# DI04006071: Railway, Harbour & Tunnel Engineering

## Lecture 2.11: Function of Super Elevation or Cant

GTU Course Instructor

Civil Engineering

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# Introduction to Super Elevation I

Super elevation, also known as cant, is the practice of raising the outer rail above the inner rail on a curved track. When a train moves along a curve, it is subjected to a centrifugal force that acts horizontally outwards from the center of the curve. If the track were kept level, this force would push the train against the outer rail, causing discomfort to passengers, uneven wear, and a risk of derailment. By introducing cant, the track provides a transverse slope that creates an inward component of the train's weight, helping to counteract the outward centrifugal force.

## Key Points

- Involves raising the outer rail relative to the inner rail.
- Creates an inward force component to counter outward centrifugal force.
- Significantly improves passenger comfort and overall safety.
- Reduces uneven wear and tear on outer rails and wheel flanges.

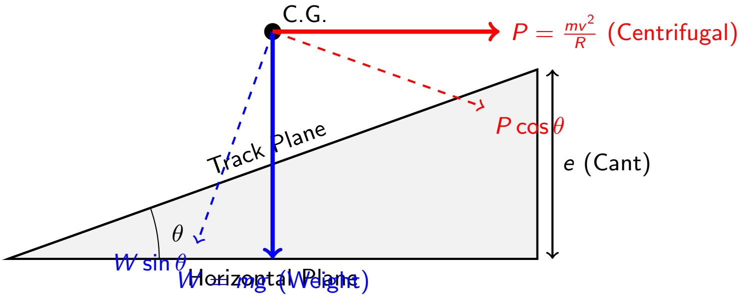
# Objectives and Functions of Cant I

The primary function of providing super elevation is to neutralize the effect of centrifugal force. This ensures that the resultant of the train's weight and the centrifugal force passes roughly through the center of the track, resulting in equal pressure on both rails. Furthermore, super elevation serves several vital operational functions. It provides a smooth and comfortable ride for passengers by eliminating the feeling of being thrown outwards. It also ensures safety against derailment by preventing excessive flange pressure on the outer rail and allows trains to maintain higher speeds on curved sections.

## Key Points

- Neutralizes centrifugal force to ensure equal rail pressure.
- Provides a smooth and comfortable ride for passengers.
- Prevents derailment by minimizing excessive lateral flange forces.
- Allows trains to safely maintain higher operational speeds on curves.

# Forces Acting on a Vehicle on a Curve I




$\boxed{\text{Equilibrium Condition: } P\cos\theta = W\sin\theta}$

# Forces Acting on a Vehicle on a Curve II

## Key Points

- W = Total weight of the vehicle acting vertically downwards.
- P = Centrifugal force ($mvˆ2/R$) acting horizontally outwards.
- Component $W \{}sin\{}theta$ acts inwards along the track plane.
- Component $P \{}cos\{}theta$ acts outwards along the track plane.

# Derivation of Super Elevation Formula I

To calculate the required super elevation ($e$), we consider the equilibrium of forces acting along the inclined plane of the track. The outward centrifugal force is $P = Wv^2 / (gR)$, where $v$ is the velocity, $R$ is the radius of the curve, and $g$ is the acceleration due to gravity. The component of $P$ parallel to the track is $P \{}cos\{}theta$, and the component of weight $W$ down the incline is $W \{}sin\{}theta$. For equilibrium, $P \{}cos\{}theta = W \{}sin\{}theta$. For small angles, $\{}cos\{}theta \{}approx 1$ and $\{}sin\{}theta \{}approx \{}tan\{}theta = e/G$, where $G$ is the dynamic gauge. Substituting these, we get $Wv^2 / (gR) = W(e/G)$, simplifying to the final formula.

# Derivation of Super Elevation Formula II

## Key Points

- Equate forces parallel to the inclined track plane.
- Assume small angle $\{}theta$: $\{}sin\{}theta \{}approx \{}tan\{}theta = e/G$.
- Substitute centrifugal force $P = Wv^2 / (gR)$.
- Derived fundamental formula: $e = Gv^2 / (gR)$.

# Equilibrium Super Elevation I

Equilibrium super elevation is the precise amount of cant required so that the resultant of the vehicle's weight and centrifugal force is perfectly perpendicular to the plane of the rails. When a train travels exactly at the equilibrium speed for a given curve, the downward pressures on the inner and outer rails are completely identical. This ideal condition minimizes rail wear, eliminates lateral forces, and maximizes passenger comfort. Since a railway line carries mixed traffic at varying speeds, providing equilibrium cant for all trains is impossible; hence, a weighted average speed is used for practical track design.

## Key Points

- Resultant force is perfectly perpendicular to the rail plane.
- Generates exactly equal pressure on both inner and outer rails.
- Eliminates lateral flange forces, minimizing track wear.
- Calculated practically using the average speed of mixed traffic.

# Maximum Limits of Super Elevation I

Indian Railways prescribes maximum limits for super elevation to ensure the safety of slow-moving trains and stationary vehicles on curves. If the cant is excessive, a slow-moving train might experience excessive load on the inner rail, increasing the risk of derailment or overturning inward due to high crosswinds. The maximum cant is generally limited to roughly 1/10th of the track gauge. The table below outlines the maximum permissible super elevation (cant) and cant deficiency for different gauges under normal conditions.

| Gauge Type | Track Gauge (mm) | Max Super Elevation (mm) | Max Cant Deficiency (mm) |
| :--- | :--- | :--- | :--- |
| Broad Gauge (BG) | 1676 | 165 | 76 |
| Meter Gauge (MG) | 1000 | 90 | 51 |
| Narrow Gauge (NG) | 762 | 65 | 38 |

# Maximum Limits of Super Elevation II

## Key Points

- Limits prevent slow trains from overturning inwards.
- Restricts excessive vertical and lateral load on the inner rail.
- Maximum cant is generally capped at 1/10th of the gauge.
- Varies depending on whether the track is BG, MG, or NG.

# Cant Deficiency I

Cant deficiency occurs when a train travels at a speed higher than the equilibrium speed for which the track's super elevation was originally designed. In this situation, the actual cant provided on the track is less than the equilibrium cant required for that higher speed. As a result, there is an unbalanced centrifugal force pushing the train outwards, which leads to higher pressure on the outer rail and a feeling of lateral acceleration for the passengers. Railway authorities enforce strict maximum allowable cant deficiency limits to ensure passenger comfort and prevent excessive track deterioration.

# Cant Deficiency II

## Key Points

- Occurs when train speed is greater than the design equilibrium speed.
- Actual cant provided is less than the theoretical equilibrium cant.
- Results in an unbalanced outward force and higher pressure on outer rail.
- Strictly limited by regulations to maintain safety and comfort.

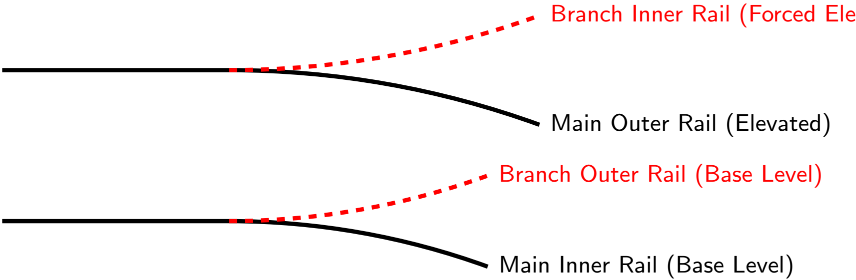
# Cant Excess I

Cant excess happens when a train travels at a speed lower than the equilibrium speed for a given curve. For a slow-moving train, the outward centrifugal force is relatively small, causing the inward component of weight due to the super elevation to dominate. This results in significantly higher vertical pressure on the inner rail. Excessive cant excess can lead to crushing of the inner rail, uneven wear of wheel treads, and dangerous conditions if a train stops completely on a sharply curved, highly canted track. To mitigate this, maximum cant excess is typically limited to 75 mm for Broad Gauge.

## Key Points

- Occurs when train speed is lower than the design equilibrium speed.
- Actual cant provided is greater than the theoretical equilibrium cant.
- Significantly increases vertical load and wear on the inner rail.
- Poses a derailment risk if trains stop on steep canted curves.

# Negative Super Elevation on Turnouts I




Negative Cant on Branch Line:
The branch's inner rail is physically higher than its outer rail, contrary to standard curve geometry.

# Negative Super Elevation on Turnouts II

## Key Points

- Occurs when a branch line diverges opposite to a main line curve.
- The elevated main line outer rail becomes the branch line inner rail.
- Forces the branch line to have its inner rail higher than its outer rail.
- Requires severe speed restrictions on the diverging branch line.

# Design Steps for Super Elevation I

Designing practical super elevation involves a series of calculated steps to safely balance the needs of fast and slow trains. First, the equilibrium speed is determined, typically taken as the weighted average speed of all traffic or roughly 75% of the maximum sanctioned speed. Second, the theoretical equilibrium cant is calculated for this speed using $e = Gv^2 / (gR)$. Third, this value is verified against the maximum permissible cant limits based on gauge. Fourth, cant deficiency (for the fastest train) and cant excess (for the slowest train) are checked against allowable limits. Finally, transition curves are designed to gradually introduce this cant.

# Design Steps for Super Elevation II

## Key Points

- Determine the equilibrium speed representing average mixed traffic.
- Calculate the theoretical equilibrium cant using the standard formula.
- Verify calculated cant against maximum permissible gauge limits.
- Check cant deficiency (fast trains) and cant excess (slow trains).
- Design appropriate transition curves to gradually apply the cant.

# Summary I

Super elevation or cant is an essential geometric feature of railway curves, fundamentally designed to counteract centrifugal force by raising the outer rail. It ensures passenger comfort, equalizes rail wear, and enhances overall safety against derailments. By carefully balancing the competing needs of fast trains (which cause cant deficiency) and slow trains (which cause cant excess), engineers calculate an optimal practical cant. Understanding permissible limits and managing special track configurations, like negative super elevation on turnouts, are critical competencies for safe and efficient railway track design.

# Summary II

## Key Points

- Cant balances centrifugal force and normalizes rail pressure on curves.
- Dramatically improves passenger comfort, safety, and track lifespan.
- Equilibrium cant calculation inherently relies on average train speed.
- Deficiency and excess limits govern the final practical design.
- Crucial for the safe operation of mixed-traffic railway networks.