Chapter 4
Highway Geometric Design (1)

AN-NAJAH NATIONAL UNIVERSITY
NABLUS, PALESTINE

Outline: Chapter 4

4.1 Design of Cross-sectional Elements

4.2 Horizontal Alignments

4.3 Vertical Alignments

4.4 Parking Facilities

4.1 Design of Cross-sectional Elements

Cross-sectional Elements

- The elements of a highway cross section consist of:
  1. **Travel Lanes**
  2. **Shoulders**
  3. **Medians**
- Marginal elements
  4. **Sidewalks**
  5. **Cross slopes**
  6. **Side slopes**
  7. **Curbs and gutters**
  8. **Guard rails**
  9. **Roadside and median barriers**
  10. **Right of way**

Cross-sectional Elements

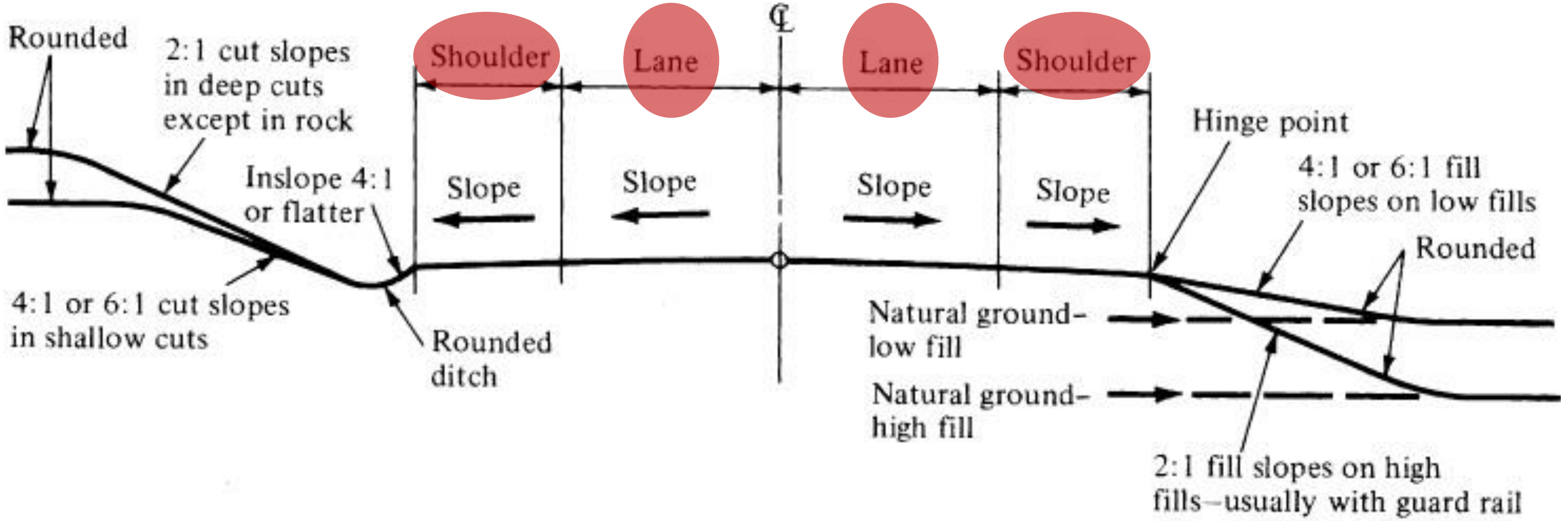


Figure 15.4 Typical Cross Section for Two-Lane Highways

** Refer to the Multimedia CD of the course*

Cross-sectional Elements

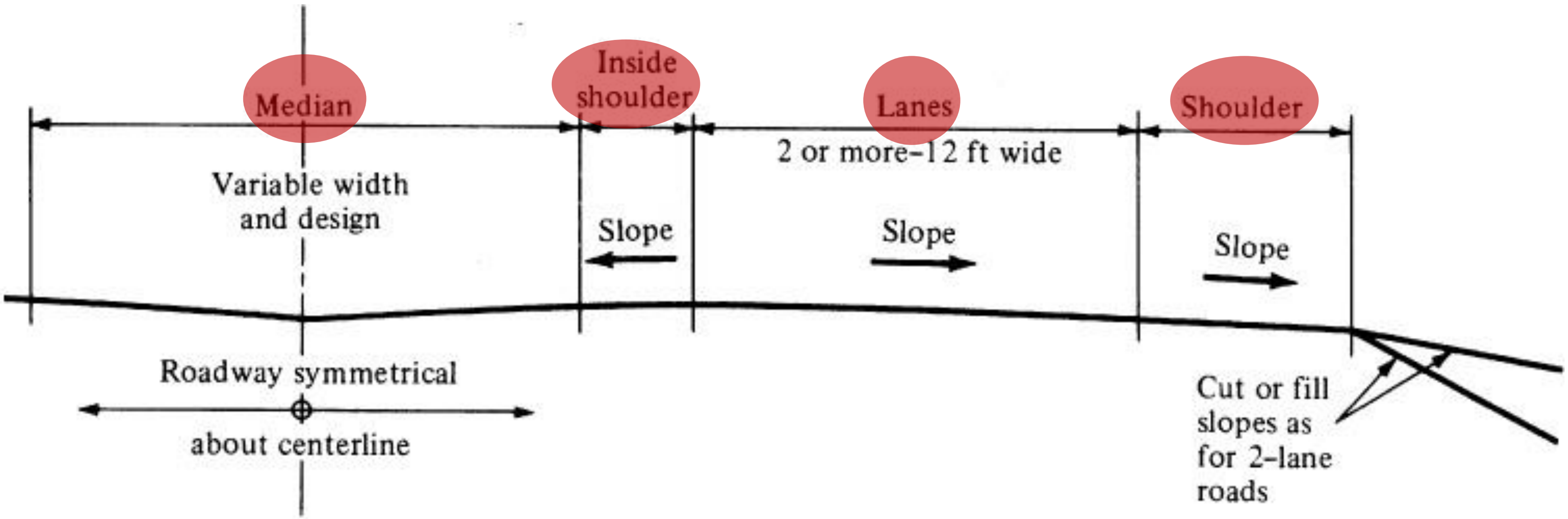


Figure 15.5 Typical Cross Section for Multilane Highways (half section)

** Refer to the Multimedia CD of the course*

1) Travel Lanes

– **Most arterials have 3.6m travel lanes** since

- The extra cost for constructing 3.6m lanes over 3.0m lanes is usually offset by the lower maintenance cost for shoulders and pavement surface, resulting in the reduction of wheel concentrations at the pavement edges.

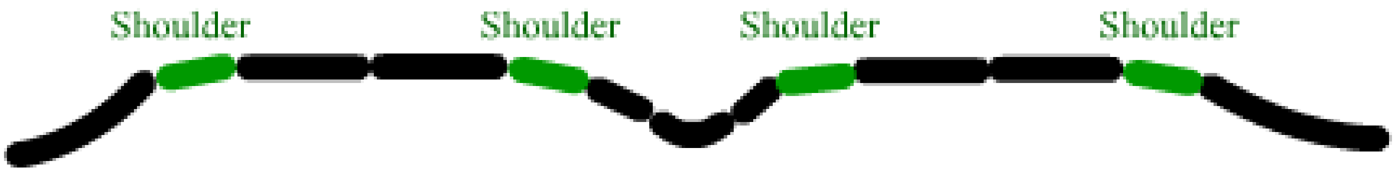
Travel lane widths usually vary from 3.0m to 3.6m. **(9.0 ft to 12.0 ft)**

1) Travel Lanes

- **On two-lane, two-way rural roads, lane widths of 3.0m or 3.3m (10 or 11 ft) may be used**. Two factors should be considered:
  - Accident rates which tend to increase
  - Capacity of a highway which significantly decreases as the lane width is reduced from 3.3m.
- **Lane width of 10 ft (3.0 m) used only on low-speed facilities.**
- **Lane width of 9 ft (2.75 m) are used occasionally in urban areas if:**
  - traffic volume is low and
  - there are extreme right-of-way constraints.

2) Shoulders

– **They function to:**
  - providing space along the highway for vehicles to stop especially during emergencies.
  - Shoulders also function to laterally support the pavement structure.
  - In some cases, bicycles are permitted to use a highway shoulder particularly on rural and collector roads



Shoulder width is usually 1.2m to 1.8m

2) Shoulders

- Shoulder width is known as either graded or usable.
  - **Graded shoulder width** is the whole width of the shoulder.
  - **Usable shoulder width** is that part of the graded shoulder that can be used to accommodate parked vehicles. .
- Dimensions of usable shoulder:

Min 2 ft

If pedestrian or bicycles are permitted **4 ft**.

↓

6 ft to 8 ft

1.8 m to 2.4 m

↓

Max of 10 ft

on highways with a large number of trucks and heavy traffic volumes and high speeds.

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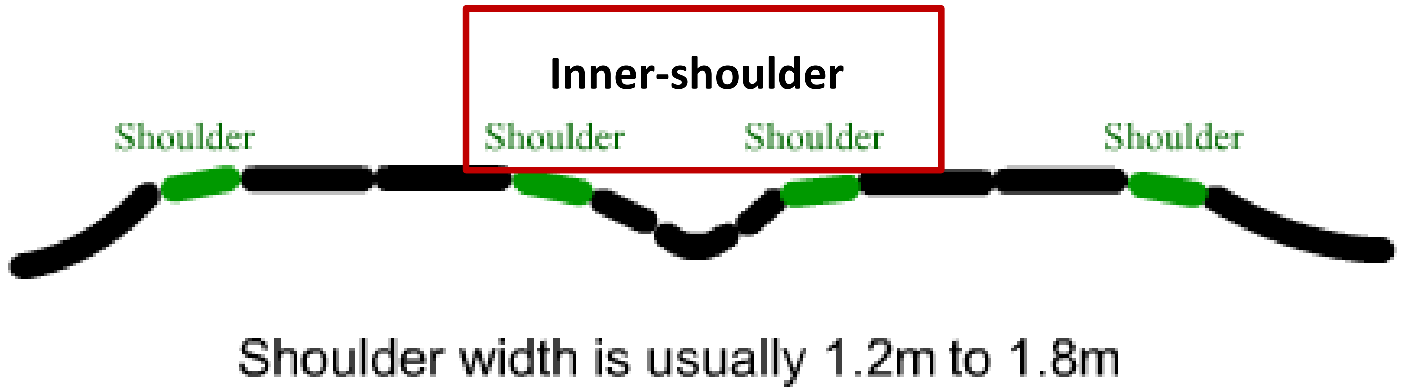
2) Shoulders

– **Inner usable shoulders in four- lane two-way highways can be min 3 ft.**
  - since drivers rarely use the median shoulder for stopping
– **Inner usable shoulders in 6-lane two-way highways can be min 8 ft**
  - Since drivers in the lane next to the median find it difficult to maneuver to the outside shoulder when there is a need to stop.



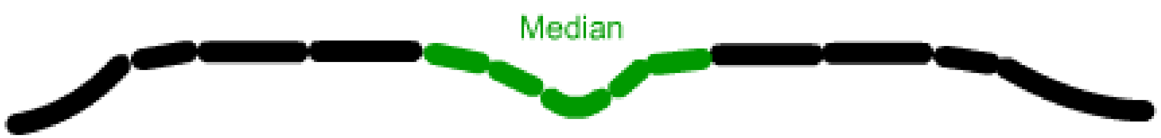
2) Shoulders

– **All shoulders should be flush with the edge of the traveled lane and sloped to facilitate the drainage of surface water on the traveled lanes.**
  - Recommended slopes are **2 to 6 percent** for bituminous and concrete-surfaced shoulders.
  - **4 to 6 percent** for gravel or crushed-rock shoulders

– **Rumble strips may be used on paved shoulders along arterials as a safety measure to warn motorists that they are leaving the traffic lane.**

3) Medians

- **It is the element of a divided highway that separates the lanes in opposing directions.**
- **The functions**
  - 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



Median width for urban collector streets
vary from 0.6m to 12.5m

3) Medians

- **Medians can be**
  - **Raised**: are frequently used in **urban arterial streets** because:
    - they facilitate the control of left-turn traffic at intersections by using part of the median width for left-turn-only lanes.
    - Some disadvantages include
      - » possible loss of control of the vehicle if the median is accidentally struck,
      - » they cast a shadow from oncoming headlights, which results in drivers finding it difficult to see the curb.

a – Step-shaped in-situ | b – Pre-cast concrete | c – Steel guardrail | d – NJ-shaped in-situ

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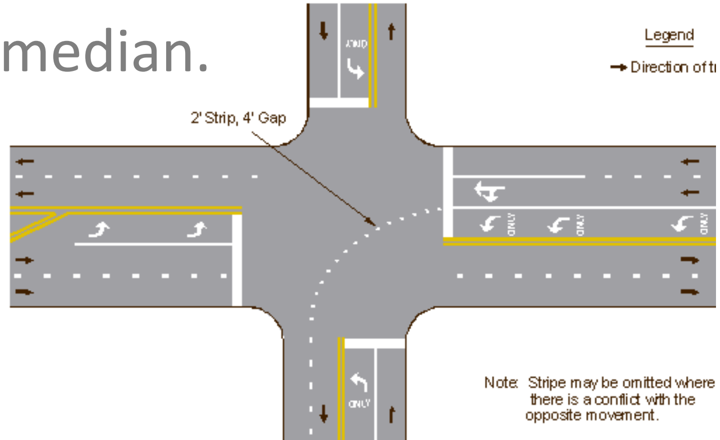
3) Medians

– Flushed Medians

- They are commonly used in **urban arterial**
- They can also be used on freeways, but with a median barrier.
- To facilitate drainage of surface water, it should be crowned.
- The practice in urban areas of converting them into two-way left-turn lanes is common, since:
  - – capacity of the urban highway is increased while maintaining some features of a median.

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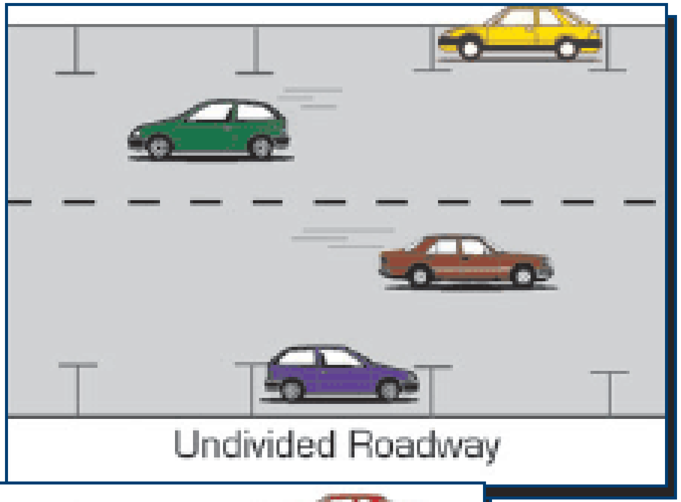

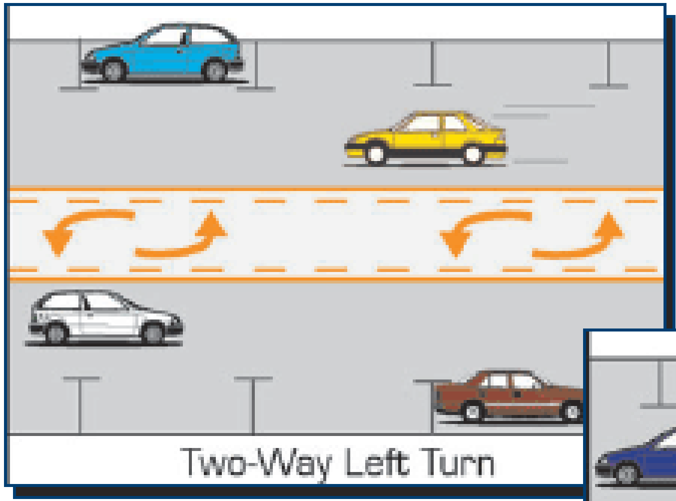

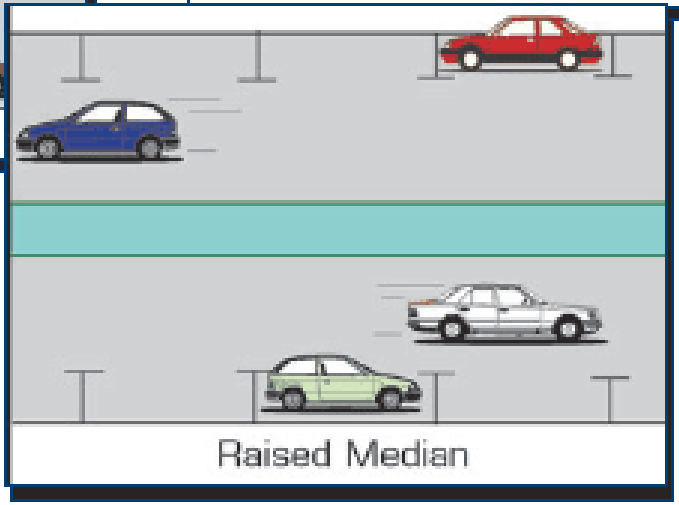

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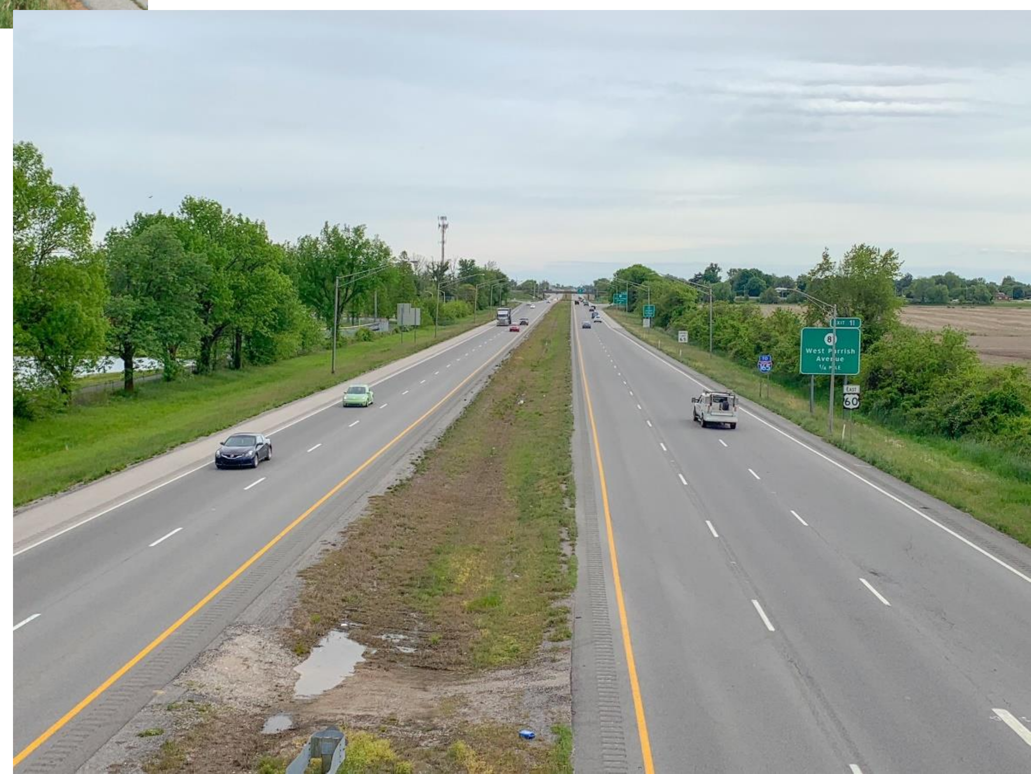
3) Medians

- **Depressed Medians**
  - They are generally used on freeways and are more effective in draining surface water.
  - A side slope of 6:1 is suggested for depressed medians, although a slope of 4:1 may be adequate.


West Parrish Avenue

3) Medians

- **The width of a median is the distance between the edges of the inside lanes, including the median shoulders.**
- Median widths should be as wide as possible but should be balanced with the other elements of the cross section, and the cost involved.
  - ASSHTO recommends minimum width of **10 ft (3m)** for **four-lane urban freeways**
  - A minimum of **22 ft, preferably 26 ft**, is recommended for **six or more lanes of freeways.**
  - **In urban collector streets**, when the median is a paint-striped separation, **2 to 4 ft** medians are required.

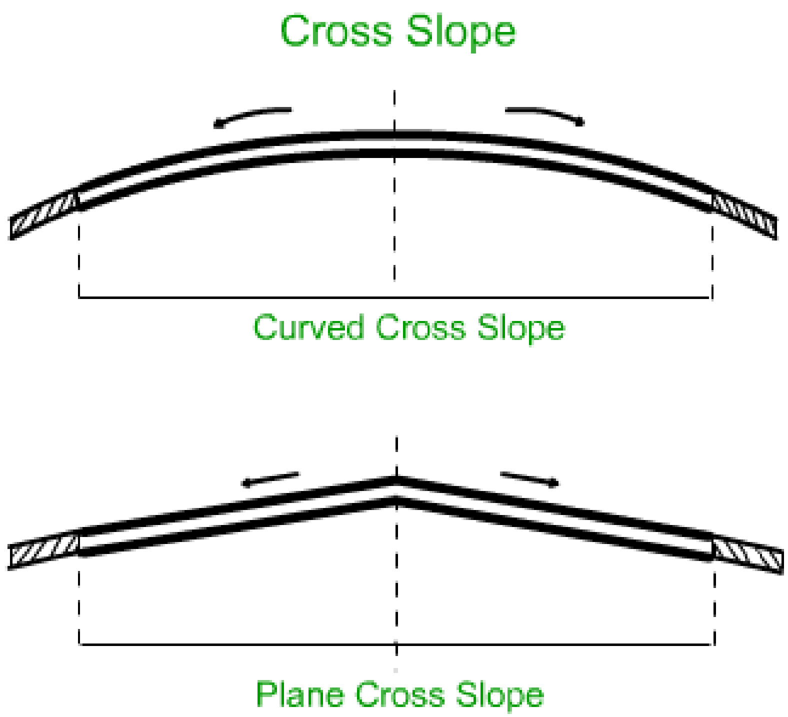
4) Sidewalks

- **Commonly used in urban area not in rural areas.**
  - Generally, sidewalks should be provided when pedestrian traffic is high along main or high-speed roads in either rural or urban areas.
  - When no shoulders are provided on arterials, sidewalks are necessary even when pedestrian traffic is low.
  - A minimum clear width of 4 ft in residential areas and a range of 4 to 8 ft in commercial areas.
  - To encourage pedestrians to use sidewalks, they should have all-weather surfaces since pedestrians will tend to use traffic lanes rather than unpaved sidewalks.

5) Cross Slopes

– **Plan and curved cross slopes.**

- The curved cross section has one advantage which is that **the slope increases outward to the pavement edge, thereby enhancing the flow of surface water away from the pavement**.
  - **A disadvantage is they are difficult to construct**.
- Plane cross slopes consist of uniform slopes at both sides of the crown.



5) Cross Slopes

– **On divided highways:**

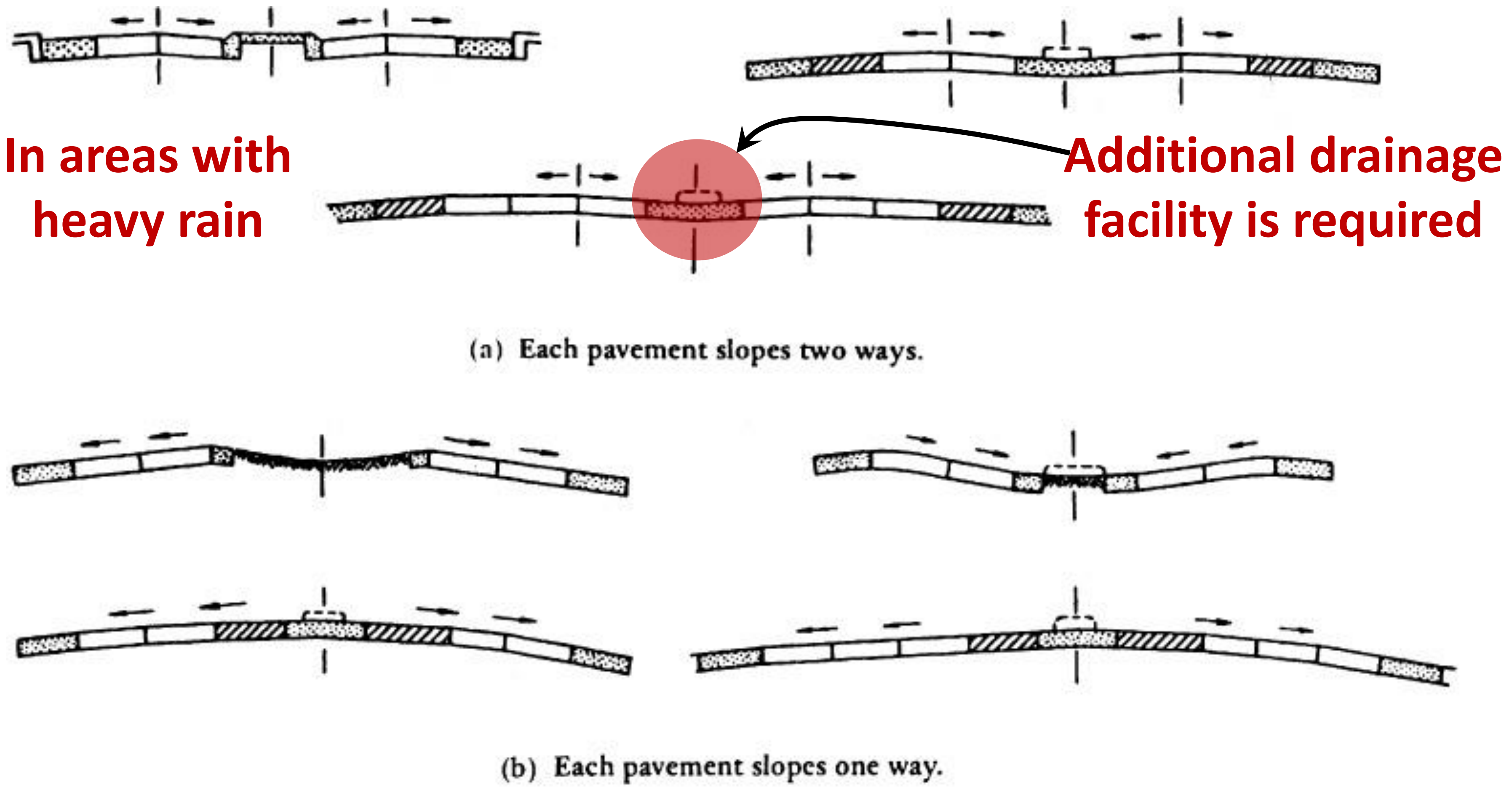


Figure 15.9 Basic Cross Slope Arrangements for Divided Highways

SOURCE: *A Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

5) Cross Slopes

- **In defining the rate of cross slope for design, two conflicting factors should be considered:**
  - Steep cross slope is required for drainage purposes,
  - Steep cross slopes are undesirable since vehicles will tend to drift to the edge of the pavement, particularly under icy conditions.
- **Recommended rates are:**
  - **1.5 to 2 percent for high type pavements.**
  - **2 to 6 percent for low-type pavements.**
- High-type pavements have wearing surfaces that can adequately support the expected traffic load without visible distress due to fatigue and are not susceptible to weather conditions.
- Low-type pavements are used mainly for low-cost roads and have wearing surfaces ranging from untreated loose material to surface-treated earth.

6) Side Slopes

– **Side slopes are provided on embankments and fills to provide stability for earthworks.**

– **They also serve as a safety feature by providing a recovery area for out-of-control vehicles.:**

  • the important sections of the cross slope are the hinge point, the foreslope, and the toe of the slope.

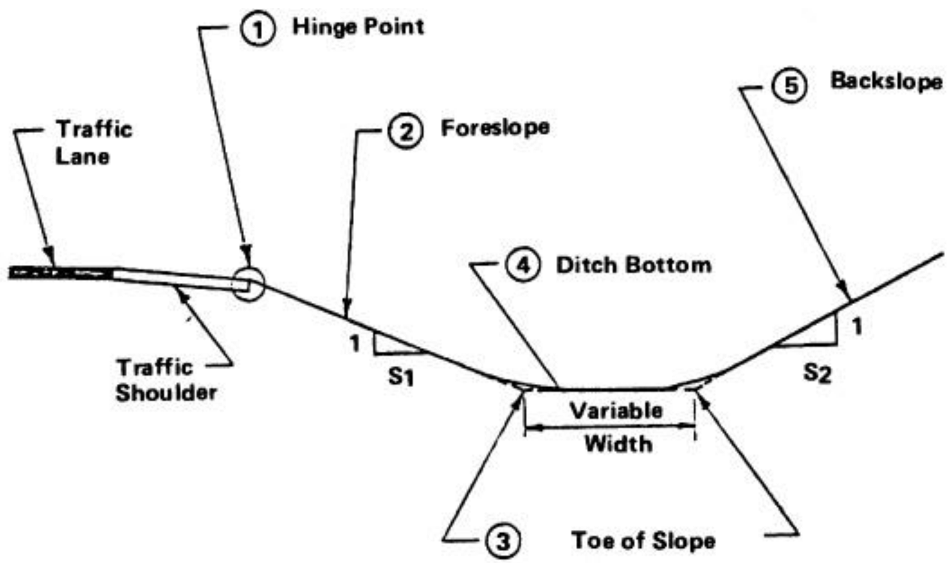


Figure 15.10 Designation of Roadside Regions

SOURCE: *A Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

6) Side Slopes

- **The hinge point is potentially hazardous since it may cause vehicles to jump into air while crossing it, resulting in loss of control by the driver.**
- **The foreslope is the area that serves principally as a recovery area, where:**
  - vehicle speeds can be reduced and
  - other recovery maneuvers taken to regain control of the vehicle.
- **The gradient of the foreslope should therefore not be high.**

Table 15.3 Guide for Earth Slope Design

	Earth Slope, for Type of Terrain		
Height of Cut or Fill (ft)	*Flat or Rolling*	*Moderately Steep*	*Steep*
0–4	6:1	6:1	4:1
4–10	4:1	4:1	2:1*
10–15	4:1	2.50:1	1.75:1*
15–20	2:1*	2:1*	1.75:1*
Over 20	2:1*	2:1*	1.75:1*

*Slopes 2:1 or steeper should be subject to a soil stability analysis and should be reviewed for safety.

7) Curbs and Gutters

- **Curbs** are raised structures mainly made of Portland cement concrete that are used on urban highways to
  - delineate pavement edges and pedestrian walkways.
  - control drainage, improve aesthetics, and reduce right of way.
- **Curbs are classified to Vertical and Sloping (mountable).**
  - Vertical curbs are designed to prevent vehicles from leaving the highway.
    - Height ranges from 6 to 8 inch (15 to 20 cm) with steep sides.
  - Sloping curbs are designed so that vehicles can cross if necessary

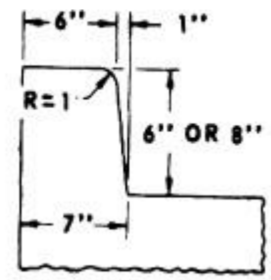
- Vertical

- Sloping/ Mountable

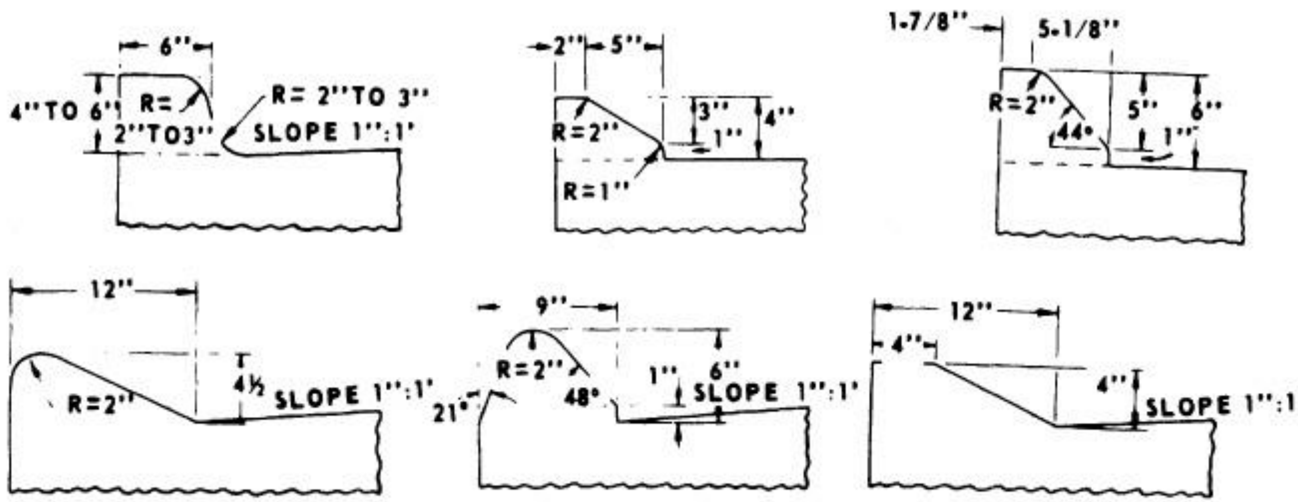
Curb and Gutter

7) Curbs and Gutters

– **Curbs are classified to Vertical and Sloping (mountable).**



(a) Vertical curb



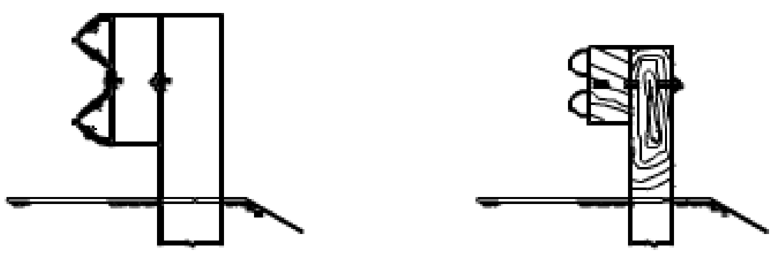
(b) Sloping curbs

Figure 15.8 Typical Highway Curbs

SOURCE: *A Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

8) Guard Rails

- They are longitudinal barriers placed on the outside of sharp curves and at sections with high fills.
- They are also used at the outside of curved highway segments
- **Their main function** is to prevent vehicles from leaving the roadway.
- They are installed at embankments higher than 8 ft and when shoulder slopes are greater than 4:1



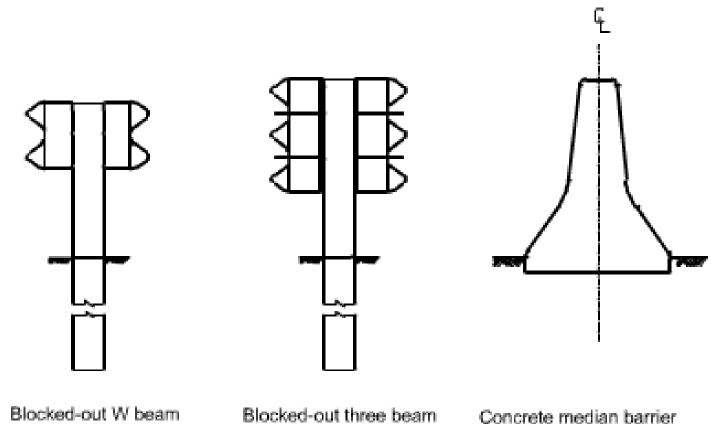
W beam and the box beam

Different Types of Guard Rails

Weak Post System

9) Roadside and Median Barriers

- **Median barrier** is defined as a longitudinal system used to prevent an errant vehicle from crossing to the opposing direction .
- It is used when
  - traffic volumes are high,
  - access to multilane highways and other highways is partially controlled.
  - the median of a divided highway has physical characteristics that may create unsafe conditions



Typical Roadside and Median Barriers

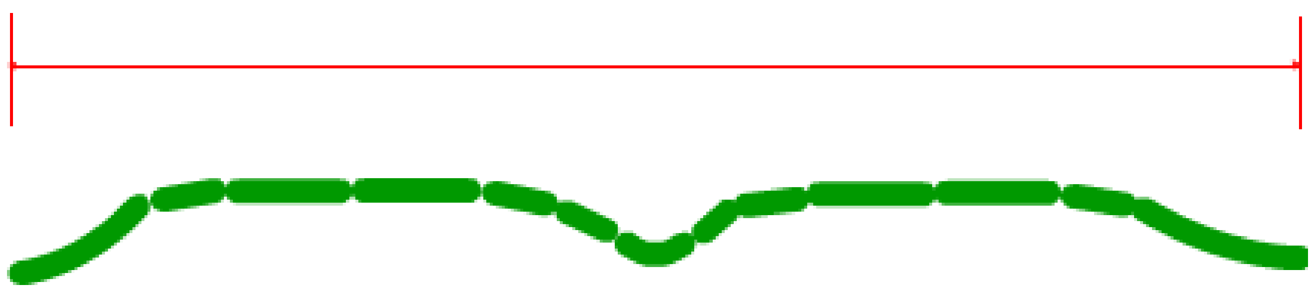

TON AVE

9) Roadside and Median Barriers

- **Roadside barriers** protect vehicles from obstacles or slopes on the roadside.
- They also may be used to shield pedestrians and property from the traffic stream
- The selection of the most desirable system should provide the required degree of shielding at the lowest cost.

10) Right of Way

- **The right of way** is the total land area acquired for the construction of the highway.
  - Its width should be enough to accommodate all the elements of the highway cross section, any planned widening of the highway, and any public utility facilities that will be installed along the highway.



The total land area acquired for the construction of the highway

10) Right of Way

- **Maximum highway grades:** The maximum grades for a highway depends on the design speed and the design vehicle.
- Grades of **4 to 5 percent** have little or no effect on passenger cars, except for those with high weight /horsepower ratios.
- Grade has a greater impact on trucks.
  - Truck speed may increase up to 5 percent on downgrades and decrease by 7 percent on upgrades, depending on the percent and length of the grade.
- **Maximum grades** have been established based on the operating characteristics of the design vehicle on the highway.

10) Right of Way

- **Maximum grades** have been established based on the operating characteristics of the design vehicle on the highway.
- Note the recommended maximum grades should not be used frequently, particularly when grades are long and the traffic includes a high percentage of trucks.
- **Minimum grades** depend on the drainage conditions of the highway.

Table 15.4 Recommended Maximum Grades

Rural Collectors[a] — *Design Speed (mi/h)*									
Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
Grades (%)									
Level	7	7	7	7	7	7	6	6	5
Rolling	10	10	9	9	8	8	7	7	6
Mountainous	12	11	10	10	10	10	9	9	8

Urban Collectors[a] — *Design Speed (mi/h)*									
Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
Grades (%)									
Level	9	9	9	9	9	8	7	7	6
Rolling	12	12	11	10	10	9	8	8	7
Mountainous	14	13	12	12	12	11	10	10	9

Rural Arterials — *Design Speed (mi/h)*									
Type of Terrain	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*
Grades (%)									
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5

Rural and Urban Freeways[b] — *Design Speed (mi/h)*							
Type of Terrain	*50*	*55*	*60*	*65*	*70*	*75*	*80*
Grades (%)							
Level	4	4	3	3	3	3	3
Rolling	5	5	4	4	4	4	4
Mountainous	6	6	6	5	5	–	–

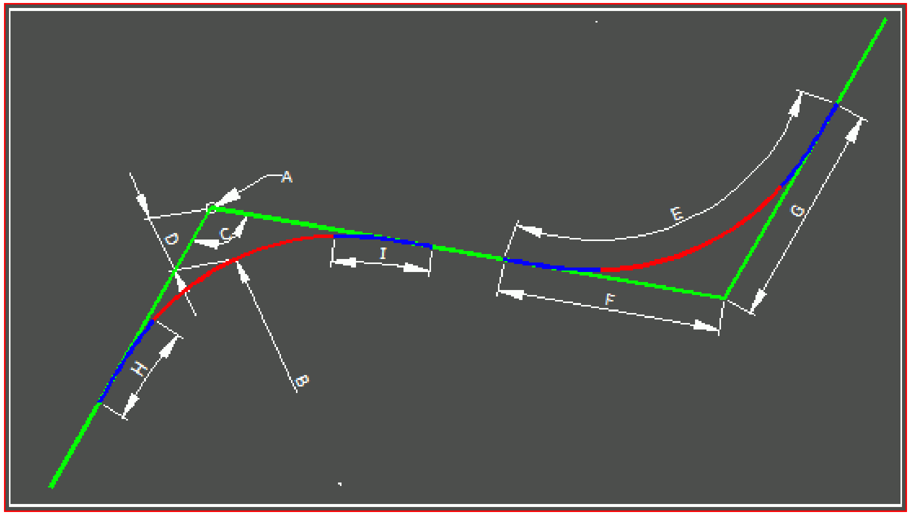
Urban Arterials — *Design Speed (mi/h)*							
Types of Terrain	*30*	*35*	*40*	*45*	*50*	*55*	*60*
Grades (%)							
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

[a]Maximum grades shown for rural and urban conditions of short lengths (less than 500 ft) and on one-way downgrades may be up to 2% steeper.
[b]Grades that are 1% steeper than the value shown may be used for extreme cases in urban areas where development precludes the use of flatter grades and for one-way downgrades, except in mountainous terrain.
SOURCE: Adapted from A *Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

4.2 Horizontal Alignments

Design of Horizontal Alignments

- Horizontal alignment consists of straight sections of the road, known as tangents, connected by horizontal curves.
- The design of the horizontal alignment contains the determination of:
  - Minimum radius
  - Length of the curve,
  - Horizontal offsets from the tangents to the curve to facilitate Locating the curve in the field



Design of Horizontal Curves

- Types of Horizontal curves:
  1. **Simple**
  2. **Compound**
  3. **Reversed**
  4. **Spiral (transition)**
     - To avoid a sudden change from a tangent with infinite radius to a curve of finite radius, a curve with radii varying from infinite value to the radius of the circular curve is placed between the circular curve and the tangent. Such a curve is known as the transition curve.

1. Simple Curves

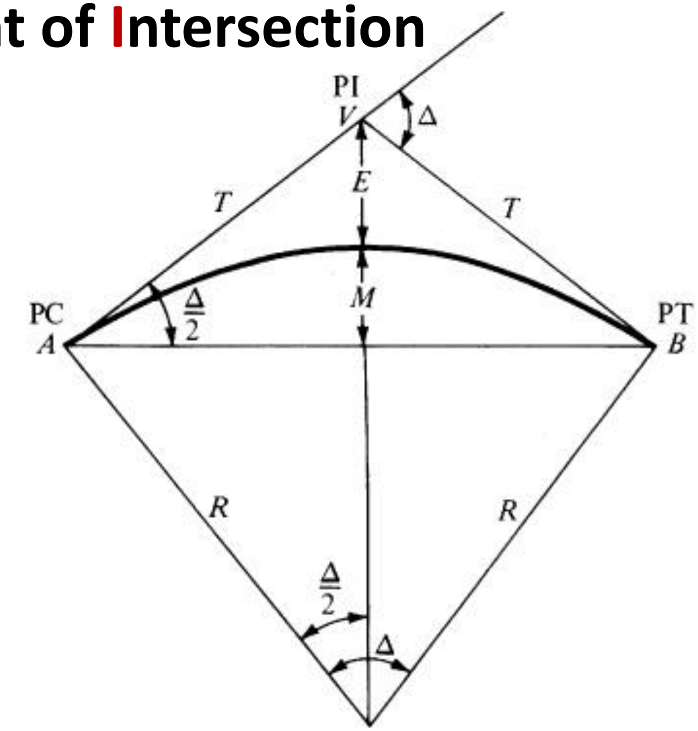
- The curves are usually segments of circles
- The minimum radius of a horizontal curve depends on:
  - Design speed
  - Superelevation (e),
  - Coefficient of side fictions (fs)

$$R = \frac{u^2}{g\,(e + f_s)}$$

- The **minimum radius** corresponds to the **maximum recommended superelevation rate** which depends on:
  - Location of the highway
  - Weather conditions (e.g., the occurrence of snow),
  - Distribution of slow-moving vehicles.

1. Simple Curves

- Assuming that the SSD is unobstructed, then the design of the curve is as follows.



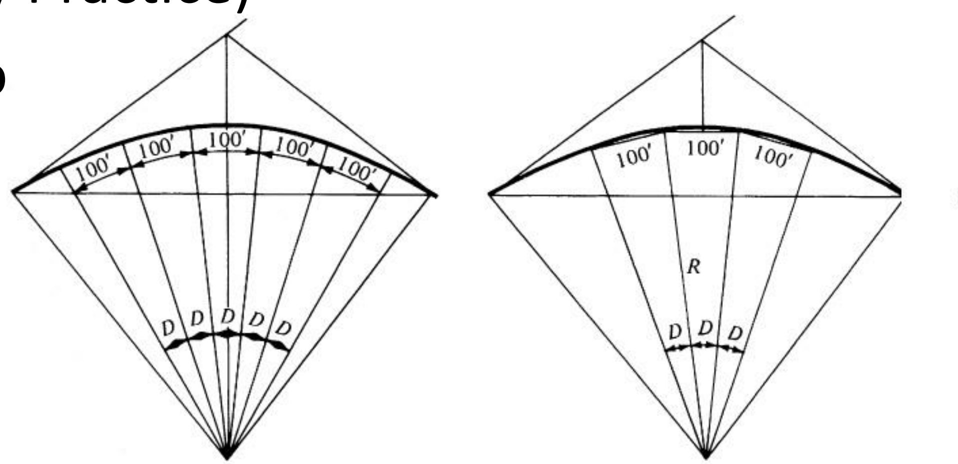
R = radius of circular curve
T = tangent length
Δ = intersection angle
M = middle ordinate

PC = point of curve
PT = point of tangent
PI = point of intersection
E = external distance

Figure 15.18 Layout of a Simple Horizontal Curve

1. Simple Curves

- A simple circular curve is described either by its
  - **Radius**
  - **Degree of the curve:** the angle subtended at the center by a circular arc of 100 ft (Highway Engineering)
- There are two ways to define **degree of the curve D**, which is based on
  - 100 ft of ***arc*** length (Highway Practice)
  - 100 ft of ***chord*** length (Railro



(a) Arc definition (b) Chord definition

Figure 15.19 Arc and Chord Definitions for a Circular Curve

1. Simple Curves

- If **θ** is the **angle in radians** subtended at the center by an arc of a circle, the length of that arc is given by: $L = R\theta$

$$R = \frac{180 \times 100}{\pi D_a^{\circ}}$$

$$R = \frac{5729.6}{D_a^{\circ}}$$

$$R = \frac{50}{\sin D_c^{\circ}/2}$$

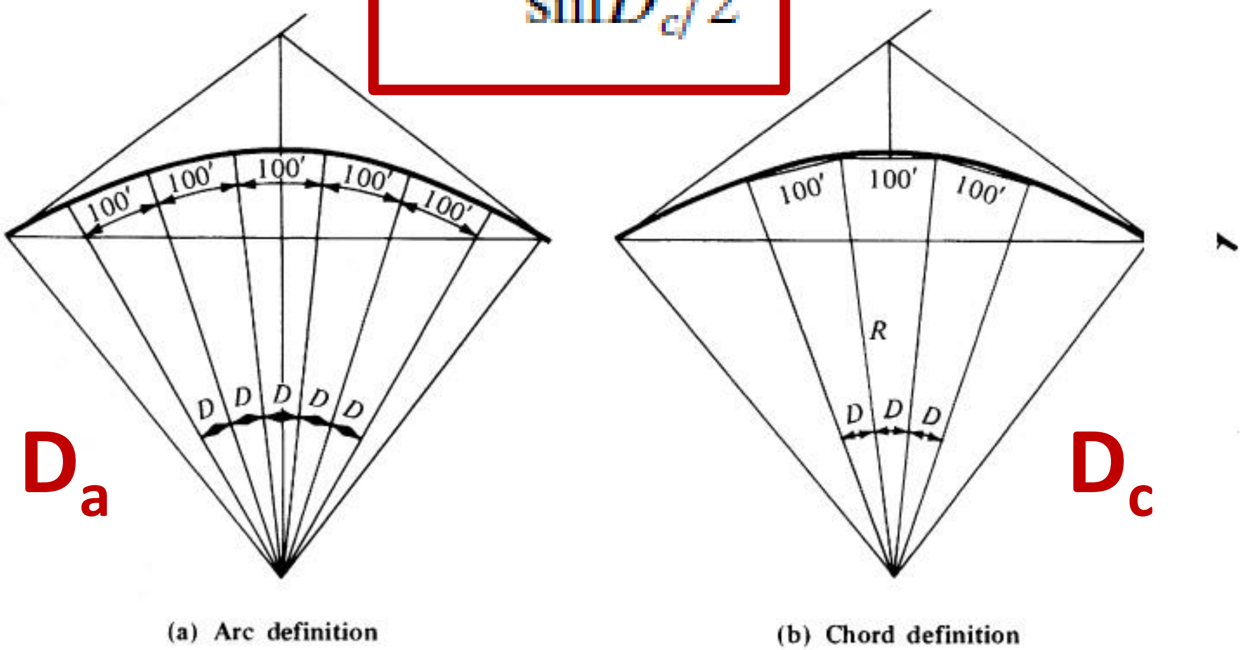


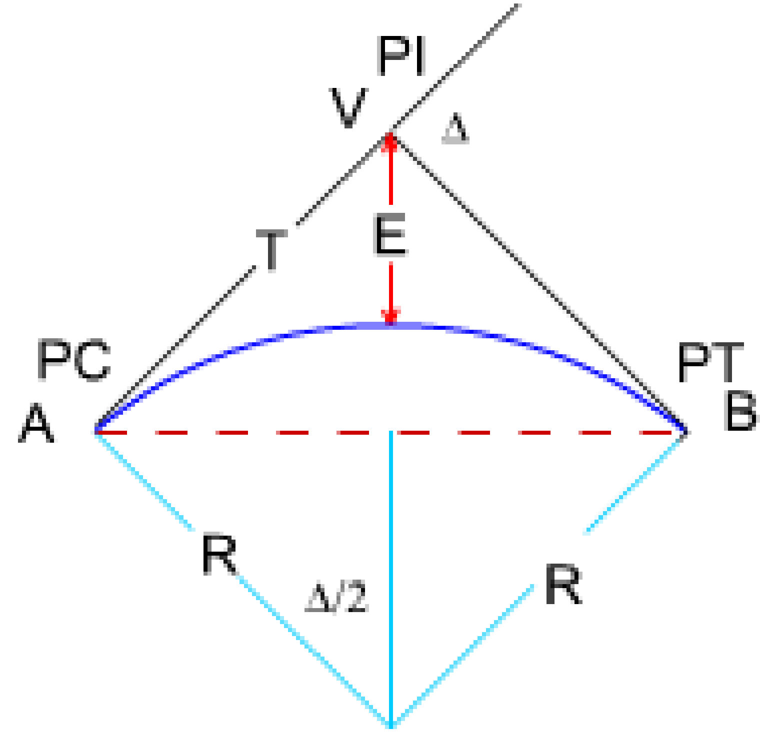
Figure 15.19 Arc and Chord Definitions for a Circular Curve

1. Simple Curves

- **Formulas for Simple Curves**

PC = Point of Curve
PT = Point of tangent
PI = Point of intersection
Δ = deflection angle
R = radius of circular curve

Intersection angle



where :

$$T = R \tan \frac{\Delta}{2}$$ Equation 3.5

$$C = 2R \sin \frac{\Delta}{2}$$ Equation 3.6

$$E = R\left(\frac{1}{\cos \frac{\Delta}{2}} - 1\right)$$ Equation 3.7

$$M = R\left(1 - \cos \frac{\Delta}{2}\right)$$ Equation 3.8

$$L = \frac{R \Delta \pi}{180}$$ Equation 3.9

1. Simple Curves

- **Field Location of a Simple Horizontal Curve.**
  - Simple horizontal curves are usually set out in the field by staking out points on the curve using:
    - **Deflection angles** measured from the tangent at the point of curve (PC)
    - **Lengths of the chords** joining consecutive whole stations.

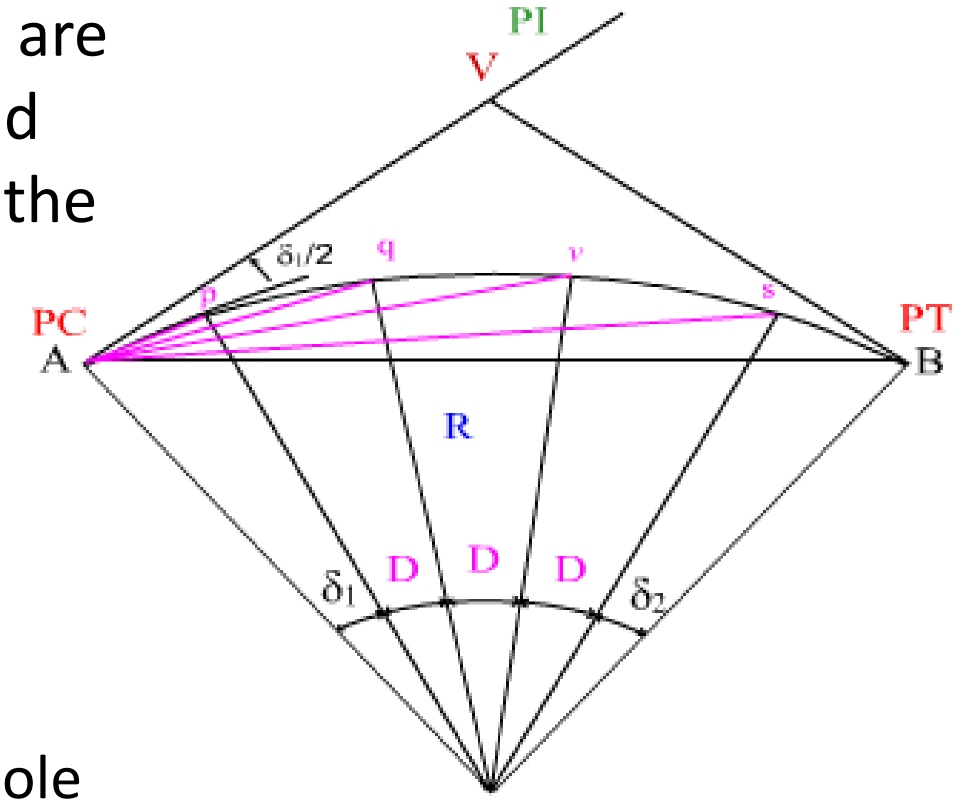


Figure 3.10 Deflection Angles on a Simple Circular Curve

1. Simple Curves

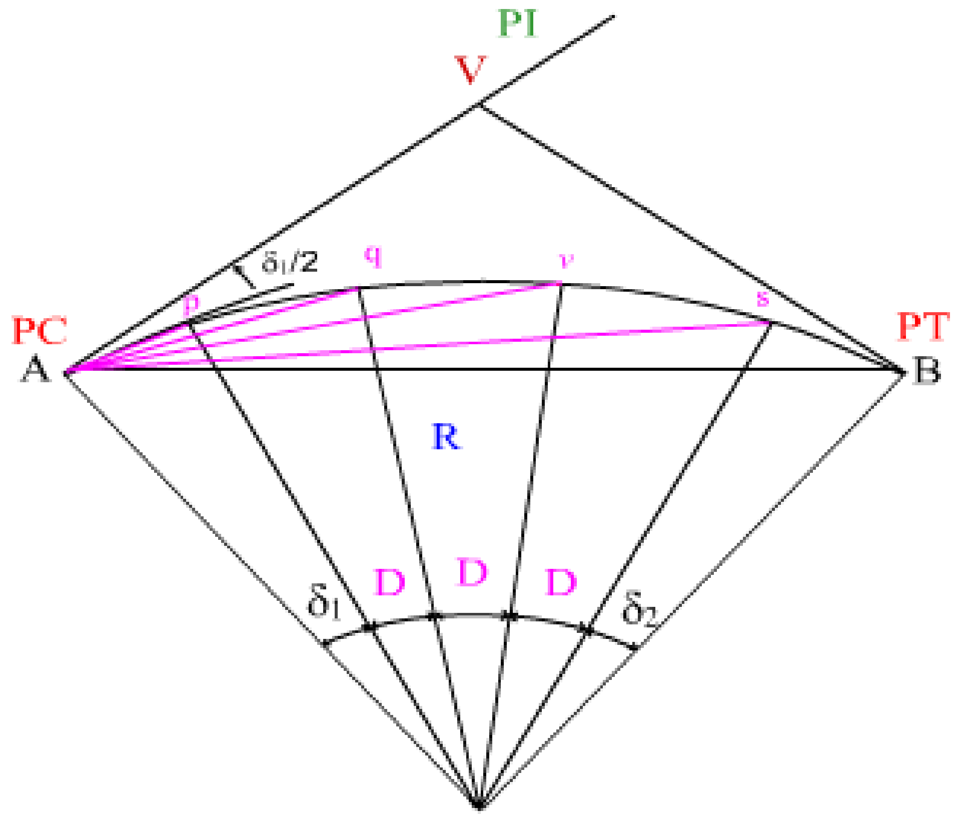
- **Field Location of a Simple Horizontal Curve.**

$$l_1 = \frac{R\pi}{180}\,\delta_1$$

$$C_1 = 2R\sin\frac{\delta_1}{2}$$

$$C_D = 2R\sin\frac{D}{2}$$

$$C_2 = 2R\sin\frac{\delta_2}{2}$$



nple Circular Curve

where
C_1, C_D and C_2 are the first, intermediate, and last chords, respectively.

Example 1

Example 3.1: Design of a Horizontal Curve

The deflection angle of a 3° cruve is 50°25'. Determine the length of the curve?

$$\text{Radius of curve} = \frac{1718}{D}$$

$$\text{Radius of curve} = \frac{1718}{3} = 572.55 \text{ m}$$

$$\text{Length of curve} = \frac{R\Delta\pi}{180}$$

$$\text{Length of curve} = \frac{572.66*50°25'*p}{180} = 503.58 \text{ m}$$

Example 15.13 (Page 804)

Given a circular curve connecting 2 tangents that deflect an angle of 48°. The PI is at station (948+67.32) and the design speed of the highway is 60 mi/h. Determine the point of the tangent and the deflection angles to full stations for laying out the curve.

First determine the radius of the curve using Equation 16.24,

$$R = u^2 / [15(e + f_s)]$$

For u = 60 mi/h, from Table 3.4, $f_s = 0.12$, e = 0.08

$$R = (60)^2 / [15(0.08+0.12)]$$

$$R = 1200 \text{ ft}$$

The length of the tangent, T, can be found using Equation 16.28,

$$T = R \tan(\Delta/2) = 1200(\tan(48/2))$$

$$T = 534.27 \text{ ft}$$

The length of the curve, L, is given by:

$$L = R\Delta\pi / 180 = 1200(48)(3.1415926) / 180$$

$$L = 1005.30 \text{ ft}$$

Example 2

Station of the PC can be found by subtracting the tangent length from the station of the PI.

$PC = (948+67.32) - (5+34.27) = 943+33.05$

Station of the PT can be found by adding the length of the curve to the station of the PC.

$PT = (943+33.05) + (10+5.30) = 953+38.35$

First full station is located at 944+00

$\delta_1 / \Delta = l_1 / L$

$\delta_1 / 48 = 66.95 / 1005.3$

$\delta_1 = 3.197°$

The first chord can be found using Equation 16.34,

$C_1 = 2R \sin(\delta_1/2) = 2(1200) \sin(3.197 / 2)$

$C_1 = 66.94$ ft

The first deflection angle $= \delta_1/2 = 1.598$

Last full station is located at 953+00

$\delta_2 / \Delta = l_2 / L$

$\delta_2 / 48 = 38.35 / 1005.30$

$\delta_2 = 1.831$

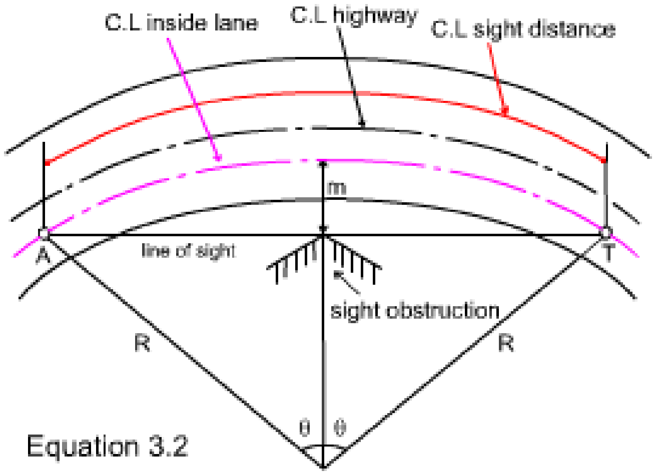
The last chord can be found using Equation 16.34,

$C_2 = 2R \sin(\delta_2/2) = 2(1200) \sin(1.831 / 2)$

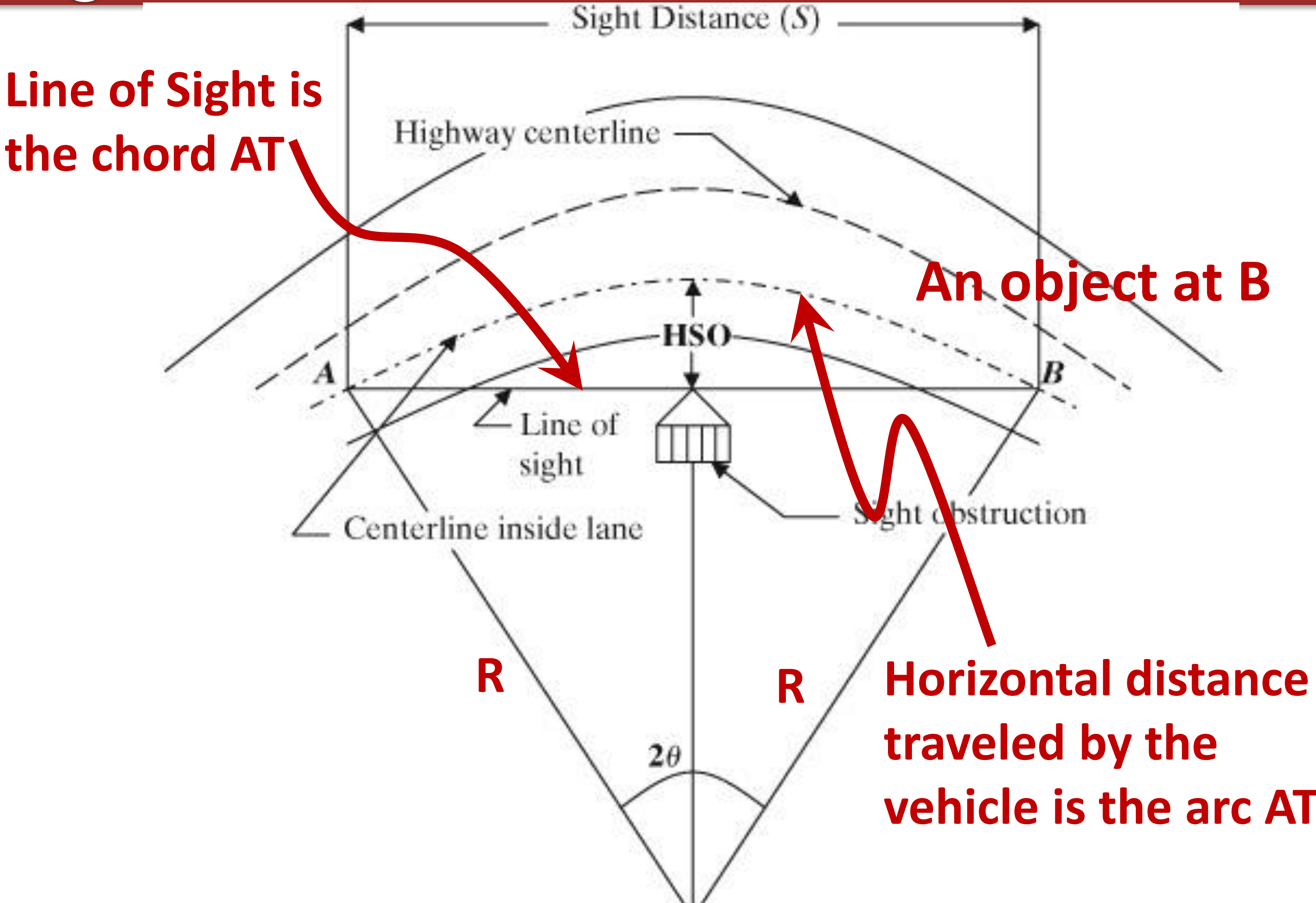
$C_2 = 38.35$ ft

Sight Distance on Horizontal Curves

- **Previously we assumed that there are no constraints on the design of horizontal curves.**
  - At a horizontal curve if an object located near the inside edge of the road, this may interface with the view of the driver, which will result in **a reduction of the driver's sight** distance ahead.
    - It is necessary to design the curve so that the **available sight distance is at least equal to the safe SSD**.



Sight Distance on Horizontal Curves



Sight Distance on Horizontal Curves

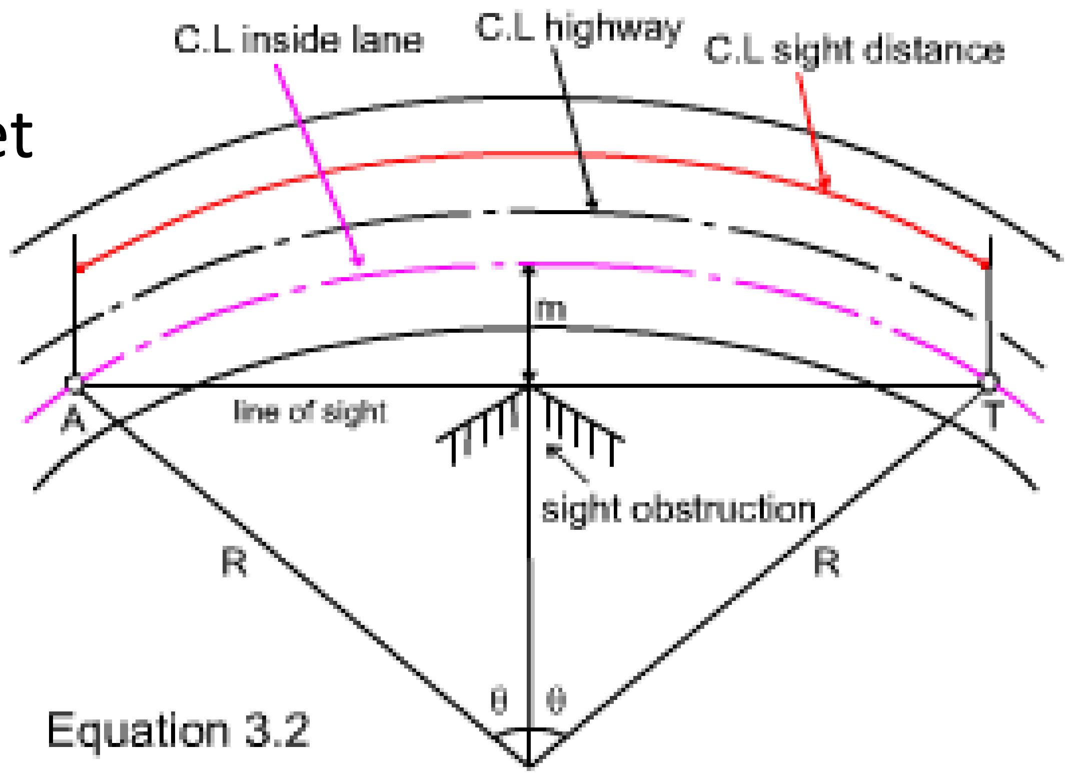
m is called **HSO**

Horizontal **S**ightline **O**ffset

$$S = \frac{2R\theta\pi}{180}$$

$$m = R(1 - \cos\theta)$$

$$m = R\left(1 - \cos\frac{28.65}{R}S\right)$$



Equation 3.2

where:

m = middle ordinate

R = radius of horizontal curve

S = sight distance

2θ = the angle subtended at the center of the circle by the arc AT

Figure 3.7 Sight Distance on Horizontal Curves

Sight Distance on Horizontal Curves

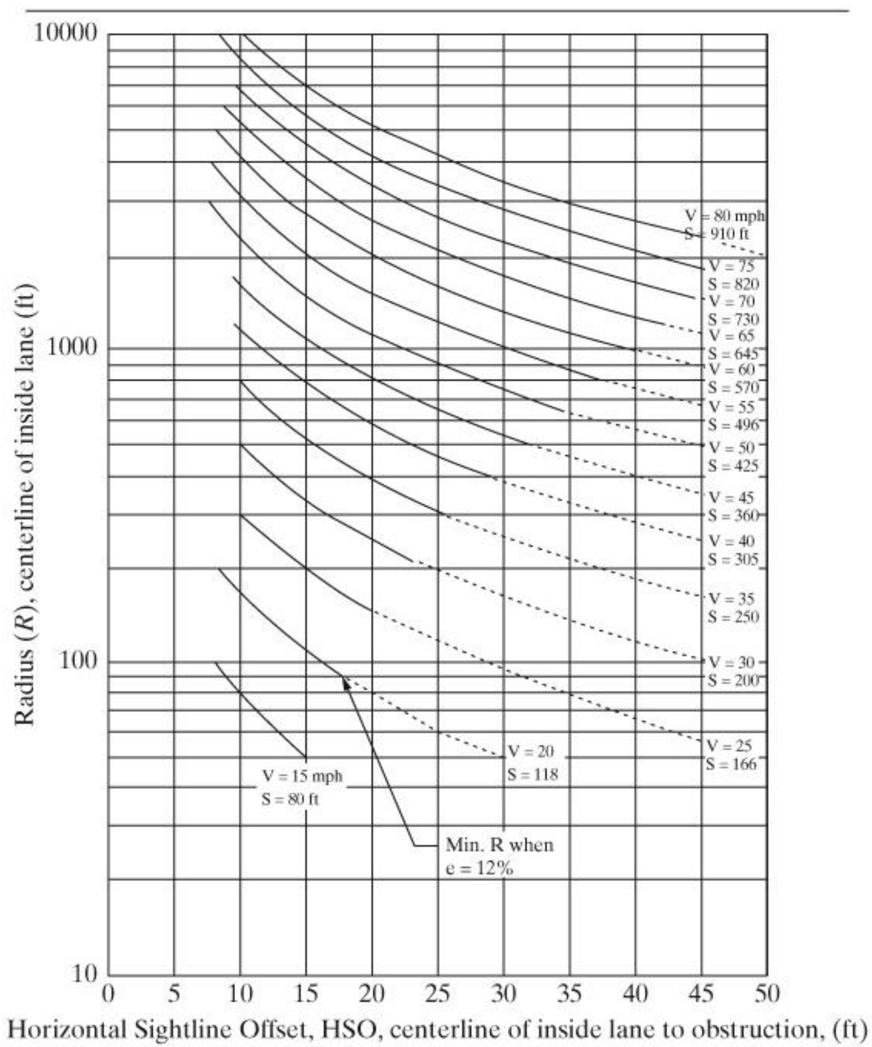


Figure 15.26(b) Horizontal Curves with Sight-Distance Restrictions and Range of Lower Values for Stopping Sight Distances

SOURCE: *A Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2001. Used with permission.

Example

Example 15.8 Location of Object Near a Horizontal Curve

A horizontal curve with a radius of 800 ft connects the tangents of a two-lane highway that has a posted speed limit of 35 mi/h. If the highway curve is not superelevated, $e = 0$, determine the horizontal sightline offset (HSO) that a large billboard can be placed from the centerline of the inside lane of the curve, without reducing the required SSD. Perception-reaction time is 2.5 sec, and $f = 0.35$.

Solution:

- Determine the required SSD.

$$SSD = 1.47\,ut + u^2/30\,(f \pm G)$$

$$(1.47 \times 35 \times 25) + \frac{(35)^2}{30(0.35)} = 245.29 \text{ ft}$$

- Determine m using Eq. 15.39.

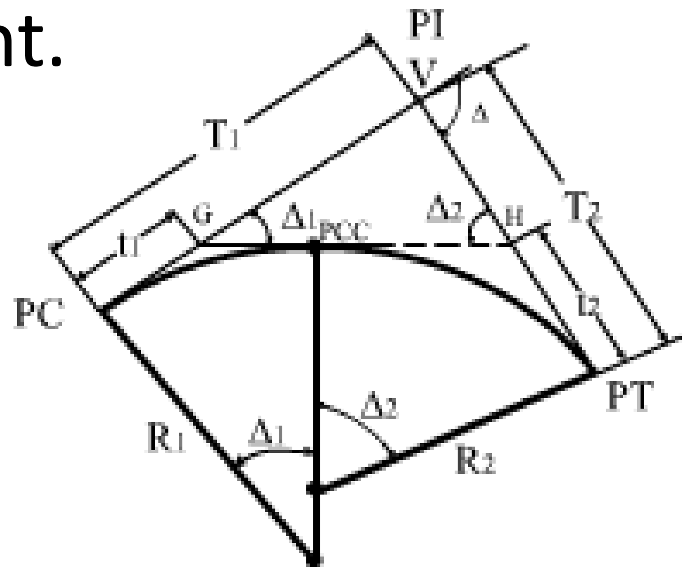
$$m = 800\left[1 - \cos\left(\frac{28.65}{800}(245.29)\right)\right] = 800(1 - 0.988) \text{ ft}$$

$$= 9.6 \text{ ft}$$

Check solution using Fig. 15.26(b).
For $R = 800$ and $V = 35$ mph from Figure 15.26(b) m is estimated to be 9.5 ft.

2. Compound Curves

- Compound curves consist of two or more curves in succession, turning in the same direction, with any two successive curves having a common tangent point.



R_1, R_2 = radii of simple curves forming compound curve

Δ_1, Δ_2 = deflection angles of simple curves

Δ = deflection angle of compound curve

gent lengths of simple curves

T_1, T_2 = tangent lengths of compuond curve

PCC = point of compound curve

PI = point of intersection

PC = point of curve

PT = point of tangent

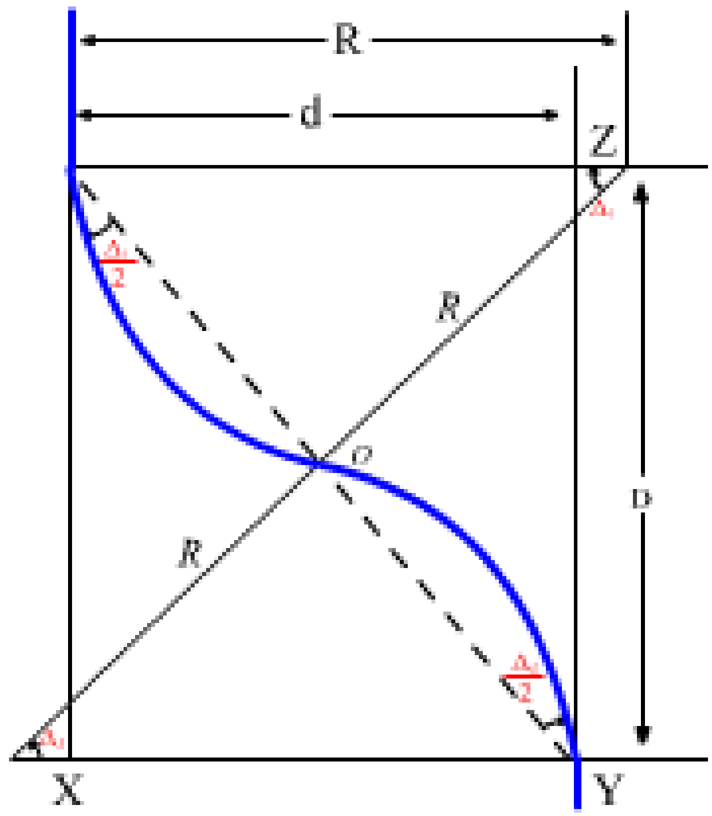
2. Compound Curves

- These curves are used mainly in obtaining desirable shapes of the horizontal alignment, particularly at:
  - at-grade intersections, ramps of interchanges, and
  - highway sections in difficult topographic areas.
- To avoid abrupt changes in the alignment, the radii of any two simple curves that form a compound curve **should not be widely different**.
  - AASHTO recommends that the ratio of the flatter radius to the sharper radius at intersections should not be greater than **2:1**.
- To provide smooth transition from a flat curve to a sharp curve, the length of each curve should not be too short.

3. Reverse Curves

- Reverse curves usually consist of two simple curves with:
  - equal radii
  - turning in opposite directions
  - with a common tangent.

- They are generally used to change the alignment of a highway.
- Reverse curves are seldom recommended because
  - sudden changes to the alignment make it difficult for drivers to keep in their lanes.



R= radius of simple curves

Δ1 ,Δ2 = deflection angles of simple curves

d = distance between parallel tangents

D = distance between tangent points

4. Transition (Spiral) Curves

- Transition curves are placed **between tangents and circular** curves **or between two adjacent circular curves** having substantially different radii.
- If the transition curve is a spiral, the degree of curve between the tangent and the circular curve varies from 0 at the tangent end to the degree of the circular curve D_a at the curve end.

4. Transition (Spiral) Curves

- **The minimum length of a spiral transition curve should be the larger of the these two values :**

$$L_{s,\min} = \frac{3.15u^3}{RC} \qquad (15.37)$$

$$L_{s,\min} = \sqrt{24(p_{\min})R} \qquad (15.38)$$

where

L_s = minimum length of curve (ft)
u = speed (mi/h)
R = radius of curve (ft)
C = rate of increase of radial acceleration (ft/sec^2/sec). Values range from 1 to 3
$P_{\min}$ = minimum lateral offset between the tangent and the circular curve (0.66 ft)

indicates the level of comfort and safety involved.

4. Transition (Spiral) Curves

Important

- In fact, many highway agencies **do not use transition curves**, since drivers will usually guide their vehicles into circular curves gradually.

- A practical alternative for determining the minimum length of a spiral is **to use the length required for superelevation runoff**.

Length of Superelevation Runoff
when Spiral Curves Are Not Used.

- The tangent is joined directly with the main circular curve called "***tangent-to-curve transition***".
- If the curve is superelevated at a rate of **e** ft /ft., an appropriate transition length must be provided.
- This superelevation transition length is composed of:
  - **superelevation runoff**
  - **tangent runout.**

Length of Superelevation Runoff
when Spiral Curves Are Not Used.

- ***Superelevation runoff*** : is defined as the distance over which the pavement cross slope on the outside lane changes from **zero** (flat) to **full superelevation** of the curve (*e*)
- For highways where :
  - rotation is about any pavement reference line
  - the rotated width has a common superelevation,
- The superelevation can be calculated by:

$$L_r = \frac{(wn_1)e_d}{\Delta}(b_w)$$

L_r = minimum length of superelevation runoff
Δ = maximum relative gradient (%) (0.78% @ 15 mph to 0.35% @ 80 mph)
n_1 = number of lanes rotated
b_w = adjustment factor for number of lanes rotated ($1 = 1.00, 2 = 0.75, 3 = 0.67$)
w = width of one traffic lane (ft) (typically 12 ft.)
e_d = design superelevation rate (%)

Length of Superelevation Runoff
when Spiral Curves Are Not Used.

- Minimum recommended superelevation runoff length:

Table 15.12 Superelevation Runoff L_r (m) for Horizontal Curves

Two-lane → 1; Multilane → 2

e (%)	*Design Speed (km/h)*													
	32		*48*		*64*		*80*		*96*		*112*		*128*	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.0	9.6	14.7	10.8	16.5	12.3	18.6	14.4	21.6	15.9	24.0	18.0	27.0	20.7	30.9
3.0	14.7	21.9	16.5	24.6	18.6	27.9	21.6	32.4	24.0	36.0	27.0	40.5	30.9	46.2
4.0	19.5	29.1	21.9	32.7	24.9	37.2	28.8	43.2	32.1	48.0	36.0	54.0	41.1	61.8
5.0	24.3	36.6	27.3	40.8	30.9	46.5	36.0	54.0	39.9	60.0	45.0	67.5	51.3	77.1
6.0	29.1	43.8	32.7	49.2	37.2	55.8	43.2	64.8	48.0	72.0	54.0	81.0	62.1	92.7
7.0	34.2	51.0	38.1	57.3	43.5	65.1	50.4	75.6	56.1	84.0	63.0	94.5	72.0	108.0
8.0	39.0	58.5	43.5	65.4	49.8	74.4	57.6	86.4	63.9	96.0	72.0	108.0	82.2	123.3
9.0	43.8	65.7	49.2	73.5	55.8	83.7	64.8	97.2	72.0	108.0	81.0	121.5	92.7	138.9
10.0	48.6	72.9	54.6	81.9	62.1	93.0	72.0	108.0	80.1	120.0	90.0	225.0	102.9	154.2
11.0	53.4	80.4	60.0	90.0	68.4	102.3	79.2	118.8	87.9	132.0	99.0	148.5	113.1	169.8
12.0	58.5	87.6	65.4	98.1	74.4	111.6	86.4	129.6	96.0	144.0	108.0	162.0	123.3	185.1

Note: (1) Two-lane – 3.6 m 2% cross slope
(2) Multilane – 3.6 m each direction rotated separately

Length of Superelevation Runoff
when Spiral Curves Are Not Used.

- ***Theoretically***, superelevation runoff should be placed entirely on the tangent section **thus providing full superelevation between the PC and PT**.
- ***In practice***, sharing the runoff between tangent and curve:
  - Reduces peak lateral acceleration and its effect on side friction.
  - Motorists tend to adjust their driving path by steering a "**natural spiral**" thus supporting the observation that some of the runoff length should be on the curve.

Length of Superelevation Runoff
when Spiral Curves Are Not Used.

- ***Tangent runout*** : consists of the length of roadway needed to accomplish a change on the outside-lane cross slope from normal (i.e., 2 percent) to zero, or vice versa
- The minimum length of tangent runout:

$$L_t = \frac{e_{NC}}{e_d} L_r$$

L_t = minimum length of tangent runout (ft)
e_{NC} = normal cross slope rate (%)
e_d = design superelevation rate (%)
L_r = minimum length of superelevation runoff (ft)

Table 15.12 Superelevation Runoff L_r (m) for Horizontal Curves

e (%)	*Design Speed (km/h)*													
	32		*48*		*64*		*80*		*96*		*112*		*128*	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.0	9.6	14.7	10.8	16.5	12.3	18.6	14.4	21.6	15.9	24.0	18.0	27.0	20.7	30.9
3.0	14.7	21.9	16.5	24.6	18.6	27.9	21.6	32.4	24.0	36.0	27.0	40.5	30.9	46.2
4.0	19.5	29.1	21.9	32.7	24.9	37.2	28.8	43.2	32.1	48.0	36.0	54.0	41.1	61.8
5.0	24.3	36.6	27.3	40.8	30.9	46.5	36.0	54.0	39.9	60.0	45.0	67.5	51.3	77.1
6.0	29.1	43.8	32.7	49.2	37.2	55.8	43.2	64.8	48.0	72.0	54.0	81.0	62.1	92.7
7.0	34.2	51.0	38.1	57.3	43.5	65.1	50.4	75.6	56.1	84.0	63.0	94.5	72.0	108.0
8.0	39.0	58.5	43.5	65.4	49.8	74.4	57.6	86.4	63.9	96.0	72.0	108.0	82.2	123.3
9.0	43.8	65.7	49.2	73.5	55.8	83.7	64.8	97.2	72.0	108.0	81.0	121.5	92.7	138.9
10.0	48.6	72.9	54.6	81.9	62.1	93.0	72.0	108.0	80.1	120.0	90.0	225.0	102.9	154.2
11.0	53.4	80.4	60.0	90.0	68.4	102.3	79.2	118.8	87.9	132.0	99.0	148.5	113.1	169.8
12.0	58.5	87.6	65.4	98.1	74.4	111.6	86.4	129.6	96.0	144.0	108.0	162.0	123.3	185.1

Note: (1) Two-lane – 3.6 m 2% cross slope
(2) Multilane – 3.6 m each direction rotated separately

Length of Superelevation Runoff with Spiral Curves.

- AASHTO recommends that when spiral curves are used in transition design,
  - Superelevation runoff should be achieved over the length of the spiral curve.

Length of spiral curve = Length of superelevation runoff

Length of Superelevation Runoff
with Spiral Curves.

Table 15.13 Tangent Runout Length for Spiral Curve Transition Design

	Tangent Runout Length (ft)				
	Superelevation Rate (%)				
Design Speed (mi/h)	*2*	*4*	*6*	*8*	*10*
15	44	—	—	—	—
20	59	30	—	—	—
25	74	37	25	—	—
30	88	44	29	—	—
35	103	52	34	26	—
40	117	59	39	29	—
45	132	66	44	33	—
50	147	74	49	37	—
55	161	81	54	40	—
60	176	88	59	44	—
65	191	96	64	48	38
70	205	103	68	51	41
75	220	110	73	55	44
80	235	118	78	59	47

Note: (1) Values for e = 2% represent the desirable lengths of the spiral curve transition.
(2) Values shown for tangent runout should also be used as the minimum length of the spiral transition curve.

SOURCE: Adapted from *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

Attainment of Superelevation

- The change from a crowned cross section to a superelevated one be achieved without causing any discomfort to motorists or creating unsafe conditions.
- There are four methods:
  1. **Crowned pavement is rotated about the centerline.**
  2. **Crowned pavement is rotated about the inside edge.**
  3. **Crowned pavement is rotated about the outside edge.**
  4. **A straight cross-slope pavement is rotated about the outside edge.**

**** Refer to the Multimedia CD of the course***

Attainment of Superelevation

- Superelevation on **divided highways** can be achieved through one of the follwoing methods :
  - **Method 1** involves superelevating the whole cross section, including the median, as a plane section.
    - Rotation is done about the centerline of the median.
    - Only for narrow medians and moderate superelevation rates
  - **Method 2** involves rotating each pavement separately around the median edges, while keeping the median in a horizontal plane.
    - When median width is 30 ft or less,
  - **Method 3** treats the two pavements separately, resulting in variable elevation differences between the median edges
    - When median width is 40 ft or greater.

Highway Geometric Design

Thank You Very Much