Superelevation

Design Manual
Chapter 2
Alignments
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Superelevation is the banking of a roadway along a horizontal curve so motorists can safely and comfortably maneuver the curve at reasonable speeds. A steeper superelevation rate is required as speeds increase or horizontal curves become tighter.

Definitions

Side Friction - the friction force between a vehicle's tires and the pavement which 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 change the cross slope from 0% to the full superelevation rate.

Tangent Runout Length (x) - the length required to change the cross slope from 0% to the normal cross slope.

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.

Quick Tips:

- The State's maximum superelevation rate is 8%
- The superelevation rate for new or reconstructed roadways should be limited to 6% for roadways with a design speed greater than 45 mph to limit cross-slope shoulder break on the high side of superelevated curves to 8% or less.
- Superelevation Distribution Method 2 is preferred for roadways with a design speed of 45 mph or less, but may be optional for urban roadways.
- Design exceptions are required for superelevation rates that are less than the values shown in the tables in Section 2A-3.
- Refer to the tables in Section 2A-3 for values superelevation rates, runoff

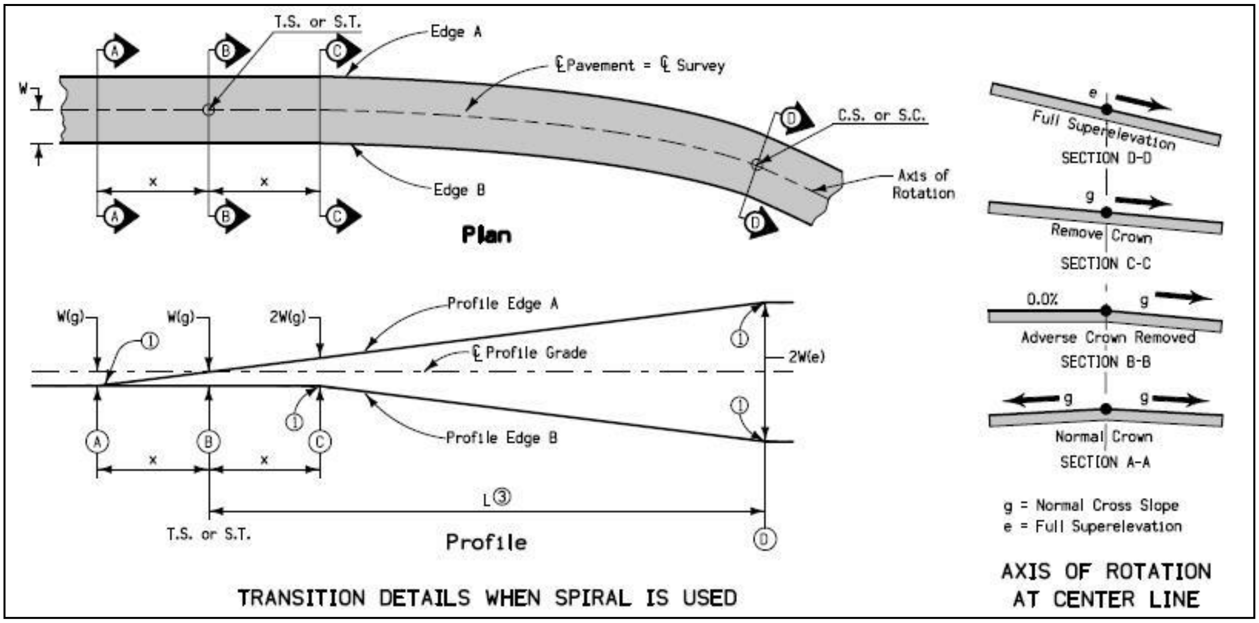


Figure 1: Graphical definitions of superelevation terms for a two lane roadway.

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 usually 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. Refer to Section 1C-1 for maximum superelevation rates for 3R projects and new construction or reconstruction projects.

Superelevation and Side Friction Factor

Superelevation rate and side friction demand, also referred to as the side friction factor, establish radii for horizontal curves. Side friction factor represents the friction between the tires and pavement surface. This friction results in a lateral acceleration that acts upon a vehicle, and which occupants within the vehicle can feel. Like superelevation, side friction factor is limited for design speeds.

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 or exceeds 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 or braking, or both, to reduce lateral acceleration to an acceptable level. Often the driver's comfort determines superelevation requirements, not the vehicle and roadway characteristics. On low speed roadways, drivers will accept more lateral acceleration, thus permitting a larger side friction factor. As speeds increase, drivers become less tolerant of lateral acceleration, requiring a reduction in side friction factor.

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 1 below.

Table 1: Maximum side friction factors (f_{max}).

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

Source: AASHTO Greenbook 2011 Table 3-7.

Curves should not be designed with side friction factors greater than the values shown in Table 1.

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 distribution Method 2 and Method 5 depending upon the type of roadway.

Low Speed Roadways

Method 2 is commonly used for low speed roadways. With Method 2, side friction is primarily used to control lateral acceleration, and superelevation is added to radii after the maximum side friction factor has been used. Superelevation is not needed for radii that require less than the maximum friction factors shown in Table 1. Distribution Method 2 increases the lateral acceleration, creating some additional discomfort to the driver for some curves.

Urban Roadways

Drivers are willing to accept more discomfort on roadways in urban areas, 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.

Ramps

Method 2 superelevation distribution is also well suited for curves on ramps near at-grade terminals. Curves near at-grade terminals are usually short and drivers are traveling at reduced speeds.

The relationship between superelevation rate and minimum radius for Method 2 distribution can be expressed as follows:

$$R = \frac{V^2}{15(0.01e + f_{max})}$$

where:

V = design speed, mph.

e = superelevation rate, %.

f_{max} = maximum friction factor for the design speed.

R = Radius of the curve, feet.

Table 10 of Section 2A-3 provides minimum turning radii for various superelevation rates and design speeds, based upon Method 2 distribution.

High Speed Roadways

Method 5 is used for high speed roadways. With 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.

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*. An Excel file has been created using these formulas and is provided at the link below.

Superelevation Spreadsheet

Note: When calculating superelevation rates manually, round values of e up to the nearest 2/10ths of a percent for new construction. AAHSTO notes precision greater than 2/10ths of a percent is not necessary.

Method 5 superelevation distribution should be used for curves on ramps near free-flow terminals and curves on directional and semi-directional ramps.

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 (PV series).

For cases not covered by the Standards, the axis of rotation should be clearly shown on the typical cross section and modified superelevation detail.

Undivided Roadways

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

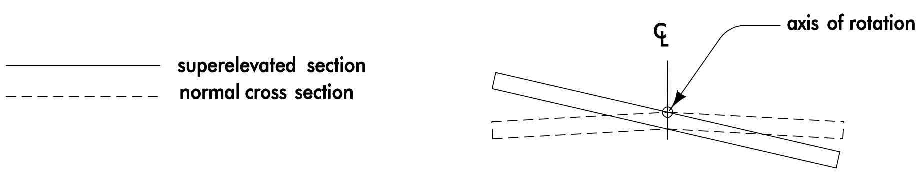


Figure 2: The axis of rotation for undivided highways.

Highways with painted medians are rotated about the centerline (See Section 3E-1 for medians details).

Divided Roadways

Depressed Medians

Multi-lane roadways 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.

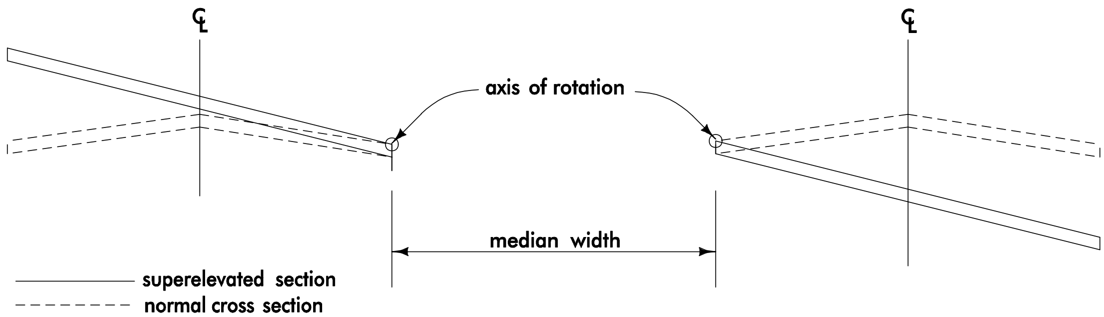


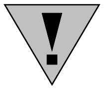
Figure 3: The axis of rotation for multi-lane highways with depressed medians.

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.

Closed Medians

Roadways with closed medians (concrete barrier rail) should be superelevated with the axis of rotation at the inside edge of the travel way with the profile grade at the centerline of the roadway. Maintaining a uniform cross-section for the median pad is preferred in order to simplify design and construction by having a roadway without a split median barrier.

With this method, to maintain a uniform median pad cross-section and to maintain high side and low side shoulder treatments described in Section 3C-3, the axis of rotation profile reference line does not coincide with the profile grade line. The axis of rotation profile reference line is also not shown as a horizontal line like other roadways without a closed median, See Standard Road Plan PV-305 for details.



> The superelevation tools through GEOPAK do not automatically create superelevation shapes for closed median roadways as described above. The designer has to modify the superelevation input file to rotate the shoulders and pavement sections as shown on the Standard Road Plans.

Ramps

The axis of rotation for ramps should be at the baseline. The baseline is usually located to the right side of the direction of travel.

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 4 shows the relationship between relative transition length (L), superelevation (e), and pavement width (w).

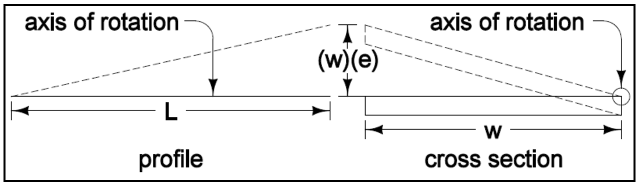


Figure 4: Runoff length and superelevation.

From Figure 4, the following formula can be derived:

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

Maximum design values for the relative gradient are shown in Table 2.

Table 2: 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

Source: AASHTO Greenbook 2011 Table 3-15.

Superelevation Runoff Length

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).

$$L = \frac{12e}{G} \alpha$$

where:

e = full superelevation (%)

G = Relative gradient (%)

α = adjustment factor (dimensionless) to account for the number of lanes being rotated. See table 3 for common values.

Table 3: 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:

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

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 spiral curve transition, 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).

Other proportions (60 percent to 90 percent) of the runoff length placed on the tangent section are acceptable where site conditions do not allow 70 percent. If site conditions require this, the Designer must include a modified standard road plan in the construction plan set detailing the non-standard proportion.

Auxiliary Lanes

Low Side of Superelevated Roadways

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.

High Side of Superelevated Roadways

Acceleration lanes on the highside of a superelevated roadway preferably should have the same cross slope as the adjacent pavement. Normally the cross slope of an acceleration lane will need to transition downward from the adjacent pavement near an intersection, creating a crossover crown line. Desirably the algebraic difference in the crossover crown line should be limited to 4 or 5 percent. Table 4 from Exhibit 9-49 in AASHTO's *A Policy on Geometric Design of Highways and Streets*, suggests the maximum differences in crossover crown lines, related to the speed of the turning roadway at an intersection.

Table 4: Maximum Algebraic Difference in Cross Slope at Turning Roadway Terminals.

Design speed of exit or entrance curve (mph)	Maximum algebraic difference in cross slope at crossover line (%)
20 and under	5.0 to 8.0
25 and 30	5.0 to 6.0
35 and over	4.0 to 5.0

Source: AASHTO Greenbook 2011 Table 9-20.

Cross Slope Transition

Preferably the cross slope rate of transition for the auxiliary lane should equal the cross slope rate of transition of the adjacent pavement. In areas near an intersection a faster rate of transition may be desirable.

The designer should refer to Table 2 for the maximum grade change in the profile edge of pavement to determine the maximum rate of transition per station.

For example: If the design speed of the limiting curve of a turning roadway has a design speed of 15 mph, the relative gradient of the edge of pavement is 0.78 (1:128). This results in a rate of change in cross slope of 6.5% for a 12 foot lane per station (100 ft).

$$\frac{L \times G}{w} = \frac{100 \times 0.78}{12} = 6.5\%$$

Shoulder Treatment in Superelevated Curves

See Section 3C-3.

Chronology of Changes to Design Manual Section:

002A-002 Superelevation

6/25/2019	Revised	Updated hyperlinks. Updated header logo and text.
7/18/2013	Revised	Added Quick Tips. Clarified Method 2 is preferred for roads (rural and urban) with design speeds of 45 mph or less (including ramps). Also noted design exceptions are required for e less than values in Section 2A-3.
12/10/2010	Revised	Rewrote auxillary lanes section to comply with AASHTO crown break guidance.
5/28/2010	Revised	Update standard numbers