

Transportation Engineering I

Geometric Design of Highways

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Geometric Design of Highway

- 3.1 Definition and scope of Geometric Design
- 3.2 Design Controls and Criteria
- 3.3 Elements of Cross-section: Urban Roads, Rural Roads
- 3.4 Elements of Horizontal Alignment
 - 3.4.1 Definition and Types of Horizontal Curve
 - 3.4.2 Design of Horizontal Curve Including Night Visibility Consideration
 - 3.4.3 Sight Distance: Stopping Sight Distance, Overtaking Sight Distance, Set-back from Obstructions
 - 3.4.4 Super-elevation
 - 3.4.5 Extra-widening
 - 3.4.6 Transition Curve: Definition and Types of Transition Curve, Design of Transition Curve
- 3.5 Elements of Vertical Alignment
 - 3.5.1 Definition and Types of Gradient
 - 3.5.2 Momentum Grade
 - 3.5.3 Grade Compensation
 - 3.5.4 Definition and Types of Vertical Curve
 - 3.5.5 Design of Vertical Summit Curve
 - 3.5.6 Design of Vertical Valley Curve
 - 3.5.7 Lowest and Highest point of vertical curve

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3.1 Definition and Scope of Geometric Design

- **Definition**
 - Dimension and layout of
 - Physical elements of the highway
 - visible to drivers and users
 - Designed for optimum efficiency in traffic operation with maximum safety and comfort at reasonable cost
- **Scope**
 - **Cross sectional elements**
 - Traffic Lane, carriageway, shoulder, median strip, right of way, side slope, camber, superelevation, extra widening.
 - **Sight Distance Characteristics**
 - Stopping sight distance, overtaking distance
 - **Elements of horizontal and vertical alignment**
 - Radius of curve, curve length, transition curve, grades, etc.

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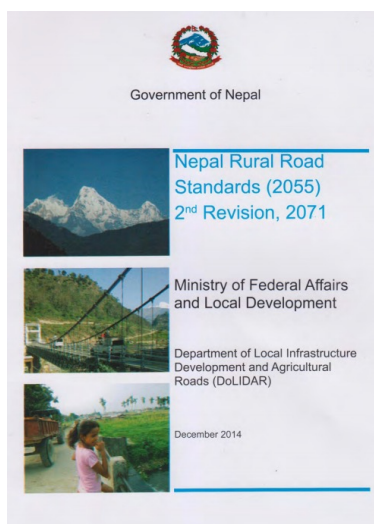
3.2 Introduction to Road Standards in Nepal (Strategic Roads, Local Roads and Urban Roads)

- Nepal Road Standard 2070
- Nepal Rural Road Standard 2071
- Nepal Urban Road Standard 2076

Government of Nepal
Ministry of Physical Infrastructure & Transport
Department of Roads
Planning and Design Branch
Road and Traffic Unit
Babarmahal, Kathmandu

Nepal Road Standard 2070

July,
2013



Government of Nepal
Ministry of Urban Development
Singhadurbar, Kathmandu

Nepal Urban Road Standard- 2076

2076, Jestha

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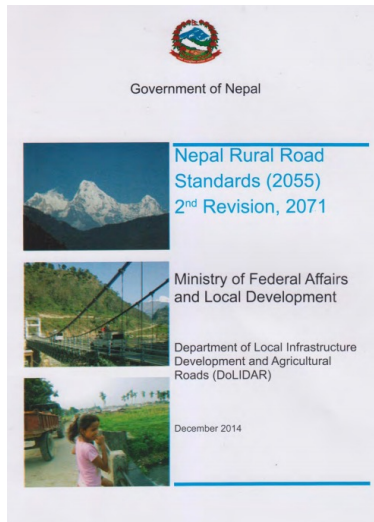
3.3 Design Controls and Criteria: Criteria for Geometric Design

- Speed
- Safety
- Comfort
- Economy

Government of Nepal
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Nepal Road Standard 2070



Government of Nepal
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Nepal Urban Road Standard- 2076

2076, Jestha

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3.3 Design Controls and Criteria: Design Controls

- **Design Speed**
 - Highest speed with which an individual can travel with safety on the road under consideration when the weather conditions are favorable.
 - Governs design of almost all elements.

Table 7-1 Design Speeds, km/h

Road Class	Plain	Rolling	Mountainous	Steep
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

Source: NRS 2070

Table 6-1 Terrain Classification

S.No.	Terrain Type	Percent Cross Slope	Degree
1	Plain	0-10	0° – 5.7°
2	Rolling	> 10-25	> 5.7° – 14°
3	Mountainous	>25-60	> 14° – 31°
4	Steep	>60	> 31°

Source: NRS 2070

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3.3 Design Controls and Criteria: Design Controls

- **Design Speed**

- Highest speed with which an individual can travel with safety on the road under consideration when the weather conditions are favorable.
- Governs design of almost all elements.

Road Categories	Hills		Terai	
	Ruling	Minimum	Ruling	Minimum
District Road (Core Network)	25	20	50	40
Village Road	15		30	

Source: NRRS 2071

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3.3 Design Controls and Criteria: Design Controls

- **Design Speed**

- Highest speed with which an individual can travel with safety on the road under consideration when the weather conditions are favorable.
- Governs design of almost all elements.

Table 13: Recommended Design Speeds for Different Classes of Urban Roads

Type of Road	Design Speed (Km/hr)
Arterial Roads	40-50
Sub Arterial Roads	30-40
Collection Roads	20-30
Local Streets	10-20

Source: NURS 2076

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3.3 Design Controls and Criteria: Design Controls

- **Design Vehicle**

- Vehicle that governs the design.
- Vehicle dimension, weight, operating characteristics affect the design.

4.1 Vehicle Dimensions

The maximum dimensions of vehicles considered for design of roads in Nepal are as follows:

Maximum Width, m	2.50
Maximum Height, m	4.75
Maximum Length, m	18.00
Maximum single axle load, kN	100

Source: NRS 2070

3.3 Design Controls and Criteria: Design Controls

- **Design Vehicle**

- Vehicle that governs the design.
- Vehicle dimension, weight, operating characteristics affect the design.

5.1 Vehicle type and dimension

In Nepal the most commonly used vehicles are of Indian make. Vehicle types adopted here are 'Type-2 both single tire and dual tire' having two axles and the maximum axle weight is 10.2 tonnes for rear axle with the following dimension.

Width – overall width 2.5 m

Height – 3.8 m for normal application

Length of wheel base – 6.1 m

Length – maximum overall length excluding front and rear bumpers, 11 m.

(Source: IRC: 64-1996)

Source: NRRS 2071

3.3 Design Controls and Criteria: Design Controls

- **Topography**

- The design standards specified for different classes of roads vary depending on the terrain classification.

Table 6-1 Terrain Classification

S.No.	Terrain Type	Percent Cross Slope	Degree
1	Plain	0-10	0° – 5.7°
2	Rolling	> 10-25	> 5.7° – 14°
3	Mountainous	>25-60	> 14° – 31°
4	Steep	>60	> 31°

Source: NRS 2070

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3.3 Design Controls and Criteria: Design Controls

- **Topography**

- The design standards specified for different classes of roads vary depending on the terrain classification.

4 TERRAIN CLASSIFICATION

A simple classification of Terrain into 'Terai' and 'Hill' is adopted based on the topography of country. While classifying terrain, short isolated stretches of varying terrain should not be taken into consideration. Generally, 'Terai' covers the plain and rolling terrain and varies from 0 to 25 percent cross slope, 'Hills' covers mountainous and steep terrain and varies from 25 to 60 percent and more.

Source: NRRS 2071

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3.3 Design Controls and Criteria: Design Controls

Traffic Composition

- Vehicles and road users with different characteristics.
- Traffic composition affects capacity and other design considerations.

Table 4-1 Vehicle types, Equivalency Factors

SN	Vehicle Type	Equivalency Factor
4	Bicycle, Motorcycle	0.5
1	Car, Auto Rickshaw, SUV, Light Van and Pick Up	1.0
2	Light (Mini) Truck, Tractor, Rickshaw	1.5
3	Truck, Bus, Minibus, Tractor with trailer	3.0
5	Non-motorized carts	6

Source: NRS 2070

SN	Vehicle Type	Equivalency Factor
1	Car, Light Van, jeeps and Pick Up	1.0
2	Light Truck up to 2.5 tonnes gross	1.5
3	Truck up to 10 tonnes gross	3.0
4	Truck up to 15 tonnes gross	4.0
5	4W Tractor towed trailers -standard	3.0
6	2W Tractor towed trailers -standard	1.5
7	Bus up to 40 passengers, Minibus	3.0
8	Bus over 40 passengers	4.0
9	Motocycle or scooter	0.5
10	Bicycle	0.5
11	Rickshaw and Tricycle carrying goods	1.0
12	Auto Rickshaw	0.75
13	Hand Cart	2.0
14	Bullock Cart with Tire	6.0
15	Bullock Cart with Wooden Wheel	8.0
16	Mula or Horse drawn carts	6.0
17	Pack Animal and mules	2.0
18	Pedestrian	0.2
19	Porter	0.40

(Source: Nepal Rural Road Standard, 2055)

Source: NRRS 2071

Table 4: Passenger car unit (PCU)

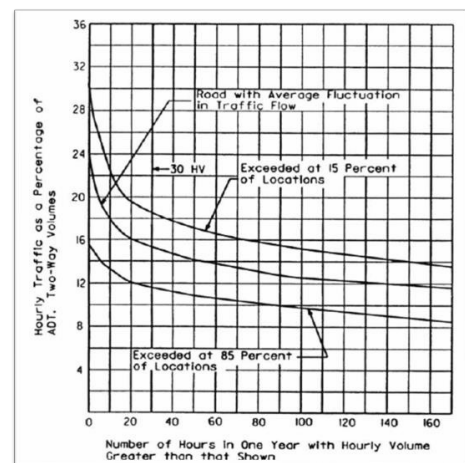
S	Vehicle Type	Equivalency
1	Motorcycle, Bicycle, Porter	0.5
2	Car, Auto Rickshaw, SUV, Light Van, Pick	1.0
3	Light (Mini) Truck, Tractor, Rickshaw	1.5
4	Truck, Bus, Minibus, Tractor with trailer	3.0
5	Non-motorized carts	6.0

Source: NURS 2076

3.3 Design Controls and Criteria: Design Controls

Design Volume and Capacity

- Number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specified time interval.
- An index of importance of highway.
- Usually expressed as vehicles per unit time.
 - Average Annual Daily Traffic (AADT), Average Annual Weekday Traffic (AAWT), Average Daily Traffic (ADT), Average Weekday Traffic (AWT)



3.3 Design Controls and Criteria: Design Controls

- **Design Volume and Capacity**
 - **Traffic Capacity**
 - Maximum number of vehicles in a lane or a roadway that can pass a given point in unit time usually an hour, i.e. vehicles per hour per lane of roadway.
 - Ratio of volume to capacity affects the level of service of the road.
 - Design capacity is required to determine the number of lanes required and the total width of the road.
 - **Basic/Theoretical Capacity**
 - Under the most ideal roadway and traffic conditions which can possibly be attained.
 - **Possible Capacity**
 - Under prevailing roadway and traffic conditions.
 - **Design/Practical Capacity**
 - Without traffic density being so great to cause unreasonable delay, restrictions to drivers freedom to maneuver under the prevailing roadway and traffic conditions. Used for design.

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3.3 Design Controls and Criteria: Design Controls

- **Design Volume and Capacity**

Table 5-1: Capacity of Roads, PCU/day

S. No.	Category	Plain		Rolling		Mountainous and steep	
		Low curvature (0-50 deg/km)	High curvature (>50 deg/km)	Low curvature (0-100 deg/km)	High curvature (>100 deg/km)	Low curvature (0-200 deg/km)	High curvature (>200 deg/km)
1	Single Lane Road(3.75 m) with good quality shoulders at least 1.0m wide	2000	1900	1800	1700	1600	1400
2	Intermediate lane Road(5.5m) with good quality shoulders at least 1.0m wide	6000	5800	5700	5600	5200	4500
3	Double lane Road(7.0m) with good quality shoulders at least 1.0m wide	15000	12500	11000	10000	7000	5000
4	Four lane road with a minimum 3.m wide median	40000	35000	32500	30000	25000	20000

Source: NRS 2070

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3.3 Design Controls and Criteria: Design Controls

- **Design Volume and Capacity**

Table 5: Traffic Capacity

Design Parameters	District Road (Core Network)		Village Road	
	Hill	Terai	Hill	Terai
Design Capacity- in both directions (Vehicle per day/PCU per day)	200 (400)	400 (800)	100 (200)	200 (400)

(Source: Nepal Rural Road Standard, 2055)

Source: NRRS 2071

No. of traffic lanes and width	Traffic flow	Capacities in PCUs per hour for various traffic conditions		
		Roads with no frontage access, no standing vehicles, very little cross traffic	Roads with frontage access but no standing vehicle and high capacity intersections	Roads with free frontage access, parked vehicles and heavy cross traffic
1-Lane (3.5-4.0m)	One way	750	700	650
2-lane (7-7.5m)	One way	2400	1500	1200
	Two way	1500	1200	750
3-lane (10.5m)	One way	3600	2500	2000
4-lane (14.0m)	One way	4800	3000	2400
	Two way	4000	2500	2000
6-lane (21.0m)	One way*	3600	2500	2200
	Two way	6000	4200	3600

* For three lanes in predominant direction flow.

Source: NURS 2076

3.3 Design Controls and Criteria: Design Controls

- **Road User Behavior**
 - Both pedestrians and drivers show different behavior.
 - Its influence cannot be quantified but should not be ignored.

3.3 Design Controls and Criteria: Design Controls

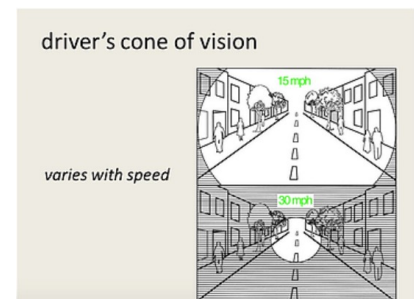
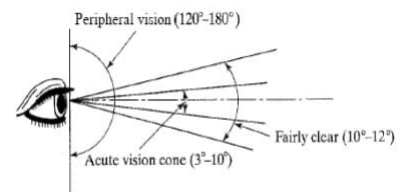
- **Road User Behavior**
 - Physical Characteristics
 - Mental Characteristics
 - Psychological Characteristics
 - Environmental Factors

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3.3 Design Controls and Criteria: Design Controls

- **Road User Behavior**
 - Physical Characteristics
 - **Permanent:** Vision, hearing, strength, smell
 - **Temporary:** Fatigue, illness, effect of drugs
 - **Vision**
 - About 90% of the information is received in visual.
 - Human eye sees and evaluates the size, shape and color of an object and estimate the distance and speed of the bodies.
 - Visual acuity is the ability to see fine details clearly.
 - Peripheral vision relates to an individual's ability to see objects not necessarily clearly. Such vision serves as a warning sign.



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3.3 Design Controls and Criteria: Design Controls

- **Road User Behavior**
 - Physical Characteristics
 - **Permanent:** Vision, hearing, strength, smell
 - **Temporary:** Fatigue, illness, effect of drugs
 - **Hearing**
 - Important to both drivers and pedestrians. However, more important for pedestrians.
 - Can be helpful in gaining information regarding warning sounds as sirens, horns, bells, etc.
 - It has been found that drivers with hearing problem can have 1.8 times more crashes than the drivers with normal hearing.
 - **Strength**
 - Most important for drivers driving heavy vehicles.

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3.3 Design Controls and Criteria: Design Controls

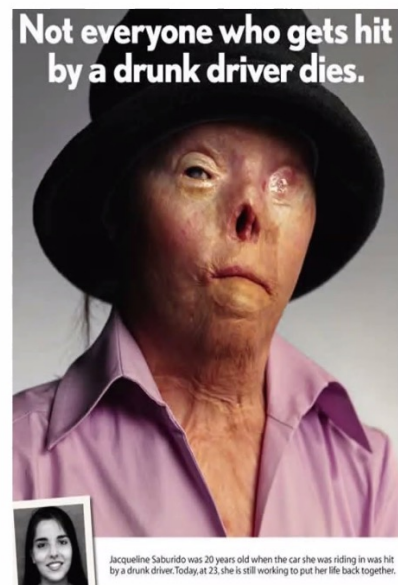
- **Road User Behavior**
 - Physical Characteristics
 - **Permanent:** Vision, hearing, strength
 - **Temporary:** Fatigue, illness, effect of drugs
 - **Fatigue**
 - Tired drivers usually suffer from lack of concentration and have longer perception-reaction time.
 - More likely to commit an error of judgement on the roadway.
 - **Illness**
 - May cause physical inability to drive, mental tension and lack of concentration.

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3.3 Design Controls and Criteria: Design Controls

- **Road User Behavior**
 - Physical Characteristics
 - Permanent: Vision, hearing, strength
 - Temporary: Fatigue, illness, effect of drugs
 - Effect of drug and alcoholic drink
 - Lack of concentration and overconfidence.

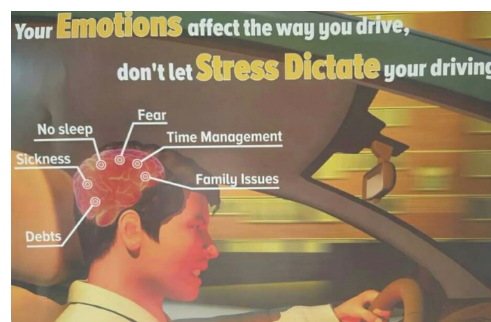


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3.3 Design Controls and Criteria: Design Controls

- **Road User Behavior**
 - Mental Characteristics
 - Knowledge, intelligence, skill, experience and literacy can affect the road user characteristics.
 - Psychological Characteristics
 - Emotional factors as attentiveness, fear, anger, impatience, distraction and worries may lead to lack of concentration of road user towards traffic regulations and may not have right attitude to the other traffic.



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3.3 Design Controls and Criteria: Design Controls

- **Environmental and other Factors**
 - Air pollution, sound pollution, landscaping, aesthetic conditions and road side environment should be considered in design.

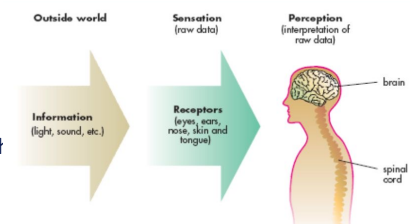
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3.3 Design Controls and Criteria: Design Controls

- **Perception and Reaction**
- Perception is a process of extracting information from the environment.

The driver tends to attain movement from one point to other through three tasks.



- **Control** – physical manipulation of the vehicle through **lateral and longitudinal control** by steering, acceleration and braking.
- **Guidance** – driver's decision process, a task of **selecting safe speed, path**. Information comes from the environment, traffic control devices and other traffic surroundings.
- **Navigation** - driver's ability to execute a trip from **origin to destination** for which the information comes from maps, signs and landmarks.

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3.3 Design Controls and Criteria: Design Controls

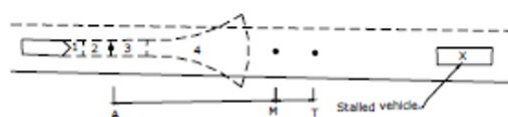
- **Perception and Reaction**
- Perception time may be divided into two parts:
 - **Perception delay** – time between visibility and point of perception.
 - **Appreciation interval** – time required to determine that there is a potential hazard.
- Reaction involves analytical and decision making portion.
- Total reaction time involves reaction plus actual control response.

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3.3 Design Controls and Criteria: Design Controls

- **Driving Strategy**



Driver Strategy (Vanstrum and Caples, 1971)

- **Distance 1** - during the perception time.
- **Distance 2** - during the time needed to take a decision.
- **Distance 3** - during the reaction time.
- **Distance 4** - minimum stopping distance.
- **T** – True point of no return (last point at which action can be taken to avoid hazard).
 - If hazard is in motion, T will also be in motion.
- **M** – Mental point of driver (last point at which action must be taken).

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3.3 Design Controls and Criteria: Design Controls

- **PIEV Theory**
 - **Perception** – the recognition or realization of stimulus exists and requires response.
 - Sees a sign
 - **Intellection** – an interpretation/identification of the stimulus.
 - Identifies it as a STOP sign
 - **Emotion** – the determination of an appropriate response to the stimulus
 - Person is aware that, a brake need to be applied.
 - **Volition** – the physical response resulting from the decision
 - Applies brake.

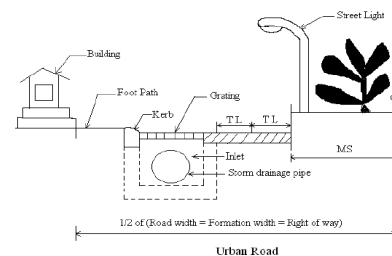
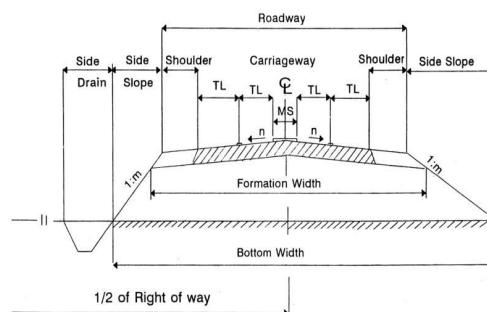


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3.4 Elements of Cross Section: Urban Road, Rural Road

- **Cross section of Road**
 - Section along the width of the road and perpendicular to the center line of the road.
 - Includes traffic lane, carriageway, shoulder, side slope, side drain, right of way, lay-bys, camber, superelevation, extra widening, footpath, kerb, median strips, cycle track, service roads, green belts, etc.

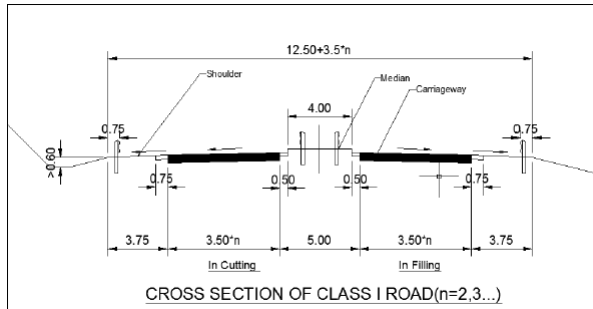


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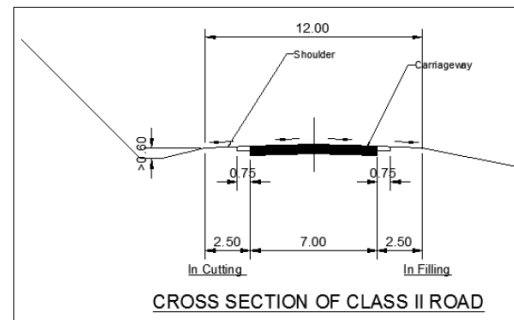
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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road



Source: NRS 2070

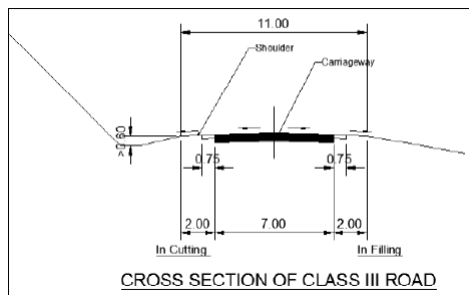


Source: NRS 2070

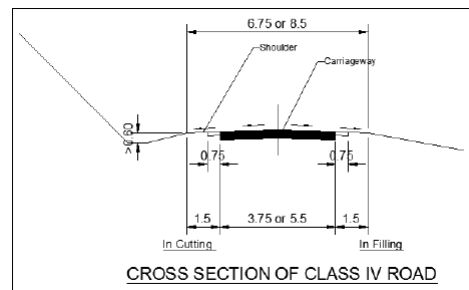
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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road



Source: NRS 2070

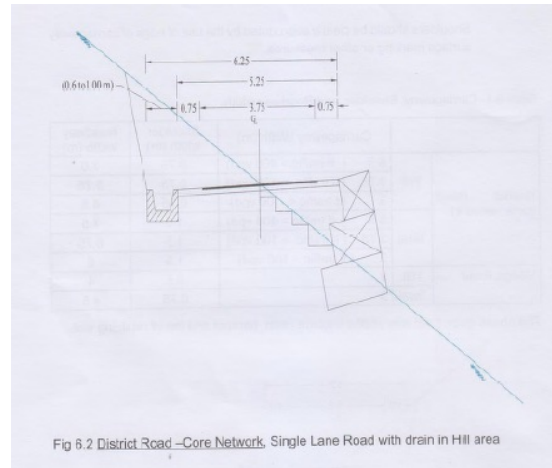
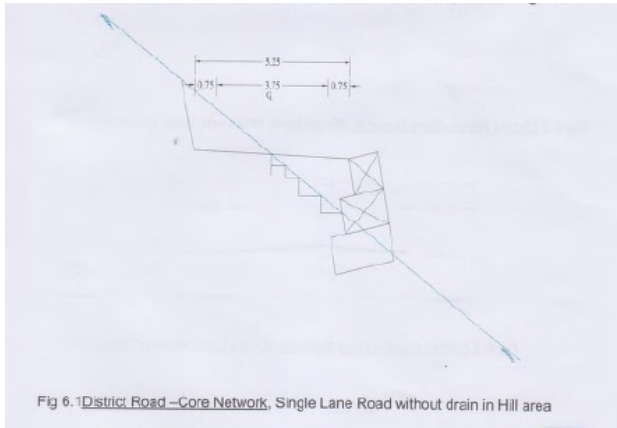


Source: NRS 2070

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3.4 Elements of Cross Section: Urban Road, Rural Road

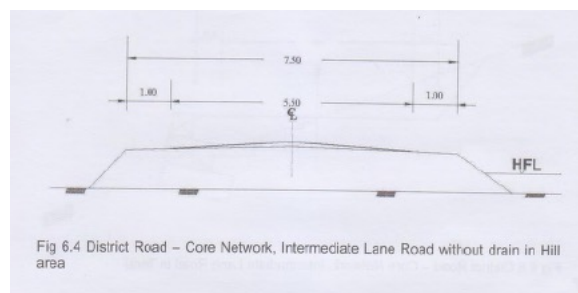
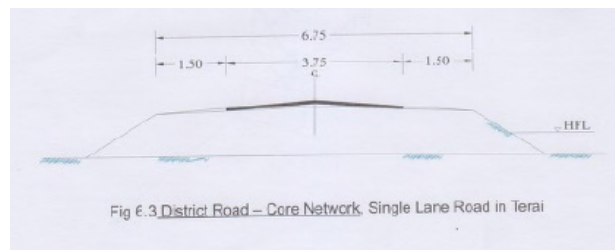
- Cross section of Road



Source: NRRS 2071

3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road



Source: NRRS 2071

3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road

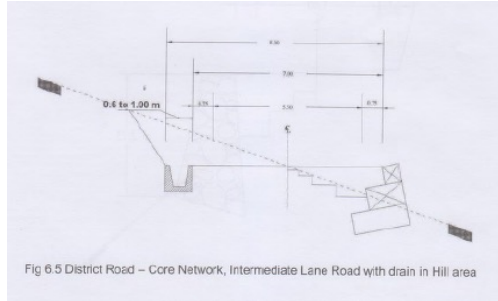


Fig 6.5 District Road – Core Network, Intermediate Lane Road with drain in Hill area

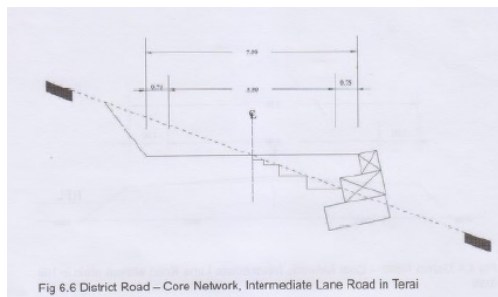


Fig 6.6 District Road – Core Network, Intermediate Lane Road in Terai

Source: NRRS 2071

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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road

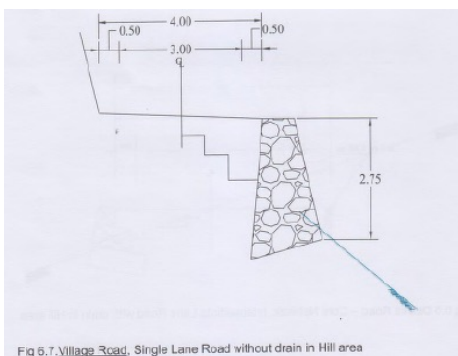


Fig 6.7 Village Road, Single Lane Road without drain in Hill area

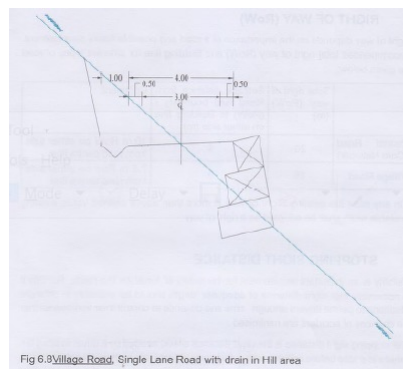


Fig 6.8 Village Road, Single Lane Road with drain in Hill area

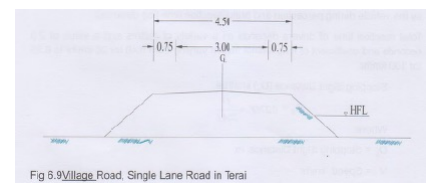


Fig 6.9 Village Road, Single Lane Road in Terai

Source: NRRS 2071

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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road

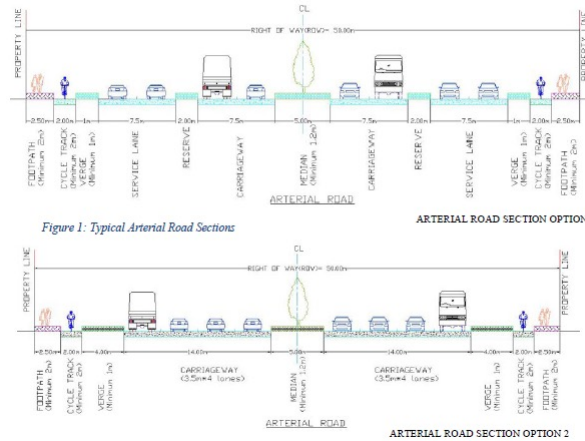


Figure 1: Typical Arterial Road Sections

Source: NURS 2076

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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road

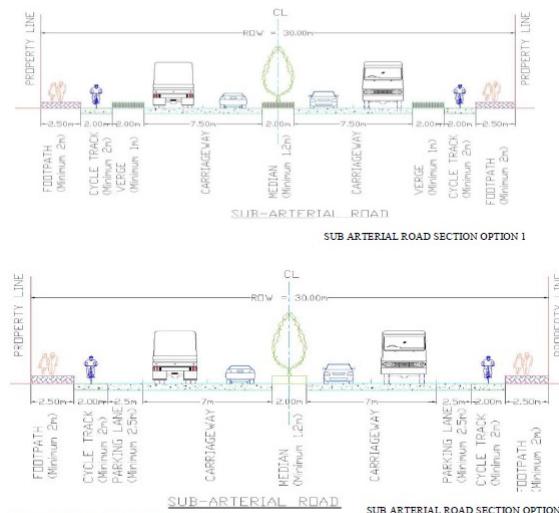


Figure 2: Typical Sub-Arterial Road Sections

Source: NURS 2076

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3.4 Elements of Cross Section: Urban Road, Rural Road

- Cross section of Road**

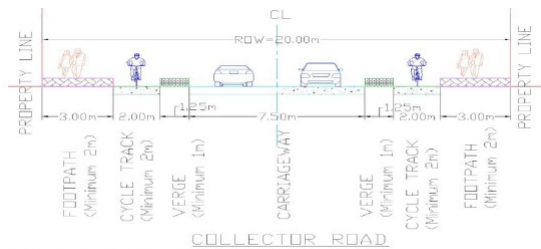


Figure 3: Typical Collector Road Section

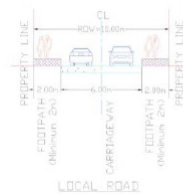


Figure 4: Typical Local Road Section

Source: NURS 2076

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3.4 Elements of Cross Section: Urban Road, Rural Road

- Carriageway/Pavement Width (C_w)**

- Main width of the road meant for vehicular traffic movement.

$$C_w = T_w \cdot N$$

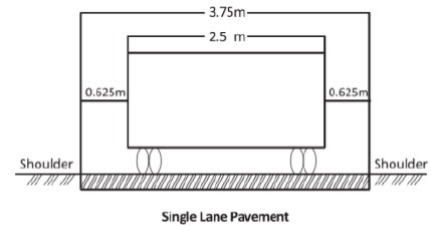
where,

T_w = Width of traffic lane

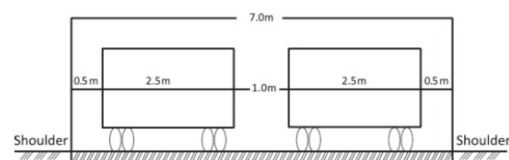
n = Number of traffic lane

- Width of Traffic Lane (T_w)**

- Width of carriageway on which a standard vehicle can move safely in one direction along the road.
- Sum of width of design vehicle and minimum side clearance on either side of road (side clearance required for safety between vehicle and edge of carriageway and for safety between vehicle and adjacent traffic).



Single Lane Pavement



Double Lane Pavement

41

3.4 Elements of Cross Section: Urban Road, Rural Road

Carriageway/Pavement Width (C_w)

- Main width of the road meant for vehicular traffic movement.

$$C_w = T_w \cdot N$$

where,

T_w = Width of traffic lane

n = Number of traffic lane

Number of traffic lane required for a road (n)

$$n = \frac{N}{C}$$

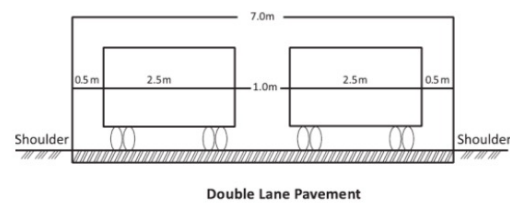
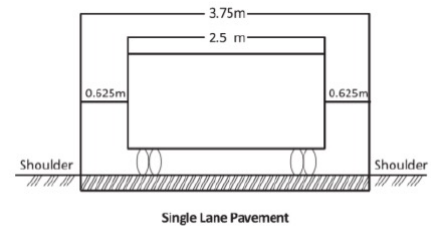
where,

N = Design hourly volume of traffic

C = Theoretical or basic capacity of traffic lane

C = $\frac{1000V}{S}$ where, V = Design speed in kmph

S = center to center distance between front and rear vehicles



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3.4 Elements of Cross Section: Urban Road, Rural Road

Carriageway/Pavement Width (C_w)

Table 11-1 Width of Carriageways, m

Single lane road	Intermediate lane	Multilane pavements width per lane
3.75 (upto 3.0 m in difficult terrain)	5.5	3.5

Source: NRS 2070

- b. In case of single lane roads it is recommended to have two treated shoulders on either side to make a total width of 5.5m of treated surface.

Source: NRRS 2071

Table 6.1- Carriageway, Shoulder, and Roadway width.

		Carriageway Width (m)	Shoulder width (m)	Roadway width (m)
District Road (core network)	Hill	5.5 (if traffic > 400 vpd)	0.75	7.0
		3.75 (if traffic > 100 vpd)	0.75	5.25
	Terai	3 (if traffic < 100 vpd)	0.75	4.5
		5.5 (if traffic > 400 vpd)	1.0	7.5
Village Road	Hill	3.75 (if traffic > 100 vpd)	1.5	6.75
	Terai	3 (if traffic < 100 vpd)	1.5	6
Village Road	Hill	3	0.5	4
	Terai	3	0.75	4.5

The above given road way widths exclude drain, parapet and top of retaining wall.

Table 17: Recommended Carriage Width

Description	Width, m
Arterial and Sub-arterial roads:	
a) Single lane	3.5
b) 2-lane without raised kerb	7
c) 2-lane lane with raised kerb	7.5
d) Multi-lane carriageway, width per lane	3.5
Collector streets:	
a) Single lane	3.5
b) 2-lane without raised kerb	7
c) 2-lane lane with raised kerb	7.5
d) 3-lane with or without kerb	10.5/11.0
e) 4 lane with or without kerb	14
Local street, per lane	3

Note: Minimum width of a kerbed urban road is 5.5 m including allowance for a stalled vehicle.

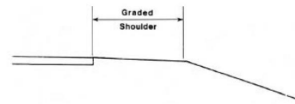
Source: NURS 2076

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3.4 Elements of Cross Section: Urban Road, Rural Road

Shoulders

- Provided along the road edge.
- Serves as an emergency lane for parking vehicles with som



Advantages

- Provide space for parking vehicles and support removal of out of order vehicles.
- Provide space for fixing up traffic signs and signals.
- Provide space for people to walk.
- Provide opportunities for overtaking in single lane road.
- Adds structural strength of the pavement and provide lateral stability.
- Increase the lateral clearance and the sight distance.



Table 11-2 Width of Shoulders, m

Road Class	Class I	Class II	Class III	Class IV
Minimum shoulder width, m	3.75	2.5	2.0	1.5

Source: NRS 2070

3.4 Elements of Cross Section: Urban Road, Rural Road

Roadway/Formation Width

- Sum of widths of pavements or carriageway including separators if any and shoulders.
- Top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

Side Slope of Fill/Cut

- Earthwork is provided with side slopes to keep the slope stable and free from slides.
- Flatter slopes are preferred for traffic safety (for filling zone) and sight distance (for cutting zone).

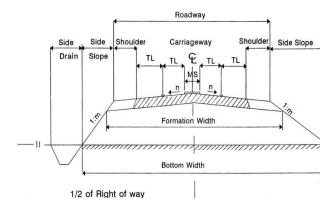


Table 11-5 Cuttings side slopes

Soil type	Side Slope(vertical:horizontal)
Ordinary Soil	1:2 to 1:1
Disintegrated rock or conglomerate	1:1/2 to 1:1/4
Soft rock, shale	1:1/4 to 1:1/8
Medium Rock	1:1/12 to 1:1/16
Hard Rock	Almost vertical

Table 11-4: Embankment Side Slopes

Height, m	Side Slope(vertical:horizontal)
<1.5	1:4
1.5-3.0	1:3
3.0-4.5	1:2.5
4.5-12.0	1:2
>12.0	Design specially

Source: NRS 2070

3.4 Elements of Cross Section: Urban Road, Rural Road

- **Right of Way (ROW) / Land Width of Road**
 - Width of the land acquired to accommodate the width of carriageway, the shoulders and road margins.
 - Includes drainage facilities, frontage roads, land required for future expansion.
 - Contributes to proper visibility.
 - **Building Line:** No building activity is permitted at all between this line and the road boundary.
 - **Control Line:** Provided to exercise control of building construction up to a set back distance.

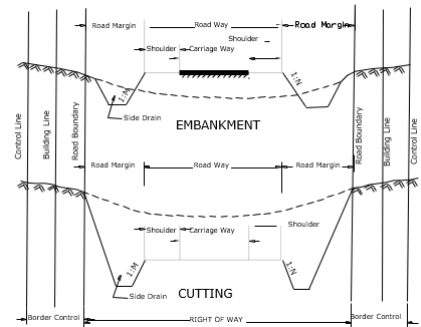


Table 16: Right of Way Width

Classification	Recommended Right of Way Width , m
Arterial	50
Sub-arterial	30
Collector	20
Local	10

Table 11-6: Right of way

Road Type	Total Right of Way,m
Highways	50
Feeder Roads	30
District Roads	20

Source: NRS 2070

	Total right of way (RoW) (m)	Setback distance from Road land boundary / (RoW) to Building line on either side (m)	Comment
District Road (Core Network)	20	6	10 m RoW on either side from road centre line
Village Road	15	3	7.5 m Row on either side from road centre line

Source: NRRS 2071

Source: NURS 2076

3.4 Elements of Cross Section: Urban Road, Rural Road

- **Lay-bys**
 - Intermittent shoulders provided in situations where the continuous shoulder on either side cannot be provided.

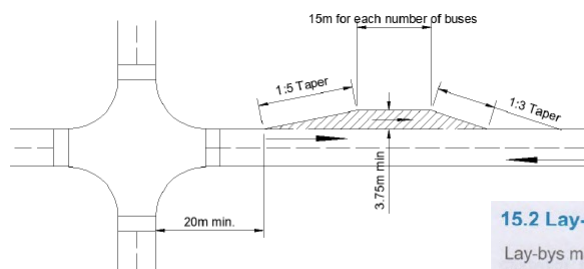


Figure 13-3 :Bus Lay Bys Plan

Source: NRS 2070

15.2 Lay-bys

Lay-bys may be provided for parking or for bus stops to allow vehicles to stop safely without impeding passing traffic. The minimum bus lay-by width shall be 3 m (i.e minimum 6 m carriageway widths) and the length 12 m along the outside edge and 30 m along the inside edge. This means that passing zones and lay bys should be tapered gradually towards the carriageway so that vehicles can leave or join the traffic stream safely.

Source: NRRS 2071

3.4 Elements of Cross Section: Urban Road, Rural Road

- **Footpath (Sidewalk)**
 - Provided for the movement of pedestrian traffic.
 - Raised at certain height from the carriageway by laying stone or concrete block to ensure safety of the pedestrians.

Table 13-1: Width of footpath

Hourly Design Flow(bothways) of 15 min peak period	Footpath width,m
Upto 500	1.5
500-1500	2.0
1500-2500	2.5
2500-3500	3.0

Source: NRS 2070

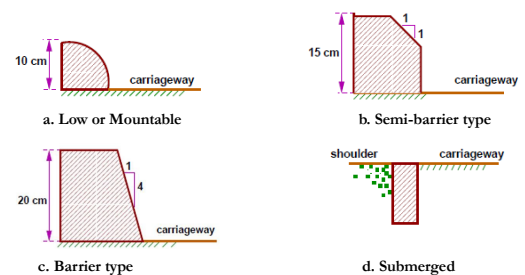
Table 18: Capacity of Footpaths

Number of Pedestrians per hour		Required width of Footpath, m
All in one direction	In both directions	
2400	800	2
3600	2400	2.5
4800	3200	3
6000	4000	4

Source: NURS 2076

3.4 Elements of Cross Section: Urban Road, Rural Road

- **Kerbs**
 - A raised structure at footpaths/islands/parking spots to isolate them from the carriageway.
 - A boundary between carriageway and shoulder in rural roads.
 - Separates vehicular traffic from pedestrians.
 - Provides firm support to the footpath.
 - Facilitates drainage.



4.9 Kerbs

Kerbs shall be provided in Urban roads considering appropriate situation for use of each type as indicated below:

- Mountable type: within the roadway at channelization schemes, medians, outer separators and raised medians on bridges
- Semi-barrier type: on the periphery of the roadway where pedestrian traffic is light and a barrier type could tend to reduce traffic capacity.
- Barrier type: Built-up areas adjacent to footpaths with considerable pedestrian traffic.

Source: NURS 2076

3.4 Elements of Cross Section: Urban Road, Rural Road

- **Median**

- Central raised strip to separate opposite stream of traffic.
- Minimize head-on collision and head light glare.

drainage and other determinants. Minimum width of median at intersections to accomplish various purposes should be as follows:

- Pedestrians refuse, 1.2 m.
- Median lane for protection of vehicle making right turn, 4.0 m.
- Absolute width of median in urban areas is 1.2 m a desirable minimum is 5 m.
- Fence or any other barrier medium should be provided at middle of median.

Source: NURS 2076



3.4 Elements of Cross Section: Urban Road, Rural Road

- **Cycle Lane**

- A paved area adjacent to and flush with the traffic lane pavement for the movement of cyclists.
- Should be continuous and provide uninterrupted movement.
- Should be physically separated from the main carriageway to ensure comfort and safety.

The minimum width of cycle track should be 2 m.

Table 19: Capacity of Cycle Tracks

Width of Cycle track	Capacity in number of cycles/hour	
	One-way traffic	Two-way traffic
Two lanes (3 m)	250-600	50-250
Three lanes (4 m)	> 600	250-600
Four lanes (5m)	---	> 600

Source: NURS 2076

13.3 Bicycle Tracks

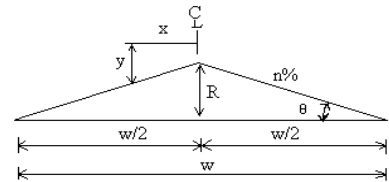
- In all roads with ADT of more than 4000 PCU and movement of bicycles more than 1000 nos/day bicycle tracks should be constructed. The minimum width of each lane of the bicycle track should be 1.2m for each direction of movement.
- The track should be constructed on a separate formation or at least 1 m away from the edge of the roadway.

Source: NRS 2070

3.4 Elements of Cross Section: Urban Road, Rural Road

Camber

- Transverse slope given to the road surface.
- Provided by raising the center of the carriageway with respect to edges.
- The highest point is called crown.
- Expressed in % slope.



Purpose:

- To drain out surface water and protect the bituminous pavement layers as continued contact with water causes stripping of bitumen from the aggregates.
- To quickly dry out the pavement surface and ensure safety.
- To protect sub-grade preventing infiltration of water.

Required camber depends on:

- Amount of rainfall
- Type of pavement

3.4 Elements of Cross Section: Urban Road, Rural Road

Camber

Table 11-3 Camber, %

Pavement type	Cement Concrete	Bituminous	Gravel	Earthen
Camber, %	1.5 to 2.0	2.5	4.0	5.0

Source: NRS 2070

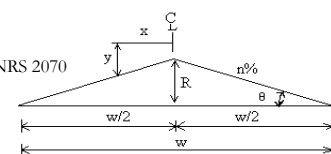


Table 13.1. Recommended camber cross slope

Camber		District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
Carriageway cross slope (%)	Earthen (existing)	5	5	5	5
	Gravel	4	4	4	4
	Bituminous Seal Coat	3	3	-	-

Source: NRRS 2071

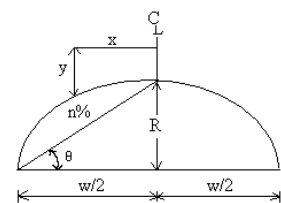
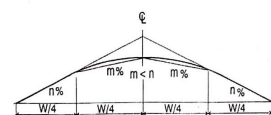
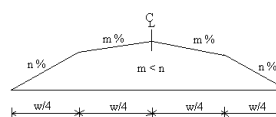


Table 20: Recommended Camber

Surface Type	Camber, %
WBM or gravel	2.5 to 3.5 %
Thin bituminous surfacing	2 to 2.5 %
High type bituminous surfacing or Cement concrete surfacing	1.5 to 2 %

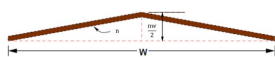
Source: NURS 2076



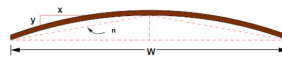
3.4 Elements of Cross Section: Urban Road, Rural Road

Camber

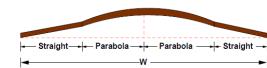
- Excessive camber should be avoided because:
 - Vehicles will tend to tilt and there will be possibilities of overturning and skidding of loaded trucks.
 - Edge of road surface will wear out faster than central part.
 - Vehicles will tend to move along the centerline and the road capacity will be reduced.
 - Formation of cross-ruts.
 - Overtaking operation will be more dangerous.



Straight Line Camber



Parabolic Camber

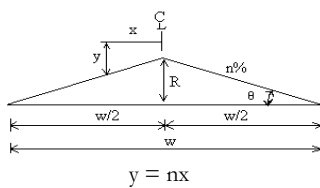


Composite Camber

3.4 Elements of Cross Section: Urban Road, Rural Road

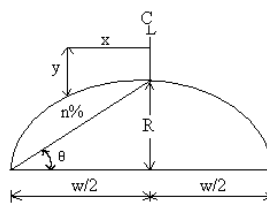
Camber

Straight Line Camber



- Used when very flat camber is provided as in cement concrete pavements.

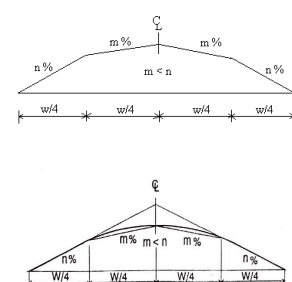
Parabolic Camber



$$y = \frac{2n}{W} x^2$$

- Flatter profile at the middle.
- Provide favorable condition for overtaking at high speed.
- Suitable for roads with high speed traffic.

Composite Camber



- Increases contact area of wheel and decreases intensity of pressure.

3.4 Elements of Cross Section: Urban Road, Rural Road

Camber: Numerical

In a region of heavy rainfall WBM pavement is to be constructed. If the width of the road is 3.75 m, find the height of the crown with respect to the edges. What would be the height of crown with respect to the edges if 7.5 m width bituminous pavement is to be constructed?

Single lanes.

St line camber:
 $y = nx$
 $R = nx$
 $R = n \times \frac{3.75}{2}$
 Considering $n = 3\%$
 $R = 0.03 \times \frac{3.75}{2} = 0.05625$

Bituminous:
 $R = nx$
 $R = n \times \frac{7.5}{2}$
 $R = 0.02 \times \frac{7.5}{2} = 0.075$

Parabolic camber:
 $y = \frac{2n}{w} x^2$
 $R = \frac{2n}{w} \times \left(\frac{w}{2}\right)^2$
 For WBM: $R = \frac{2 \times 0.03}{3.75} \times \left(\frac{3.75}{2}\right)^2 = 0.05625$
 For Bituminous: $R = \frac{2 \times 0.02}{7.5} \times \left(\frac{7.5}{2}\right)^2 = 0.075$

3.4 Elements of Cross Section: Urban Road, Rural Road

Camber: Numerical

In a region of heavy rainfall WBM pavement is to be constructed. If the width of the road is 3.75 m, find the height of the crown with respect to the edges. What would be the height of crown with respect to the edges if 7.5 m width bituminous pavement is to be constructed?

$y = nx$ $R = n \times \frac{W}{2}$ For WBM pavement $R = 0.03 \times \frac{3.75}{2}$ $R = 0.05625$	$y = nx$ $R = n \times \frac{W}{2}$ For bituminous pavement $R = 0.02 \times \frac{7.50}{2}$ $R = 0.075$	$y = \frac{2n}{W} x^2$ $R = \frac{2n}{W} \times \left(\frac{W}{2}\right)^2$ For WBM pavement $R = 0.03 \times \left(\frac{3.75}{2}\right)$ $R = 0.05625$	$y = \frac{2n}{W} x^2$ $R = \frac{2n}{W} \times \left(\frac{W}{2}\right)^2$ For bituminous pavement $R = 0.02 \times \left(\frac{7.5}{2}\right)$ $R = 0.075$
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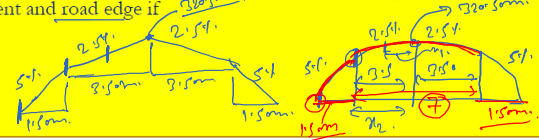
3.4 Elements of Cross Section: Urban Road, Rural Road

Camber: Numerical

The center line of two lane road has an elevation 320.50m. The camber of the pavement is 2.50% and cross slope of shoulder is 5%. Calculate the elevation of pavement at center of lane, edge of pavement and road edge if

- Straight line camber is to be provided.
- Parabolic camber is to be provided.
- Composite camber is to be provided.

Take width of the lane as 3.50m and shoulder width as 1.50m.



Elevation of center of the lane = $320.50 - y_1$
 $= 320.50 - (n \times x_1^2)$
 $= 320.50 - \left[\frac{2.5}{100} \times \left(\frac{3.5}{2} \right)^2 \right]$
 $= 320.456 \dots \text{m}$

Edge of the pavement = $320.50 - n \times x_2^2$
 $= 320.50 - \frac{2.5}{100} \times 3.5^2$
 $= 320.4125 \dots$

Edge of road = $\text{Edge of pavement} - \frac{5}{100} \times 1.5^2$
 $= 320.4125 - \frac{5}{100} \times 1.5^2$
 $= 320.3875 \dots \text{m}$

Elevation of center of lane = $320.50 - y_1$
 $= 320.50 - \frac{2n}{w} \times x_1^2$
 $= 320.50 - 2 \times \frac{2.5}{7 \times 100} \times \left[\frac{3.5}{2} \right]^2$
 $= 320.478 \dots \text{m}$

Edge of pavement = $320.50 - y_2$
 $= 320.50 - \frac{2n}{w} \times x_2^2$
 $= 320.50 - \frac{2 \times 2.5}{7 \times 100} \times \left[\frac{3.5}{2} \right]^2$
 $= 320.4125 \dots \text{m}$

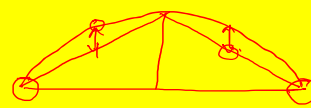
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The center line of two lane road has an elevation 320.50m. The camber of the pavement is 2.50% and cross slope of shoulder is 5%. Calculate the elevation of pavement at center of lane, edge of pavement and road edge if

- Straight line camber is to be provided.
- Parabolic camber is to be provided.
- Composite camber is to be provided.

Take width of the lane as 3.50m and shoulder width as 1.50m.



Straight line

center of lane = $320.456 \dots \text{m}$

Edge of pavement = $320.4125 \dots \text{m}$

Edge of road = $320.3875 \dots \text{m}$

Parabolic

$320.478 \dots \text{m}$

$320.4125 \dots \text{m}$

$320.3875 \dots \text{m}$

Edge of road = $\text{Edge of pavement} - \frac{2n}{w} \times x^2$

Edge of road = $\text{Edge of pavement} - n \times x$
 $= 320.4125 - \frac{5}{100} \times 1.50$
 $= 320.3875 \dots \text{m}$

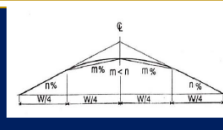
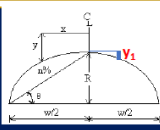
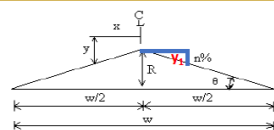
3.4 Elements of Cross Section: Urban Road, Rural Road

Camber: Numerical

The center line of two lane road has an elevation 320.50m. The camber of the pavement is 2.50% and cross slope of shoulder is 5%. Calculate the elevation of pavement at center of lane, edge of pavement and road edge if

- Straight line camber is to be provided.
- Parabolic camber is to be provided.
- Composite camber is to be provided.

Take width of the lane as 3.50m and shoulder width as 1.50m.



Considering straight line camber

a) Elevation of road surface at the center of the lane

$$RL \text{ of crown} - y_1$$

$$RL \text{ of crown} - n \times \frac{w}{4}$$

$$320.50 - 0.025 \times \frac{3.5}{4} = 320.45 \text{ m}$$

b) Elevation at the edge of pavement

$$RL \text{ of crown} - n \times \frac{w}{2} = 320.50 - 0.025 \times \frac{3.5}{2} = 320.41 \text{ m}$$

c) Elevation at the edge of shoulder

$$RL \text{ of edge of pavement} - n \times 1.50$$

$$320.41 - 0.05 \times 1.50 = 320.335 \text{ m}$$

Considering parabolic camber

a) Elevation of road surface at the center of the lane

$$RL \text{ of crown} - y_1$$

$$RL \text{ of crown} - \frac{2n}{w} x^2$$

$$RL \text{ of crown} - \frac{2n}{w} \times \left(\frac{w}{4}\right)^2$$

$$320.50 - 0.025 \times 7 / 8 = 320.478 \text{ m}$$

b) Elevation at the edge of pavement

$$RL \text{ of crown} - \frac{2n}{w} \times \left(\frac{w}{2}\right)^2 = 320.50 - 0.025 \times 7/2 = 320.41 \text{ m}$$

c) Elevation at the edge of shoulder

$$RL \text{ of edge of pavement} - \frac{2n}{w} \times 1.50^2 = 320.41 - 0.075 = 320.335 \text{ m}$$

Considering composite camber

a) Elevation of road surface at the center of the lane

$$RL \text{ of crown} - y_1$$

$$RL \text{ of crown} - \frac{2n}{w} x^2$$

$$RL \text{ of crown} - \frac{2n}{w} \times \left(\frac{w}{4}\right)^2$$

$$320.50 - 0.025 \times 7 / 8 = 320.478 \text{ m}$$

b) Elevation at the edge of pavement

$$RL \text{ of crown} - \frac{2n}{w} \times \left(\frac{w}{2}\right)^2 = 320.50 - 0.025 \times 7/2 = 320.41 \text{ m}$$

c) Elevation at the edge of shoulder

$$RL \text{ of edge of pavement} - n \times 1.50$$

$$= 320.41 - 0.05 \times 1.50 = 320.335 \text{ m}$$

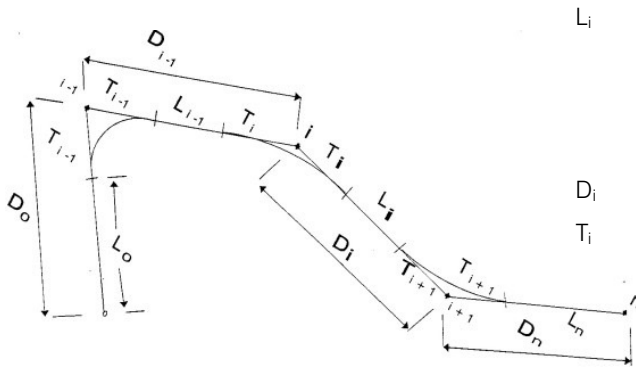
3.5 Elements of Horizontal Alignment

- Definition and types of horizontal curve
- Design of horizontal curve
- Design of elements of horizontal curve
 - Superelevation
 - Extra widening
 - Transition curve
 - Sight distance

3.5 Elements of Horizontal Alignment: Horizontal Curve

Tangent

- Straight line obtained by joining the two successive points of intersections of the two straight traverse lines along the route.

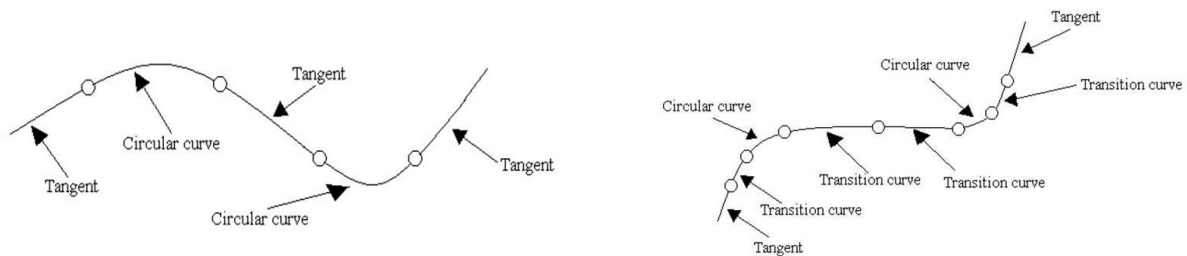


L_i = Net length of tangent between IP_i and IP_{i+1}
 = $D_i - T_{i+1}$ for first line
 = $D_i - T_i$ for last line
 = $D_i - (T_i + T_{i+1})$ for intermediate lines
 D_i = Distance between IP_i and IP_{i+1}
 T_i = Tangent length of i^{th} curve

3.5 Elements of Horizontal Alignment: Horizontal Curve

Horizontal Curve

- Circular curve with or without transition curve.
- Necessary for gradual change in direction when the deviation in horizontal alignment is encountered.
- Should be gradual to secure safety together with comfort to the passengers.

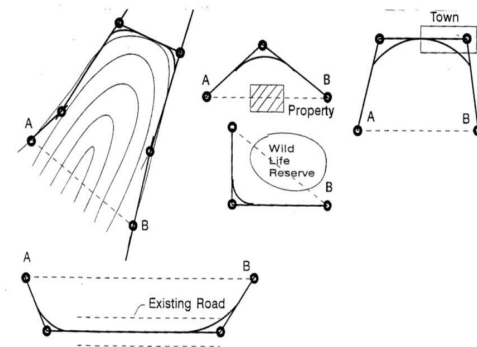


3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Horizontal Curve**

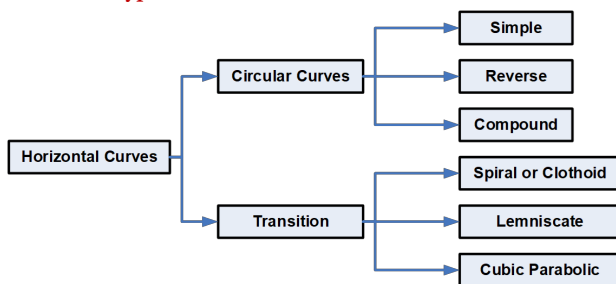
• **Reasons of deviations**

- Topography
- Restriction imposed by property
- To provide access to particular locality
- To avoid structures with religious, cultural and environmental values
- To make use of existing right of ways
- To keep the driver alert.

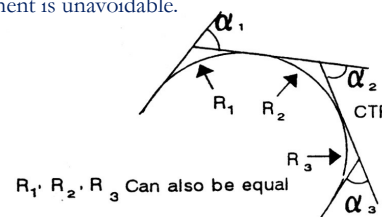


3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Types of Horizontal Curve**

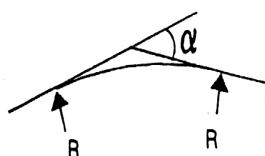


- **Compound Curve:** Adopted where deviation of alignment is unavoidable.

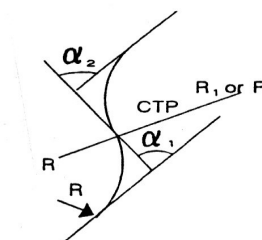


R_1, R_2, R_3 Can also be equal

• **Circular Curve**



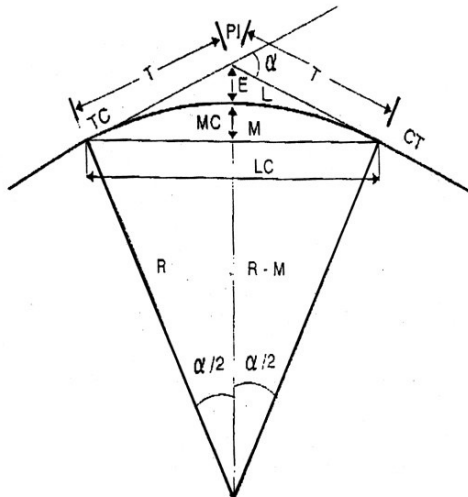
- Simple circular curve: Adopted for slow moving traffic.



- **Reverse curve:** Adopted when there is obstruction on either side of straight alignment usually in mountains.

3.5 Elements of Horizontal Alignment: Horizontal Curve

• Elements of Circular Curve



- PI: Point of Intersection, Apex point
- TC: Tangent to curve, Beginning of curve
- CT: Curve to tangent, End of curve
- MC: Middle point of curve
- α : Angle of deviation
- R: Radius of curve
- T: Tangent length, distance between PI to tangent point
- E: Apex distance, distance from PI to MC
- L: Length of curve
- M: Chord to curve length (Mid ordinate)
- LC: Long chord length.

From the geometry

$$T = R \tan \alpha/2$$

$$E = R (\sec \alpha/2 - 1)$$

$$M = R (1 - \cos \alpha/2)$$

$$L = \frac{\pi R \alpha}{180}$$

$$LC = 2R \sin \alpha/2$$

3.5 Elements of Horizontal Alignment: Horizontal Curve

• Curve: Numerical

While measuring angle by theodolite at a certain deviation point by setting zero along preceding deviation point, the reading was equal to $230^{\circ}40'45''$. The radius of circular curve to be provided was 200m. Calculate the elements of curve.

$$\Delta = 230^{\circ}40'45'' - 180^{\circ} = 50^{\circ}40'45''$$

$$R = 200\text{m}$$

$$T = R \tan \Delta/2 = 200 \times \tan \frac{50^{\circ}40'45''}{2} = 94.70\text{m}$$

$$E = R (\sec \Delta/2 - 1) = 200 \times (\sec \frac{50^{\circ}40'45''}{2} - 1) = 21.29\text{m}$$

$$M = R (1 - \cos \Delta/2) = 19.243\text{m}$$

$$L = \frac{\pi R \Delta}{180} = \frac{\pi \times 200 \times 50^{\circ}40'45''}{180} = 196.92\text{m}$$

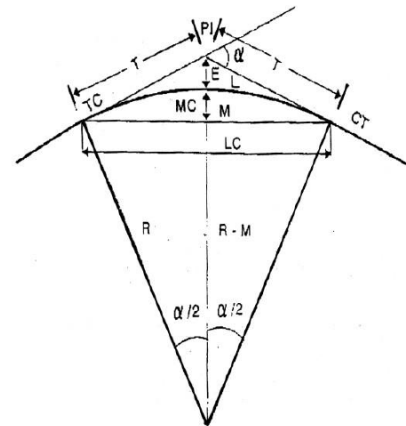
$$LC = 2R \sin \Delta/2 = 171.193\text{m}$$

3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Curve: Numerical**

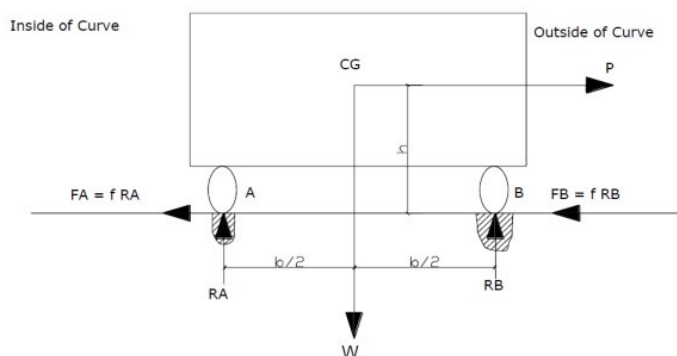
While measuring angle by theodolite at a certain deviation point by setting zero along preceding deviation point, the reading was equal to 230°40'45". The radius of circular curve to be provided was 200m. Calculate the elements of curve.

$T = R \tan \alpha/2$ $E = R (\sec \alpha/2 - 1)$ $M = R (1 - \cos \alpha/2)$ $L = \frac{\pi R \alpha}{180}$ $LC = 2R \sin \alpha/2$	$T = R \tan \alpha/2 = 200 * \tan \frac{50^{\circ}40'45''}{2} = 94.71\text{m}$ $E = R (\sec \alpha/2 - 1) = 200 * (\sec \frac{50^{\circ}40'45''}{2} - 1) = 21.29\text{m}$ $M = R (1 - \cos \alpha/2) = 200 * (1 - \cos \frac{50^{\circ}40'45''}{2}) = 19.24\text{ m}$ $L = \frac{\pi R \alpha}{180} = \frac{\pi * 200 * 50^{\circ}40'45''}{180} = 177\text{ m}$ $LC = 2R \sin \alpha/2 = 2 * 200 * \sin \frac{50^{\circ}40'45''}{2} = 170\text{ m}$
--	---



3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Design of Horizontal Curve**



- P: Centrifugal force, kg
- W: Weight of the vehicle, kg
- RA, RB: Normal reactions of the pavement on the wheels
- FA, FB: Frictional resistance between tire and pavement

Centrifugal force: $P = \frac{Wv^2}{gR}$

- v: Speed of vehicle, m/sec
- R: Radius of the circular curve, m
- g: Acceleration due to gravity, 9.81 m/sec²

Centrifugal ratio/Impact factor: $\frac{P}{W} = \frac{v^2}{gR}$

3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Design of Horizontal Curve**

• **Overtuning effect**

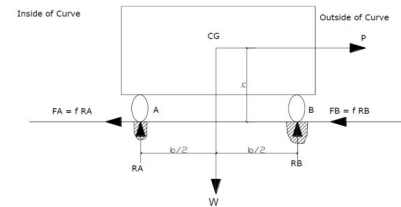
- Tendency of centrifugal force to overturn the vehicle outwards about the outer wheels B.
- Equilibrium/Limiting Condition

$$Ph = W \frac{b}{2}$$

$$\frac{P}{W} = \frac{v^2}{gR} = \frac{b}{2h}$$

- For safety,

$$\frac{b}{2h} > \frac{v^2}{gR}$$



P : Centrifugal force, kg
 W : Weight of the vehicle, kg
 R_A, R_B : Normal reactions of the pavement on the wheels
 F_A, F_B : Frictional resistance between tire and pavement

Centrifugal force: $P = \frac{Wv^2}{gR}$

v : Speed of vehicle, m/sec
 R : Radius of the circular curve, m
 g : Acceleration due to gravity, 9.81 m/sec²

Centrifugal ratio/Impact factor: $\frac{P}{W} = \frac{v^2}{gR}$

3.5 Elements of Horizontal Alignment: Horizontal Curve

• **Design of Horizontal Curve**

• **Skidding effect:**

- The tendency of the vehicles to skid laterally outward due to centrifugal force.
- Equilibrium/Limiting conditions:

$$P = F_A + F_B = f(R_A + R_B) = fW$$

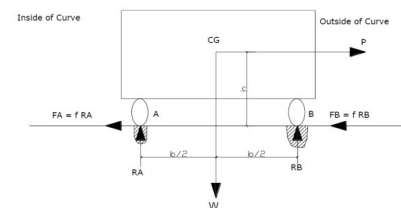
$$\frac{P}{W} = f$$

f is the coefficient of lateral friction

- For safety,

$$f > \frac{v^2}{gR}$$

- If $f < b/2h$, skidding
- If $b/2h < f$, overturning before skidding



P : Centrifugal force, kg
 W : Weight of the vehicle, kg
 R_A, R_B : Normal reactions of the pavement on the wheels
 F_A, F_B : Frictional resistance between tire and pavement

Centrifugal force: $P = \frac{Wv^2}{gR}$

v : Speed of vehicle, m/sec
 R : Radius of the circular curve, m
 g : Acceleration due to gravity, 9.81 m/sec²

Centrifugal ratio/Impact factor: $\frac{P}{W} = \frac{v^2}{gR}$

3.5 Elements of Horizontal Alignment: Horizontal Curve

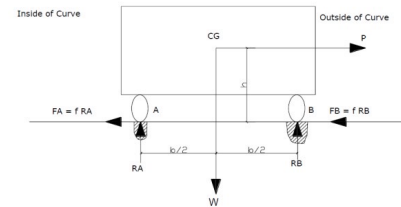
- **Design of Horizontal Curve**

- **Comfort to the passenger**

- When vehicles enters the curved path, the passengers inside are pushed to the sideways (fling) due to the lateral force.
 - The lateral force should not exceed the value at which passenger feels discomfort.

Speed(km/h)	f
120	0.09
100	0.12
80	0.14
60	0.17
40	0.23
30	0.28
20	0.33

Source: NRS 2070



P: Centrifugal force, kg
W: Weight of the vehicle, kg
R_A, R_B: Normal reactions of the pavement on the wheels
F_A, F_B: Frictional resistance between tire and pavement

Centrifugal force:
$$P = \frac{Wv^2}{gR}$$

v: Speed of vehicle, m/sec
R: Radius of the circular curve, m
g: Acceleration due to gravity, 9.81 m/sec²

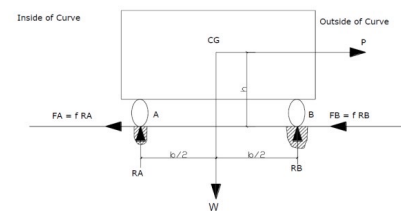
Centrifugal ratio/Impact factor:
$$\frac{P}{W} = \frac{v^2}{gR}$$

3.5 Elements of Horizontal Alignment: Horizontal Curve

- **Design of horizontal curve**

- **Economy in Travel**

- The lateral force on the wheels causes slipping of wheels and rotation of wheels around the vertical axis called yawing.
 - This causes sharp rise in engine horse power consumption and wear and tear of tires.



P: Centrifugal force, kg
W: Weight of the vehicle, kg
R_A, R_B: Normal reactions of the pavement on the wheels
F_A, F_B: Frictional resistance between tire and pavement

Centrifugal force:
$$P = \frac{Wv^2}{gR}$$

v: Speed of vehicle, m/sec
R: Radius of the circular curve, m
g: Acceleration due to gravity, 9.81 m/sec²

Centrifugal ratio/Impact factor:
$$\frac{P}{W} = \frac{v^2}{gR}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Radius of Horizontal Curve**

- Ruling radius (Maximum e and f):

$$R_{ruling} = \frac{v^2}{g(e+f)}$$

- Minimum radius for different combination of design speed and super elevation:

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Radius of Horizontal Curve**

- Radius of Curves from Night Visibility Considerations
 - Half of the road crashes occurs at night.
 - Visibility is attained by headlights.

From figure, $\beta = 2\alpha$

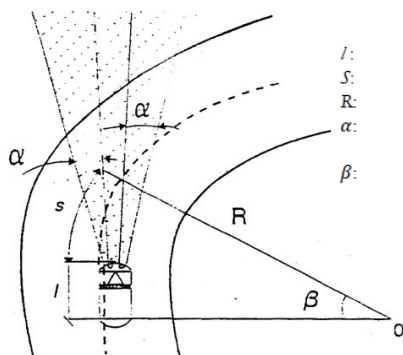
$$(S + l) = R\beta \times \frac{\pi}{180}$$

$$R = \frac{(S+l)180}{\pi\beta}$$

$$R = \frac{(S+l)180}{\pi \times 2\alpha} = \frac{28.6(S+l)}{\alpha}$$

Since $l \ll S$,

$$R \approx \frac{30S}{\alpha}$$



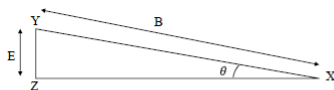
- l : Length of the wheelbase
- S : Distance of the object from driver
- R : Radius of curve required to see the object
- α : Angle of headlight beam dispersion on horizontal plane
- β : Angle subtended by an arc of a length equal (S+l)

- α is 2° approximately.
- For sight distance of 100m to 300m, radius required is 1500m to 4500m.
- Often not possible in hill roads.

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**

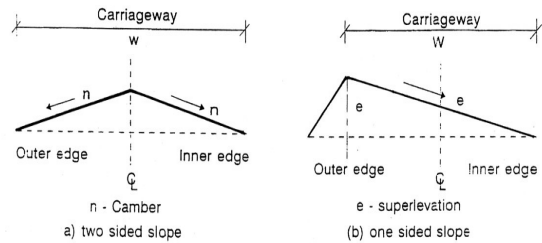
- Transverse slope provided at the horizontal curve to counteract the centrifugal force by raising the outer edge of the pavement with respect to the inner edge.



$$e = \frac{YZ}{XZ} = \tan \theta$$

θ is very small,

$$\therefore e = \tan \theta \approx \sin \theta = \frac{E}{B}$$



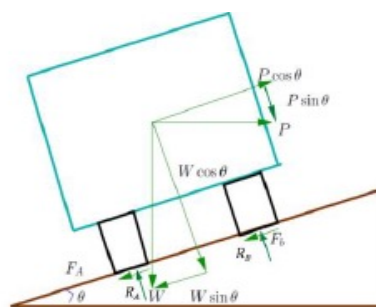
Two forms of road surface

- Superelevation rate (e) is measured as relative elevation of the outer edge of the pavement to the width of the pavement.

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**

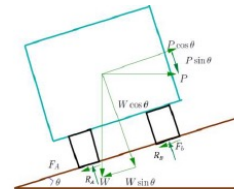
- Analysis of Superelevation



- P : Centrifugal force, kg
- W : Weight of the vehicle, kg
- R_A, R_B : Normal reactions of the pavement on the wheels
- F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - Analysis of Superelevation



P : Centrifugal force, kg
 W : Weight of the vehicle, kg
 R_A, R_B : Normal reactions of the pavement on the wheels
 F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

❖ Resolving all the forces perpendicular to the road surface:

$$R_A + R_B = P \sin \theta + W \cos \theta$$

❖ Resolving all the forces parallel to the road surface:

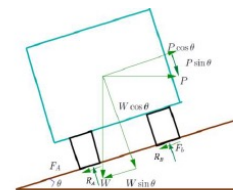
$$P \cos \theta = W \sin \theta + F_A + F_B$$

$$= W \sin \theta + f R_A + f R_B = W \sin \theta + f (R_A + R_B)$$

where f : Coefficient of lateral friction

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - Analysis of Superelevation



P : Centrifugal force, kg
 W : Weight of the vehicle, kg
 R_A, R_B : Normal reactions of the pavement on the wheels
 F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

So,

$$P \cos \theta = W \sin \theta + f (P \sin \theta + W \cos \theta)$$

$$\Rightarrow P (\cos \theta - f \sin \theta) = W (\sin \theta + f \cos \theta)$$

$$\Rightarrow \frac{P}{W} = \frac{\sin \theta + f \cos \theta}{\cos \theta - f \sin \theta} = \frac{\tan \theta + f}{1 - f \tan \theta} = \frac{e + f}{1 - fe}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - Analysis of Superelevation

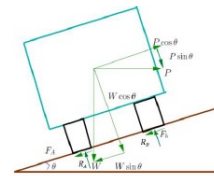
For design, $f = 0.15$ maximum $e = 7\%$, so

$$1 - fe = 1 - 0.15 * 0.07 = 0.9895 \approx 1$$

Therefore,
$$\frac{P}{W} = e + f = \frac{v^2}{gR}$$

Where,

- e : Rate of super elevation
- f : Coefficient of lateral friction 0.15
- v : Speed of vehicle in m/sec
- R : Radius of the curve in m
- g : Acceleration due to the gravity 9.81 m/sec^2



- P : Centrifugal force, kg
- W : Weight of the vehicle, kg
- R_A, R_B : Normal reactions of the pavement on the wheels
- F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - Analysis of Superelevation

If speed of the vehicle is represented as V kmph

$$e + f = \frac{(0.278V)^2}{9.81R} = \frac{V^2}{127R}$$

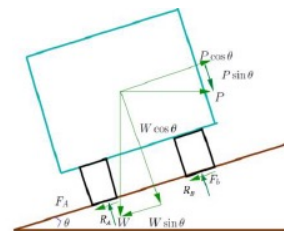
❖ Case I: If $f=0$, $e = \frac{V^2}{127R}$

- Pressures on both the wheels of the vehicle become equal.
- Equilibrium superelevation, very high

❖ Case II: If $e=0$, $f = \frac{V^2}{127R}$

- Speed should be restricted to

$$V = \sqrt{127fR}$$



- P : Centrifugal force, kg
- W : Weight of the vehicle, kg
- R_A, R_B : Normal reactions of the pavement on the wheels
- F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

❖ Case III: If $e=0.07$, $f = 0.15$

- Speed should be restricted to

$$V_a = \sqrt{127R(e + f)}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking**

• **Analysis of Superelevation**

❖ Resolving all the forces perpendicular to the road surface:

$$R_A + R_B = P \sin \theta + W \cos \theta$$

❖ Resolving all the forces parallel to the road surface:

$$P \cos \theta = W \sin \theta + F_A + F_B$$

$$= W \sin \theta + fR_A + fR_B = W \sin \theta + f(R_A + R_B)$$

where f : Coefficient of lateral friction

So,

$$P \cos \theta = W \sin \theta + f(P \sin \theta + W \cos \theta)$$

$$\Rightarrow P(\cos \theta - f \sin \theta) = W(\sin \theta + f \cos \theta)$$

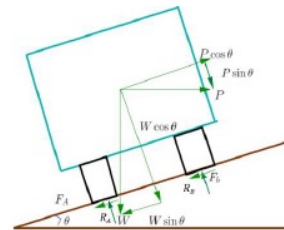
$$\Rightarrow \frac{P}{W} = \frac{\sin \theta + f \cos \theta}{\cos \theta - f \sin \theta} = \frac{\tan \theta + f}{1 - f \tan \theta} = \frac{e + f}{1 - fe}$$

For design, $f = 0.15$ maximum $e = 7\%$, so
 $1 - fe = 1 - 0.15 \cdot 0.07 = 0.9895 \approx 1$

Therefore, $\frac{P}{W} = e + f = \frac{v^2}{9R}$

Where,

- e : Rate of super elevation
- f : Coefficient of lateral friction 0.15
- v : Speed of vehicle in m/sec
- R : Radius of the curve in m
- g : Acceleration due to the gravity 9.81 m/sec²



- P : Centrifugal force, kg
- W : Weight of the vehicle, kg
- R_A, R_B : Normal reactions of the pavement on the wheels
- F_A, F_B : Frictional resistance between tire and pavement acting transversely along the pavement surface towards the centre of the curve.

If speed of the vehicle is represented as V kmph

$$e + f = \frac{(0.278V)^2}{9.81R} = \frac{v^2}{127R}$$

❖ Case II: If $e=0, f = \frac{v^2}{127R}$

• Speed should be restricted to

$$V = \sqrt{127fR}$$

❖ Case I: If $f=0, e = \frac{v^2}{127R}$

- Pressures on both the wheels of the vehicle become equal.
- Equilibrium superelevation, very high

❖ Case III: If $e=0.07, f=0.15$

• Speed should be restricted to

$$V_a = \sqrt{127R(e + f)}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking**

• **Maximum Superelevation**

- For fast moving vehicles, higher superelevation may provide easy conditions but causes lots of inconvenience to slow moving and specially heavily loaded trucks.

Maximum superelevation to be provided is limited to:

- In plain and rolling terrain 7%
- In snow bound areas 7%
- In hilly areas not bound by snows 10%

Source: NRS 2070

Maximum Super Elevation Value

In plain terrain, non-motorized vehicles travel with high centre of gravity, so the maximum value of super elevation shall be limited to the following values;

Terai	7%
Hill	10%

Source: NRRS 2071

• **Minimum Superelevation**

Minimum value of superelevation should be equal to the rate of camber of the pavement. Source: NRS 2070

The designer should aim at providing flatter super elevation but it should not be less than the camber.

Source: NRRS 2071

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Design of Superelevation**
 - For fast moving vehicles, higher superelevation without considering coefficient of friction is reasonable.
 - For slow moving vehicles lower superelevation considering coefficient of friction is safe..

Superelevation is provided on horizontal curves. Value of superelevation is calculated using following formula:

$$e = \frac{V^2}{127R} - f \dots \dots \dots 11-1$$

Where,
 e-value of superelevation, m/m
 R-Radius of horizontal curve
 V-Design Speed, km/h
 f-co-efficient of lateral friction, depends on the vehicle speed and taken as in Table 24-4

$e = \frac{v^2}{225R} \dots \dots \dots$ Equation 6

Where, V is the speed in Km/h and R is the radius of the curve.

Super elevation obtained from the expression should be limited to 7 percent. However, on the urban sections with frequent intersections, it will be desirable to limit the super elevation to 4 percent for convenience in construction and for facilitating easy and safe turning movement of vehicles.

Table 24-4: Coefficient of lateral friction

Speed(km/h)	f
120	0.09
100	0.12
80	0.14
60	0.17
40	0.23
30	0.28
20	0.33

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Design Procedure (IRC):**
 - Step 1: Calculate the superelevation for 75% design speed without considering coefficient of friction f.

$$e = \frac{(0.75v)^2}{gR} \text{ or } \frac{(0.75V)^2}{127R}$$
 - Step 2: If the calculated value of $e < \frac{1}{15}$ (7%), the value so obtained is provided.
 If $e > 7\%$, provide a maximum e of 7% and proceed to step 3 and 4.
 - Step 3: Check the coefficient of lateral friction for the maximum $e = 7\%$.

$$f = \frac{V^2}{127R} - e$$
 - If calculated $f < 0.15$, the maximum e of 7% is safe for the design speed. If $f > 0.15$, proceed to step 4.
 - Step 4: Calculate the allowable speed for $e = 7\%$ and $f = 0.15$.

$$V_a = \sqrt{127 R(e + f)}$$

If $V_a < \text{design speed}$, the speed is limited to V_a and needs a warning sign and speed limit regulations.

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

The design speed of a highway with mixed traffic is 75kmph and radius of horizontal curve is 190m. Design superelevation for the highway. If the maximum superelevation of 7% is not to be exceeded, calculate the maximum allowed speed on this horizontal curve. Assume coefficient of lateral friction is 0.15.

Handwritten solution steps:

$$e = \frac{(0.75v)^2}{127R}$$

$$= \frac{(0.75 \times 75)^2}{127 \times 190}$$

$$= 0.1311 > 0.07$$

Since $e > 0.07$, we use $e = 0.07$.

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

$$0.07 + f = \frac{v^2}{127R}$$

$$f = \frac{v^2}{127 \times 190} - 0.07$$

$$= 0.1631 > 0.15$$

Since $f > 0.15$, we use $f = 0.15$.

$$V_a = \sqrt{127R(e+f)}$$

$$= \sqrt{127 \times 190 \times (0.07 + 0.15)}$$

$$= 72.86 \text{ kmph}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

The design speed of a highway with mixed traffic is 75 kmph and radius of horizontal curve is 190 m. Design superelevation for the highway. If the maximum superelevation of 7% is not to be exceeded, calculate the maximum allowed speed on this horizontal curve. Assume coefficient of lateral friction is 0.15.

Step 1: Calculate the superelevation for 75% design speed without considering coefficient of friction f .

$$e = \frac{(0.75v)^2}{gR} \text{ or } \frac{(0.75V)^2}{127R}$$

$$e = \frac{(0.75 \times 75)^2}{127 \times 190}$$

$$e = 0.13$$

Step 2: If the calculated value of $e < \frac{1}{15}$ (7%), the value so obtained is provided. If $e > 7\%$, provide a maximum e of 7%.

Take $e = 0.07$

Step 3: Check the coefficient of lateral friction for the maximum $e = 7\%$.

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

$$f = \frac{(75)^2}{127 \times 190} - 0.07$$

$$f = 0.16$$

If calculated $f < 0.15$, the maximum e of 7% is safe for the design speed. If $f > 0.15$, proceed to step 4.

Step 4: Calculate the allowable speed for $e = 7\%$ and $f = 0.15$.

$$V_a = \sqrt{127R(e+f)}$$

$$V_a = \sqrt{127 \times 190 \times (0.07 + 0.15)}$$

$$V_a = 72.86 \text{ kmph}$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

Single lane $\rightarrow 3.75m$ two lane road $= 7m$ Introduce rate $= 5.5m$

A two lane road with a design speed 80kmph has horizontal curve of radius 480m. Design the rate of superelevation for mixed traffic. By how much should the outer edges of the pavement be raised with respect to the inner edge, if the width of the pavement at the horizontal curve is 7.50 m.

$E = e \times B$
 \uparrow width of pavement

$f = 0$ $e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 80)^2}{127 \times 480} = 0.059 < 0.07$

Adopt $e = 0.059$

$E = 0.059 \times 7.5 = 0.4429 \text{ m}$

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

A two lane road with a design speed 80kmph has horizontal curve of radius 480 m. Design the rate of superelevation for mixed traffic. By how much should the outer edges of the pavement be raised with respect to the inner edge, if the width of the pavement at the horizontal curve is 7.50 m.

Step 1: Calculate the superelevation for 75% design speed without considering coefficient of friction f .

$$e = \frac{(0.75v)^2}{gR} \text{ or } \frac{(0.75V)^2}{127R}$$

$$e = \frac{(0.75 \cdot 80)^2}{127 \cdot 480}$$

$$e = 0.059$$

Step 2: If the calculated value of $e < \frac{1}{15}$ (7%), the value so obtained is provided. If $e > 7\%$, provide a maximum e of 7%.

Take $e = 0.059$

Step 3: Raising of outer edge with respect to the inner edge of pavement.

$$E = eB$$

$$E = 0.059 \cdot 7.50$$

$$E = 0.44 \text{ m}$$

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

$R=140m$; $V=60kmph$; $f=0.15$

The radius of circular curve is 140 m, the design speed is 60kmph and the design coefficient of lateral friction is 0.15.

- a) Calculate the superelevation required if full lateral friction is assumed to develop.
- b) Calculate the coefficient of friction needed if no superelevation is provided.
- c) Calculate the equilibrium superelevation if the pressure on inner and outer wheels should be equal.

a) $e+f = \frac{v^2}{127R}$
 \downarrow
 0.15
 $e+0.15 = \frac{60^2}{127 \times 140}$
 $e = 0.0524$

b) $e+f = \frac{v^2}{127R}$
 $f = \frac{60^2}{127 \times 140}$
 $= 0.2025$

c) $f=0$
 $e+f = \frac{v^2}{127R}$
 $e = \frac{60^2}{127 \times 140}$
 $= 0.2025$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• **Superelevation/Cant/Banking: Numerical**

The radius of circular curve is 140 m, the design speed is 60 kmph and the design coefficient of lateral friction is 0.15.

- a) Calculate the superelevation required if full lateral friction is assumed to develop.
- b) Calculate the coefficient of friction needed if no superelevation is provided.
- c) Calculate the equilibrium superelevation if the pressure on inner and outer wheels should be equal.

a) For full lateral friction to develop

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

$$e + f = \frac{60^2}{127 \times 140}$$

$$e = \frac{60^2}{127 \times 140} - 0.15$$

$$e = 0.052$$

b) When no superelevation is provided

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

$$f = \frac{60^2}{127 \times 140}$$

$$f = 0.202$$

c) Condition of equilibrium

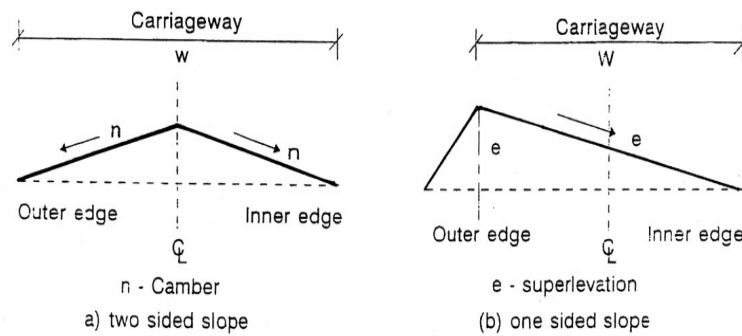
$$e = \frac{v^2}{127R}$$

$$e = \frac{60^2}{127 \times 140}$$

$$e = 0.202$$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**



- The provision of superelevation from cambered to full superelevation should be made gradually.

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

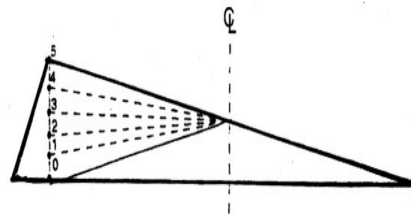
- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Elimination of crown of the cambered section
 - Rotation of the pavement cross section to attain full superelevation

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Elimination of crown of the cambered section
 - By rotation of the outer surface
 - The outer half of the cross slope is rotated about the crown at a desired rate such that the surface falls on the same plane as the inner half,

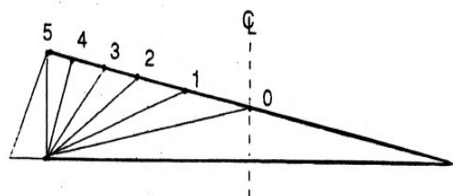


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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Elimination of crown of the cambered section
 - By shifting position of crown (Diagonal crown method):
 - The crown is progressively shifted outwards, thus increasing the width of the inner half of cross-section progressively.

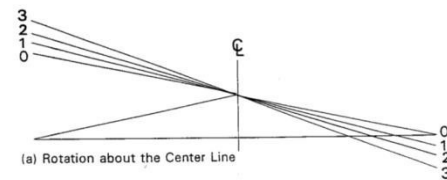
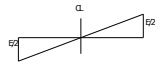


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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Rotation of the pavement cross section to attain full superelevation
 - Rotation of roadway surface about its center line
 - Full superelevation is attained by depressing the inner edge and raising the outer edge.
 - Balanced earthwork and least distortion to center line.

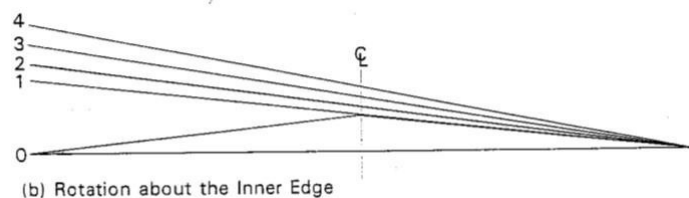


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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Rotation of the pavement cross section to attain full superelevation
 - Rotation of roadway surface about its inner edge:
 - Inner edge is taken as axis of rotation. Outer edge is raised.
 - Provided in very flat terrain with high rainfall to prevent damage.

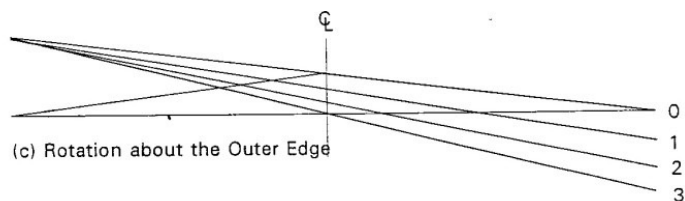


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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Involves
 - Rotation of the pavement cross section to attain full superelevation
 - Rotation of roadway surface about its outer edge:
 - Outer edge is taken as axis of rotation. Inner edge is depressed.

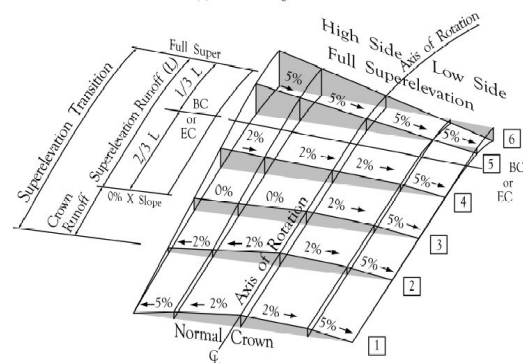


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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Superelevation/Cant/Banking**
 - **Method of Providing Superelevation**
 - Selection of method depends on rainfall and terrain type.
 - The crowned cross-slope should be changed to single cross-slope before start of the circular curve and full superelevation should be provided at the start of the circular curve.
 - Where transition curve cannot be provided for some reasons, $2/3^{\text{rd}}$ of the superelevation will be attained on the straight section before the start of the circular curve and balance $1/3^{\text{rd}}$ on the curve (IRC).



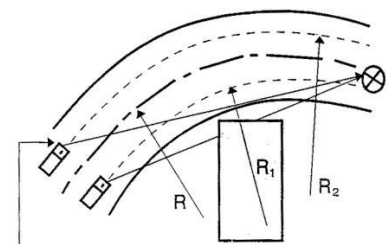
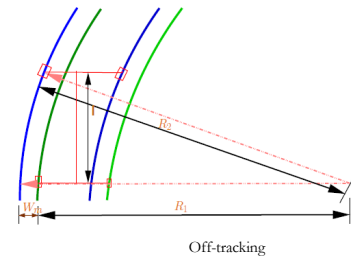
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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- It is common to widen the pavement for small radius horizontal curve.
- The increased width is called extra widening of the pavement.
 - Reasons of providing extra width
 - Off-tracking due to rigidity of wheelbase
 - Tendency of driver to use outer lane for greater visibility
 - Transverse skidding at higher speeds
 - Psychological tendency to maintain greater clearance in cu with safety considerations
 - Trailer units require larger width at the curves



Tendency to use outer lane for greater visibility

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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Amount of extra widening to be provided depends on:
 - Length of wheel base of the vehicle 'l'
 - Radius of the curve 'R'
 - Psychological factor

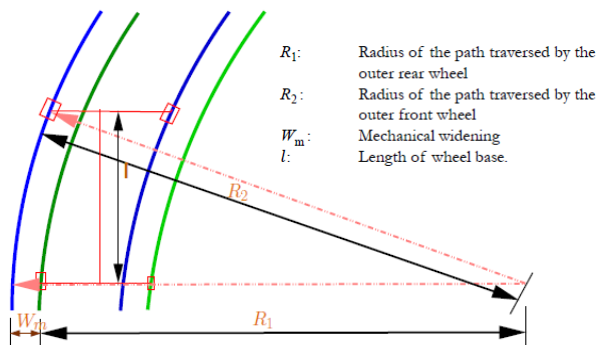
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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Analysis of Extra Widening
 - Mechanical Widening
 - The widening required to account for the off-tracking



$$R_2 = R_1 + W_m$$

$$R_2^2 = R_1^2 + l^2 = (R_2 - W_m)^2 + l^2$$

$$R_2^2 = R_2^2 - 2R_2W_m + W_m^2 + l^2$$

$$2R_2W_m - W_m^2 = l^2$$

$$W_m = \frac{l^2}{2R_2 - W_m}$$

$$R_2 \cong R_1 \cong R \text{ (Mean radius) and } W_m \ll R:$$

$$W_m = \frac{l^2}{2R}$$

For road with n lanes:

$$W_m = \frac{nl^2}{2R}$$

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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Analysis of Extra Widening
 - Psychological Widening
 - Widening provided for psychological reasons: Tendency of drivers to drive near outer edge of pavement in curves, tendency of drivers to keep greater clearance for crossing and overtaking.
 - Empirical relation proposed by IRC:

$$W_{psy} = \frac{V}{9.5\sqrt{R}}$$

V : Design speed in Kmph
 R : Radius of curve (m)

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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Analysis of Extra Widening

- Total Widening (W_e) required on a horizontal curve is the sum of mechanical widening and psychological widening and is given by:

$$W_e = W_m + W_{psy}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

- n : number of traffic lanes.
- l : Length of wheelbase in m.
6.1m
- V : Design speed, kmph
- R : Radius of horizontal curve, m.

3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

Table 9-4 Extrawidening on curves

Radius of curve,m		20	20-40	40-60	60-100	100-300	>300
Extra width,m	Single lane road	0.9	0.6	0.6	Nil	Nil	Nil
	Double lane road	1.5	1.5	1.2	0.9	0.6	Nil
	Multi lane(n-lane) road	0.75n	0.75n	0.6n	0.45n	0.3n	Nil

Source: NRS 2070

For single lane roads, only mechanical widening is required for low traffic speed.

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

Where,

W = Widening, m

L = length of wheel base of longest vehicle (m)

R = Radius of horizontal curve, m

The recommended increase in width is given in Table 10.2 below

Table 10.2-Recommended Minimum Widening for Single Lane Road

Curve Radius (m)	Up to 20	21-60	Above 60
Increase in width (for 3 m carriageway)(m)	1.5	0.6	Nil
Increase in width (for 3.75 m carriageway),(m)	0.9	0.6	Nil

Source: NRRS 2071

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• Extra Widening: Numerical

width of road

Find the total pavement width required for four lane highway on a horizontal curve of radius 200 m. The design speed is 50 kmph and length of the wheel base of vehicle is 6.1 m.

No of lanes = 4.
 length of carriage way = $n \times T_w$
 $= 4 \times 3.5$
 $= 14m.$
on curve.
Extra widening.
 $W_e = W_m + W_{psy}$

$W_m = \frac{n \times l^2}{2R} = \frac{4 \times 6.1^2}{2 \times 200}$
 $= 0.3721m.$
 $W_{psy} = \frac{V}{9.5\sqrt{R}} = \frac{50}{9.5\sqrt{200}} = 0.3721.$
 $W_e = W_m + W_{psy} = 0.3721 + 0.3721 = 0.7442m.$
 Total width of pavement on curve = $14 + 0.7442$
 $= 14.7442m.$

$n \times T_w + W_e$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

• Extra Widening: Numerical

Find the total pavement width required for four lane highway on a horizontal curve of radius 200 m. The design speed is 50 kmph and length of the wheel base of vehicle is 6.1 m.

$$W_e = W_m + W_{psy}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

- n : number of traffic lanes.
- l : Length of wheelbase in m.
6.1m
- V : Design speed, kmph
- R : Radius of horizontal curve, m.

$W_e = W_m + W_{psy}$
 $W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$
 $W_e = \frac{4 \times 6.1^2}{2 \times 200} + \frac{50}{9.5\sqrt{200}}$
 $W_e = 0.372 + 0.372$
 $W_e = 0.74 \text{ m}$

Total Width of the pavement = $nT_w + W_e$
 $= 4 \times 3.50 + 0.74$
 $= 14.74 \text{ m}$

3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- Extra Widening: Numerical

Calculate the extra widening required for a pavement of width 7m on a horizontal curve of radius 200m if the longest wheel base of vehicle expected on the road is 6.50m. Design speed is 65kmph.

$W = 7\text{m}$
 $R = 200\text{m}$
 $l = 6.50\text{m}$
 $V = 65\text{kmph}$

$W_e = W_m + W_{psy}$
 $= \frac{n \times l^2}{2 \times R} + \frac{V}{9.5 \times \sqrt{R}}$
 $= \frac{2 \times 6.5^2}{2 \times 200} + \frac{65}{9.5 \times \sqrt{200}}$
 $= 0.695 \text{ m}$

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- Extra Widening: Numerical

Calculate the extra widening required for a pavement of width 7 m on a horizontal curve of radius 200 m if the longest wheel base of vehicle expected on the road is 6.50 m. Design speed is 65 kmph.

$$W_e = W_m + W_{psy}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

n : number of traffic lanes.
 l : Length of wheelbase in m.
 6.1m
 V : Design speed, kmph
 R : Radius of horizontal curve, m.

$$W_e = W_m + W_{psy}$$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$W_e = \frac{2 \times 6.5^2}{2 \times 200} + \frac{65}{9.5\sqrt{200}}$$

$$W_e = 0.21 + 0.48$$

$$W_e = 0.69 \text{ m}$$

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3.5 Elements of Horizontal Alignment: Superelevation/Cant/Banking

- **Extra Widening: Numerical**

Find out the total width of pavement on a horizontal curve for a new highway with a ruling minimum radius if the speed of slow moving vehicle is 80 kmph. The highway width is 7.0m and the length of wheel base is 6.1m.

$V = 80 \text{ kmph.}$ $L = 6.1 \text{ m.}$ $W = 7 \text{ m.}$	$\text{Total width} = W + W_e$ $= 7 + W_e$ $W_e = W_m + W_{py.}$ $= \frac{n \times L^2}{2R} + \frac{V}{9.5\sqrt{R}}$ $= \frac{2 \times 6.1^2}{2 \times R} + \frac{80}{9.5\sqrt{R}}$ $= 0.7188 \text{ m.}$	$R = \frac{V^2}{127(e+f)}$ $e = 0.07$ $f = 0.15$ $R = \frac{V^2}{127(0.07+0.15)}$ $= 229.06 \text{ m.}$	Total width $= 7 + 0.7188 \text{ m.}$ $= 7.7188 \text{ m.}$
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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Methods of Introducing Extra Widening

- On curves with Transition Curve

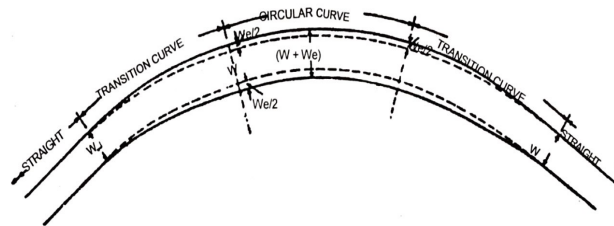
- Introduced from the beginning of the Transition Curve (TP)
- Increased at uniform rate till the full value of widening is reached at the end of the transition curve.
- The full value is continued throughout the circular curve.
- Decreased gradually along the length of transition curve.

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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**
 - Methods of Introducing Extra Widening
 - On curves with Transition Curve
 - Case I: When $300\text{ m} > R > 60\text{ m}$ → on either side of the curve.

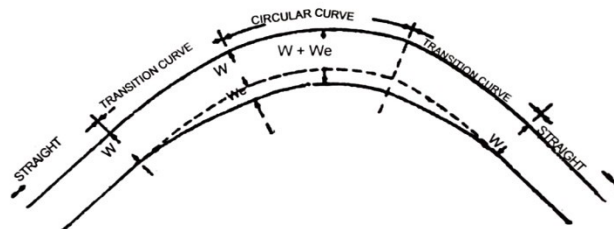


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3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**
 - Methods of Introducing Extra Widening
 - On curves with Transition Curve
 - Case II: Sharp Curves ($R: 30 - 60\text{ m}$) of hill roads on single lane roads having radius less than 150 m → on the side of the cut.



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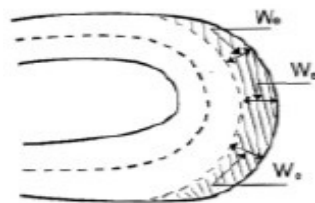
3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Methods of Introducing Extra Widening

- On curves with Transition Curve

- Case III: On mountainous roads with very small radius $r = 20 - 30$ m, vehicles with long wheelbase cannot keep within the inner half of the carriageway. In this case, extra width should be preferably be applied fully on the outside.



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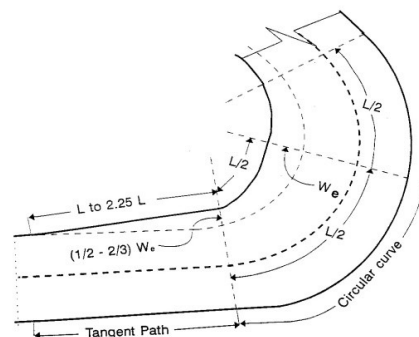
3.5 Elements of Horizontal Alignment: Extra Widening

- **Extra Widening**

- Methods of Introducing Extra Widening

- On curves without Transition Curve:

- $\frac{1}{2} W_e$ to $\frac{2}{3} W_e$ is provided before the start of the curve over L to $2.25L$ in straight part and the remaining is provided on the circular curve.



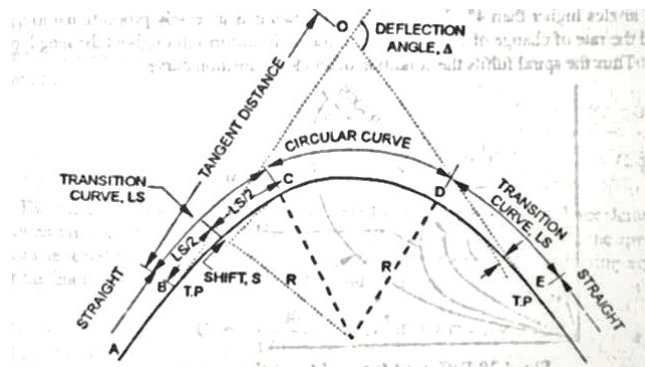
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3.5 Elements of Horizontal Alignment: Transition Curve

- **Transition Curve**

- Transition curve has a radius that decrease from infinity at the tangent point to a designed radius of the circular curve.
- It is also called easement curve.



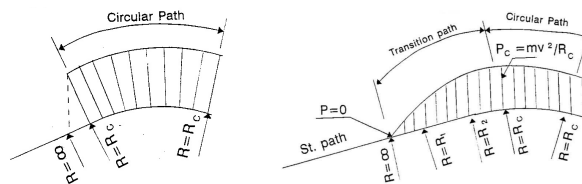
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3.5 Elements of Horizontal Alignment: Transition Curve

- **Transition Curve**

- Centrifugal force diagram without transition curve and with transition curve



- Objectives:

- To introduce gradually the centrifugal force avoiding a sudden jerk on the vehicle.
- To enable the driver turn his vehicle gradually for his/her own comfort and security.
- To introduce gradually designed superelevation and extra widening of the pavement.
- To improve the aesthetic appearance of the road.

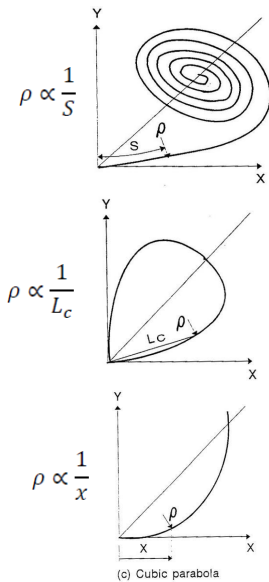
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3.5 Elements of Horizontal Alignment: Transition Curve

- **Types of Transition Curve**

- Spiral or Clothoid
 - Radius inversely proportional to its length.
 - Ideal shape for horizontal alignment of highway easy for field implementation.
- Bernoulli's Lemniscates
 - Radius inversely proportional to length of chord.
 - The decrease in radius is not uniform beyond 30 degrees deflection angle.
- Cubic Parabola
 - Radius inversely proportional to its abscissa.
 - Used in railways.



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3.5 Elements of Horizontal Alignment: Transition Curve

- **Transition Curve**

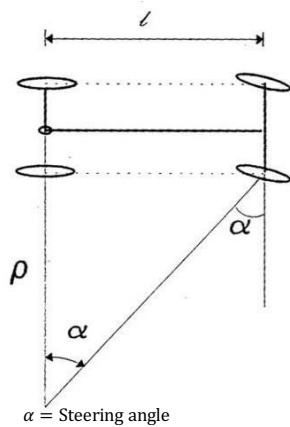
- Ideal shape of transition curve for horizontal alignment
 - Rate of introduction of centrifugal force
 - Rate of change of centrifugal acceleration
 - Should be consistent

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3.5 Elements of Horizontal Alignment: Transition Curve

• Equation of Steering Curve



▪ Assumptions:

- The speed at approach does not vary
- Driver steers the wheels of the vehicle with constant angular velocity.

▪ The vehicle is at two types of motion:

- Translational motion characterized by speed v

$$v = \frac{ds}{dt}$$

where, s = distance traveled along the transition curve

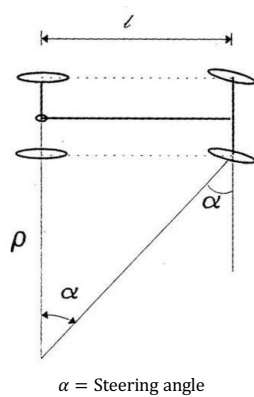
- Rotary motion characterized by angular speed w

$$w = \frac{d\alpha}{dt}$$

where, α = steering angle

3.5 Elements of Horizontal Alignment: Transition Curve

• Equation of Steering Curve



$$\tan \alpha = \frac{l}{\rho} \rightarrow \alpha = \tan^{-1} \frac{l}{\rho}$$

Since $l \ll \rho$, $\alpha = \frac{l}{\rho}$

Taking first derivative with respect to ρ

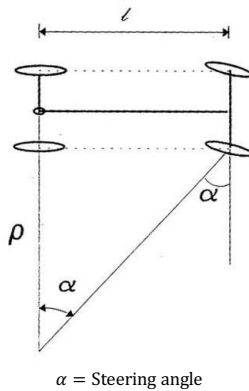
$$d \alpha = -\frac{l}{\rho^2} d\rho \rightarrow \frac{d\alpha}{dt} = -\frac{l}{\rho^2} \frac{d\rho}{dt}$$

$$\rightarrow w = -\frac{l}{\rho^2} \frac{d\rho}{dt}$$

$$\therefore ds = -\frac{lv}{w} \frac{d\rho}{\rho^2}$$

3.5 Elements of Horizontal Alignment: Transition Curve

- Equation of Steering Curve



Assuming constant angular velocity of w_0 :

Integrating both sides:

$$S = \frac{lv}{w_0\rho} + K$$

For $S = 0, \rho = \infty$

$$K = 0, S = \frac{lv}{w_0\rho}$$

$$\text{For } C = \frac{lv}{w_0},$$

$$S = \frac{C}{\rho}, \rho = \frac{C}{S} \rightarrow \rho \propto \frac{1}{S}$$

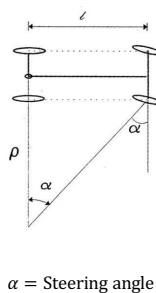
Spiral is the most appropriate curve for transition curve.

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3.5 Elements of Horizontal Alignment: Transition Curve

- Equation of Steering Curve



$$\tan \alpha = \frac{l}{\rho} \rightarrow \alpha = \tan^{-1} \frac{l}{\rho}$$

$$\text{Since } l \ll \rho, \alpha = \frac{l}{\rho}$$

Taking first derivative with respect to ρ

$$d\alpha = -\frac{l}{\rho^2} d\rho \rightarrow \frac{d\alpha}{dt} = -\frac{l}{\rho^2} \frac{d\rho}{dt}$$

$$\rightarrow w = -\frac{l}{\rho^2} \frac{d\rho}{dt}$$

$$\therefore ds = -\frac{lv}{w} \frac{d\rho}{\rho^2}$$

Assuming constant angular velocity of w_0 :

Integrating both sides:

$$S = \frac{lv}{w_0\rho} + K$$

For $S = 0, \rho = \infty$

$$K = 0, S = \frac{lv}{w_0\rho}$$

$$\text{For } C = \frac{lv}{w_0},$$

$$S = \frac{C}{\rho}, \rho = \frac{C}{S} \rightarrow \rho \propto \frac{1}{S}$$

Spiral is the most appropriate curve for transition curve.

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3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of transition curve is designed for
 - Rate of change of centrifugal acceleration to be developed gradually.
 - Rate of change of super elevation to be reasonable.
 - Minimum length requirements.

(Maximum of the length obtained for the three criteria is adopted.)

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3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve
 - Rate of change of centrifugal acceleration to be developed gradually:

NRS (2070):

$$l_s = \frac{V^3}{47CR} \quad [V \text{ in kmph}]$$

IRC:

$$\left. \begin{aligned} C &= \frac{80}{75 + 3.6v} \text{ for } v \text{ in m/s} \\ C &= \frac{80}{75 + V} \text{ for } V \text{ in kmph} \end{aligned} \right\} 0.5 < C < 0.8$$

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3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve

- Rate of change of centrifugal acceleration to be developed gradually:

- At tangent point centrifugal acceleration = 0.
 - Let the length of transition curve be l_s m, R the radius in m. If $t(s)$ is the time taken to traverse this transition length at uniform design speed of v m/sec then,

$$t = \frac{l_s}{v}$$

- Centrifugal acceleration introduced in time $t = \frac{v^2}{R}$

- Rate of change of centrifugal acceleration (C):

$$C = \frac{\frac{v^2}{R} - 0}{t} = \frac{\frac{v^2}{R}}{\frac{l_s}{v}} = \frac{v^3}{l_s R}$$

NRS (2070):

$$l_s = \frac{v^3}{47CR} \quad [V \text{ in kmph}]$$

- Length of transition curve (l_s):

$$l_s = \frac{v^3}{CR} \quad [v \text{ in m/sec}]$$

$$l_s = \frac{V^3}{46.5CR} \quad [V \text{ in kmph}]$$

IRC:

$$C = \left. \begin{array}{l} \frac{80}{75 + 3.6v} \text{ for } v \text{ in m/s} \\ \frac{80}{75 + V} \text{ for } V \text{ in kmph} \end{array} \right\} 0.5 < C < 0.8$$

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3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve

- Rate of introduction of superelevation

- Length of transition curve (l_s):

$$l_s = eN(W + We) \quad [\text{If pavement is rotated about inner edge}]$$

$$l_s = \frac{eN(W+We)}{2} \quad [\text{If pavement is rotated about center}]$$

Rate of change of the outer edge of the pavement should not be steeper than 1 in 150 in plain and rolling terrain and 1 in 60 in mountainous and steep terrain in comparison with the grade of the centre line.

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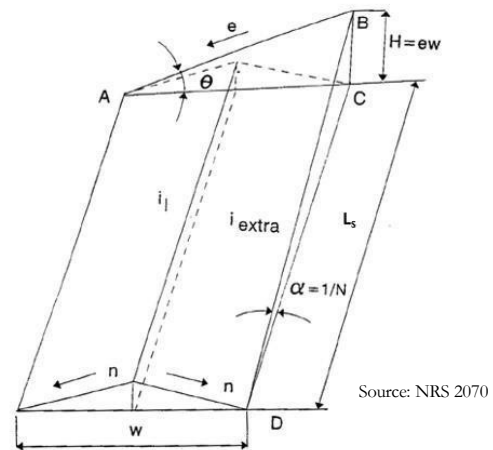
130

3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve
 - **Rate of introduction of superelevation**
 - Let e be the rate of superelevation designed for 75% design speed for a highway curve having normal pavement width of W
 - Let W_e be the extra widening provided at the circular curve so that the total pavement width = $W + W_e$.

Rate of change of the outer edge of the pavement should not be steeper than 1 in 150 in plain and rolling terrain and 1 in 60 in mountainous and steep terrain in comparison with the grade of the centre line.



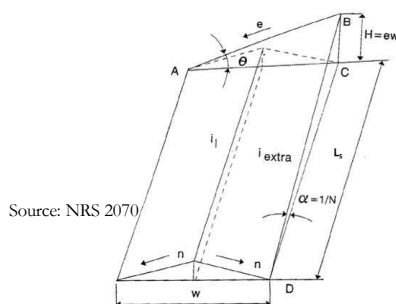
Source: NRS 2070

3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve
 - **Rate of introduction of superelevation**

Rate of change of the outer edge of the pavement should not be steeper than 1 in 150 in plain and rolling terrain and 1 in 60 in mountainous and steep terrain in comparison with the grade of the centre line.



Source: NRS 2070

- Total raising of pavement (E) for rotation about inner edge:

$$\tan \theta = \frac{E}{W + W_e} = e$$

$$E = e(W + W_e)$$

- Let rate of introduction of superelevation be 1 in N :

$$\tan \alpha = \frac{E}{l_s} = \frac{1}{N} \rightarrow E = \frac{l_s}{N}$$

$$\frac{l_s}{N} = e(W + W_e) \rightarrow l_s = Ne(W + W_e)$$

3.5 Elements of Horizontal Alignment: Transition Curve

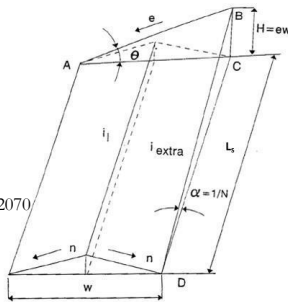
• Design of Transition Curve

▪ Length of Transition Curve

▪ Rate of introduction of superelevation

Rate of change of the outer edge of the pavement should not be steeper than 1 in 150 in plain and rolling terrain and 1 in 60 in mountainous and steep terrain in comparison with the grade of the centre line.

Source: NRS 2070



• Length of transition curve (l_s):

$l_s = eN(W + We)$ [If pavement is rotated about inner edge]

$l_s = \frac{eN(W+We)}{2}$ [If pavement is rotated about center]

3.5 Elements of Horizontal Alignment: Transition Curve

• Design of Transition Curve

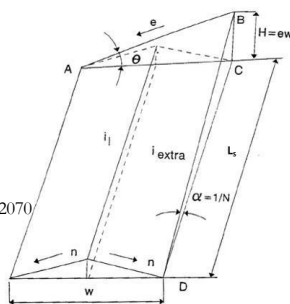
▪ Length of Transition Curve

▪ Rate of introduction of superelevation

Rate of change of the outer edge of the pavement should not be steeper than 1 in 150 in plain and rolling terrain and 1 in 60 in mountainous and steep terrain in comparison with the grade of the centre line.

- Let e be the rate of superelevation designed for 75% design speed for a highway curve having normal pavement width of W
- Let W_e be the extra widening provided at the circular curve so that the total pavement width = $W+W_e$.

Source: NRS 2070



• Total raising of pavement (E) for rotation about inner edge:

$\tan \theta = \frac{E}{W+We} = e$

$E = e(W + We)$

• Let rate of introduction of superelevation be 1 in N:

$\tan \alpha = \frac{E}{l_s} = \frac{1}{N} \rightarrow E = \frac{l_s}{N}$

$\frac{l_s}{N} = e(W + We) \rightarrow l_s = Ne(W + We)$

• Length of transition curve (l_s):

$l_s = eN(W + We)$ [If pavement is rotated about inner edge]

$l_s = \frac{eN(W+We)}{2}$ [If pavement is rotated about center]

3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve

- Minimum length requirement

- IRC empirical relations:

$$l_s = \frac{2.7V^2}{R} \quad \text{for plain and rolling terrain}$$

$$l_s = \frac{V^2}{R} \quad \text{for mountainous or steep terrain}$$

Where V is in kmph

3.5 Elements of Horizontal Alignment: Transition Curve

- **Design of Transition Curve**

- Length of Transition Curve

- The length of the transition curve l_s required on a horizontal curve depends upon the following factors:

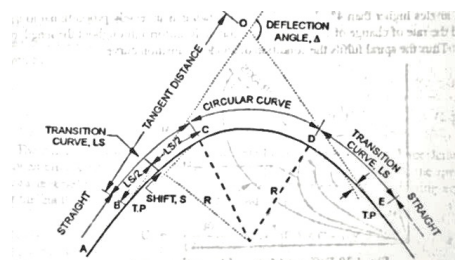
- Radius of the circular curve, R.
 - Design speed, V.
 - Allowable rate of change of centrifugal acceleration C.
 - Maximum amount of superelevation E which depends on the maximum rate of superelevation (e) and the total width of pavement (B) at the horizontal curve.
 - Whether the pavement cross section is rotated about the inner edge or the center line, after the elimination of the camber.
 - Allowable rate of introduction of superelevation which depends on the terrain.

3.5 Elements of Horizontal Alignment: Transition Curve

• Design of Transition Curve

▪ Calculation of Lateral Shift

- The transition curves are provided on both the ends of the circular curve.
- After providing the transition curve, the circular curve gets shifted towards the inner side and this shift (S) of curve can be calculated as: $Shift (S) = \frac{l^2}{24R}$, where, R is the radius of the circular curve.
- When the shift value (S) of the transition curve is less than 0.25m, no transition curve need to be provided.
- After providing the transition curve on the horizontal curve, the elements of combined curve will be:
- Tangent Length (T) = $(R + S) \tan \frac{\Delta}{2} + \frac{l_s}{2}$
- Apex Distance = $(R+S) (\sec \frac{\Delta}{2} - 1)$
- Spiral angle (ϕ_s) = $\frac{l_s}{2\pi}$ radian = $\frac{l_s \times 180}{2\pi R}$ degree
- The angle obtained by circular curve (Δ_s) = $\Delta - 2\phi_s$.
- Length of circular curve (L_c) = $\frac{\pi R \Delta_s}{180}$



3.5 Elements of Horizontal Alignment: Transition Curve

• Transition Curve: Numerical

The radius of a circular curve of two lane highway with a design speed of 70kmph is 220m. Assume extra widening is not necessary, calculate the length of the transition curve and shift of the curve. Assume other necessary data approximately. Consider the rate of introduction of superelevation be 1 in 100.

a). Rate of change of centrifugal acceleration:

$$l_s = \frac{V^3}{47.3R \cdot c}$$

$$= \frac{70^3}{47.3 \times 220 \times 0.55}$$

$$c = \frac{80}{75 + V} = 0.55$$

$$l_s = 60.77m$$

b). Rate of introduction of superelevation:

$$l_s = Ne \left(\frac{V^2}{127R} \right)^2$$

$$l_s = Ne w$$

$$l_s = 100 \times 7 \times 7 = 49m$$

Rate of introduction of superelevation:

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

$$f = 0.15$$

$$e = \frac{0.15 \cdot 70^2}{127 \cdot 220} = 0.10 > 0.07$$

Rate of introduction of superelevation:

$$l_s = Ne \left(\frac{V^2}{127R} \right)^2$$

$$l_s = 100 \times 0.07 \times \left(\frac{70^2}{127 \cdot 220} \right)^2$$

$$l_s = 49m$$

3.5 Elements of Horizontal Alignment: Transition Curve

• **Transition Curve: Numerical**

The radius of a circular curve of two lane highway with a design speed of 70kmph is 220m. Assume extra widening is not necessary, calculate the length of the transition curve and shift of the curve. Assume other necessary data approximately. Consider the rate of introduction of superelevation be 1 in 100.

<p>c) Minimum length required</p> $l_s = \frac{2.7 V^2}{R} \quad [\text{plain terrain}]$ $= \frac{2.7 \times 70^2}{220}$ $= 60.13 \text{ m}$	<p>Maximum terrain</p> $l_s = \frac{V^2}{R}$ $= \frac{70^2}{220}$ $= 22.27 \text{ m}$ <p>Adopt maximum of 3</p> $= 60.77 \text{ m}$ $\approx 61 \text{ m}$	<p>Calculation of Shift</p> $S = \frac{l_s^2}{24R}$ $= 0.633 \text{ m}$
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3.5 Elements of Horizontal Alignment: Transition Curve

• **Transition Curve: Numerical**

The radius of a circular curve of two lane highway with a design speed of 70kmph is 220 m. Assuming extra widening is not necessary, calculate the length of the transition curve and shift of the curve. Assume other necessary data approximately. Consider the rate of introduction of superelevation be 1 in 100.

<p>Length according to rate of change of centrifugal acceleration</p> $l_s = \frac{V^3}{47CR} = \frac{70^3}{47 \times C \times 220}$ $C = \frac{80}{75+V} = \frac{80}{75+70} = 0.55$ $l_s = 60.31 \text{ m}$ <p>NRS (2070):</p> $l_s = \frac{V^3}{47CR} \quad [V \text{ in kmph}]$ <p>IRC:</p> $C = \frac{80}{75 + 3.6V} \text{ for } V \text{ in m/s}$ $C = \frac{80}{75 + V} \text{ for } V \text{ in kmph}$ $0.5 < C < 0.8$	<p>Length according to rate of introduction of superelevation</p> <p>Let the rate of introduction of superelevation be 1 in 100 and rotation of pavement is about the inner edge.</p> $l_s = N \cdot e \cdot W$ <p>Design of superelevation</p> $e = \frac{V^2}{225R} = \frac{70^2}{225 \times 220} = 0.10 > 0.07$ <p>Take $e = 0.07$</p> <p>Check for f</p> $f = \frac{V^2}{127R} - e = 0.105 < 0.15 \text{ (OK)}$ $l_s = NeW = 100 \times 0.07 \times 7 = 49 \text{ m}$	<p>Minimum length recommended by IRC for plain terrain</p> $l_s = \frac{2.7 V^2}{R} = \frac{2.7 \times 70^2}{220} = 60.14 \text{ m}$ <p>Taking length of transition curve as maximum value obtained from three cases.</p> $l_s = 61 \text{ m}$ <p>Shift (S) = $\frac{l_s^2}{24R} = \frac{61^2}{24 \times 220} = 0.70 \text{ m}$</p>
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3.5 Elements of Horizontal Alignment: Transition Curve

• Transition Curve: Numerical

A national highway curve of 525m radius is to be set out to connect two straights. The maximum speed of the moving vehicles on this curve is restricted to 90kmph. Transition curve are to be introduced at each end of the curve. Calculate a) Suitable length of transition curve b) The necessary shift of the circular curve c) Chainage of Beginning of transition curve and End of transition curve. Given that the angle of intersection = 130°24', rate of change of centrifugal acceleration = 0.52 m/sec³ and the chainage at the point of intersection = 1092.50 m. Consider the rate of introduction of superelevation be 1 in 100.

<p>a) Rate of change of centrifugal acceleration:</p> $L_s = \frac{V^3}{4.7CR}$ $= \frac{90^3}{4.7 \times 525}$ <p>$C = 0.52$</p> $L_s = \frac{90^3}{4.7 \times 0.52 \times 525}$ $= 56.81 \text{ m}$	<p>b) Rate of introduction of superelevation, considering rotation of pavement about lower edge.</p> $L_s = Ne (W + ve)$ $= 100 \times e \times (7 + ve)$ $= 100 \times 0.068 \times (7 + 0.484)$ $= 50.89 \text{ m}$	<p>$ve = \frac{W + W_p}{2R} + \frac{V^2}{9.8R}$</p> $= \frac{2.7 \times 12}{2 \times 525} + \frac{90^2}{9.8 \times 525}$ $= 0.484 \text{ m}$
<p>$e + f = \frac{V^2}{12.7R} \rightarrow f = 0; e = \frac{(0.75V)^2}{12.7R}$</p> $= \frac{V^2}{22.5R}$ <p>Adopt $e = 0.068$ ← $= 0.0682007$</p>		

3.5 Elements of Horizontal Alignment: Transition Curve

• Transition Curve: Numerical

A national highway curve of 525m radius is to be set out to connect two straights. The maximum speed of the moving vehicles on this curve is restricted to 90kmph. Transition curve are to be introduced at each end of the curve. Calculate a) Suitable length of transition curve b) The necessary shift of the circular curve c) Chainage of Beginning of transition curve and End of transition curve. Given that the angle of intersection = 130°24', rate of change of centrifugal acceleration = 0.52 m/sec³ and the chainage at the point of intersection = 1092.50 m. Consider the rate of introduction of superelevation be 1 in 100.

<p>c) Minimum length required:</p> <p>Considering plan transition:</p> $L_s = \frac{2.7V^2}{R}$ $= \frac{2.7 \times 90^2}{525}$ $= 47.65 \text{ m}$ <p>Maximum of 3; $L_s = 56.82 \text{ m}$ $\approx 57 \text{ m}$</p>	<p>Shift = $\frac{L_s^2}{24R} = \frac{57^2}{24 \times 525}$</p> $= 0.258 \text{ m}$	
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3.5 Elements of Horizontal Alignment: Transition Curve

• **Transition Curve: Numerical**

A national highway curve of 525m radius is to be set out to connect two straights. The maximum speed of the moving vehicles on this curve is restricted to 90kmph. Transition curve are to be introduced at each end of the curve. Calculate a) Suitable length of transition curve b) The necessary shift of the circular curve c) Chainage of Beginning of transition curve and End of transition curve. Given that the angle of intersection = 130°24', rate of change of centrifugal acceleration = 0.52 m/sec³ and the chainage at the point of intersection = 1092.50 m. Consider the rate of introduction of superelevation be 1 in 100.

$Tangent\ Length = (R+S) \tan \frac{\Delta}{2} + \frac{l_s}{2}$
 $= (525 + 0.258) \times \tan \frac{49^\circ 36'}{2} + \frac{57}{2} = 271.20m$
 $Chainage\ of\ BOC = Chainage\ of\ IP - T.L. = 1092.50 - 271.20 = 821.30m$
 $Chainage\ of\ EOC = Chainage\ of\ BOC + l_s + l_c + l_s$
 $= 821.30 + 57 + 397.48 + 57$
 $= 1332.76m$
 $BOC = 0 + 821.30\ km$ $EOC = 1 + 332.76\ km$
 $l_c = \frac{\pi R \Delta_s}{180} = \frac{\pi \times 525 \times 49.6}{180}$
 $\phi_s = \frac{l_s \times 180}{2R} = \frac{57 \times 180}{2 \times 525} = 9.81^\circ$
 $l_c = 397.48m$
 $\Delta = 180^\circ - 130^\circ 24'$
 $= 49^\circ 36'$

3.5 Elements of Horizontal Alignment: Transition Curve

• **Transition Curve: Numerical**

A national highway curve of 525m radius is to be set out to connect two straights. The maximum speed of the moving vehicles on this curve is restricted to 90kmph. Transition curve are to be introduced at each end of the curve. Calculate a) Suitable length of transition curve b) The necessary shift of the circular curve c) Chainage of Beginning of transition curve and End of transition curve. Given that the angle of intersection = 130°24', rate of change of centrifugal acceleration = 0.52 m/sec³ and the chainage at the point of intersection = 1092.50 m. Consider the rate of introduction of superelevation be 1 in 100.

<p>Length according to rate of change of centrifugal acceleration</p> $l_s = \frac{v^3}{47CR} = \frac{90^3}{47 \times 0.52 \times 525}$ $l_s = 56.82\ m$	$W_e = \frac{W_m}{2R} + \frac{W_{py}}{9.5\sqrt{R}}$ $W_e = \frac{2 \times 6.10^2}{2 \times 525} + \frac{90}{9.5\sqrt{525}}$ $W_e = 0.48\ m$	<p>Tangent Length (T) = (R + S) Tan $\frac{\Delta}{2} + \frac{l_s}{2}$ Tangent Length (T) = (525 + 0.26) Tan $\frac{49^\circ 36'}{2} + 28.50$ Tangent Length (T) = 273.30 m</p>	
<p>Length according to rate of introduction of superelevation</p> <p>Let the rate of introduction of superelevation be 1 in 100 and rotation of pavement is about the inner edge.</p> $l_s = N^*e*(W+W_e)$ Design of superelevation $e = \frac{v^2}{225R} = \frac{90^2}{225 \times 525} = 0.069 < 0.07$ Take e = 0.069 $l_s = N^*e*(W+W_e) = 100 * 0.069 * (7+0.48)$ $l_s = 51.612\ m$	<p>Minimum length recommended by IRC for plain terrain</p> $l_s = \frac{2.7 v^2}{R} = \frac{2.7 \times 90^2}{525} = 41.65\ m$ Taking length of transition curve as maximum value obtained from three cases. $l_s = 57\ m$	<p>Spiral angle (ϕ_s) = $\frac{l_s \times 180}{2\pi R}$ degree $\Delta = 180^\circ - 130^\circ 24'$ $\Delta = 49^\circ 36'$</p>	
		<p>Length of circular curve (L_c) = $\frac{\pi R \Delta_s}{180}$ $L_c = \frac{\pi \times 525 \times 49.6}{180} = 396.37\ m$</p> <p>Total length of composite curve $L = L_c + 2l_s = 396.37 + (2 \times 57)$ $L = 510.37\ m$</p>	
		<p>Chainage of beginning of transition curve (BC) = Chainage of IP - T = 1092.50 - 273.30 = 819.20 m</p> <p>Chainage at the end of transition curve (EC) = Chainage of BC + L = 819.20 + 510.37 = 1329.57 m</p>	

3.5 Elements of Horizontal Alignment: Transition Curve

• **Design of Transition Curve**

9.2 Transition Curves or Spirals

(see also annex 24.4)

- a. Transition curves are necessary to allow a vehicle smoothly enter the circular curve from straight section and vice versa.
- b. All horizontal curves with radius less than 1000m should be provided with transition curves.
- c. When circular curves of very large radius (>1000m) are provided the effect of transition from straight section to circular section becomes negligible and no transition curves are provided.
- d. Clothoid curves (Euler's spiral) with curvature changing linearly with the length are used for transition curves.
- e. Minimum length of transition curves should be as shown in Table 9-2²

Table 9-2 Length of Transition Curves

Radius,m	20	30	50	60	80	100	150	200	250	300	400	500	1000
Length of transition curve,m	20	30	35	40	45	50	60	70	80	90	100	110	120

- f. When the shift value of the transition curve (see 24.4) is less than 0.25m no transition curve need to be provided.
- g. Details of combined circular and transition curves are given in annex 24.4

Source: NRS 2070

Table 9: Length of the Transition Curve

Curve radius, m	Design speed, Km/h				
	10	20	30	40	50
	Transition length, m				
10	30	NA			
20	15	55	NA		
30	NR	40	80	NA	
50		25	50	86	NA
100		15	25	45	70
150		NR	20	30	45
200			15	25	35
250			NR	20	30
300				15	25
400				NR	20
500					NR

NA-Not Applicable; NR-Transition not required

Source: NURS 2076

3.5 Elements of Horizontal Alignment: Sight Distance

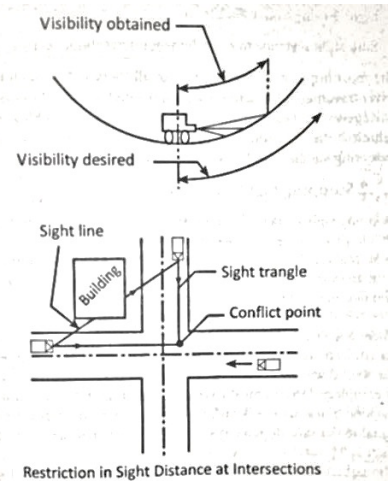
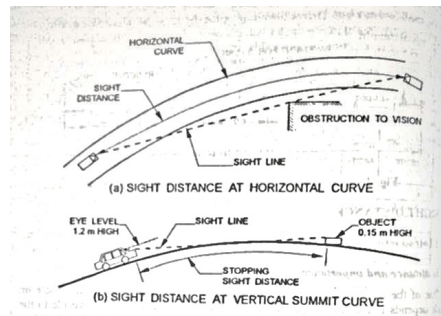
• **Sight Distance**

- It is necessary that sight distance of adequate length should be available to permit drivers enough time and distance to control their vehicles.
- The geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead.
- This distance is known as sight distance.
- Sight distance is the actual distance along the road surface which a driver from a specified height above the carriage can see objects either moving or stationary on the road surface ahead.

3.5 Elements of Horizontal Alignment: Sight Distance

Restriction to Sight Distance

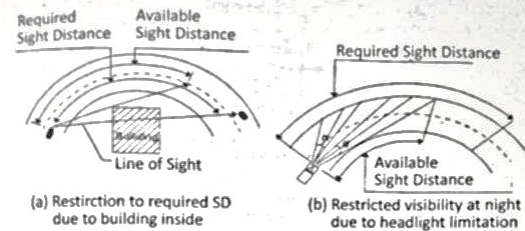
- Due to sharpness of horizontal curves
- Objects obstructing vision (building, trees, cut slope or due to inability of headlight to throw its beam along the curved alignment) at the inner side of the road curve
- Due to vertical summit curves
- At road intersections



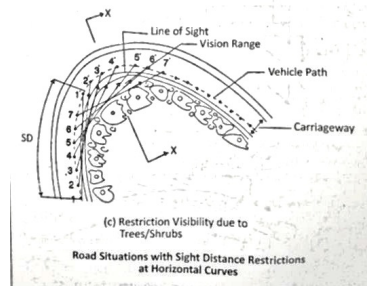
3.5 Elements of Horizontal Alignment: Sight Distance

Restriction to Sight Distance

- Due to sharpness of horizontal curves
- Objects obstructing vision (building, trees, cut slope or due to inability of headlight to throw its beam along the curved alignment) at the inner side of the road curve
- Due to vertical summit curves
- At road intersections



Road Situations with Sight Distance Restrictions at Horizontal Curves

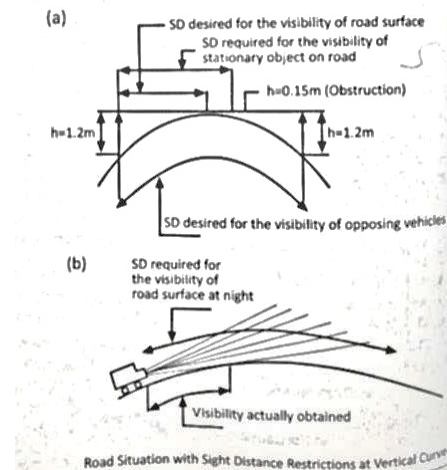


Road Situations with Sight Distance Restrictions at Horizontal Curves

3.5 Elements of Horizontal Alignment: Sight Distance

- **Restriction to Sight Distance**

- Due to sharpness of horizontal curves
- Objects obstructing vision (building, trees, cut slope or due to inability of headlight to throw its beam along the curved alignment) at the inner side of the road curve
- Due to vertical summit curves
- At road intersections



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3.5 Elements of Horizontal Alignment: Sight Distance

- **Types of sight distance**

- Following sight distance situations are considered for design:
 - Stopping sight distance (SSD) or the absolute minimum sight distance.
 - Intermediate sight distance (ISD) is defined as twice SSD.
 - Overtaking sight distance (OSD) for safe overtaking operation.
 - Headlight sight distance is the distance visible to a driver during night driving under the illumination of head lights.
 - Safe sight distance to enter into an intersection.
- The most important consideration in all these is that at all times the driver travelling at the design speed of the highway must have sufficient carriageway distance within his/her line of vision to allow him/her to stop vehicle before colliding with a slowly moving or stationary objects appearing suddenly in his/her own traffic lane.

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Stopping Sight Distance (SSD)**
 - Stopping Sight Distance (SSD) is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle travelling at a design speed, safely without collision with any other obstruction.
 - Stopping sight distance is also known as non passing or non overtaking sight distance.
 - The sight distance available on a road to a driver at any instant depends on:
 - Feature of the road ahead
Horizontal alignment / vertical profile of road / traffic conditions / position of obstructions.
 - Height of the driver's eye above the road surface.
 - Height of the object above the road surface.

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Factors governing Stopping Sight Distance (SSD)**
 - Total Reaction time of the driver
 - Speed of the vehicle
 - Efficiency of the brakes
 - Frictional resistance between the tire and the road
 - Gradient of the road

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3.5 Elements of Horizontal Alignment: Sight Distance

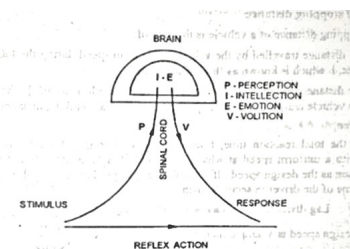
- **Factors governing Stopping Sight Distance (SSD)**
 - Total Reaction Time of the Driver
 - Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied.
 - The stopping sight distance increases with increase in reaction time of the driver.
 - The total reaction time is splitted into: perception time and brake reaction time.
 - Perception time is the time required for the driver to realize that brake must be applied.
 - It depends upon the speed of the vehicle, distance of object and other environmental conditions.
 - The brake reaction time depends on skill of the driver.
 - It is the time that elapses between the moment the foot is removed from the accelerator paddle and placed on the brake paddle and time to actuate brake action.
 - The total reaction time may be split up into four components based on PIEV theory.
 - The reaction time of 2.5 seconds is considered in the design of stopping sight distance (SSD).

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Factors governing Stopping Sight Distance (SSD)**
 - Total Reaction Time of the Driver
 - PIEV Theory
 - As per PIEV theory, reaction time of the driver can be further classified as:
 - Perception: The recognition of realization that a signal or stimulus exists and requires a response.
 - Intellection: An interpretation/identification of the stimulus.
 - Emotion: The determination of an appropriate response to the stimulus.
 - Volition: The physical response resulting from the decision.



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3.5 Elements of Horizontal Alignment: Sight Distance

- **Factors governing Stopping Sight Distance (SSD)**
 - Speed of the vehicle
 - Higher the speed of the vehicle, more will be the distance required to stop the vehicle.
 - Efficiency of brakes
 - Efficiency of brakes depend upon the age of the vehicle, vehicular characteristics, etc.
 - Higher the brake efficiency, shorter the sight distance.
 - Frictional resistance between the tyre and the road
 - When the frictional resistance is more, the vehicles stop immediately. Thus, sight distance required will be less.
 - Gradient of the road
 - While climbing up a gradient, the vehicle can stop immediately, therefore sight distance required is less.
 - While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle, therefore sight distance required will be more.

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Analysis of Stopping Sight Distance (SD)**
 - The stopping distance of a vehicle is the sum of:
 - Reaction/lag distance and braking distance
 - Reaction/lag distance
 - The distance travelled by the vehicle during the total reaction time known as lag distance/reaction distance.
- $$\text{Reaction distance (m)} = vt \quad v(\text{m/sec})$$
- $$\text{Reaction distance (m)} = 0.278Vt \quad V(\text{Kmph})$$
- t is considered 2.5 secs for the calculation of SD

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Analysis of Stopping Distance (SD)**

- Braking Distance

- The distance travelled by the vehicle after the application of the brakes to a dead stop position which is known as braking distance.

Let f : coefficient of longitudinal friction
 W : weight of vehicle
 F : maximum frictional force developed per unit length of road = $f \times W$
 l : the braking distance

Work done in stopping vehicle against frictional force = $f \times W \times l$

Kinetic energy at design speed of v (m/sec) = $\frac{1}{2}mv^2 = \frac{1}{2} \frac{Wv^2}{g}$

Equating work done in stopping vehicle and change in kinetic energy:

$$f \times W \times l = \frac{1}{2} \frac{Wv^2}{g}$$

$$\text{Braking distance } l = \frac{v^2}{2gf} \quad v(\text{m/sec})$$

$$l = \frac{v^2}{254f} \quad V(\text{Kmph})$$

At slopes:

$$(f \times W \cos \theta + \frac{W \sin \theta}{100}) l = \frac{1}{2} \frac{Wv^2}{g}$$

$\cos \theta \approx 1$, $\tan \theta = n\%$ gradient

$$\text{Braking distance } l = \frac{v^2}{2g(f \pm 0.01n)} \quad v \left(\frac{\text{m}}{\text{sec}} \right)$$

$$l = \frac{v^2}{254(f \pm 0.01n)} \quad V(\text{kmph})$$

$$SD = vt + \frac{v^2}{2g(f \pm 0.01n)} \quad v \left(\frac{\text{m}}{\text{sec}} \right)$$

$$SD = 0.278Vt + \frac{v^2}{254(f \pm 0.01n)} \quad V(\text{kmph})$$

Considering braking efficiency η :

$$SD = 0.278Vt + \frac{v^2}{254(f \pm 0.01n)\eta} \quad V(\text{kmph})$$

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Analysis of Stopping Distance (SD)**

- Braking Distance

- The distance travelled by the vehicle after the application of the brakes to a dead stop position which is known as braking distance.

Let f : coefficient of longitudinal friction
 W : weight of vehicle
 F : maximum frictional force developed per unit length of road = $f \times W$
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Work done in stopping vehicle against frictional force = $f \times W \times l$

Kinetic energy at design speed of v (m/sec) = $\frac{1}{2}mv^2 = \frac{1}{2} \frac{Wv^2}{g}$

Equating work done in stopping vehicle and change in kinetic energy:

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$$\text{Braking distance } l = \frac{v^2}{2gf} \quad v(\text{m/sec})$$

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At slopes:

$$(f \times W \cos \theta + \frac{W \sin \theta}{100}) l = \frac{1}{2} \frac{Wv^2}{g}$$

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$$l = \frac{v^2}{254(f \pm 0.01n)} \quad V(\text{kmph})$$

$$SD = vt + \frac{v^2}{2g(f \pm 0.01n)} \quad v \left(\frac{\text{m}}{\text{sec}} \right)$$

$$SD = 0.278Vt + \frac{v^2}{254(f \pm 0.01n)} \quad V(\text{kmph})$$

Considering braking efficiency η :

$$SD = 0.278Vt + \frac{v^2}{254(f \pm 0.01n)\eta} \quad V(\text{kmph})$$

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3.5 Elements of Horizontal Alignment: Sight Distance

• SD Requirements

Table 8-1: Stopping distance

Speed, km/h	20	30	40	60	80	100	120
Stopping Distance, m	20	30	50	80	130	190	260

Source: NRS 2070

Table 2: Stopping Sight Distance value for Different Speeds

Design Speed (km/h)	Lag Distance (m)	Braking Distance (m)	Stopping Sight Distance	
			Calculated (m)	Design (m)
10	6.9	1.0	7.9	10
20	13.9	3.9	17.8	20
30	20.8	8.8	29.7	30
40	27.8	16.6	44.3	45
50	34.7	26.6	61.3	65

Source: NURS 2076

Table 8.1-Safe Stopping Site Distance

Speed, km/hr	Perception and Brake Reaction Time, t (sec)	Coefficient of Longitudinal Friction	Safe Stopping Sight Distance, m
15	2.5	0.4	15
20	2.5	0.40	20
25	2.5	0.40	25
30	2.5	0.40	30
40	2.5	0.38	45
50	2.5	0.37	60

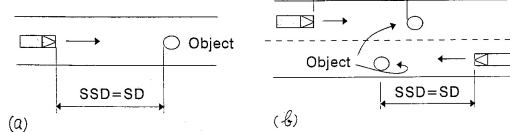
Source: NRRS 2071

3.5 Elements of Horizontal Alignment: Sight Distance

• Safe Stopping Sight Distance

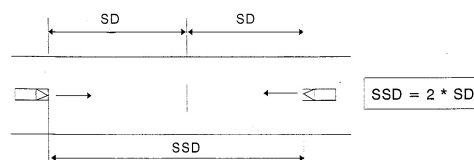
- For one way or two way movements in same number of lanes:

- SD = SSD



- For two way traffic movements in single lane:

- SSD = 2 SD (Intermediate Sight Distance ISD)



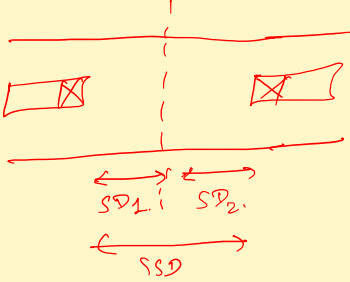
Intermediate sight distance: This is defined as twice the stopping sight distance.

When overtaking sight distance cannot be provided, intermediate sight distance (ISD) is provided to give limited overtaking opportunities to fast vehicles.

3.5 Elements of Horizontal Alignment: Transition Curve

• **Sight Distance: Numerical**

Compute the minimum sight distance required to avoid a head on collision of two busses approaching from the opposite directions. The speed of both the busses is 70 kmph. Assume a total perception and brake reaction time of 2.5 seconds. Coefficient of friction is 0.40 and brake efficiency is 50%.



Handwritten calculations for sight distance:

$$SD = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}$$

$$= 0.278 \times 70 \times 2.5 + \frac{70^2}{254 \times (0.40) \times 0.50}$$

$$= 145.11 \text{ m} = SD_1$$

$$SSD = SD_1 + SD_2 = 2 \times SD = 2 \times 145.11 = 290.22 \text{ m}$$

3.5 Elements of Horizontal Alignment: Sight Distance

• **Sight Distance: Numerical**

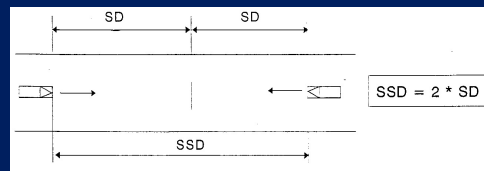
Compute the minimum sight distance required to avoid a head on collision of two busses approaching from the opposite directions. The speed of both the busses is 70 kmph. Assume a total perception and brake reaction time of 2.5 seconds. Coefficient of friction is 0.40 and brake efficiency is 50%.

$$SD = 0.278Vt + \frac{V^2}{254(f \pm 0.01n)\eta} \quad V(\text{kmph})$$

$$SD = 0.278 Vt + \frac{V^2}{254 (f \pm n) \eta}$$

$$SD = 0.278 * 70 * 2.50 + \frac{70^2}{254 * 0.40 * 0.50}$$

$$SD = 145.10 \text{ m}$$



Adopt minimum sight distance = 2 * SD = 2 * 145.10 m
Minimum sight distance = 290.20 m

3.5 Elements of Horizontal Alignment: Transition Curve

• **Sight Distance: Numerical**

Calculate the safe stopping distance for design speed of 60kmph for a) two way traffic in two lane road b) two way traffic in a single lane road.

$$SD = 0.278 Vt + \frac{V^2}{254(f \pm n) \eta}$$

$$= 0.278 \times 60 \times 2.5 + \frac{60^2}{254 \times 0.38}$$

$$= 79m.$$

$$\text{① } SSD = SD = 79m.$$

$$\text{② } SSD = 2 \times SD = 158m.$$

$60 \text{ kmph} + f = 0.38$

3.5 Elements of Horizontal Alignment: Sight Distance

• **Sight Distance: Numerical**

Calculate the safe stopping distance for design speed of 60kmph for a) two way traffic in two lane road b) two way traffic in a single lane road.

$$SD = 0.278Vt + \frac{V^2}{254(f \pm 0.01n)\eta} \quad V(\text{kmph})$$

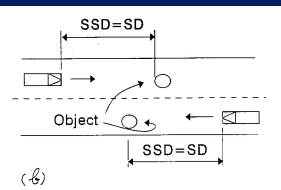
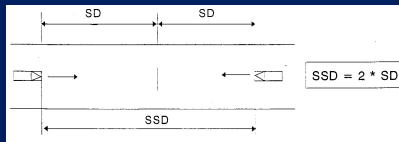
Table 24-2 : Coefficient of longitudinal friction

Speed(km/h)	ϕ
20	0.40
30	0.39
40	0.39
60	0.38
80	0.36
100	0.35
120	0.34

$$SD = 0.278 Vt + \frac{V^2}{254 (f \pm n) \eta}$$

$$SD = 0.278 * 60 * 2.50 + \frac{60^2}{254 * 0.38}$$

$$SD = 79 \text{ m}$$



- a) Safe stopping distance for two way traffic in two lane road = $SD = 79 \text{ m}$
- b) Safe stopping distance for two way traffic in a single road = $2 \times SD = 2 \times 79 = 158 \text{ m}$

3.5 Elements of Horizontal Alignment: Sight Distance

- **Sight Distance: Numerical [Practice Questions]**

Calculate the minimum sight distance required to avoid a head-on collision of two cars approaching from the opposite directions at 90 and 60 kmph. Assume a reaction time of 2.5 seconds, coefficient of friction of 0.70 and brake efficiency of 50 percent in both the cases.

Calculate the stopping sight distance on a highway at a descending gradient of 2% for a design speed of 80kmph. Assume other data.

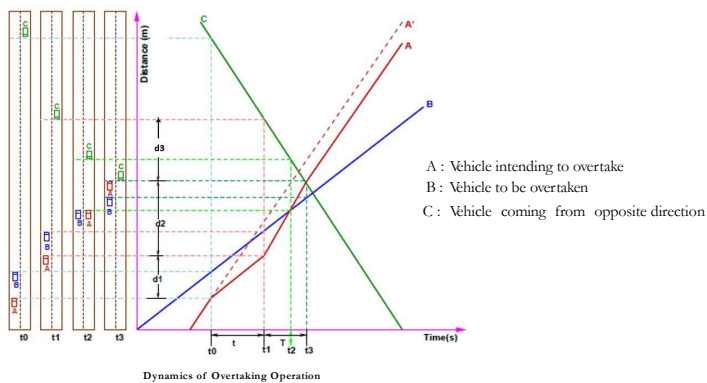
The design speed of a road is 65 kmph, the friction coefficient is 0.36 and reaction time of driver is 2.5 secs. Calculate the values of a) Head light sight distance and b) Intermediate sight distance required for the road.

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Overtaking Sight Distance (OSD)**

- Also known as passing sight distance
- Minimum distance that should be available ahead to the driver of a vehicle intending to overtake a slow vehicle, to avoid collision with vehicles coming in the opposite direction.



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3.5 Elements of Horizontal Alignment: Sight Distance

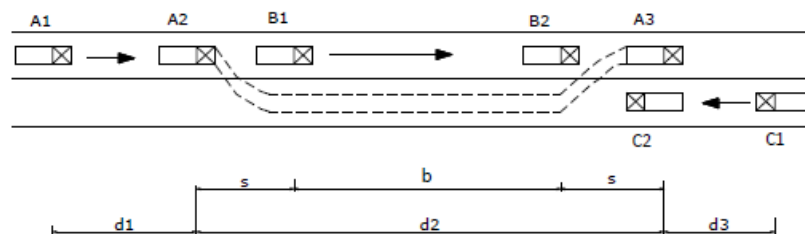
- **Factors affecting OSD**
 - Speed of overtaking, overtaken and vehicles coming from opposite direction
 - Spacing between vehicles
 - Skill and reaction time of driver
 - Rate of acceleration of overtaking vehicles
 - Gradient of road

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3.5 Elements of Horizontal Alignment: Sight Distance

- **Analysis of OSD**
 - Slow vehicle travels at uniform speed
 - Drivers require short time (2 secs in average) to perceive the situation, react and start acceleration
 - Fast vehicle reduces its speed and follows the slow vehicle as it prepares for overtaking
 - Overtaking is accomplished under a delayed start and early return and travel during actual overtaking operation is an uniformly accelerated travel.



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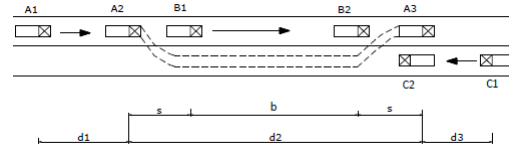
3.5 Elements of Horizontal Alignment: Sight Distance

• **Analysis of OSD**

Let

v_b : Speed of vehicle B to be overtaken m/sec

v : Design speed of the vehicle A and C in m/sec



The complete overtaking maneuver can be split up into three parts, thus dividing OSD into three parts d_1 , d_2 and d_3

- d_1 : Distance travelled by overtaking vehicle A during the reaction time (t) of the driver from A_1 to A_2 (to decide whether or not to overtake, **2 secs**)
- d_2 : Distance travelled by overtaking vehicle A from A_2 to A_3 during the actual overtaking operation in time (T)
- d_3 : distance travelled by on-coming vehicle C from C_1 to C_2 during the overtaking operation of vehicle A i.e. T secs.

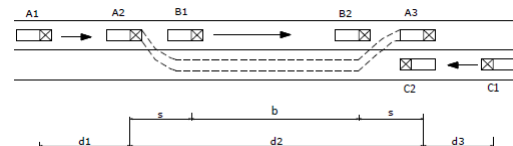
3.5 Elements of Horizontal Alignment: Sight Distance

• **Analysis of OSD**

d_1 :

- Vehicle A approaches vehicle B
- A reduces its speed to the speed of the slow vehicle B and moves behind it during the reaction time (t) till there is an opportunity for safe overtaking operation.
- The distance travelled by the vehicle A during this reaction time t between the position A_1 and A_2 is d_1 .

$$d_1 = v_b t$$

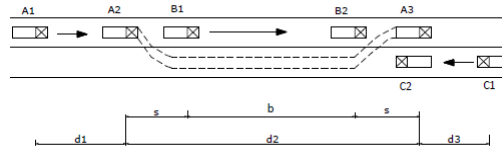


3.5 Elements of Horizontal Alignment: Sight Distance

• Analysis of OSD

- d2
- From A2 the vehicle A starts to accelerate shift to the adjoining lane, overtakes the vehicle B and shift back to the original lane ahead of B to position A3 in time T sec which is the actual duration of overtaking
- Vehicle A keeps the spacing s between A2 to B1 and between B2 to A3. s may be taken as the minimum spacings of two vehicles while moving with the speed v_b/m/s given by formula:

$$s = (0.69v_b + 6.1)$$



- The distance travelled by B during overtaking operation T between the position B1 and B2 is b. During this time vehicle A travels d₂ from position A2 to A3. So

$$d_2 = 2s + b = 2s + v_b T$$

- Assuming Vehicle A accelerated from initial velocity v_b with uniform acceleration (a):

$$d_2 = (v_b T + \frac{1}{2} a T^2)$$

- Equating:

$$2s + v_b T = (v_b T + \frac{1}{2} a T^2)$$

$$T = \sqrt{\frac{4s}{a}}$$

$$d_2 = v_b T + 2S$$

$$T = \sqrt{\frac{4s}{a}} \quad s = (0.69v_b + 6.1)$$

Speed [kmph/(m/s)]	Maximum overtaking acceleration (m/s ²)
25/6.93	1.41
30/8.34	1.30
40/11.10	1.24
50/13.86	1.11
65/18.00	0.92
80/22.20	0.73
100/27.80	0.53

Source: NRS 2070

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3.5 Elements of Horizontal Alignment: Sight Distance

• Analysis of OSD

d3:

- The distance travelled by vehicle C moving at design speed v m/s during overtaking operation of A i.e. during time T is distance d₃ between positions C₁ and C₂.

$$d_3 = vT$$

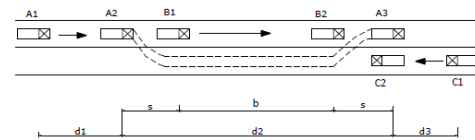
$$OSD = v_b t + v_b T + 2S + vT \quad \text{for } v \text{ in m/sec}$$

$$OSD = 0.278V_b t + 0.278V_b T + 2S + 0.278VT \quad \text{for } V \text{ in kmph}$$

When speed of overtaken vehicle V_b is not given, assume

$$V_b = (V - 16) \text{ kmph}$$

$$v_b = (v - 4.5) \text{ m/sec}$$



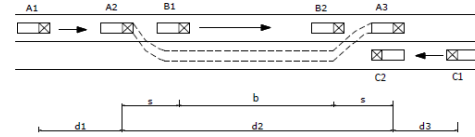
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3.5 Elements of Horizontal Alignment: Sight Distance

Recommended OSD

- Two way traffic road
OSD = $d_1+d_2+d_3$
- On divided highways and one way traffic roads, OSD = (d_1+d_2)



Intermediate sight distance (2SSD) is provided when provision of OSD is not possible.

Table 8-2: Overtaking distance

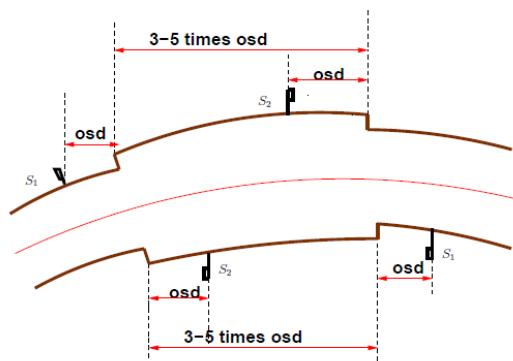
Speed, km/h	40	60	80	100	120
Minimum Overtaking Distance,m	165	300	470	640	880

Source: NRS 2070

3.5 Elements of Horizontal Alignment: Sight Distance

Overtaking Zone

- Provided when OSD cannot be provided throughout the length of highway



S_1 - Overtaking zone begin
 S_2 - End of Overtaking zone

8.4 Overtaking Zones

- In stretches of roads where sufficient overtaking sight distance cannot be provided or on single lane roads where overtaking or crossing opportunity is not available, overtaking or passing zones shall be provided.
- The width of the overtaking zone shall be the same as that of a minimum two lane road.
- Length of the overtaking zone shall be at least 3 times the overtaking distance on two and more lane roads.
- On single lane roads length of passing zones shall be at least 2 times the overtaking sight distance.
- On single lane roads overtaking/passing lanes should be provided at not more than 1km interval.
- The start and end of overtaking zone shall be well informed by placing appropriate signs at least stopping distance before the start and end of the zone.

Source: NRS 2070

3.5 Elements of Horizontal Alignment: Sight Distance

Overtaking Sight Distance: Numerical [m/s]. calculation. kmph. kmph.

The speeds of overtaking and overtaken vehicles are 70 and 40 kmph, respectively. Calculate safe overtaking sight distance considering a) two lane road with two way traffic b) two lanes with one way traffic. Assume all data suitably. Acceleration = 0.99 m/s².

$d_1 = v_b \times t$ $v_b = 40 \times \frac{5}{18} = 11.11 \text{ m/s}$ $t = 2 \text{ sec}$ $d_1 = 11.11 \times 2 = 22.22 \text{ m}$ $d_2 = v_b T + 2S$ $= 11.11 \times T + 2 \times S$ $s = 0.69 v_b + 6.1$ $= 0.69 \times 11.11 + 6.1$ $= 13.76 \text{ m}$	$T = \sqrt{\frac{4s}{a}}$ $= \sqrt{\frac{4 \times 13.76}{0.99}}$ $= 7.457 \text{ (secs)}$ $d_2 = 11.11 \times 7.457 + 2 \times 13.76$ $= 110.39 \text{ m}$ $d_3 = \frac{v \times T}{18}$ $= \frac{70 \times 7.457}{18} = 144.90 \text{ m}$ $\approx 145 \text{ m}$	<p>a) $d_1 + d_2 + d_3$ = 277.61 m</p> <p>b) $d_1 + d_2$ = 22.22 + 110.39 = 132.61 m</p>
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3.5 Elements of Horizontal Alignment: Sight Distance

Overtaking Sight Distance: Numerical

The speeds of overtaking and overtaken vehicles are 70 and 40 kmph, respectively. Calculate safe overtaking sight distance considering a) two lane road with two way traffic b) two lanes with one way traffic. Assume all data suitably. Acceleration = 0.99 m/s².

OSD = $d_1 + d_2 + d_3$ for two way traffic	OSD = $d_1 + d_2$ for one way traffic	$d_1 = v_b t$	$d_2 = v_b T + 2S$	$s = (0.69 v_b + 6.1)$	$T = \sqrt{\frac{4s}{a}}$	$d_3 = vT$
$OSD = v_b t + v_b T + 2S + vT$ for v in m/sec						
$d_1 = v_b t$ $v_b = 40 \times \frac{5}{18} = 11.11 \text{ m/sec}$ $t = 2 \text{ sec}$ $d_1 = 11.11 \times 2 = 22.22 \text{ m}$	$d_2 = v_b T + 2s = 11.11 \times T + 2s$ $T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times s}{0.99}}$ $s = 0.69 v_b + 6.10$ $s = 0.69 \times 11.11 + 6.10$ $s = 13.76 \text{ m}$ $T = \sqrt{\frac{4 \times 13.76}{0.99}} = 7.47 \text{ sec}$ $d_2 = (11.11 \times 7.47) + 2s$ $d_2 = 83 + (2 \times 13.76) = 110.52 \text{ m}$	$d_3 = vT$ $v = 70 \times \frac{5}{18} = 19.40 \text{ m/sec}$ $d_3 = 19.40 \times 7.47$ $d_3 = 144.90 \text{ m}$	Minimum length of overtaking zone = 3 OSD			
OSD = $d_1 + d_2 + d_3 = 277.64 \text{ m}$ for two way traffic		OSD = $d_1 + d_2 = 132.74 \text{ m}$ for one way traffic				

3.5 Elements of Horizontal Alignment: Sight Distance

Overtaking Sight Distance: Numerical

Calculate the safe overtaking sight distance for a design speed of 96 kmph for acceleration of 2.5 kmph/sec. Assume all other data suitably.

Velocity A, Velocity S

$V_b = \frac{(96-16)}{3.6} \text{ kmph}$ $= \frac{80 \times 5}{18} \text{ m/sec}$ $= 22.22 \text{ m/sec}$	$V_L = \frac{80 \times 5}{18} = 22.22 \text{ m/sec}$ $s = 0.69 \times 22.22 + 6.1$ $= 21.43 \text{ m}$	$d_2 = 22.22 \times 11.11 + 2 \times 21.43$ $= 289.72 \text{ m}$
$d_1 = V_b \times t$ $= \frac{80 \times 5}{18} \times 2$ $= 44.44 \text{ m}$	$T = \sqrt{\frac{4s}{a}}$ $= \sqrt{\frac{4 \times 21.43}{2.5}}$ $= \sqrt{\frac{2 \times 21.43}{0.69}}$ $= 11.15 \text{ sec}$	$d_3 = V \times T$ $= \frac{96 \times 5}{18} \times 11.11$ $= 296.27 \text{ m}$
$d_2 = V_b T + 2s$ $s = 0.69 V_b + 6.1$		$d_1 + d_2 + d_3 = 680.43 \text{ m}$ $\frac{28.66 - 4.5}{2.5} = 22.16$

3.5 Elements of Horizontal Alignment: Sight Distance

Overtaking Sight Distance: Numerical

Calculate the safe overtaking sight distance for a design speed of 96 kmph for acceleration of 2.5 kmph/sec. Assume all other data suitably.

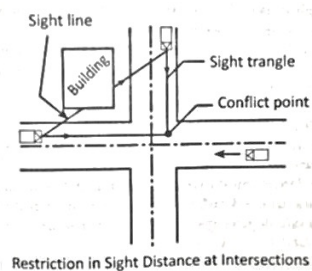
OSD = d ₁ +d ₂ +d ₃ for two way traffic	OSD = d ₁ +d ₂ for one way traffic	d ₁ = v _b t	d ₂ = v _b T + 2s	s = (0.69v _b + 6.1)	T = $\sqrt{\frac{4s}{a}}$	d ₃ = vT
OSD = 0.278V_bt + 0.278V_bT + 2S + 0.278VT for V in kmph						
Given, V = 96 kmph V _b = 96 - 16 = 80 kmph		When speed of overtaken vehicle V _b is not given, assume V _b = (V - 16) kmph v _b = (v - 4.5) m/sec				
d ₁ = 0.278V _b t d ₁ = 0.278*80*2 d ₁ = 44.80 m	d ₂ = 0.278V _b T + 2s D ₂ = 0.278*80*T + 2s T = $\sqrt{\frac{14.4s}{A}} = \sqrt{\frac{14.4+s}{2.5}}$ s = 0.69*0.278*V _b + 6.10 s = 0.20*80 + 6.10 s = 22.10 m T = $\sqrt{\frac{14.4+s}{2.5}} = \sqrt{\frac{14.40+22.10}{2.5}}$ T = 11.31 secs d ₂ = (0.278*80*11.31) + 2s d ₂ = 251.61 + (2*22.10) = 295.85 m		d ₃ = 0.278VT d ₃ = 0.278*96*11.31 d ₃ = 301.84 m			
Minimum length of overtaking zone = 3 OSD						
OSD = d ₁ +d ₂ +d ₃ = 642.49 m for two way traffic						
OSD = d ₁ +d ₂ = 340.65 m for one way traffic						

3.5 Elements of Horizontal Alignment: Sight Distance

• Sight Distance at Intersection

- At intersections, visibility should be provided for the drivers approaching the intersection from either side.
- They should be able to perceive a hazard and stop the vehicle if required.
- Stopping distance for each road can be computed from the design speed.
- The sight distance should be provided such that the drivers on either side should be able to see each other.

- Design of sight distance at intersections may be used on three possible conditions:
 - Enabling approaching vehicle to change the speed.
 - Enabling approaching vehicle to stop.
 - Enabling stopped vehicle to cross a main road.



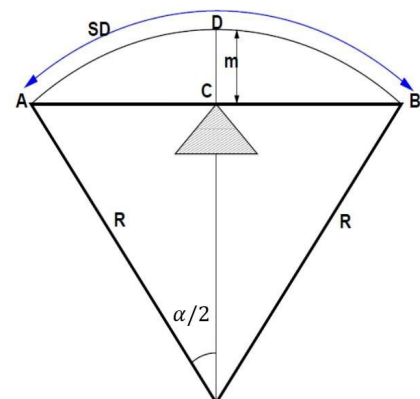
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3.5 Elements of Horizontal Alignment: Setback Distance

• Setback Distance

- Clearance distance required from the centerline of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at horizontal curve.
- Depends on:
 - Sight Distance (SSD, ISD and OSD), S
 - Radius of the curve, R
 - Length of the curve, L_c



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3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case a) $L_c > S$
 - α is angle subtended by S at the center of the curve.

We have, $OD = R$.

$$m = OD - OC = R - OC$$

In ΔOAC ,

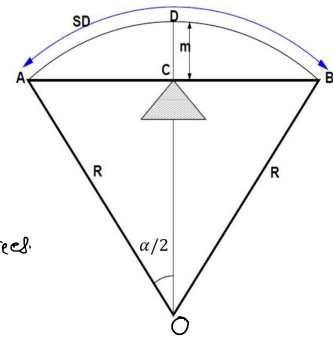
$$\cos \frac{\alpha}{2} = \frac{OC}{OA} = \frac{OC}{R} \Rightarrow OC = R \cos \frac{\alpha}{2}$$

$$m = R - R \cos \frac{\alpha}{2} = R - R \cos \left[\frac{180 \times S}{2 \times \pi \times R} \right]$$

$$m = R - R \cos \left[\frac{180 \times S}{2 \times \pi \times R} \right]$$

$$\alpha = \frac{S}{R} \text{ radians}$$

$$= \frac{180 \times S}{2 \times \pi \times R} \text{ degrees}$$



• For single lane road

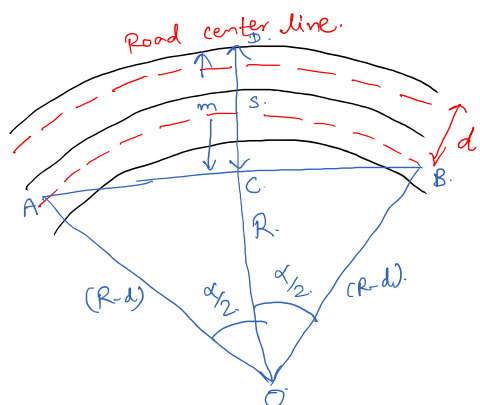
$$\alpha = \frac{S}{R} \text{ radians} = \frac{180 S}{\pi R} \text{ degrees}$$

$$m = R - R \cos \left(\frac{\alpha}{2} \right) = R - R \cos \left(\frac{180 S}{2 \pi R} \right)$$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case a) $L_c > S$
 - α is angle subtended by S at the center of the curve.



$$m = OD - OC$$

$$= R - OC$$

In ΔOAC ,

$$\cos \frac{\alpha}{2} = \frac{OC}{OA}$$

$$\cos \frac{\alpha}{2} = \frac{OC}{(R-d)}$$

$$OC = (R-d) \cos \frac{\alpha}{2}$$

$$\therefore m = R - (R-d) \cos \frac{\alpha}{2}$$

$$\alpha = \frac{S}{R-d} \text{ radians} = \frac{180 S}{\pi(R-d)} \text{ degrees}$$

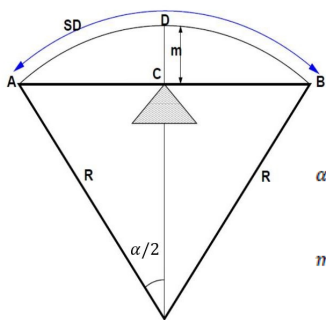
$$m = R - (R-d) \cos \left(\frac{\alpha}{2} \right) = R - (R-d) \cos \left(\frac{180 S}{2 \pi(R-d)} \right)$$

We have,
 $\alpha = \frac{S}{R-d} \text{ radians}$
 $= \frac{180 S}{\pi(R-d)} \text{ degrees}$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case a) $L_c > S$
 - α is angle subtended by S at the center of the curve.



• For single lane road

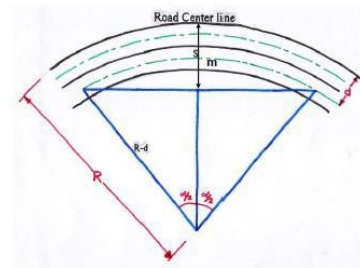
$$\alpha = \frac{S}{R} \text{ radians} = \frac{180S}{\pi R} \text{ degrees}$$

$$m = R - R \cos\left(\frac{\alpha}{2}\right) = R - R \cos\left(\frac{180S}{2\pi R}\right)$$

• For multi lane road

- Sight distance is measured along the middle of the inner side lane.

d = Distance between the center line of carriageway and the center of inner lane.



$$\alpha = \frac{S}{R-d} \text{ radians} = \frac{180S}{\pi(R-d)} \text{ degrees}$$

$$m = R - (R-d) \cos\left(\frac{\alpha}{2}\right) = R - (R-d) \cos\left(\frac{180S}{2\pi(R-d)}\right)$$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case b) $L_c < S$
 - α must be determined with reference to L_c

Calculation of m_1 .

$$m_1 = OD - OC = R - OC$$

$$OC = R \cos \alpha_2$$

$$m_1 = R - R \cos \alpha_2$$

In ΔJKL .

$$\sin \alpha_2 = \frac{JK}{JL} \Rightarrow JK = m_2 = JL \times \sin \alpha_2$$

$$= \left[\frac{S-L}{2}\right] \sin \alpha_2$$

$$m = m_1 + m_2 = R - R \cos \alpha_2 + \left[\frac{S-L}{2}\right] \sin \alpha_2$$

where,

$$\alpha = \frac{L_c}{R} \text{ radians}$$

$$\approx \frac{180L_c}{\pi R} \text{ degrees}$$

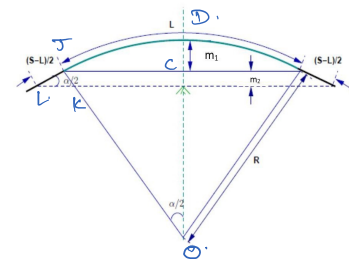
• For single lane road

$$\alpha = \frac{L_c}{R} \text{ radians} = \frac{180L_c}{\pi R} \text{ degrees}$$

$$m_1 = R - R \cos\left(\frac{\alpha}{2}\right)$$

$$m_2 = \frac{(S-L_c)}{2} \sin\left(\frac{\alpha}{2}\right)$$

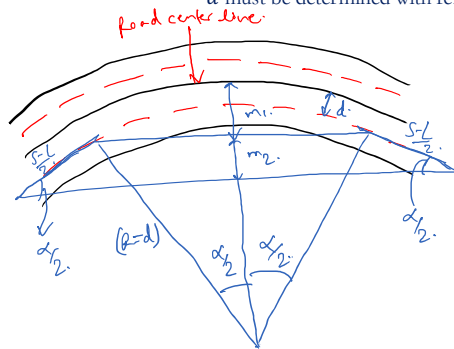
$$m = R - R \cos\left(\frac{180L_c}{2\pi R}\right) + \frac{(S-L_c)}{2} \sin\left(\frac{180L_c}{2\pi R}\right)$$



3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case b) $L_c < S$
 - α must be determined with reference to L_c



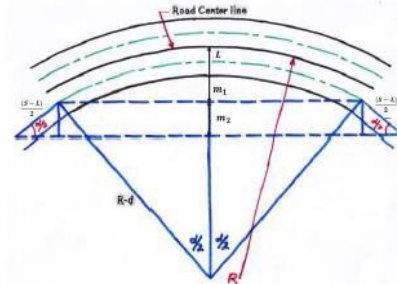
$$m = m_1 + m_2$$

$$m_1 = R - (R - d) \cos \alpha/2$$

$$m_2 = \left[\frac{S-L}{2} \right] \sin \alpha/2$$

$$m = m_1 + m_2$$

$$m = R - (R - d) \cos \alpha/2 + \left[\frac{S-L}{2} \right] \sin \alpha/2$$



d = Distance between the center line of carriageway and the center of inner lane.

- For multi lane road

$$\alpha = \frac{L_c}{R - d} \text{ radians} = \frac{180 L_c}{\pi(R - d)} \text{ degrees}$$

$$m_1 = R - (R - d) \cos \left(\frac{\alpha}{2} \right)$$

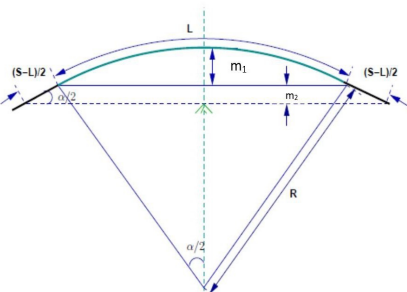
$$m_2 = \frac{(S - L_c)}{2} \sin \left(\frac{\alpha}{2} \right)$$

$$m = R - (R - d) \cos \left(\frac{180 L_c}{2\pi(R - d)} \right) + \frac{(S - L_c)}{2} \sin \left(\frac{180 L_c}{2\pi(R - d)} \right)$$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback from Obstructions**

- Case b) $L_c < S$
 - α must be determined with reference to L_c



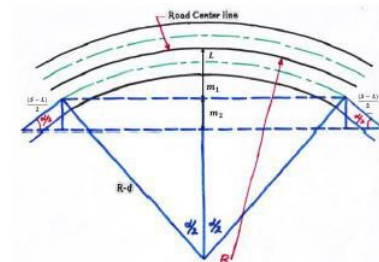
- For single lane road

$$\alpha = \frac{L_c}{R} \text{ radians} = \frac{180 L_c}{\pi R} \text{ degrees}$$

$$m_1 = R - R \cos \left(\frac{\alpha}{2} \right)$$

$$m_2 = \frac{(S - L_c)}{2} \sin \left(\frac{\alpha}{2} \right)$$

$$m = R - R \cos \left(\frac{180 L_c}{2\pi R} \right) + \frac{(S - L_c)}{2} \sin \left(\frac{180 L_c}{2\pi R} \right)$$



d = Distance between the center line of carriageway and the center of inner lane.

- For multi lane road

$$\alpha = \frac{L_c}{R - d} \text{ radians} = \frac{180 L_c}{\pi(R - d)} \text{ degrees}$$

$$m_1 = R - (R - d) \cos \left(\frac{\alpha}{2} \right)$$

$$m_2 = \frac{(S - L_c)}{2} \sin \left(\frac{\alpha}{2} \right)$$

$$m = R - (R - d) \cos \left(\frac{180 L_c}{2\pi(R - d)} \right) + \frac{(S - L_c)}{2} \sin \left(\frac{180 L_c}{2\pi(R - d)} \right)$$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback Distance: Numerical**

A four-lane divided highway has a curve 1000m long and a radius of 550m. The safe stopping sight distance was 250m. Calculate the minimum setback distance from the inner edge of a road to ensure safe visibility. The pavement width per lane is 3.50m.

$L_c > S$

Distance between the center line of carriageway and the center of inner lane.

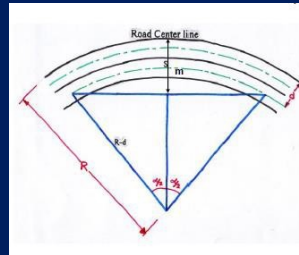
$d = \frac{4 \times 3.5}{2} - \frac{3.5}{2} = 5.25 \text{ m}$ Or, $d = 3.50 + \frac{3.50}{2}$
 $d = 5.25 \text{ m}$

Central angle subtended by the arc of length S

$\alpha = \frac{180 \cdot S}{\pi(R-d)}$

$\alpha = \frac{180 \times 250}{\pi \times (550 - 5.25)} = 26^\circ 17' 40.31''$

Setback distance from the center of the road,
 $m = R - (R-d) \cos \frac{\alpha}{2}$



$\alpha = \frac{S}{R-d} \text{ radians} = \frac{180S}{\pi(R-d)} \text{ degrees}$
 $m = R - (R-d) \cos \left(\frac{\alpha}{2} \right) = R - (R-d) \cos \left(\frac{180S}{2\pi(R-d)} \right)$

Setback distance from the edge of carriageway
 $= R - (R-d) \cos \frac{\alpha}{2} - \frac{W}{2}$
 $= 550 - (550 - 5.25) \cos \frac{26^\circ 17' 40.31''}{2} - \frac{3.50 \times 4}{2}$
 $= 12.53 \text{ m}$

Or, Setback distance from the edge of carriageway
 $= R - (R-d) \cos \frac{\alpha}{2} - (3.50 \times 2)$
 $= 12.53 \text{ m}$

3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback Distance: Numerical**

The radius of center line of circular curve is 650m and the sight distance required is 400m. The length of curve is 300m. Find out the set back from an obstruction to the center line.

$R = 650 \text{ m}$

$S = 400 \text{ m}$

$L_c = 300 \text{ m}$

$\frac{L_c}{L_c} < S$

$\alpha = \frac{L_c \times 180}{R} = \frac{180 L_c}{2R}$

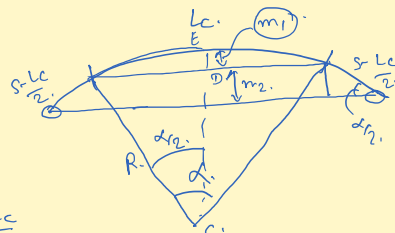
$m_1 = CE - CD$
 $= R - R \cos d_2$

$= 17.23 \text{ m}$

$\alpha = \frac{L_c}{R-d} \times \frac{180}{\pi}$
 $= \frac{180 L_c}{\pi(R-d)}$

$m_1 = CE - CD = R - (R-d) \cos \frac{\alpha}{2} = 17.23 \text{ m}$

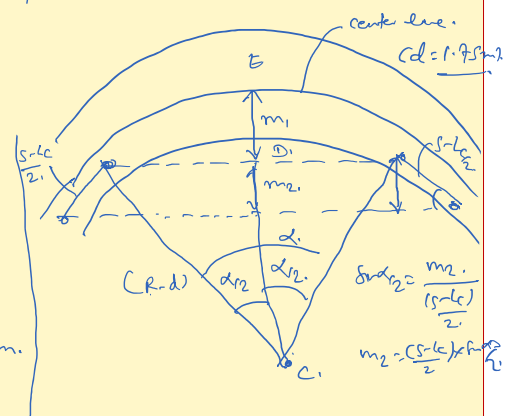
$m_2 = \frac{(S-L_c)}{2} \times \tan \frac{\alpha}{2} = 114.96 \text{ m}$ $m = m_1 + m_2 = 132.19 \text{ m}$



$\sin d_2 = \frac{m_1}{R-L_c}$

$m_2 = \frac{S-L_c}{2} \times \tan \frac{\alpha}{2} = 114.96 \text{ m}$

$m = m_1 + m_2 = 132.19 \text{ m}$



3.5 Elements of Horizontal Alignment: Setback Distance

• **Setback Distance: Numerical**

The radius of center line of circular curve is 650m and the sight distance required is 400m. The length of curve is 300m. Find out the set back from an obstruction to the center line.

$$L_c < S$$

Distance between the center line of carriageway and the center of inner lane.

$$d = \frac{2 \times 3.5}{2} - \frac{3.5}{2} = 1.75 \text{ m} \quad \text{Or, } d = \frac{3.50}{2}$$

$$d = 1.75 \text{ m}$$

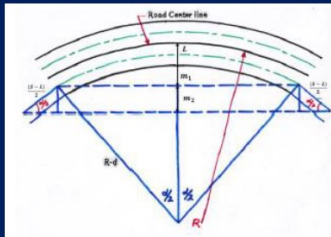
Central angle subtended by the arc of length S

$$\alpha = \frac{180 L_c}{\pi (R-d)}$$

$$\alpha = \frac{180 \times 300}{\pi \times (650 - 1.75)} = 26^\circ 30' 56.14''$$

Setback distance from the center of the road,

$$m = R - (R-d) \cos \frac{\alpha}{2} + \frac{S-L_c}{2} \sin \frac{\alpha}{2}$$



$$m = R - (R-d) \cos \left(\frac{180 L_c}{2\pi(R-d)} \right) + \frac{(S-L_c)}{2} \sin \left(\frac{180 L_c}{2\pi(R-d)} \right)$$

$$m = R - (R-d) \cos \frac{\alpha}{2} + \frac{S-L_c}{2} \sin \frac{\alpha}{2}$$

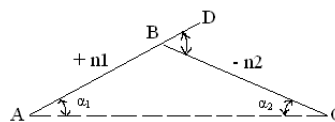
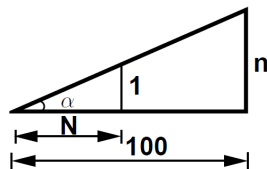
$$m = 650 - (650 - 1.75) \cos \frac{26^\circ 30' 56.14''}{2} + \frac{400 - 300}{2} \sin \frac{26^\circ 30' 56.14''}{2}$$

$$m = 30.49 \text{ m}$$

Elements of Vertical Alignment: Gradient

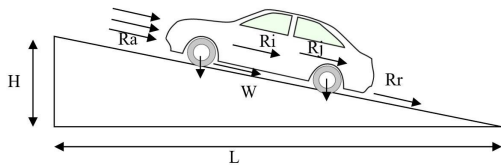
• **Gradient**

- Rate of rise or fall along the length of road.
- Expressed as a ratio of 1 in N (1 vertical to N horizontal) or n%



Elements of Vertical Alignment: Gradient

Resistance to Traction



- Air resistance (R_a)
 - Caused by:
 - Reaction pressure of the air against the front of the vehicle.
 - Friction of the air against the sides of the vehicle body.
 - Eddying of the air steam behind the vehicle, under the body and around the wheels.

- Rolling Resistance (R_r)
 - Resistance against the impact when the vehicle wheels run over the irregular road surface.
- Grade Resistance (R_i)
 - Resistance against the additional force required to move the vehicle up along the inclined plane.
- Inertial Resistance (R_i)
 - Inertial resistance is due to the tendency of the vehicle to continue its original state of uniform motion of acceleration or deceleration.
- Total force required for the vehicle to overcome tractive resistance is given by:

$$P = R_a + R_r \pm R_i \pm R_j$$

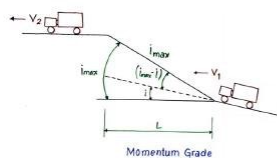
Dynamic factor: $P/W = f(R_r, R_i, R_j)$

- Tractive force or effort to be gained by vehicle engine mainly depends on the gradient i .

Elements of Vertical Alignment: Gradient

Momentum Grade

- Grades on which the momentum gained by the vehicles at the beginning of a steep climbing section is used to overcome the road resistance due to grade.
- Practical significance when the steeper grade is encountered after the mild grade.
- Economic, reduced tractive effort.
- For every momentum grade there is certain length L that can be overcome with approach speed to get the desired exit speed.
- The difference in momentum is used to overcome the additional resistance due to resultant grade ($i_{max} - i$).



- V_1 : Approach Speed
- V_2 : Exit speed
- i : Gradient at the approach section
- i_{max} : Maximum steep grade
- L : Length of road section with grade i_{max}

Grade resistance: $R_g = W(i_{max} - i)$

Change in momentum in terms of kinetic energy = Work done by vehicle in overcoming the grade resistance

$$\frac{\beta m}{2} (V_1^2 - V_2^2) = LW(i_{max} - i)$$

$$L = \frac{\beta (V_1^2 - V_2^2)}{2g(i_{max} - i)}$$

Where, β = Coefficient of inertia

(Air resistance is assumed constant)

Elements of Vertical Alignment: Gradient

- **Momentum Grade**

- The maximum economic ascending grade
 - Permit the vehicle to ascend without any shifting of gears and within a reasonable speed change.
- The safe descending grade for economical operation
 - Does not require the use of brakes and on which the vehicle shall not develop unsafe speed.
- Magnitude of momentum grade should be selected in such a way as not to get the end speed too low
- For a given magnitude of momentum grade, its length should be such that the end speed should be within the reasonable limit.

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Elements of Vertical Alignment: Gradient

- **Types of Grade**

Classification as per Indian Road Practice:

- Ruling Gradient
- Limiting Gradient
- Exceptional Gradient
- Minimum Gradient

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Elements of Vertical Alignment: Gradient

Types of Grade: Ruling Gradient

- Maximum gradient within which the designer attempts to design the vertical profile (design gradient)
- Adopted as a normal course in design and accordingly the quantities of cut and fill are balanced.
- Amount of gradient should be such that the vehicle could overcome the long stretch of road with this gradient with an economic consumption of fuel.
- Depends on
 - The type of terrain
 - Length of grade
 - Speed of vehicles
 - Power of the vehicles
 - Type of traffic
 - Presence of horizontal curves in the road alignment.

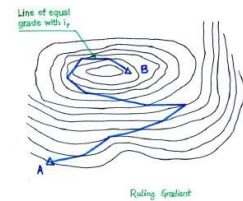


Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
1	Ruling gradient (%)	7	5*	7	5*
2	Limiting gradient (%)	10	6	10	6
3	Exceptional gradient (%)	12	7	12	7
4	Limitation of maximum gradient length (m) above average gradient of 7%	300	-	300	-
5	Maximum recovery gradient (%) to be applied after gradient in excess of 7% for a minimum recovery length of 150 m	4	-	4	-
6	Maximum gradient at bridge approach (%)	6	5*	6	5
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

Elements of Vertical Alignment: Gradient

Types of Grade: Ruling Gradient

- In flat terrain or plain country possible to adopt a flat gradient. In hill roads, uneconomical or sometimes not even possible.
- IRC recommendation:
 - Plain and rolling terrain: 3.33%
 - Mountainous terrain: 5%
 - Steep terrain: 6%

Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
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6	Maximum gradient at bridge approach (%)	6	5*	6	5
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

Elements of Vertical Alignment: Gradient

Types of Grade: Limiting Gradient

- Steeper than ruling gradient
- May be used in restricted length if significant savings in earth works and other aspects can be achieved
- Should be followed by a stretch of road having very small gradient or a leveled road
- Preferable:
 - Limiting grade would not exceed the momentum grade for a particular or desired exit speed
 - At the beginning of limiting grade section, road should have enough length to gain the momentum.
- IRC recommendation:
 - Plain and rolling terrain: 5%
 - Mountainous terrain: 6%
 - Steep terrain: 7%

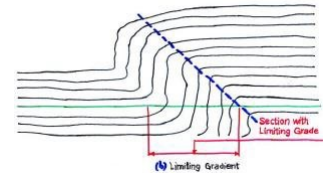


Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
1	Ruling gradient (%)	7	5*	7	5*
2	Limiting gradient (%)	10	6	10	6
3	Exceptional gradient (%)	12	7	12	7
4	Limitation of maximum gradient length (m) above average gradient of 7%	300	-	300	-
5	Maximum recovery gradient (%) to be applied after gradient in excess of 7% for a minimum recovery length of 150 m	4	-	4	-
6	Maximum gradient at bridge approach (%)	6	5*	6	5*
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

Elements of Vertical Alignment: Gradient

Types of Grade: Exceptional Gradient

- Exceptional Gradient
 - Even steeper than limiting gradient
 - Provided only in exceptional cases
 - on approaches to cause ways
 - near hair pin bends
 - Allowed only for short stretches (not more than 100m in a stretch)
 - Should be provided only in very difficult situation where they can not be avoided.
 - IRC recommendation:
 - Plain and rolling terrain: 6.67%
 - Mountainous terrain: 7%
 - Steep terrain: 8%

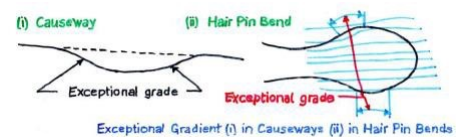


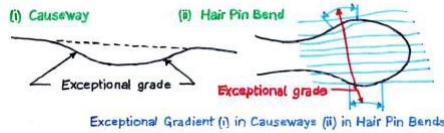
Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
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1	Ruling gradient (%)	7	5*	7	5*
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5	Maximum recovery gradient (%) to be applied after gradient in excess of 7% for a minimum recovery length of 150 m	4	-	4	-
6	Maximum gradient at bridge approach (%)	6	5*	6	5*
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

Elements of Vertical Alignment: Gradient

• **Types of Grade: Exceptional Gradient**



Design Speed, km/h	20	30	40	60	80	100	120
Maximum Gradient, %	12	10	9	7	6	5	4

Gradient, %	4	5	6	7	9	10	12
Maximum(critical) Length, m	600	450	400	300	200	150	150

Source: NRS 2070

Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
1	Ruling gradient (%)	7	5*	7	5*
2	Limiting gradient (%)	10	6	10	6
3	Exceptional gradient (%)	12	7	12	7
4	Limitation of maximum gradient length (m) above average gradient of 7%	300	-	300	-
5	Maximum recovery gradient (%) to be applied after gradient in excess of 7% for a minimum recovery length of 150 m	4	-	4	-
6	Maximum gradient at bridge approach (%)	6	5*	6	5
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

Most urban roads carry mixed traffic including slow moving vehicles like bicycles. Besides this, urban roads generally have intersections at frequent intervals. In view of this, as a general rule, a gradient of 4 percent should be considered the maximum for urban roads. On roads carrying predominantly slow moving traffic, however, the gradient should desirably not exceed 2 percent. At intersections, the road should be as near levels as possible.

Gradient	4	5	6	7	9	10	12
Maximum critical Length of grade, m	600	450	400	300	200	150	150

Source: NURS 2076

Elements of Vertical Alignment: Gradient

• **Types of Grade: Minimum Gradient**

- Minimum Gradient
 - Provided to facilitate longitudinal drainage in flat terrain
 - Depends on
 - Rainfall
 - Type of soil
 - Type of lining and other site conditions
 - IRC recommendation: 0.5%

Minimum longitudinal gradients for longitudinal drainage purpose is 0.5% Source: NRS 2070

Table 12.1 Recommended gradients

S. N.	Design Standard	District Road (Core Network)		Village Road	
		Hill	Terai	Hill	Terai
1	Ruling gradient (%)	7	5*	7	5*
2	Limiting gradient (%)	10	6	10	6
3	Exceptional gradient (%)	12	7	12	7
4	Limitation of maximum gradient length (m) above average gradient of 7%	300	-	300	-
5	Maximum recovery gradient (%) to be applied after gradient in excess of 7% for a minimum recovery length of 150 m	4	-	4	-
6	Maximum gradient at bridge approach (%)	6	5*	6	5
7	Minimum gradient on hill roads (for better drainage) (%)	0.5 (max1%)	-	0.5 (max1%)	-

Source: NRRS 2071

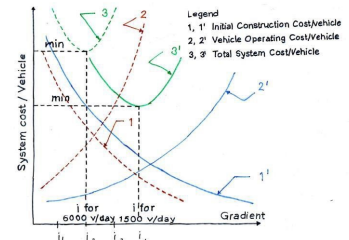
Design elements	Gradient, %	
	Desirable minimum, %	Absolute minimum, %
Kerbed pavement	0.5	0.3
Side ditches lined	0.5	0.2

Source: NURS 2076

Elements of Vertical Alignment: Gradient

Factors Governing Selection of Grades

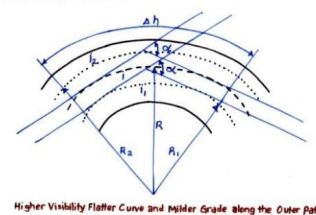
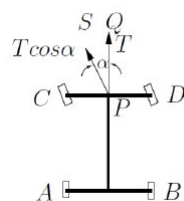
- Depends on many factors:
 - Topography soil type, floor levels of surrounding developed areas especially with reference to surface and sub-surface drainage, depth of water table
 - Mandatory and obligatory points
 - Types and importance of highway design speed, characteristics of anticipated traffic
 - Steep gradients for undulating country might reduce the earthwork and initial construction cost but vehicle are required to be on low gears and will have high operating cost.
 - In determining the maximum grade for a particular road, the initial construction cost must be weighed against the long term effect of vehicle operation cost.



Elements of Vertical Alignment: Curve Resistance

Curve Resistance

- When a vehicle moves on a horizontal curve, the rear wheels do not follow the direction of the front wheel.
- The decrease in the tractive force ($T - T \cos \alpha$) due to turning of vehicle on horizontal curve is called curve resistance.
- In addition, there is significant loss of tractive efforts in curves due to various reasons:
 - Increased rolling resistance
 - Increased grade resistance
 - Increased air resistance



Elements of Vertical Alignment: Grade Compensation

- Grade Compensation**

- Deduction of grade at horizontal curves to compensate for the loss of tractive effort in curves.
- Little data available to specify the required amount of grade compensation at horizontal curves.

10.1.2 Grade Compensations

- Maximum value of longitudinal gradient shall be eased by 0.5% for each rise of 500m above mean sea level.
- Due to loss of tractive efforts of the vehicle on curves it is recommended to ease the gradients by an amount calculated as follows:

$$\text{Grade compensation (\%)} = \frac{30 + R}{R} \dots \dots \dots 10-1$$

subject to a maximum of 75/R, where R-radius in m.

- It is not necessary to compensate grades below 4%.

Source: NRS 2070

Elements of Vertical Alignment: Grade Compensation

- Grade Compensation: Numerical**

$$5\% = \frac{5}{100} = \left(\frac{1}{20}\right) \quad (\text{in } \%)$$

The ruling gradient in a road is 5% or 1 in 20 and the radius of the horizontal curve is 100 m. Determine the compensated gradient on the curve.

Amount of grade compensation: $\frac{30+R}{R} = \frac{30+100}{100} = \frac{130}{100} = 1.3\%$ Grade Compensation.
Compensated gradient.

Maximum grade compensation = $\frac{75}{R} = \frac{75}{100} = 0.75\%$

Adopted grade compensation = 0.75%

Compensated gradient = 5% - 0.75%
= 4.25%

Elements of Vertical Alignment: Grade Compensation

- Grade Compensation: Numerical

The ruling gradient in a road is 5% or 1 in 20 and the radius of the horizontal curve is 100 m. Determine the compensated gradient on the curve.

Radius of the curve = 100 m

$$\text{Amount of grade compensation} = \frac{30+R}{R}$$

$$\text{Amount of grade compensation} = \frac{30+100}{100}$$

$$\text{Amount of grade compensation} = 1.3\%$$

$$\text{Maximum grade compensation} = \frac{75}{R}$$

$$\text{Maximum grade compensation} = \frac{75}{100}$$

$$\text{Maximum grade compensation} = 0.75\%$$

$$\text{Compensated gradient} = 5\% - 0.75\%$$

$$\text{Compensated gradient} = 4.25\%$$

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Elements of Vertical Alignment: Grade Compensation

- Grade Compensation: Numerical

The ruling gradient in a road is 6% and the radius of the horizontal curve is 50 m. Determine the compensated gradient on the curve.

Grade = 6%.

R = 50m.

$$\text{Grade Compensation} = \frac{30+R}{R} = \frac{30+50}{50} = \frac{80}{50} = 1.6 \quad \left[\frac{75}{R} = \frac{75}{50} = 1.5\% \right]$$

$$\text{Compensated grade} = 6\% - 1.5\%$$

$$\boxed{4.5\%}$$

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Elements of Vertical Alignment: Grade Compensation

- **Grade Compensation: Numerical**

The ruling gradient in a road is 6% and the radius of the horizontal curve is 50 m. Determine the compensated gradient on the curve.

Radius of the curve = 50 m

$$\text{Amount of grade compensation} = \frac{30+R}{R}$$

$$\text{Amount of grade compensation} = \frac{30+50}{50}$$

$$\text{Amount of grade compensation} = 1.6 \%$$

$$\text{Maximum grade compensation} = \frac{75}{50}$$

$$\text{Maximum grade compensation} = \frac{75}{50}$$

$$\text{Maximum grade compensation} = 1.5 \%$$

$$\text{Compensated gradient} = 6\% - 1.5\%$$

$$\text{Compensated gradient} = 4.5\%$$

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Elements of Vertical Alignment: Vertical Curves

- **Vertical Curves**

- When two different or contrary gradients meet, they are connected by a curve in vertical plane which is known as vertical curve.
- Provided to secure safety and adequate visibility together with comfort to the passengers.

- Types of Vertical Curves

- Summit/Crest Curve

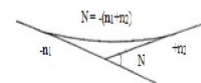
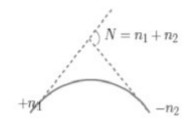
- Vertical curve having convexity upwards

- Valley/Sag Curve

- Vertical curve having concavity upwards or convexity downwards

- Various forms of curve can be used:

- Circular
- Parabolic (Quadratic, Cubic)
- Transition
- Circular and Transition



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Elements of Vertical Alignment: Vertical Curves

- Vertical Curves**

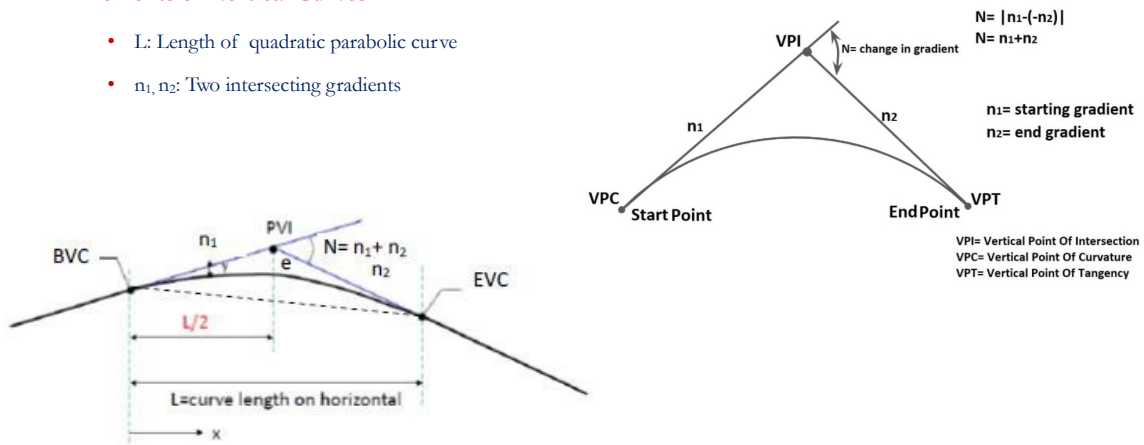
- Tendency to use parabolic curve:
 - Ease in laying out.
 - Ease in enabling the comfortable, transition from one grade to another.

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Elements of Vertical Alignment: Vertical Curves

- Elements of Vertical Curves**

- L: Length of quadratic parabolic curve
- n_1, n_2 : Two intersecting gradients



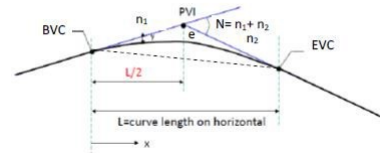
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Elements of Vertical Alignment: Vertical Curves

• Elements of Vertical Curves

• Assumptions

- The curve is so flat that:
- Length of curve = Length of chord = Length of horizontal projection
- For any value of n_1 and n_2 , PVI bisects the curve in equal parts.
- Angle made by tangents to the horizontal are very small. So tangent of this angle is equal to the angle themselves (in radians).
- The curve is so flat that a portion of parabola in the curve may be substituted by a circular curve of radius R.



Elements of Vertical Alignment: Vertical Curves

• Elements of Vertical Curves

General equation of quadratic parabola:
 $y = ax^2 + bx + c$

Equation of parabola with origin at BVC:
 $y = ax^2 + bx$

Slope at any point:
 $\frac{dy}{dx} = 2ax + b$

The rate of change of slope
 $\frac{d^2y}{dx^2} = 2a = K$ (Constant) = Rate of change of gradient

Using boundary conditions:

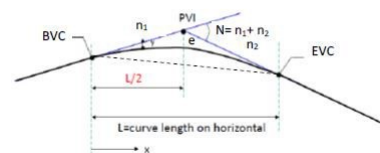
For $x = 0$, $\frac{dy}{dx} = n_1 \rightarrow b = n_1$

For $x = L$, $\frac{dy}{dx} = -n_2 \rightarrow -n_2 = 2aL + n_1 \rightarrow a = -\frac{n_1 + n_2}{2L} = -\frac{N}{2L}$

So, $a = \frac{N}{2L}$

Equation of vertical curve (simple parabola):

$y = \pm ax^2$, $a = \frac{N}{2L}$ (+ for valley curve and - for summit curve)



Elements of Vertical Alignment: Vertical Curves

- Elements of Vertical Curves

Highest or lowest point on the profile along the curve:

Often necessary

- to check or ensure that minimum sight distance or
- to meet the drainage requirements

For maximum or minimum point:

$$\frac{dy}{dx} = 0 \rightarrow 0 = 2ax + n_1$$

$$x = \frac{n_1 L}{N} \text{ from BVC}$$

Replacing the parabolic curve with circular curve:

Summit curve: $y = -ax^2 = -\frac{Nx^2}{2L} = -\frac{x^2}{2R}$

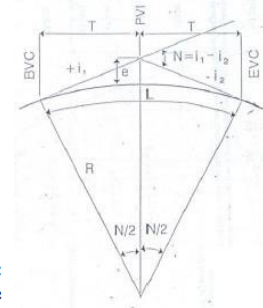
Valley curve: $y = ax^2 = \frac{Nx^2}{2L} = \frac{x^2}{2R}$

Tangent length (T) = $\frac{L}{2} = \frac{NR}{2}$

Length of curve (L) = $2T = NR$

Apex distance (e) = $\frac{T^2}{2R}$

Highest or lowest point position $x = n_1 R$



Elements of Vertical Alignment: Vertical Curves

- Vertical Curves: Numerical

Calculate the elements of vertical curve from the given data: Ascending grade = 5%, Descending grade = 2%, Radius, R = 10000 m.

$n_1 = +5\%$

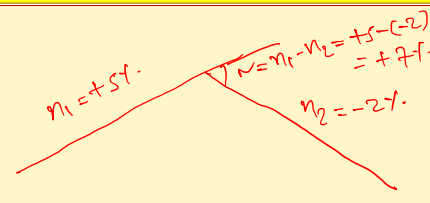
$n_2 = -2\%$

$N = +7\% \text{ (} +5 - (-2) \text{)} = 7\% = 0.07$

$T = \frac{L}{2} = \frac{NR}{2} = \frac{0.07 \times 10000}{2} = 350 \text{ m}$

$L = 2T = 2 \times 350 \text{ m} = 700 \text{ m}$

$e = \frac{T^2}{2R} = \frac{350^2}{2 \times 10000} = 6.125 \text{ m}$

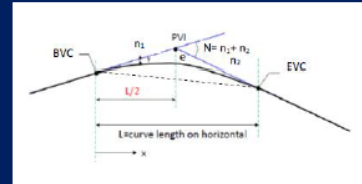


Elements of Vertical Alignment: Vertical Curves

• **Vertical Curves: Numerical**

Calculate the elements of vertical curve from the given data: Ascending grade = 5%, Descending grade = 2%, Radius, R = 10000 m.

Ascending grade (n_1) = 5%
 Descending grade (n_2) = -2%
 Deviation angle (N) = $n_1 - n_2$
 Deviation angle (N) = $5 - (-2) = 7\% = 0.07$
 Tangent Length (T) = $\frac{NR}{2} = \frac{0.07 \times 10000}{2} = 350$ m
 Length of curve (L) = $2T = 2 \times 350 = 700$ m
 Apex Distance (e) = $\frac{T^2}{2R} = \frac{350^2}{2 \times 10000} = 6.125$ m



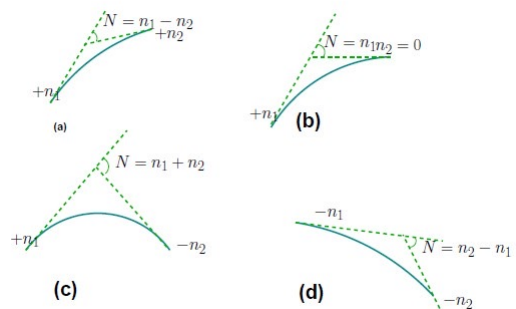
Replacing the parabolic curve with circular curve:
 Summit curve: $y = -ax^2 = -\frac{Nx^2}{2L} = -\frac{x^2}{2R}$
 Valley curve: $y = ax^2 = \frac{Nx^2}{2L} = \frac{x^2}{2R}$
 Tangent length (T) = $\frac{L}{2} = \frac{NR}{2}$
 Length of curve (L) = $2T = NR$
 Apex distance (e) = $\frac{T^2}{2R}$
 Highest or lowest point position $x = n_1 R$

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Elements of Vertical Alignment: Vertical Curves

• **Design of Summit Curves**

- Curve having convexity upwards
- Provided with
 - a) An ascending gradient meets another ascending gradient of lower value.
 - b) An ascending gradient meets a level gradient.
 - c) An ascending gradient meets a descending gradient.
 - d) A descending gradient meets another descending gradient of higher value.

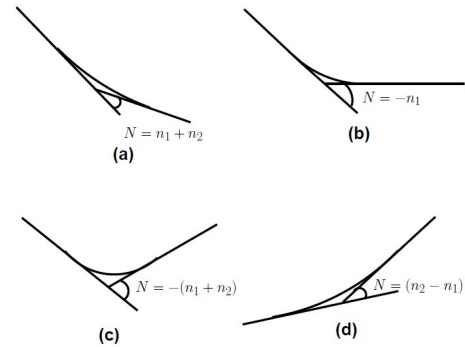


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Elements of Vertical Alignment: Vertical Curves

• Design of Valley Curve

- Curve having concavity upwards or convexity downwards.
- Provided when:
 - a) A descending gradient meets another descending gradient of lower value.
 - b) A descending gradient meets a level gradient.
 - c) A descending gradient meets an ascending gradient.
 - d) An ascending gradient meets another ascending gradient of higher value.



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Elements of Vertical Alignment: Vertical Curves

• Design of Summit Curves

- In summit curve, centrifugal force act upwards against gravity. So, pressure on tyre and springs is reduced and there is less discomfort to the passengers.
- Sight distance is the most important factor that guides the design of summit curve.
- Circular curve provides constant sight distance, so is considered as an ideal curve.
- In practice, simple parabolic curve is used as:
 - For small deviation angle, length of curve is quite large and parabolic summit curve is identical to circular arc between the tangential points.
 - Easy calculation and good riding comfort.
- Transition curve is not provided for summit curve as:
 - With introduction of transition curve, sight distance does not remain constant.
 - Summit curves have large radius and TC is not required.

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Elements of Vertical Alignment: Vertical Curves

• Design of Summit Curves

• When $L > S$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

- N : Deviation angle
- h_1 : Height of driver's eye level from the road surface
- h_2 : Height of obstruction on road

For S: SSD, $h_1=1.2\text{m}$, $h_2=0.15$

$$L = \frac{NS^2}{4.4}$$

For S: OSD/ISD, $h_1=1.2\text{m}$, $h_2=1.2\text{m}$

$$L = \frac{NS^2}{9.6}$$

• When $L < S$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

For S: SSD, $h_1=1.2\text{m}$, $h_2=0.15$

$$L = 2S - \frac{4.4}{N}$$

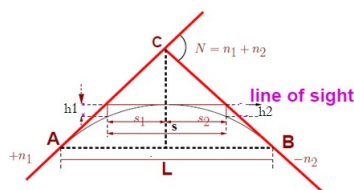
For S: OSD/ISD, $h_1=1.2\text{m}$, $h_2=1.2\text{m}$

$$L = 2S - \frac{9.6}{N}$$

Elements of Vertical Alignment: Vertical Curves

• Design of Summit Curves

• When $L > S$



- N : Deviation angle
- h_1 : Height of driver's eye level from the road surface
- h_2 : Height of obstruction on road

$$y = ax^2$$

$$a = \frac{N}{2L}$$

$$h_1 = aS_1^2$$

$$h_2 = aS_2^2$$

$$S_1 = \sqrt{\frac{h_1}{a}}$$

$$S_2 = \sqrt{\frac{h_2}{a}}$$

$$S_1 + S_2 = \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}}$$

$$S^2 = \left(\frac{1}{\sqrt{a}}\right)^2 (\sqrt{h_1} + \sqrt{h_2})^2$$

$$S^2 = \frac{2L}{N} (\sqrt{h_1} + \sqrt{h_2})^2$$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

For S: SSD, $h_1=1.2\text{m}$, $h_2=0.15$

$$L = \frac{NS^2}{4.4}$$

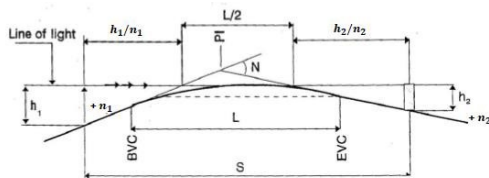
For S: OSD/ISD, $h_1=1.2\text{m}$, $h_2=1.2\text{m}$

$$L = \frac{NS^2}{9.6}$$

Elements of Vertical Alignment: Vertical Curves

• Design of Summit Curves

• When $L < S$



$$S = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{n_2}$$

For minima,

$$\frac{dS}{dn_1} = -\frac{h_1}{n_1^2} + \frac{h_2}{(N-n_1)^2} = 0$$

$$h_1(N-n_1)^2 = h_2n_1^2$$

Taking square roots on both sides

$$\sqrt{h_1}(N-n_1) = \sqrt{h_2}n_1$$

$$n_1(\sqrt{h_1} + \sqrt{h_2}) = N\sqrt{h_1}$$

$$n_1 = \frac{N\sqrt{h_1}}{(\sqrt{h_1} + \sqrt{h_2})}$$

So,

$$\begin{aligned} S &= \frac{L}{2} + \frac{h_1}{\frac{N\sqrt{h_1}}{(\sqrt{h_1} + \sqrt{h_2})}} + \frac{h_2}{N - \frac{N\sqrt{h_1}}{(\sqrt{h_1} + \sqrt{h_2})}} \\ &= \frac{L}{2} + \frac{h_1(\sqrt{h_1} + \sqrt{h_2})}{N\sqrt{h_1}} + \frac{h_2(\sqrt{h_1} + \sqrt{h_2})}{N(\sqrt{h_1} + \sqrt{h_2}) - N\sqrt{h_1}} \\ &= \frac{L}{2} + \frac{\sqrt{h_1}(\sqrt{h_1} + \sqrt{h_2}) + \sqrt{h_2}(\sqrt{h_1} + \sqrt{h_2})}{N} \\ &= \frac{L}{2} + \frac{(\sqrt{h_1} + \sqrt{h_2})^2}{N} \end{aligned}$$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

For S: SSD, $h_1=1.2\text{m}$, $h_2=0.15$

$$L = 2S - \frac{4.4}{N}$$

For S: OSD/ISD, $h_1=1.2\text{m}$, $h_2=1.2\text{m}$

$$L = 2S - \frac{9.6}{N}$$

Elements of Vertical Alignment: Vertical Curves

• Vertical Curves: Numerical

$h_1 = h_2 = 1.22\text{m}$

Design a vertical curve for the following data: $n_1 = +2.5\%$, $n_2 = -1.2\%$, OSD = 245 m, height of driver's eye from the road surface = 1.22 m.

$L > S$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$h_1 = h_2 = 1.22\text{m}$

$$L = \frac{N \times 245^2}{2(\sqrt{1.22} + \sqrt{1.22})^2}$$

$$= \frac{0.037 \times 245^2}{2(\sqrt{1.22} + \sqrt{1.22})^2} = 227.55\text{m}$$

$L > S$

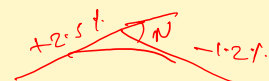
But $L < S$

Consider $L < S$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

$$= 2 \times 245 - \frac{(\sqrt{2 \times 1.22} + \sqrt{2 \times 1.22})^2}{0.037}$$

$$= 226.22\text{m}$$



$$N = n_1 - n_2$$

$$= 2.5 - (-1.2)$$

$$= 3.7\%$$

$$= 0.037$$

Elements of Vertical Alignment: Vertical Curves

• **Vertical Curves: Numerical**

Design a vertical curve for the following data: $n_1 = +2.5\%$, $n_2 = -1.2\%$. OSD = 245 m, height of driver's eye from the road surface = 1.22 m.

Considering $L > S$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$h_1 = h_2 = 1.22$ m

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$$N = n_1 - n_2$$

$$N = 2.50 - (-1.20)$$

$$N = 3.70\% = 0.037$$

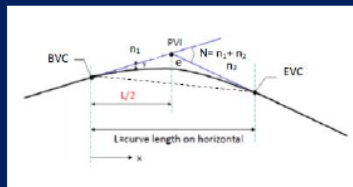
$$\text{OSD} = S = 245 \text{ m}$$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$$L = \frac{0.037 * 245^2}{2(\sqrt{1.22} + \sqrt{1.22})^2}$$

$$L = 227.60 \text{ m}$$

But $L < S$



Considering $L < S$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

$$L = (2 * 245) - \frac{(\sqrt{2 * 1.22} + \sqrt{2 * 1.22})^2}{0.037}$$

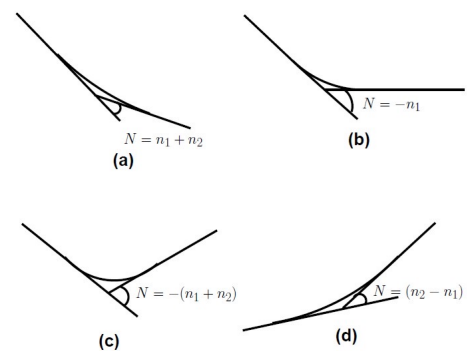
$$L = 226.30$$

$L < S$ (OK)

Elements of Vertical Alignment: Vertical Curves

• **Design of Valley Curve**

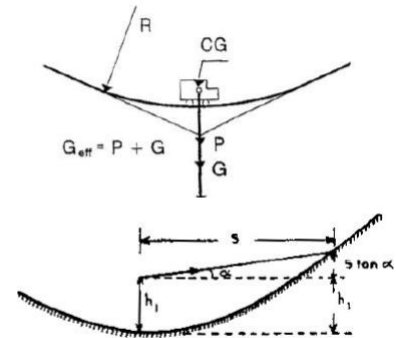
- Curve having concavity upwards or convexity downwards.
- Provided when:
 - a) A descending gradient meets another descending gradient of lower value.
 - b) A descending gradient meets a level gradient.
 - c) A descending gradient meets an ascending gradient.
 - d) An ascending gradient meets another ascending gradient of higher value.



Elements of Vertical Alignment: Vertical Curves

• **Design of Valley Curve**

- Factors affecting:
 - Comfort condition: Centrifugal force acts downwards along with the weight of the vehicle, so there is riding comfort.
 - Safety condition for night driving: Visibility is reduced during night and depends on headlight sight distance.



Elements of Vertical Alignment: Vertical Curves

• **Design of Valley Curve**

- A) For comfort condition:

Length of valley curve:

$$L = 2l_s = 2 \sqrt{\frac{Nv^3}{c}} \quad \text{for } v \text{ in } \frac{\text{m}}{\text{sec}}$$

$$L = 0.38\sqrt{NV^3} \quad \text{for } V \text{ in kmph, } c = 0.6\text{m/sec}^3$$

- c: Rate of change of centrifugal acceleration
- R: Minimum radius of the curve
- v: Design speed
- t: time to travel length of transition curve l_s

- A) For safety condition:

- When $L > S$

$$L = \frac{NS^2}{2h_1 + 2S \tan \alpha}$$

$$L = \frac{NS^2}{1.5 + 0.035S}$$

- When $L < S$

$$L = 2S - \frac{2h_1 + 2S \tan \alpha}{N}$$

$$L = 2S - \frac{1.5 + 0.035S}{N}$$

- N: Deviation angle
- h_1 : Height of headlight beam from road surface (0.75m)
- α : Headlight beam dispersion angle in vertical plane in degrees
- S: Sight distance required

Elements of Vertical Alignment: Vertical Curves

Design of Valley Curve

- A) For comfort condition:
 - Determined based on the allowable rate of change of centrifugal acceleration (0.6m/sec³)
 - For gradual introduction of centrifugal force, ideal curve is transition curve. Two similar transition curves of equal length is provided.
 - Cubic parabola is preferred as computation of ordinates is easier. For setting out of cubic parabola.

$$y = bx^3 \text{ where } b = \frac{2N}{3L^2}$$

Lowest point at $x = L\sqrt{\frac{h_1}{2N}}$ from BVC

$$c = \frac{\frac{v^2}{R} - 0}{t} = \frac{\frac{v^2}{R}}{\frac{l_s}{v}} = \frac{v^3}{l_s R}$$

$$l_s = \frac{v^3}{cR}$$

For cubic parabola:

$$R \text{ (at } l_s) = \frac{l_s}{N}$$

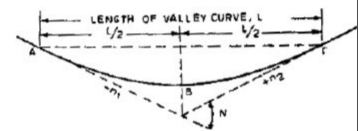
$$l_s = \frac{v^3}{c \frac{l_s}{N}} \rightarrow l_s^2 = \frac{Nv^3}{c} \rightarrow l_s = \sqrt{\frac{Nv^3}{c}}$$

Length of valley curve:

$$L = 2l_s = 2\sqrt{\frac{Nv^3}{c}} \text{ for } v \text{ in } \frac{\text{m}}{\text{sec}}$$

$$L = 0.38\sqrt{NV^3} \text{ for } V \text{ in kmph, } c = 0.6\text{m/sec}^3$$

- c: Rate of change of centrifugal acceleration
- R: Minimum radius of the curve
- v: Design speed
- t: time to travel length of transition curve l_s



Elements of Vertical Alignment: Vertical Curves

Design of Valley Curve

- B) For safety condition:
 - The driver should have adequate headlight sight distance equal to SSD at any point on the curve.
 - CASE I: When $L > S$
 - N: Deviation angle
 - h_1 : Height of headlight beam from road surface (0.75m)
 - α : Headlight beam dispersion angle in vertical plane in degrees
 - S: Sight distance required

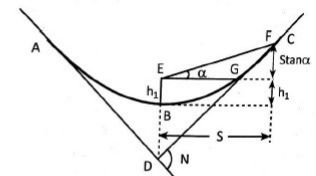
For simple parabolic curve:

$$y = ax^2, \quad a = \frac{N}{2L}$$

$$h_1 + S \tan \alpha = aS^2 = \frac{NS^2}{2L}$$

$$L = \frac{NS^2}{2h_1 + 2S \tan \alpha}$$

$$L = \frac{NS^2}{1.5 + 0.035S}$$



Elements of Vertical Alignment: Vertical Curves

Design of Valley Curve

- B) For safety condition:
 - The driver should have adequate headlight sight distance equal to SSD at any point on the curve.

CASE II: When $L < S$

N: Deviation angle

h_1 : Height of headlight beam from road surface (0.75m)

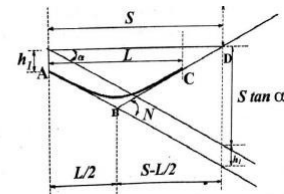
α : Headlight beam dispersion angle in vertical plane in degrees

S: Sight distance required

$$h_1 + S \tan \alpha = \left(S - \frac{L}{2} \right) N$$

$$L = 2S - \frac{2h_1 + 2S \tan \alpha}{N}$$

$$L = 2S - \frac{1.5 + 0.035S}{N}$$



Elements of Vertical Alignment: Vertical Curves

Vertical Curves: Numerical

A valley curve is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfil both comfort condition and headlight sight distance requirements for a design speed of 80 kmph. Assume allowable rate of change of centrifugal acceleration $C = 0.6 \text{ m/sec}^2$.

$N = n_1 - n_2 = -\frac{1}{25} - \frac{1}{30} = -0.0733$
 $V = 80 \text{ kmph} = 80 \times \frac{5}{18} = 22.22 \text{ m/sec}$

$L = 2 \sqrt{\frac{N V^2}{C}} = 2 \sqrt{\frac{0.0733 \times 22.22^2}{0.6}} = 72.22 \text{ m}$ *Comfort Condition*

Safety condition:
 $MSD = SSD$
 $SSD = 0.278 V t + \frac{V^2}{254 f}$ (length)
 $= 0.278 \times 80 \times 2.50 + \frac{80^2}{254 \times 0.36}$
 $= 125.60 \text{ m}$

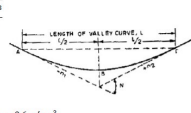
$L > S$: $L = \frac{N S^2}{1.5 + 0.035 \times S}$
 $= \frac{0.0733 \times 125.60^2}{1.5 + (0.035 \times 125.60)}$
 $= 196.121 \text{ m} > 125.60 \text{ (comfort)}$ *f = 0.36*
 $L = 196.121 \text{ m}$

$L > S$ and $L < S$ conditions are noted in the diagram.

Elements of Vertical Alignment: Vertical Curves

Vertical Curves: Numerical

A valley curve is formed by a descending grade of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfil both comfort condition and headlight sight distance requirements for a design speed of 80 kmph. Assume allowable rate of change of centrifugal acceleration $C = 0.6 \text{ m/sec}^2$.

$n_1 = -1/25$ $n_2 = +1/30$ $V = 80 \text{ kmph}$ $V = 80 * \frac{5}{18} = 22.22 \text{ m/sec}$ $N = n_1 - n_2$ $N = -\frac{1}{25} - \frac{1}{30} = -\frac{11}{150}$ $C = 0.60 \text{ m/sec}^2$	<p>Length of curve for comfort condition:</p> $L = 2 \sqrt{\frac{Nv^3}{C}}$ $L = 2 \sqrt{\frac{0.0733 * 22.22^3}{0.60}}$ $L = 73.10 \text{ m}$	 <p>Length of valley curve:</p> $L = 2L_s = 2 \sqrt{\frac{Nv^3}{C}} \text{ for } v \text{ in } \frac{\text{m}}{\text{sec}}$ $L = 0.38 \sqrt{\frac{N}{V^3}} \text{ for } V \text{ in kmph, } C = 0.6 \text{ m/sec}^2$ $L = \frac{NS^2}{1.5 + 0.035S}$
<p>Length for head light sight distance:</p> $\text{HSD} = \text{SSD}$ $\text{SSD} = 0.278 Vt + \frac{v^2}{254f}$ $\text{SSD} = 0.278 * 80 * 2.50 + \frac{80^2}{254 * 0.36}$ $\text{SSD} = 55.60 + 70$ $\text{SSD} = 125.60 \text{ m}$	<p>Assuming $L > \text{SSD}$</p> $L = \frac{1.5 + 0.035S}{0.0773 * 125.60^2}$ $L = \frac{1.5 + 0.035 * 125.60}{5.896}$ $L = \frac{1219.43}{5.896}$ $L = 206.82 \text{ m} > \text{SSD (Assumption is correct)}$	<p>Accepting higher value of length of valley curve, we have,</p> <p>Length of valley curve = 210m</p>

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Elements of Vertical Alignment: Vertical Curves

The highest point on the summit curve is at a distance

$$\frac{n_1 L}{N} \text{ from the tangent point on the first grade } n_1.$$

The lowest point on the valley curve is to be located for providing the cross drainage facility.

The lowest point on the valley curve will be on the bisector of the angle between the grades, if the gradients on either side are equal.

When the gradients are not equal, the lowest point lies on the side of flatter grade, and this point is at a

distance $X_o = L \sqrt{\frac{n_1}{2N}}$ from the tangent point of the first grade n_1 .

$$\text{Tangent Correction} = \frac{x^2}{2R}$$

$$\text{Tangent Correction} = \frac{(g_1 - g_2)x^2}{200L}$$

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Elements of Vertical Alignment: Vertical Curves

Vertical Curves: Numerical

A 2% gradient meets a -0.25% gradient at a chainage of 1085 m and at the reduced level of 76.55 m if the sight distance be 304.80m, determine the length of the vertical curve and the reduced levels of the tangents points and the highest point on the curve. Assume that the eye level of the driver eye is 1.143 m and the height of the obstruction is 0.10 m.

$S = 304.80\text{m}$, $N = n_1 - n_2 = 2 - (-0.25) = 2.25 \therefore 0.0225$
 $L > S$
 $L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$
 $h_1 = 1.143\text{m}$
 $h_2 = 0.10\text{m}$
 $L = \frac{0.0225 \times 304.80^2}{2(\sqrt{1.143} + \sqrt{0.10})^2} = 544.59\text{m} > 304.80\text{m}$ (Assumption correct)

$PVI = 1085\text{m}$, 76.55m
 272.295 (from PVI to BVC)
 272.295 (from PVI to EVC)
 544.59 (total length L)
 Elevation of BVC = $76.55 - 0.02 \times 272.295 = 71.10\text{m}$
 Elevation of EVC = $76.55 + 0.0025 \times 272.295 = 75.87\text{m}$

Considering $L > S$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

Considering $L < S$

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

Elements of Vertical Alignment: Vertical Curves

Vertical Curves: Numerical

A 2% gradient meets a -0.25% gradient at a chainage of 1085 m and at the reduced level of 76.55 m if the sight distance be 304.80m, determine the length of the vertical curve and the reduced levels of the tangents points and the highest point on the curve. Assume that the eye level of the driver eye is 1.143 m and the height of the obstruction is 0.10 m.

Distance of highest point from BVC = $n_1 \times \frac{L}{N} = \frac{0.02 \times 544.59}{0.0225} = 484.08\text{m}$
 Distance of highest from EVC = $545 - 484.08 = 60.51\text{m}$ (Point A)

Elevation of point A = $76.55 - 0.0025 \times (272.295 - 60.51) = 76.021\text{m}$
 Target correction = $\frac{n^2}{2R} = \frac{n^2}{2 \times \frac{L}{N}} = 0.075\text{m}$
 Elevation of highest point on curve = $76.021\text{m} - 0.075\text{m} = 75.946\text{m}$

Elements of Vertical Alignment: Vertical Curves

- A 2% gradient meets a -0.25% gradient at a chainage of 1085 m and at the reduced level of 76.55 m if the sight distance be 304.80m, determine the length of the vertical curve and the reduced levels of the tangents points and the highest point on the curve. Assume that the eye level of the driver eye is 1.143 m and the height of the obstruction is 0.10 m.

$h_1 = 1.143 \text{ m}, h_2 = 0.10 \text{ m}$

Considering $L > S$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$$N = n_1 - n_2$$

$$N = 2.0 - (-0.25) = 2.25 \%$$

$$N = 0.0225$$

$$SSD = S = 304.80 \text{ m}$$

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

$$L = \frac{0.0225 \times 304.80^2}{2(\sqrt{1.143} + \sqrt{0.10})^2} = 545 \text{ m}$$

$$\text{Tangent Length } T = \frac{L}{2} = \frac{545}{2}$$

$$T = 272.50 \text{ m}$$

Elevation at the beginning of vertical curve = Elevation of PVI - $n_1 \cdot T$
Elevation of BVC = $76.55 - 0.02 \times 272.50 = 71.10 \text{ m}$

Elevation at the end of vertical curve = Elevation of PVI - $n_2 \cdot T$
= $76.55 - 0.0025 \times 272.50 = 75.87 \text{ m}$

Distance of highest point from the BVC = $n_1 \cdot \frac{L}{N}$

Distance of highest point from BVC = $0.02 \times \frac{545}{0.0225}$

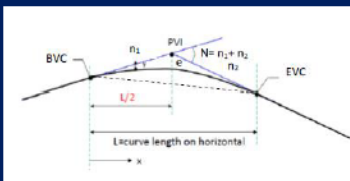
Distance of highest point from BVC = 484.44 m

Distance of highest point from EVC (x) = $545 - 484.44$

Distance of highest point from EVC (x) = 60.56 m

Elevation at the corresponding point on tangent line = $76.55 - (0.0025) \times (272.50 - 60.56) = 76.01 \text{ m}$

Tangent correction = $-\frac{x^2}{2R} = -\frac{60.56^2}{2 \times \frac{L}{N}} = -\frac{60.56^2}{2 \times \frac{545}{0.0225}} = -0.0785 \text{ m}$



Elevation of highest point of the curve = $76.01 - 0.0785 = 75.93 \text{ m}$

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Elements of Vertical Alignment: Vertical Curves

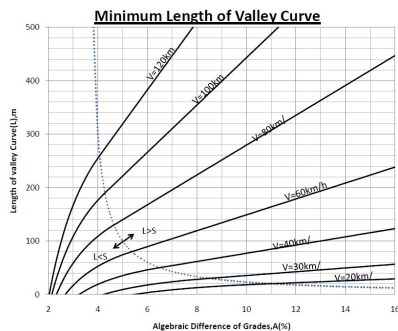


Figure 24-5: Minimum Length of Valley Curve

Source: NRS 2070

Design Speed (Kmph)	Maximum grade change (%) not requiring a vertical curve	Minimum length of vertical curve (m)
Up to 35	1.5	15
40	1.2	20
50	1.0	30

Source: NRRS 2071

Design Speed, km/h	Maximum Grade Change (%) not requiring a Vertical Curve	Minimum Length of Vertical Curve (m)
10	1.8	10
20	1.6	12
30	1.5	15
40	1.2	25
50	1.0	30

Source: NURS 2076

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Thank You!

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