TOPIC 7

Highway Location, Geometrics, & Drainage

TOPIC 7
Part 2

Geometric Design of Highway Facilities

Introduction

- Geometric design deals with the dimensioning of the elements of highways, such as:
  - vertical and horizontal curves,
  - cross sections,
  - truck climbing lanes,
  - bicycle paths and pedestrian walkways, and
  - parking facilities
- The characteristics of driver, pedestrian, vehicle, and road, serve as the basis for determining the physical dimensions of these elements.
- For example, lengths of vertical curves or radii of circular curves are determined to assure that the minimum stopping sight distance is provided to highway users for the design speed of the highway
- The fundamental objective of geometric design is to produce a smooth-flowing and safe highway facility, an objective that only can be achieved by providing a consistent design standard that satisfies the characteristics of the driver and the vehicles that use the road
- There is no single set of standards is suitable for all highways

Introduction

- The American Association of State Highway and Transportation Officials (AASHTO) serves a critical function in developing guidelines and standards used in highway geometric design.
- The membership of AASHTO includes representatives from every state highway and transportation department in the U.S. as well as the Federal Highway Administration (FHWA).
- The association has several technical committees that consider suggested standards from individual states. When a standard is approved, it is adopted and used by the member states.
- The AASHTO publication "*A Policy on Geometric Design of Highways and Streets*" provides the standards for geometric design of highways.
- Other examples of highway design guidelines include:
  - RDA's Volume 2 for Low Volume Roads Manual Volume, "*Geometric Design and Road Safety*"
  - SATCC's "*Code of Practice for the Geometric Design of Trunk Roads*"
  - Canada's *"Transportation Association of Canada, TAC"*
- In this chapter, the principles and theories used in the design of horizontal and vertical alignments are presented together with the current standards used for geometric design, as recommended by AASHTO.

Factors Influencing Highway Design

- Highway design is based on specified design standards and controls which depend on the following roadway system factors:
  - 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
- These factors are often interrelated. For example, design speed depends on functional classification which is usually related to expected traffic volume.

Factors Influencing Highway Design

- In most instances, the principal factors used to determine the standards to which a particular highway will be designed are:
  - the level of service to be provided,
  - expected traffic volume, design speed, and
  - the design vehicle
- These factors, coupled with the basic characteristics of the driver, vehicle, and road, are used to determine standards for the geometric characteristics of the highway, such as cross sections and horizontal and vertical alignments

Factors Influencing Highway Design

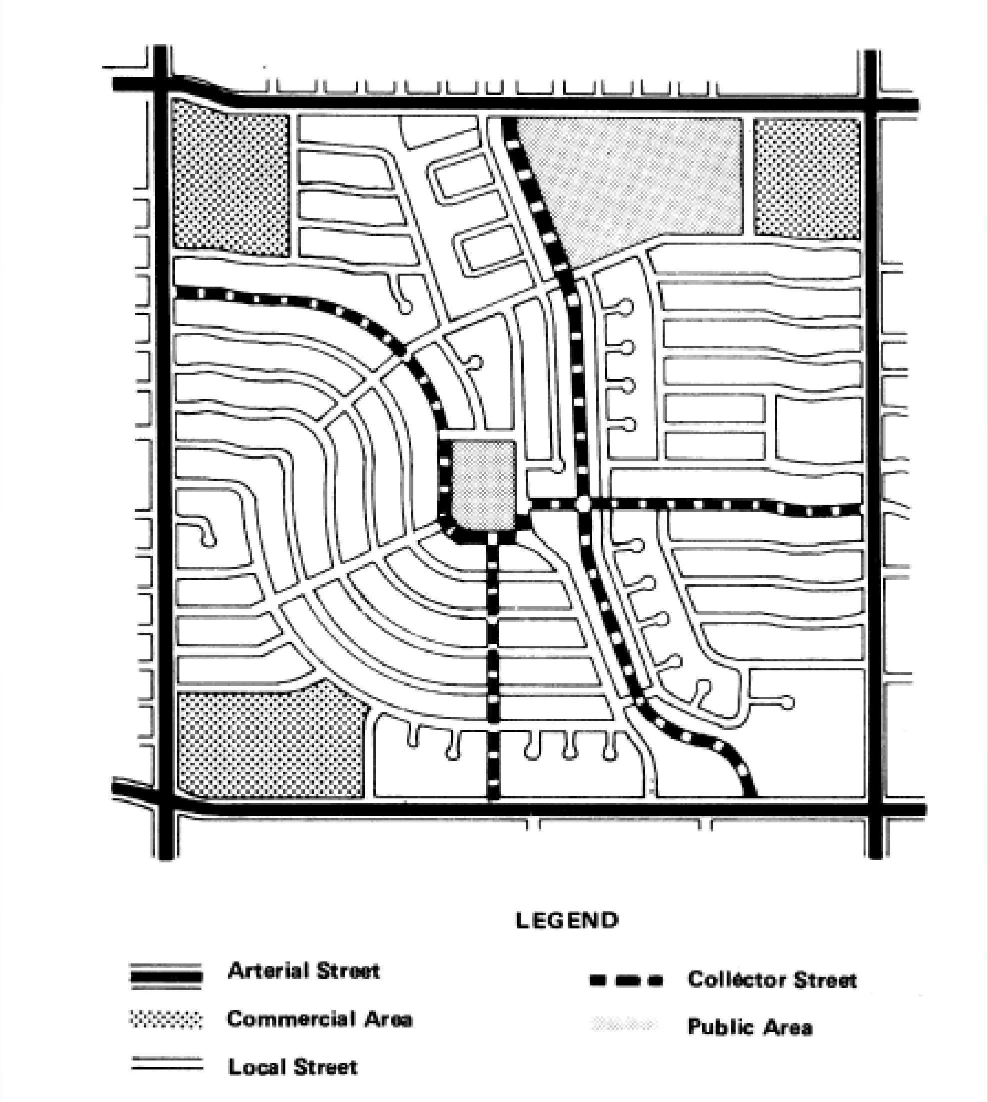
Highway Functional Classification

- Highways are classified according to their functions in terms of the service they provide.
- The classification system facilitates a systematic development of highways and the logical assignment of highway responsibilities among different jurisdictions
- Highways and streets are categorized as rural or urban roads, depending on the area in which they are located.
- This initial classification is necessary because urban and rural areas have significantly different characteristics with respect to the type of land use and population density, which in turn influences travel patterns.
- Within the classification of urban and rural, highways are categorized into the following groups:
  - Principal arterials
  - Minor arterials
  - Major collectors
  - Minor collectors
  - Local roads and streets

Factors Influencing Highway Design

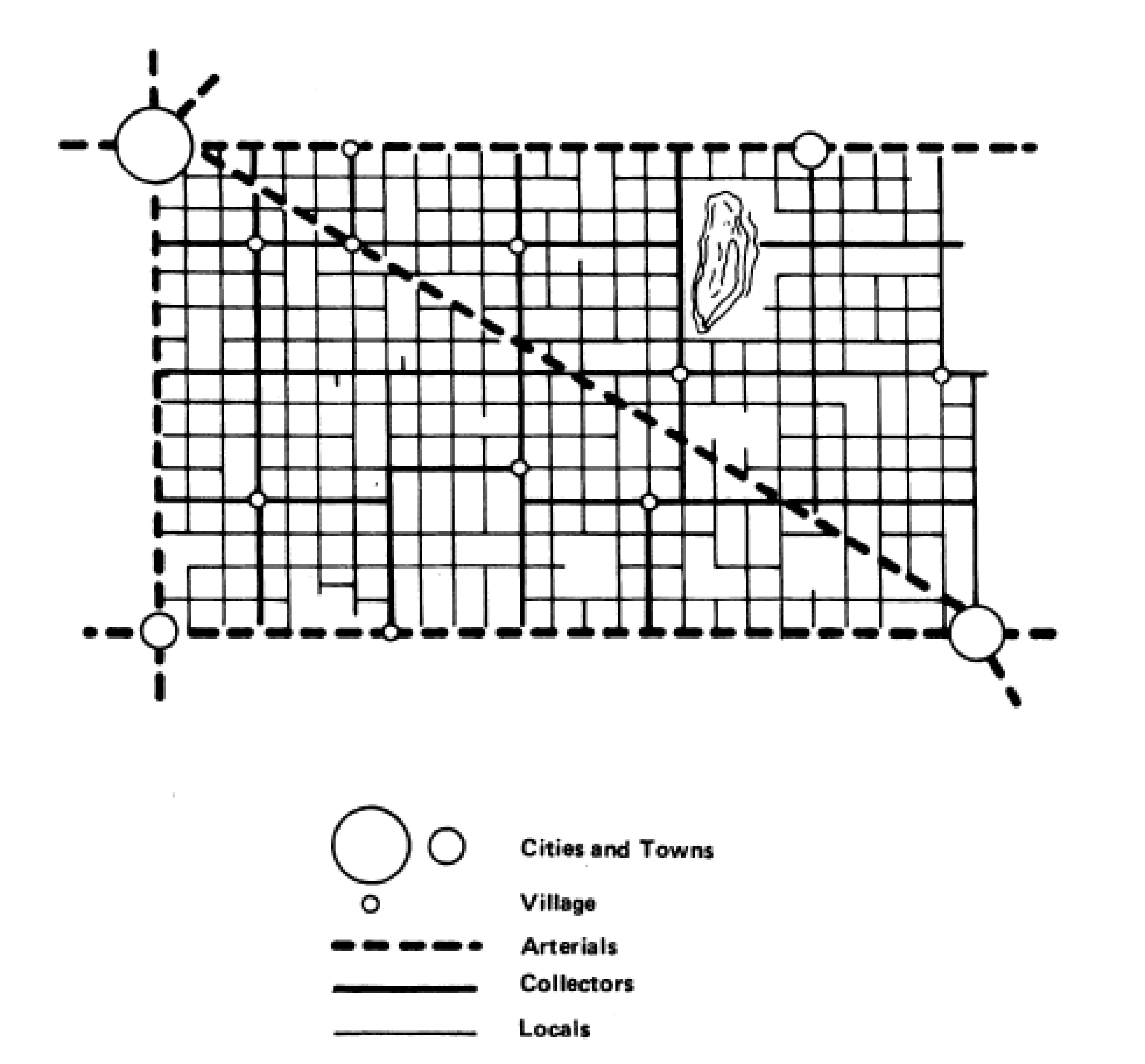
Highway Functional Classification

- Freeways are not listed as a separate functional class since they are generally classified as part of the principal arterial system. However, they have unique geometric criteria that require special design consideration



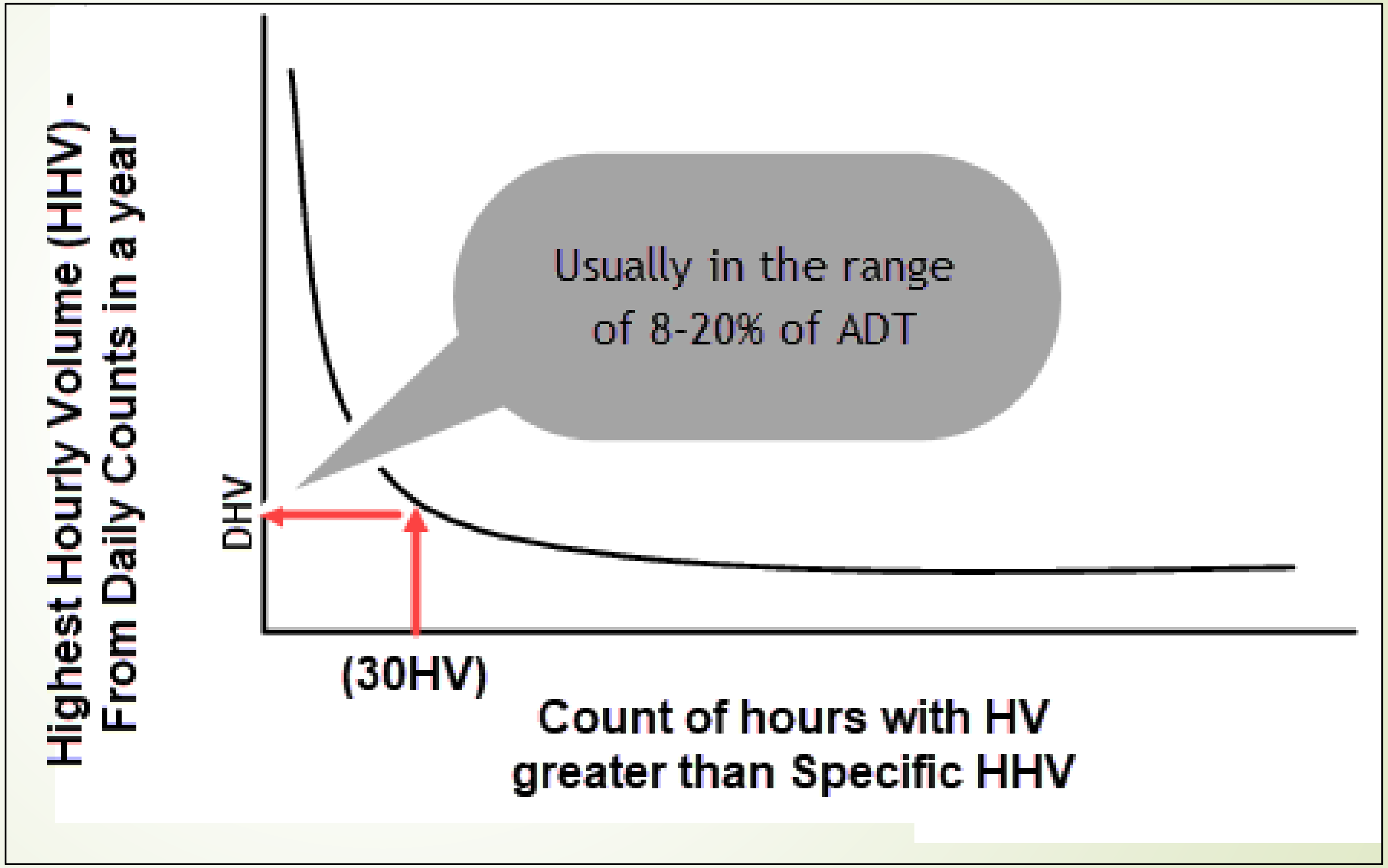
Functional Classes for an Urban Road Network

Functional Classes for Rural Highway Network



Factors Influencing Highway Design

- **Design Hourly Volume (DHV)**
- The design hourly volume (DHV) is the projected hourly volume that is used for design.
- Usually the 30th highest hourly volume (30HV)
- This volume is usually taken as a percentage of the **expected ADT** on the highway
  - – DHV = 0.12 to 0.18 ADT (rural highways)
  - – DHV = 0.08 to 0.12 ADT (urban highways)
- One other alternative is to use the average of the highest afternoon peak hour volume for each week in the year as the DHV.



Factors Influencing Highway Design

Design Speed

– Old definition:

» The maximum safe speed that can be maintained over a specified section of the highway when conditions are favorable such that the design features of the highway govern

– New definition:

» A selected speed used to determine the various geometric design features of the roadway (AASHTO 2001/04/11)

» The speed set for the design of those geometric features of the roadway that affect vehicle operation (TAC 2017)

❖ A design speed is selected to achieve a desired level of operation and safety on the highway

❖ Design Speed depends on:

» Road's functional class, topography, and land use or

» The 85th percentile speed

❖ For highway design, topography is generally classified into three groups: level, rolling, and mountainous terrain.

Factors Influencing Highway Design

Design Speed in Green Book

(suggested minimum design speed)

Rural Collectors

Type of terrain	Metric			US Customary		
	Design speed (km/h) for specified design volume (veh/day)			Design speed (mph) for specified design volume (veh/day)		
	0 to 400	400 to 2000	over 2000	0 to 400	400 to 2000	over 2000
Level	60	80	100	40	50	60
Rolling	50	60	80	30	40	50
Mountainous	30	50	60	20	30	40
Note: Where practical, design speeds higher than those shown should be considered.						

Exhibit 6-1. Minimum Design Speeds for Rural Collectors

Factors Influencing Highway Design

Minimum Design Speeds for Various Functional Classifications

Class		*Speed (mi/h)* 20	30	40	50	60	70
Rural principal arterial	Min 50 mi/h for freeways			x	x	x	x
Rural minor arterial				x	x	x	x
Rural Collector Road	DHV over 400			x	x	x	
	DHV 20-400			x	x	x	
	DHV 100-200		x	x	x		
	Current ADT over 400		x	x	x		
	Current ADT under 400	x	x	x			
Rural Local Road	DHV over 400		x	x	x		
	DHV 200-400		x	x	x		
	DHV 100-200		x	x	x		
	Current ADT over 400		x	x	x		
	Current ADT 250-400	x	x	x			
	Current ADT 50-250	x	x				
	Current ADT under 50	x	x				
Urban principal arterial	Minimum 50 mi/h for freeways		x	x	x	x	x
Urban minor arterial			x	x	x	x	
Urban collector street			x	x	x		
Urban local street		x	x				

Factors Influencing Highway Design

Design Vehicle

- ❖ The vehicle selected to represent all vehicles on the highway
- ❖ Its weight, dimensions, and operating characteristics are used to establish the design standards of the highway
- ❖ The vehicle type selected as the design vehicle is the largest that is likely to use the highway with **considerable frequency**.
- ❖ The selected design vehicle is used to determine critical design features such as radii at intersections and turning roadways as well as highway grades.

Factors Influencing Highway Design

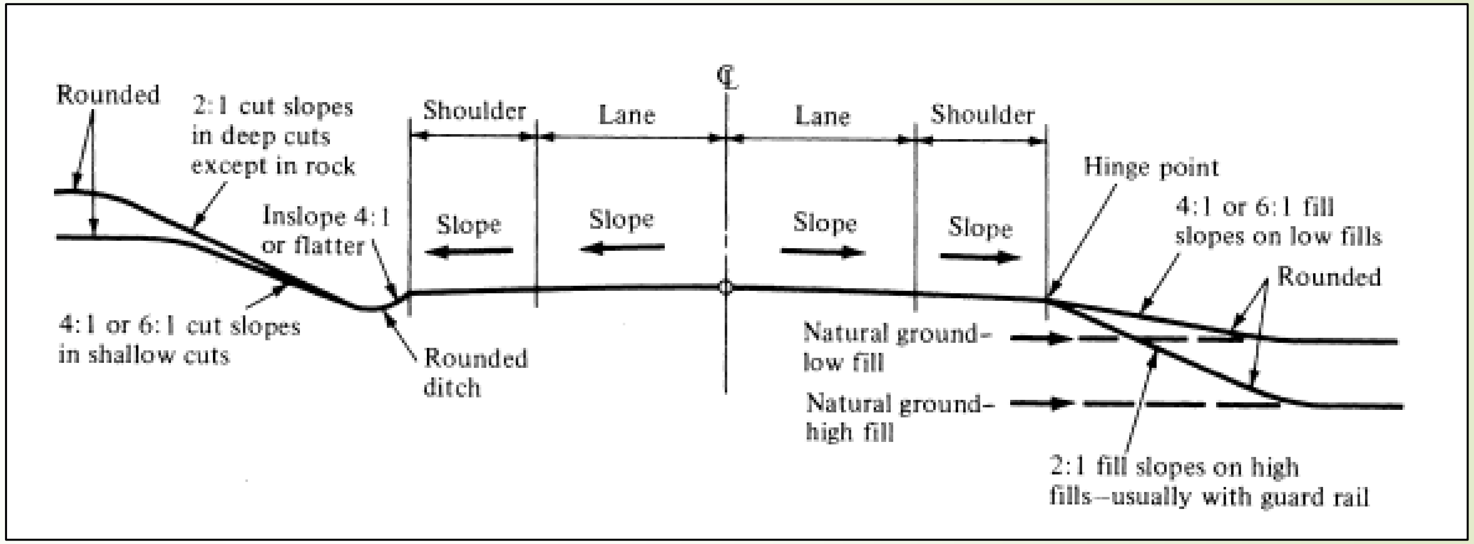
Design Vehicle

- The following guidelines apply when selecting a design vehicle:
  - When a parking lot or a series of parking lots are the main traffic generators, the passenger car may be used.
  - For the design of intersections at local streets and park roads, a single-unit truck may be used.
  - At intersections of state highways and city streets that serve buses with relatively few large trucks, a city transit bus may be used.
  - At intersections of highways and low-volume county highways or township/local roads with less than 400 ADT, either an 84-passenger large school bus 40 ft long or a 65-passenger conventional bus 36 ft long may be used. The selection of either of these will depend on the expected usage of the facility.
  - At intersections of freeway ramp terminals and arterial crossroads, and at intersections of state highways and industrialized streets that carry high volumes of traffic, the minimum size of the design vehicle should be WB-20.

Factors Influencing Highway Design

Cross-Section Elements

- The principal elements of a highway cross section consist of:
  - the travel lanes,
  - shoulders, and
  - medians (for some multilane highways).
- Marginal elements include:
  - median and roadside barriers,
  - curbs,
  - gutters,
  - guard rails,
  - sidewalks, and
  - side slopes



Factors Influencing Highway Design

Cross-Section Elements

1. **Travel Lanes**:

- ❖ Width is usually 3 -3.5 m (affects safety and LOS)
- ❖ 2.7 m lanes can be used on urban highways if traffic volume is low and there are extreme right-of-way constraints. Such lanes are usually widened on horizontal curves
- ❖ When pavement surfaces are less than 7.0 m, the crash rates for large trucks tend to increase
- ❖ Also, as the lane width is reduced from 3.5 m, the capacity of a highway significantly decreases.

2. **Shoulders**:

- ❖ Provide an area along the highway for vehicles to stop
- ❖ Provide an escape-way during erratic passes on two-lane highways
- ❖ Provide lateral support to the pavement structure
- ❖ Minimum width = 0.6 m; preferably 1.8-2.5 m
- ❖ For highways with large volumes or large volumes of trucks recommended width = 3 – 3.5 m

Factors Influencing Highway Design

Cross-Section Elements

3. **Medians**:

- ❖ A median is the section of a divided highway that separates the lanes in opposing directions.
- ❖ The width of a median is the distance between the edges of the inside lanes, including the median shoulders.
- ❖ 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

Factors Influencing Highway Design

- Medians can either be:

1. raised,
2. depressed or,
3. flush

- Median widths vary from a minimum of 0.6 to 25 m or more
- In general, the wider the median, the more effective it is in providing safe operating conditions and a recovery area for out-of-control vehicles.
- A minimum width of 3 m is recommended for use on four-lane urban freeways

Factors Influencing Highway Design

Cross-Section Elements

4. **Roadside and Median Barriers**:

- A median barrier is defined as a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions
- Roadside barriers, on the other hand, protect vehicles from obstacles or slopes on the roadside.
- They also may be used to shield pedestrians and property from the traffic stream. The provision of median barriers must be considered when traffic volumes are high
- Roadside barriers should be provided whenever conditions exist requiring the protection for vehicles along the side of the road.
- For example, when the slope of an embankment is high or when traveling under an overhead bridge, the provision of a roadside barrier is warranted.
- Median barriers can be composed of cable or post and beam systems or concrete

Factors Influencing Highway Design

Cross-Section Elements

4. Guard Rails:

- Guard rails are longitudinal barriers placed on the outside of sharp curves and at sections with high fills.

- Their main function is to prevent vehicles from leaving the roadway. They are installed at embankments higher than 2.5 m and when shoulder slopes are greater than 4:1.

- Shapes commonly used include the W beam and the box beam. The weak post system provides for the post to collapse on impact, with the rail deflecting and absorbing the energy due to impact.

Factors Influencing Highway Design

Cross-Section Elements

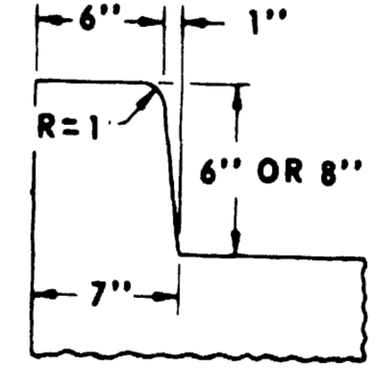
5. Curbs and Gutters:

- ❖ Curbs are raised structures made of either Portland cement concrete or bituminous concrete (rolled asphalt curbs) that are used mainly on urban highways to delineate pavement edges and pedestrian walkways.

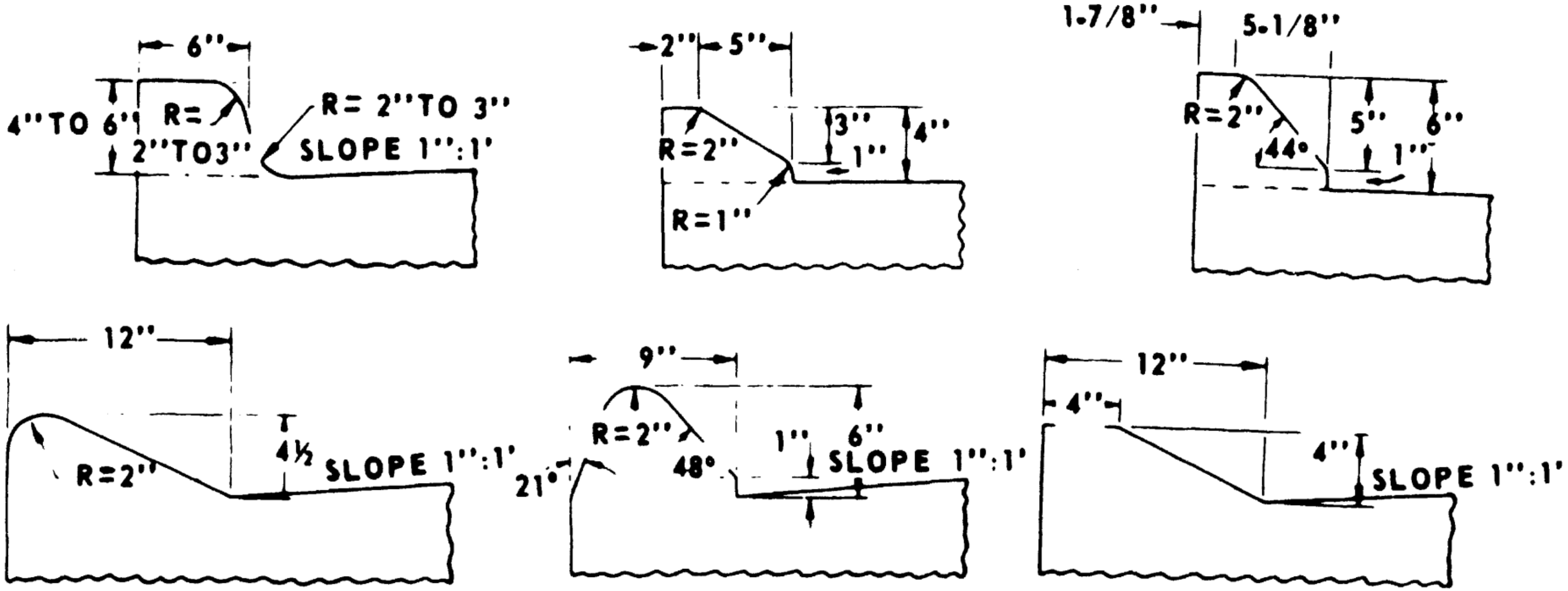
- ❖ Curbs are also used to control drainage, improve aesthetics, and reduce right of way

- ❖ Gutters or drainage ditches are usually located on the pavement side of a curb to provide the principal drainage facility for the highway.

- ❖ They are sloped to prevent any hazard to traffic



(a) Vertical curb



(b) Sloping curbs

Factors Influencing Highway Design

Cross-Section Elements

6. Sidewalks:

- ❖ Sidewalks are usually provided on roads in urban areas, but are uncommon in rural areas.
- ❖ Nevertheless, the provision of sidewalks in rural areas should be evaluated during the planning process to determine sections of the road where they are required.
- ❖ For example, rural principal arterials may require sidewalks in areas with high pedestrian concentrations, such as adjacent to schools, industrial plants, and local businesses
- ❖ To encourage pedestrians to use sidewalks, they should have all-weather surfaces since pedestrians will tend to use traffic lanes rather than unpaved sidewalks

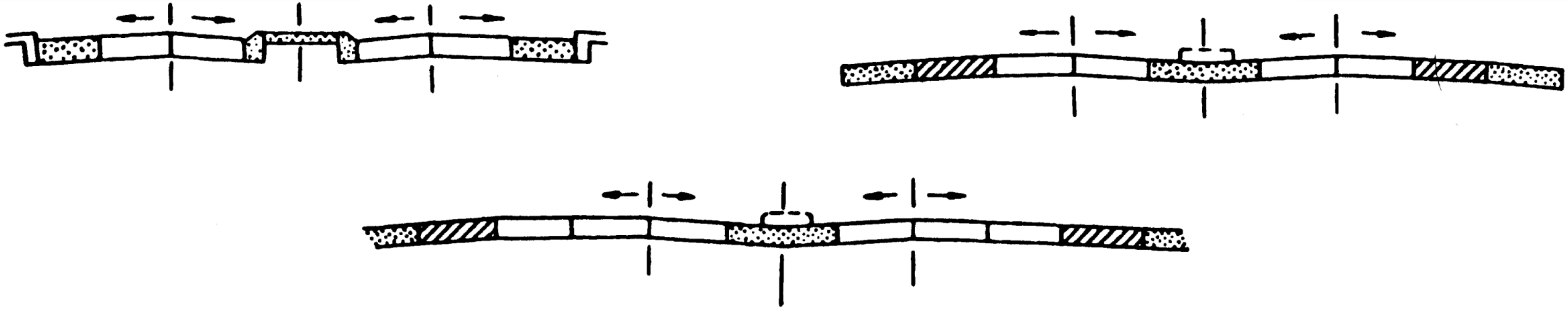
Factors Influencing Highway Design

Cross-Section Elements

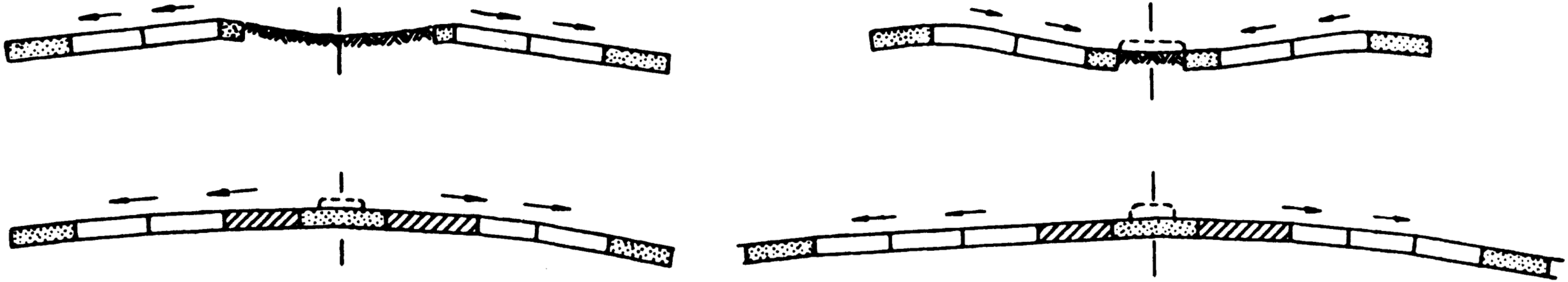
7. Cross Slopes:

- ❖ Straight sections on two-lane highways are sloped from the middle downward (crown section)
- ❖ On multi-lane highways, several arrangements can be used
- ❖ Recommended rate for cross-slope on high type pavements is 1.5 to 2 % and increases as the pavement type worsens
- ❖ Shoulder slope is usually higher than the lane slope
- ❖ The curved cross section has one advantage of enhancing the flow of surface water away from the pavement.

A disadvantage is they are difficult to construct.



(a) Each pavement slopes two ways.



(b) Each pavement slopes one way.

Factors Influencing Highway Design

Cross-Section Elements

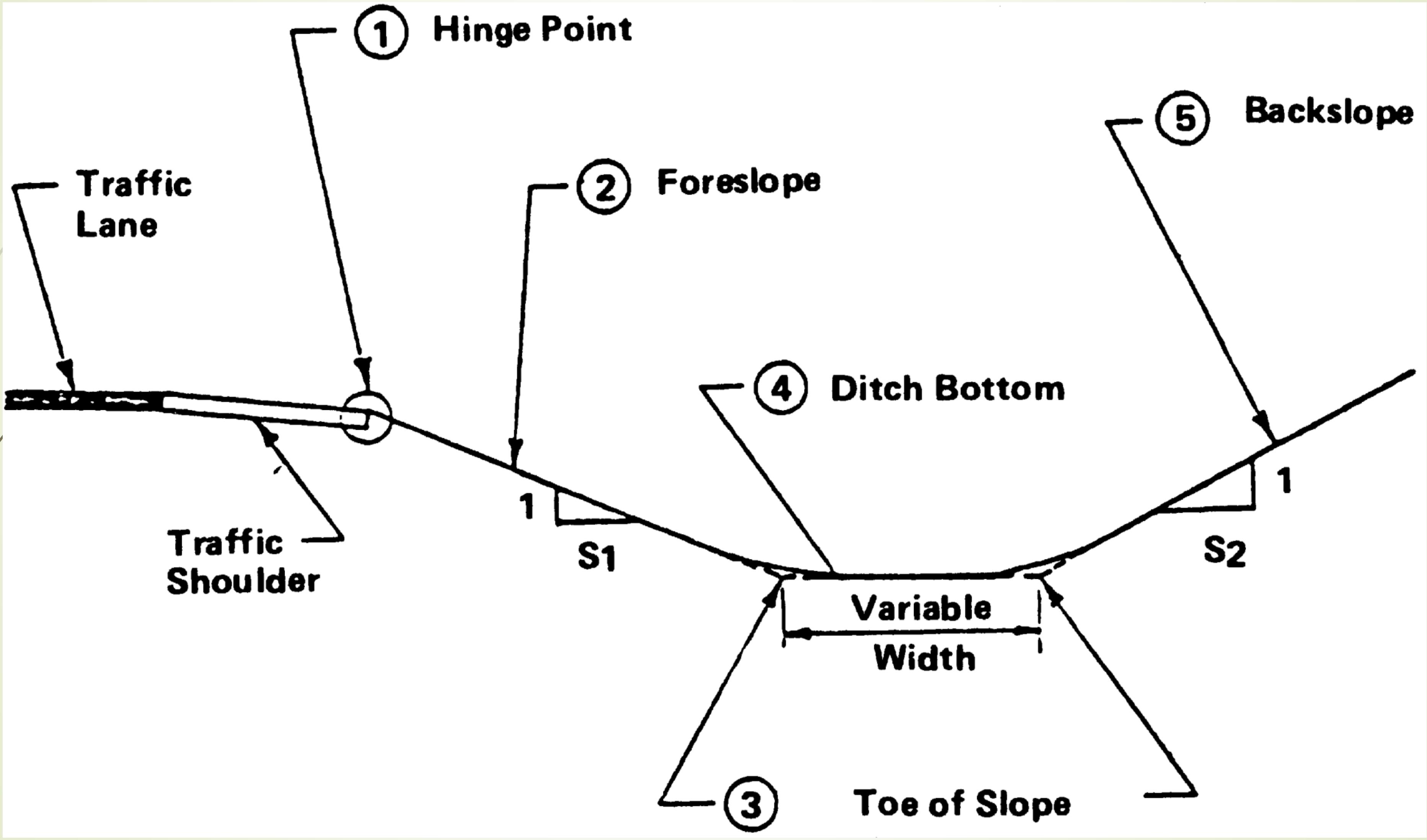
8. **Side Slopes**:

- ❖ Provide stability for earth work and serve as a safety feature by providing a recovery area for out of-control vehicles
- ❖ In cut sections, a down slope and a drainage ditch may be added
- ❖ Foreslope should be 3:1 (H:V) or flatter

9. **Right-of-Way**:

- ❖ The total area required for the construction of the highway
- ❖ Should accommodate all cross-section elements

Factors Influencing Highway Design



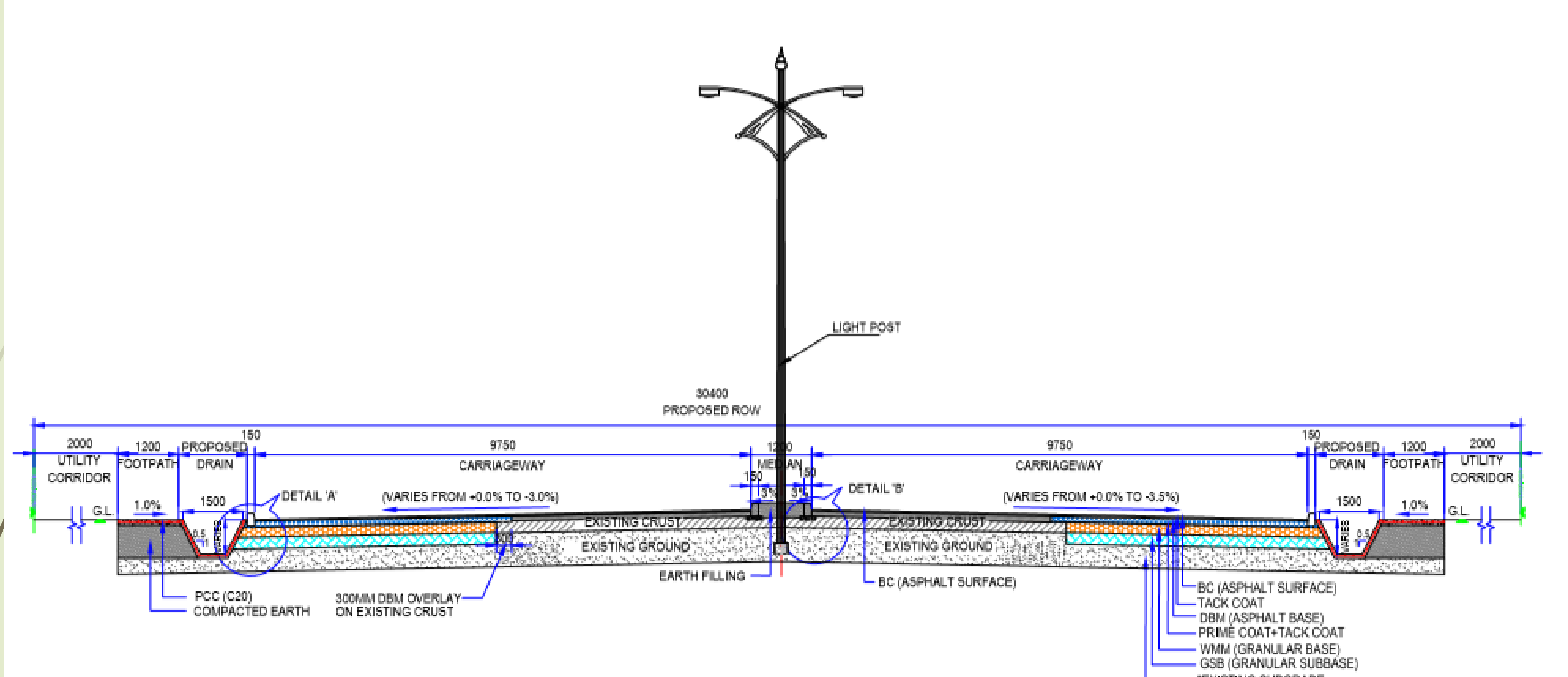
Factors Influencing Highway Design

Table 15.3 Guide for Earth Slope Design

Height of Cut or Fill (ft)	*Earth Slope, for Type of Terrain* 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.
SOURCE: *Roadside Design Guide*, American Association of State Highway and Transportation Officials, Washington, D.C., 2002. Used with permission.

Factors Influencing Highway Design



TCS - 01 TYPICAL CROSS SECTION OF CONCENTRIC WIDENING (30MM OVERLAY)

Maximum Highway Grades

- Selection of maximum grades for a highway depends on the design speed and the design vehicle
- It is generally accepted that grades of 4 to 5 percent have little or no effect on passenger cars
- Maximum grades have been established based on the operating characteristics of **the design vehicle on the highway**
- These vary from 5 percent for a design speed of 110 km/h to between 7 and 12 percent for a design speed of 50 km/h, depending on the type of highway
- The tables on the next slide give some recommended values of maximum grades based on **highway class, speed, and terrain**

Maximum Highway Grades

- These 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.

- Zero percent grades may be used on uncurbed pavements with adequate cross slopes to laterally drain the surface water.

- It is customary to use a minimum of 0.5 percent in such cases, although this may be reduced to 0.3 percent on high-type pavement constructed on suitably crowned, firm ground.

Maximum Highway 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

Maximum Highway Grades

	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

Maximum Highway Grades

Table 3.3.1: Maximum Gradients[56]

Design Speed (km/h)	30/40/50		60		70		80		90		100		110		120/130	
Topography	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	M
RLU	7	11	7	11	6	9	6	8	5	7	5	7	-	-	-	-
RCU	-	-	6	10	6	9	5	8	5	7	5	7	-	-	-	-
RCD	-	-	-	-	6	9	5	8	5	7	5	7	-	-	-	-
RAU	-	-	-	-	-	-	4	7	4	6	3	6	3	6	3	5
RAD	-	-	-	-	-	-	4	7	4	6	3	6	3	5	3	5
RFD	-	-	-	-	-	-	-	-	-	-	3	5	3	5	3	5
ULU-Residential	8	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ULU-Industrial-Commercial	6	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UCU- Residential	8	12	7	11	7	10	-	-	-	-	-	-	-	-	-	-
UCU-Industrial-Commercial	6	12	6	11	6	9	6	8	-	-	-	-	-	-	-	-
UCD	6	10	6	9	5	8	5	7	-	-	-	-	-	-	-	-
UAU	6	10	6	6	5	8	5	7	-	-	-	-	-	-	-	-
UAD	-	-	3	6	3	6	3	6	3	6	3	5	-	-	-	-
UED	-	-	-	-	-	-	5	6	4	5	4	5	4	5	3	5
UFD	-	-	-	-	-	-	-	-	4	5	3	5	3	5	3	5

Notes:
1. Short grades less than 150 m in length, and one-way downgrades may be 1% higher on urban roads, and 2% higher on low volume rural roads
2. R refers to rolling topography
3. M refers to mountainous topography.

Design of Alignment

- The alignment of a highway is composed of vertical and horizontal elements

- The vertical alignment includes:
  1. straight (tangent) highway grades and
  2. the parabolic curves that connect these grades.

- The horizontal alignment includes:
  1. the straight (tangent) sections of the roadway and
  2. the circular curves that connect their change in direction.

- It is important that the alignment of a given section has consistent standards to avoid sudden changes in the vertical and horizontal layout of the highway

- It is also important that both horizontal and vertical alignments be designed to complement each other

- It is important that coordination of the vertical and horizontal alignments be considered at the early stages of preliminary design

Vertical Alignment

Vertical Curves

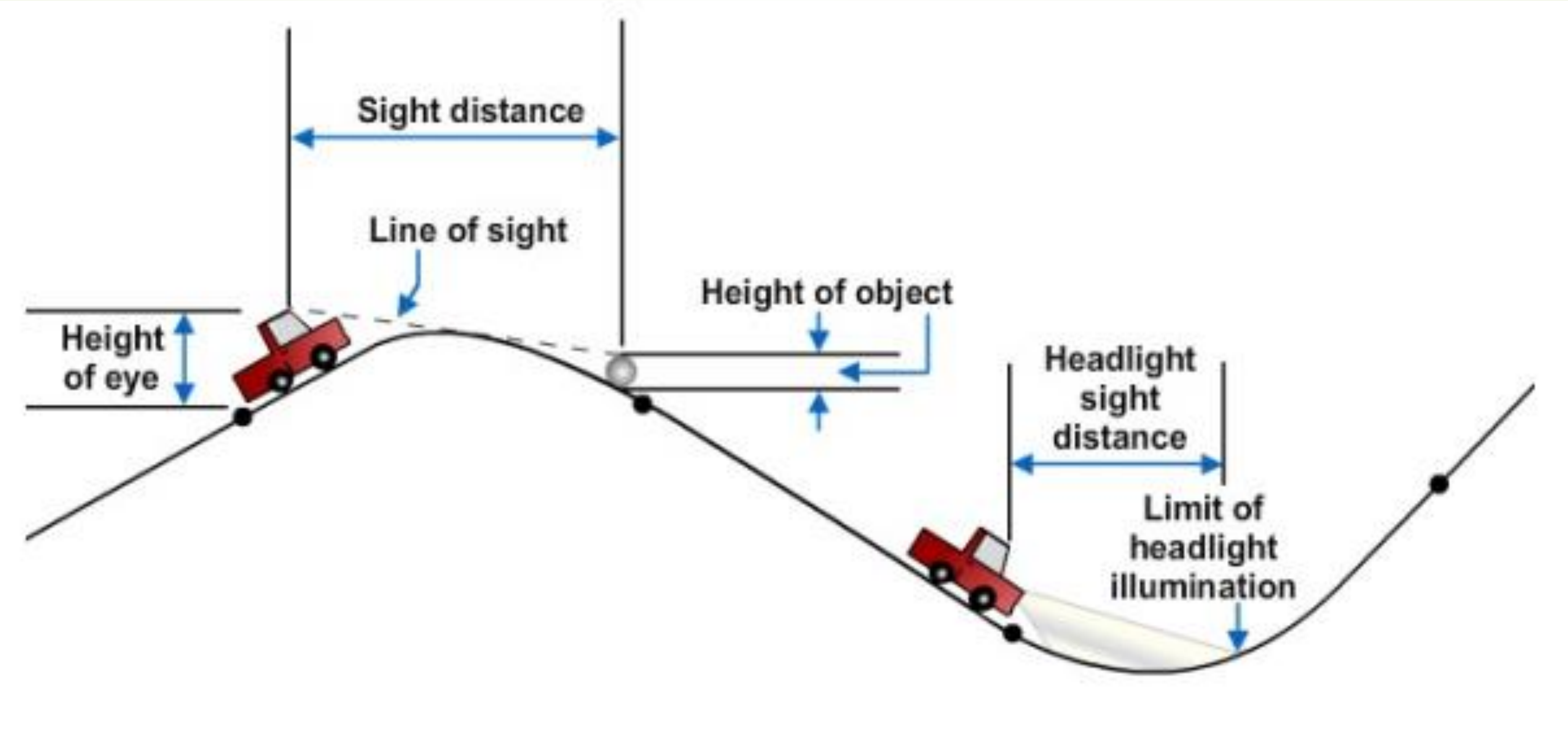
- ❖ Provide gradual change from one tangent to another for a smooth vehicle operation

- ❖ Usually parabolic curves

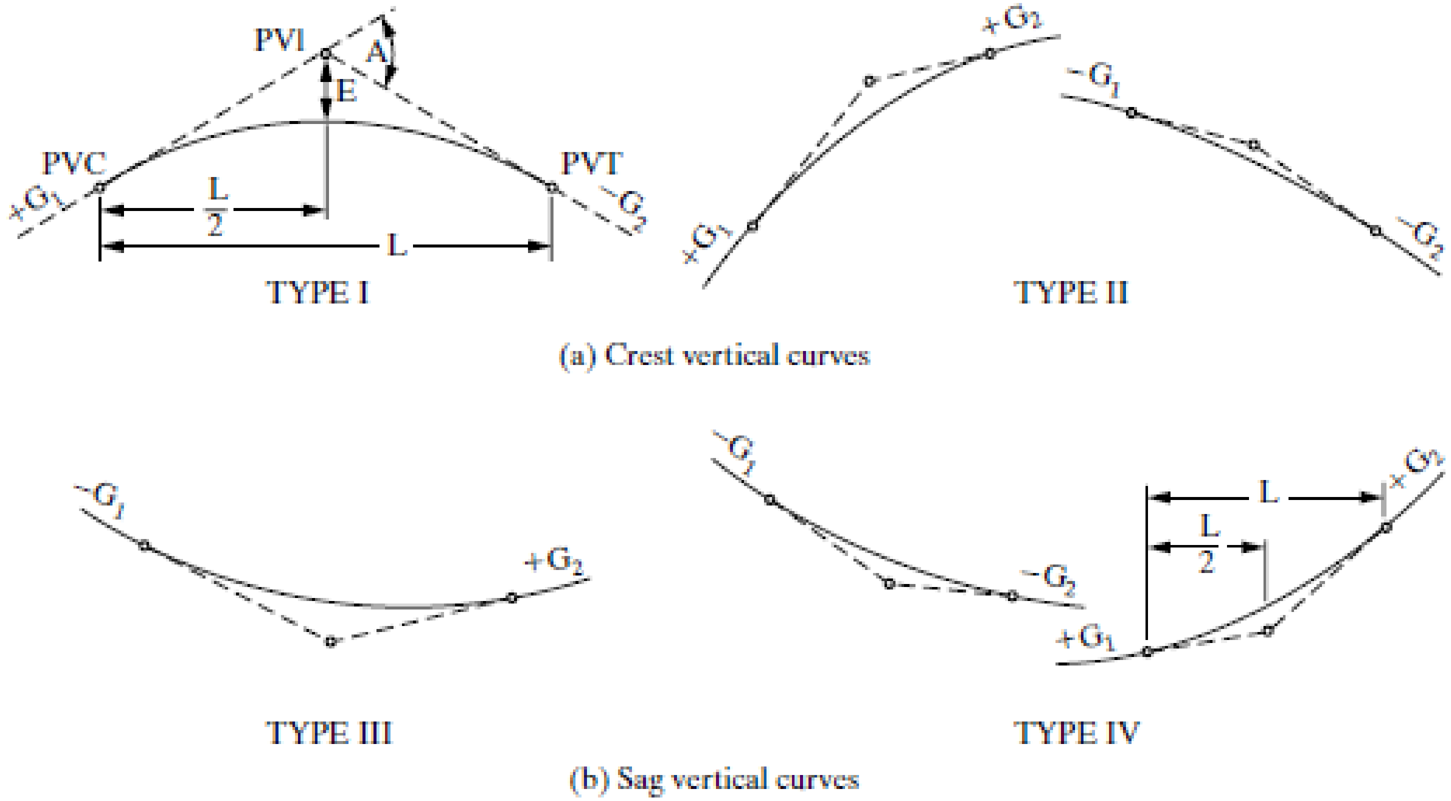
- ❖ Vertical Curves should satisfy the following:
  - – Sight distance
  - – Drainage
  - – Driver comfort
  - – Pleasant appearance

- ❖ Vertical Curves can either be:
  - – Crest Curves or
  - – Sag Curves

Vertical Alignment



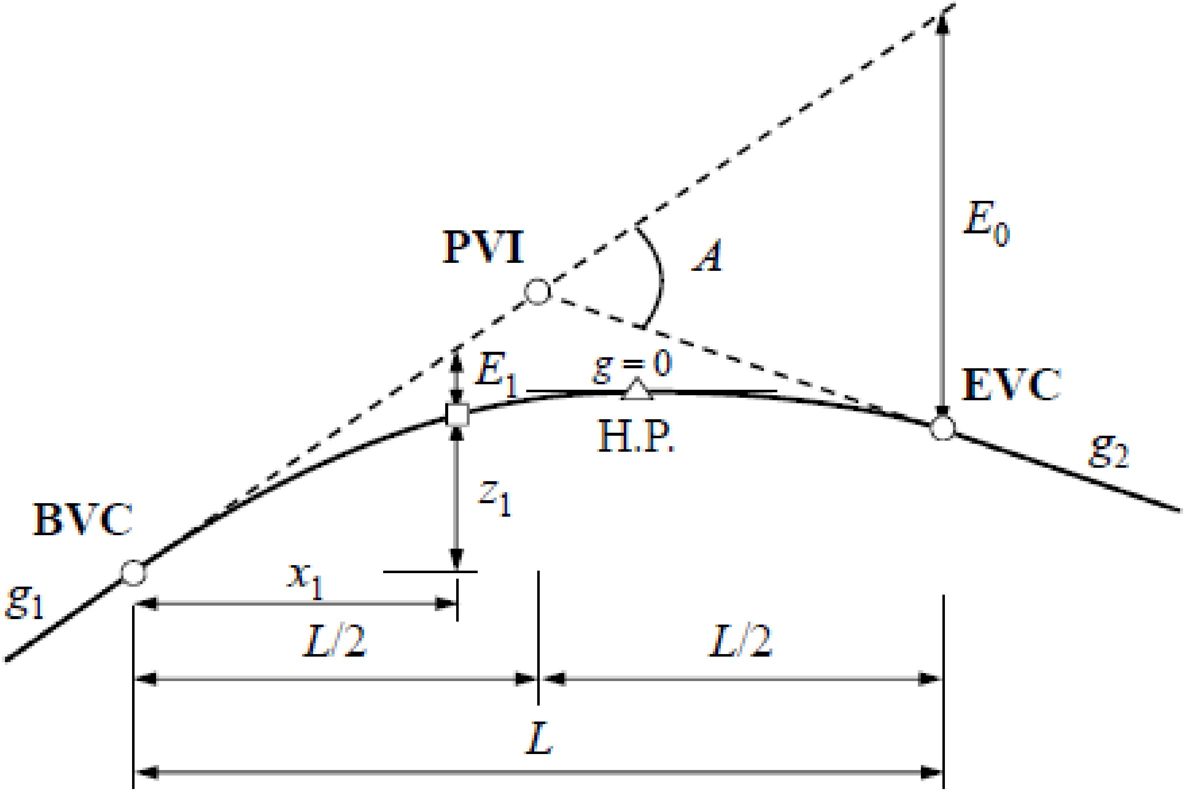
Vertical Alignment



G_1 , G_2 = grades of tangents (%)
A = algebraic difference
L = length of vertical curve
PVC = point of vertical curve
PVI = point of vertical intersection
PVT = point of vertical tangent

Vertical Alignment

Formulation of Vertical Curves



- Vertical curves have a constant rate of change of slope ($1/K$), where K = the curve length per 1% change of slope

$\therefore L = K \times A$ where $A = |g_2 - g_1|$

Vertical Alignment

$$E_0 = \frac{AL}{200}$$

$$\frac{E_1}{E_0} = \frac{x_1^2}{L^2} \rightarrow E_1 = \frac{x_1^2}{L^2} E_0 = \frac{Ax_1^2}{200L}$$

Elevation at any point = Elevation on the first tangent – E

$$z_1 = \frac{g_1\, x_1}{100} - E_1 = \frac{g_1\, x_1}{100} - \frac{Ax_1^2}{200L}$$

- In general, the equation of the vertical curve:

$$z = \frac{g_1\, x}{100} - \frac{Ax^2}{200L}$$

- For highest (lowest) point:

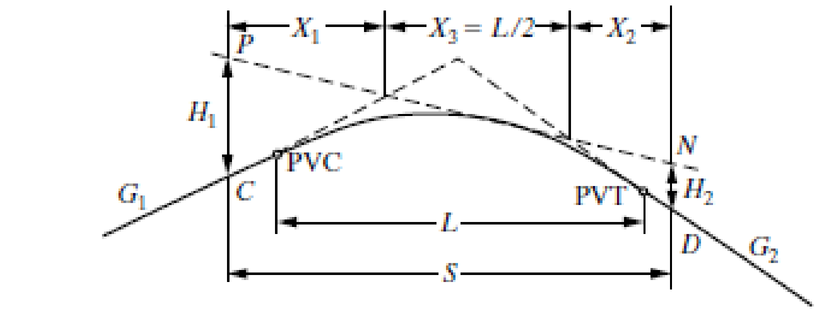
$$\frac{dz}{dx} = \frac{g_1}{100} - \frac{Ax}{100L} = 0$$

$$\therefore x = \frac{g_1 L}{A}$$

Design of Vertical Crest Curves

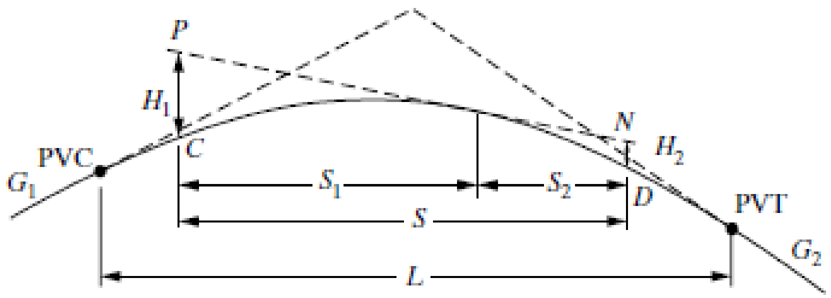
Design of Crest Vertical Curves based on SSD

- Provision of a minimum stopping sight distance (SSD) is the only criterion used for design of a crest vertical curve
- There are two possible scenarios that control the design length of the crest vertical curve:
  - the SSD is greater than the length of the vertical curve, and
  - the SSD is less than the length of the



L = length of vertical curve (ft)
S = sight distance (ft)
H_1 = height of eye above roadway surface (ft)
H_2 = height of object above roadway surface (ft)
G_1, G_2 = grades of tangents (%)
PVC = point of vertical curve
PVT = point of vertical tangent

Sight Distance on Crest Vertical Curve ($S > L$)



L = length of vertical curve (ft)
S = sight distance (ft)
H_1 = height of eye above roadway surface (ft)
H_2 = height of object above roadway surface (ft)
G_1, G_2 = grades of tangents (%)
PVC = point of vertical curve
PVT = point of vertical tangent

Vertical Crest Curves

❖ The minimum length of the vertical curve for the required sight distance is obtained as follows:

1. Scenario 1; S>L

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

$$K = \frac{2S}{A} - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A^2}$$

2. Scenario 2; S<L

$$L = \frac{A\,S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

$$K = \frac{S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

Vertical Crest Curves

- It had been the practice to assume that the height H_1 of the driver is 1.15 m, and the height of the object is 0.15 m.

- Due to the increasing number of compact automobiles on highways, the height of the driver's eye is now assumed to be 1.08 m, and the object height, considered to be the taillight of a passenger car, is 0.6 m.

Minimum Length of Vertical Crest Curves based on Appearance Criterion

1. $TAC\ (2017) pg\ 3.65{:}\ \ L\ (m) = V\ \left(\frac{km}{h}\right)$

2. $AASHTO\ (2011)\ pg\ 3-153{:}\ \ L\ (m) = 0.6\,V\ \left(\frac{km}{h}\right)$

Vertical Crest Curves

Maximum Length of Vertical Crest Curves based on Drainage Criterion

- This criterion is different from the others in that there is a maximum length requirement rather than a minimum length

- Maximum length of a crest curve depends on drainage requirements:
  - – Minimum grade of 0.35% should be reached within 15 m from highest point (TAC 2017; pg 3.66)
  - – Maximum K = 43 m
  - – Same criterion applies in AASHTO (2011) pg 3-156 but a minimum grade of 0.30 is to be reached within 15 m (50 ft) from highest point
  - – Maximum K = 51 m (167 ft)

Vertical Sag Curves

- **Design of Vertical Sag Curves Based on SSD**
  - Minimum length of a sag vertical curve depends on sight distance and comfort requirements
  - However, sag curves in fact enhance sight distance during the daytime
  - Sight distance on sag curves is restricted during the nighttime

If $S > L$:

$$L = 2S - \frac{200(h_h + S\ \tan\beta)}{A}$$

$$K = \frac{2S}{A} - \frac{200(h_h + S\ \tan\beta)}{A^2}$$

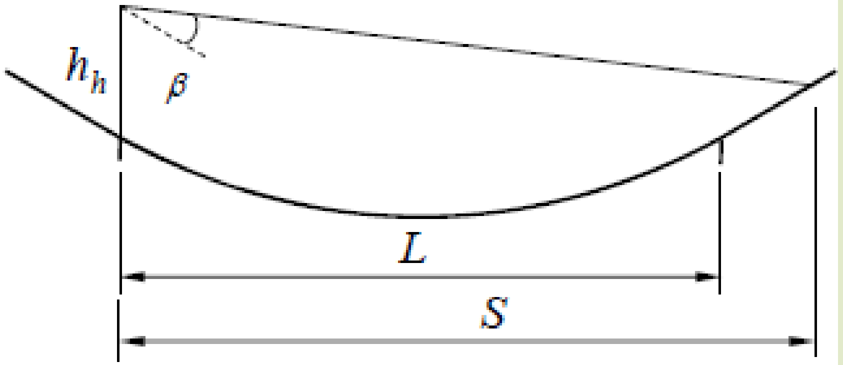
If $S \leq L$:

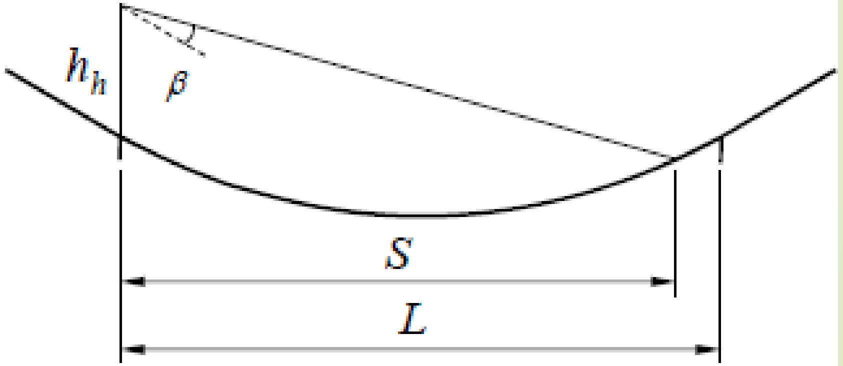
$$L = \frac{A\,S^2}{200(h_h + S\ \tan\beta)}$$

$$K = \frac{S^2}{200(h_h + S\ \tan\beta)}$$

Where:

- $h_h = 0.6$ m [2 ft]
- β = angle of upward light spread = 1°





Vertical Sag Curves

Minimum Length of Vertical Curves based on Comfort Criterion

- ❖ Based on the fact that when a vehicle travels on a sag vertical curve, both the gravitational and centrifugal forces act in combination, resulting in a greater effect than on a crest vertical curve where these forces act in opposition to each other

- ❖ It is generally accepted that a comfortable ride will be provided if the radial acceleration is not greater than 0.3 m/s^2

- ❖ The following expression is used for comfort criterion:

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

where:

L = length of sag vertical curve, m;
A = algebraic difference in grades, percent;
V = design speed, km/h

- ❖ Corresponding K values are given b

$$K(\text{m}) = \frac{V^2\ (\text{km/h})}{395}$$

- ❖ This criterion is useful only on roads with good street lighting

Vertical Sag Curves

Minimum Length of Vertical Curves based on Appearance Criterion

- The criterion for acceptable appearance is usually satisfied by assuring that the minimum length of the **sag curve** is not less than expressed by the following equation:

1. $TAC\ (2017)pg\ 3.65{:}\ L\ (m) = V\ \left(\frac{km}{h}\right)$

Maximum Length of Vertical Sag Curves based on Drainage Criterion

- The drainage criterion for sag vertical curves must be considered when the road is curbed.

- Maximum curve length for drainage: similar to crest curves

Vertical Alignment

Example 1 - Vertical Curves

A sag vertical curve is to be designed to join a -5% grade to a +2% grade. If the design speed is 65 km/h, determine the minimum length of the curve that will satisfy all criteria. Assume $a = 3\ m/s^2$ and perception-reaction time = 2.5 sec.

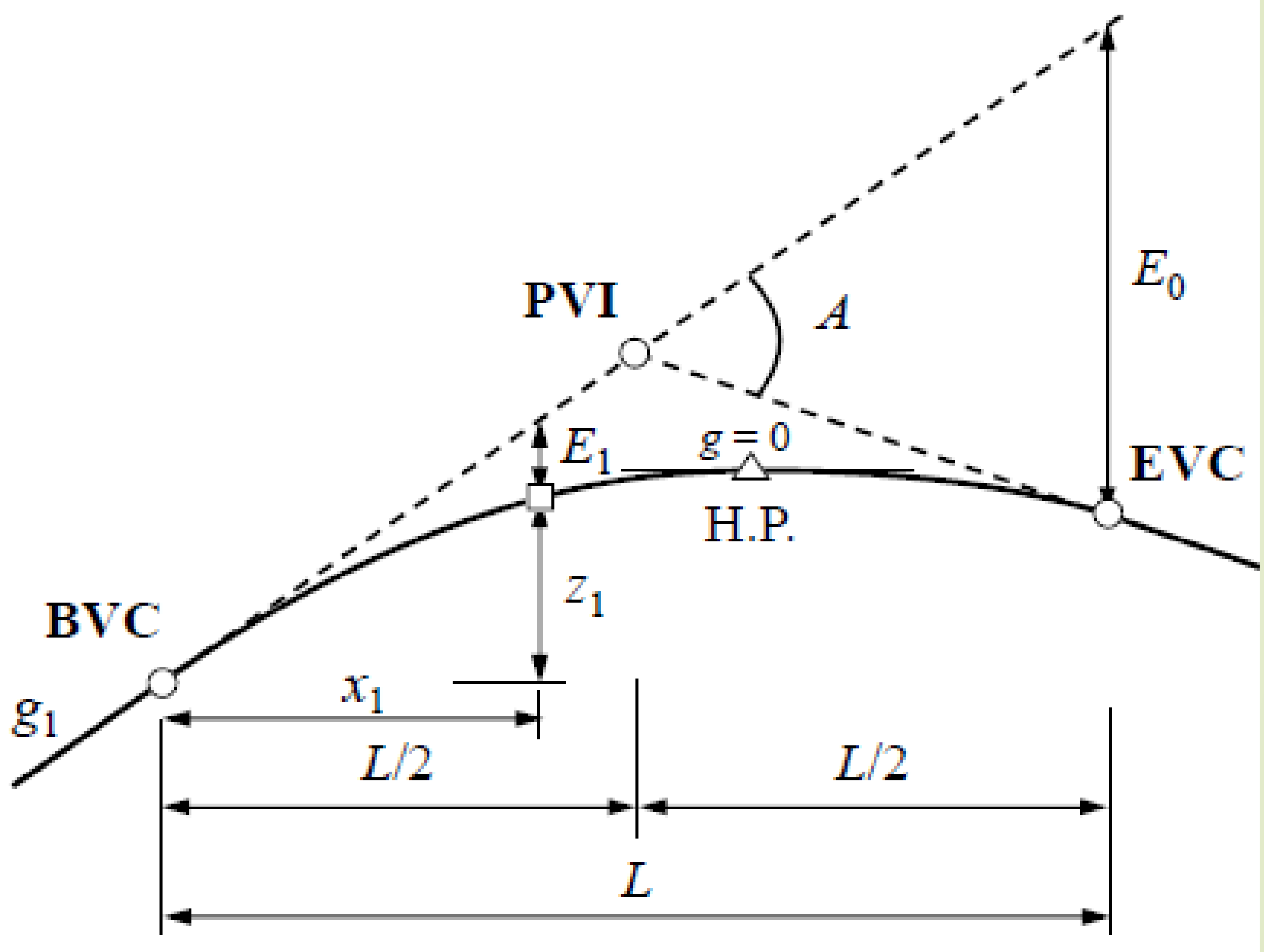
Minimum Length of Crest and Sag Curves based on K factors

- K-Value represents the horizontal distance along which a 1% change in grade occurs on the vertical curve.
- It expresses the abruptness of the grade change in a single value
- K-Value is used as a convenient "shortcut" to compute the minimum length for a crest vertical curve
- K = **the curve length per 1% change of slope**
- Therefore:

  L = K * A

- Where:

  $A = |g_2 - g_1|$



Vertical Alignment

- The K factors calculated using these formulas are tabulated in the design guides

Values of *K* for Sag Vertical Curves Based on Stopping Sight Distance

Design Speed (mi/h)	*Stopping Sight Distance (ft)*	*Rate of Vertical Curvature, K*[a]	
		Calculated	*Design*
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	425	95.7	96
55	495	114.9	115
60	570	135.7	136
65	645	156.5	157
70	730	180.3	181
75	820	205.6	206
80	910	231.0	231

[a]Rate for vertical curvature, K, is the length of curve (ft) per percent algebraic difference intersecting grades (A).

$$K = L/A$$

SOURCE: Based on *A Policy on Geometric Design of Highways and Streets*, 2004, AASHTO, Washington, D.C.

Vertical Alignment

Values of *K* for Crest Vertical Curves Based on Stopping Sight Distance

Design Speed (mi/h)	Stopping Sight Distance (ft)	Rate of Vertical Curvature, K^a	
		Calculated	Design
15	80	3.0	3
20	115	6.1	7
25	155	11.1	12
30	200	18.5	19
35	250	29.0	29
40	305	43.1	44
45	360	60.1	61
50	425	83.7	84
55	495	113.5	114
60	570	150.6	151
65	645	192.8	193
70	730	246.9	247
75	820	311.6	312
80	910	383.7	384

[a]Rate of vertical curvature, *K*, is the length of curve per percent algebraic difference in intersecting grades (*A*).

$$K = L/A$$

SOURCE: Based on *A Policy on Geometric Design of Highways and Streets*, 2004, AASHTO, Washington, D.C.

Vertical Alignment

Procedure for Designing of Vertical Curves

Step 1:

- ❖ Determine the minimum length of curve to satisfy SSD while considering other criteria (comfort, appearance, drainage)
  - – Use tables or equations

Step 2:

- ❖ Determine from the layout plans the station and elevation of PVI

Step 3:

- ❖ Compute the stations and elevations of BVC and EVC

Step 4:

- ❖ Compute the vertical offsets, Y, at frequent stations along the curve

$$Y = \frac{A x^2}{200L}$$

Vertical Alignment

Procedure for Designing of Vertical Curves

Step 5:

- Compute elevations on the curve for each station

$$Elev = Elev\,(BVC) \pm \frac{g_1\,x}{100} \mp Y$$

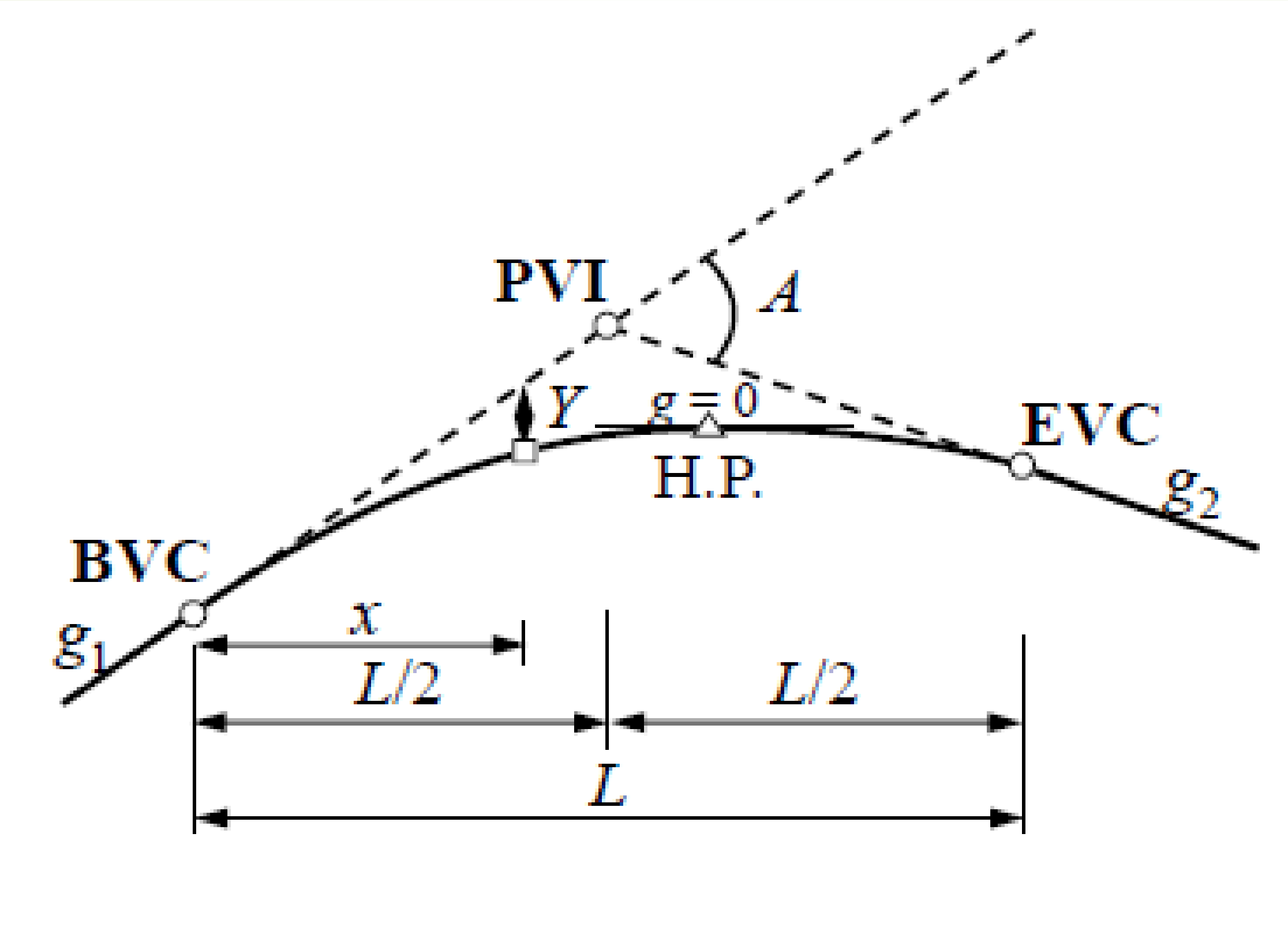
Step 6:

- Compute the location and elevation of the highest (crest) or lowest (sag) point on the curve

$$x_{HP\ or\ LP} = \frac{g_1 L}{A}$$

Vertical Alignment

Elevation of Crest and Sag Curves



Vertical Alignment

Example:

A crest vertical curve joining a + 3 percent and a -4 percent grade is to be designed for 90 km/h. If the tangents intersect at station (34+560.00) at an elevation of 250.00 m. determine the stations and elevations of the BVC and EVC. Also, calculate the elevations of intermediate points every 50 m.

- Given: $g_1 = +3\%; g_2 = -4\%$
  - $A = g_2 - g_1 = -7\% \rightarrow$ crest curve
  - $g_{av} = -0.5\%$
- Calculate SSD:
  - $SSD = 0.278\ P\ V + \frac{V^2}{254\left(\frac{a}{g} \pm G\right)} = 0.278 \times 2.5 \times 90 + \frac{90^2}{254\left(\frac{3.4}{9.81} - 0.005\right)} =$ 155.81 m
- Calculate curve length:
  - Assume $S \leq L$: $L = \frac{|A|\ S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} = \frac{7 \times 155.81^2}{200\left(\sqrt{1.08} + \sqrt{0.6}\right)^2} = 258.27 \cong 260$ m
  - Assumption is correct
  - Curve length could have been calculated using K from Tables

Vertical Alignment

- Calculate stations and elevations of BVC and EVC:
  - $Sta.(BVC) = Sta.(PI) - \frac{L}{2} = (34 + 560) - \frac{260}{2} = (34 + 430)$
  - $Sta.(EVC) = Sta.(PI) + \frac{L}{2} = (34 + 560) + \frac{260}{2} = (34 + 690)$
  - $Elev.(BVC) = 250.00 - \frac{|g_1|L}{200} = 250.00 - \frac{3 \times 260}{200} = 246.10 \text{ m}$
  - $Elev.(EVC) = 250.00 - \frac{|g_2|L}{200} = 250.00 - \frac{4 \times 260}{200} = 244.80 \text{ m}$
- Calculate station and elevation of HP:
  - $x_{HP} = \frac{|g_1|L}{|A|} = \frac{3 \times 260}{7} = 111.43 \text{ m}$
  - $Sta.(HP) = Sta.(BVC) + x_{HP} = (34 + 430) + 111.43 = (34 + 541.43)$
  - $Elev.(HP) = Elev.(BVC) + \frac{|g_1|x_{HP}}{100} - \frac{|A|x_{HP}^2}{200L} = 246.10 + \frac{3 \times 111.43}{100} - \frac{7 \times (111.43)^2}{200 \times 260} = 247.77 \text{ m}$

Vertical Alignment

- Calculate elevation every 50 m:
  - $Elev = Elev\,(BVC) + \frac{|g_1|x}{100} - \frac{|A|x^2}{200L}$

Point	Station	Distance from BVC (m)	Tangent elevation (m)	Vertical offset (m)	Curve elevation (m)
BVC	34+430.00	0	246.100	0.000	246.10
	34+450.00	20	246.700	0.054	246.65
	34+500.00	70	248.200	0.660	247.54
HP	34+541.43	111.43	249.443	1.671	247.77
	34+550.00	120	249.700	1.938	247.76
	34+600.00	170	251.200	3.890	247.31
EVC	34+650.00	220	252.700	6.515	246.18

Horizontal Alignment

- Horizontal alignment consists of straight section (tangents) connected by horizontal curves
- Curves can be circular arcs or spirals
- The design of the horizontal alignment entails:
  - determination of the minimum radius,
  - determination of the length of the curve, and
  - computation of the horizontal offsets from the tangents to the curve to facilitate locating the curve in the field

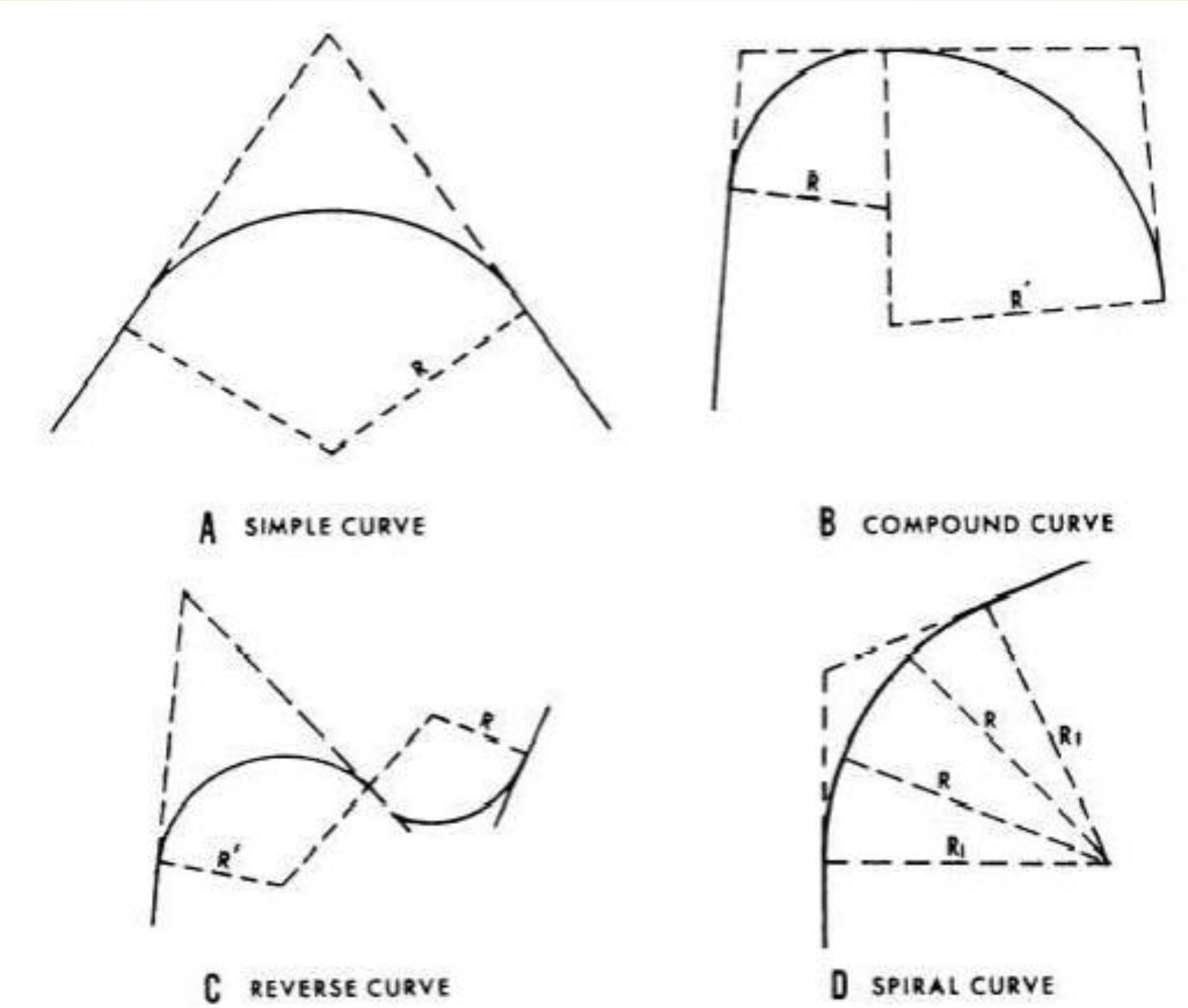
Horizontal Alignment

- In some cases, to avoid a sudden change from a tangent with infinite radius to a curve of finite radius, a curve with radii varying from infinite to the radius of the circular curve is placed between the circular curve and the tangent.

- Such a curve is known as a **spiral or transition curve**.

- There are four types of horizontal curves: **simple**, **compound**, **reversed**, and **spiral**. Computations required for each type are presented in the following sections.

Horizontal Alignment



Horizontal Alignment

1. **Simple Curves**

- The simple curve is an arc of a circle.
- The radius of the circle determines the sharpness or flatness of the curve.

2. **Compound Curve**

- Frequently, the terrain will require the use of the compound curve. This curve normally consists of two simple curves joined together and curving in the same direction

3. **Reverse Curve**

- A reverse curve consists of two simple curves joined together, but curving in opposite direction.
- For safety reasons, the use of this curve should be avoided when possible

4. **Spiral Curve (Transitional Curve)**

- The spiral is a curve that has a varying radius.
- It is used on railroads and most modern highways.
- Its purpose is to provide a transition from the tangent to a simple curve or between simple curves in a compound curve

Horizontal Alignment – Simple Curve

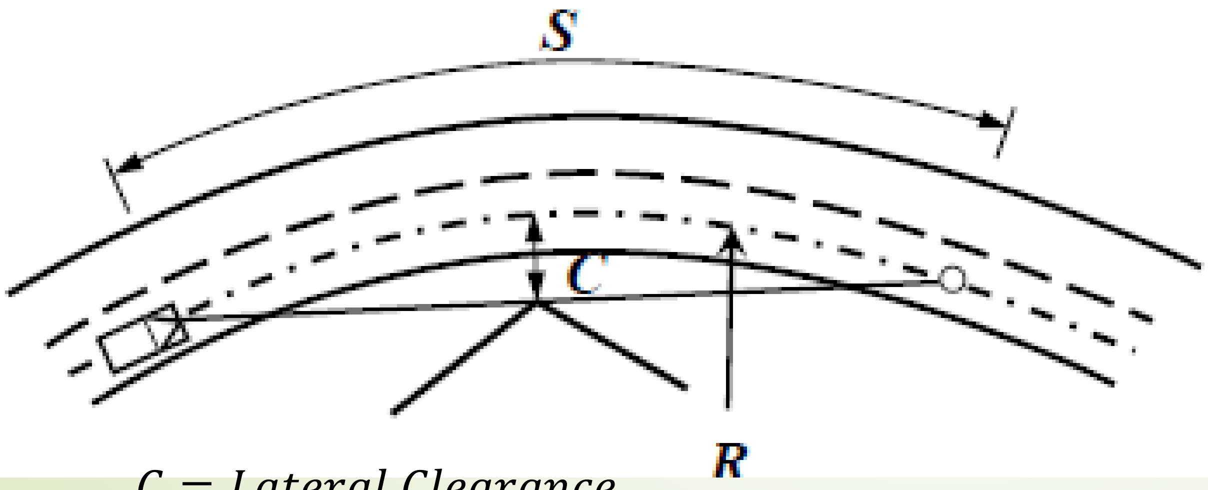
❖ Minimum radius of a circular horizontal curve is governed by:

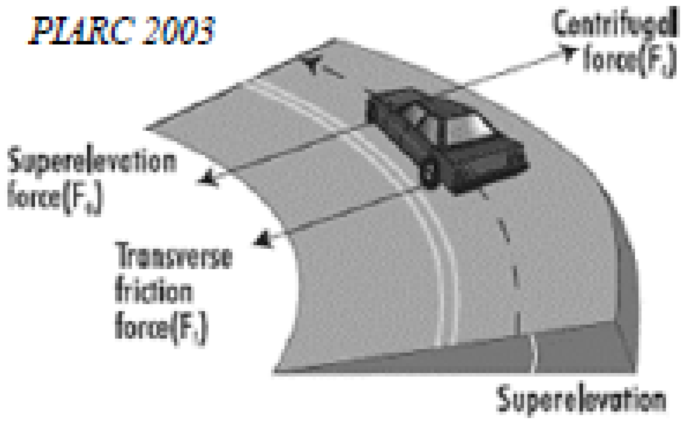
– Vehicle stability and driver comfort

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

– Sight distance (due to object in the inside of the curve)

$$C = R\left(1 - \cos\frac{90S}{\pi R}\right)$$





$C = Lateral\ Clearance$

Horizontal Alignment – Simple Curve

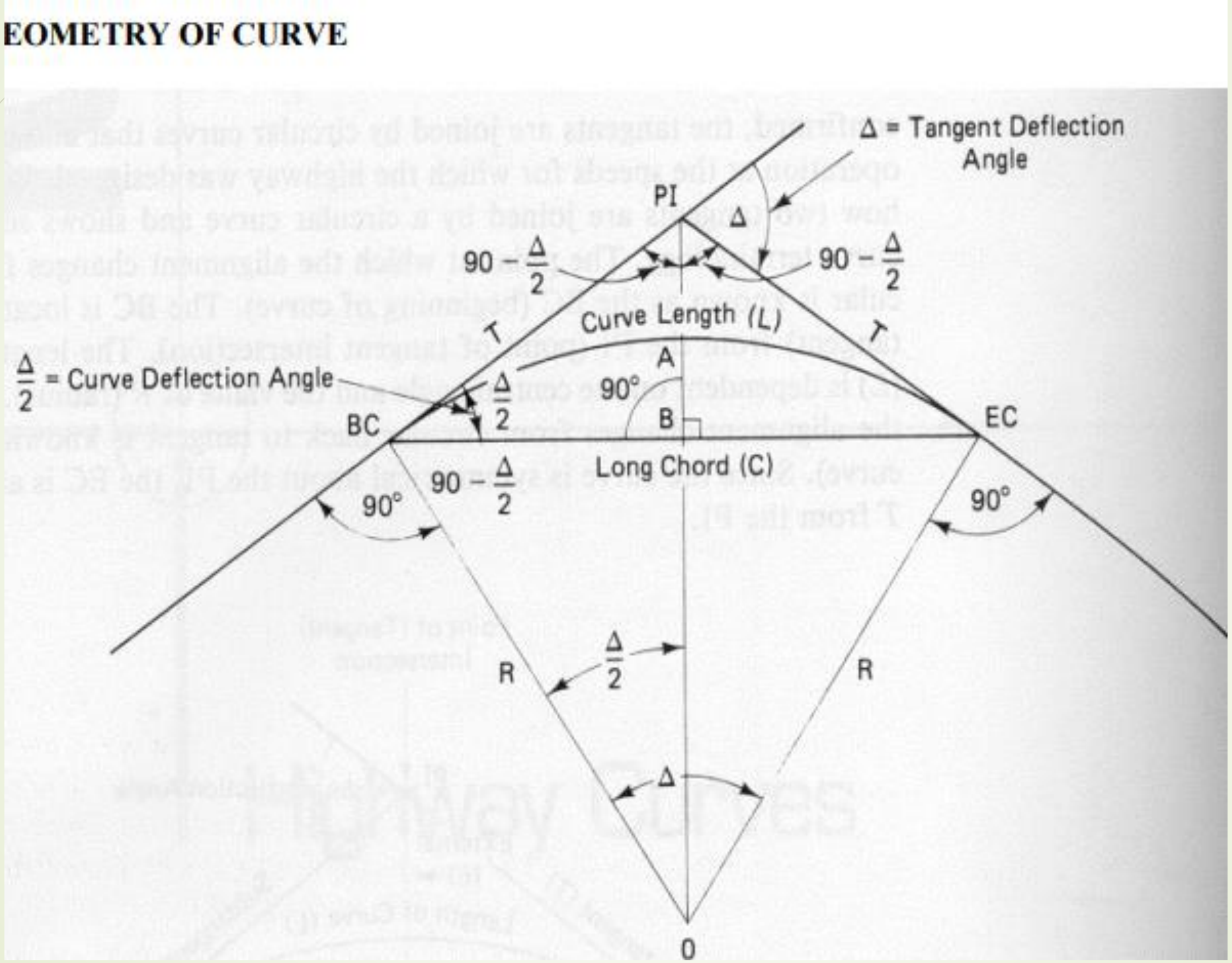
Example:

A horizontal curve with a radius of 200 m connects the tangents of a two-lane highway that has a posted speed limit of 60 km/h. If the highway curve is not superelevated ($e = 0$) and the coefficient of side friction is 0.15:

- Check that the radius meets the design requirements.
- 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.

- Check minimum required radius:
  - $R_{\text{min}} = \frac{V^2}{127(f_s+e)} = \frac{(60)^2}{127(0.15+0)} = 188.89 \text{ m}$
  - $R > R_{min} \rightarrow$ curve meets design requirements
- Calculate SSD:
  - $SSD = 0.278\,PV + 0.039\frac{V^2}{a} = 0.278 \times 2.5 \times 90 + 0.039 \times \frac{60^2}{3.4} = 82.99 \cong 83 \text{ m}$
- Calculate minimum horizontal sightline offset (HSO):
  - $C = R\left(1 - \cos\frac{90S}{\pi R}\right) = 200\left(1 - \cos\frac{90\times 83}{\pi\times 200}\right) = 4.29 \text{ m}$

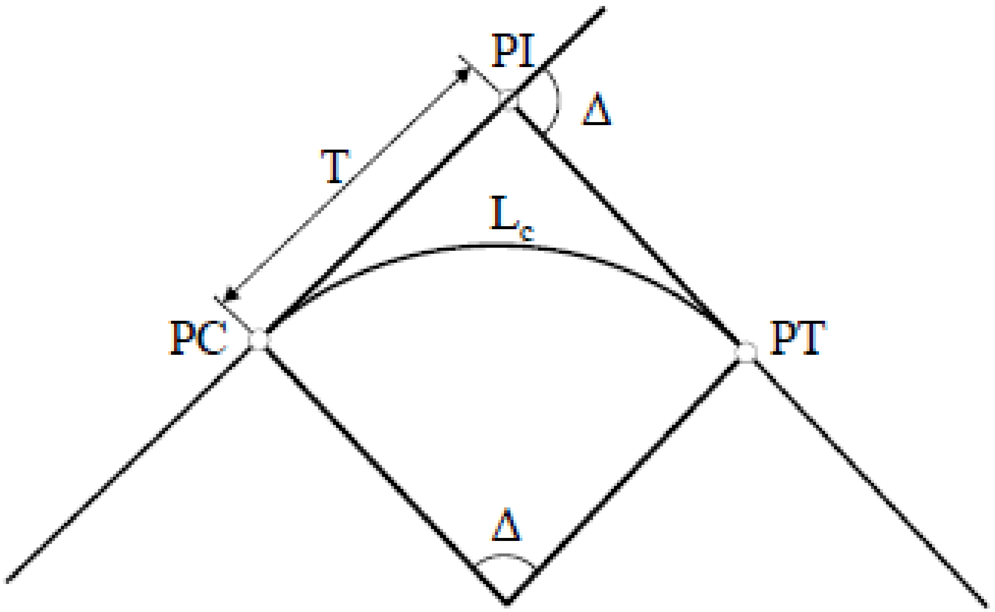
Horizontal Alignment – Simple Curve



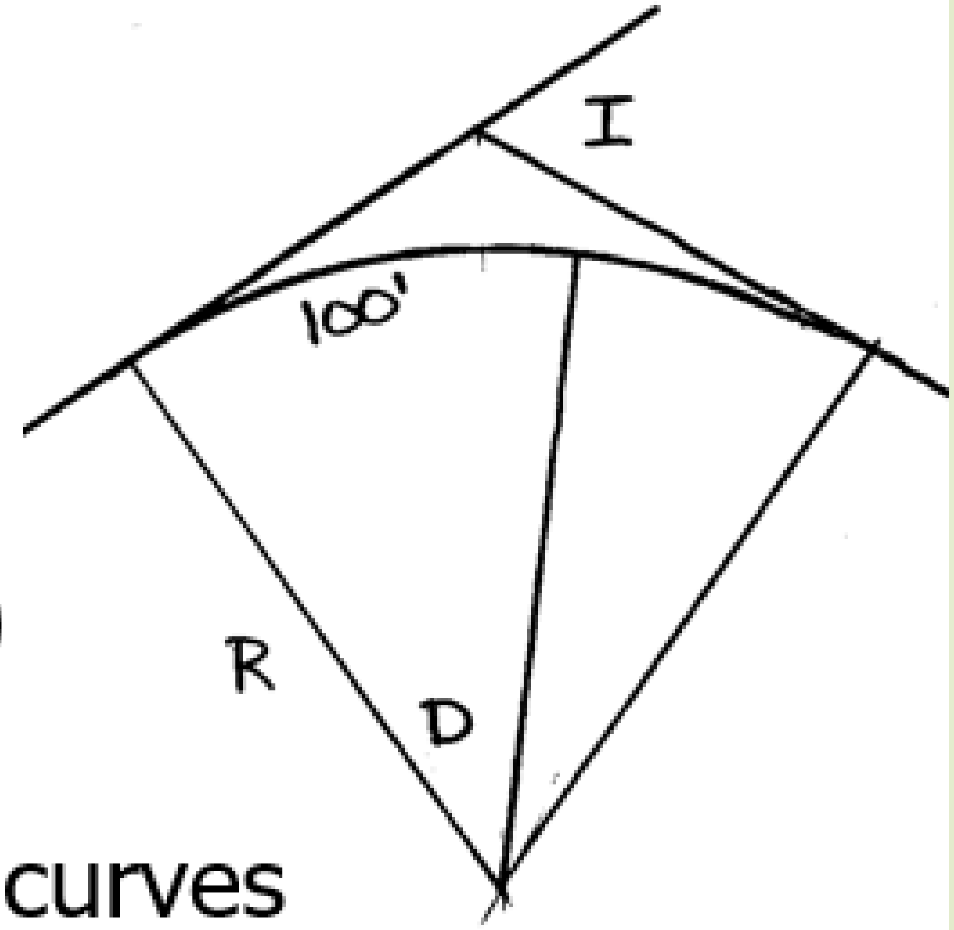
Horizontal Alignment – Simple Curve

Horizontal Curve Geometry (Simple Curve)

- $T = R \times \tan\left(\frac{\Delta}{2}\right)$
- Station of PC = Station of PI $-$ T
- $L_C = R \times \Delta \times \frac{\pi}{180}$
- Station of PT= Station of PC $+ L_C$
- Station of PT $\neq$ Station of PI $+$ T



- D defines Radius
- Chord Method
  - R = 50/sin(D/2)
- Arc Method
  - $(360/D)=100/(2\pi R)$
  - R = 5729.578/D
- D used to describe curves



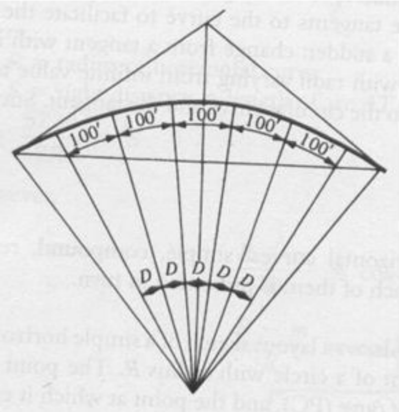
Staking of Horizontal Curves

Note:

Properties of Circular Curves

Degree of Curvature

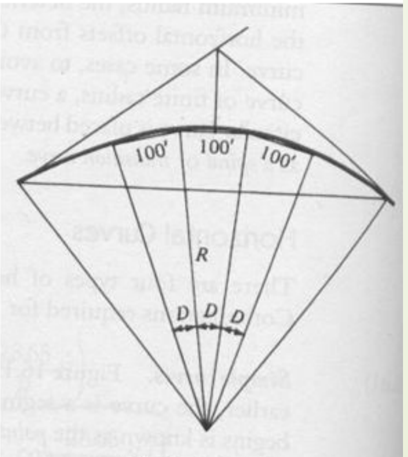
- Traditionally, the "steepness" of the curvature is defined by either the **radius (R)** or the **degree of curvature (D)**
- Degree of curvature = angle subtended by an arc of length 100 feet



(a) Arc definition

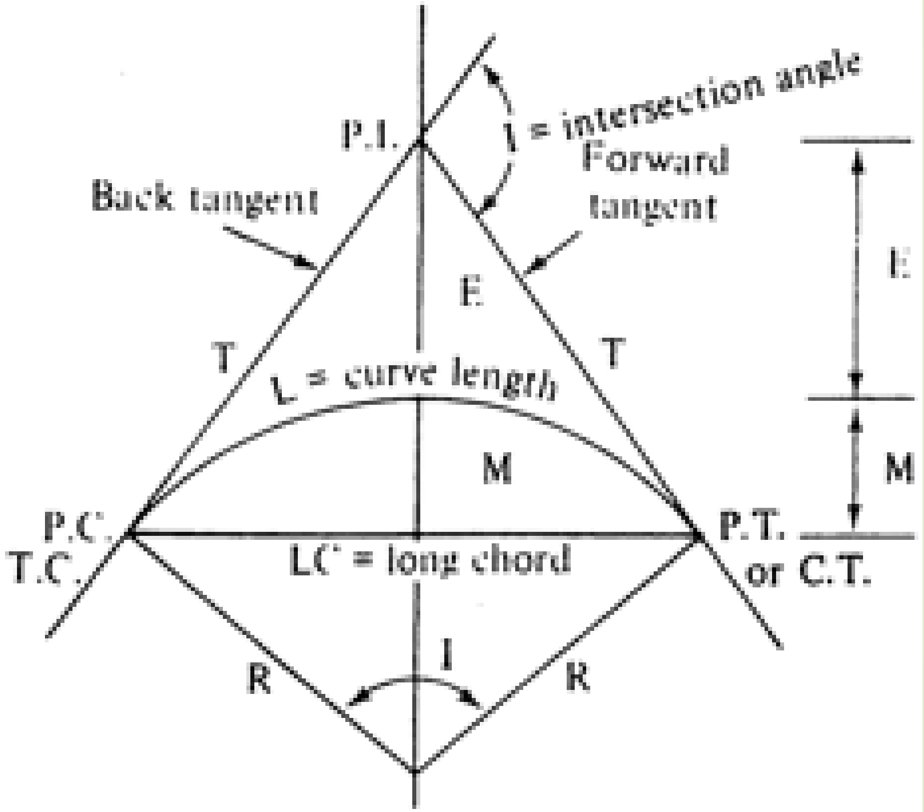
R = 5730 / D

(Degree of curvature is <u>not</u> used with metric units because D is defined in terms of feet.)

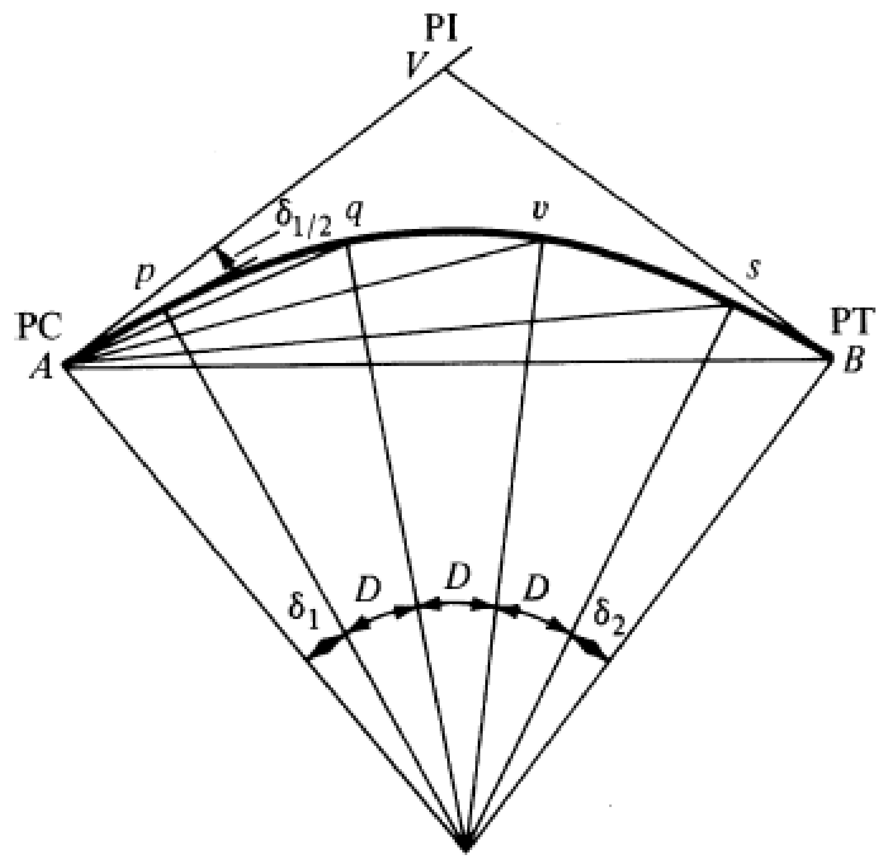


(b) Chord definition

- $L = 100I/D$
- $T = R \cdot \tan(I/2)$
- $L.C. = 2R \cdot \sin(I/2)$
- $E = R(1/\cos(I/2) - 1)$
- $M = R(1 - \cos(I/2))$



Staking of Horizontal Curves



Deflection Angles on a Simple Circular Curve

Staking of Horizontal Curves

Example - Staking of Horizontal Curves

Prepare a table giving chords and deflection angles for staking out a 450-m-radius circular curve with a total deflection angle of 17°. The PC point is at station 22+40. Give deflection angles and chords for full stations and +20 points.

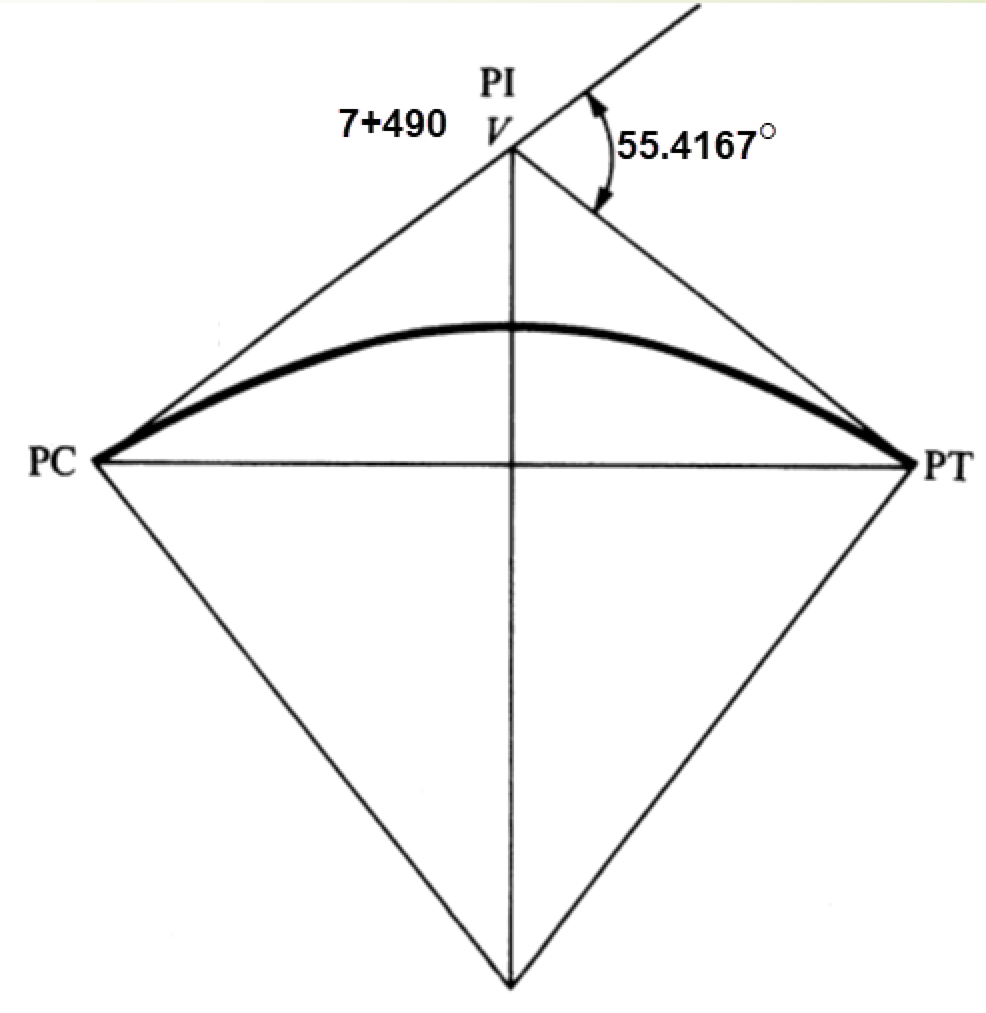
Station	Arc Length, m	Angle at Centre	Deflection Angle		Chord, m
		Radians	Radians	Degrees	
22+40	0	0	0.00	0.0	0.000
22+60	20	0.044	0.02	1.3	19.998
22+80	40	0.089	0.04	2.5	39.987
23+00	60	0.133	0.07	3.8	59.956
23+20	80	0.178	0.09	5.1	79.895
23+40	100	0.222	0.11	6.4	99.794
23+60	120	0.267	0.13	7.6	119.645
23+73.5	133.5	0.297	0.15	8.5	133.011

Staking of Horizontal Curves

Example - Staking of Horizontal Curves

The intersection angle of a 4° curve is 55.4167° and the PI is located at station 7+490. Determine the length of the curve, the station of the PT, the deflection angles and the chord lengths for setting out the curve at whole stations from the PC.

The figure illustrates a layout of the curve.



Staking of Horizontal Curves

Calculate Radius of curve:

$$R(ft) = \frac{5729.6}{D} = \frac{5729.6}{4º} = 1432.4\ ft = 436.626\ m$$

$$Calculate\ T\ (m) = Rtan\left(\frac{55.4167°}{2}\right) = 436.626 * tan(\frac{55.4167°}{2}) = 229.315\ m$$

$$Calculate\ Length\ of\ Curve\ (ft) = \left(\frac{100*55.4167°}{4}\right) = 1385.42\ ft = 422.28\ m$$

$$Calculate\ Length\ of\ Curve\ (m) = \left(\frac{2*\pi * 436.626 * 55.4167°}{360}\right) = 422.3\ m$$

$$PC = PI - T = (7 + 490) - (0 + 229) = \mathbf{7 + 261}$$

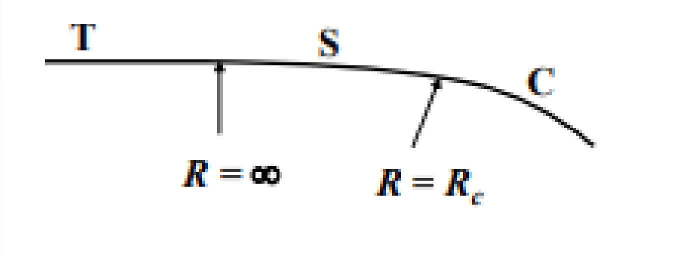
$$PT = PC + L = (7 + 261) + 422.28 = \mathbf{7 + 683}$$

Staking of Horizontal Curves

Station	Arc Length, m	Angle at Centre	Deflection Angle		Chord, m
		Radians	Radians	Degrees	
7+261	0	0	0.00	0.0	0.000
7+300	39	0.08932	0.04	2.6	38.987
7+400	139	0.31835	0.16	9.1	138.414
7+500	239	0.54738	0.27	15.7	236.027
7+600	339	0.77641	0.39	22.2	330.549
7+683	422	0.9665	0.48	27.7	405.766

Horizontal Alignment – Spiral Curve

- Spiral (transition) curves are curves with changing radii, and are placed between tangents and circular curves or between two successive circular curves



- Common form for spiral curves:

$$R \propto \frac{1}{L}, \text{ or}$$
$$R\,L = A^2\ (A = \text{spiral parameter})$$

Design Speed (km/h)	40			50			60			70			80		
		A			A			A			A			A	
Radius (m)	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane
7000	NC			NC			NC			NC			NC		
5000	NC			NC			NC			NC			NC		
4000	NC			NC			NC			NC			NC		
3000	NC			NC			NC			NC			RC		
2000	NC			NC			NC			RC	275	275	RC	300	300
1500	NC			NC			RC	225	225	RC	250	250	0.024	250	250
1200	NC			NC			RC	200	200	0.023	225	225	0.028	225	225
1000	NC			NC	170	170	0.021	175	175	0.027	200	200	0.032	200	200
900	NC			NC	150	150	0.023	175	175	0.029	200	200	0.034	200	200
800	NC			RC	150	150	0.025	160	160	0.031	175	175	0.036	175	175
700	NC			0.021	140	140	0.027	150	150	0.034	175	175	0.039	175	175
600	NC	120	120	0.024	125	125	0.030	140	140	0.037	175	175	0.042	175	175
500	RC	100	100	0.027	120	120	0.034	125	125	0.041	150	150	0.046	150	160
400	0.023	90	90	0.031	100	100	0.038	115	120	0.045	140	150	0.051	135	150
350	0.025	90	90	0.034	100	100	0.041	110	115	0.048	125	135	0.054	125	140
300	0.028	80	80	0.037	90	100	0.044	100	110	0.051	120	125	0.057	125	135
250	0.031	75	80	0.040	85	90	0.048	90	100	0.055	120	125	0.060	125	125
220	0.034	70	80	0.043	80	90	0.050	90	100	0.057	110	120	0.060	125	125
200	0.036	70	75	0.045	75	90	0.052	85	100	0.059	110	110			
180	0.038	60	75	0.047	70	90	0.054	85	90	0.060	110	110			
160	0.040	60	75	0.049	70	85	0.056	85	90						
140	0.043	60	75	0.052	65	80	0.059	85	90						
120	0.046	60	70	0.055	65	75	0.060								
100	0.049	50	65	0.058	65	70									
90	0.051	50	60	0.060	65	70									
80	0.054	50	60	0.060	65	70									
70	0.056	50	60												
60	0.059	50	60												
	0.059	50	60												
min R	min R = 55			min R = 90			min R = 130			min R = 190			min R = 250		

Design Speed (km/h)	90			100			110			120			130		
		A			A			A			A			A	
Radius (m)	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane	e	2 lane	3&4 lane
7000	NC			NC			NC			RC			RC	710	710
5000	NC			NC			RC	555	555	RC	580	580	RC	600	600
4000	NC			RC	475	475	RC	495	495	RC	515	515	0.023	540	540
3000	RC	390	390	RC	410	410	0.022	430	430	0.024	450	450	0.036	465	465
2000	0.023	300	300	0.026	335	335	0.029	350	350	0.034	365	365	0.04	380	380
1500	0.029	270	270	0.032	290	290	0.036	305	305	0.042	315	315	0.049	330	335
1200	0.033	240	240	0.038	260	260	0.043	270	270	0.049	285	290	0.055	295	320
1000	0.037	225	225	0.043	235	235	0.048	245	255	0.054	260	280	0.058	280	300
900	0.039	200	200	0.045	225	225	0.051	235	250	0.058	250	270	0.06	280	300
800	0.042	200	200	0.048	210	215	0.054	220	240	0.06	250	260			
700	0.045	185	195	0.051	200	210	0.058	220	235	0.06	250	260			
600	0.048	175	185	0.054	190	200	0.06	220	220						
500	0.052	160	175	0.059	190	190	0.06	220	220						
400	0.057	160	165	0.060	190	190									
350	0.059	160	160												
300	0.060	160	160												
min R	min R = 340			min R = 440			min R = 600			min R = 750			min R = 950		

$e_{max} = 0.06$

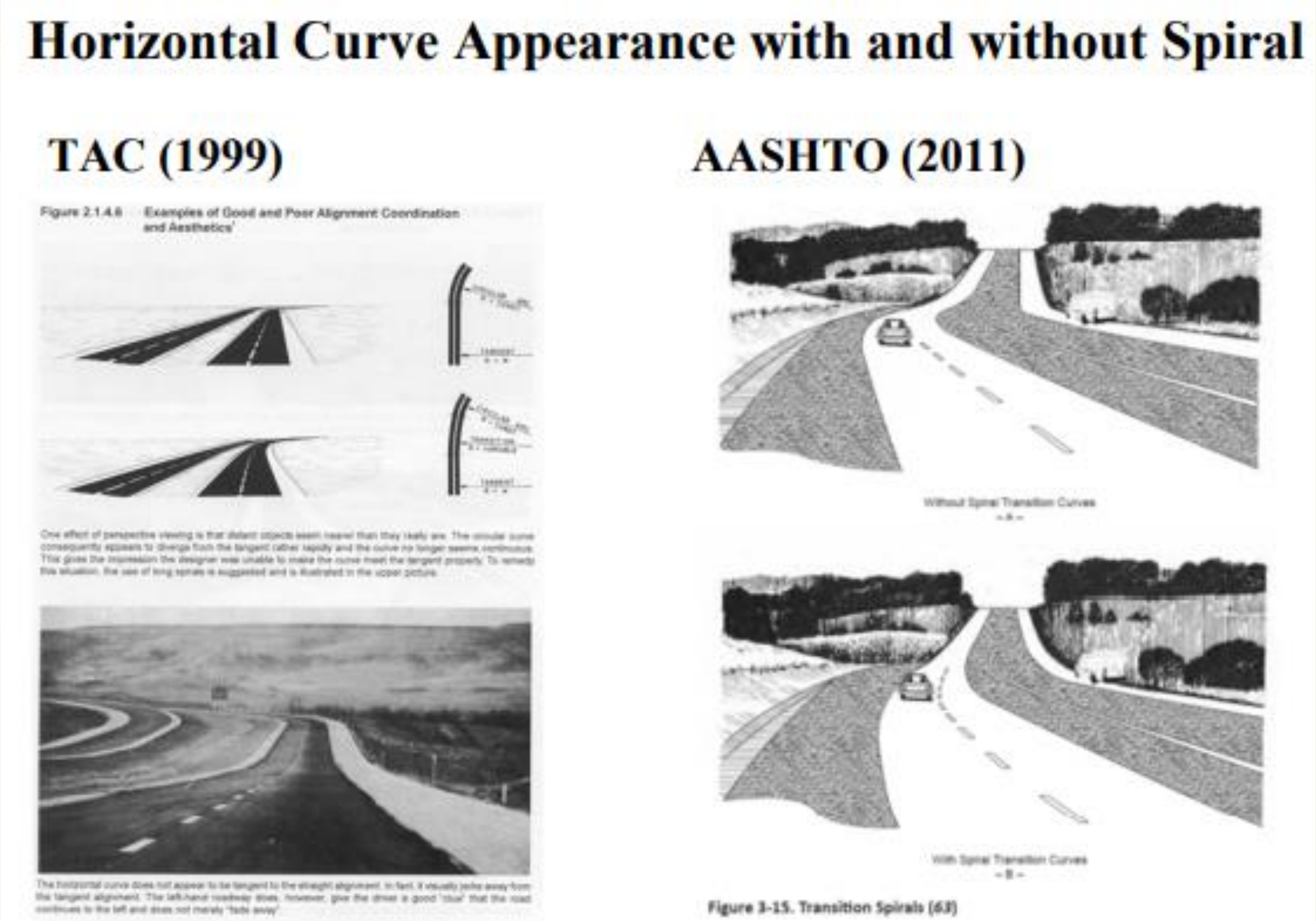
Notes: e = superelevation (m/m)
A = spiral parameter in metres
NC = normal cross section
RC = remove adverse crown and superelevate at normal rate
Spiral length, L = A^2 / Radius
Spiral parameters are minimum and higher values may be used
For 6 lane pavement: above the dashed line use 4 lane values, below the dashed line, use 4 lane values x 1.15.

A divided road having a median less than 3 m wide may be treated as a single pavement.

Horizontal Alignment – Spiral Curve

- Functions of spiral curves:
  - Limit rate of change of centripetal acceleration
    - $L = \frac{0.0214V^3}{RC}$
      - » $V = km/h$, $R = m$
      - » $C = 0.6\ m/s^3$
  - Provide enough length of superelevation runoff
  - Add to the highway aesthetics
  - AASHTO adds a driver comfort criterion to provide a lateral shift in vehicle path consistent with driver's natural path
    - $L = \sqrt{24(p_{min})R}$
      - » $p_{min} = 0.2\ m\ (0.66\ ft)$

Horizontal Alignment – Spiral Curve



Horizontal Alignment – Spiral Curve

Desirable Lengths of Spiral Curves

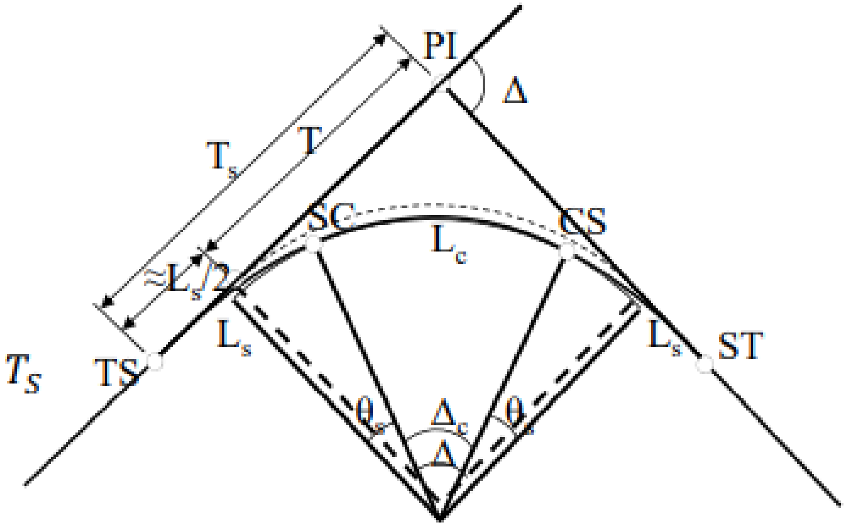
Design Speed (mi/h)	*Spiral Length (ft)*
15	44
20	59
25	74
30	88
35	103
40	117
45	132
50	147
55	161
60	176
65	191
70	205
75	220
80	235

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

Horizontal Alignment – Spiral Curve

Geometry of Horizontal Curve with Spiral

- $\Delta = \Delta_C + 2\theta_s$
- $L_s = \frac{A^2}{R}$
- $\theta_s = \frac{L_s}{2R} \times \frac{180}{\pi}$
- $L_C = R \times \Delta_C \times \frac{\pi}{180}$
- $T_s \cong R \times Tan\frac{\Delta}{2} + \frac{L_s}{2}$
- Station of TS = Station of PI $- T_s$
- Station of SC = Station of TS $+ L_s$
- Station of CS = Station of SC $+ L_C$
- Station of ST = Station of CS $+ L_s$



Horizontal Alignment – Spiral Curve

For any spiral point i:

$$l_i = Sta_i - Sta_{TS}$$ Arc distance

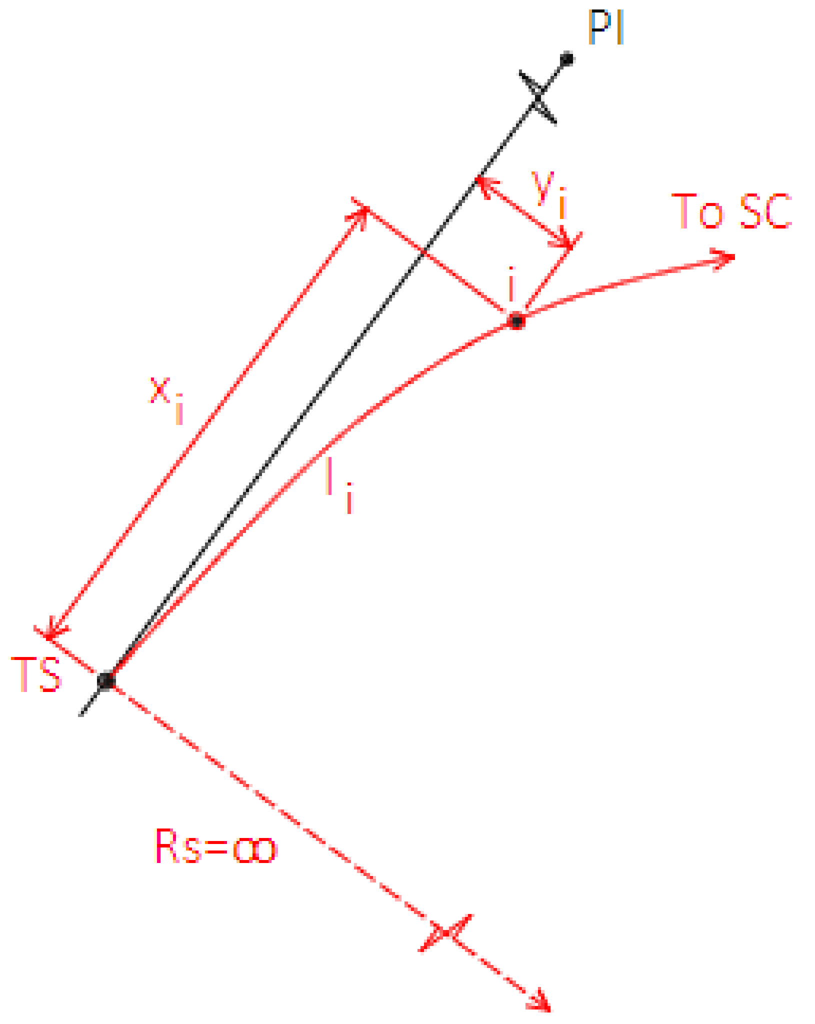
$$R_i = R_c \left[\frac{L_s}{l_i} \right]$$ Spiral radius

$$\delta_i = \frac{l_i^2}{2R_c L_s}$$ Spiral angle, radians

$$\delta_i = \left[\frac{l_i}{L_s} \right]^2 \Delta_s$$ Spiral angle, degrees

$$a_i = \left[\frac{l_i}{L_s} \right]^2 \left[\frac{\Delta_s}{3} \right]$$ Deflection angle, degrees

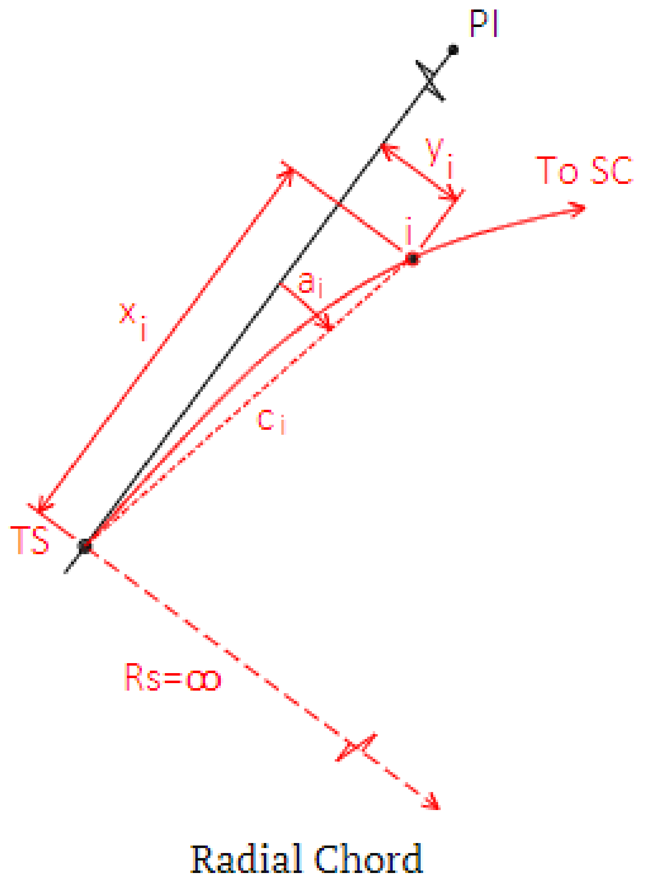
Horizontal Alignment – Spiral Curve



$$y_i = \frac{l_i^3}{6R_cL_s}$$

$$x_i = l_i - \frac{y_i^2}{2l_i}$$

Horizontal Alignment – Spiral Curve



$$c_i = \sqrt{x_i^2 + y_i^2}$$

Staking of Horizontal Curves

Example - Staking of Spiral Curves

A roadway goes from tangent alignment to a 250-m circular curve by means of a 80-m-long spiral transition curve. The deflection angle between the tangents is 45°.

a) Assume that the station of the P.I., measured along the back tangent, is 250+00, and compute the stations of the TS, SC, CS, and ST.

b) Prepare a table giving coordinates, spiral angles, deflection angles and chords (from the TS) for full stations and +20 points

Staking of Spiral Curves

Given Data:

$R_c = 250\ m$
$L_s = 80\ m$
$= 80\ m$
$\Delta = 45°$
$PI = 250 + 00\ m$

$$Calculate\ T\ (m) = R tan\left(\frac{\Delta}{2}\right) + \frac{L_s}{2} = 250 * tan\left(\frac{45}{2}\right) + \frac{80}{2} = 143.6\ m$$

$$TS = PI - T_s = (250 + 00) - (1 + 44) = \mathbf{248} + \mathbf{56}$$

$$SC = TS + L_s = (248 + 56) + (0 + 80) = \mathbf{249} + \mathbf{36}$$

Staking of Spiral Curves

$$Calculate\ L_c(m) = R * \Delta_c \frac{\pi}{180}$$

$$\Delta = \Delta_c + 2 * \theta_s$$

$$\theta_s = \frac{L_s}{2R} * \frac{180}{\pi} == \frac{80}{2*250} * \frac{180}{\pi} = 9.12^o$$

$$\Delta_c = 45 - 18.33 = 26.67^o$$

$$L_c(m) = 250 * 26.67 * \frac{\pi}{180} = 116.35\ \text{m}$$

$$CS = SC + L_c = (249 + 36) - (1 + 16) = \mathbf{250 + 52}$$

$$ST = CS + L_s = (250 + 52) + (0 + 80) = \mathbf{251 + 32}$$

Station	Spiral Arc Length L_i, m	Spiral Radius, R_i	Spiral Angle at Centre		Spiral Deflection Angle	Yi	Yi^2	Xi	Xi^2	Chord, m
			Radians	Degrees	Degrees					
248 +56	0	Infinite	0	0.0	0.00	0.00	0.00		0.00	0.000
248+ 60	4	5000.00	0.0004	0.0	0.01	0.00	0.00	4.00	16.00	4.000
248 + 80	24	833.33	0.0144	0.8	0.27	0.12	0.01	24.00	575.99	24.000
249 + 00	44	454.55	0.0484	2.8	0.92	0.71	0.50	43.99	1935.50	44.000
249 + 20	64	312.50	0.1024	5.9	1.95	2.18	4.77	63.96	4091.23	64.000
249 + 36	80	250.00	0.16	9.2	3.04	4.27	18.20	79.89	6381.81	80.000

Superelevation Runoff

- Highway cross section on straight segments is "normal crown"
- On curved segments, it is "superelevated"
- To change a normal crown section into a superelevated section, a superelevation runoff length is required
- Superelevation runoff length equals the length of the spiral curve
- If no spiral curve is used:
  - Superelevation runoff length is based on the criterion of maximum relative slope between outer pavement edge and centerline

- $L_r = \frac{(w\, n_1) e_d}{\Delta} (b_w)$
  - » L_r = *minimum length of superelevation runoff*
  - » Δ = *maximum relative slope*
  - » n_1 = *number of lanes rotated = one half of all lanes for rotation around centerline*
  - » b_w = *adjustment factor for number of lanes rotated*
  - » w = *width of one traffic lane*
  - » e_d = *design superelevation rate*

- Superelevation runoff length is distributed on the tangent and curve
- Distance on the tangent ranges from 60 to 80%

Superelevation Runoff

- The distance needed to change the outside-lane cross slope from normal to zero, or vice versa, is called tangent runout

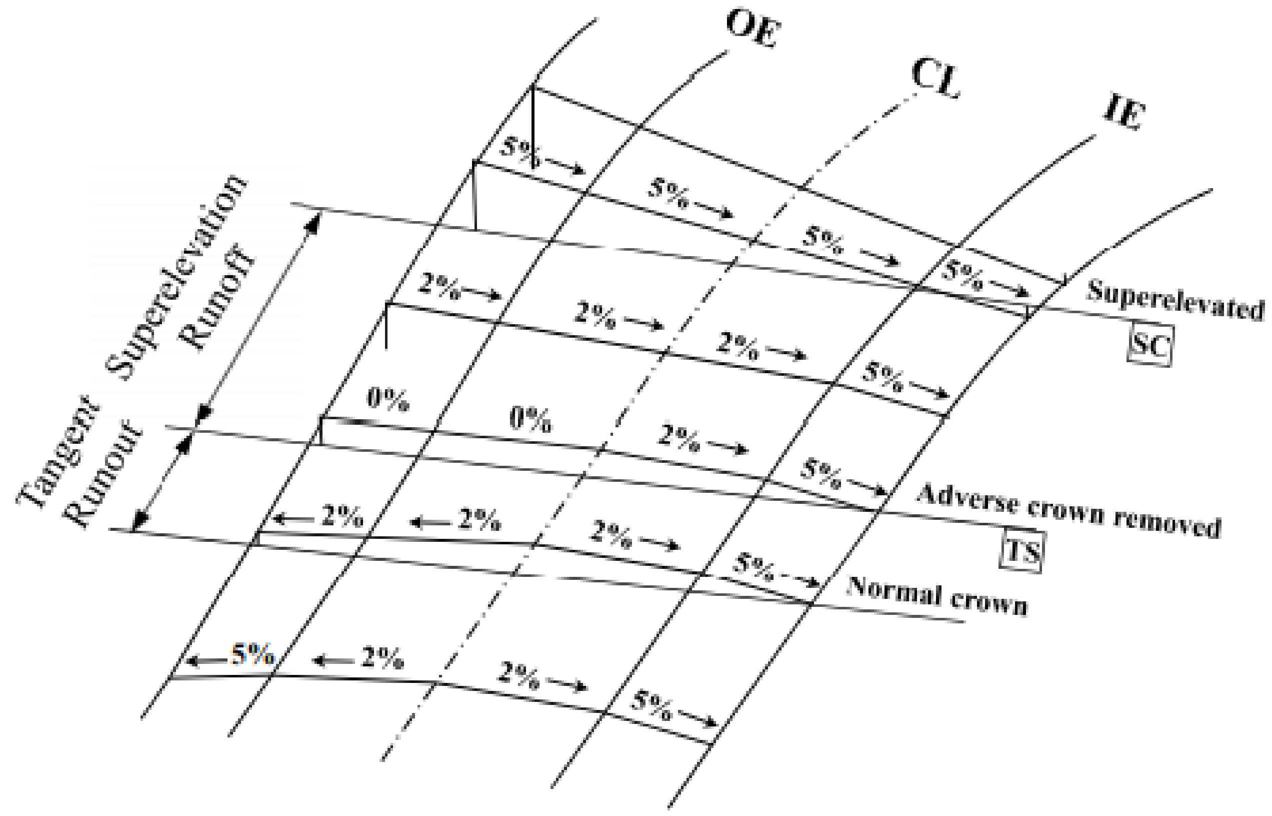
– $L_t = \frac{e_{NC}}{e_d} L_r$
  - L_t = minimum length of tangent runout
  - e_{NC} = normal cross slope rate
  - e_d = design superelevation rate
  - L_r = minimum length of superelevation runoff

– L_t can also be estimated using the relative slope between the outer pavement edge and centerline

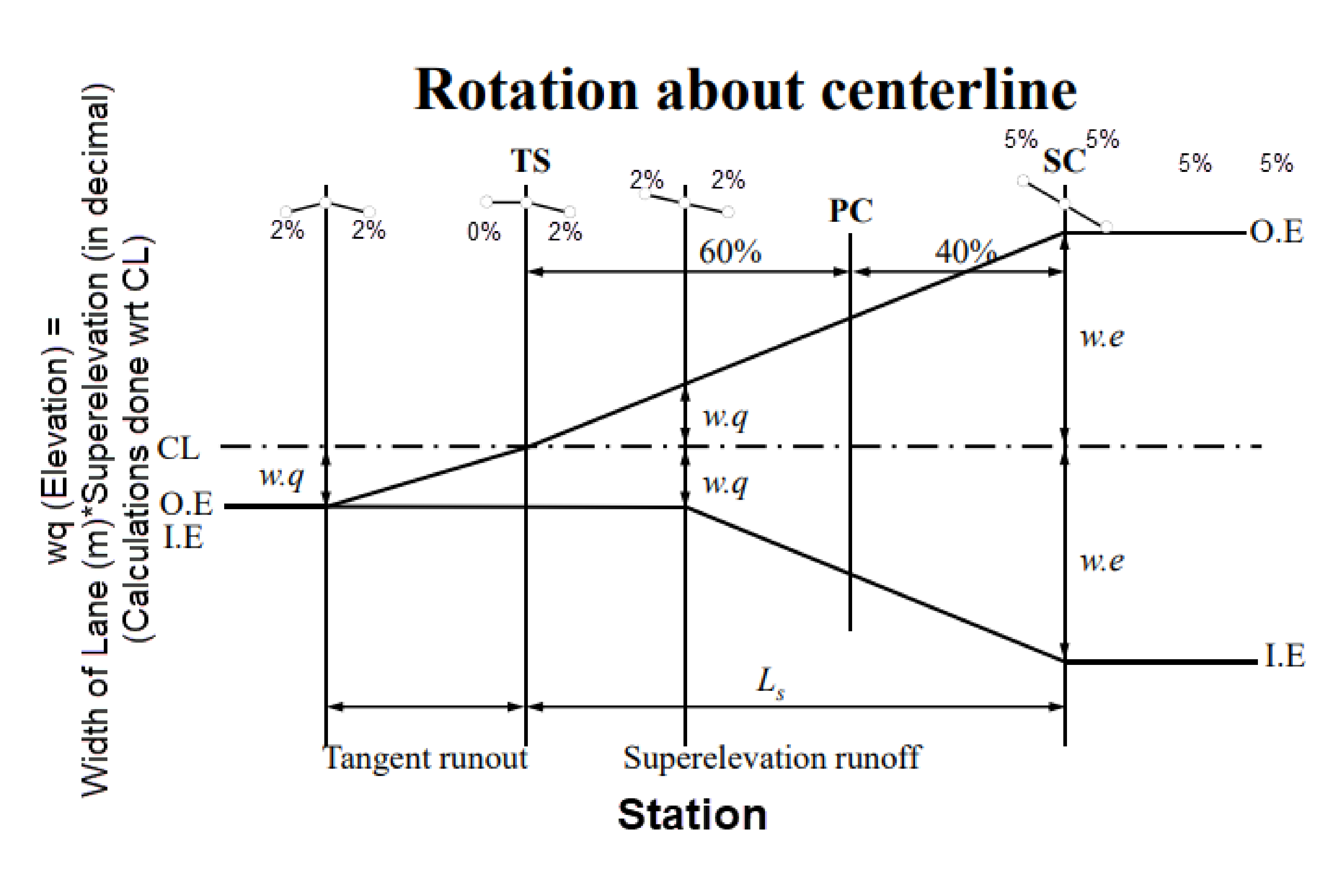
- Superelevation can be attained by revolving section about:
  - Centerline
  - Inside edge
  - Outside edge

Superelevation Runoff

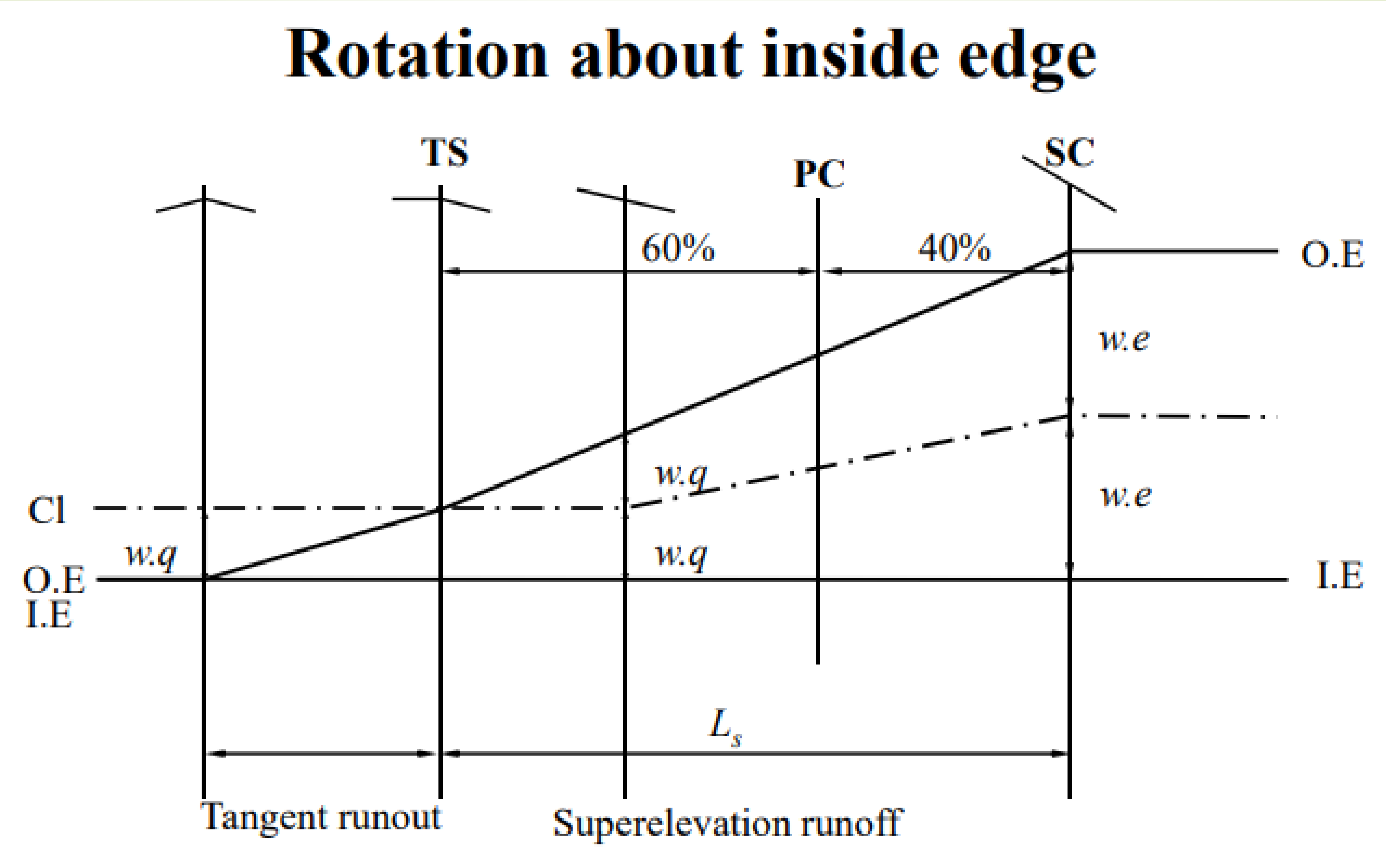
Rotation about centerline



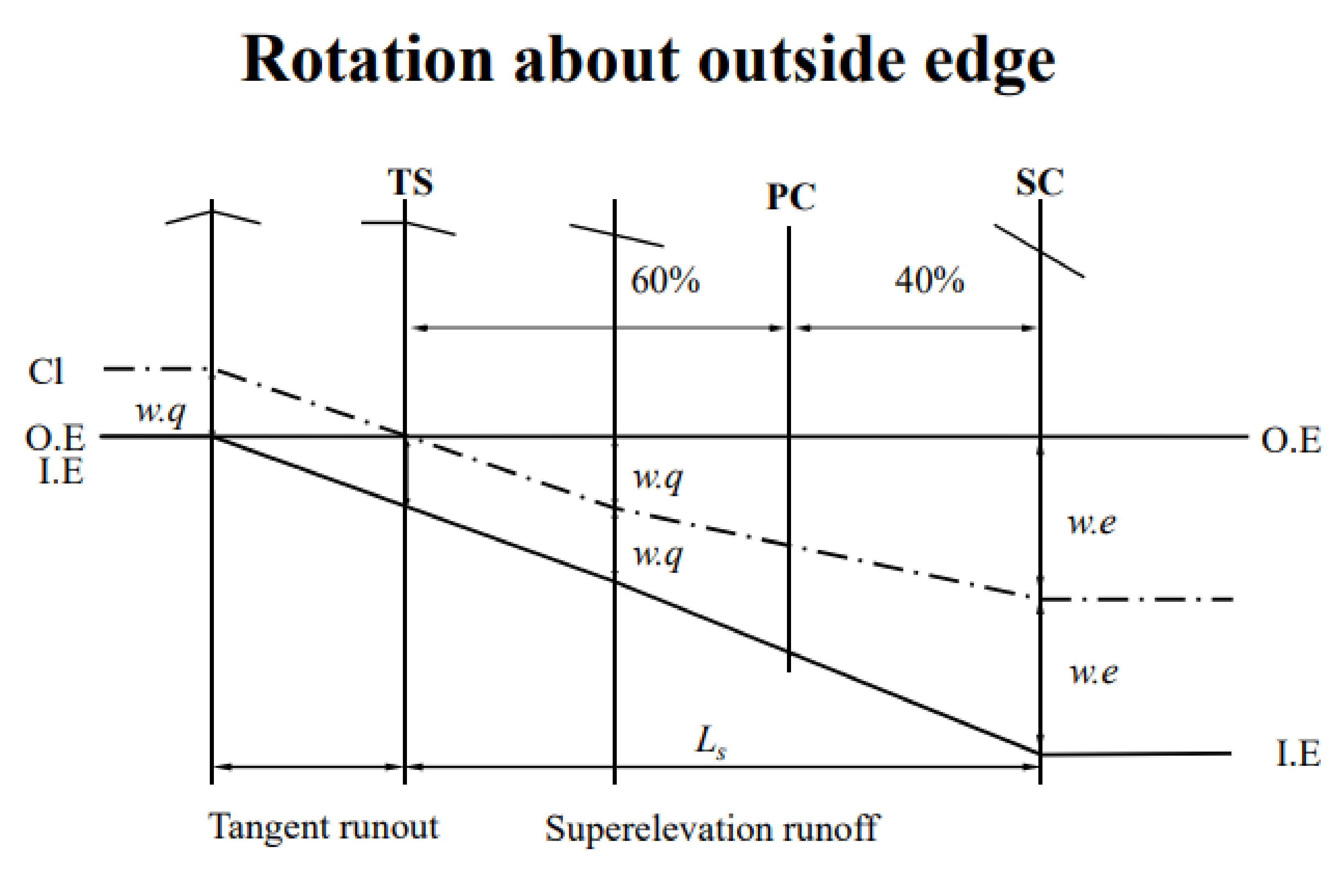
Superelevation Runoff



Superelevation Runoff



Superelevation Runoff



R (m)	V_d=30km/h e (%)	L(m)	V_d=40 km/h e (%)	L (m)	V_d=50 km/h e (%)	L (m)	V_d=60 km/h e (%)	L(m)	V_d=70 km/h e (%)	L(m)	V_d=85 km/h e (%)	L(m)	V_d=100 km/h e (%)	L(m)	V_d= 120 km/h e (%)	L(m)
7000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
5000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0
3000	NC	0	NC	0	NC	0	NC	0	NC	0	NC	0	RC	56	2.4	101
2500	NC	0	NC	0	NC	0	NC	0	NC	0	RC	47	2.1	56	2.9	101
2000	NC	0	NC	0	NC	0	NC	0	NC	0	2.2	47	2.6	56	3.5	101
1500	NC	0	NC	0	NC	0	NC	0	RC	39	2.5	47	3.4	56	4.6	101
1400	NC	0	NC	0	NC	0	RC	33	2.1	39	2.6	47	3.6	56	4.9	101
1300	NC	0	NC	0	NC	0	RC	33	2.2	39	2.8	47	3.8	56	5.2	101
1200	NC	0	NC	0	NC	0	RC	33	2.4	39	3.0	47	4.1	56	5.6	101
1000	NC	0	NC	0	RC	28	2.2	33	2.8	39	3.5	47	4.8	56	6.5	101
900	NC	0	NC	0	RC	28	2.4	33	3.1	39	4.2	47	5.2	56	7.1	101
800	NC	0	NC	0	RC	28	2.7	33	3.4	39	4.6	47	5.7	56	7.6	103
700	NC	0	RC	22	2.2	28	3.0	33	3.8	39	5.1	47	6.3	56	8.0	108
600	NC	0	RC	22	2.6	28	3.4	33	4.3	39	6.5	47	6.9	56	R_{min} = 665	
500	NC	0	2.2	22	3.0	28	3.9	33	4.9	39	7.2	47	7.8	56		
400	RC	17	2.7	22	3.6	28	4.7	33	5.7	39	7.8	51	8.0	64		
300	2.1	17	3.4	22	4.5	28	5.6	34	6.7	44	8.0	55	R_{min} = 395			
250	2.5	17	4.0	22	5.1	28	6.2	37	7.3	48	R_{min} = 270					
200	3.0	17	4.6	24	5.8	31	7.0	42	7.9	52						
175	3.4	17	5.0	26	6.2	33	7.4	44	8.0	52						
150	3.8	18	5.4	28	6.7	36	7.8	47	R_{min} = 175							
140	4.0	19	5.6	29	6.9	37	7.9	47								
130	4.2	20	5.8	30	7.1	38	8.0	48								
120	4.4	21	6.0	31	7.3	39	R_{min} = 125									
110	4.7	23	6.3	32	7.6	41										
100	4.9	23	6.5	33	7.8	42										
90	5.2	25	6.9	36	7.9	43										
80	5.5	26	7.2	37	8.0	43										
70	5.9	28	7.5	39	R_{min} = 80											
60	6.4	31	7.8	40												
50	6.9	33	8.0	41												
40	7.5	36	R_{min} = 50													
30	8.0	38														
	R_{min}=30															

e_{max}	= 8.0%
R	= radius of curve
V	= assumed design speed
e	= rate of superelevation
L	= minimum length of runoff(does not include tangent runout)
NC	= normal crown section
RC	= remove adverse crown, superelevation at normal crown slope

Note : Lengths rounded in multiples of 10m to permit simpler calculations

Computers in Geometric Design

Example – Superelevation Runoff

A horizontal curve with spiral is designed for a two-lane road in mountainous terrain. The following data are known:

- Design speed = 100 km/h
- Deflection angle = 32 degrees
- Station of PI: 16+192.50
- Superelevation rate, $e = 0.06$
- Lane width = 3.65 m
- Normal cross slope, $q = 0.02$
- Slope of the O.E. @ tangent runout = 1:400

Note:

Take 100 km/h ≅ 65 mph, and $f_s = 0.12$:

Required:

- Determine the length of spiral curve and stations of TS, SC, CS, and ST.
- Draw a neat sketch for the development of superelevation if the cross-section is rotated about the centreline.
- Draw neat sketches for the highway's cross-section at stations: (15+900), (16+017), (16+080), and (16+115)

$$R = \frac{V^2}{127(f_s + e)} = \frac{100^2}{127(0.12 + 0.06)} \cong 437.50 \text{ m}$$

$$A \cong 190 \text{ m}$$

$\therefore L_S = A^2/R = (190)^2/437.50 \cong 82.50$ m

$$T_S \cong R \tan\frac{\Delta}{2} + \frac{L_s}{2} = 166.70 \text{ m}$$

$$\theta_S \cong \frac{L_s}{2R} \times \frac{180}{\pi} = 5.40°$$

$$\Delta_C = \Delta - 2\,\theta_S = 21.20°$$

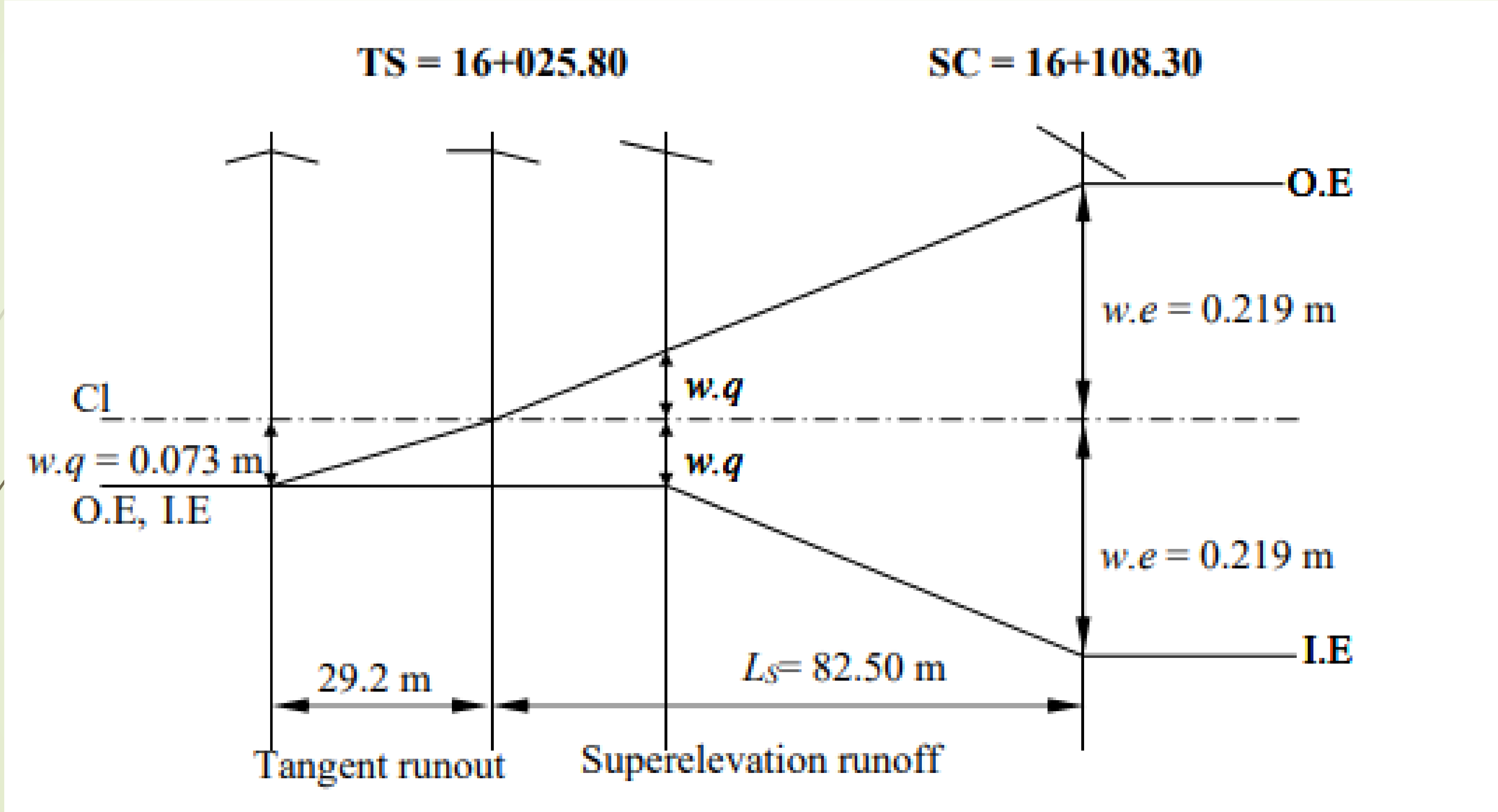
$$L_C = R\,\Delta_C \times \frac{\pi}{180} = 161.88 \text{ m}$$

Sta (TS) = Sta (PI) – T_S = 16+192.50 – 166.70 = 16+025.80 m
Sta (SC) = Sta (TS) + L_S = 16+025.80 + 82.50 = 16+108.30 m
Sta (CS) = Sta (SC) + L_C = 16+108.30 + 161.88 =16+270.18 m
Sta (ST) = Sta (CS) + L_S = 16+270.18 + 82.50 =16+352.68 m

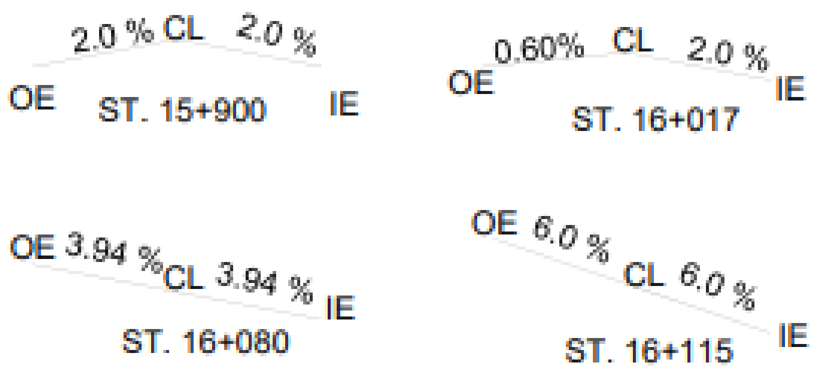
Lane width = 3.65 m; normal cross slop (q) = 2%; and supeerelevation = 6% (given)
$\therefore$ $w.q$ = 3.65 * 0.02 = 0.073 m; $w.e$ = 3.65 * 0.06 = 0.219 m

Slope of the O.E. @ tangent runout = 1: 400
$\therefore$ Tangent runout = 400 * 0.073 = 29.2 m

Superelevation development by rotation around centerline:


TS = 16+025.80
SC = 16+108.30
O.E
w.e = 0.219 m
w.q
Cl
w.q = 0.073 m
w.q
O.E, I.E
w.e = 0.219 m
I.E
29.2 m
Ls= 82.50 m
Tangent runout
Superelevation runoff

Cross-Sections Calculations:



- ST. (15+900): on tangent before beginning of tangent runout
  Right lane slope = 2%
  Left lane slope = 2%
- ST. (16+017): on tangent runout
  Right lane slope = 2%
  Left lane slope = [(16025.8-16017)/29.2]*2% = 0.60%
- ST. (16+080): on spiral
  Right lane slope = [(16080-16025.8)/82.5]*6% = 3.94% [min slope for right lane is 2%]
  Left lane slope = 3.94%
- ST. (16+115): on curve
  Left and right lane slope = 6.0 %

Design Consistency

- High collision occurrence has been experienced on sections that lack geometric design consistency
- Design consistency may be defined as the degree to which highway systems are designed and constructed to avoid critical driving manoeuvres that can lead to collision risk
- It refers to the ability of the highway geometry to conform to driver expectancy
- A consistent highway design is one that ensures that successive geometric elements are coordinated in a manner to produce harmonious driver performance without surprising events
- Evaluating design consistency and identifying any inconsistencies during the design stage of newly designed highways can significantly improve the safety of the highway network

Design Consistency

- Current geometric design guides in North America are based on the design speed concept
- All design elements are selected based on a pre-set arbitrary value of design speed
- The design elements determined in this case are considered minimum values
- Designers are encouraged to adopt higher values
- This may lead to alignments with abrupt changes or considerable differences between successive elements
- Drivers are assumed to adhere to a maximum posted speed that is less than the design speed
- Field observations have shown that drivers adopt an operating speed that is dependent on the road features rather than the posted speed
- An alternative design approach is directed at ensuring design consistency between geometric elements
- Based on the predicted operating speed and has been adopted in a number of European countries
- The German design guidelines specify that the expected operating speed, determined as the 85th percentile speed, should not exceed the design speed by more than 20 km/h (iterative process)

Design Consistency

Design Consistency in TAC (2017)

❖ From 1999, the TAC guide has included a discussion on design consistency that suggests three principles for evaluating consistency of a road design

I. **Cross section consistency**

– Cross section dimensions, such as lane and shoulder widths and clear zone configurations, and other features, such as marker posts or roadside barriers, should be consistently applied on a specific road

II. Operating speed consistency

– It is suggested to enhance the safety of a road by producing a design which encourages operating speed uniformity and avoiding speed variations

III. Driver workload consistency

– If the workload a driver experiences drops too low or rises too high, collision rate can increase

Horizontal Alignment – Spiral Curve

Design Consistency Safety Criteria in TAC (2017)

- The expected difference between estimated 85th percentile speeds along the highway and the design speeds of the highway:

Rating	Criterion
Good	$\lvert V_{85} - V_d \rvert \leq 10$km/h
Fair	10 km/h < $\lvert V_{85} - V_d \rvert \leq 20$ km/h
Poor	$\lvert V_{85} - V_d \rvert > 20$km/h

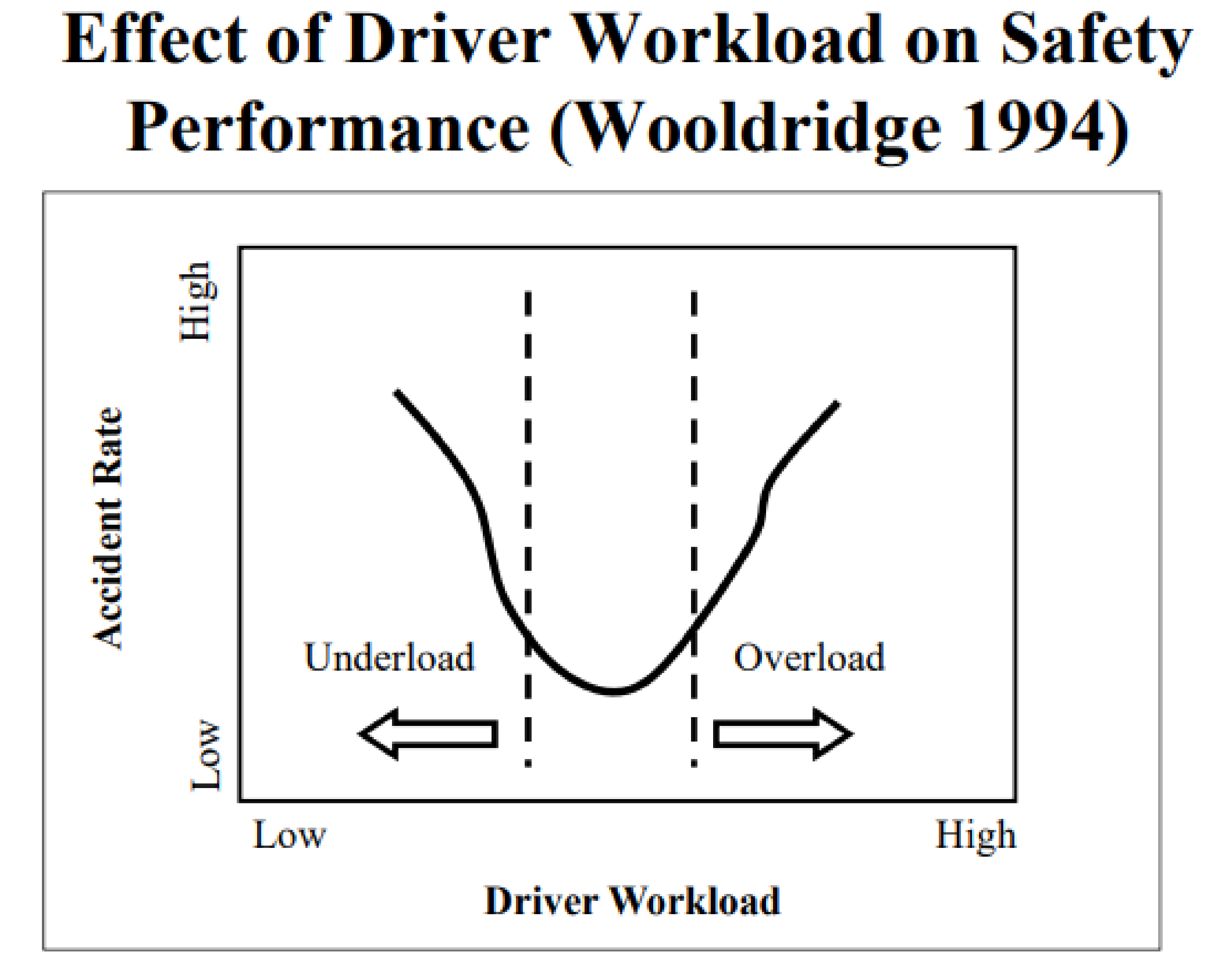
Where V_d = design speed, V_{85} = 85th percentile speed

- The expected reduction in estimated 85th percentile speeds between successive alignments elements (e.g. from an approach tangent to its succeeding horizontal curve):

Rating	Criterion
Good	$\lvert V_{85i} - V_{85i+1} \rvert \leq 10$km/h
Fair	10 km/h < $\lvert V_{85i} - V_{85i+1} \rvert \leq 20$ km/h
Poor	$\lvert V_{85i} - V_{85i+1} \rvert > 20$km/h

Where V85i = 85th percentile speed of element i, V_{85i+1} = 85th percentile speed of element i+1

Horizontal Alignment – Spiral Curve



Special Facilities for HGV

I. **Climbing Lanes**

–Extra lane in the upgrade direction for use by heavy vehicles whose speeds are significantly reduced by the grade.

–Eliminates the need for drivers of light vehicles to reduce their speed when they encounter a heavy slow-moving vehicle

II. Emergency Escape Ramps

– Provided on the downgrade of a highway for use by a truck that has lost control and cannot slow down.

–When a vehicle enters the escape ramp, its speed is gradually reduced, and eventually it stops

Bicycle Facilities

- The bicycle, a viable alternative mode of transportation, is popular, particularly in urban and suburban areas as a means to travel within the community both for recreation and necessary travel.

- Thus, the bicycle is an important element in the design of highways

- Two types of bicycle facilities can be considered:

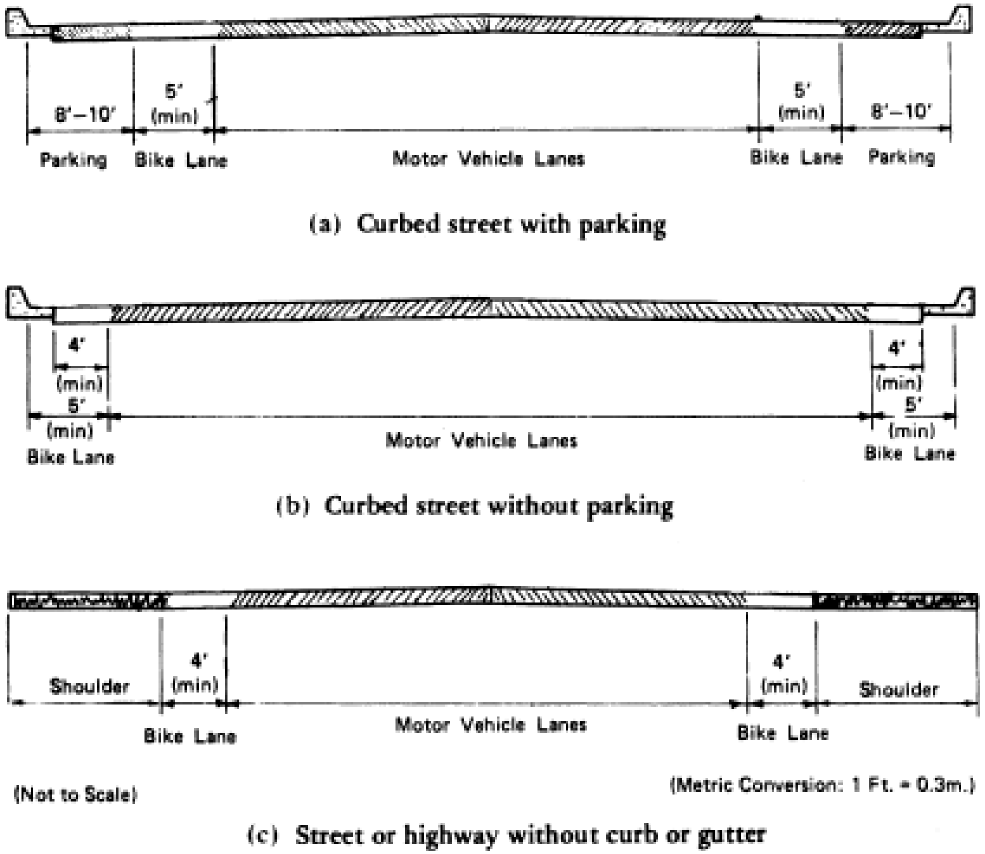
1. lanes that are contiguous with the existing street and highway system; and
2. Paths that are constructed on a dedicated right-of-way for the exclusive use of bicycles.
   - –Minimum Reccommended Design Speed is 30 km/h (20 km/h for unpaved roads)
   - –Grades should not be more than 5%

- A **bicycle lane** is that part of the street or highway specifically reserved for the exclusive or preferential use of bicycle riders.

- Bicycle lanes can be delineated by striping, signing, or pavement markings.

- These lanes should always be in the direction of traffic flow

Bicycle Facilities



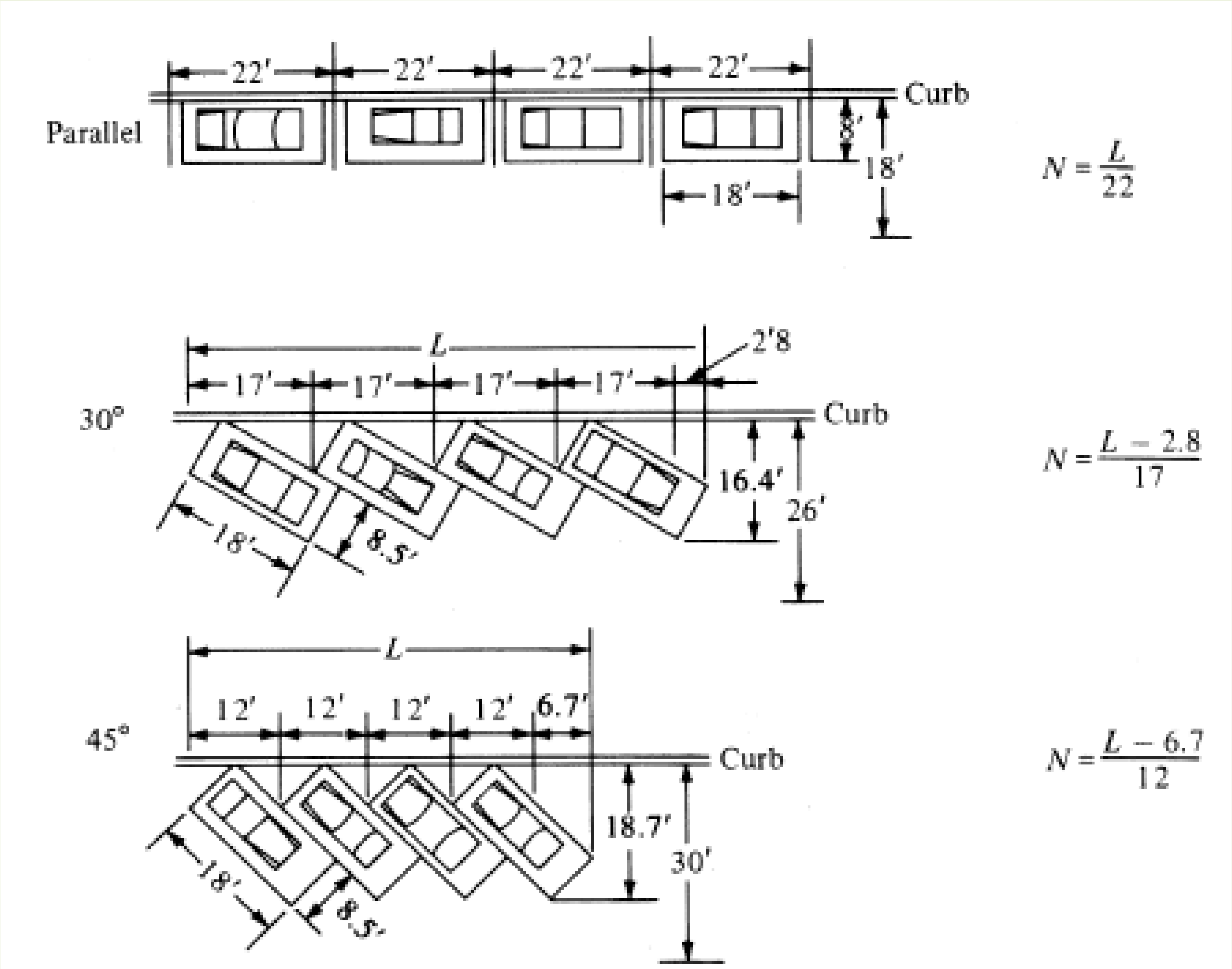
Typical Bicycle Lane Cross Sections

SOURCE: *Guide for Development of Bicycle Facilities*, American Association of State Highway and Transportation Officials, Washington, D.C., 1999. Used with permission.

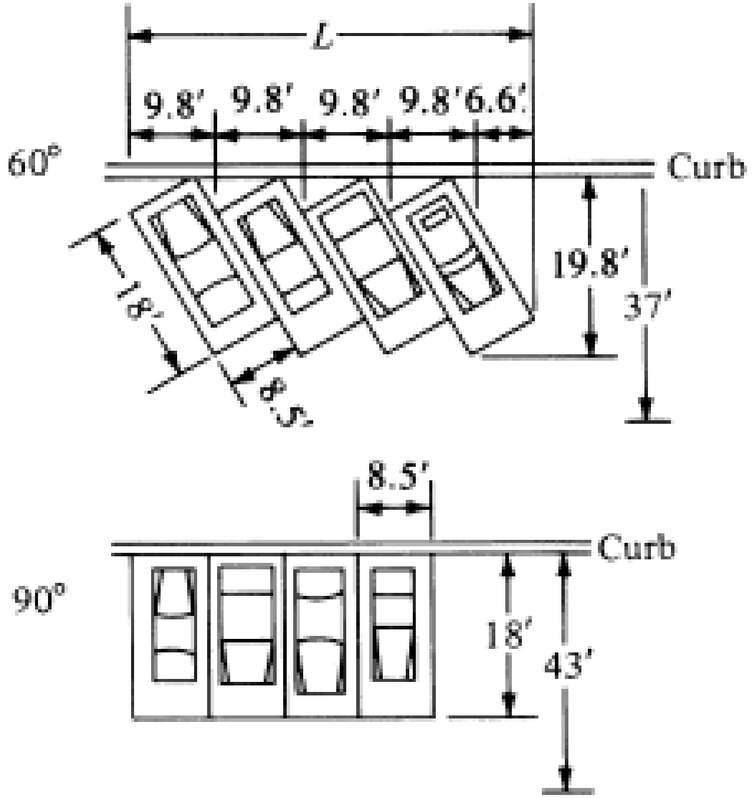
Parking Facilities

- The geometric design of parking facilities involves the dimensioning and arranging of parking bays to provide safe and easy access without restricting the flow of traffic on the adjacent traveling lanes.
- On-street parking facilities may be designed with parking bays parallel or inclined to the curb
- More parking bays as the angle of inclination increases from parallel (0 degrees) to perpendicular (90 degrees.)
- Higher inclination angle results in encroachment and higher crash rates
- For trucks and other types of vehicles, Use dimensions of the design vehicle.
- The primary aim in designing off-street parking facilities is to obtain as many spaces as possible within the area provided

Parking Facilities



Parking Facilities



$$N = \frac{L - 6.6}{9.8}$$

$$N = \frac{L}{8.5}$$

N = number of spaces
L = curb length

Street Space Used for Various Parking Configurations

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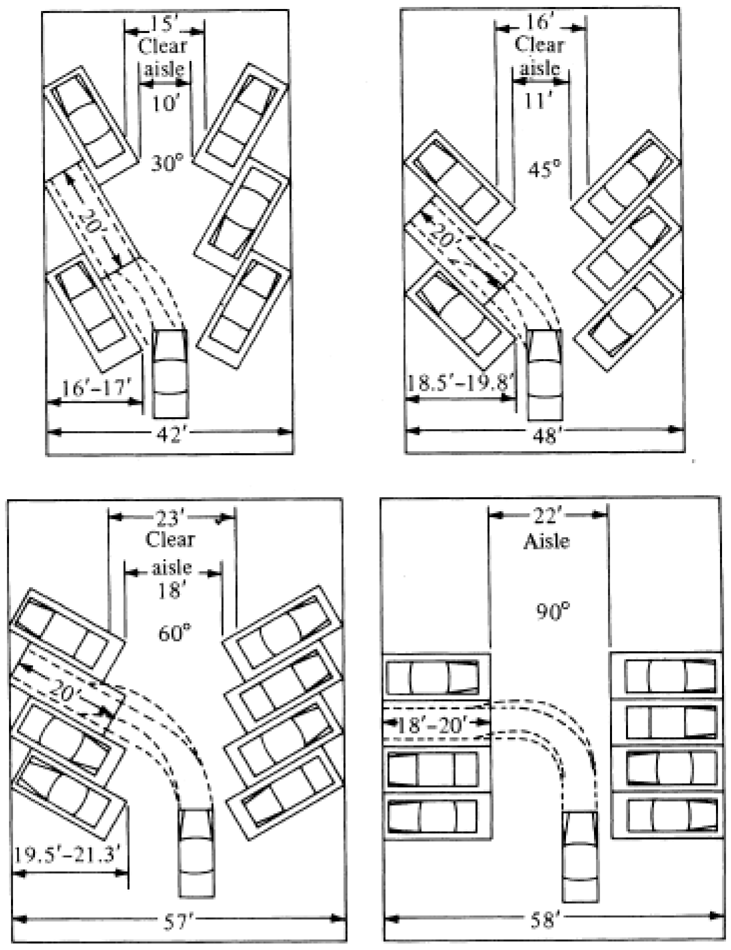
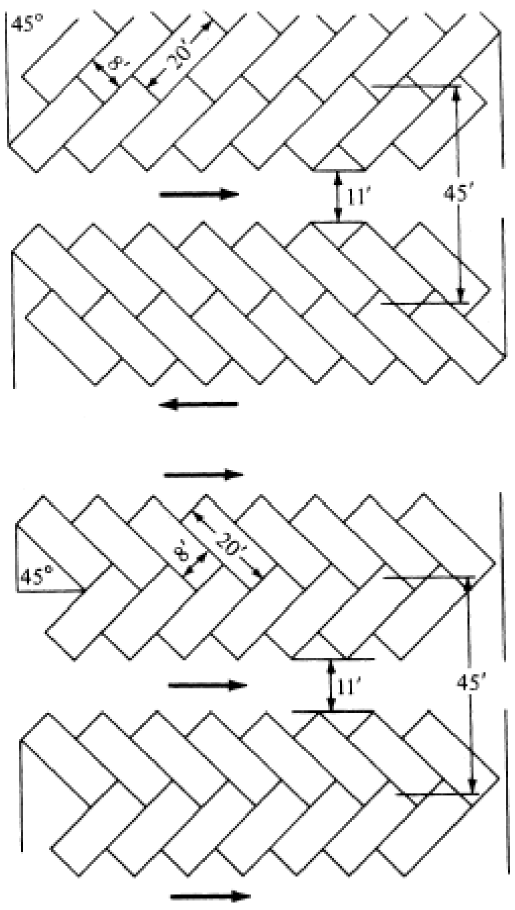
Parking Facilities



Parking Stall Layout

Parking Facilities



Herringbone Layout of Parking Stalls in an On-Surface Lot

Computers in Geometric Design

- Computer programs are available to carry out all the designs discussed in this chapter.
- The types and availability is constantly changing.
- Most highway agencies have developed programs suitable for their individual hardware systems which may not easily be used by another agency if they are non-compatible
- The intention of this section is to let the reader know of the opportunities available in computer-aided design in highway engineering, **rather than simply enumerating an array of different computer programs.**
- Many programs currently in use may become outdated as new programs become available, so the reader is advised to stay current about changes in computer hardware and applications software.

Assignment

1. Identify Critical Design Parameters in Highway Geometric Design and Compare the Minimum Recommended Values that are found in AASHTO, SATCC, and RDA Geometric Design Standards

2. Identify two computer programs that are commonly used in your country, provide a methodology on how they are used, and finally use the given raw data to carry out the geometric design in these computer programs

Thank You!!!