TRAFFIC ENGINEERING

SAB3843

GEOMETRIC DESIGN OF ROADS

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and

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SOME MAJOR ELEMENTS OF ROAD GEOMETRY:

- Horizontal alignment,
- Vertical alignment,
- Sight distances,
- Cross-section, etc.

Each element is designed in accordance with various standard of practices such as JKR, LLM, AASHTO, etc. to meet traffic flow characteristics.

Why must we follow the standard code of practice in the design?:

- To ensure uniformity in the design,
- To ensure smooth/consistent, safe and reliable traffic movements, and
- To assist engineers in designing the engineering details of the road sections (less subjective decision).

Aspects considered in road design

- ***Function*** – to serve as inland linkage between locations for moving people and goods.
- ***Safety*** – roadways must be designed with safety characteristics.
- ***Comfort*** – road features must be designed and built for comfort riding quality.
- ***Economic*** – in terms of construction and vehicle's operating costs.
- ***Aesthetic*** – roadways must be built as an element of the environment; its design must include aethetical values to suit the existing environment.

Road Classifications for Planning & Design Purposes:

Four (4) Categories of Urban Roads:

1. Expressway – divided highway for through traffic & all junctions are grade separated.
2. Arterial – major road, e.g., to carry traffic from residential area to the vicinity of CBD.
3. Collector – road to serve as a collector or distributor of traffic between arterial and local road systems.
4. Local street – basic road network within a neighborhood and serves primarily to offer direct access to collectors.

Definition of R and U??

Road Classifications for Planning & Design Purposes:

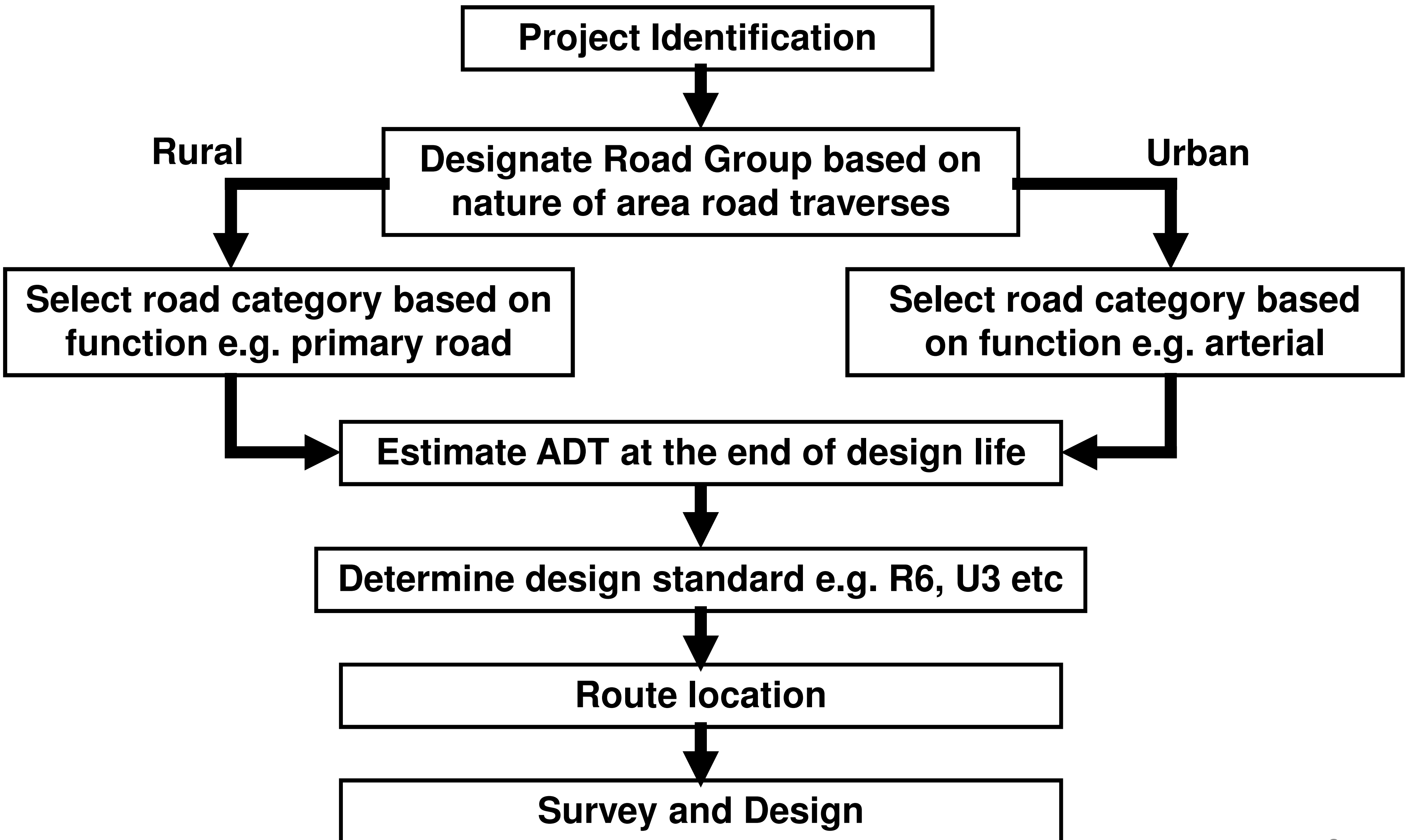
Five (5) Categories of Rural Roads:

1. Expressway – divided highway for through traffic & all junctions are grade separated.
2. Highway – interstate national network & to serve long to intermediate trip lengths. It complements the expressway network.
3. Primary road – major road network within a state.
4. Secondary road – major road network within a district or regional development area.
5. Minor road – local roads.

Design Standard Classifications:

- **R6/U6** – highest geometric design standards; traveling speed ≥90 km/h; divided highway with full access control (F).
- **R5/U5** – high geometric standards with speed ≥80 km/h; combination of divided & undivided sections; partial access control (P).
- **R4/U4** – medium geometric standards with speed ≥70 km/h; usually with partial access control (P).
- **R3/U3** – low geometric standard to serve local traffic; partial (P) or no access control (N); speed 60 km/h.
- **R2/U2** – low geometric standards for low volume of local traffic; speed 50 km/h; no access control (N).
- **R1/U1** – lowest geometric standards; speed ≤40 km/h

Flow Chart for Selection of Road Design Standards



Selection of Design Standard

ADT / Area & Road Category	All traffic volume	>10,000	3,000 to 10,000	1,000 to 3,000	150 to 1,000	< 150
RURAL:						
Expressway	**R6**	-	-	-	-	-
Highway	**R5**	-	-	-	-	-
Primary road	-	**R5**	**R4**	-	-	-
Secondary rd.	-	-	**R4**	**R3**	-	-
Minor road	-	-	-	-	**R2**	**R1**
URBAN:						
Expressway	**U6**	-	-	-	-	-
Arterials	-	**U5**	**U4**	-	-	-
Collector	-	**U5**	**U4**	**U3**	-	-
Local street	-	-	**U4**	**U3**	**U2**	**U1**

Selection of Access Control

Design Standard / Area & Road Category	R6/U6	R5/U5	R4/U4	R3/U3	R2/U2	R1/U1
RURAL:						
Expressway	F	-	-	-	-	-
Highway	-	P	-	-	-	-
Primary road	-	P	P	-	-	-
Secondary rd.	-	-	P	P	-	-
Minor road	-	-	-	-	N	N
URBAN:						
Expressway	F	-	-	-	-	-
Arterials	-	P	P	-	-	-
Collector	-	P	P	P	-	-
Local street	-	-	N	N	N	N

Criteria that govern the geometric design

a) *Terrain* – influences the design of both horizontal and vertical alignments. Earthworks and construction costs usually depend on the vertical alignment and terrain. Operational characteristics, x section,

Road terrain is divided into 3 types, i.e:

(i) Level – if the average slope of the contour is less than 3%.

(ii) Rolling – if slope in the range of 3 – 25%

(iii) Mountainous – if slope greater than 25%.

b) Design Speed

Road Hierarchy	Design Speed (km/h)		
	Terrain		
	Level	*Rolling*	*Mountainous*
R6	110	100	80
R5	100	90	70
R4	90	80	60
R3	80	60	50
R2	60	50	40
R1	50	50	30

c) *Design traffic volume & Ingress/Egress control* – the ADT stated in Table may be taken as an estimate of traffic at the end of the design life of the road to build.
The ingress/egress control depends on the requirements and its suitability with the type of the road to build.

d) *Design vehicle* – Weight, size, and operational characteristics of a vehicle determine the design of the basic elements of a road section, i.e., radius of road bends, pavement width, uphill and downhill gradients, etc. Standards for design vehicle are stipulated in REAM-GL 2/2002.

e) *Capacity* – ideal condition, design volume, service volume, and LOS and v/c

Design of the highway elements

- Sight distances
- Alignments

Sight Distances

Sight distance is the forward distance measure from vehicle within which all objects are visible by the driver while driving. The distance is influenced by factors such as:

- ✓Driver's perception & reaction time,
- ✓Deceleration & acceleration rates,
- ✓Friction between tyre and road surface,
- ✓Height of the driver's eyes & objects on the road, etc.

Braking or Stopping Sight Distance

Consists of two components:

(a) Distance travelled during perception time (d_1):

$$d_1 = 0.28Vt \ \text{meter}$$

with V = vehicle's speed (km/h)

t = perception–reaction time (sec)

(b) Distance travelled during braking (d_2):

$$d_2 = \frac{V^2 - U^2}{254(f + G)} \ \text{meter.}$$

V = initial speed (km/h)

U = final speed (km/h) = 0 if vehicle stops

G = gradient of the road

f = side friction between road surface and tyre

Stopping Sight Distance = 0.28Vt + (V^2 – U^2)/254(f + G) meter

Some examples of the application of sight distance design

- to ensure that safety elements are included in the geometry design

- to determine the locations of warning/reminder system to the drivers/users

EXAMPLE 1

- A driver takes 3.2 s to react to a complex situation while traveling at a speed of 55 km/h. How far does the vehicle travel before the driver initiates a physical response to the situation (i.e., putting his or her foot on the brake) ?.

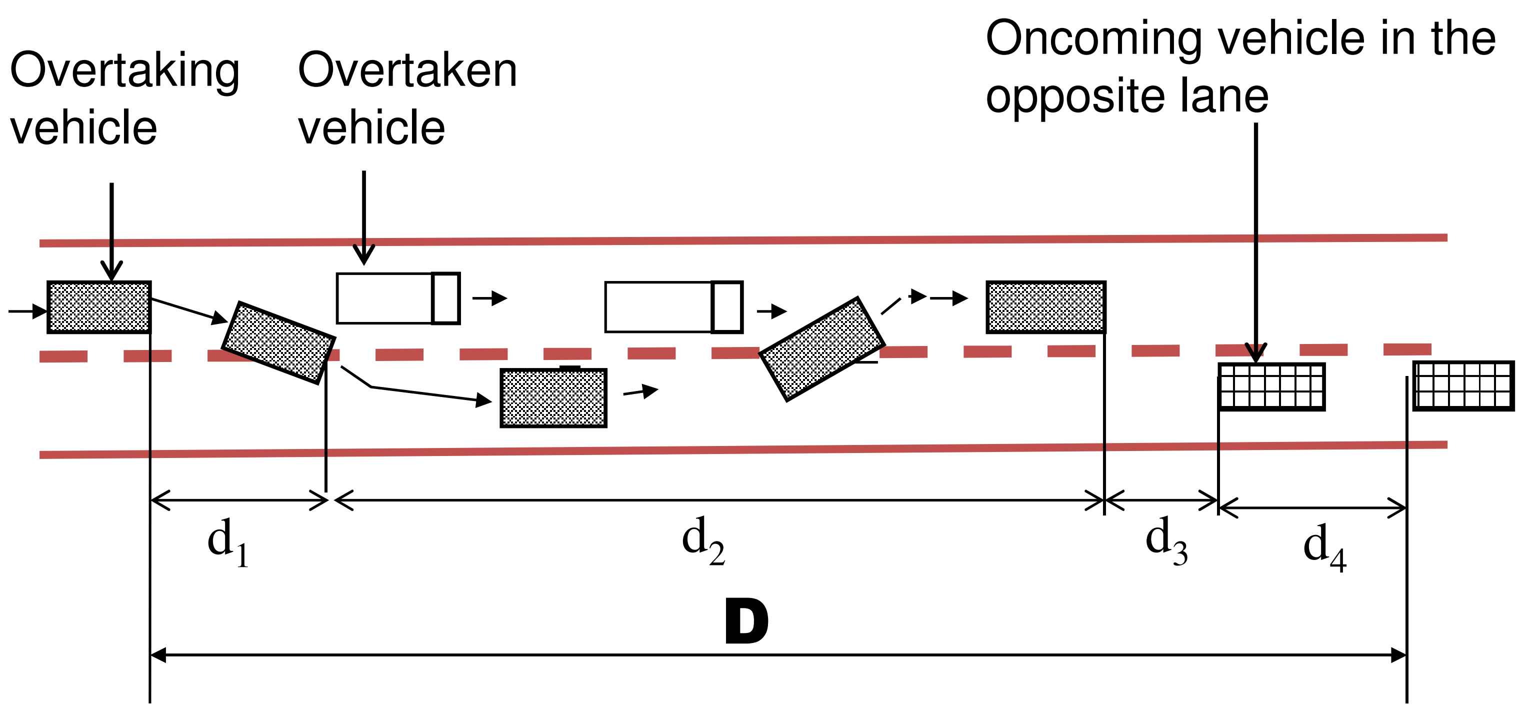
EXAMPLE 2

- What is the safe stopping distance for a section of rural freeway with a design speed of 80 km/h on a 4% uphill grade ?. Use perception-reaction time of 2.5 s and coefficient of friction of 0.25.

EXAMPLE 3

- Drivers must slow down from 110 km/h to 70 km/h to negotiate a severe curve on a rural highway. A warning sign for the curve is clearly visible for a distance of 50 m. How far in advance of the curves must the sign be located in order to ensure that vehicles have sufficient distance to safely decelerate? Use the perception-reaction time of 1.5 s and coefficient of friction of 0.30.

Passing or Overtaking Sight Distance



$$D = d_1 + d_2 + d_3 + d_4$$

Minimum Passing Sight Distances

Design Speed (km/h)	Minimum Passing Sight Distance (m)
110	730
100	670
90	610
80	550
70	490
60	410
50	350
40	290
30	230

Criteria for measuring sight distance?
REAM pg 31

Design of the highway Elements

- **Horizontal & vertical alignments** concern with the design of the turning radius and road gradients. To meet the safety requirements, road physical design is balanced with the characteristics that influence drivers such as *sight distance*.

Horizontal Alignment

- It concerns with the design of the road section as it is seen from bird's eye view – a straight section or a road bend.

- If a road bend is required, what is shape and what is the radius of the bend?
  - Base on a simple circular curve
  - Base on a spiral curve (i.e. a combination of a circular curve and transition curves)

Minimum Radius of Circular Curve

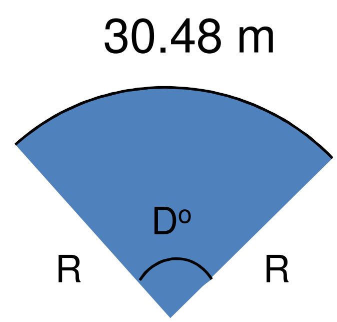
$$R = \frac{V^2}{127\,(e + f)} \text{ meter}$$

V = design speed in km/h

e = superelevation

f = road surface friction

Degree of Curvature



Degree of curvature, D

$$\frac{2\pi R}{360} = \frac{30.48}{D}$$

$$D = \frac{30.48(360)}{2\pi R}$$

Length of the curve, L

$$\frac{L}{30.48} = \frac{\theta}{D}$$

$$L = 30.48\left(\frac{\theta}{D}\right)$$

$$or$$

$$L = R \times \frac{2\pi\theta}{360}$$

Length of the long chord, L.C.

$$L.C. = 2R \sin\left(\theta/2\right)$$

Length of the tangent, T

$$T = R \tan\left(\theta/2\right)$$

Length of the external distance, E

$$E = T \tan\left(\theta/4\right)$$

Length of the middle ordinate, M

$$M = E \cos\left(\theta/2\right)$$

Once the length of the tangent and the length of the curve are known, the stations for the PC and PT can be determined:

$$P.C. = P.I. - T$$

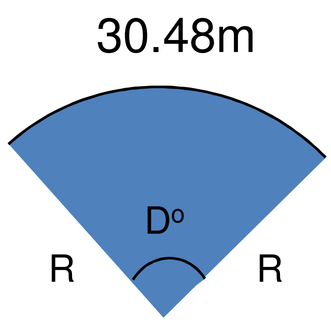
$$P.T. = P.C. + L$$

EXAMPLE 4

- The point of intersection (P.I.) of two tangent lines is station 15+20. The radius of curvature is 275 m, and the angle of deflection is 52^{o}. Find the length of the curve, the station for the P.C. and P.T., and all other relevant characteristics of the curve (L.C., M, E).

SOLUTION

$$\frac{2\pi R}{360} = \frac{30.48}{D}$$



$$D = \frac{30.48(360)}{2\pi R} = \frac{30.48(360)}{2\pi(275)} = 6.35^{o}$$

Length of the curve

$$\frac{L}{30.48} = \frac{\theta}{D}$$

$$L = 30.48\left(\frac{\theta}{D}\right) = 30.48\left(\frac{52^{o}}{6.35^{o}}\right) = 249.64\,m$$

SOLUTION

Length of the long chord

$$L.C. = 2R \sin\left(\theta/2\right) = 2 \times 275 \times \sin\left(52/2\right) = 241.10\,m$$

Length of the tangent

$$T = R \tan\left(\theta/2\right) = 275 \tan\left(52/2\right) = 134.13\,m$$

Length of the external distance

$$E = T \tan\left(\theta/4\right) = 134.13 \tan\left(52/4\right) = 30.97\,m$$

Length of the middle ordinate

$$M = E \cos\left(\theta/2\right) = 30.97 \cos\left(52/2\right) = 27.84\,m$$

SOLUTION

Once the length of the tangent and the length of the curve are known, the stations for the PC and PT can be determined:

$$P.C. = P.I. - T = 1520 - 134.13 = 1385.87 = 13 + 85.87 \quad sta$$

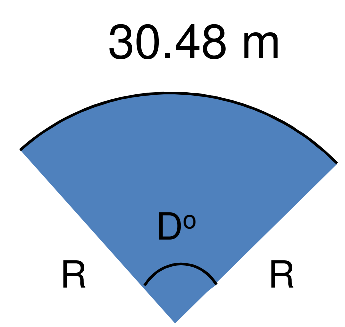
$$P.T. = P.C. + L = 1385.87 + 249.64 = 1635.51 = 16 + 35.51 \quad sta$$

EXAMPLE 5

- Two tangent lines meet at Station 320+15. The radius of curvature is 360m, and the angle of deflection is 14^{o}. Find the length of the curve, the station for the P.C. and P.T., and all other relevant characteristics of the curve (L.C., M, E).

SOLUTION

$$\frac{2\pi R}{360} = \frac{30.48}{D}$$



$$D = \frac{30.48(360)}{2\pi R} = \frac{30.48(360)}{2\pi(360)} = 4.85^{o}$$

Length of the curve

$$\frac{L}{30.48} = \frac{\theta}{D}$$

$$L = 30.48\left(\frac{\theta}{D}\right) = 30.48\left(\frac{14^{o}}{4.85^{o}}\right) = 87.94m$$

SOLUTION

Length of the long chord

$$L.C. = 2R \sin\left(\theta/2\right) = 2 \times 360 \times \sin\left(14/2\right) = 87.75\,m$$

Length of the tangent

$$T = R \tan\left(\theta/2\right) = 360 \tan\left(14/2\right) = 44.20\,m$$

Length of the external distance

$$E = T \tan\left(\theta/4\right) = 44.20 \tan\left(14/4\right) = 2.70\,m$$

Length of the middle ordinate

$$M = E \cos\left(\theta/2\right) = 2.70 \cos\left(14/2\right) = 2.68\,m$$

SOLUTION

Once the length of the tangent and the length of the curve are known, the stations for the PC and PT can be determined:

$$P.C. = P.I. - T = 32015 - 44.20 = 31970.8 = 319 + 70.8 \ sta$$

$$P.T. = P.C. + L = 31970.8 + 87.94 = 32058.74 = 320 + 58.74 \ sta$$

Transition or Spiral Curve

- When vehicles enter or leave a circular horizontal curve, the gain or loss of centrifugal force cannot be effected instantaneously, considering safety and comfort.
- In such cases, the insertion of transition curves between tangents and circular curves warrants consideration.

A properly designed transition curve provides the following advantages

- A natural, easy to follow path for drivers such that the centrifugal force increases and decreases gradually as a vehicle enters and leaves a circular curve
- A convenient desirable arrangement for superelevation runoff
- Flexibility in the widening of sharp curves
- Enhancement in the appearance of the highway.

A basic formula used for computing the minimum length of a spiral is

$$L_p = \frac{v^3\left(1 - \frac{R \times g \times e}{v^2}\right)}{c \times R} metre$$

Where:

Lp =minimum length of spiral (metre)
V = design speed (metre/sec)
R = radius of the circular curve (metre)
g = acceleration due to gravity = 9.81 m/s^2
e = superelevation (percent per hundred)
c = rate of increase of centrifugal acceleration (between 0.30 and 0.91 m/s^3)

Example (P 6)

A curve has been designed using combination of circular and spiral curve for 90km/hr and:

Deflection angle = 15° 30″

Side friction = 0.12

Superelevation = 6%

Radial acceleration = $0.9 m/s^3$

Determine the minimum radius, length of transition curve, and total length of the curve

Superelevation table, methods of attaining superelevation, widening

Vertical Alignment

- Concerns with the design of the longitudinal cross–section of a roadway
- Vertical curves are in the shape of a parabola.

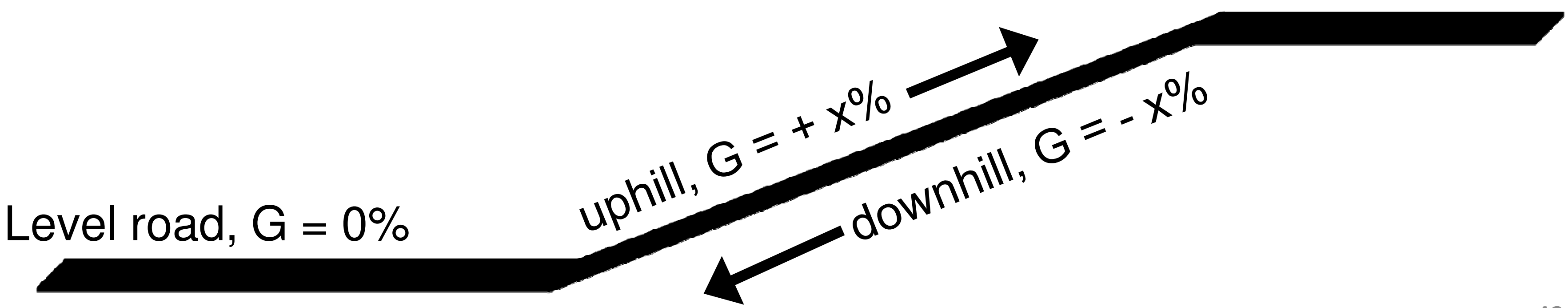
- Types of vertical curves:
  - Uphill or downhill slopes
  - Crest vertical curves – the entry tangent grade is greater than the exit tangent grade.
  - Sag vertical curves - the entry tangent grade is lower than the exit tangent grade.

Uphill and Downhill Slopes

- Gradient or slope must be selected in such a way that the performance of vehicles are not affected especially the uphill gradient.

Two aspects considered are:

- Maximum Gradient
- Length of Critical Gradient



Refer REAM pg 45-46

Design speed (km/h)	Desired maximum gradient (%)	Acceptable maximum gradient (%)
120	2	5
100	3	6
80	4	7
60	5	8
50	6	9
40	7	10
30	8	12
20	9	15

Refer REAM pg 46-47

Design speed (km/h)	Gradient (%)	Length of the critical gradient (m)
120	3 4 5	500 400 300
100	4 5 6	500 400 300
80	5 6 7	500 400 300
60	6 7 8	300 250 200

EXAMPLE 7

- A vertical curve of 300m is designed to connect a grade of +4% to a grade of -5%. The V.P.I. is located at station 15+55 and has a known elevation of 150m. Find the following:

- (a) the station of the V.P.C. and the V.P.T.
- (b) the elevation of the V.P.C. and the V.P.T.
- (c) the location and elevation of the high point on the curve.

SOLUTION

(a) Stations for the V.P.C. and the V.P.T.

Length along a vertical curve is measured in the plan view. Thus for a curve of 300m, the V.P.I. is located at the midway point i.e. 150m away from the V.P.C. and the V.P.T. Thus the stations for these points are:

V.P.C.= (15+55) – 150 = 14+05 m

V.P.T. = (15+55) + 150 = 17+05 m

SOLUTION

(b) i. Elevation of the V.P.C.

The grade between the V.P.C. and V.P.I. is +4%. The V.P.C., therefore has an elevation of:

$$Y_{VPC} = Y_o = 0.04(-150) + 150 = 144 \text{ m}$$

(b) ii. Elevation of the V.P.T.

The elevation of the V.P.T. is at the end of the vertical curve, at a distance of 300 m (L=3) from the V.P.C. Therefore:

$$Y_{VPT} = \frac{rx^2}{2} + G_1 x + Y_o = \left(\frac{-5-4}{2\times 3}\right)3^2 + 4(3) + 144 = 142.5m$$

SOLUTION

(c) High point of the curve and the elevation

The high point on the curve is located at the point where the first derivative of the curve is "zero". This occurs when x is:

$$x = \frac{-G_1 L}{G_2 - G_1} = \frac{-4(3)}{-5-4} = 1.33$$

Then, the elevation of the high point is found by using the curve equation:

$$Y_X = \frac{rx^2}{2} + G_1 x + Y_o = \left(\frac{-5-4}{2\times 3}\right)1.33^2 + 4(1.33) + 144 = 146.67m$$

EXAMPLE 8

- A -2.5% grade is connected to a +1.0% grade by means of a 180m vertical curve. The P.I. station is 121+21 and the P.I. elevation is 88.888m above sea level. What are the station and elevation of the lowest point on the vertical curve?

SOLUTION

Rate of change of grade:

$$r = \frac{G_2 - G_1}{L} = \frac{1.0\% - (-2.5\%)}{1.80\ sta} = 1.944\% / sta$$

Station of the low point:

$$At\ low\ po\text{int}, \frac{dY_X}{dx} = 0$$

$$\frac{dY_X}{dx} = 0 = rx + G_1$$

$$or$$

$$x = \frac{-G_1}{r} = -\left(\frac{-2.5}{1.944}\right) = 1.29 = 1 + 29\ \ sta$$

$$Station\ of\ \ BVC : (121 + 21) - (0 + 90) = 120 + 31$$

$$Station\ of\ \ low\ \ po\text{int} = (120 + 31) + (1 + 29) = 121 + 60$$

SOLUTION

Elevation of BVC:

$$Y_o = 88.888m + (-0.9\ \ sta)(-2.5\%) = 91.138m$$

Elevation of low point:

$$Y_X = \frac{rx^2}{2} + G_1 x + Y_o$$

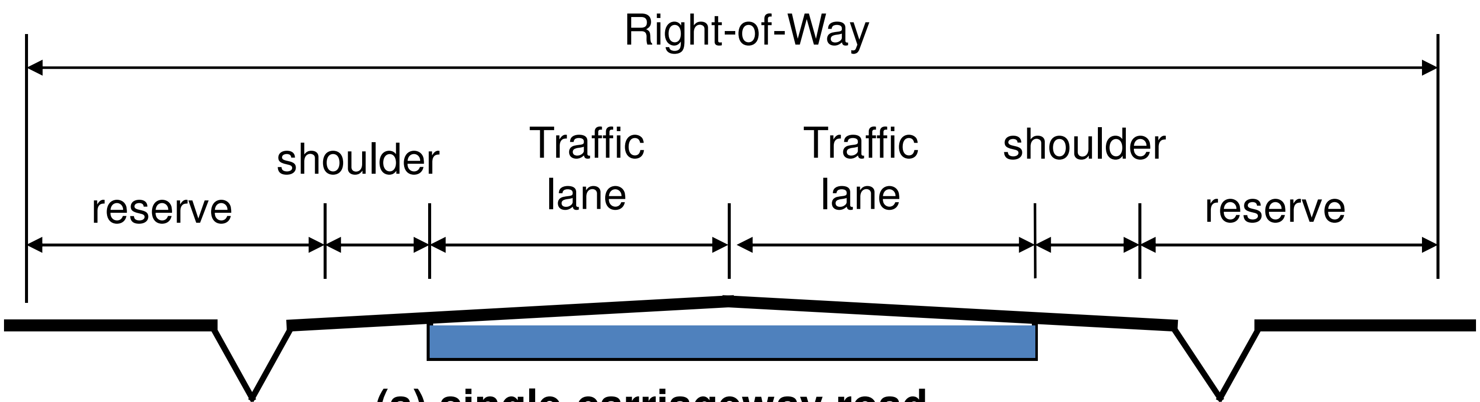
$$= \frac{(1.944\% / sta)(1.29\ \ sta)^2}{2} + (-2.5\%)(1.29\ \ sta) + 91.138m$$

$$= 89.531m$$

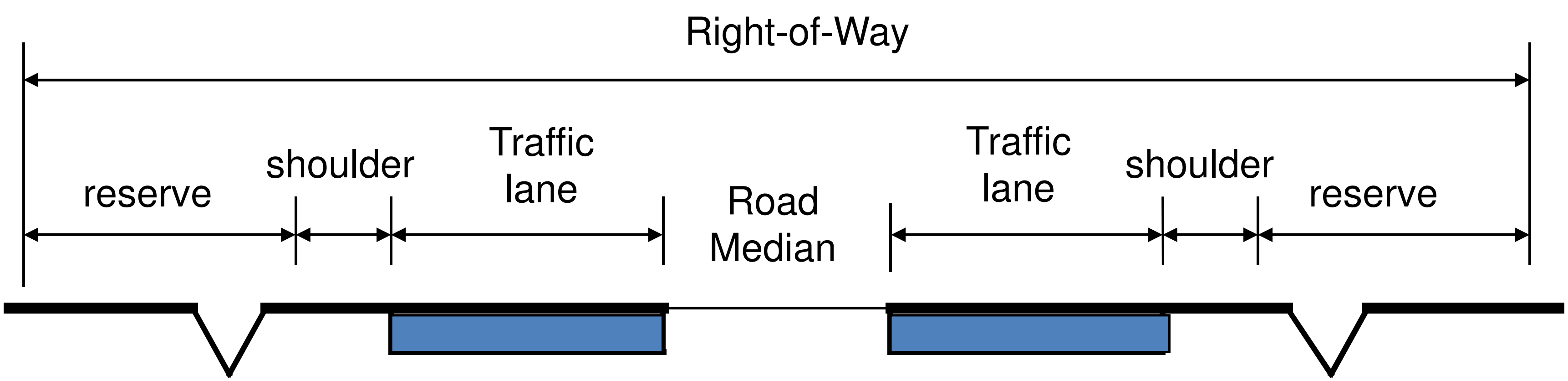
Other Considerations
REAM GL-2/2002

1. Maximum grades T 4-9x
2. Minimum grades
3. Critical grade length F 4-5
4. Climbing lanes for two-lane roads
5. Passing lane section in two-lane roads
6. Climbing lane on multilane roads
7. Combination of vertical and horizontal curve

Typical Elements of Highway Cross-section



(a) single-carriageway road



(b) dual-carriageway road

Problem Solving (PO4)

- Horizontal curve R = 250m of two lane highway with speed limit of 60 km/h, the curve is not super-elevated. Determine the horizontal sight line offset (HSO) where a billboard can be placed from the centerline of the inside lane of the curve, without reducing the required SSD. PIEV = 2.5s and f = 0.35

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