QUICK GUIDES FOR DEVELOPMENT PROPOSALS SERIES

Curved Roads and Superelevation

Land Transport Authority

We Keep Your World Moving

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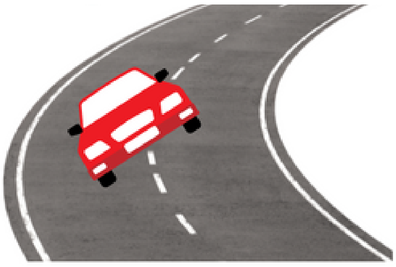
ISSUE 10

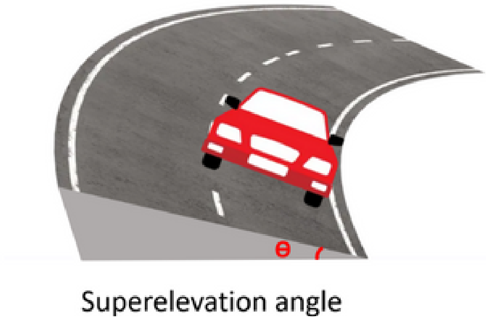
How Does SUPERELEVATION Keep Roads Safer?

Curve with No Superelevation



High risk for vehicles to skid or tip in a curve without superelevation, especially at higher speeds

Curve with Superelevation



Low risk of skidding or tipping in a curve with superelevation, even at higher speeds

Fig 1 : How Does Superelevation Keep Roads Safer?

Have you ever wondered why velodromes are banked at an angle? This is because objects travelling through a curved path are subjected to centrifugal forces. If a cyclist was to pick up speed on a flat circular track, he will find it difficult to stay on course. The banking on a velodrome allows cyclists to stay on course by creating a centripetal force that counteracts the centrifugal force.

Fig 2 : Cyclists on a Velodrome

This is the same reason that superelevation is applied for curved roads where the outer edge is intentionally designed to be higher than the inner curve. Superelevation improves road safety as it helps motorists to stay on course while traversing road curves. Without superelevation, vehicles would be more likely to skid through road curves, or even tip and roll over, especially in wet conditions or at high speeds.

Besides centrifugal and centripetal forces, a vehicle will also be subject to frictional forces, its own weight, the reaction normal force and momentum as it travels through a curve. A superelevated curve balances the various forces and allows the vehicle to continue in its circular motion without skidding or tilting.

Forces Associated with Superelevation

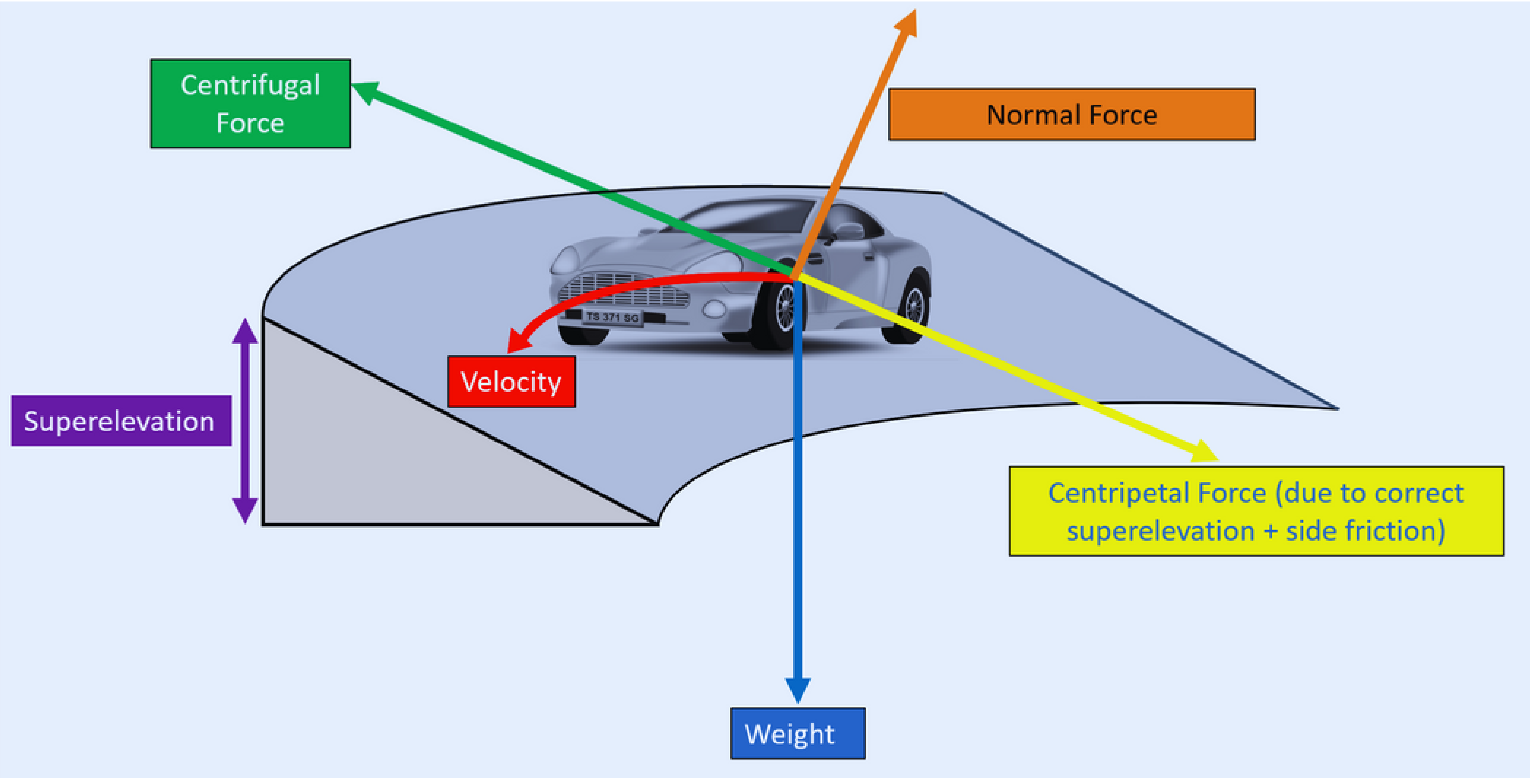


Fig 3 : Forces Associated with Superelevation

Forces

- **Centrifugal force -** The sideways force acting on an object that pushes it away from the centre of the curve that it is travelling on.
- **Centripetal force** - The sideways force acting on an object that pulls it towards the centre of the curve that it is travelling on.
- **Side friction** - The resistance created between the vehicle's rubber tyres and the road surface.
- **Weight** - The gravitational pull on the vehicle.
- **Velocity** - The speed of the vehicle.

2.2 DEFINITIONS OF SUPERELEVATION AND RELATED TERMS

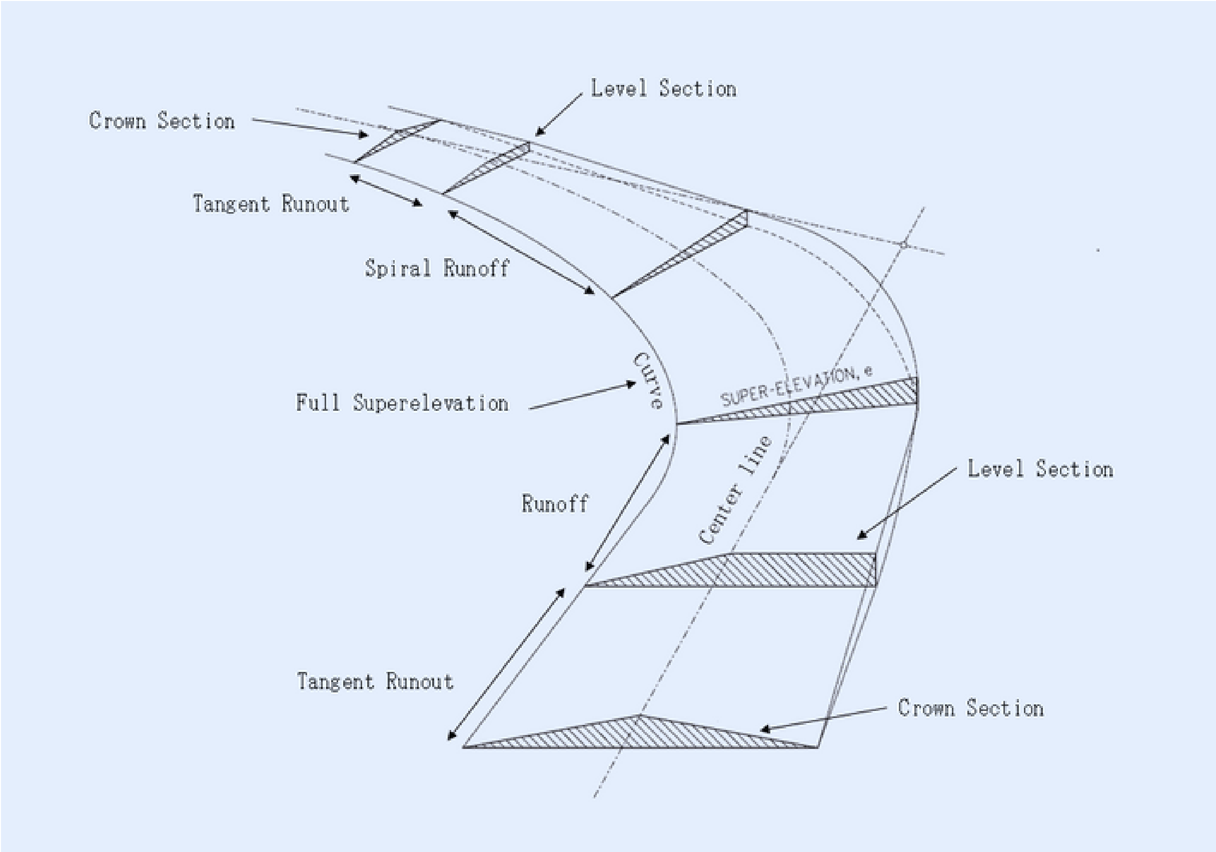


Fig 4 : Components of Superelevation

Definitions

- **Superelevation -** The rotation of the road on the approach to and through a horizontal curve.
- **Crossfall -** The slope, measured at the right angle to the alignment of the carriageway.
- **Crown -** The highest point on a road's surface. A centerline crown is a slightly elevated point at the center of the road from which water sheds in both directions.
- **Radius of curve -** Radius is measured by envisioning a full circular curve, then measuring the distance from the center of the circle to its outer edge. The smaller the radius, the more centrifugal force is invoked.
- **Full Superelevation -** The point in a curve when the entire segment of roadway is subject to superelevation, usually at the curve's apex.
- **Maximum superelevation rate** - The highest percentage of angle allowed to prevent the danger of vehicles overturning.
- **Minimum superelevation** - The lowest percentage of angle allowable for road drainage purposes, especially on a large-radius horizontal curve.
- **Runoff length** (also known as superelevation runoff length) - The distance required to transition the outside lane of a roadway from a flat cross slope to full superelevation. Usually runs from the end of the tangent runout to the full superelevation section.
- **Side friction** (also known as lateral friction) - The resistance between the surface of the road and a vehicle's rubber tires, which inhibits motion and slows vehicles down.
- **Spiral runoff** - A section of highway that transitions the angle and width between a section of tangent runout and a section of full superelevation, making it easier for drivers to navigate the change in curvature and angle.
- **Superelevation rate** - The degree of banking imposed on a horizontal curve to safely counterbalance the centrifugal force of a vehicle on the curve.
- **Tangent runout** - The distance needed to change from a normal crown section of road to a point where the adverse cross slope is removed and the outside lane is level (level section).

2.3 DERIVING THE DESIRED SUPERELEVATION

The desired superelevation is given by the formula below:

$$e + f = \frac{V^2}{127R}$$

Where

e = Super-elevation (m/m)

f = Side friction factor (see table below)

V = Design Speed (km/h)

R = Radius of Curve (m)

Note: This formula is intended to determine the required superelevation to be provided along a curve based on the design speed, curve radius and the side friction factor. The formula is not meant to derive the minimum radius of a curve (R) in which road superelevation is not required (i.e. e=0). A minimum superelevation should be provided for drainage purposes. Further details are found in section 2.5.

Selection of Side Friction Factor values:

Design Speed, V (km/h)	40	50	60	70	80	90
Side Friction Factor, f	0.16	0.16	0.15	0.15	0.14	0.13

2.4 SUPERELEVATION DEVELOPMENT LENGTH

The superelevation development length is the length of road which is required to be rotated so as to achieve the required superelevation. It is measured from the point where a normal crossfall is applied, to the point where the road is fully rotated. The development length shall satisfy the larger value obtained from the following two formulae:

Eqn (1): $$L_e = \frac{|e_1 - e_2| V}{R}$$

Eqn (2): $$L_e = |e_1 - e_2| W \times 100$$

Le = Superelevation development length (m)

e1 = Crossfall of carriageway

e2 = Superelevation at ends of the development length (m/m)

V = Design speed (km/h)

W = Maximum width from axis of rotation to edge of running lane (m)

R = Rate of rotation; use 0.126 for design speeds less than 80km/h and use 0.09 for design speeds for 80km/h and above

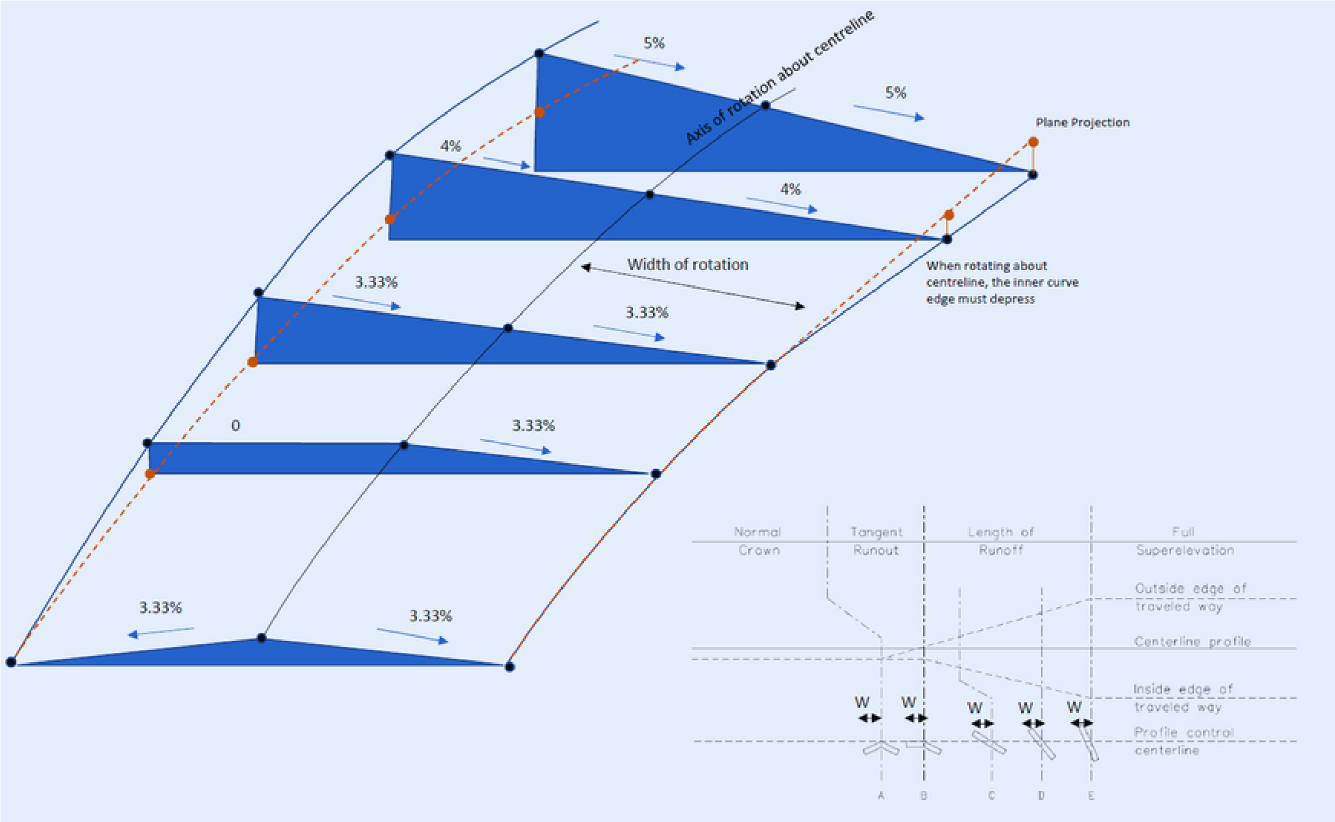


Fig 5 : Superelevation Development Length, With Axis of Rotation About Centreline

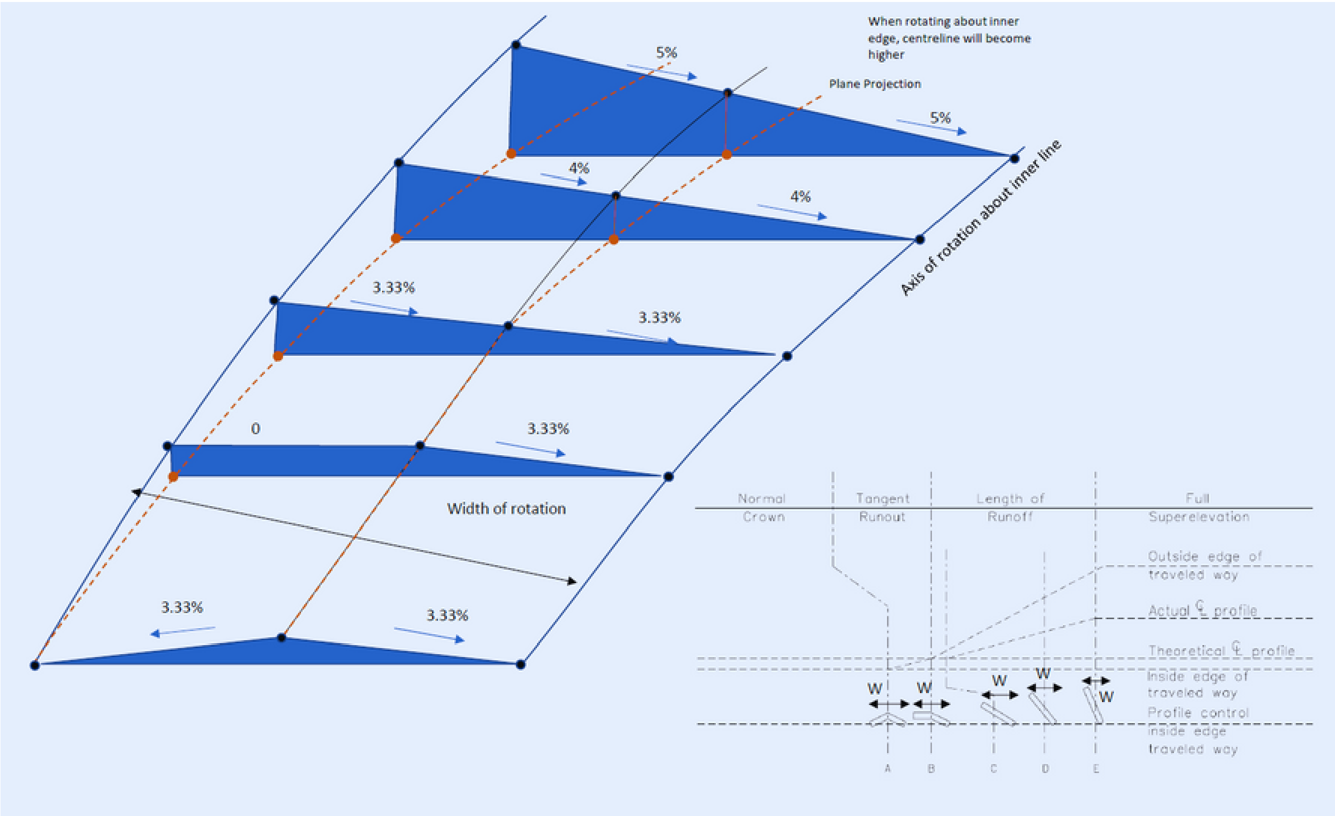


Fig 6 : Superelevation Development Length, With Axis of Rotation About Inner Line

Points to note:

- A transition zone between the tangent and horizontal curve is needed to gradually introduce the superelevation.
- To prevent water drainage issues on the road surface, the low point of the vertical profile should not coincide with the region where crossfall is near or at 0%
- The distribution of the development length (to achieve superelevation) is as such:
  - **For simple curves :** 2/3 length along tangent and 1/3 along curve.
  - **For curvature with transition curve :** superelevation to be effected along the full length of the curve.

2.5 MINIMUM REQUIRED SUPERELEVATION

A road surface is generally not flat. Even on a straight road, a minimum vertical profile of 0.4% and a desirable cross-slope (superelevation) of 3.33% are required to ensure adequate drainage of surface runoff.

Fig 7 : Cross-slope on a straight road

Whenever the formula given in section 2.3 results in a negative value or a value lower than the desired crossfall of a road, the minimum superelevation shall be provided at the desirable crossfall sloping towards the inner radius of the carriageway as shown in table below:

Crossfall	At-grade road and road on other structure	Tunnel
Desirable	1:30 (3.33%)	1:40 (2.5%)

Please see some examples given below for the minimum superelevation to be adopted:

	Case 1	Case 2	Case 3	Case 4
Design Speed	60 km/hr			
Radius	135m	150m	175m	200m
Calculated Superelevation, e	0.060 m/m (6%)	0.039 m/m (3.9%)	0.012 m/m (1.2%)	-0.008 m/m (-0.827%)
LTA Clause 10.4.2.5.2 e < 0 (negative value) OR e < 3.33% ?	No (use calculated superelevation value)		Yes (use desirable crossfall value of 3.33%)	
Superelevation / crossfall to be provided	6% (superelevation)	3.9% (superelevation)	3.33% (crossfall)	3.33% (crossfall)
Slope direction	towards inner radius of road bend			

2.6 SUPERELEVATION DRAINAGE PROVISIONS

When the road that is superelevated has a centre median, the centre median width must minimally be 1.4m. This is to accommodate a 0.6m (internal width) of drain for surface runoff. Slot holes along the centre median will not be allowed as it could result in "aquaplaning" (also known as hydroplaning). This would further reduce the side friction required to counter the various forces described in section 2.1. The drain shall be provided throughout the superelevation development length. The superelevation shall be clearly shown in the longitudinal section plan.

For a divided carriageway, a covered drain has to be provided along the centre median with a minimum width of 1.4m based on a drain width of 600mm (internal). Open slotted drainage channels are not allowed as it is not effective to provide proper drainage and it can also pose safety hazards for pedestrians

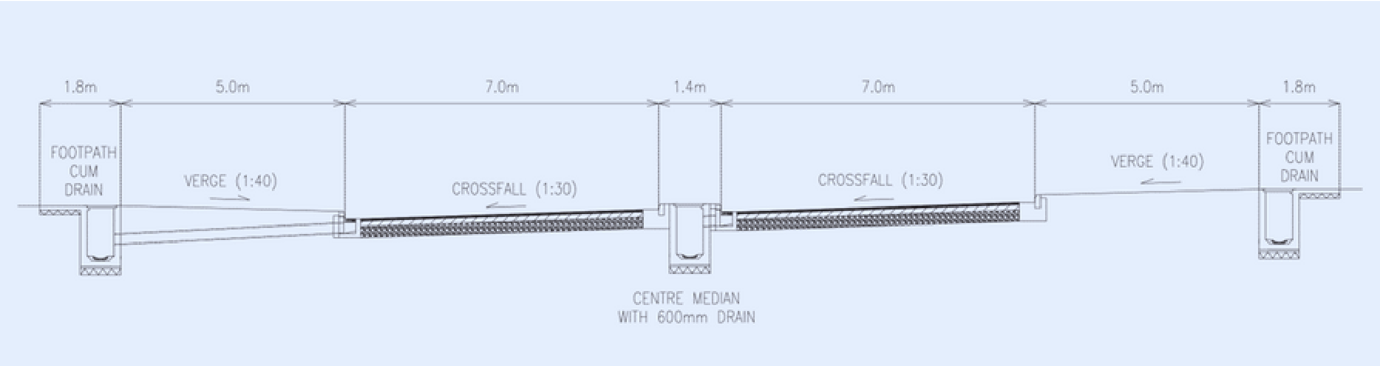


Fig 8 : Cross-section of a Road With a Covered Drain Along The Centre Median

2.7 CONSEQUENCES OF OMITTING SUPERELEVATION?

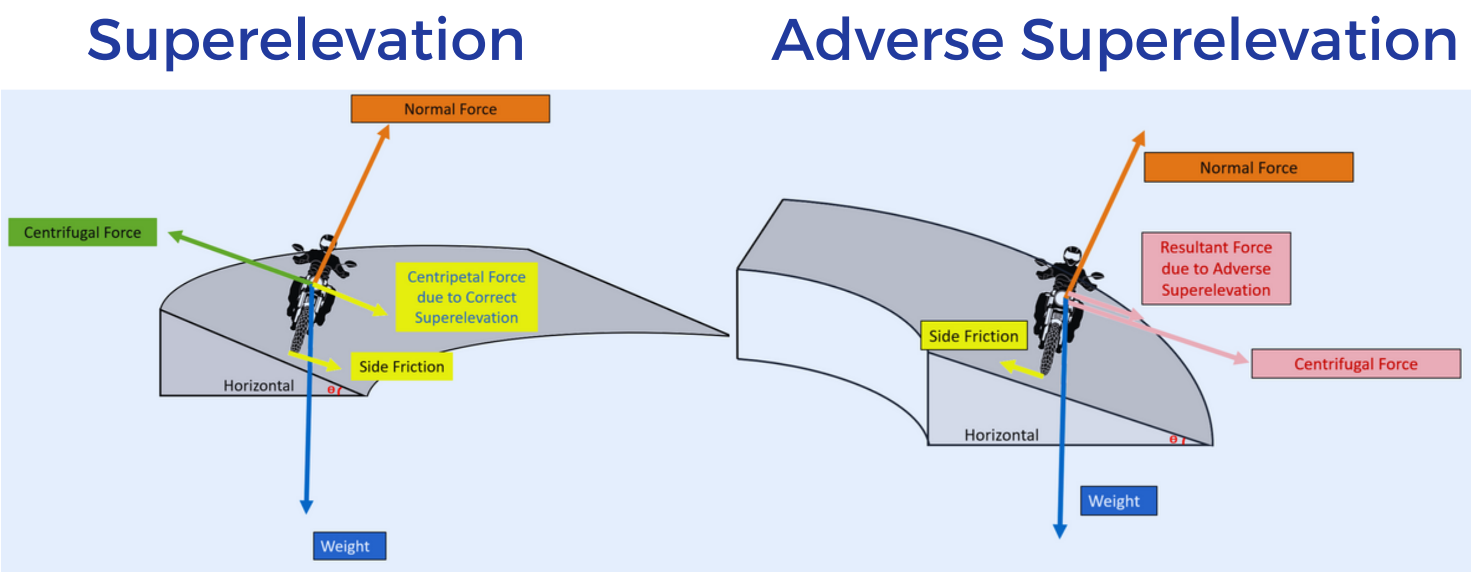


Fig 9 : Superelevation and Motorcycles

Superelevation is a critical element in road design. A lack of superelevation, adverse superelevation (or adverse crossfall) can lead to skidding or tilting as the forces acting on the vehicle do not balance out adequately. This leads to a risk of vehicles drifting to the fast lane or even onto the lane carrying the oncoming traffic.

Motorcyclists tend to be most disadvantaged if superelevation is not provided. The limited wheel contact with the road surface offers little side friction to counter the forces acting on the motorcycle.

Adverse crossfall requires the motorcyclist to rely more on the grip of the tyres to negotiate a curve. Further, it reduces the amount of ‘lean’ a motorcyclist can use to negotiate a curve. The combination of both of these issues can result in a motorcycle losing its stability and grip while going through a curve.

Large vehicles are especially susceptible to crashes due to rollover because of their high center of gravity. If they try to negotiate a road with adverse crossfall at a high speed, they are vulnerable to overturning.

Inadequate superelevation can also lead to road damage caused by poorly distributed load. This can result in higher costs to maintain curved sections of roads.

3.0 CONCLUSION

A good road design includes provision of superelevation and crossfall to enable vehicles to safely negotiate road bends and allow for adequate drainage. It is particularly important for motorcycles and vehicles with high centre of gravity that are relatively more prone to stability issues as compared to typical passenger cars.

Fig 10 : A Superelevated Road Bend