SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Addis Ababa Institute of Technology

HIGHWAY ENGINEERING I
CENG 3202

Chapter III
Geometric Design of Highways

2012EC (2019/20) 2nd Sem

Tamru T.

Defintion – Geometric Design

- **Geometric design** **is the process whereby the layout of the road in the terrain is designed to meet the needs of the road users.**

The Design Process

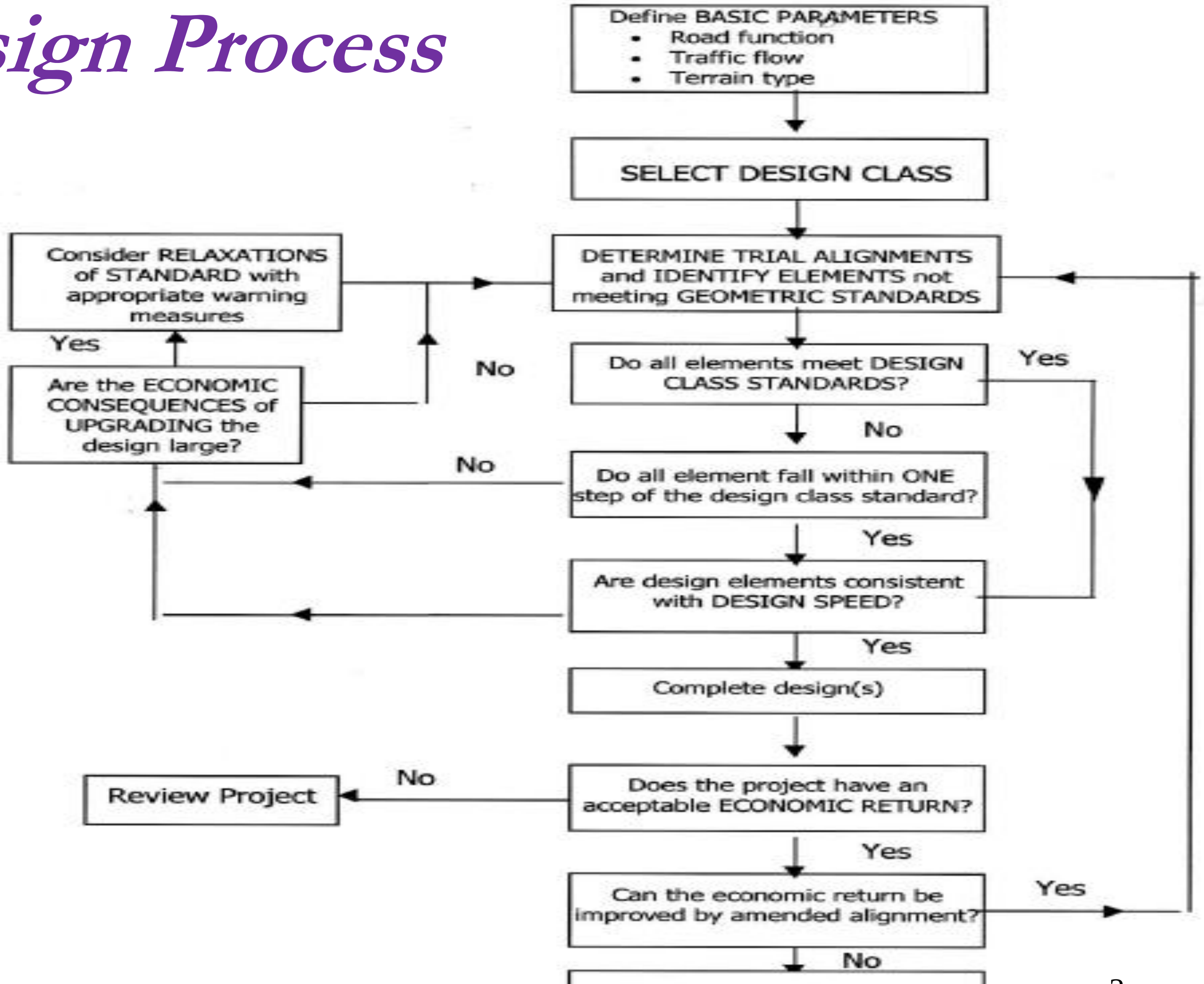


Figure 5-1: The Design Process

Geometric features

- **Horizontal alignment**
- **Vertical alignment.**
- **Cross-section**

Geometric design standards

1. Standards are intended to provide minimum levels of safety and comfort for drivers by the provision of adequate sight distances, coefficients of friction and road space for vehicle manoeuvres;
2. They provide the framework for economic design; and
3. They ensure a consistency of alignment.

The design standards must take into account the environmental road conditions, traffic characteristics, and driver behaviour.

Geometric design and standards

- Topography, land use and physical features.
- Environmental considerations.
- Road safety considerations.
- Road function and control of access.
- Traffic volume and capacity.
- Design speed and other speed controls.
- Design vehicle and vehicle characteristics.
- Economic and Financial considerations.
- Alternative construction technologies.

Geometric Design – Selection design standard

- **The section of design standards is related to**
  - **road function,**
  - **volume of traffic and**
  - **terrain**

Highway Design Controls

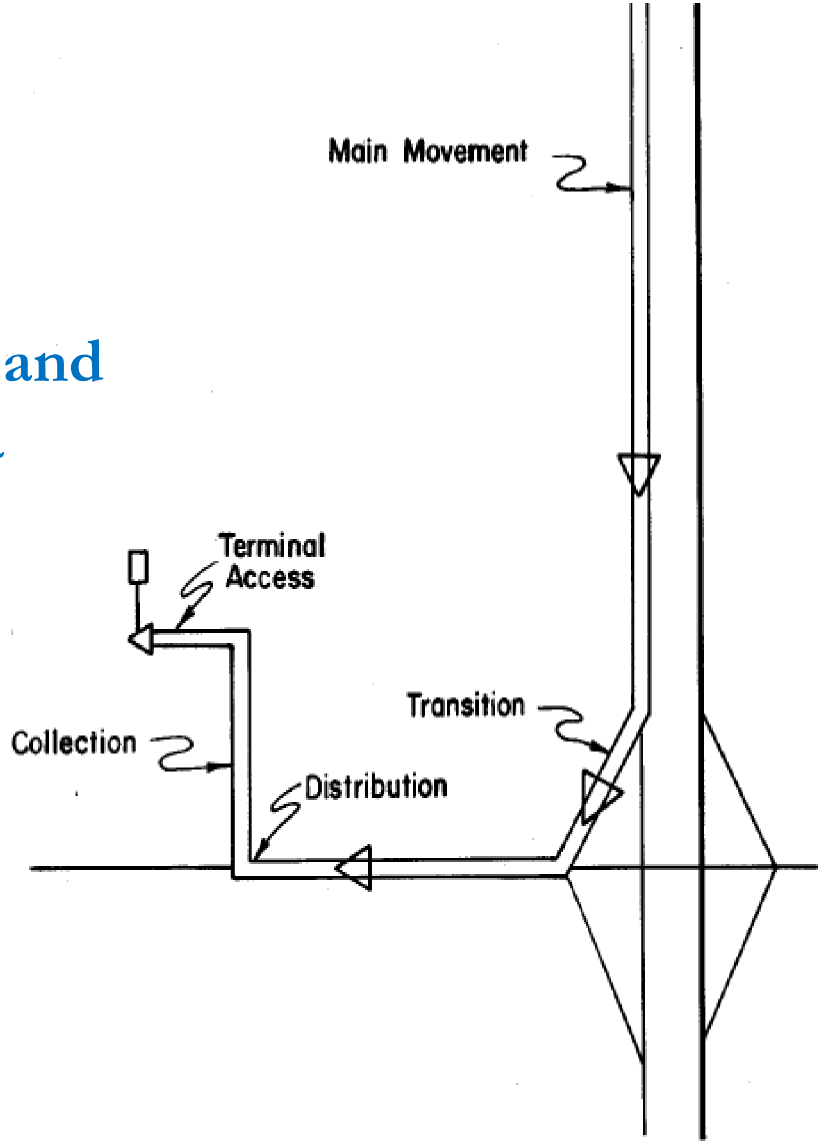
- Functional classification
- Design hourly traffic volume and vehicle mix
- Design speed
- Design vehicle
- Cross section of the highway, such as lanes, shoulders, and medians
- Presence of heavy vehicles on steep grades
- Topography of the area that the highway traverses
- Level of service
- Available funds
- Safety
- Social and environmental factors

Highway Function

Mobility & Accessibility

Mobility: The ability to move goods and passengers to their destination. (in a reasonable time)

Accessibility: The ability to reach desired destination,

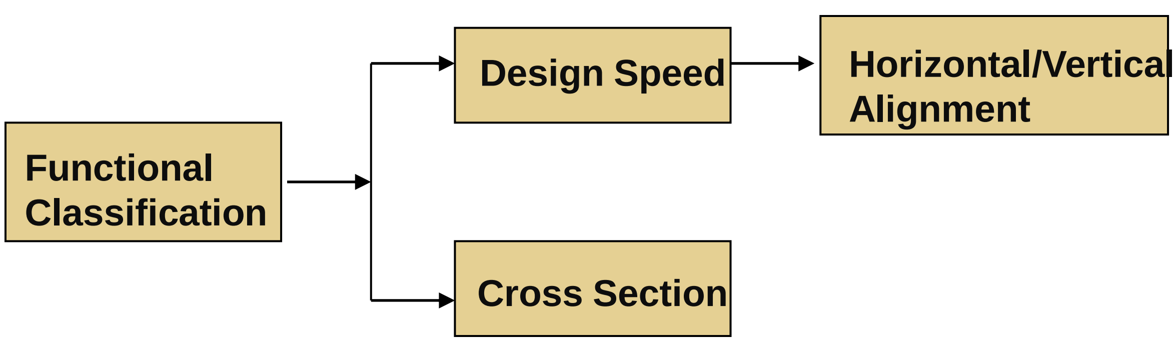


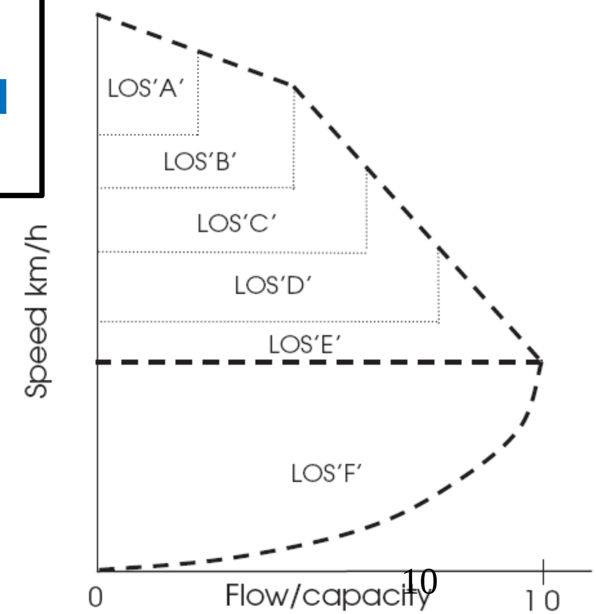
Highway Function (cont'd)

The first step in the design process is to define the function that the facility is to serve.

The level of service required to fulfill this function for the anticipated volume and composition of traffic provides a rational and cost-effective basis for the <u>selection of design speed</u> and <u>geometric criteria</u> within the range of values available to the designer (for the specified functional classification).

The use of functional classification as a design type should appropriately integrate the highway planning and design process.





Road Functional Classification (ERA)

- **I. Trunk Roads (Class I)**

  Centres of international importance and roads terminating at international boundaries are linked with Addis Ababa by trunk roads.

- **II. Link Roads (Class II)**

  Centres of national or international importance, such as principal towns and urban centres, must be linked between each other by link roads.

- **III. Main Access Roads (Class III)**

  Centres of provincial importance must be linked between each other by main access roads.

- **IV. Collector Roads (Class IV)**

  Roads linking locally important centres to each other, to a more important centre, or to higher class roads must be linked by a collector road.

- **V. Feeder Roads (Class V)**

  Any road link to a minor centre such as market and local locations is served by a feeder road.

Design standard, AADT, Road function

Road Functional Classification	Design Standard	Design Traffic Flow (AADT) (Mid-life)	Surface Type
TRUNK	DC8	10,000 – 15,000	Paved
TRUNK, LINK	DC7	3,000 – 10,000	Paved
TRUNK, LINK	DC6	1,000 – 3,000	Paved
TRUNK, LINK, MAIN ACCESS	DC5	300 – 1,000	Paved
TRUNK, LINK, MAIN ACCESS, COLLECTOR	DC4 (2)	150 – 300	Paved
			Unpaved
LINK, MAIN ACCESS, COLLECTOR, FEEDER	DC3 (2)	75 – 150	Paved
			Unpaved
MAIN ACCESS, COLLECTOR, FEEDER	DC2 (2)	25 – 75	Paved
			Unpaved
FEEDER	DC1	1 – 25	Unpaved
FEEDER	Basic Access	<10	Unpaved

Source:
ERA 2013 GDM

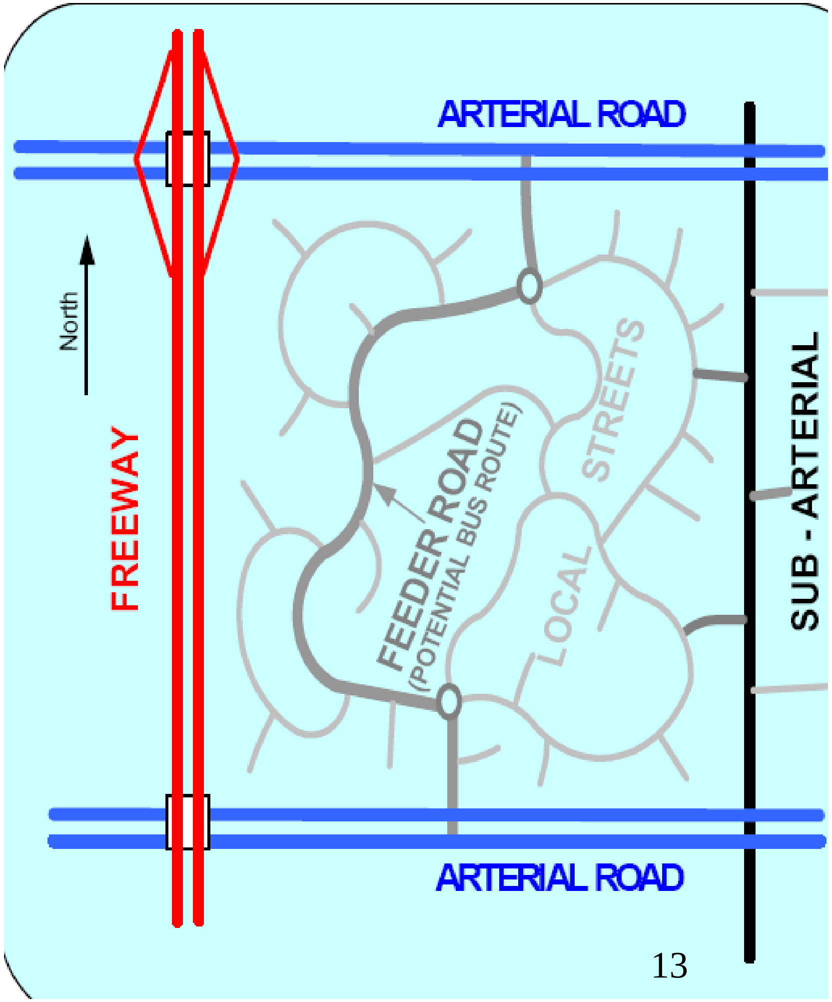
(2) The choice of *design standard depends on the numbers of Large Heavy Vehicles as well as AADT*

Road functional classification (AACRA)

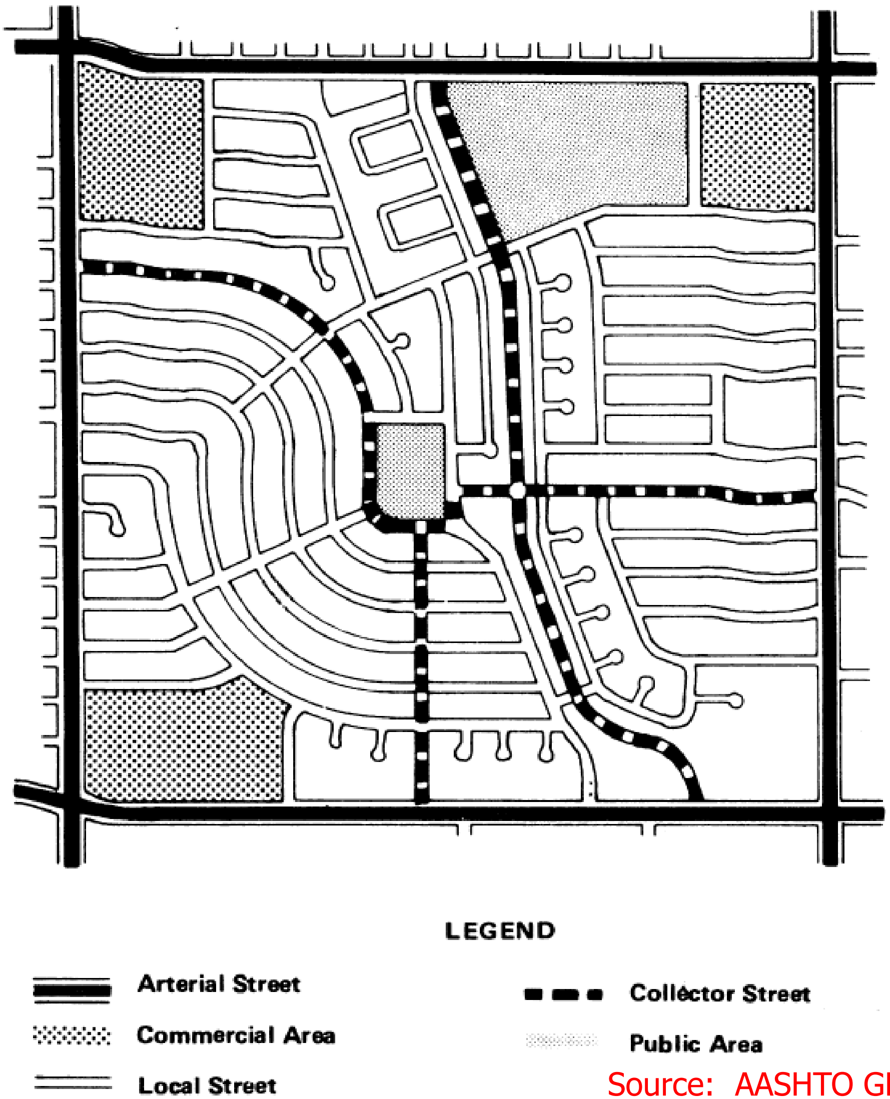
- Arterial roads (including freeways)
- Sub-arterial roads
- Feeder roads
- Local roads

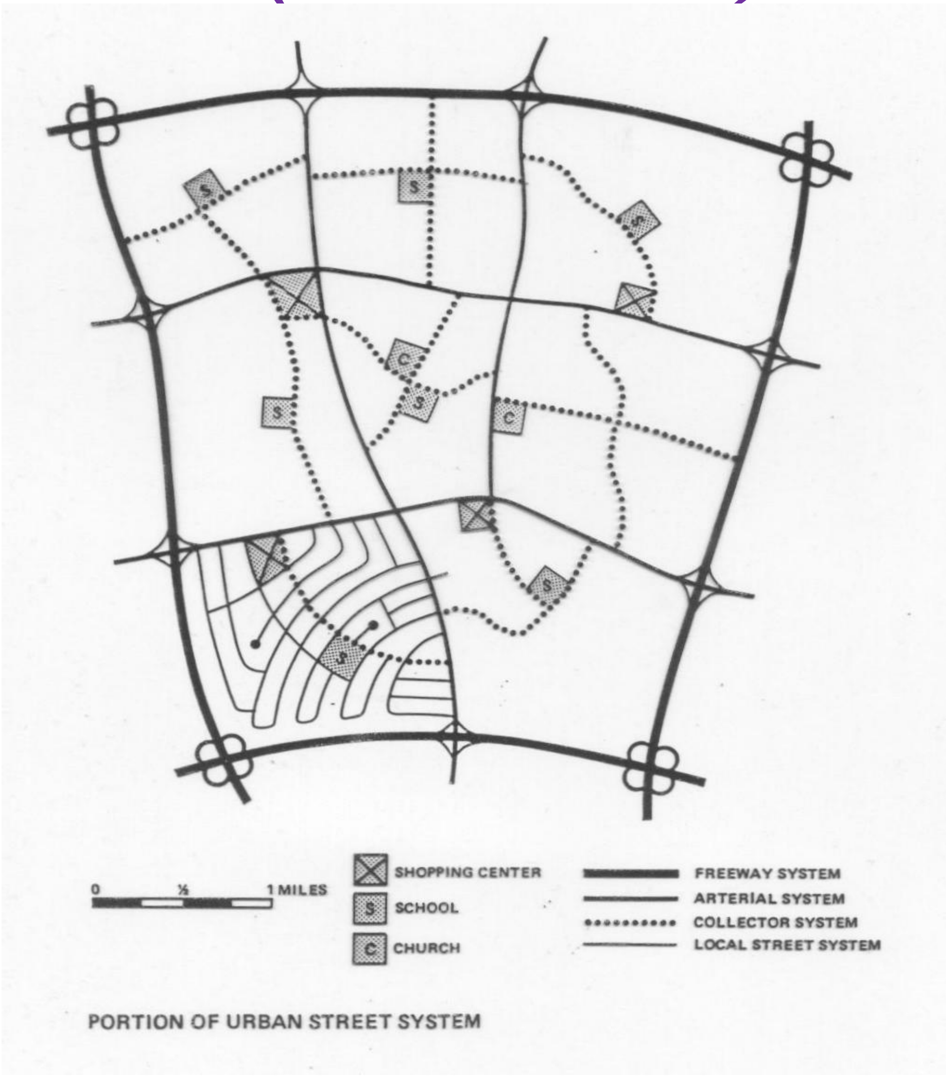
Arterials --- high mobility, low access, long trips, fast speeds

Source: AACRA GDM



Urban road classification (AASHTO)





Source: AASHTO GDMHS

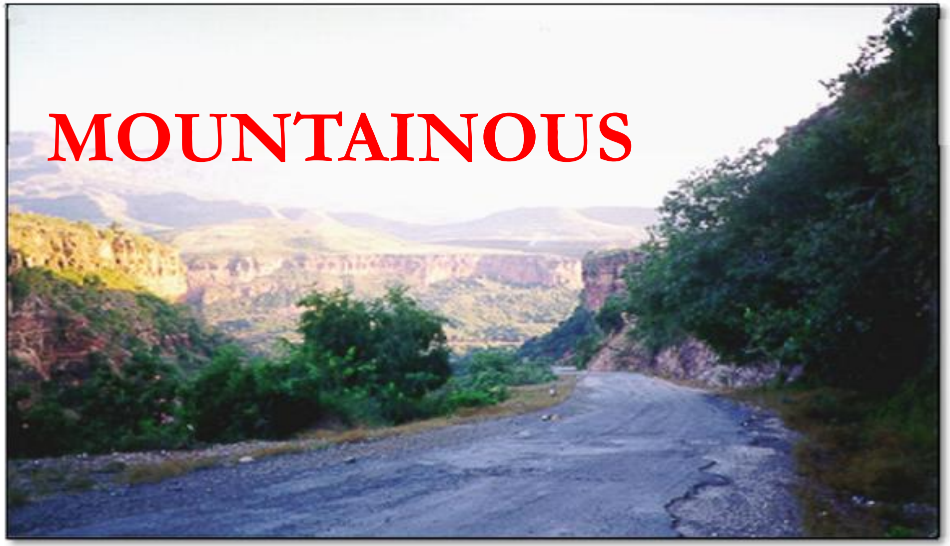
Design traffic volume

- The design of a road should be based in part on factual traffic volumes.
- It affects widths, alignments, and gradients
- Available in terms of annual average daily traffic (AADT)
- Using road functional classification selection and design traffic flow, a design class, or standard, is selected

Terrain Classification

- The geometric design elements of a road depend on the transverse terrain through which the road passes.
  - **FLAT:** slope from 0 – 5%
  - **ROLLING:** slope from 5% - 25%
  - **MOUNTAINOUS:** slope from 25% - 50%
  - **ESCARPMENT:** slope in excess of 50%

Terrain Classification



Design Speed

- is used as an index which links road function, traffic flow and terrain to the design parameters of sight distance and curvature
- design elements such as lane and shoulder widths, horizontal radius, super elevation, sight distance and gradient are directly related to, and vary, with design speed.

Design Speed

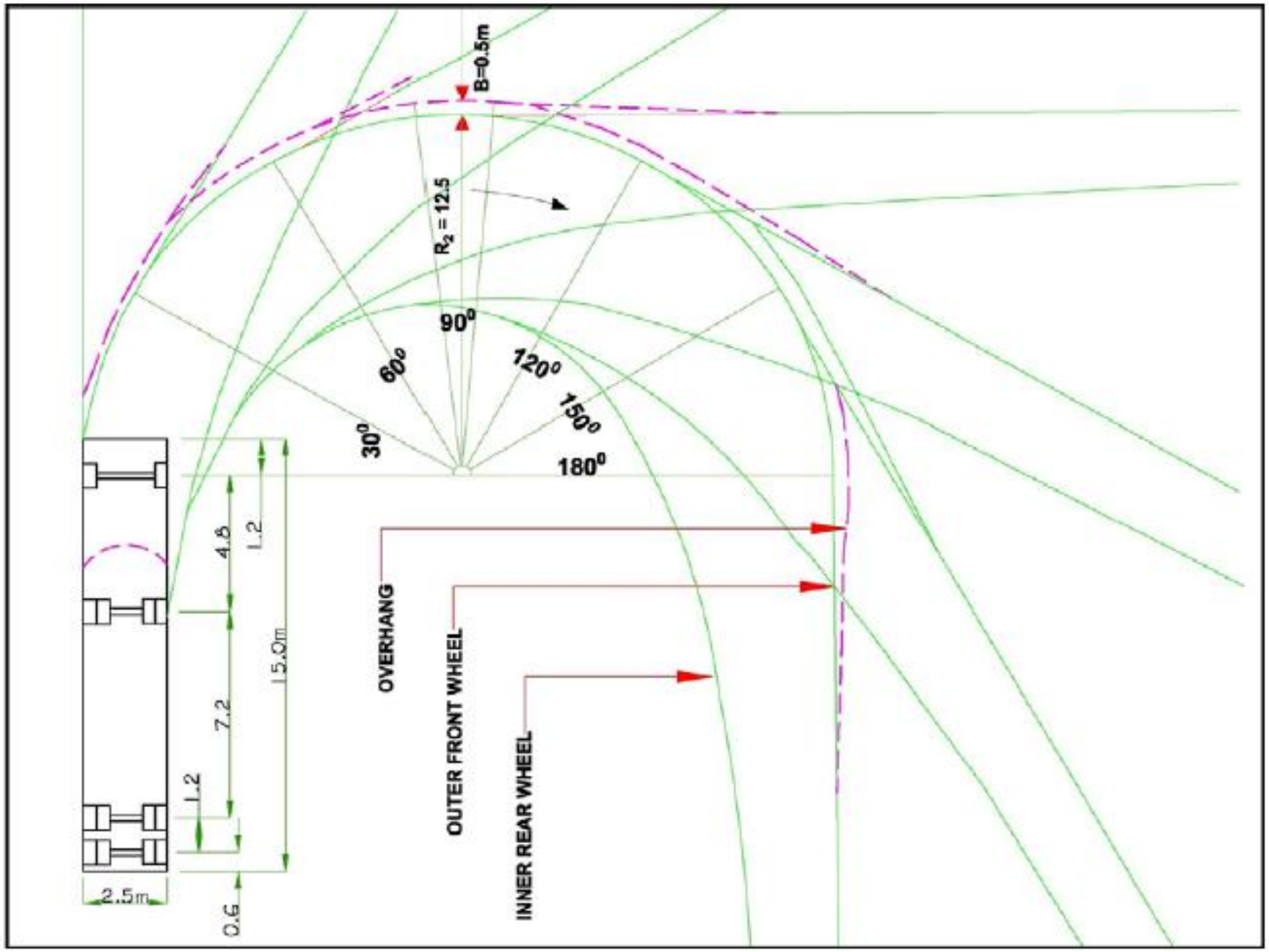
Design standard	Design speed (km/h)				
	Flat	Rolling	Mountain	Escarpment	Urban
DC 8	120	100	85	70	50
DC 7	120	100	85	70	50
DC 6	100	85	70	60	50
DC 5	85	70	60	50	50
DC 4	70	60	50 (46) [1]	25	50
DC 3	70	60	50 (46) [1]	25	50
DC 2	60	50	40(37) [1]	20	50
DC 1	50	40	30	20	40

Source: ERA 2013 GDM

Design Vehicle

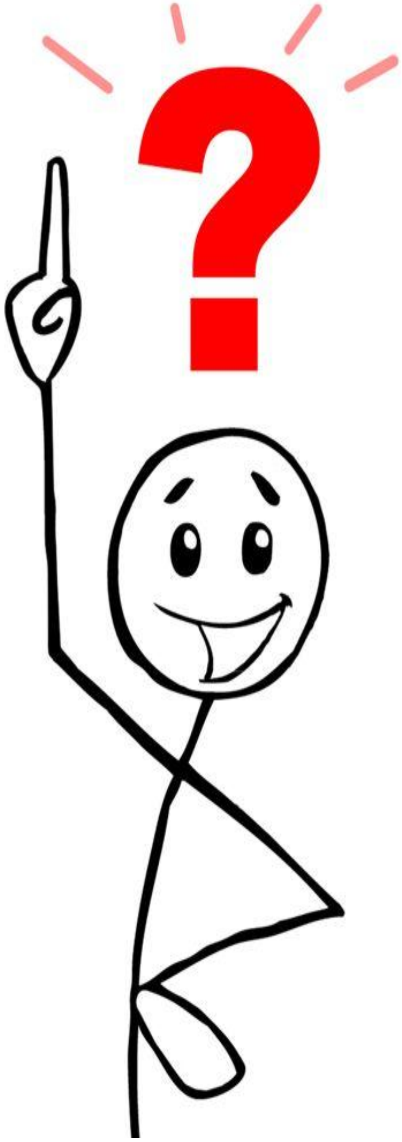
- **Vehicle characteristics and dimensions affecting design include power to weight ratio, minimum turning radius and travel path during a turn, and vehicle height and width.**
- **The road elements affected include the selection of maximum gradient, lane width, horizontal curve widening, and junction design.**

Design Vehicles in Ethiopia



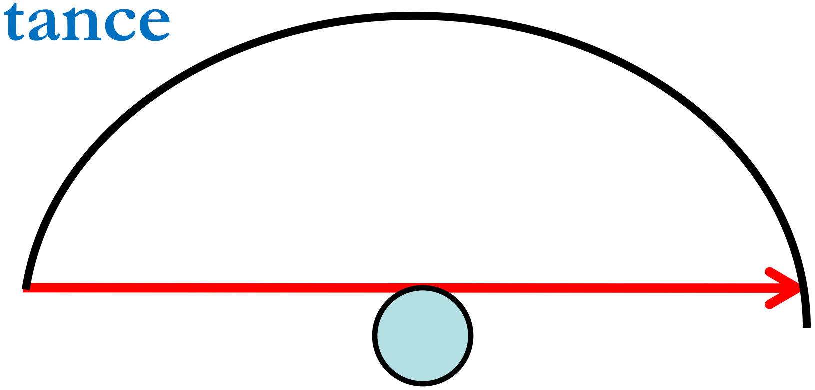
Dimensions and Turning Radius for a Semi-Trailer Combination

Source: ERA 2013 GDM



Sight Distance

- Stopping sight distances
- Passing sight distances
- Meeting Sight Distance



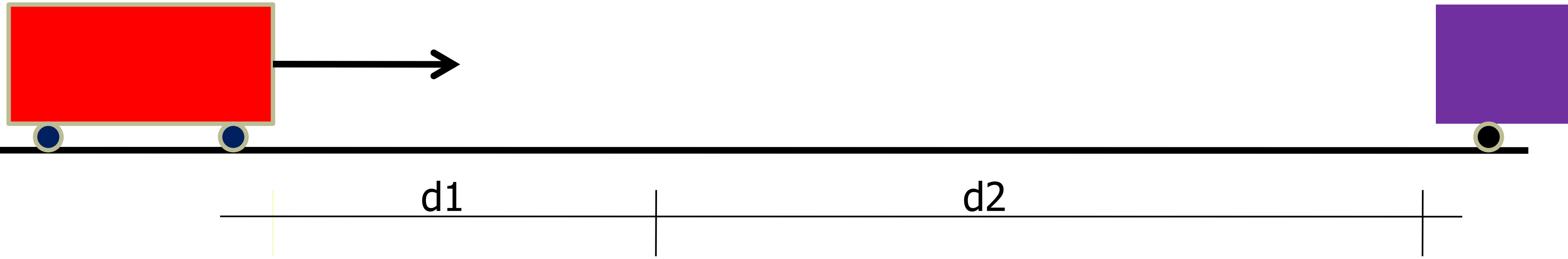
Stopping sight distance

- A vehicle travelling at the design speed to stop before reaching a stationary object in its path.

$$d = (0.278)(t)(V) + \frac{V^2}{\left(254(f + g/100)\right)}$$

where

- d is distance in meters
- t driver's reaction time (=2.5 sec)
- V is initial speed (in Km/h)
- f is coefficient of friction b/n the tyre and road
- g = gradient of road as a percentage (downhill is negative)



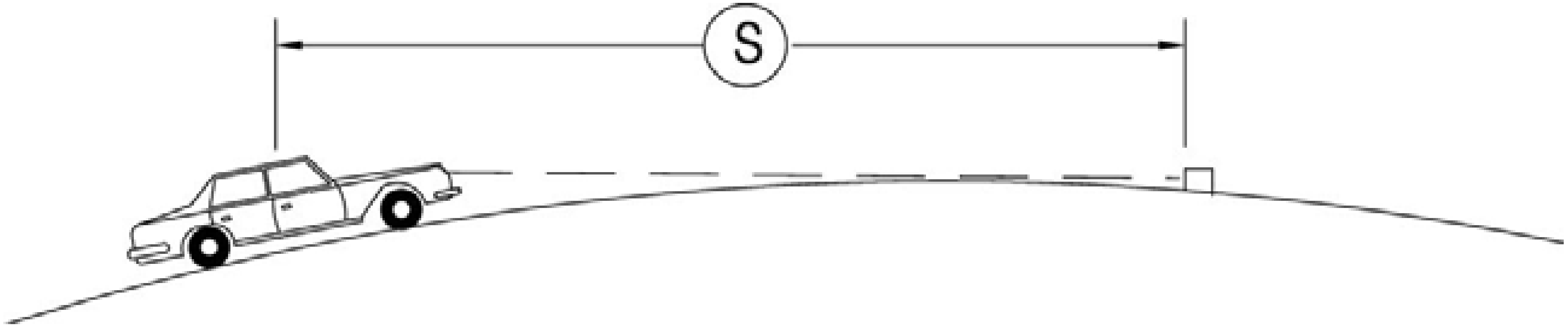
- **d1 = the distance travelled for reaction time**
- **d2 = braking distance**

$d1 = Vt = (10/36)Vt = 0.278Vt$, V in Km/hr, t is the reaction time = 2.5 sec

$d2 = V^2/2a = V^2/2gf = (V/3.6)^2/(2x9.81f) = V^2/254f$

Control of Sight Distance

- Sight distances should be checked during design, and adjustments made to meet the minimum requirements.
  - Driver's eye height: 1.07 meters
  - Object height for stopping sight distance: 0.15 meters
  - Object height for passing sight distance: 1.30 meters



Control of Sight Distance

Design Speed (km/h)	Coefficient of Friction (f)	Stopping Sight Distance (m)			Minimum Passing Sight Distance (m) (from formulae)	Passing Sight Distance to allow manoeuvre to be aborted (m)
		g = 0	g = 5%	g = 10%		
20	.42	18	18	19	160	-
25	.41	23	24	25	190	50
30	.40	30	32	33	220	80
40	.37	45	47	50	285	135
50	.35	65	70	75	350	180
60	.33	85	90	105	415	230
70	.315	110	120	140	480	270
80	.305	140	155	180	545	310
85	.295	155	175	205	575	330
90	.29	170	195	230	610	345
100	.285	210	240	285	675	375
110	.28	245	285	340	740	405
120	.28	285	330	400	805	425

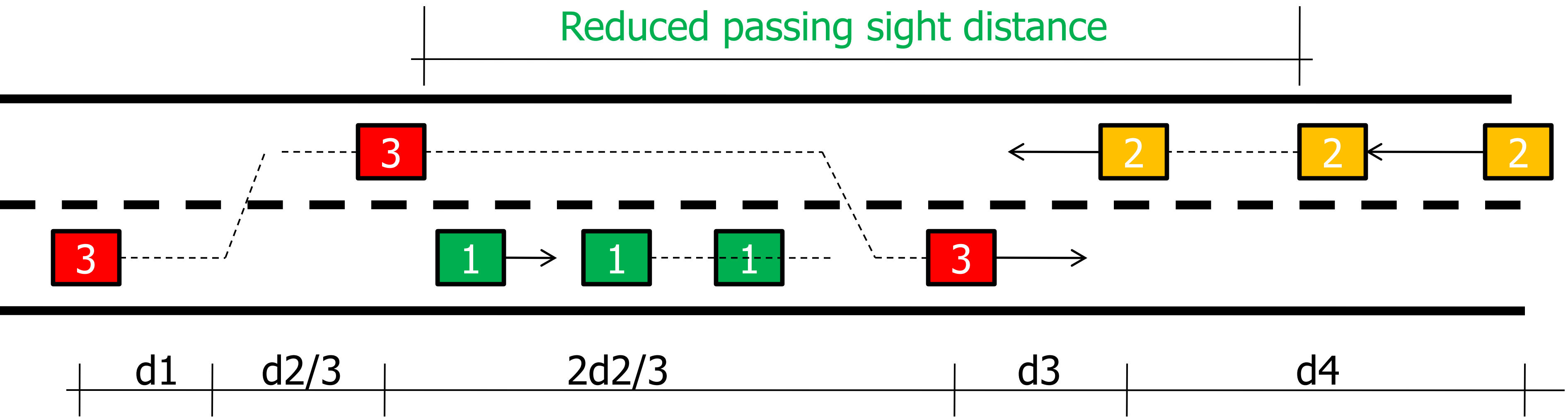
Stopping Sight Distance: Single Lane Roads (meeting sight distance)

- **It is required to enable both approaching drivers to stop.**

- **This distance is the sum of the stopping sight distance for the two vehicles, plus a 30 meter safety distance.**

Passing Sight Distance (PSD)

- This is the minimum sight distance on two-way single roadway roads that must be available to enable the driver of one vehicle to pass another vehicle safely without interfering with the speed of an oncoming vehicle travelling at the design speed.



Passing sight distance

PSD = d1 + d2 + d3 + d4
where

- d1 = initial manoeuvre distance, including a time for perception and reaction
- d2 = distance during which passing vehicle is in the opposing lane
- d3 = clearance distance between vehicles at the end of the manoeuvre
- d4 = distance traversed by the opposing vehicle

$$d_1 = 0.278\, t_1 \left(v - m + \frac{at_1}{2}\right)$$

where

t1 = time of initial manoeuvre, s

a = average acceleration, km/h/s

v = average speed of passing vehicle, km/h

m = difference in speed of passed vehicle and passing vehicle, km/h

$$d_2 = 0.278\, vt_2$$

where

t2 = time passing vehicle occupies left lane, s

v = average speed of passing vehicle, km/h

d3 = clearnace distance taken from table below

Speed Group (km/h)	50-65	66-80	81-100	101-120
d_3 (m)	30	55	80	100

d4 = distance traversed by the opposing vehicle, which is approximately equal to d2 less the portion of d2 whereby the passing vehicle is entering the left lane, estimated at:

$$d_4 = 2d_2/3$$

Example

Calculate the safe stopping sight distance for design speed of 50km/hr,

a. Two way traffic on two lane road
b. Two way traffic on single lane road

Example

Calculate the minimum sight distance required to avoid a head on collusion of two cars approaching from opposite direction at 90 and 60 km/hr. coefficient of friction 0.7 and a brake efficiency 50%.

Quiz 1

A driver of a car applied the brakes and barely avoided hitting an obstacle on a roadway section which has a 5 percent gradient. The vehicle left skid marks 26 meters. Assuming that the coefficient of friction is 0.6 and the driver was travelling down the grade; determine whether the problem was the speed limit of 60kph on the section or driver violation of the speed limit.

If it is the driver fault or speed limit what was the driver / limit speed?

Horizontal Alignment

- There are many factors that forced to change the alignment of routes.
- When there is change in direction a horizontal curve is inserted for smooth transition
- Design elements in horizontal alignment
  - the tangent, or straight section,
  - the circular curve,
  - the transition curve (spiral) and
  - the superelevation section.

Straight section

- They provide better visibility and more passing opportunities.
- However, long tangent sections increase the danger from headlight glare and usually lead to excessive speeding.
- In hot climate areas, long tangents have been shown to increase driver fatigue and hence cause accidents.

The Cirular Curve

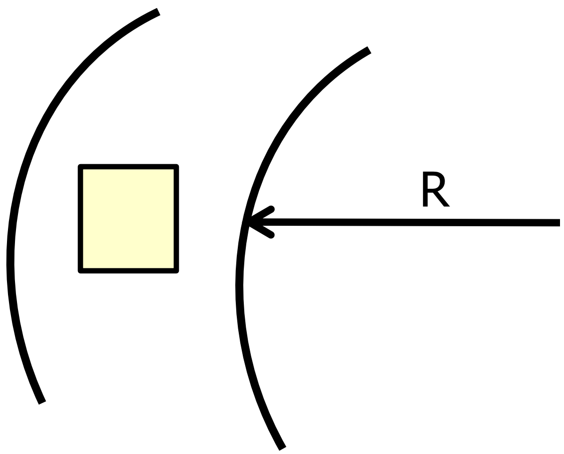
- There is centrifugal force on the vehicle
- This is balanced by super-elevation and friction between the tyre and the road

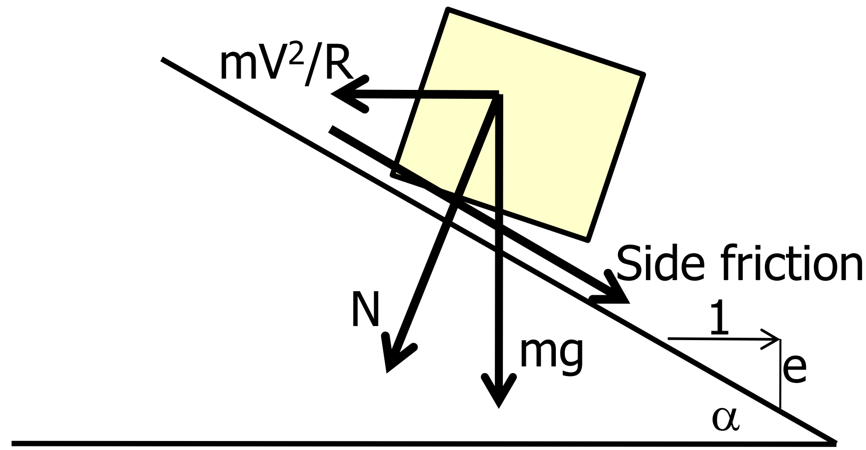
- For particular design speed, the minimum radius of the curve is

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

  - where Vd is the deisgn speed
  - e super elevation in%
  - f friction ceofficient

Minimum Circular Curve Radius





$$(mV^2/R)\cos\alpha = mg\sin\alpha + Nf$$

$R = V^2/127(e+f)$

Where: V is the design speed in km/hr
e is the superelevation
f is the side friction coefficient

Elements of Circular Curve

1) Δ : Deflection Angle by Arc Definition (in degrees)

2) R : Radius of Curve by Arc Definition

3) T (Tangent Distance) $T = R\tan\frac{\Delta}{2}$

4) E (External Distance) $E = R\left[\mathrm{Sec}\frac{\Delta}{2} - 1\right]$

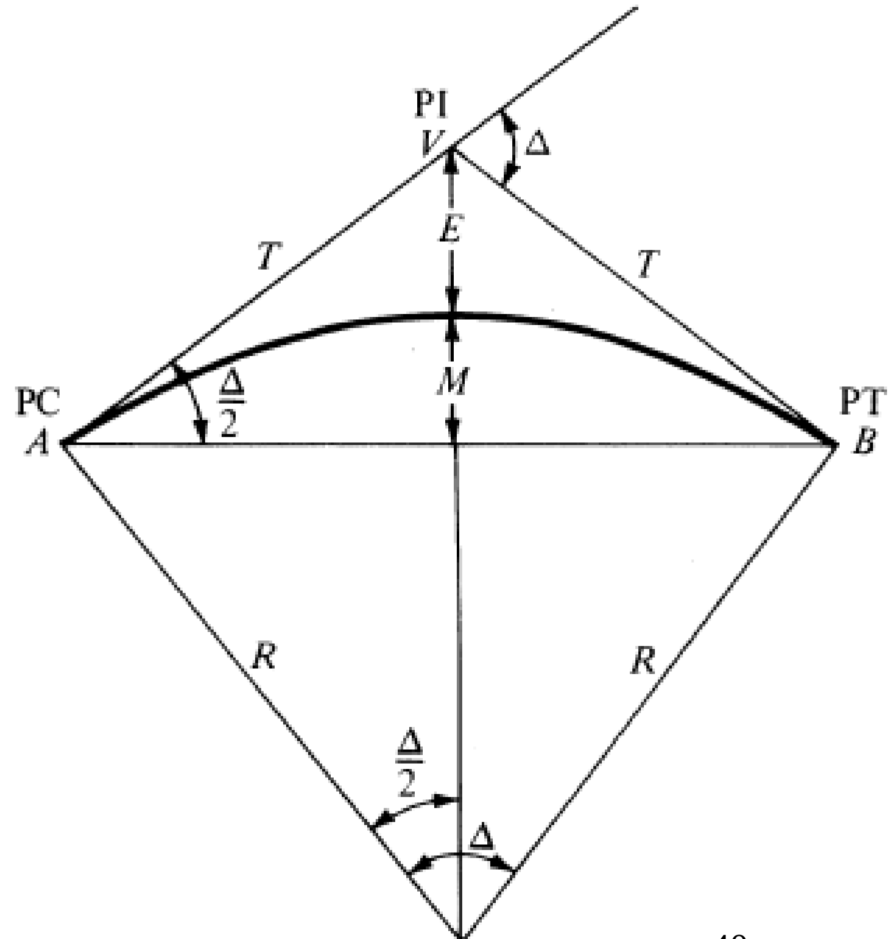
5) L (Curve Length) $L = \Delta \times R\frac{2\Pi}{360}$

6) M (Middle Ordinate) $M = R\left|1 - \cos\frac{\Delta}{2}\right|$

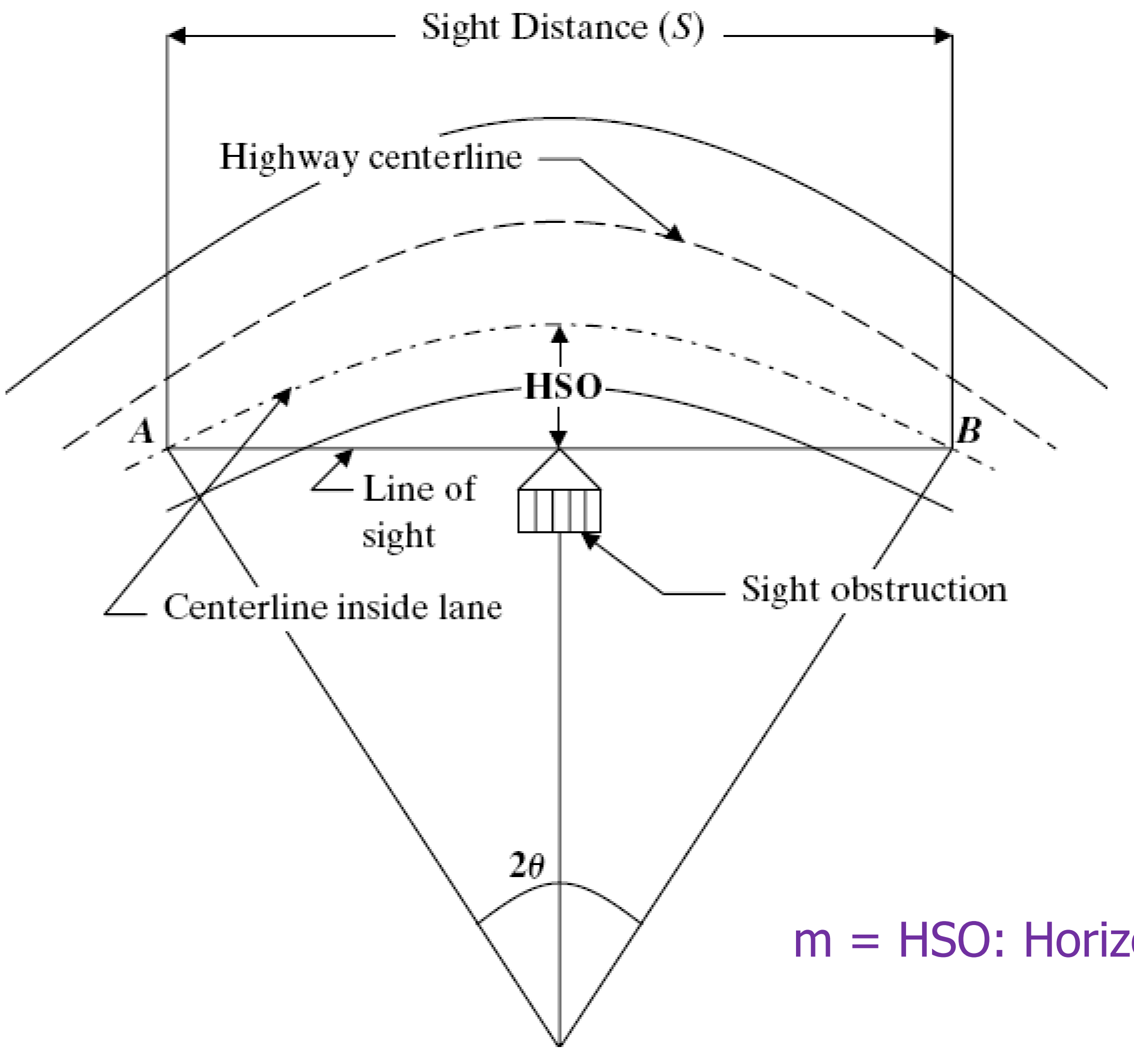
7) C (Chord from P.C. to P.T.) $C = 2R\sin\frac{\Delta}{2}$

8) Point-of-Curvature (P.C.) Station P.C.= P.I. – T

9) Point-of-Tangency (P.T.) Station P.T. = P.C.+ L

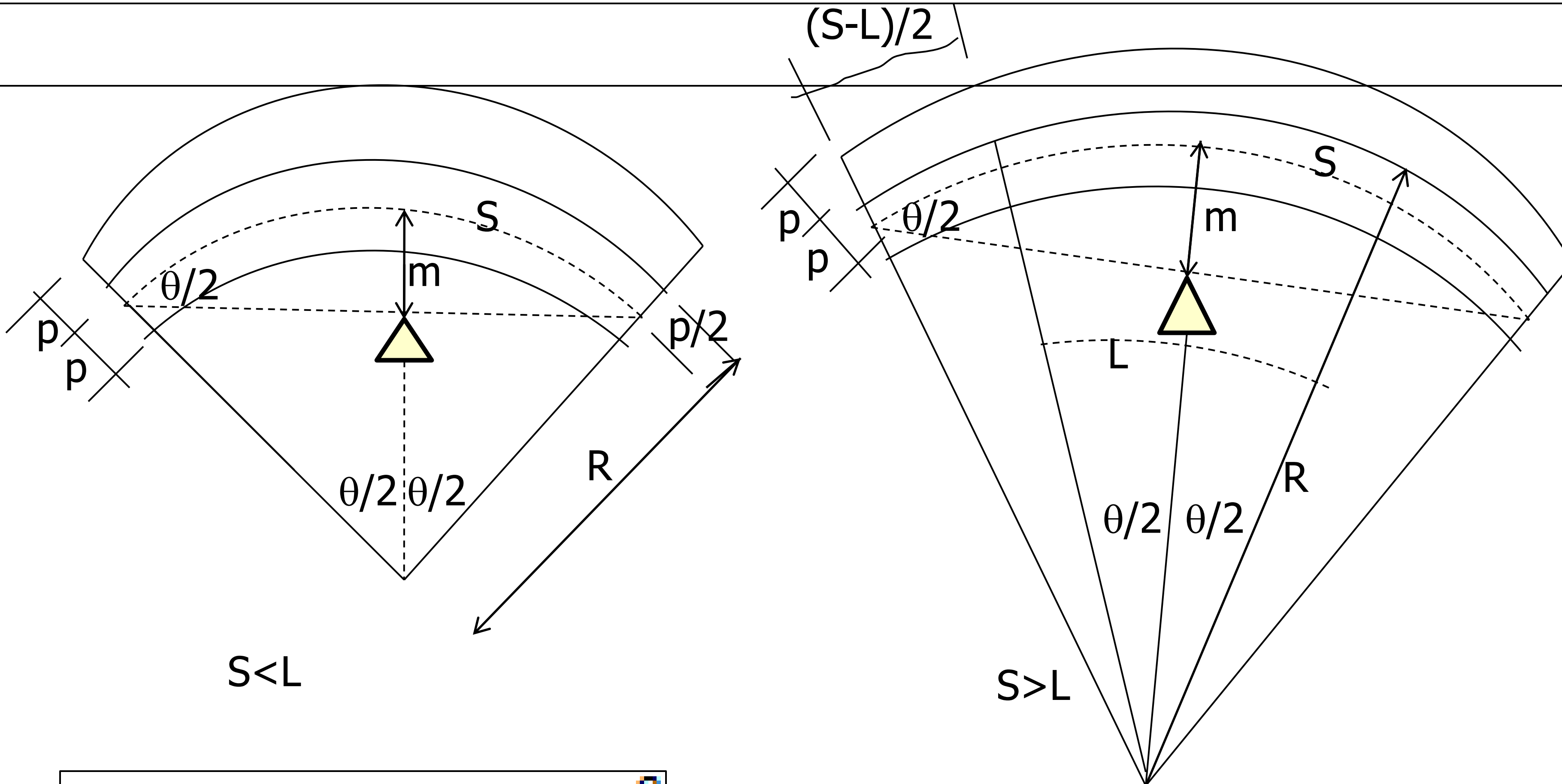


Horizontal curve sight distance



- Sight line is a chord of the circular curve
- Sight Distance is curve length measured along centerline of inside lane

m = HSO: Horizontal Sightline Offset



$$m = R - \left(R - \frac{p}{2}\right)\cos\frac{\theta}{2}$$

$$m = R - \left(R - \frac{p}{2}\right)\cos\frac{\theta}{2} + \frac{(S-L)}{2}\sin\frac{\theta}{2}$$

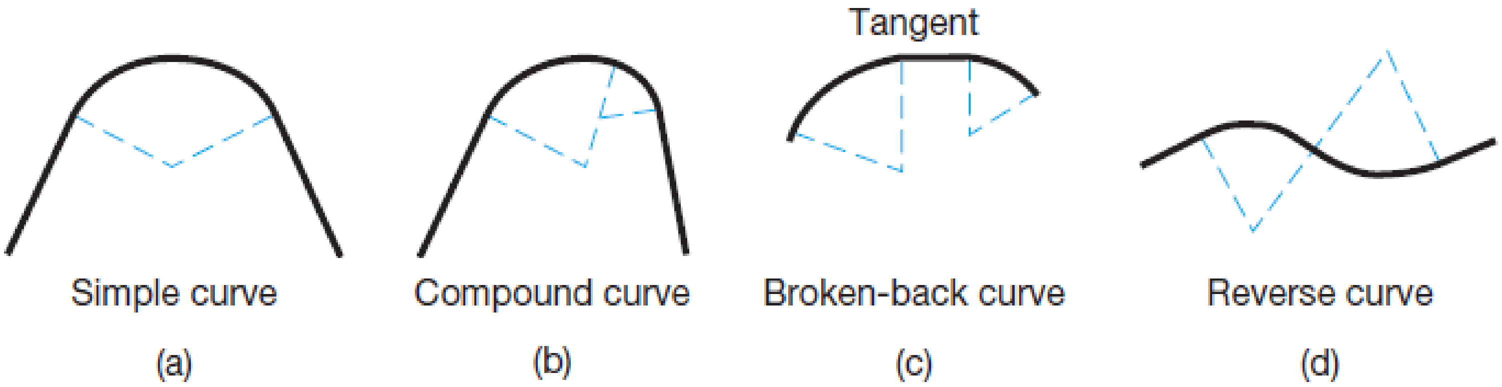
Set-back distance at obstruction of horizontal curves

Example 1

A 2-lane 7.3 m wide single carriageway road has a curve radius of 600m with deflection angle of 60°. The minimum sight stopping distance required is 160 m. Calculate the required distance to be kept clear of obstructions in meters.

Reverse Curves, Broken-Back Curves, and Compound Curves

- **Avoid abrupt reverse curves; It make difficult for the driver to remain within his lane.**
- **Avoid "broken-back“ curves except where very unusual topographical or right-of-way dictates; Drivers do not generally anticipate successive curves in the same direction.**

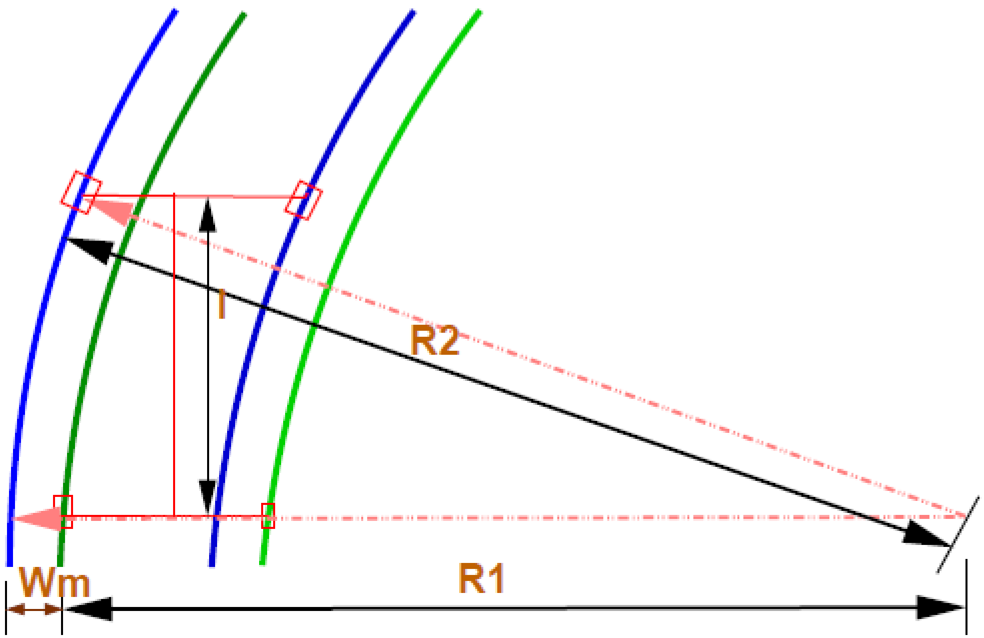


Widening on curves

- Driver on the design speed find it difficult to follow the lane on curves and there is a tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.
- Curve widening avoids this problem.
- Curve widening shall generally be applied to both sides of the roadway. It should start at the beginning of the transition curve and be fully widened at the start of the circular curve.

Radius of Curve (m)	Curve Widening: Single Lane (m)	Curve Widening: Two Lanes (m)	Fill Widening	
			Height of fill (m)	Amount (m)
>250	0.0	0.0	0.0-3.0	0.0
120- 250	0.0	0.6	3.0- 6.0	0.3
60-120	0.0	0.9	6.0 - 9.0	0.6
40-60	0.6	1.2	Over 9.0	0.9
20-40	0.6	1.5	Over 9.0	0.9
<20	See Section 8.10: Switchbacks			

Mechanical and Psychological widening



$$
\begin{aligned}
R_2^2 &= R_1^2 + l^2 \\
&= (R_2 - W_m)^2 + l^2 \\
&= R_2^2 - 2R_2W_m + W_m^2 + l^2
\end{aligned}
$$

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

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

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

$$W_d^{\min} = \frac{0.5nl^2}{R_d^{\min}} + \frac{0.105V_d}{\left[R_d^{\min}\right]^{0.5}}$$

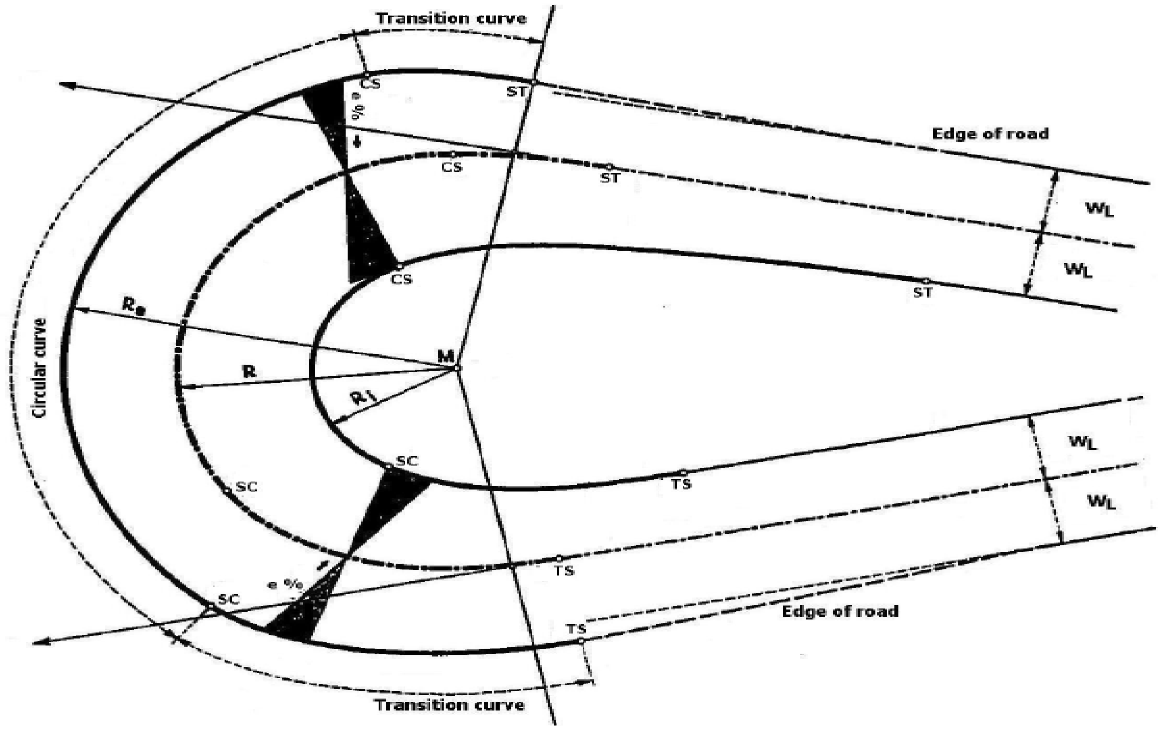
where: W_d^{min} = desirable minimum amount of widening (m)
n = number of traffic lanes
l = length of wheel base of the design vehicle (m)
V_d = design speed (kph)
R_d^{min} = minimum desirable radius of curve (m)

Example 2

Find the extra widening for a two way road with 7 m lane width, R=250m, longest wheel base, l =7m, V=70kmph.

Switchback Curves

- Switchback curves are used where necessary in traversing mountainous and escarpment terrain.
- Employing a radius of 20m or less, with a minimum of 10m, they are generally outside of the standards for all road design standards DC1-DC10.

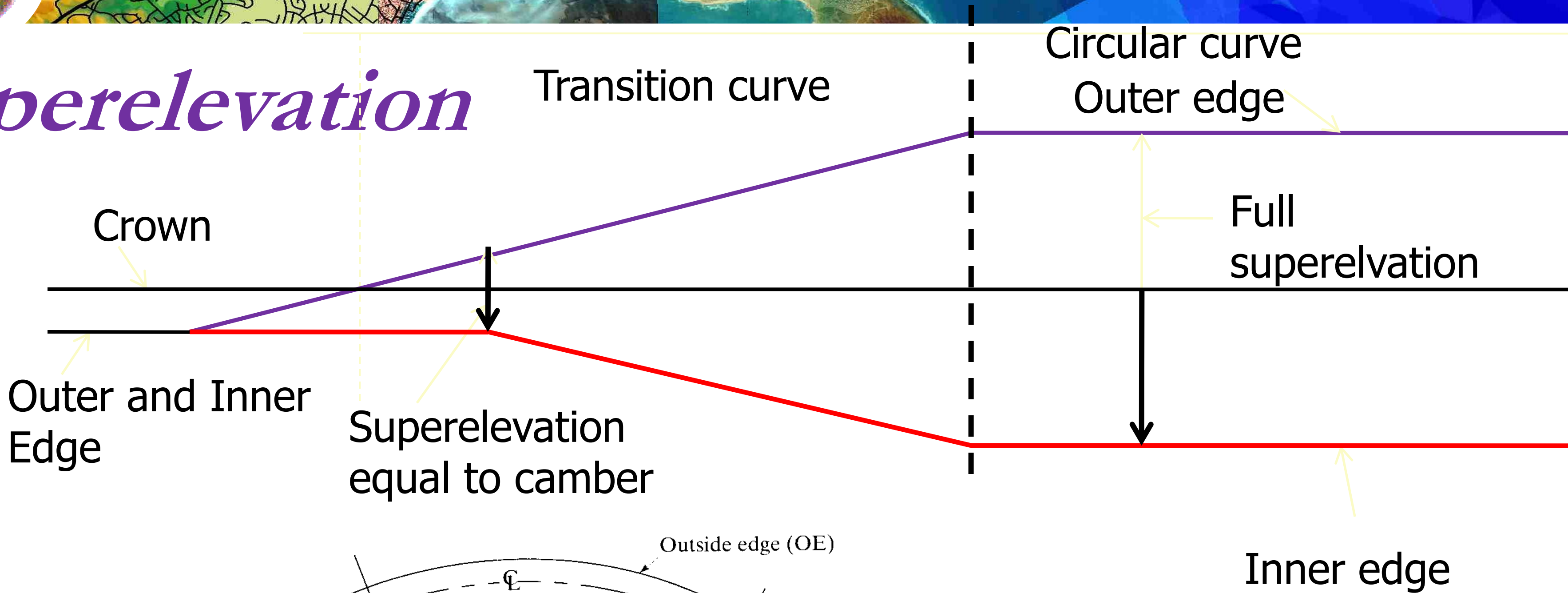


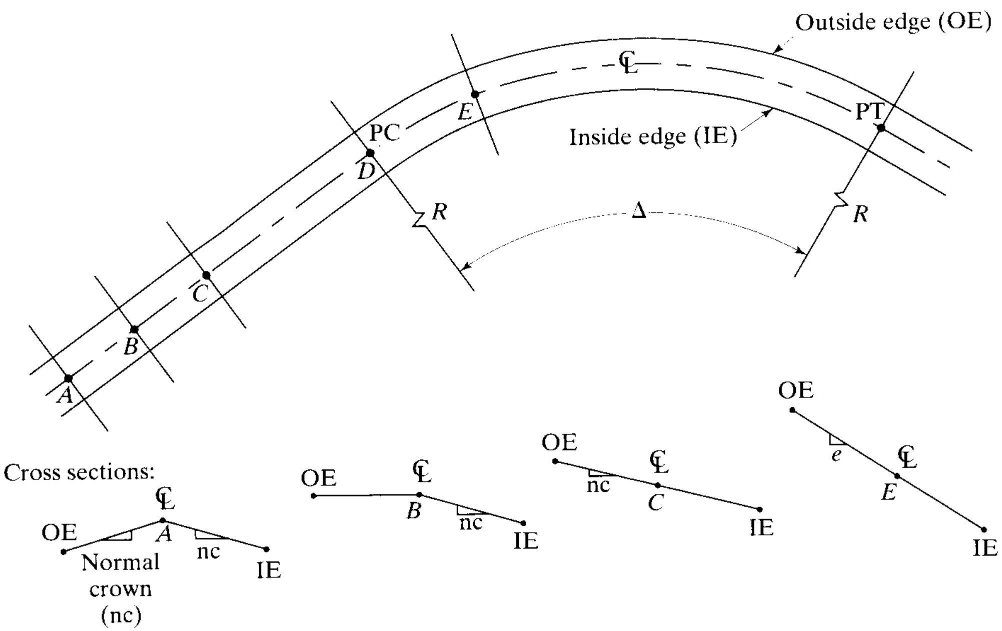
Transition curves

- A constantly changing radius curve

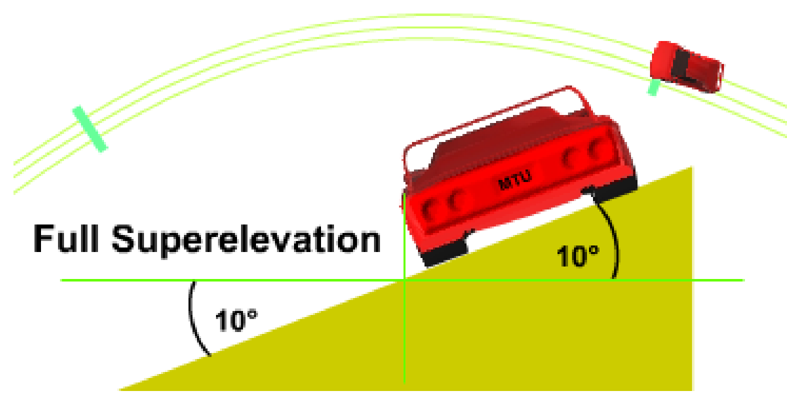
- For Ethiopian roads, transition curves are a requirement for trunk and link road segments having a design speed of equal to or greater than 80 km/hr.

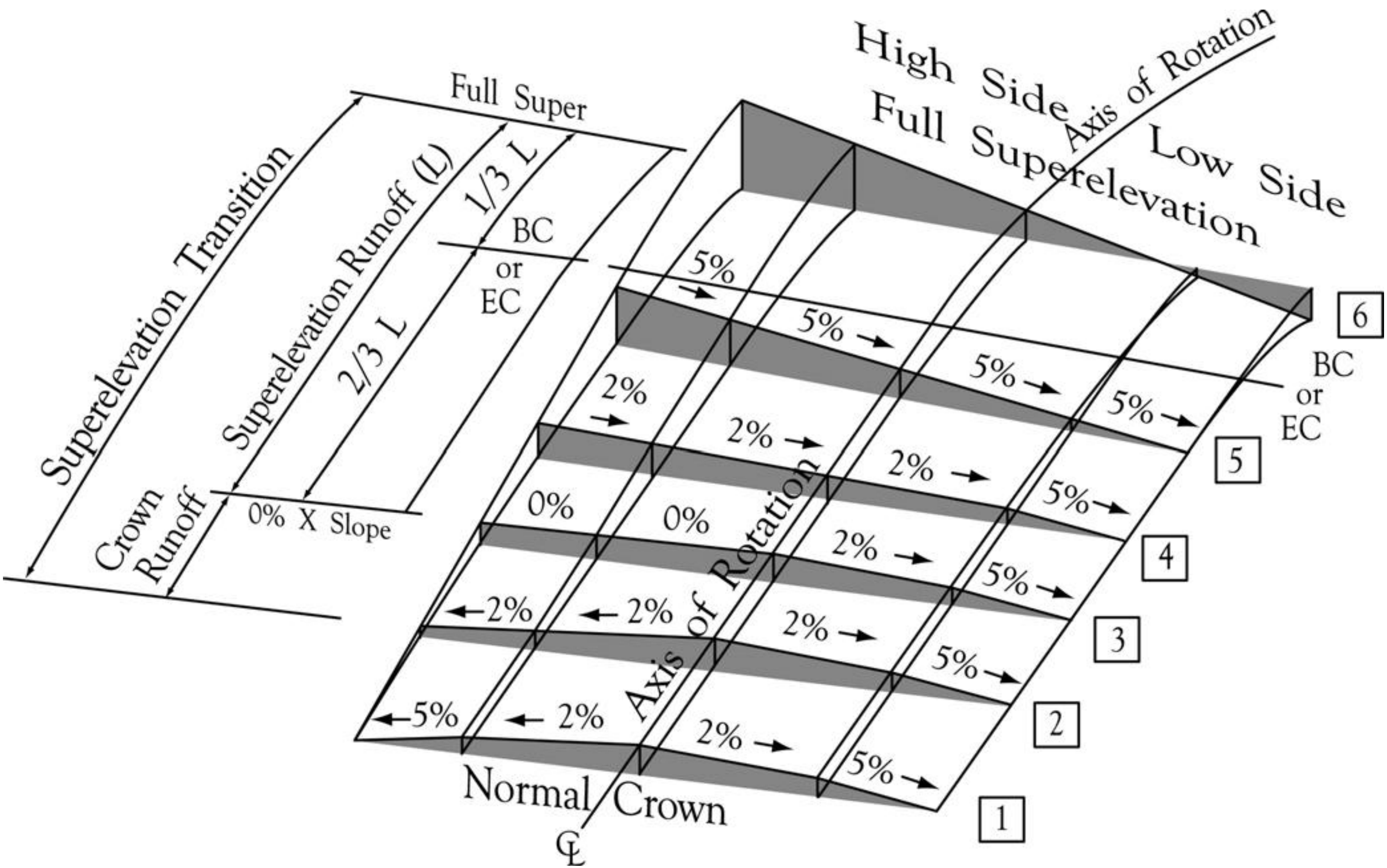
Superelevation





Note: ℄ = center line




High Side
Axis of Rotation
Low Side
Full Superelevation
Full Super
Superelevation Transition
Superelevation Runoff (L)
1/3 L
2/3 L
BC
or
EC
Crown
Runoff
0% X Slope
5%
2%
0%
Axis of Rotation
Normal Crown
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2
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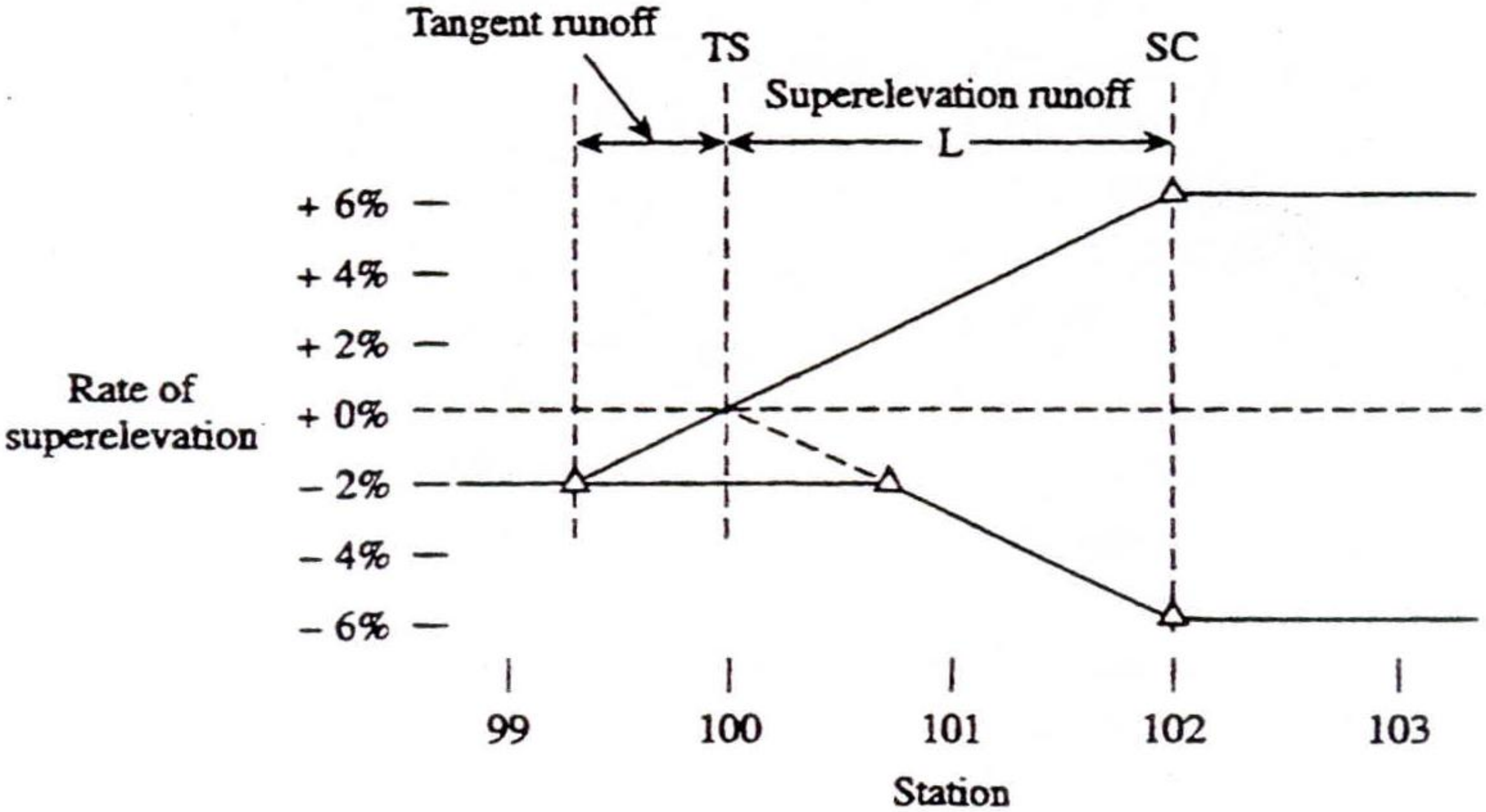
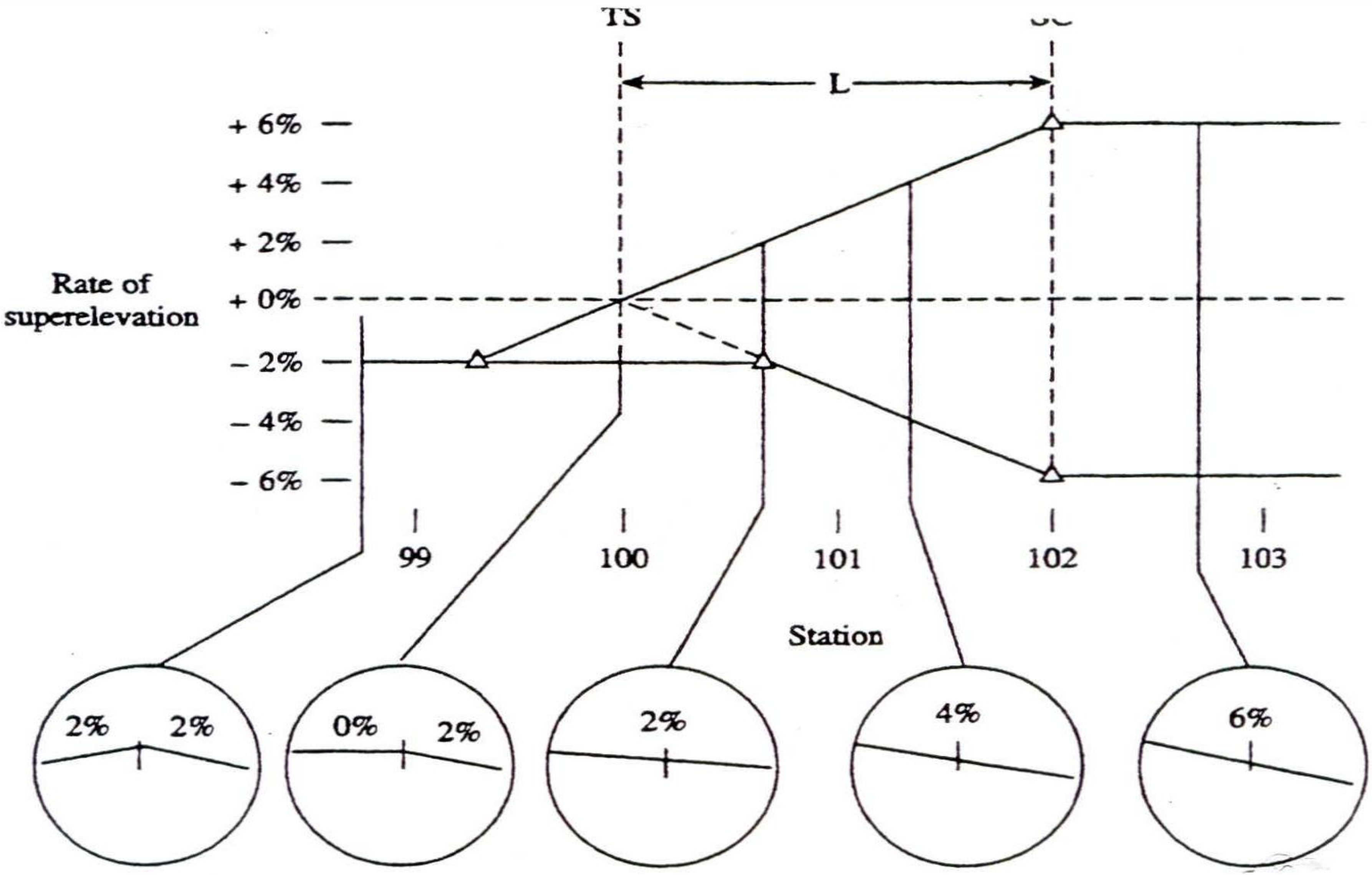
5
6


Tangent runoff
TS
SC
Superelevation runoff
L
+ 6%
+ 4%
+ 2%
+ 0%
– 2%
– 4%
– 6%
Rate of superelevation
99
100
101
102
103
Station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Rate of superelevation
99
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101
102
103
Station
2%
2%
0%
2%
2%
4%
6%

General Controls for Horizontal Alignment

- Alignment should be consistent with the topography
- The number curves should be kept to minimum
- Alignment should avoid abrupt turns
- Avoid sharp curve at the end of long tangent
- The use of sharp curves should be avoided on high fills
- While abrupt reversal in curvature is to avoided, the use of reverse curves becomes unavoidable in hilly terrain. Provide long transitional curves for super elevation run-off.
- Avoid broken back curves since they are not pleasing and hazardous
- Compound curves may be used in preferernce to broken-back arrangement
- The horizontal alignment should blend with the vertical harmoniously

Example 3

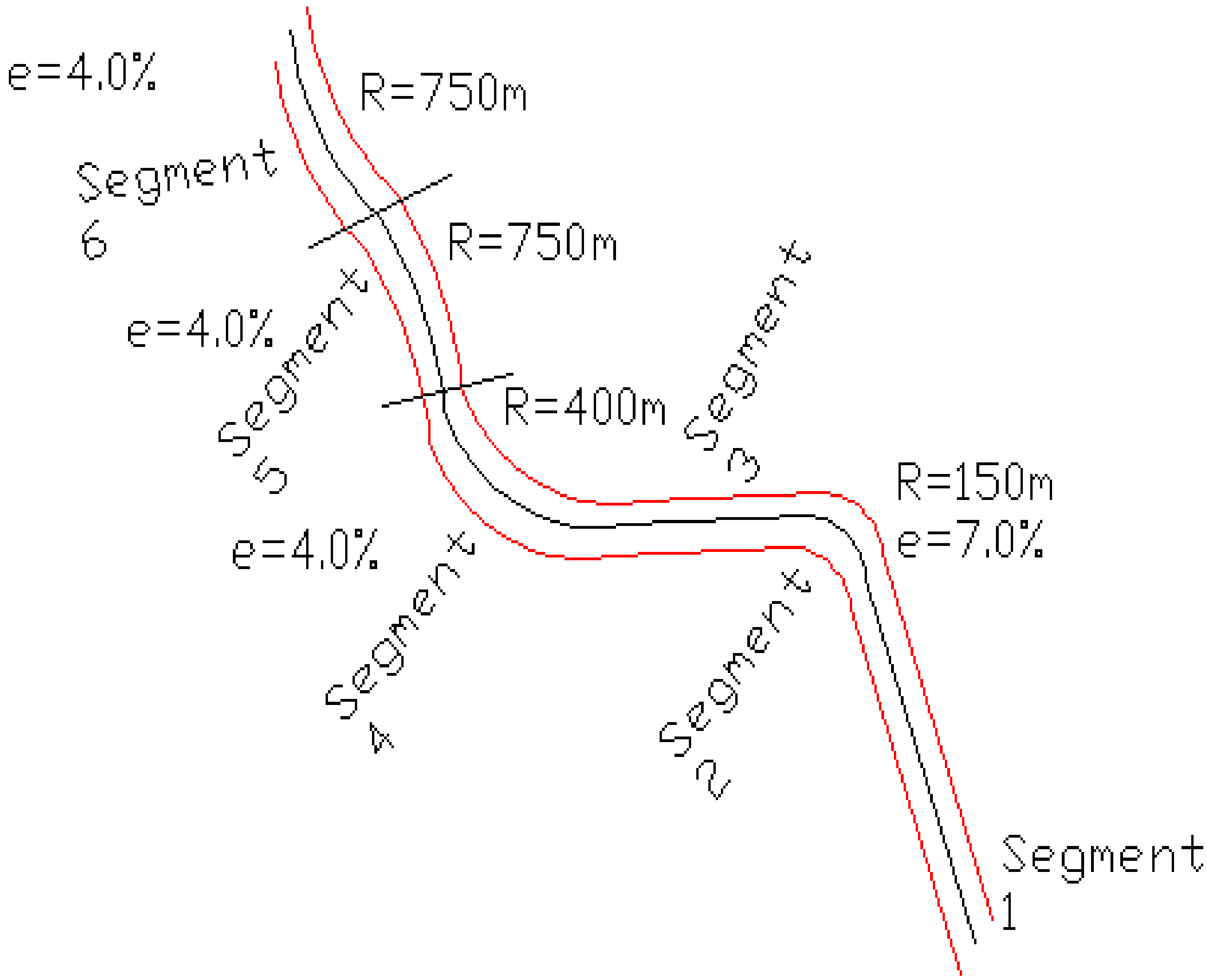
Compute the minimum radius of a circular curve for a highway designed for 110 km/h. The maximum superelevation rate is 12%.

Example 4

The design speed of asphalt concrete paved highway designed for construction is 80kph. During right-of-way reservation period it was found out that the space available for horizontal curve is only adequate for provision of maximum 200m radius. Can this speed be safely maintained on the road? If not, what should be done?

Example 5

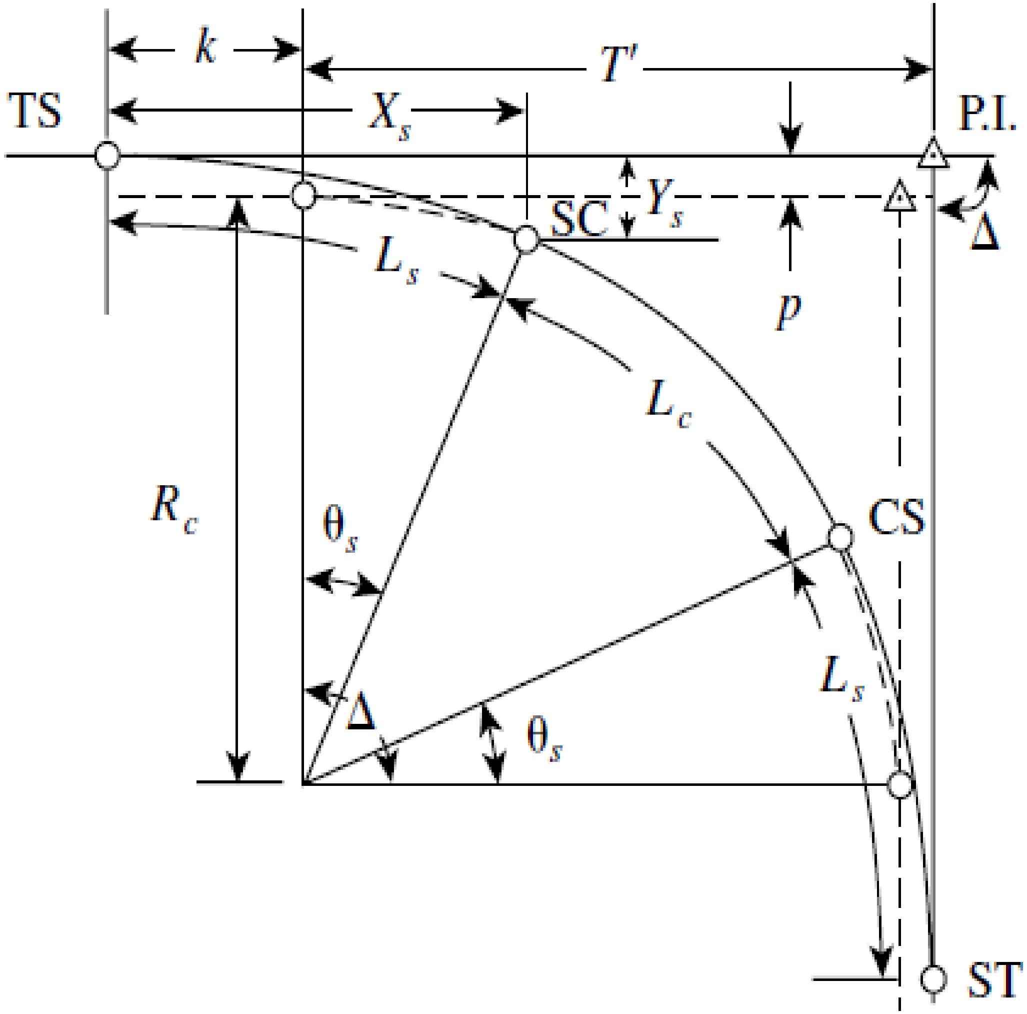
Consider the horizontal alignment of an existing road shown in Fig. below. Do you consider this alignment adequate for an operating speed of 100kph? If not, where and what are the design inadequacies?



e=4.0%
R=750m
Segment 6
R=750m
e=4.0%
Segment 5
R=400m
Segment 3
R=150m
e=7.0%
e=4.0%
Segment 4
Segment 2
Segment 1

Exercise

A two-lane highway (3.6 m lanes) with a design speed of 100 km/h has a 400 m radius horizontal curve connecting tangents with bearings of N75E° and S78E° . Determine the superelevation rate, the length of spiral if the difference in grade between the centerline and edge of traveled way is limited to 1/200, and the stations of the TS, SC, CS, and ST, given that the temporary station of the P.I. is 150 + 00. The length of the spiral should be rounded up to the next highest 20 m interval.



$$A = \sqrt{L_s R_c}$$

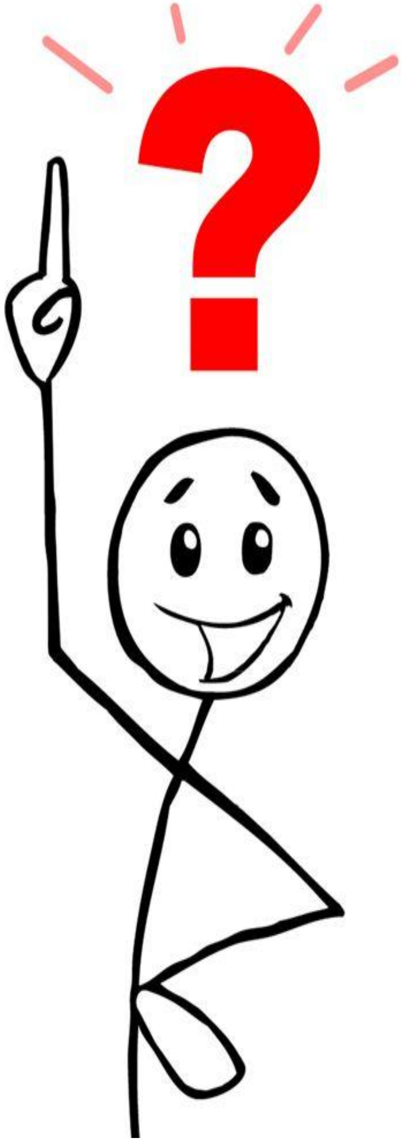
$$X = L - \frac{L^5}{40A^4} + \frac{L^9}{3{,}456A^8} + \cdots$$

$$Y = \frac{L^3}{6A^2} - \frac{L^7}{336A^6} + \frac{L^{11}}{42{,}240A^{10}} + \cdots$$

$$p = Y_s - R_c\,(1 - \cos\theta_s)$$

$$k = X_s - R_c \sin\theta_s \qquad \theta_s = \frac{L_s}{2R_c}$$

$$T' = (R_c + p)\tan\left(\frac{\Delta}{2}\right)$$

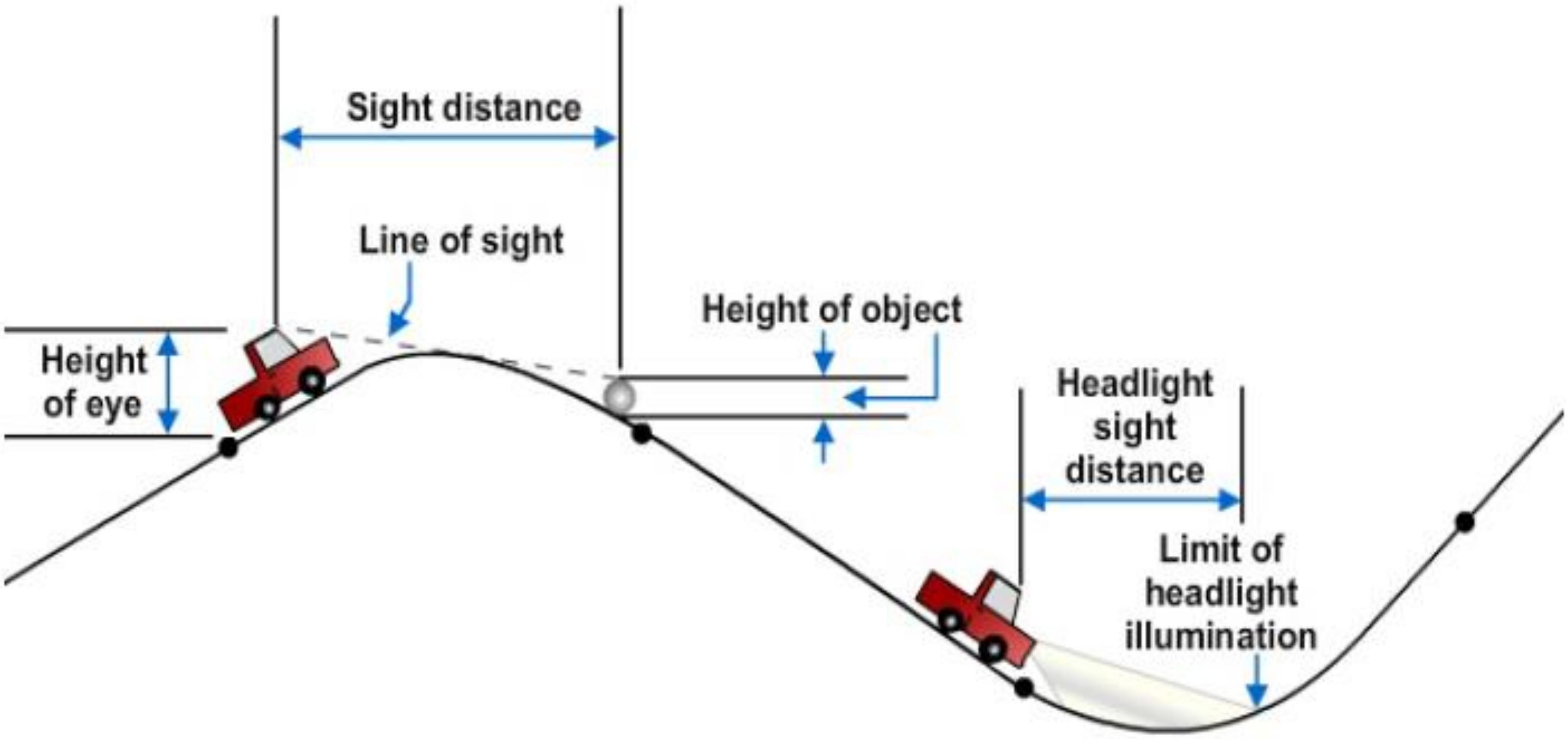


Vertical Alignment

Reduced Speed

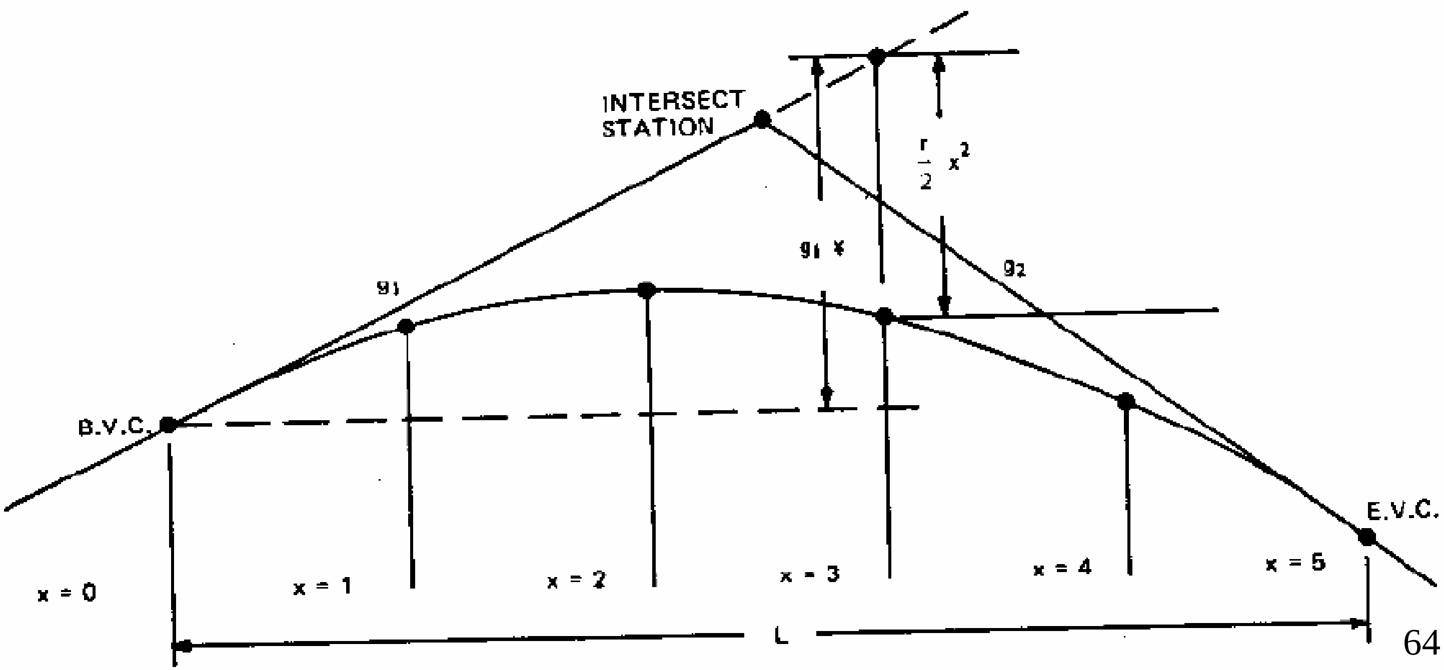
Increased Speed

Vertical alignment



Vertical alignment

- Vertical curvature (sight distance)
- Gradient (Vehicle performance and level of service)



Vertical Curve Formula

$$r = \frac{g_2 - g_1}{L} \qquad y = \frac{rx^2}{2} + g_1 x + \text{elevation of BVC}$$

Where

r = rate of change of grade per section (%)
g1 = starting grade (%)
g2 = ending grade (%)
L = length of curve (horizontal distance m)
y = elevation of a point on the curve
x = distance in stations from the BVC (meters/100)
BVC = beginning of the vertical curve
EVC = end of the vertical curve

Example 6

Given the profile below, determine:

a. **The length of vertical curve needed to make the highest point on the vertical curve come out exactly over the centerline of the cross road at station 150 + 70.**

b. **The vertical clearance between the profile grade on the vertical curve and the centerline of the cross road.**

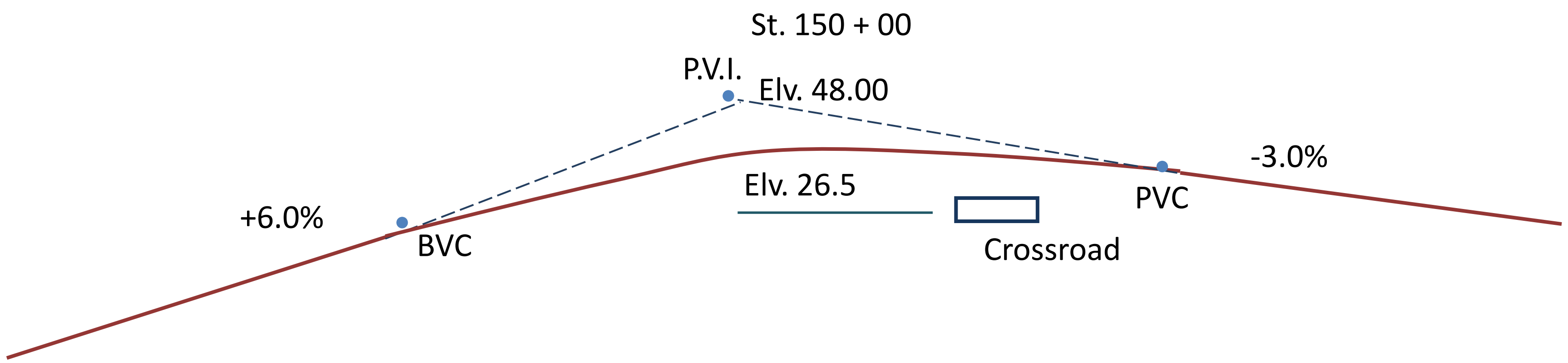
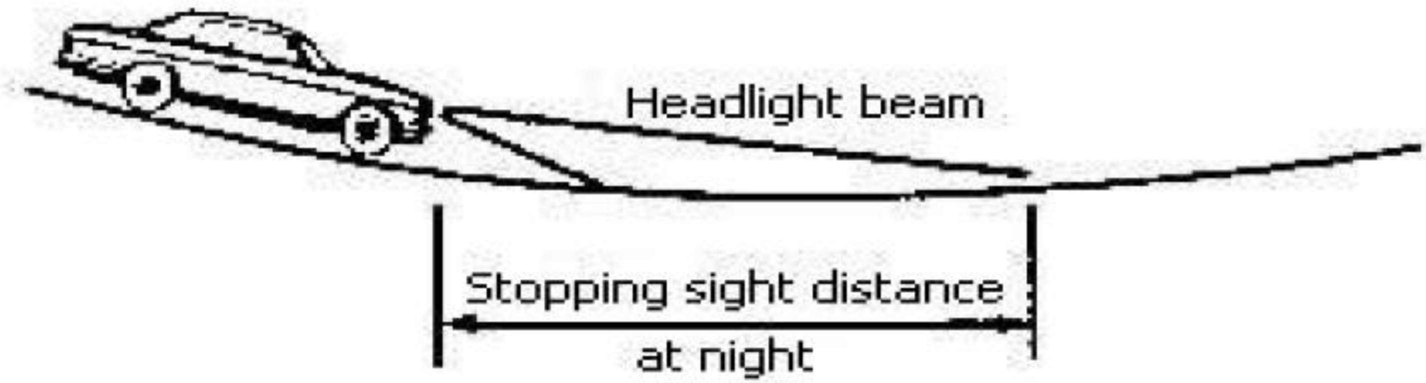
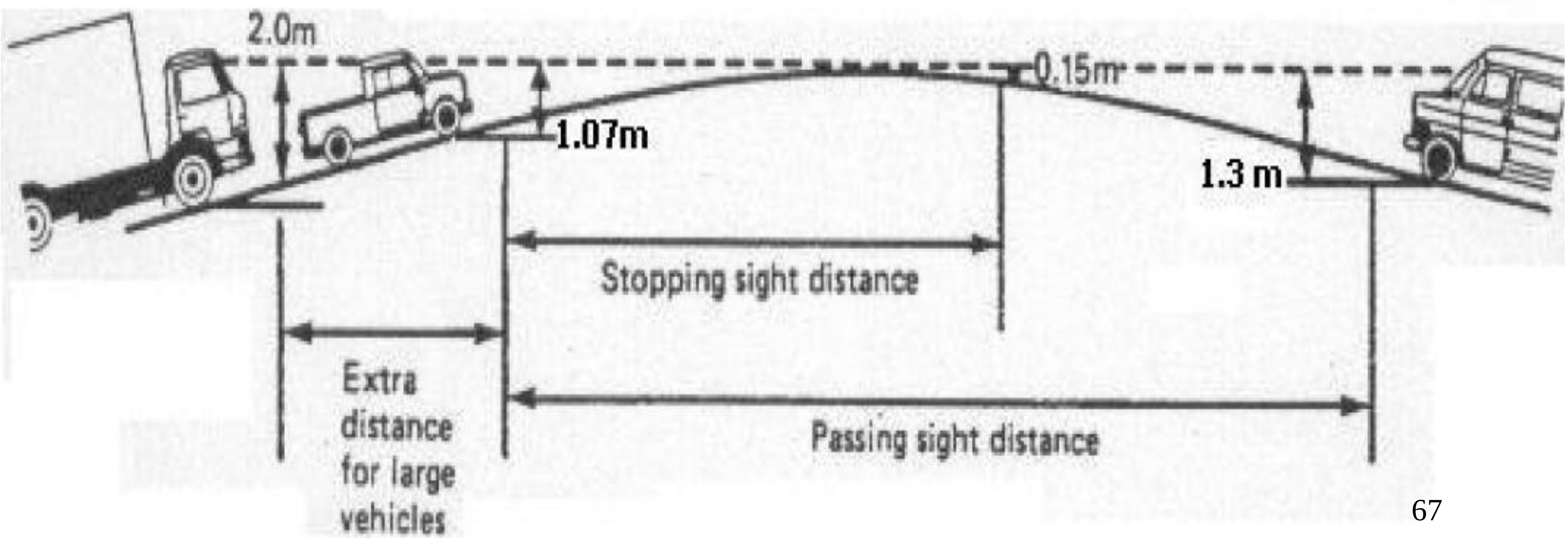


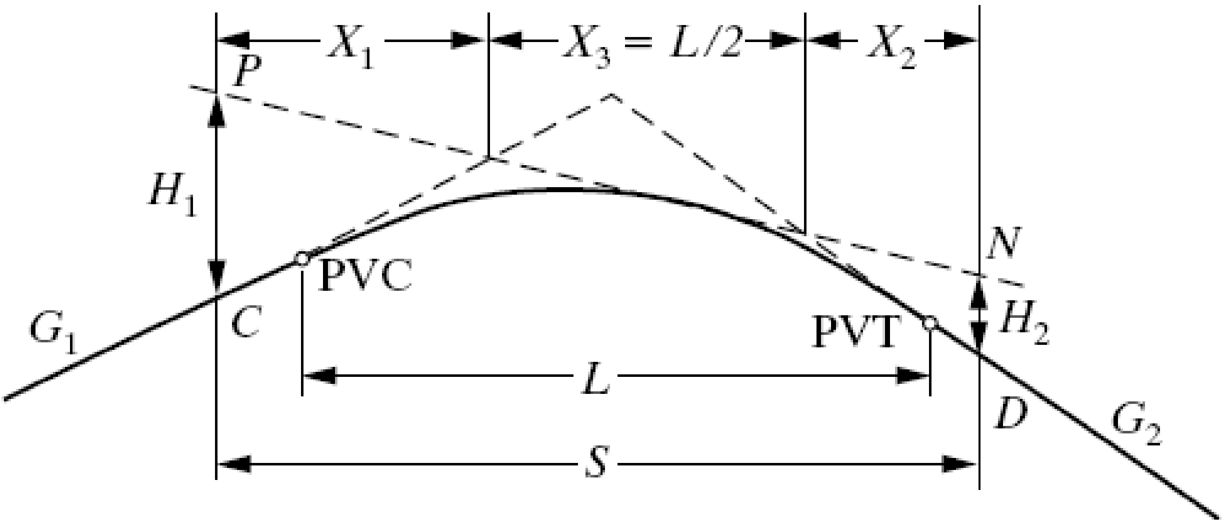
Figure Profile view

Sight distance on vertical curve





Length of Summit Vertical Curve -SD



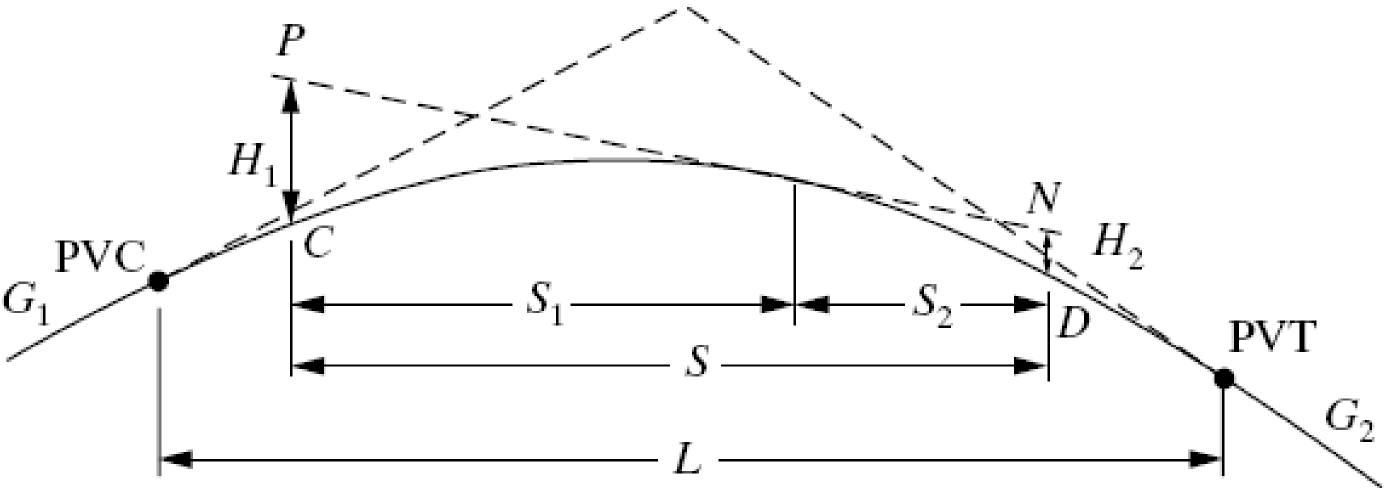
where,
L = length of vertical curve, m
S = sight distance, m
A = algebraic difference in grades, %
H1 = height of eye above roadway surface, m
H2 = height of object above roadway surface, m

$$L_{min} = 2S - \frac{200(\sqrt{H_1} + \sqrt{H_2})^2}{A} \text{ (for } S > L)$$

$X_1 = H_1/g_1$, $X_2 = H_2/g_2$
$H_1/g_1, + L/2 + H_2/g_2 = S$

$$L_{min} = \begin{cases} \frac{AS^2}{404} & \text{when } S \le L \\ 2S - \frac{404}{A} & \text{when } S \ge L \end{cases}$$

Length of Summit Vertical Curve -SD



$$L_{min} = \frac{AS^2}{200(\sqrt{H_1} + \sqrt{H_2})^2} \text{ (for } S < L)$$

$H_1 = S_1^2/C$, $H_2 = S_2^2/C$ $C = 2L/A$

Length of Summit Vertical Curve -SD

When the height of eye and the height of object are 1070mm and 600mm, respectively, as used for stopping sight distance, the equation become:

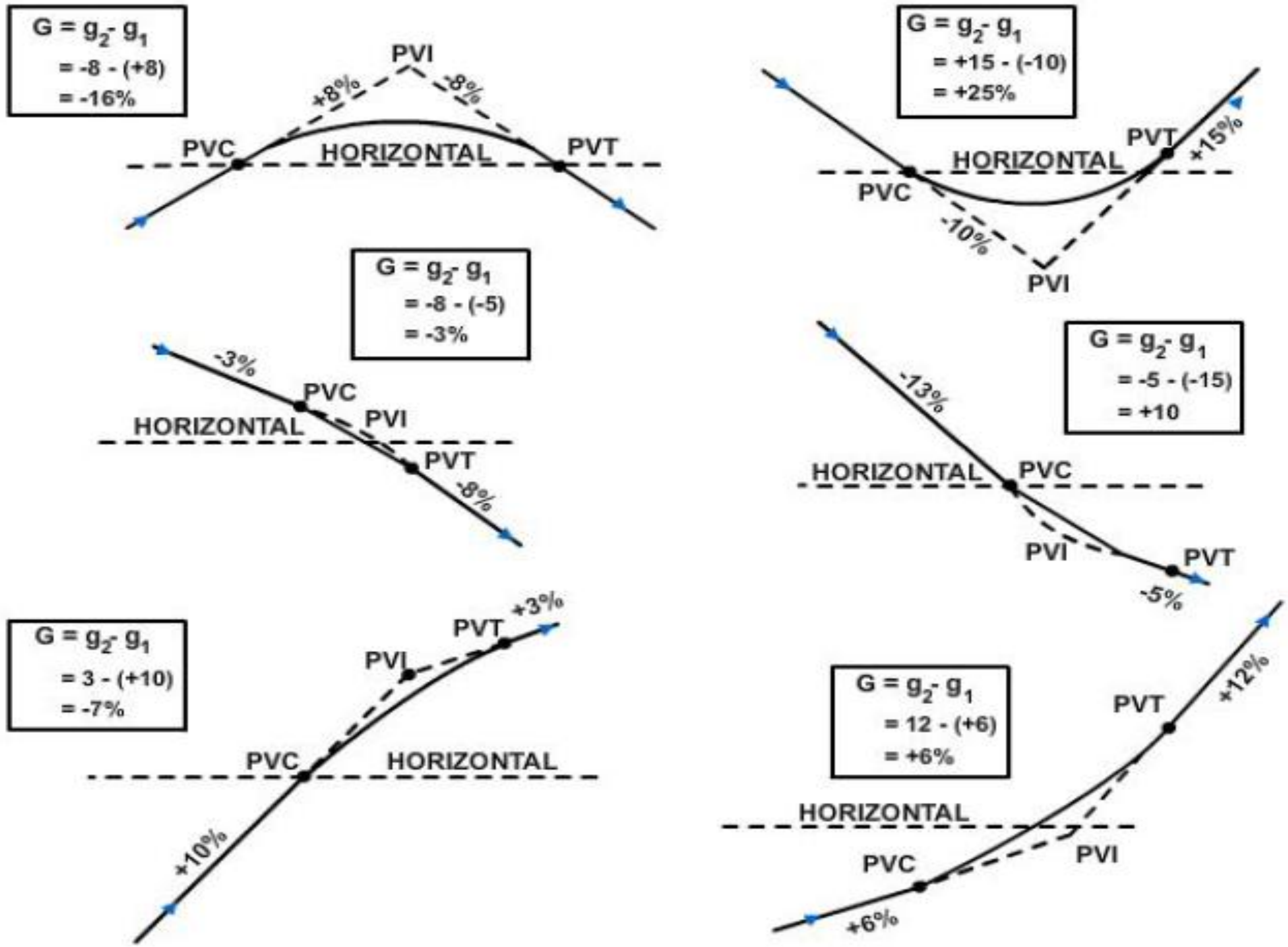
When S is $< L$,

$$L = \frac{AS^2}{404}$$

When S is $> L$,

$$L = 2S - \frac{404}{A}$$

Algebraic differences of grades



Example 7

Compute the minimum length of vertical curve that will provide 190 m stopping sight distance for a design speed of 100 km/h at the intersection of a +2.60% grade and a -2.40% grade.

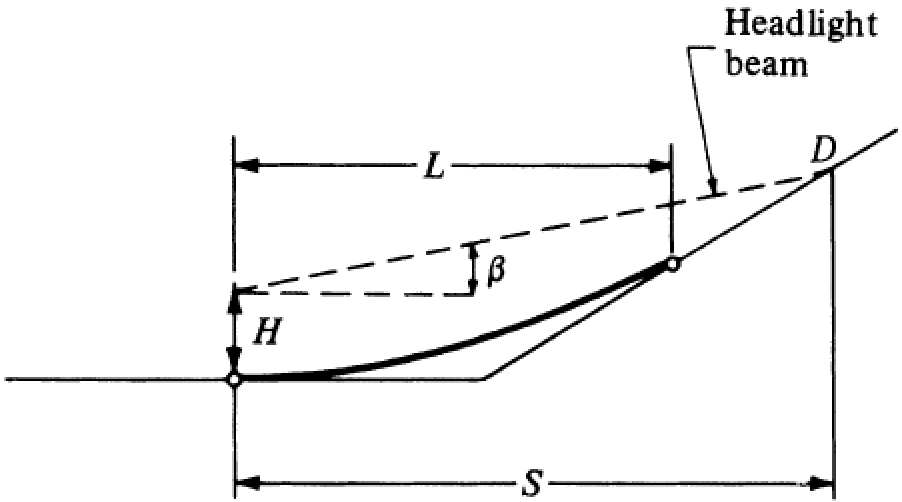
Sag Vertical Curves

Design Criteria:

1. Headlight sight distance
2. Rider Comfort
3. Drainage Control
4. Aesthetics (rule of thumb)

Headlight sight distance

Length of Sag Vertical Curves – night time



$$L_{min} = 2S - \frac{200(H + S \tan \beta)}{A} \text{ (for } S > L)$$

$$L_{min} = \frac{AS^2}{200(H + S \tan \beta)} \text{ (for } S < L)$$

H = 0.60 m

$\beta = 1°$

$$L_{min} = \begin{cases} \dfrac{AS^2}{200[0.6 + S(\tan 1°)]} = \dfrac{AS^2}{120 + 3.5S} & \text{when } S \leq L \\ 2S - \dfrac{200[0.6 + S(\tan 1°)]}{A} = 2S - \dfrac{120 + 3.5S}{A} & \text{when } S \geq L \end{cases}$$

Example 8

Compute the minimum length of vertical curve that will provide 220 m stopping sight distance for a design speed of 110 km/h at the intersection of a -3.50% grade and a +2.70% grade.

Driver comfort

Length of Sag Vertical Curve

- **Sag curves has a greater ease of visibility, comfort is more likely to be the primary design criterion for them.**

$$L \geq \frac{AV^2}{395}$$

where

- **L** is the required vertical sag curve length (m)
- **V** is the speed of the vehicle (km/hr)
- **A** is g2 – g1 in percent
- The vertical radial acceleration of the vehicle is assumed to be 0.3 m/s2

Aesthetics

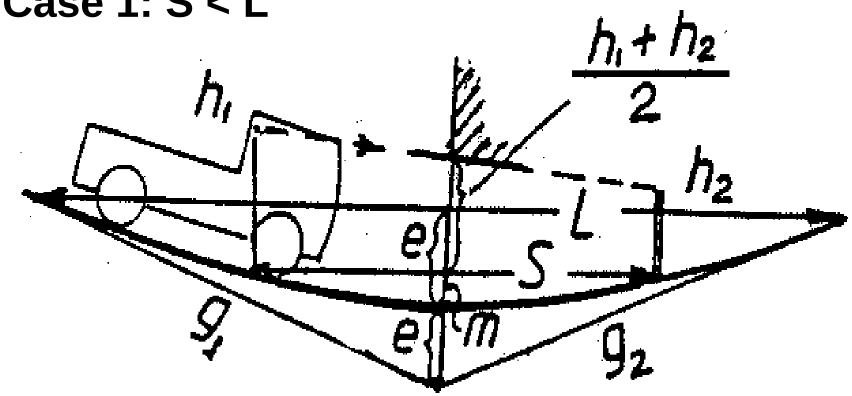
Length of Sag Vertical Curve

Rule of thumb

$$L_{\min} = 30A$$

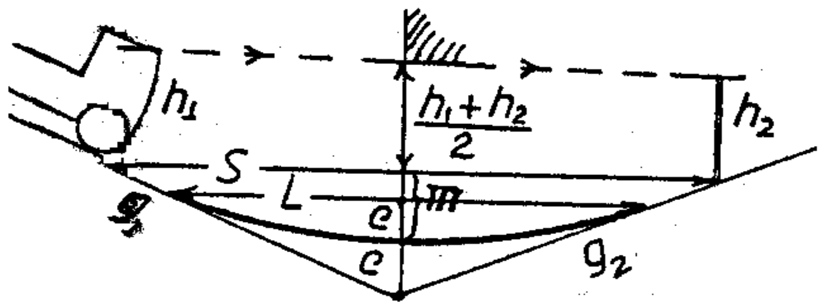
Sight Distances at Underpass Structures:

Case 1: S < L



$$L = \frac{S^2 A}{8m}$$

Case 2: S > L



where:
m = C – $(h_1+h_2)/2$

C = Vertical clearance distance

$$L = 2S - \frac{8m}{A}$$

AASHTO recommendations: h_1 = 1.829m, h_2 = 0.457m and C = 5.182m

Length of Crest and Sag Vertical Curves Based on K Factors

The minimum lengths of crest and sag curves have been designed to provide sufficient stopping sight distance. The design is based on minimum allowable "K" values, as defined by the formula:

$$K = L/A$$

Where

K = limiting value, horizontal distance required to achieve a 1% change in grade

L = length of vertical curve (m)

A = Algebraic difference in approach and exit grades (%)

K value for crest curve

Table 9-1: Minimum Values for Crest Vertical Curves (Paved Roads)

Design Speed (km/h)	K for Stopping Sight Distance			K for Passing Sight Distance
	$h_2 = 0m$	$h_2 = 0.2m$	$h_2 = 0.6m$	
20	2	1	1	10
25	3	1	1	30
30	4	2	1	50
40	10	5	3	90
50	20	10	7	130
60	35	17	11	180
70	60	30	20	245
80	95	45	30	315
85	115	55	35	350
90	140	67	45	390
100	205	100	67	480
110	285	140	95	580
120	385	185	125	680

K values for crest curve

Table 9-2: Minimum Values for Crest Vertical Curves (Unpaved Roads)

Design Speed (km/h)	K for Stopping Sight Distance			K for Passing Sight Distance
	$h_2 = 0m$	$h_2 = 0.2m$	$h_2 = 0.6m$	
20	2	1	1	10
25	3	1	1	30
30	5	2	2	50
40	11	6	4	90
50	25	11	8	135
60	45	20	15	185
70	75	35	25	245
80	120	58	40	315
85	150	72	50	350
90	185	90	60	390
100	270	130	88	480

K values for sag curve

Table 9-3: Minimum Values of K for Sag Curves

Design Speed (km/h)	K for driver comfort
20	1.0
25	1.5
30	2.5
40	4.
50	6.5
60	9
70	12
80	16
85	18
90	20
100	25
110	30
120	36

Example 9

An engineer is assigned to design a vertical curve for a paved highway with the design speed is 85 kmph. Knowing that the gradients are 3% uphill and -2% downhill. What is the minimum design length of the vertical curve for an object height is 0.6m?

Maximum Gradients

➢ depend on a number of factors

- severity and length of gradient;
- level and composition of traffic; and
- the number of overtaking opportunities on the gradient and in its vicinity

Table 9-4: Maximum Gradients for Paved Sections

Topography	Maximum Gradient (%), for Paved Sections									
	DC8, DC7, DC6		DC5, DC4		DC3, DC2		DC1		Basic Access	
	D	A	D	A	D	A	D	A	D	A
Flat	3	5	4	6	6	8	6	10		
Rolling	4, 5	7	6	8	7	9	7	10		
Mountainous	6, 7	9	8	10	10	12	10	12	NA	NA
Escarpment	6, 7	9	8	10	10	12	10	12		
Urban	6	8	7	9	7	9	7	9		

Note: D is the desirable value, A is the absolute value.

General Controls for Vertical Alignment

- The grade should be smooth with gradual change-consistent with the class of highway and terrain. Numerous breaks and short length of grades should be avoided
- Hidden profile should be avoided
- A broken-back grade line should be avoided
- Intersection on grades should be avoided as far as possible

Exercise

A highway reconstruction project is being undertaken to reduce accident rates on the highway. The reconstruction involves a major re-alignment of the highway such that a 100kph design speed is attained. At one point on the highway, a 240m equal tangent crest vertical curve exists. Measurements show that, at 106m from the BVC, the vertical curve offset is 0.9m. Assess the adequacy of the existing curve in light of the reconstruction design speed of 100kph and, if the existing curve is inadequate, compute a satisfactory curve length.

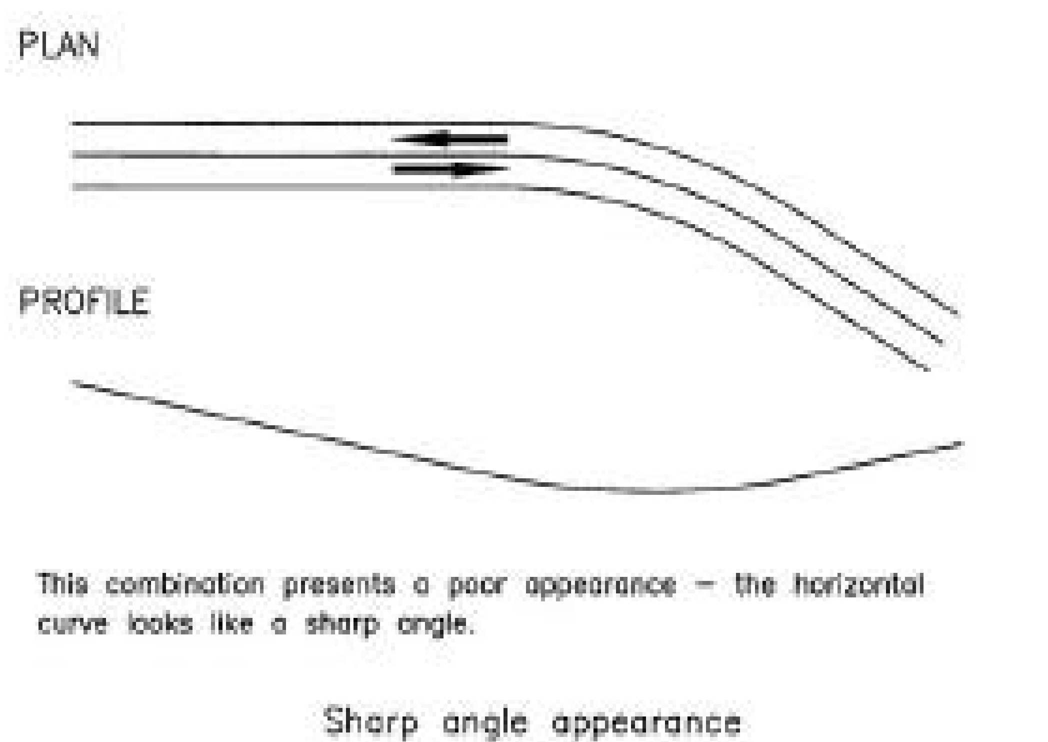
Phasing of horizontal and vertical curve

- **It shows their coordination so that the line of the road appears to a driver to flow smoothly, avoiding the creation of hazards and visual defects.**

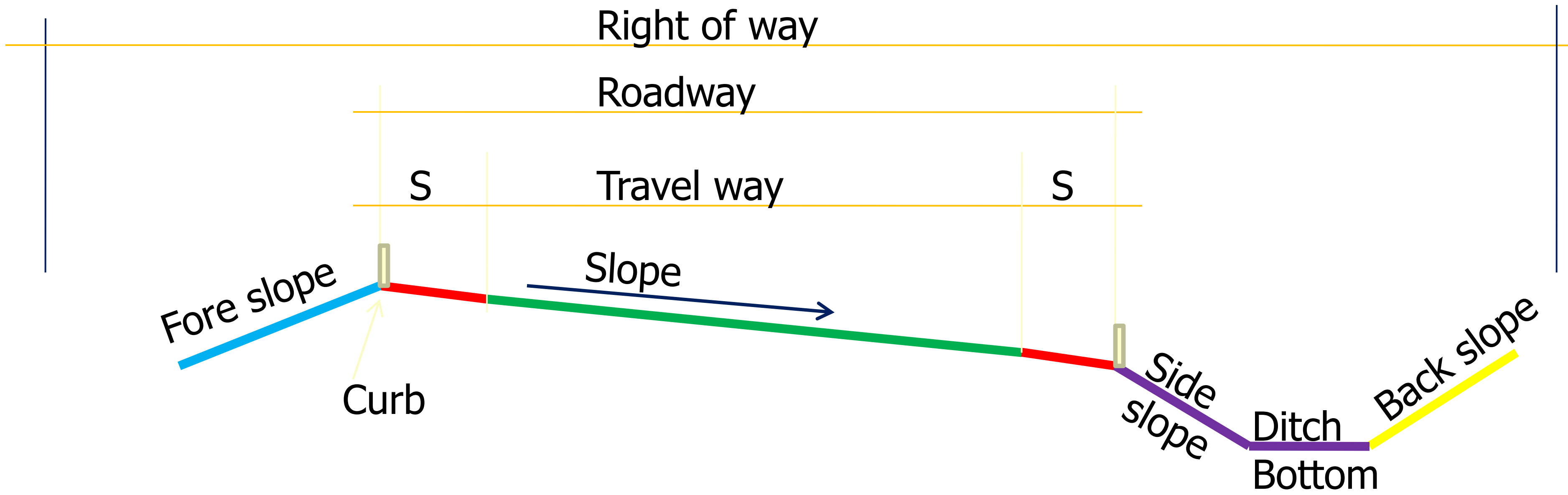
- **When horizontal and vertical curves are adequately separated or when they are coincident → no mis-phasing problem**

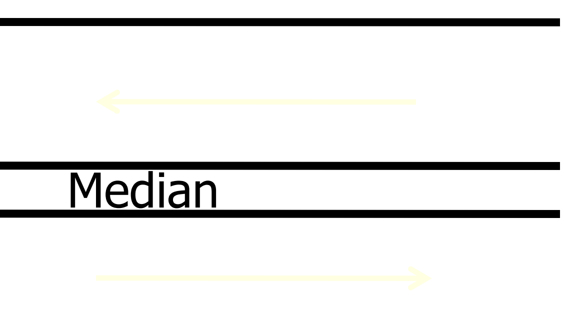
Mis-phasing solutions

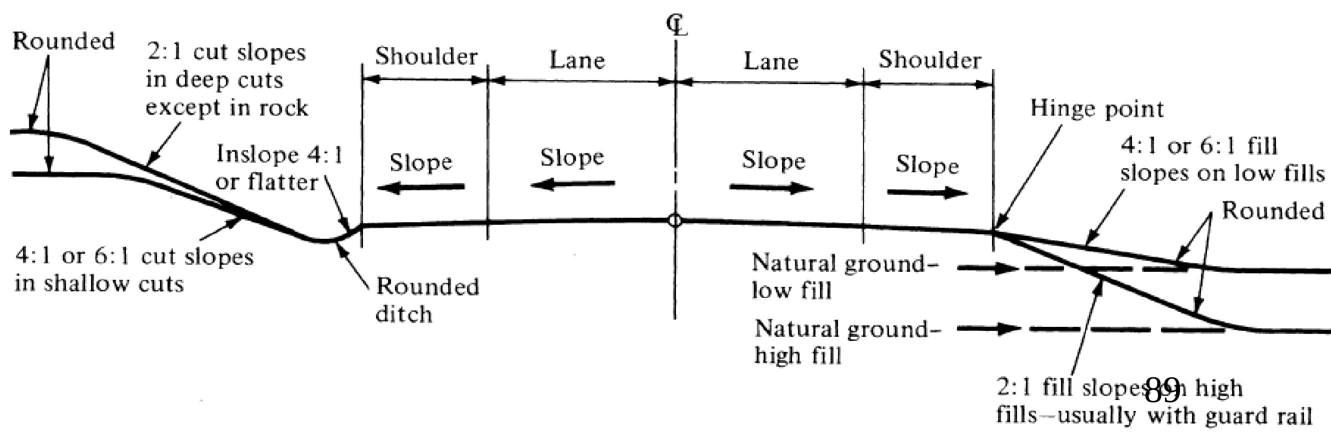
- **Separating the curves or by adjusting their lengths such that vertical and horizontal curves begin at a common station and end at a common station.**



Cross Section Element







Cross section elements - Defn

- **Right-of-ways:** provided in order to accommodate road width and to enhance the safety, operation and appearance of the roads.
- **Lane Widths:** width to accommodate one car
- **Shoulder**: for the accommodation of stopped vehicles; animals, and pedestrians; emergency use; the recovery of errant vehicles
- **Normal crossfall (or camber, crown):** provide adequate surface drainage
- **Side Slopes and Back Slopes:** to insure the stability of the roadway and to provide a reasonable opportunity for recovery of an out-of-control vehicle.
- **Curbs and Gutters:** Curbs are raised to delineate pavement edges and pedestrian walkways
- **Clear Zone:** an unencumbered roadside recovery area that is as wide as practical on a specific highway section.

Medians

A median is the section of a divided highway that separates the lanes in opposing direction. The functions of a median include:

- Providing a recovery area for out-of-control vehicles
- Separating opposing traffic
- Providing stopping areas during emergencies
- Providing storage areas for left-turning and U-turning vehicles
- Providing refuge for pedestrians
- Reducing the effect of headlight glare
- Providing temporary lanes and cross-overs during maintenance operations