TRANSPORTATION ENGINEERING

DIPLOMA WALLAH

CIVIL

JHARKHAND UNIVERSITY OF TECHNOLOGY (JUT)

TRANSPORTATION ENGINEERING - SIGHT DISTANCE AND HORIZONTAL ALIGNMENT

Factors Affecting Stopping Sight Distance (SSD)

Definition 💙

Stopping Sight Distance (SSD) is the minimum distance required for a vehicle traveling at design speed to come to a complete stop after the driver perceives an obstacle and applies brakes. It comprises two components: lag distance (distance traveled during perception-reaction time) and braking distance (distance required to stop after braking begins). SSD is fundamental to highway safety design and is critical for vertical curve design, horizontal curve design with obstructions, and intersection sight distance requirements.

Explanation (8 key points)

1. SSD depends directly on design speed - higher speeds require longer distances.
2. Perception-reaction time (typically 2.5 seconds) represents driver's delay in responding to hazards.
3. Braking distance depends on friction between tire and pavement surface.
4. Pavement condition (wet vs. dry) significantly affects braking distance.
5. Vehicle type and load affect braking performance differently.
6. Grade (uphill or downhill) affects braking distance through gravitational component.
7. Driver characteristics and vehicle condition variations are accounted for through standard assumptions.
8. SSD must be continuously available along the entire road length for safety.

Factors Affecting SSD (Detailed)

1. Design Speed (V):

- Primary factor determining SSD
- SSD proportional to V^2 (for braking distance component)
- Higher speeds require exponentially longer stopping distances
- Example: 50 km/h design speed → SSD ≈ 60m; 100 km/h → SSD ≈ 180m (3x distance for 2x speed)

2. Perception-Reaction Time (t):

- Standard value: 2.5 seconds (used in IRC and international standards)
- Represents: Perception of hazard (0.5s) + Decision time (0.5s) + Reaction time (1.5s)
- Affected by:
  - Driver alertness (reduced if fatigued, drowsy)
  - Road conditions and visibility
  - Complexity of decision needed
  - Age of driver (elderly may have longer reaction time)
- Standard 2.5s is conservative (75th percentile), ensuring most drivers can stop

3. Coefficient of Friction (f):

- Friction between tire and pavement surface
- Design values per IRC:
  - Dry pavement: f = 0.35-0.40
  - Wet pavement: f = 0.30-0.35
  - Design typically uses 0.35-0.37 (accounting for wet conditions)
- Affected by:
  - Surface type (concrete, bituminous, gravel)
  - Surface texture (polished vs. rough)
  - Tire condition (new vs. worn)
  - Pavement conditions (wet, muddy, oily, icy)
  - Vehicle weight and load distribution

4. Grade (G):

- Uphill grades reduce braking distance (gravity assists braking)
- Downhill grades increase braking distance (gravity opposes braking)

- Effect significant on grades > 3%
- Grade represented as percentage: +3% for uphill, -5% for downhill

5. Vehicle Type:

- Different vehicles have different braking characteristics
- Passenger cars: Better braking performance
- Heavy trucks: Reduced braking efficiency (weight increase)
- Buses: Variable depending on load
- Design assumes passenger car performance (most critical)

6. Pavement Condition:

- Wet pavement reduces friction by 10-25%
- Muddy or oily surfaces further reduce friction
- Icy surfaces can reduce friction by 50%+
- Design assumes worst-case (wet) pavement for safety

7. Vehicle Condition:

- Tire tread depth affects grip
- Brake condition affects stopping power
- Suspension affects stability during braking
- Design assumes reasonably maintained vehicles

8. Environmental Conditions:

- Visibility and lighting affect perception
- Weather (rain, fog, snow) affects both visibility and traction
- Time of day (nighttime reduces visibility)
- Design assumes daylight, clear weather for SSD

Standard Values of SSD as per IRC

IRC Recommendations (Based on Design Speed)

Design Speed (km/h)	SSD (m) - Dry Pavement	SSD (m) - Wet Pavement	Remarks

30	30	35	Rural low-speed roads
40	45	55	
50	60	75	District roads
65	85	105	State highways
80	120	145	National highways
100	180	220	Expressways
120	250	300	High-speed expressways

Note: IRC uses conservative approach; design typically uses dry pavement values to provide safety margin in wet conditions.

Expression for Calculating SSD

Formula:

$$SSD = V \times t + \frac{V^2}{254(f \pm G)}$$

Where:

- **SSD** = Stopping Sight Distance (m)
- **V** = Design speed (km/h)
- **t** = Perception-reaction time (seconds) = 2.5s standard
- **f** = Coefficient of friction (0.35-0.40)
- **G** = Grade (as decimal; +G for uphill, -G for downhill)
- **254** = Constant derived from unit conversion (2g × 127, where g = 9.81 m/s^2)

Derivation:

Component 1: Lag Distance (Distance during reaction time)

$$D_{\text{lag}} = V \times t$$

Where:

- V in km/h must be converted to m/s: V (m/s) = V (km/h) ÷ 3.6
- Distance = (V/3.6) × t

- For standard t = 2.5s: D_lag = (V × 2.5)/3.6 = 0.694V meters

Component 2: Braking Distance

Using work-energy theorem:

$$\text{Braking force} = m(f \pm G)g$$

Where:

- m = vehicle mass
- g = 9.81 m/s² (gravitational acceleration)
- (+G) for uphill, (-G) for downhill

Using kinematic equation: $v^2 = u^2 + 2as$

At stop, v = 0:

$$0 = (V/3.6)^2 - 2 \times (f \pm G) \times g \times D_{\text{braking}}$$

Solving for D_braking:

$$D_{\text{braking}} = \frac{(V/3.6)^2}{2 \times (f \pm G) \times g}$$

Substituting g = 9.81:

$$D_{\text{braking}} = \frac{V^2}{2 \times 9.81 \times 3.6^2 \times (f \pm G)} = \frac{V^2}{254(f \pm G)}$$

Total SSD:

$$SSD = V \times t + \frac{V^2}{254(f \pm G)}$$

With standard t = 2.5s (or 0.694V as derived):

$$SSD = 0.694V + \frac{V^2}{254(f \pm G)}$$

Or simplified (commonly used):

$$SSD = 0.7V + \frac{V^2}{254f} \text{ (for level grade)}$$

Numerical Example:

Calculate SSD for 80 km/h design speed on level road with f = 0.37:

$$SSD = 80 \times 2.5/3.6 + \frac{80^2}{254 \times 0.37}$$
$$SSD = 55.6 + \frac{6400}{94} = 55.6 + 68.1 = 123.7 \text{ m}$$

IRC standard for 80 km/h: 120m (matches closely)

Factors Affecting Overtaking Sight Distance (OSD)

Definition 💙

Overtaking Sight Distance (OSD) is the minimum distance required for a vehicle to safely overtake another vehicle on a two-lane two-way road and return to its original lane before meeting an oncoming vehicle. OSD is significantly longer than SSD because it must accommodate the overtaking maneuver and safety clearances. OSD is fundamental to two-lane highway design, determining where overtaking is permitted and where no-passing zones must be marked.

Explanation (8 key points)

1. OSD is typically 3-4 times longer than SSD due to complex maneuver involved.
2. Composed of four distance components reflecting different phases of overtaking.
3. Speed difference between overtaking and overtaken vehicles critical to maneuver length.
4. Oncoming traffic speed affects required safety clearance and maneuvering time.
5. Vehicle dimensions and maneuverability determine time needed for safe overtaking.
6. Grade (uphill vs. downhill) affects acceleration ability of overtaking vehicle.
7. Visibility and weather conditions affect driver's decision to overtake.
8. OSD cannot be provided continuously on all two-lane roads due to terrain and cost.

Factors Affecting OSD (Detailed)

1. Design Speed:

- Higher speeds require longer overtaking distances
- Overtaking vehicle must accelerate from initial speed to higher speed
- Time for overtaking increases with initial speed
- Distance proportional to time squared

2. Speed Difference Between Vehicles:

- Overtaking vehicle accelerates relative to overtaken vehicle
- Smaller speed difference requires longer overtaking time
- Typical assumption: Overtaking vehicle 15-20 km/h faster than overtaken
- Overtaken vehicle usually truck/bus: 50 km/h; Overtaking car: 65-70 km/h

3. Vehicle Dimensions:

- Length of overtaking vehicle (car ~5.5m, truck ~12m)
- Length of overtaken vehicle (truck ~12m, bus ~10m)
- Width of vehicles and clearances determine lateral distances

4. Acceleration Capability:

- Overtaking vehicle must accelerate during maneuver
- Acceleration rate depends on:
  - Vehicle power and weight ratio
  - Road grade (reduced uphill, increased downhill)
  - Vehicle condition and driver skill
- Typical acceleration: 1.0-1.5 m/s^2 for laden trucks, 2.0-2.5 m/s^2 for cars

5. Grade:

- Uphill grade reduces overtaking vehicle acceleration → longer distance needed
- Downhill grade increases acceleration → shorter distance sufficient
- Grade effect significant on steep sections (>3%)

6. Opposing Traffic Speed:

- Faster oncoming traffic reduces safe gap for overtaking maneuver
- At higher speeds, smaller gap acceptable (relative motion faster)
- Must provide clearance for oncoming vehicle to pass safely

7. Driver Behavior:

- Driver's willingness to take risk affects overtaking decision
- Conservative drivers may wait longer before overtaking
- Aggressive drivers may complete overtakes at higher risk
- Design assumes reasonable driver behavior (not excessive risk-taking)

8. Road Conditions:

- Wet pavement reduces acceleration and braking capabilities
- Poor visibility limits safe overtaking
- Curved sections restrict sight distance for overtaking vehicles
- Design assumes good conditions and straight road sections

Standard Values of OSD as per IRC

IRC Recommendations

Design Speed (km/h)	OSD (m)	Remarks
50	300	District roads
65	470	State highways
80	640	National highways
100	900	Expressways (if 2-lane)

Note: OSD not typically applied to expressways; expressways are divided highways where opposing traffic is separated.

Expression for Calculating OSD

Four-Component Model:

$$OSD = d_1 + d_2 + d_3 + d_4$$

Where:

- $\mathbf{d_1}$ = Distance traveled during initial maneuver (overtaking vehicle moves out)
- $\mathbf{d_2}$ = Distance traveled by overtaking vehicle in opposing lane
- $\mathbf{d_3}$ = Safety clearance between overtaking vehicle and oncoming vehicle

- $\mathbf{d_4}$ = Distance traveled by oncoming vehicle during overtaking time

Detailed Calculation of Components:

Component d_1: Initial Maneuver Distance

Represents time for overtaking vehicle to move from behind overtaken vehicle to fully in opposing lane.

$$d_1 = 0.278 \times V \times t_1 + \frac{1}{2} \times a \times t_1^2$$

Where:

- V = Initial speed of overtaking vehicle (km/h) = speed of overtaken vehicle
- t_1 = Time for initial maneuver ≈ 2-3 seconds (typically 2s used)
- a = Acceleration (m/s^2) ≈ 0.5 m/s^2 (assumed for safe acceleration)

Simplified for typical values:

$$d_1 = 0.278 \times V \times 2 + \frac{1}{2} \times 0.5 \times 2^2$$
$$d_1 = 0.556V + 1 \text{ (meters)}$$

Component d_2: Distance in Opposing Lane

Time in opposing lane consists of:

- Acceleration phase (same t_1 as initial maneuver)
- Continued travel at higher speed back to original lane

Total time in opposing lane: t_2 ≈ 6-8 seconds (typically 6-7s for calculations)

$$d_2 = 0.278 \times V \times t_2 + \frac{1}{2} \times a \times t_2^2$$

Where t_2 = 6-7 seconds

For typical values (V = 65 km/h, t_2 = 6.5s, a = 0.6 m/s^2):

$$d_2 = 0.278 \times 65 \times 6.5 + \frac{1}{2} \times 0.6 \times 6.5^2$$
$$d_2 \approx 117 + 13 = 130 \text{ m}$$

Component d_3: Safety Clearance

Distance between rear of overtaking vehicle and front of oncoming vehicle.

Typical values: 30-90m (IRC recommends using the formula-derived value)

For higher speeds: d_3 = 30 + 0.3V (meters), where V in km/h

Component d_4: Distance of Oncoming Vehicle

Distance traveled by oncoming vehicle at its speed during the overtaking time.

Oncoming vehicle speed typically assumed = Design speed

Time of overtaking ≈ $t_1 + t_2$ (total time occupying opposing lane and approach)

$$d_4 = 0.278 \times V_{\text{oncoming}} \times (t_1 + t_2)$$

For symmetric design (overtaking and oncoming at same speed V):

$$d_4 = 0.278 \times V \times 8.5 \text{ (for } t_1 = 2\text{s}, t_2 = 6.5\text{s)}$$

Complete OSD Formula (IRC Approach):

$$OSD = 9.5V + 0.278Vt_2 + \frac{1}{2}at_2^2$$

Where:

- First term (9.5V): Represents empirical combination of d_1 and clearances
- Other terms: d_2 and d_4 components combined

Simplified IRC Formula:

$$OSD = 0.278V(2t_1 + t_2) + \frac{1}{2}a(t_1^2 + t_2^2) + d_3$$

With standard values (t_1 = 2s, t_2 = 6.5s, a = 0.5 m/s², d_3 = 50m):

$$OSD \approx 9.5V + 50 \text{ (simplified)}$$

More detailed:

$$OSD = \frac{V(3.5V + 24.5)}{3.6} + 50$$

Or in IRC terms for easy calculation:

$$OSD \approx 0.278V \times 8.5 + 0.5 \times 0.5 \times (4 + 42.25) + 50$$

Practical IRC Formula (Commonly Used):

$$OSD = 5.7V + 12.5 \text{ (for level road, V in km/h, result in meters)}$$

However, IRC provides **tabulated values** (shown above) which are used in practice rather than manual calculation.

Numerical Example:

Calculate OSD for 80 km/h design speed:

Using IRC tabulated value: **OSD = 640m**

Verification using formula components:

- $d_1 \approx 0.556 \times 80 + 1 \approx 45$m (initial maneuver)
- $d_2 \approx 0.278 \times 80 \times 6.5 \approx 144$m (distance in opposing lane)
- $d_3 \approx 30 + 0.3 \times 80 = 54$m (safety clearance)
- $d_4 \approx 0.278 \times 80 \times 8.5 \approx 189$m (oncoming vehicle)
- **Total ≈ 45 + 144 + 54 + 189 = 432m** (theoretical)

IRC uses 640m (more conservative, accounting for additional safety margins and driver behavior variations)

Intermediate Sight Distance (ISD)

Definition

Intermediate Sight Distance is the sight distance provided periodically on two-lane roads where full OSD cannot be provided continuously due to terrain or cost constraints. ISD is typically 2 × SSD, allowing some overtaking opportunities while being more economical than providing full OSD everywhere.

Expression for ISD:

$$ISD = 2 \times SSD$$

Or alternatively:

$$ISD = 2 \times (V \times t + \frac{V^2}{254(f \pm G)})$$

IRC Recommendations:

Design Speed (km/h)	ISD (m)
50	120

65	170
80	240
100	360

Applications:

- Two-lane roads in hilly terrain where full OSD impractical
- Provided every 1.5-3.0 km
- Length of ISD section: Minimum 300-500m
- Marked with dashed center line (overtaking permitted) vs. solid line (no overtaking)

Headlight Sight Distance (HSD)

Definition

Headlight Sight Distance is the distance illuminated by vehicle headlights during nighttime driving, limiting safe operating speed and stopping ability on unlit roads. HSD is critical for sag (valley) vertical curves where headlight beam may not illuminate far enough for the speed at which drivers travel.

Expression for HSD on Valley Curves:

For design of sag vertical curves, headlight sight distance is critical:

$$L = \frac{AS^2}{120 + 3.5S}$$

Where:

- **L** = Length of vertical curve (m)
- **A** = Algebraic difference in grades (% sum)
- **S** = Headlight sight distance (m)

Alternative form:

$$S = \frac{L(120 + 3.5S)}{A}$$

Or solving for L (when HSD required):

$$L_{\text{min}} = \frac{2AS^2}{120 + 3.5S}$$

Where S = SSD (headlight sight distance typically = SSD at design speed)

Physical Basis:

Headlight beam characteristics:

- Height of headlight: 0.75m above pavement
- Beam angle upward: 1° above horizontal
- Object height: 0.15m on pavement
- Beam reach distance depends on curve radius

For sag curve with radius R:

$$\text{Sight Distance} = \sqrt{2 \times R \times h}$$

Where h = vertical rise = 0.75m (headlight) + 0.15m (object) = 0.9m

Standard Assumptions:

- **Headlight Height:** 0.75m above pavement (passenger car standard)
- **Beam Angle:** 1° above horizontal (typical for low beam)
- **Object Height:** 0.15m (tar/pothole on roadway)
- **Beam Intensity:** Limited effective range 30-50m on low beam

IRC Recommendations for HSD:

Design Speed (km/h)	Recommended HSD (m)
50	60
65	85
80	120
100	180

Note: HSD typically equals SSD at the design speed, ensuring stopping is possible even in darkness.

Overtaking Zones

Definition

Overtaking zones are road sections where overtaking is safely permitted, marked with dashed centerline. They are strategically located based on sight distance availability and traffic conditions.

Characteristics:

Length Requirements:

- Minimum: 300m (represents one vehicle's overtaking maneuver + safety)
- Desirable: 500m or more
- Spacing: Typically 1.5-3.0 km apart on two-lane roads

Marking:

- Dashed yellow centerline: Overtaking permitted
- Continuous yellow centerline: No overtaking (SSD < OSD)
- Spacing: Overtaking zones typically 15-20% of road length

Location Criteria:

- Straight sections with adequate sight distance
- Sections approaching uphill grades (avoid on uphill)
- Away from intersections and access points
- Sections with low traffic volumes

Safety Requirements:

- Clear sight of oncoming traffic
- No physical obstructions
- Good pavement condition
- Adequate width for maneuver

Summary of Sight Distance Formulas

Type	Formula	Standard Value Example (80 km/h)
SSD	$V \times t + \frac{V^2}{254f}$	120m
OSD	Based on 4-component model	640m
ISD	2 × SSD	240m
HSD	$\frac{AS^2}{120+3.5S}$ for curve length	120m

PART B: HORIZONTAL ALIGNMENT ELEMENTS

Objectives of Horizontal Alignment Design

Definition 💙

Horizontal alignment refers to the layout of the road in plan view (bird's eye perspective), consisting of straight sections (tangents) and curved sections connecting them. The objectives of horizontal alignment design are to route the road efficiently through terrain while maintaining safety, comfort, and cost-effectiveness. Proper alignment minimizes earthwork and environmental impact, provides safe sight distances, accommodates design vehicles, and creates a pleasing aesthetic while serving the intended transportation function.

Explanation (8 key points)

1. Alignment must connect origin and destination efficiently while serving intermediate areas.
2. Safety is paramount: Adequate sight distance, safe speeds, and clear zones required.
3. Geometric design standards ensure consistency and predictability for drivers.
4. Superelevation and curve design work together to maintain vehicle stability.
5. Transition curves provide gradual changes in curvature preventing abrupt steering inputs.
6. Cost optimization: Minimize earthwork while meeting design standards.
7. Environmental considerations: Route avoidance of sensitive areas.
8. Comfort: Adequate sight distance, smooth curves, and appropriate grades for smooth ride.

Detailed Objectives

1. Safety:

- Provide adequate sight distance for all driving maneuvers
- Avoid sharp curves causing loss of control at design speed
- Maintain clear zones free of hazards
- Design consistent with driver expectations (no surprises)
- Reduce conflict points with other traffic

2. Efficiency:

- Directness: Minimize route length between origin and destination

- Minimize grade: Reduce fuel consumption and emissions
- Reduce construction costs through earthwork minimization
- Future expandability without major reconstruction

3. Comfort:

- Smooth curves: Gradual curvature changes (transition curves)
- Adequate sight distance: Reduce driver stress from restricted vision
- Smooth grades: Avoid sudden changes causing passenger discomfort
- Logical, predictable alignment: Drivers understand road behavior

4. Economy:

- Minimize earthwork volume (cutting and filling)
- Minimize material requirements (pavement, structures)
- Reduce environmental impacts (lower remediation costs)
- Optimize construction method selection

5. Environmental Integration:

- Avoid sensitive areas (forests, wetlands, heritage sites)
- Minimize land acquisition and displacement
- Integrate with natural landscape
- Minimize noise and air quality impacts

6. Geometric Consistency:

- Follow IRC and international geometric design standards
- Consistent design speed throughout corridor
- Avoid abrupt standard changes
- Predictable by driver experience

Design Speed

Definition 💙

Design speed is the maximum safe speed at which a vehicle can travel on a road section under favorable conditions without exceeding the safe limits of the geometric elements. It is the basis for all geometric design parameters including curve radii, sight distances, grade limits, and superelevation rates. Design speed must be selected considering traffic characteristics, existing conditions, and functional classification, and maintained consistently through corridor sections.

Explanation (8 key points)

1. Design speed is basis for all geometric parameters - critical selection.
2. Should reflect actual operating speeds (85th percentile speed) with safety margin.
3. Must be consistent with road classification and functional purpose.
4. Terrain and environmental constraints may limit design speed achievable.
5. Changing design speed mid-corridor requires careful transition (curve length adjustment).
6. Posted speed limit should not exceed design speed capability.
7. Too high design speed increases cost; too low under-utilizes investment.
8. Clear, consistent design speed improves safety and operational efficiency.

Design Speed Selection:

By Road Classification (IRC Recommendations):

Road Classification	Rural Design Speed (km/h)	Urban Design Speed (km/h)
National Highway (Expressway)	100-120	80-100
National Highway (2-lane)	80-100	60-80
State Highway	65-80	50-65
Major District Road	50-65	40-50
Other District Road	40-50	30-40
Village Road	30-40	20-30

Terrain Adjustment:

- Plain terrain: Use higher design speed (less constraints)
- Rolling terrain: 10-15 km/h reduction
- Mountainous terrain: 20-30 km/h reduction (steep grades, limited space)

Design Speed and Minimum Curve Radius:

The fundamental relationship:

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

Where:

- R = Radius of horizontal curve (m)
- V = Design speed (km/h)
- e = Superelevation rate (decimal)
- f = Coefficient of lateral friction (0.15-0.20)

Standard Design Speeds by Functional Category:

Expressway/Limited Access Highway:

- Design speed: 100-120 km/h
- Characteristics: Grade-separated intersections, no at-grade access, high-speed consistent operation
- Minimum curve radius: 600-900m

National Highway/Major Arterial:

- Design speed: 80-100 km/h
- Characteristics: Limited access, controlled intersections, long straight sections
- Minimum curve radius: 430-600m

State Highway/Secondary:

- Design speed: 65-80 km/h
- Characteristics: Some local access, signal-controlled intersections
- Minimum curve radius: 250-430m

District Road/Tertiary:

- Design speed: 50-65 km/h
- Characteristics: Local traffic focus, grade crossings common
- Minimum curve radius: 180-250m

Village Road/Local:

- Design speed: 30-50 km/h
- Characteristics: Pedestrian/vehicle mix, frequent access
- Minimum curve radius: 80-150m

Types of Curves Provided in Horizontal Alignment

Simple Curve

Definition:
A simple curve is a single circular arc of constant radius connecting two straight sections (tangents) intersecting at an angle.

Characteristics:

- Uniform radius throughout
- Simplest type geometrically
- Least comfortable at high speeds
- Most economical for low-speed roads

When Used:

- Design speeds ≤ 50 km/h (rural roads, district roads)
- Where space constraints exist
- Lower-cost projects with budget constraints
- Low-traffic roads where comfort less critical

Geometric Elements:

- Point of Curvature (PC): Where curve begins
- Point of Tangency (PT): Where curve ends
- Radius: R (constant throughout)
- Deflection angle: Δ (angle between tangent extensions)

Advantages:

- Simple calculation and field setting out
- Lower construction cost
- Minimal land requirement

Disadvantages:

- Sudden centrifugal force introduction (discomfort at speed)
- Passenger discomfort and safety concerns at high speeds
- Abrupt change from straight to curved path

Compound Curve

Definition:
A compound curve consists of two or more consecutive circular arcs with different radii, all curving in the same direction, connecting two straight sections.

Characteristics:

- Two or more different radii
- Flatter curve first, then sharper curve (or vice versa)
- More flexible adaptation to terrain
- Point of Compound Curvature (PCC) where radii change

When Used:

- Mountainous terrain with varying constraints
- Railway curves in steep terrain
- Adaptive routing to avoid obstacles
- Better adaptation than simple curve when terrain complex

Configuration Options:

1. **Flatter then sharper:** Larger radius → smaller radius
2. **Sharper then flatter:** Smaller radius → larger radius (less common)

Design Rules (IRC):

- Ratio of radii: Sharper radius should not be less than 2/3 of flatter radius
- Example: If R_1 = 450m, then R_2(minimum) = 300m
- Avoid extreme ratio differences

Advantages:

- Better adaptation to terrain
- More economical alignment in complex terrain
- Allows fitting in restricted right-of-way

Disadvantages:

- Complex design and calculation
- Difficult field setting out (two different radii)
- More complex contracts and execution
- Additional surveying required at PCC

Reverse Curve

Definition:
A reverse curve (serpentine curve) consists of two circular curves with opposite curvature directions, forming an S-shape, connecting two straight sections that may be parallel or at slight angle.

Characteristics:

- Two curves bending opposite directions (left then right)
- Creates S-shaped alignment
- Centrifugal force reverses direction abruptly at Point of Reverse Curvature (PRC)
- Minimal or no tangent between curves

When Used:

- Connecting parallel roads or tracks
- Grade separation transitions
- Valley crossings requiring directional reversal
- Limited practical use on modern highways (safety concerns)

Geometric Elements:

- First curve: Left (or right) turn
- Second curve: Opposite direction
- Point of Reverse Curvature (PRC): Where direction reverses
- Ideally: Same radius for both curves (symmetric)

IRC Recommendations for Reverse Curves:

- Minimum tangent length between curves: At least design speed in meters
    - Example: 80 km/h design speed → 80m minimum tangent
    - Lower speeds: Minimum 20m tangent
- Avoid on high-speed roads (100+ km/h) due to centrifugal force reversal
- Use with care on moderate-speed roads

Advantages:

- Useful for specific geometric constraints

- Economical space utilization

Disadvantages:

- Sudden centrifugal force reversal (discomfort, safety)
- Difficult sight distance maintenance (PRC may be blind spot)
- Complex drainage at PRC
- Driver discomfort at high speeds
- Limited application on modern highways

Transition Curve (Spiral)

Definition:
A transition curve (spiral or clothoid) is a curve of gradually changing radius, inserted between a straight section and a circular curve, allowing gradual introduction of centrifugal force and smooth superelevation transition.

Characteristics:

- Radius varies continuously from ∞ (at tangent start) to R (at circular curve junction)
- Provides smooth transition from straight to curved motion
- Allows gradual superelevation application along length
- Improves safety and comfort significantly

Types:

- **Spiral (Clothoid):** Most common, radius inversely proportional to length
- **Cubic Parabola:** Approximation of spiral for easier calculation
- **Lemniscate:** Alternative mathematical form

Geometry:

- Tangent-to-Spiral (T.S.): Where spiral begins
- Spiral-to-Curve (S.C.): Where spiral ends and circular curve begins
- Curve-to-Spiral (C.S.): Where circular curve ends and exit spiral begins
- Spiral-to-Tangent (S.T.): Where spiral ends

Length Calculation:

IRC formula for minimum transition curve length:

$$L_s = \frac{V^3}{C \times R}$$

Or practical formula:

$$L_s = 2.7 \times \frac{V^2}{R}$$

Where:

- Ls = Length of transition curve (m)
- V = Design speed (km/h)
- R = Radius of main circular curve (m)
- C = Rate of change of centrifugal acceleration (0.5-0.8 m/s^3)

IRC Minimum Values:

Design Speed (km/h)	Minimum Ls (m)
50	20
65	25
80	30
100	40
120	50

Example Calculation:
For V = 80 km/h, R = 300m:

$$L_s = 2.7 \times \frac{80^2}{300} = 2.7 \times \frac{6400}{300} = 2.7 \times 21.3 \approx 58m$$

Benefits of Transition Curves:

- Smooth centrifugal force introduction (no sudden jerk)
- Gradual superelevation application reduces need for abrupt transitions
- Improved driver comfort and reduced vehicle oscillation
- Better vehicle tracking and reduced tire wear
- Improved safety through smooth geometric flow
- Reduced accident rates compared to simple curves

When Required:

- **Mandatory:** Design speed ≥ 60 km/h (all expressways, national highways)
- **Recommended:** Design speed ≥ 50 km/h
- **Optional:** Lower design speeds (rural roads may omit for cost)

Disadvantages:

- Increased total curve length (longer alignment)
- More complex design calculations
- Difficult field setting out (non-standard geometry)
- Higher cost than simple curves alone

Superelevation (e)

Definition 💙

Superelevation is the transverse slope provided on a horizontal curve, tilting the outer edge higher than the inner edge. This banking helps counteract centrifugal force, reducing required friction and improving vehicle stability and comfort on curves. Superelevation is expressed as a ratio or percentage of the curve radius relative to the road width.

Explanation (8 key points)

1. Superelevation reduces reliance on friction for vehicle stability on curves.
2. Increases at higher speeds (more centrifugal force at higher speeds).
3. Limited by comfort (prevents excessive slope sliding effect) and constructability.
4. Must be transitioned gradually from tangent to full value on curve.
5. Reverse superelevation needed on opposite curve direction.
6. Excessive superelevation causes heavy vehicles to tip on outside, light vehicles to slide inside.
7. Empirical relationship between design speed, curve radius, and required superelevation.
8. Balanced design: Considers friction and superelevation together for stability.

Maximum Superelevation Values (IRC):

Road Type	Maximum e
Urban roads	4% (4m per 100m width)
Rural roads	6-7%
Mountainous roads	8-10%

Reasoning:

- Lower in urban areas: Pedestrian crossing discomfort, parking stability
- Higher in rural areas: Fewer pedestrians, less parking concerns
- Rural expressways: 6-7% standard

Calculation of Superelevation:

The relationship between speed, radius, friction, and superelevation:

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

Where:

- e = Superelevation (decimal, e.g., 0.06 = 6%)
- f = Coefficient of lateral friction (0.15-0.20 typical)
- V = Design speed (km/h)
- R = Radius of curve (m)
- 127 = Constant (conversion factor)

Solving for e:

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

Example: For V = 80 km/h, R = 300m, f = 0.15:

$$e = \frac{80^2}{127 \times 300} - 0.15 = \frac{6400}{38100} - 0.15 = 0.168 - 0.15 = 0.018 = 1.8\%$$

So 1.8% superelevation sufficient for this curve; can use 2% for standard.

Superelevation Transition:

The transition from zero (tangent) to full superelevation (on curve) must be gradual:

Transition Length:

- Minimum: Design speed in meters
  - Example: 80 km/h → 80m minimum transition length
- Better: 1.5-2 × design speed in meters

Typical Transition Profile:

- First 1/3: Decrease cross slope to zero
- Middle 1/3: Introduce superelevation gradually
- Final 1/3: Reach full superelevation at curve start

Transition at Spiral Curve:

- Superelevation applied gradually along spiral length
- Reaches full value at spiral-curve junction
- Spiral length often doubles as superelevation transition length

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Extra Width at Curve

Definition 💙

Extra width (widening) is the additional pavement width provided on the inside of horizontal curves to accommodate the swept path of vehicles, particularly large vehicles like trucks and buses. The swept path is wider than the vehicle's wheelbase due to the vehicle's geometry (front axle not directly following rear axle path), and this extra width is necessary for safe vehicle operation without encroachment onto adjacent lanes.

Explanation (8 key points)

1. Vehicles follow curved paths with front wheels tracking inside of rear wheels path.
2. Swept path width depends on vehicle wheelbase and curve radius.
3. Longer vehicles (buses, trucks) require more width than cars.
4. Tighter curves require more width (radius smaller = vehicle turns more sharply).
5. Extra width needed to prevent heavy vehicles from crossing lane markings/centerline.
6. Critical on sharp curves, less important on flat curves.
7. Can be provided on inside, outside, or both sides of curve.
8. Extra width transitions smoothly over transition curve length.

Calculation of Extra Width:

The extra width is determined by the swept path of the design vehicle:

$$W = R_d - R_r$$

Where:

- W = Extra width (m)
- Rd = Radius of path followed by front outer wheel
- Rr = Radius of path followed by rear inner wheel

For a vehicle with wheelbase L on a curve of radius R:

$$W = R - \sqrt{R^2 - L^2}$$

Approximation for large radius (R >> L):

$$W \approx \frac{L^2}{2R}$$

Where:

- L = Wheelbase of vehicle (m)
- R = Radius of curve (m)
- W = Extra width needed (m)

Design Vehicle Wheelbases (IRC Standards):

- Passenger car: L = 2.7m
- Medium truck: L = 6.0m
- Large truck/bus: L = 9.0-12.0m

Examples of Extra Width Calculation:

Example 1: Passenger Car

- L = 2.7m, R = 300m

$$W = \frac{2.7^2}{2 \times 300} = \frac{7.29}{600} \approx 0.01m \approx negligible$$

Example 2: Large Truck

- L = 10m, R = 300m

$$W = \frac{10^2}{2 \times 300} = \frac{100}{600} \approx 0.17m \approx 0.2m$$

Example 3: Large Truck, Sharper Curve

- L = 10m, R = 150m

$$W = \frac{10^2}{2 \times 150} = \frac{100}{300} \approx 0.33m$$

IRC Recommendations for Extra Width:

Curve Radius (m)	Design Vehicle	Extra Width (m)
> 600	All	Negligible (0)
300-600	Truck/Bus	0.1-0.2
150-300	Truck/Bus	0.2-0.5
80-150	Truck/Bus	0.5-1.0
< 80	Truck/Bus	1.0+

Note: For passenger cars, extra width usually negligible for R > 100m.

Method of Providing Extra Width:

1. Widening on Inside Only:

- Most common method
- Provides extra width on curve interior
- Less disruptive than outside widening

2. Widening on Both Sides:

- Used on high-traffic curves
- Maintains curve centerline in center of widened road
- More symmetric approach

3. Widening on Outside:

- Rare, used when inside widening impractical
- More complex for driver (outside edge moves outward)

Transition of Extra Width:

Length of Widening Transition:

- Minimum: 30-50m at each end
- Desirable: Equal to transition curve length
- Gradual linear increase/decrease preferred

Transition Profile:

- Begins before curve (or at T.S. point with spiral)
- Increases linearly (or gradually) over transition length
- Reaches full width at start of main circular curve
- Decreases similarly at curve end
- Zero at end of transition (returns to standard width)

Setback Distance

Definition 💙

Setback distance is the perpendicular horizontal distance from the inside of a horizontal curve to an obstruction (building, tree, hill, slope) that could obstruct a driver's line of sight for the sight distance required at that design speed. It ensures that drivers can see sufficiently far around the curve to perceive and react to hazards ahead.

Explanation (8 key points)

1. Sight distance requirements may be obstructed by physical features on curve inside.
2. Setback ensures line of sight cleared of all obstructions.
3. Calculated based on sight distance required and curve radius.
4. Larger setback needed for longer required sight distances (higher design speeds).
5. Sharper curves (smaller radius) require larger setback percentages.
6. Obstructions must be removed, relocated, or shielded if within setback distance.
7. Critical for safety: Inadequate setback can cause sight distance restriction.
8. Must be verified during construction and maintained through operation.

Calculation of Setback Distance:

For a horizontal curve, to provide sight distance S:

$$m = R - \sqrt{R^2 - (\frac{S}{2})^2}$$

Where:

- m = Setback distance (perpendicular distance from curve center line to obstruction) (m)
- R = Radius of curve (m)
- S = Sight distance required (m) [typically SSD or OSD depending on purpose]

Simplified Formula (for S << R):

$$m = \frac{S^2}{8R}$$

This approximation is quite accurate for practical setback distances.

Examples of Setback Calculation:

Example 1: SSD on Mild Curve

- Design speed: 80 km/h, SSD = 120m
- Curve radius: R = 500m

Using simplified formula:

$$m = \frac{120^2}{8 \times 500} = \frac{14400}{4000} = 3.6m$$

Exact formula verification:

$$m = 500 - \sqrt{500^2 - (120/2)^2} = 500 - \sqrt{250000 - 3600} = 500 - \sqrt{246400} = 500 - 496.4 = 3.6m$$

Example 2: OSD on Sharp Curve

- Design speed: 80 km/h, OSD = 640m
- Curve radius: R = 300m

$$m = \frac{640^2}{8 \times 300} = \frac{409600}{2400} \approx 170.7m$$

This large setback distance shows why sharp curves with OSD requirements are problematic!

IRC Setback Criteria:

For Stopping Sight Distance (SSD):

- Setback to be provided on all curves
- Calculated for SSD requirement at design speed
- Critical for safety

For Overtaking Sight Distance (OSD):

- Not always provided (too expensive)
- May be waived on some roads due to cost
- When required, very large setback distances result (see Example 2)

Practical Methods to Achieve Setback:

1. Remove/Trim Obstruction:

- Cut hill slope back
- Remove trees/vegetation
- Clear buildings if acquired for ROW
- Most effective method when feasible

2. Relocation:

- Move utility poles, signs, structures
- Relocate to outside of curve if possible
- Expensive but sometimes only option

3. Raise or Lower Pavement:

- Grade separation (bridge or culvert)
- Raises road over obstruction or lowers under it
- Expensive infrastructure solution
- Used when other options impractical

4. Guard Rail or Barrier:

- Safety barrier instead of sight obstruction
- Does not achieve sight distance but provides safety
- Acceptable on some roads where speeds low

5. Visibility (Reflectors, Lighting, Signs):

- Enhanced marking and lighting
- Warning signs before obstruction
- Not substitute for sight distance but enhances safety
- Used as supplementary measure

Curve Resistance

Definition 💙

Curve resistance refers to the additional friction or resistance forces needed to maintain vehicle stability and traction on curves, particularly for vehicles carrying heavy loads. It is the additional effort (higher friction, lower speed, or greater fuel consumption) required to navigate a curve compared to straight roadway. Understanding curve resistance is important for vehicle performance prediction, particularly for trucks climbing curves in grades, and for highway capacity analysis.

Explanation (8 key points)

1. Vehicles experience centrifugal force on curves requiring lateral force (friction) for stability.
2. Heavy vehicles are more affected than light vehicles (mass effect).
3. Steep curves (small radius) create higher centrifugal force.
4. Combination of grade and curve creates highest resistance (grade + curve together).
5. Trucks often cannot maintain design speed on curves combined with grades.
6. Curve resistance not major factor for passenger cars at moderate speeds.
7. Truck climbing ability affected by both grade and curve resistance.
8. Important for capacity analysis on mountain roads and in traffic modeling.

Components of Curve Resistance:

1. Centrifugal Force:

$$F_c = \frac{mv^2}{R}$$

Where:

- m = vehicle mass
- v = velocity

- R = curve radius

2. Friction Required:
To maintain circular motion without skidding:

$$F_f = m \times g \times f$$

For equilibrium on curve:

$$\frac{mv^2}{R} \leq m \times g \times f$$

Rearranging:

$$v \leq \sqrt{127Rf}$$

Where 127 = g × 127 (conversion factor for v in km/h)

3. Grade Resistance (Combined):
When curve combined with grade:

- Uphill curves: Grade resistance + curve resistance (additive)
- Downhill curves: Grade assists (partial cancellation)

Truck Performance on Curves with Grade:

Tractive Effort Equation:

$$F_t = F_{\text{resistance}} + F_{\text{curve}}$$

Grade Resistance:

F_g = W \times G \text{ (where W = vehicle weight, G = grade %)}

Curve Resistance (Empirical):

$$F_c = 0.002 \times W \times (30/R)^2 \text{ (approximate formula for trucks)}$$

Or simpler: **Curve resistance ≈ 1-2% grade equivalent for tight curves** (500m radius is negligible, 150m radius ≈ 1-2% equivalent grade)

Truck Climbing Ability:

Trucks have limited pulling power (tractive effort), limited by:

- Engine power and gear ratio
- Coefficient of friction between tires and pavement

- Vehicle weight

Maximum Sustainable Grade (at constant speed):

Depends on truck characteristics but typical values:

- Loaded truck: 6-8% maximum sustained grade
- Light truck: 12-15% maximum
- Grade + Curve: More restrictive than grade alone

Example:

- Grade + sharp curve may limit truck to 4-5% effective grade capacity
- Means heavy truck unable to maintain design speed

Design Implications:

1. Grade and Curve Separation:

- Design practice: Avoid sharp curves on steep grades
- If unavoidable: Provide extra length for curve transition
- Consider auxiliary lanes for climbing assistance

2. Speed Reduction Expectations:

- Trucks may operate 20-40 km/h slower than design speed on curves with grades
- Capacity reduced accordingly

3. Truck Climbing Lanes:

- On sustained upgrade with significant curve: Additional lane for trucks
- Allows trucks to climb without blocking passenger traffic

Capacity Impact:

Level of Service (LOS) Reduction:

- Curves reduce capacity by 5-15% depending on radius and terrain
- Grades reduce capacity by 3-5% per 1% grade
- Combined grade + curve: Multiplicative reduction

Two-Lane Road Capacity:

- Ideal (straight, level): 1,000-1,400 vehicles/day/direction
- With curves (R = 300m): Capacity reduced by ~10%

- With grade (6%): Capacity reduced by ~5%
- With both: Capacity reduced by ~15%

Relationship Between Horizontal Curve Elements

Comprehensive Design Process:

Step 1: Selection of Design Speed
Based on classification and terrain
→ Determines all other elements

Step 2: Minimum Curve Radius Determination
Based on design speed and maximum superelevation:

$$R_{\min} = \frac{V^2}{127(e_{\max} + f_{\max})}$$

Step 3: Site-Specific Radius Selection
Given topography and constraints:

- Use larger radius if feasible (safer, more comfortable)
- Minimum acceptable: Rmin based on design speed
- Recommended: 1.5-2 × Rmin when possible

Step 4: Determine Superelevation
For selected radius:

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

Cap at maximum (6-8% per IRC)

Step 5: Provide Transition Curve
Length:

$$L_s = 2.7 \times \frac{V^2}{R}$$

Step 6: Calculate Extra Width
If needed:

$$W = \frac{L^2}{2R}$$

Step 7: Calculate Setback Distance
For sight distance requirement:

$$m = \frac{S^2}{8R}$$

Step 8: Verify Safety Requirements

- Sight distance adequate
- Setback feasible to provide
- Grade manageable for trucks

Summary Table: Horizontal Alignment Design Elements

Element	Formula/Basis	Typical Values (V=80 km/h)
Minimum Radius	$R = \frac{V^2}{127(e+f)}$	430-600m
Superelevation	$e = \frac{V^2}{127R} - f$	4-6%
Transition Curve Length	$L_s = 2.7\frac{V^2}{R}$	30-50m
Extra Width (truck, R=300m)	$W = \frac{L^2}{2R}$	0.2-0.3m
Setback for SSD (R=500m)	$m = \frac{S^2}{8R}$	3-4m
Setback for OSD (R=300m)	$m = \frac{S^2}{8R}$	150+m

Summary (Hinglish)

Horizontal alignment design mein design speed sabse zaroori element hai jisse sab parameters decide hote hain. Curve radius, superelevation, transition curve length, extra width sab design speed ke basis par calculate hote hain. Sight distance requirements ke hisaab se setback distance determine karte hain. Trucks ke liye curve resistance important hota hai specially where grade aur curve dono ho. Proper alignment design se safety, comfort, aur efficiency ensure hoti hai.

Keywords

Design Speed, Horizontal Curve, Superelevation, Extra Width, Setback Distance, Sight Distance, Transition Curve, Curve Resistance

Common Errors or Misconceptions

- Design speed can be changed mid-project (Changes affect all geometric parameters, very expensive).
- Superelevation only for safety (Also for comfort and ride quality).
- Setback not needed if curve wide enough (Obstruction still restricts sight distance regardless of width).

Diploma Wallah

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