

Superelevation

Design Manual
Chapter 2
Alignments

Originally Issued: 12-31-97
Revised: 06-30-09

Superelevation is the banking of the roadway along a horizontal curve so motorists can safely and comfortably maneuver the curve at reasonable speeds. As speeds increase and horizontal curves become tighter a steeper superelevation rate is required.

Definitions

Side Friction - the friction force between a vehicle's tires and the pavement that prevents the vehicle from sliding off the roadway.

Axis of Rotation - the point on the cross section about which the roadway is rotated to attain the desired superelevation.

Superelevation Rate (e) - the cross slope of the pavement at full superelevation.

Superelevation Runoff Length (L) - the length required to transition the outside lane(s) of the roadway from a zero (flat) cross slope to full superelevation, or vice versa.

Tangent Runout Length (x) - the length required to transition the outside lane(s) of the roadway from a normal crowned section to a point where the outside lane(s) have zero (flat) cross slope, known as the point where the roadway removes adverse crown.

Relative Gradient (G) - the slope of the edge of pavement relative to the axis of rotation.

Width (w) - the distance from the axis of rotation to the outside edge of traveled way.

Figure 1 shows these definitions graphically.

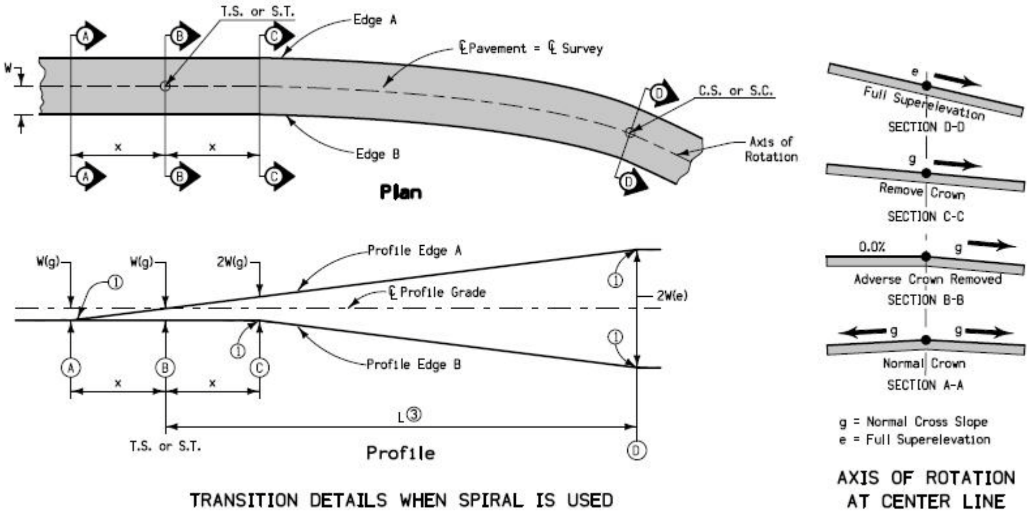

Figure 1: Graphical definitions of superelevation in terms for a two lane roadway.

Superelevation Rate (e)

In Iowa, the superelevation rate is limited to a maximum of 8%. This reduces the risk of slow moving vehicles sliding down a superelevated roadway during winter conditions. For new construction, the superelevation rate is limited to 6%. This allows the shoulders to slope away from the driving lanes without exceeding AASHTO's 8 percent maximum value for crossover breaks. The superelevation rate for new urban facilities is limited to 4% due to the frequency of cross streets, driveways, and entrances adjoining the curve, as well as the possibility of vehicles stopping on the curve at signalized intersections. The Department's current policy on maximum superelevation rates are summarized in Table 1.

Table 1: Maximum superelevation rates.

	Rural Facilities	Urban Facilities
New or Reconstruction	6%	4%
3R/4R	Maintain original design up to 8% unless problems exist	6%

Superelevation and Side Friction

Side Friction Demand Factor

The side friction demand is the amount of friction required for a given velocity and geometric design. The following formula shows the relationship between side friction demand, superelevation rate, speed, and radius of curvature.

$$f_d = \frac{\mathrm{v}^2}{\mathrm{gR}} - \frac{\mathrm{e}}{100}$$

where:

v = velocity of the vehicle, ft/s (m/s).

g = gravity, 32.2 ft/s^2 (9.81 m/s^2).

R = radius of the curve, ft (m).

e = superelevation rate, %.

Maximum Side Friction Factors (f_{max})

When establishing the maximum side friction factor to use for horizontal curve design, the vehicle's need for side friction, as well as driver comfort, must be taken into account.

Side Friction (vehicle's need)

A vehicle will begin to skid when the side friction demand equals the maximum amount of friction that can be developed between the tires and the pavement. This maximum friction, with a factor of safety to account for variations in the speed, tire conditions, and pavement conditions, is the maximum design friction factor based upon vehicle need.

Side Friction (driver comfort)

Through a horizontal curve, drivers can experience a feeling of being pushed outward. If this feeling becomes uncomfortable, the driver will compensate by flattening out their path (increasing R) or braking (decreasing v) to reduce lateral acceleration, and subsequently f_d, to an acceptable level. Often it is the driver's comfort that determines the superelevation requirements, not the vehicle and roadway characteristics. On low speed roadways, drivers will accept more lateral acceleration, thus permitting a larger side friction demand. As speeds increase, drivers become less tolerant of lateral acceleration, requiring a reduction in side friction demand.

Based upon research of the above factors, 🕮 AASHTO's *A Policy on Geometric Design of Highways and Streets* lists maximum side friction factors for use in design of horizontal curves. These are summarized in Table 2 below.

Table 2: Maximum side friction factors

Design Speed (mph)	f_{max}	Design Speed (mph)	f_{max}
15	0.32	50	0.14
20	0.27	55	0.13
25	0.23	60	0.12
30	0.20	65	0.11
35	0.18	70	0.10
40	0.16	75	0.09
45	0.15	80	0.08

Distribution of Superelevation (e) and Side Friction (f)

Chapter 3 of 🕮 AASHTO's *A Policy on Geometric Design of Highways and Streets* discusses five methods of controlling lateral acceleration on curves using e, *f*, or both. Iowa DOT uses Method 2 and Method 5 depending upon the type of roadway.

Low speed urban roadways

- **Method 2:** friction is primarily used to control lateral acceleration and superelevation is added only when side friction would exceed acceptable values.

Drivers are willing to accept more discomfort on low speed urban roadways due to the anticipation of more critical conditions. In addition, several factors make it difficult, if not impossible, to apply superelevation to urban roadways:

- Frequency of cross streets and driveways.
- Vehicles stopping on curves at signalized intersections.
- Meeting the grade of adjacent properties.
- Surface drainage.
- Pedestrian ramps.
- Wider pavement area.

Method 2 is well suited for low speed urban roadways, since it relies first on side friction, then on superelevation to control lateral acceleration. The relationship between superelevation rate and minimum radius for Method 2 distribution can be expressed as follows:

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

where:

V = design speed, mph.
e_{max} = maximum superelevation rate, %.
f_{max} = maximum friction factor for the design speed.
R = Radius of the curve, feet.

Table 14 of Section 2A-3 provides minimum turning radii for various superelevation rates and design speeds.

High speed roadways or ramps

- **Method 5:** side friction and superelevation are both applied using a curvilinear relationship with the inverse of the radius.

At higher speeds, drivers are less comfortable with lateral acceleration through curves. Method 5, works well for determining the distribution of superelevation and side friction for high speed roadways, because superelevation is progressively added as speed increases. It also works well for turning roadways such as ramps.

Superelevation tables for high speed roadways are included in Section 2A-3.The superelevation rate for Method 5 distribution can also be calculated manually using the equations provided in 📖 AASHTO's *A Policy on Geometric Design of Highways and Streets*. When calculating superelevation rates manually round values of e up to the nearest 2/10ths of a percent. An Excel file has been created using these formulas and is provided at the link below.

Superelevation Spreadsheet

Axis of Rotation

The axis of rotation is the point on the cross section about which the roadway is rotated to attain the desired superelevation. For standard situations the axis of rotation is shown on the appropriate Standard Road Plan (RP series). **For cases not covered by the Standards, the axis of rotation should be clearly shown on the typical cross section.**

Undivided highways should be superelevated with the axis of rotation at the roadway's centerline (see Figure 2).

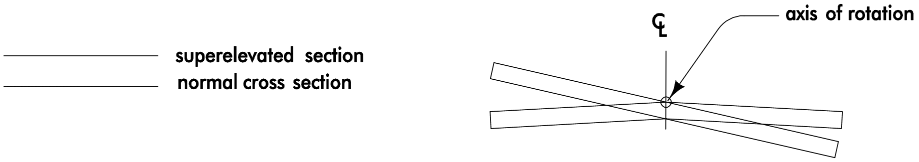

Figure 2: The axis of rotation for undivided highways.

Multi-lane highways with depressed medians should be superelevated with the axis of rotation at the median edges of the 📖 traveled way (see Figure 3). With this method, the cross section of the median remains relatively uniform. This method is also used for two-lane roadways that will ultimately become one direction of a divided highway.

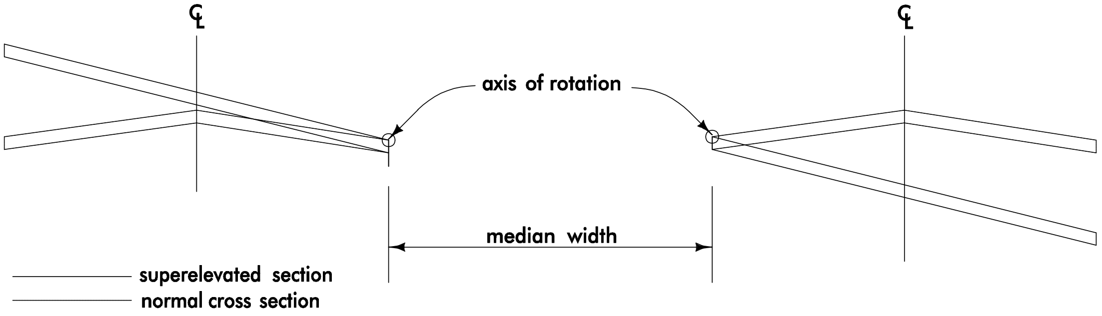

Figure 3: The axis of rotation for multi-lane highways with depressed medians.

Although 📖 AASHTO's *A Policy on Geometric Design of Highways and Streets* suggests moving the axis of rotation back to the roadway centerlines for wider medians, the Department's policy is to keep the axis of rotation at the median edge of the traveled way, regardless of median width. This method may require additional earthwork, but it is preferred for reasons of constructability, simplicity of design, and the appearance of a uniform median cross section. Facilities that have wide medians with independent profile grades and/or construction centerlines may be treated as two-lane (undivided) highways, if the resulting median cross section is acceptable.

Highways with painted medians are rotated about the centerline (see Section 3E-1 for definitions of the various medians).

Roadways with closed medians (concrete barrier rail) should be superelevated with the axis of rotation at the inside shoulder edges. With this method, the cross section of the median pad remains relatively uniform.

The axis of rotation for ramps should be at the baseline. The baseline is usually the lower side of a normal cross section.

Superelevation Transitions

To provide comfort and safety, superelevation should be introduced and removed uniformly. The distance required to transition into and out of superelevation is a function of the relative gradient, width of pavement rotated, and superelevation rate.

Relative Gradient

The slope of the edge of pavement relative to the axis of rotation is referred to as “the relative gradient” (G). Figure 1 shows the relationship between relative transition length (L), superelevation (e), and pavement width (w).

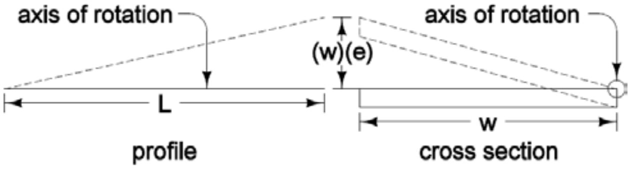

Figure 3: Runoff length and superelevation.

From Figure 3, the following formula can be derived:

$$G = \frac{w \times e}{L}$$

Maximum design values for the relative gradient are shown in Table 3.

Table 3: Maximum relative gradients.

Design Speed (mph)	Maximum Relative Gradient, %, (and Equivalent Maximum Relative Slopes) for profiles between the edge of a two-lane roadway and the axis of rotation	
	Maximum Relative Gradient (G)	Equivalent Maximum Relative Slope
15	0.78	1:128
20	0.74	1:135
25	0.70	1:143
30	0.66	1:152
35	0.62	1:161
40	0.58	1:172
45	0.54	1:185
50	0.50	1:200
55	0.47	1:213
60	0.45	1:222
65	0.43	1:233
70	0.40	1:250
75	0.38	1:263
80	0.35	1:286

Superelevation Runoff Length

The runoff length is the length required to transition the outside lane(s) of the roadway from a zero (flat) cross slope to full superelevation, or vice versa. The following formula is used to determine the runoff length (L).

$$L = \left[\frac{12e}{G}\right]\alpha$$

where:

e = full superelevation (%)

G= Relative gradient (%)

α = adjustment factor (dimensionless) to account for the number of lanes being rotated. See table 4 for common values.

Table 4: Adjustment factor for common roadway widths

Roadway Type	α
two lane undivided (w = 12 ft)	1.00
four lane divided (w = 24 ft)	1.50
six lane divided (w = 36 ft)	2.00
six lane divided with inside shoulder (w = 46 ft)	2.42
eight lane divided (w = 48 ft)	2.50
eight lane divided with inside shoulder (w = 58 ft)	2.92
standard ramp (w = 16 ft)	1.17
standard loop (w =18 ft)	1.25

The adjustment factor (α) for different roadway widths can be calculated manually using the following equation:

$$\alpha = 1 + 0.0417\left(w - 12\right)$$

where:

w = the distance from the axis of rotation to the outside edge of traveled way (ft)

Runout Length

The runout length (x) is the length required to transition the outside lane(s) of the roadway from a normal crowned section to a point where the outside lane(s) have zero (flat) cross slope, known as the point where the roadway removes adverse crown. For consistency, the same relative gradient is used. This means the ratio of the transition length to the runoff length is the same as the ratio of the normal cross slope to the full superelevation:

$$\frac{x}{L} = \frac{g}{e}$$

where:

x = runout length, feet.

L = superelevation runoff length, feet.

g = normal cross slope, %.

e = full superelevation, %.

From this, the runout length is determined as:

$$x = \frac{g}{e}L$$

where x, L, g, and e are as explained above.

Placing Superelevation Transition

How superelevation transition is placed is critical to driver safety and comfort. If all the transition is placed prior to the curve, the driver, while on the tangent, is forced to steer in a direction opposite the curve to avoid drifting into opposing lanes. If all the superelevation transition is placed in the curve, the lateral acceleration the driver experiences upon entering the curve may be intolerable. In addition, side friction may not be sufficient to prevent the vehicle from skidding off the road. Two methods for overcoming these problems are:

- Place superelevation transition in a transition spiral curve, or
- If a spiral curve is not used, place a portion of the superelevation transition in the tangent, and the rest in the horizontal curve.

The superelevation tables in Section 2A-3 provide maximum radii for which spiral curves should be used to introduce superelevation transition. These maximums are found in AASHTO's *A Policy on Geometric Design of Highways and Streets*. They are based on curve radii which suggests an operational and safety benefit from the use of spiral transition curves. The length of the spiral should be set equal to the runoff length.

If a spiral curve is not used, 70 percent of the superelevation runoff length is developed on the tangent section of the roadway, with 30 percent developed on the circular curve. The variable (m) on the Standard Road Plans represents the 30 percent of the superelevation runoff developed on the circular curve. Superelevation at the PC or PT of a curve is equal to 0.70(e).

Acceleration Lanes

Acceleration lanes on the low side of a superelevated roadway should have the same cross slope as the adjacent pavement and match the superelevation rate of transition. Acceleration lanes on the high side of a superelevated roadway should be sloped away from the adjacent pavement, with a cross slope that does not exceed an 8 percent crown break. When determining the width of pavement which is to be rotated for superelevation transition lengths, the auxiliary lanes are not to be included.

Shoulder Superelevation

See Section 3C-3.