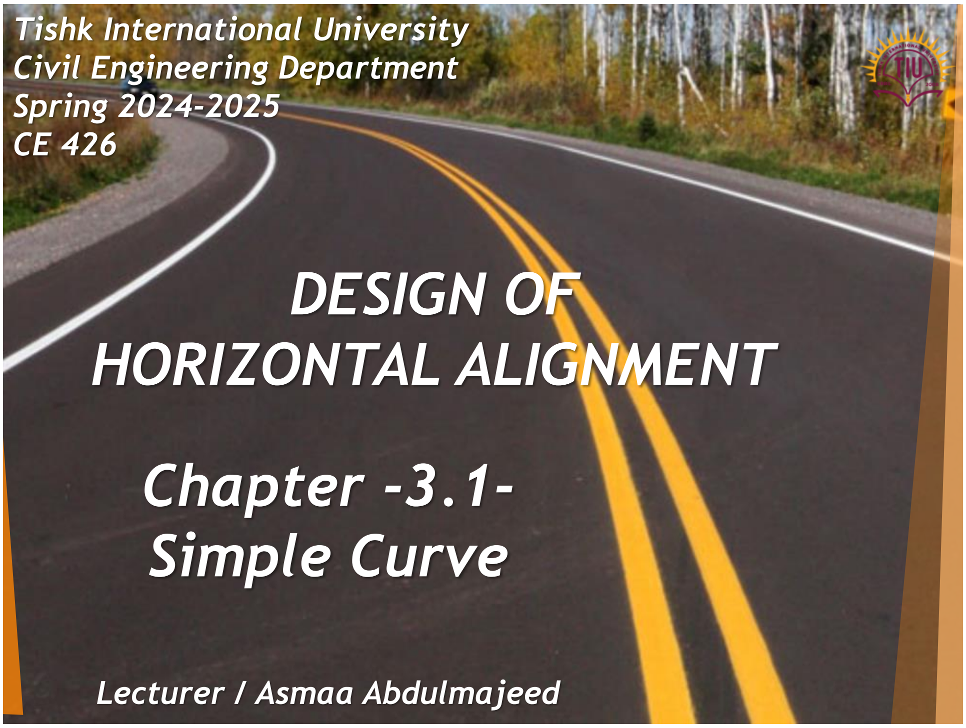
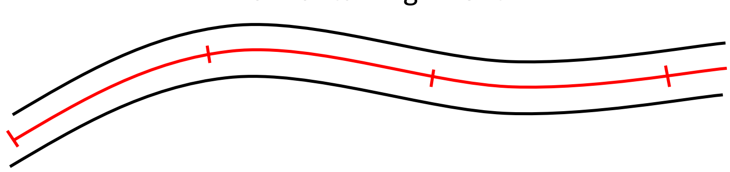


1

Horizontal Alignment

- Horizontal alignment refers to the layout of a roadway in a horizontal plane, determining the direction and curvature of the road as viewed from above.
- It consists of straight sections (tangents) and curved sections that provide smooth transitions for vehicles. The design of horizontal alignment directly impacts the safety, comfort, and efficiency of the roadway.

Horizontal Alignment



2

Horizontal Alignment

- Geometric Elements of Horizontal Curves
- Transition or Spiral Curves
- Superelevation Design
- Sight Distance

3

- The design of the horizontal alignment entails the determination of the minimum radius, determination of the length of the curve, and the computation of the horizontal offsets from the tangents to the curve to facilitate locating the curve in the field.
- 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.*

4

Definitions

Horizontal Curves: Curves used in horizontal planes to connect two ***straight tangent sections***.

1. Simple Curve:

- Circular arc connecting ***two tangents***. The most common.

2. Compound Curve:

- A curve which is composed of ***two or more circular arcs*** of ***different radii*** tangent to each other, ***with centers on the same side of the alignment***. (A series of two or more curves with different radii in the same direction).
- Compound highway curves should also be used with caution, and when conditions make their use necessary, the radius of the flatter curve should not exceed 1.5 times the radius of the sharper curve (Iraqi Building Code).

3. Spiral Curve: A curve whose radius decreases uniformly from infinity at the tangent to that of the curve it meets.

4. Broken-Back Curve:

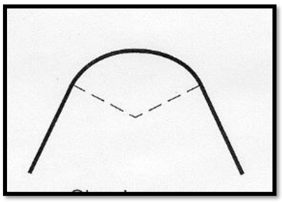
- *The combination of short length of tangent* (less than 100 ft) connecting *two circular arcs* that have centers on the same side.
- The arrangement should be avoided in horizontal alignment of highway except for very unusual topographical or ROW conditions (Iraqi Building Code).

5. Reverse Curve:

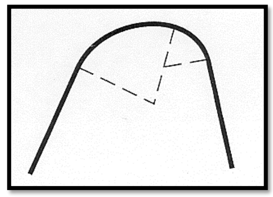
- Two circular arcs tangent to each other, with their centers on opposite sides of the alignment.
- Reverse curves would be used only for low-speed roads, such as those in mountainous terrain (Iraqi Building Code).

Types of Circular Curves

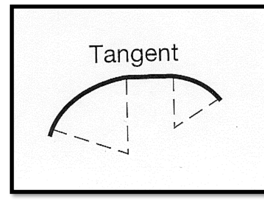
Simple Curve



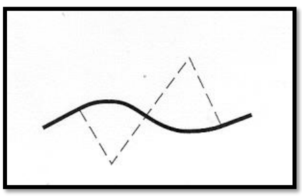
Compound Curves



Broken-Back Curves



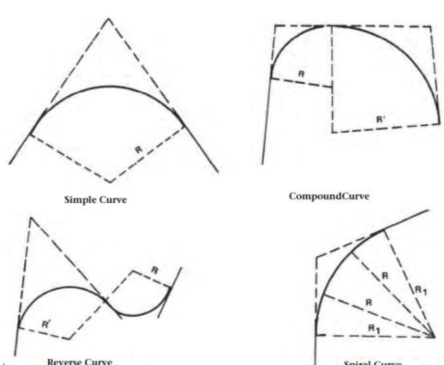
Reverse Curves

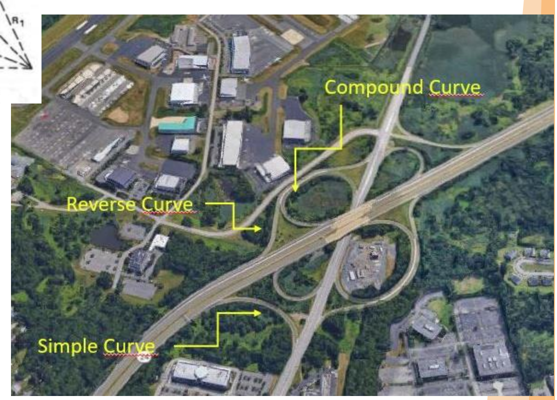


Broken-Back Curves should be avoided if possible. It is better to replace the Curves with a larger radius circular curve.

A tangent should be placed between reverse Curves.

7





8

Easement Curves: curves used to lessen the effect of the sudden change in curvature at the junction of either a tangent and a curve, or of two curves.

Super elevation: a difference of elevation between the edges of the cross section, to overcome the effect of centrifugal force. Changes gradually in a spiral curve, inversely proportion to the radius.

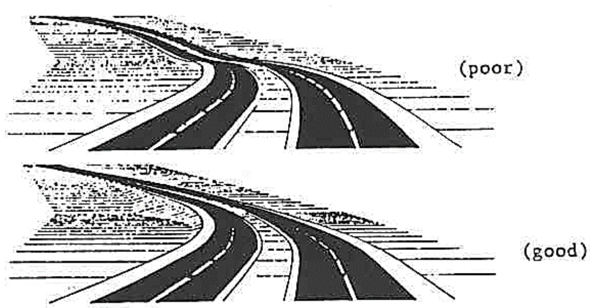
When to Use What

Simple circular curves are the most common type.

Spirals are used at highway exits, sometimes, and all the times in railroad curves.

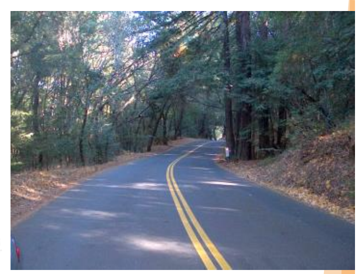
The rest of curves are used when the designer has to.

9

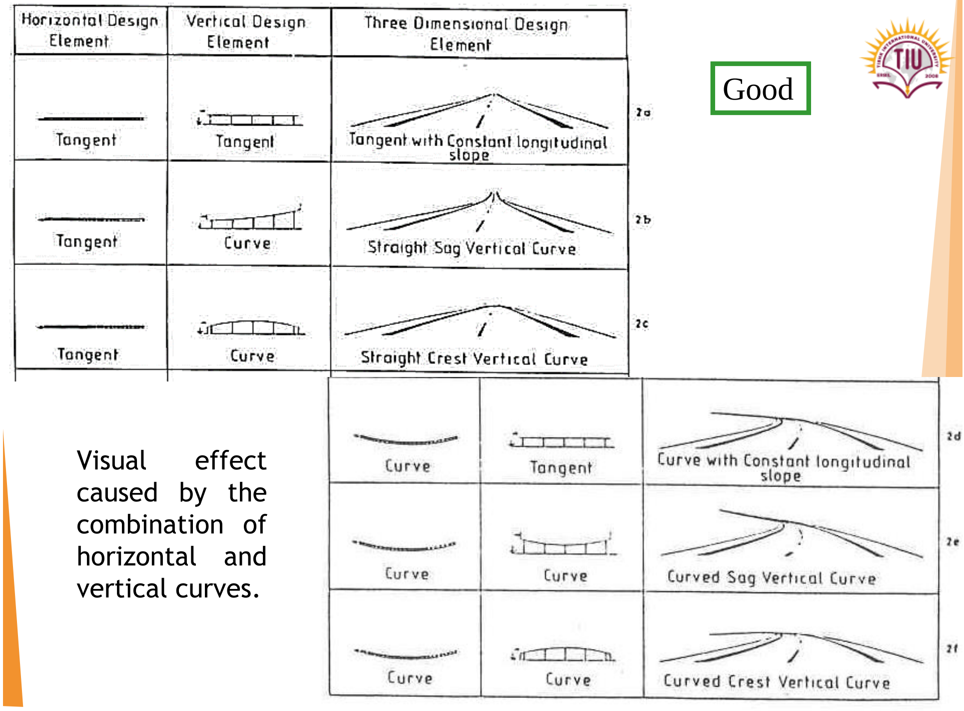


(Above) Short Sag on Long Horizontal Curve
(Below) Long Sag on Long Horizontal Curve

Broken-Back Vertical Curve



10

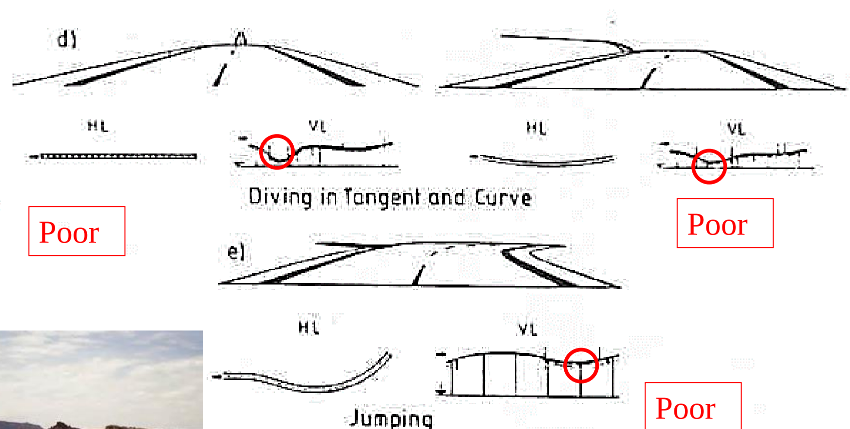


Good

Visual effect caused by the combination of horizontal and vertical curves.

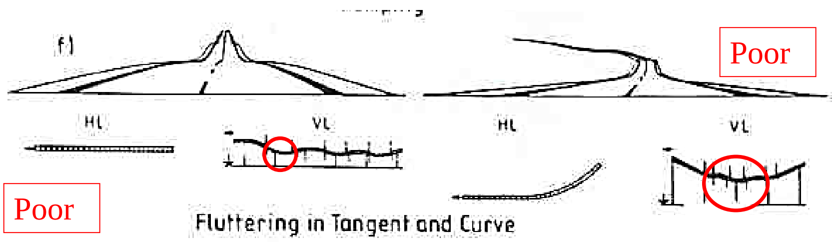
11

Visual effect caused by the combination of horizontal and vertical curves

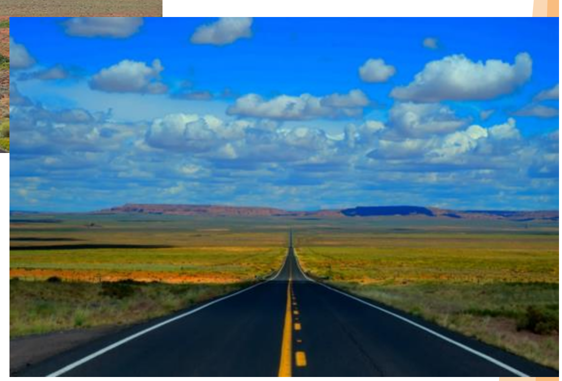


12

Visual effect caused by the combination of horizontal and vertical curves.



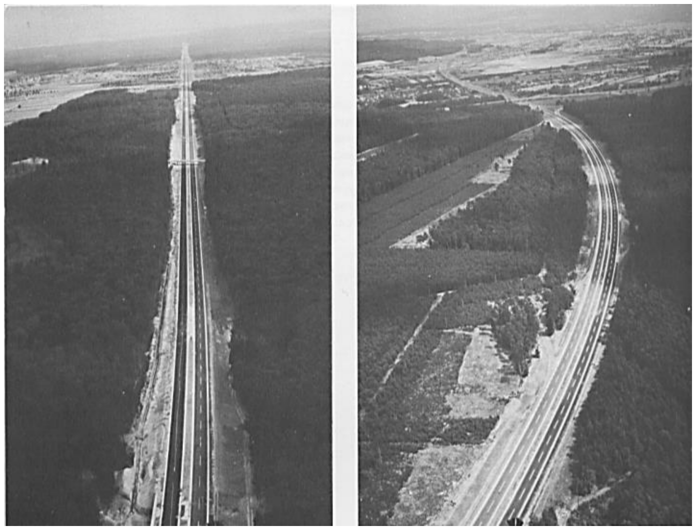
13



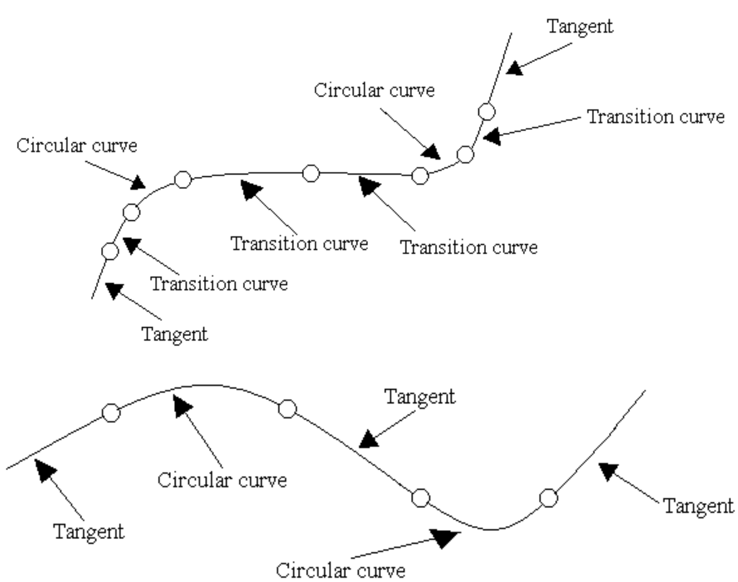
The alignment should be designed to enhance attractive scenic views of the natural and manmade environment.

14

Horizontal Alignment



Tangents Curves



Horizontal alignments with and without transition curves.

Simple Curve (Circular Curve)

Simple Curve (Circular Curve)

Figure 15.18 is a layout of a simple horizontal curve. The curve is a segment of a circle with radius *R*, The relationship is shown to be;

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

Where R= —

R = Minimum curve radius (m or ft)

u = Design speed (m/s or ft/s)

g = Acceleration due to gravity (9.81 m/s^2 or 32.2 ft/s^2)

e = superelevation

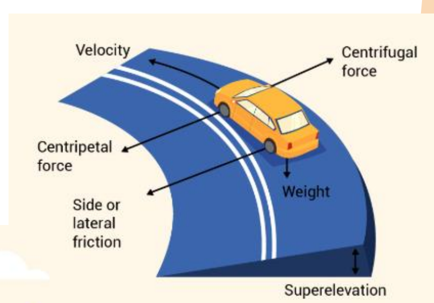
fs = side friction factor

- Design based on appropriate relationship between design speed and curvature and their relationship with side friction and superelevation.
  - R_{min} related to max. f and max. e allowed
  - f decreases as speed increases (less tire/pavement contact)
- Along circular path, vehicle undergoes centripetal acceleration toward center of curvature (lateral acceleration).
- Balanced by superelevation and weight of vehicle (friction between tire and roadway).
- Reason for super: banking of curve, retard sliding, allow more uniform speed, also allow use of smaller radii curves (less land).

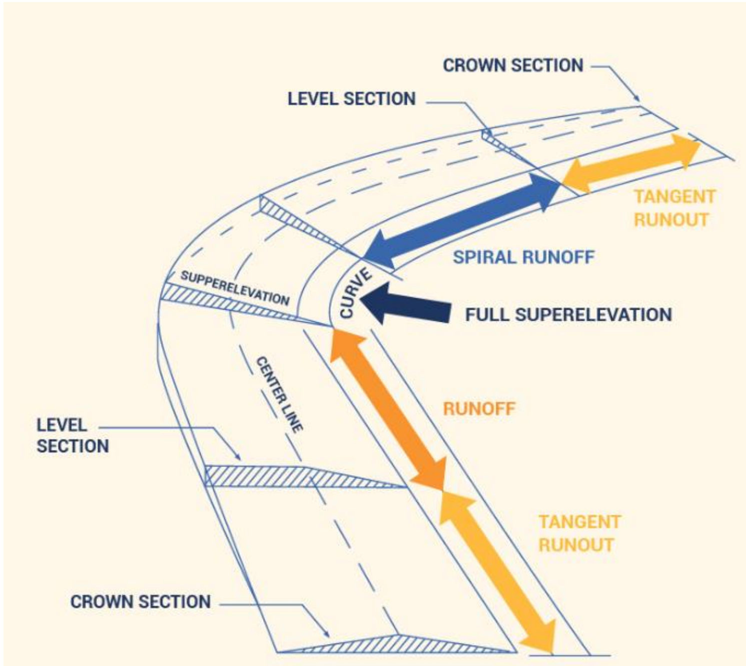
19

Superelevation

Superelevation (e) is the transverse slope (or banking) provided on a horizontal curve to counteract the effect of centrifugal force and reduce reliance on tire friction. It helps vehicles negotiate curves safely by tilting the road surface **toward the center of the curve.**

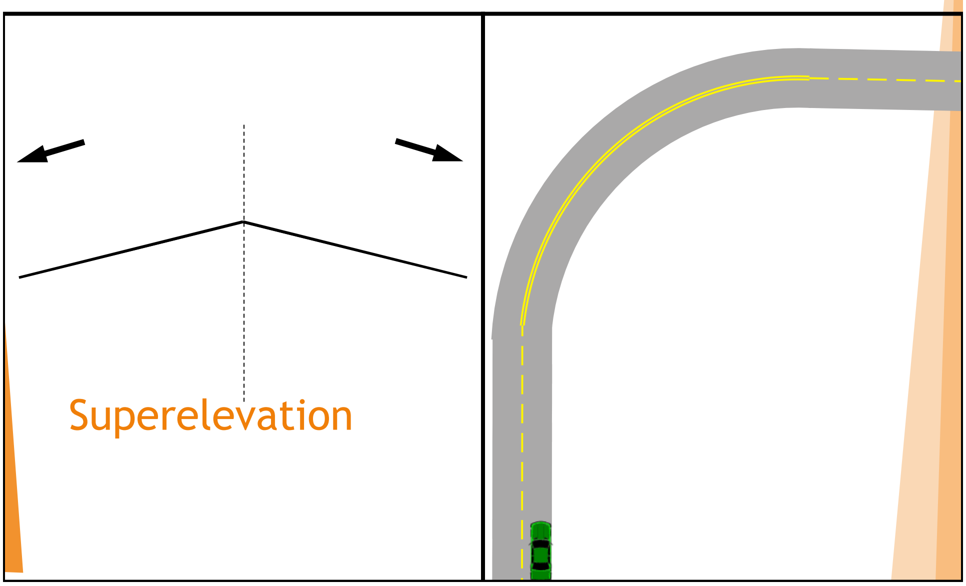


20



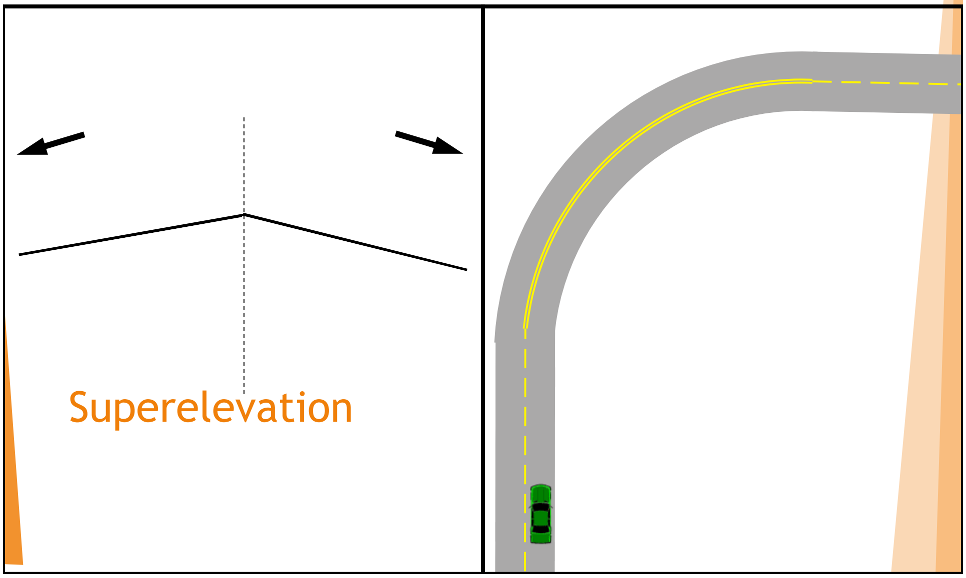
21

Concept of Super-elevation



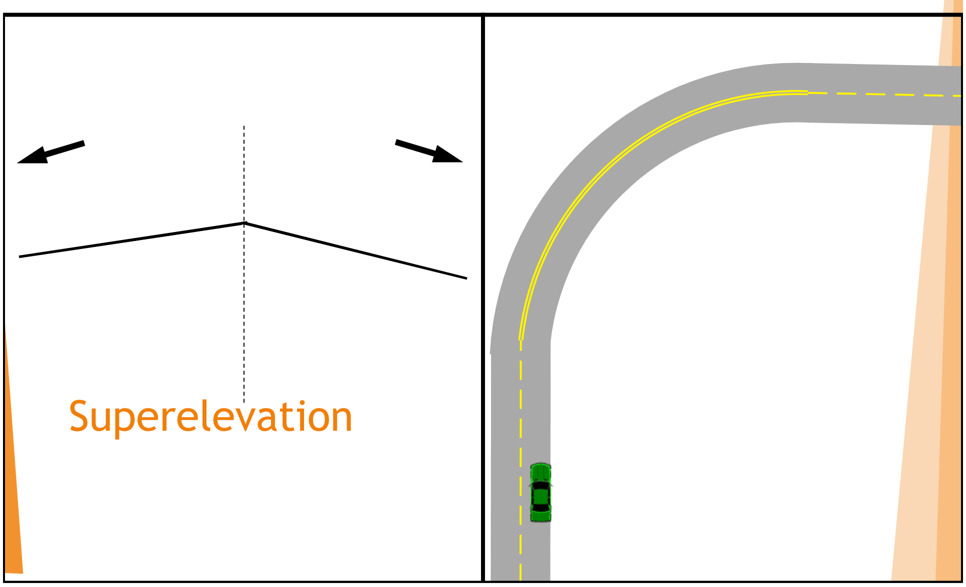
22

Concept of Super-elevation



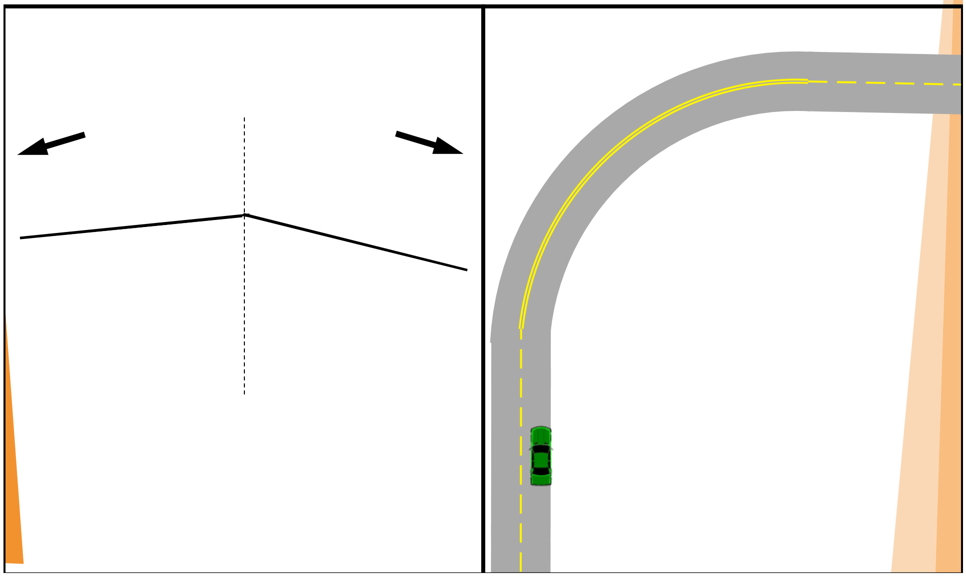
23

Concept of Super-elevation



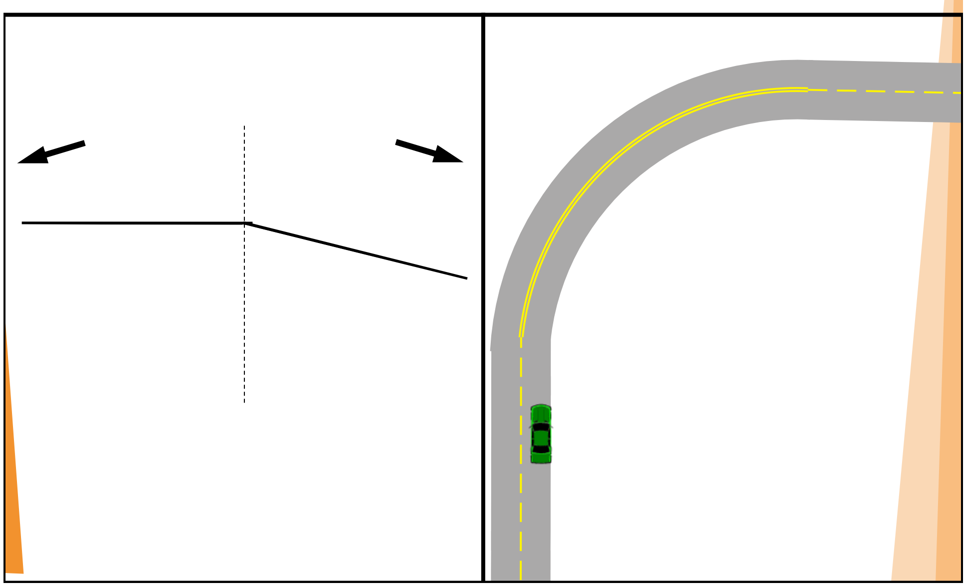
24

Concept of Super-elevation



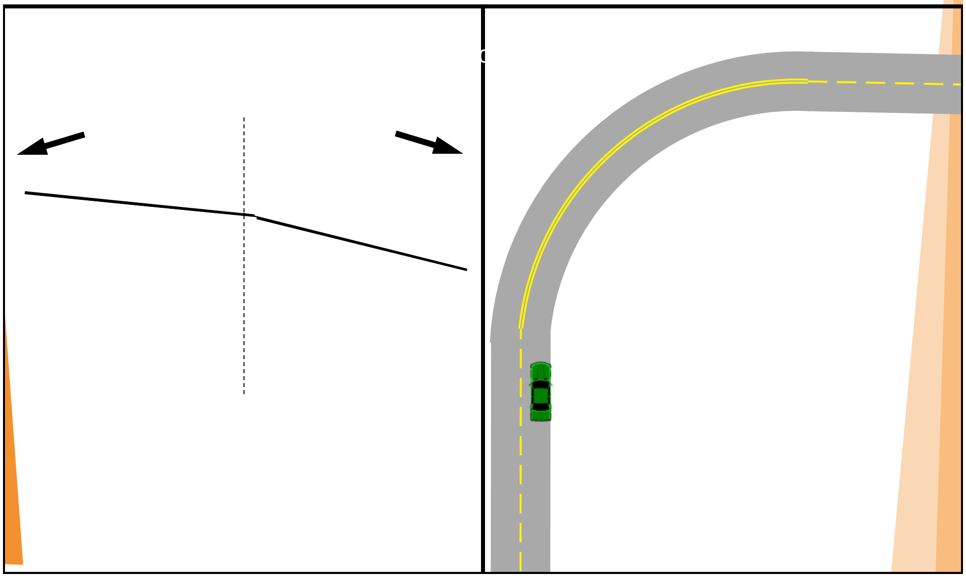
25

Concept of Super-elevation



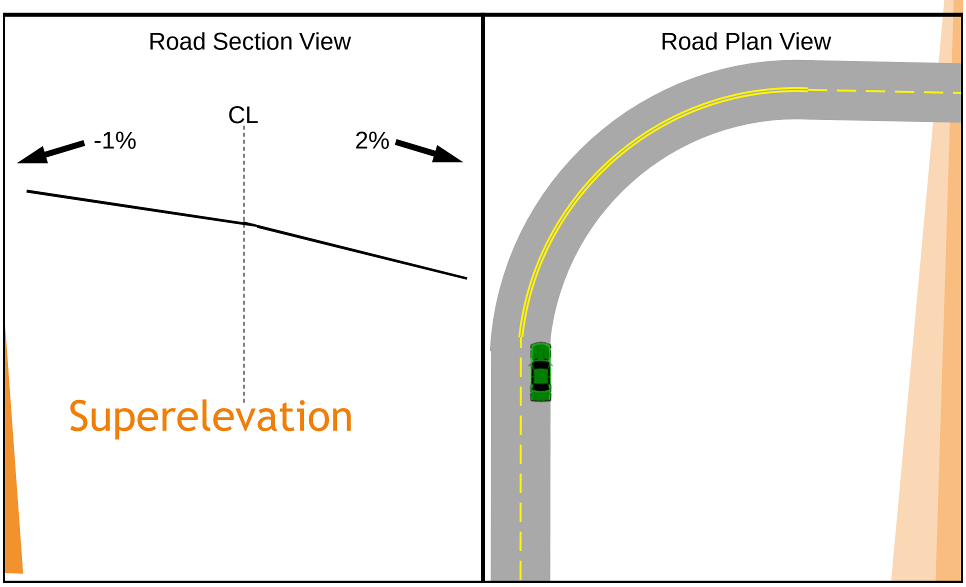
26

Concept of Super-elevation



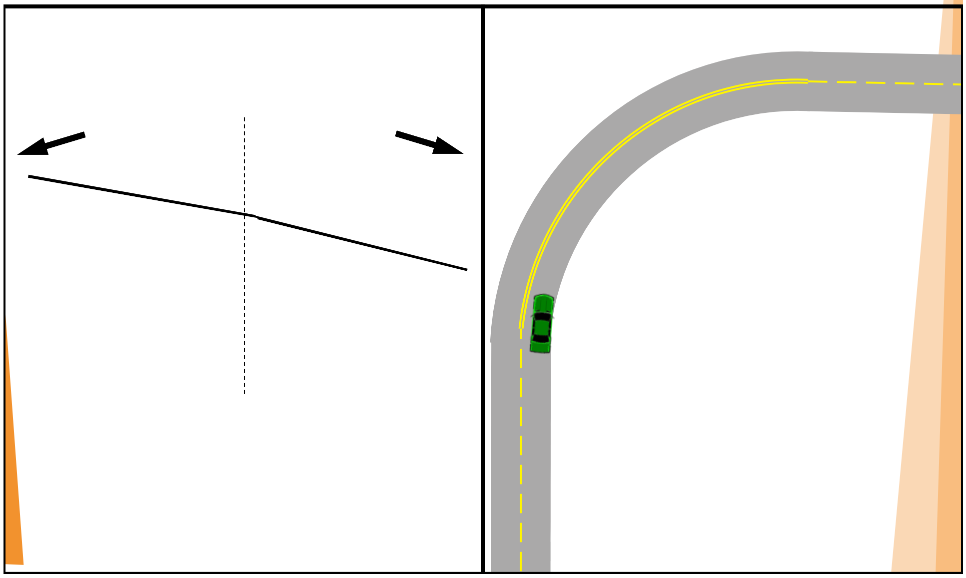
27

Concept of Super-elevation



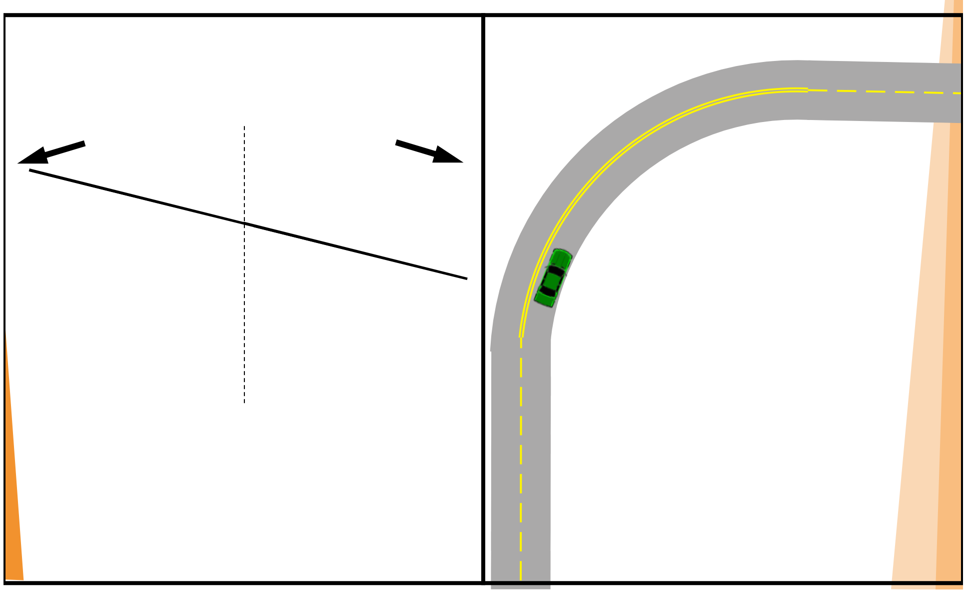
28

Concept of Super-elevation



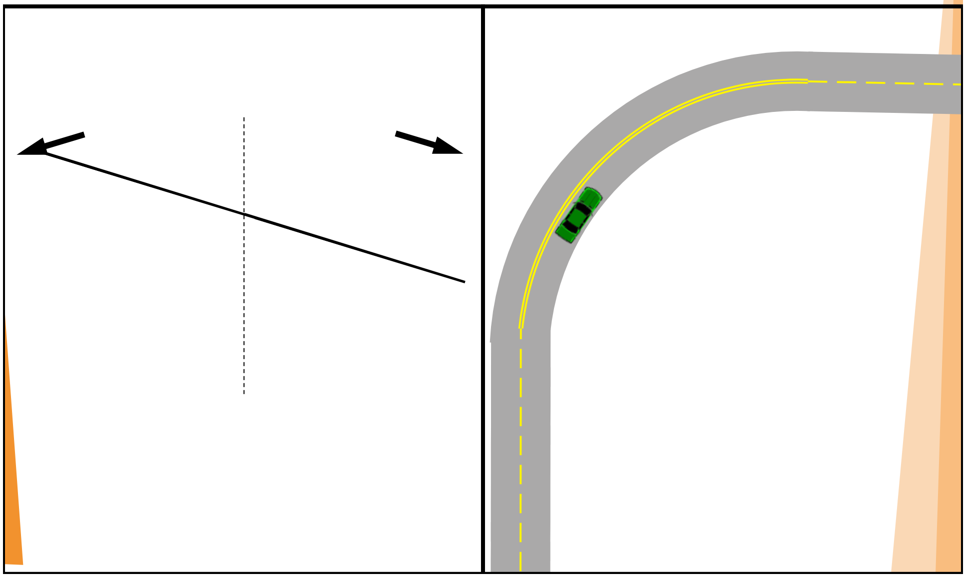
29

Concept of Super-elevation



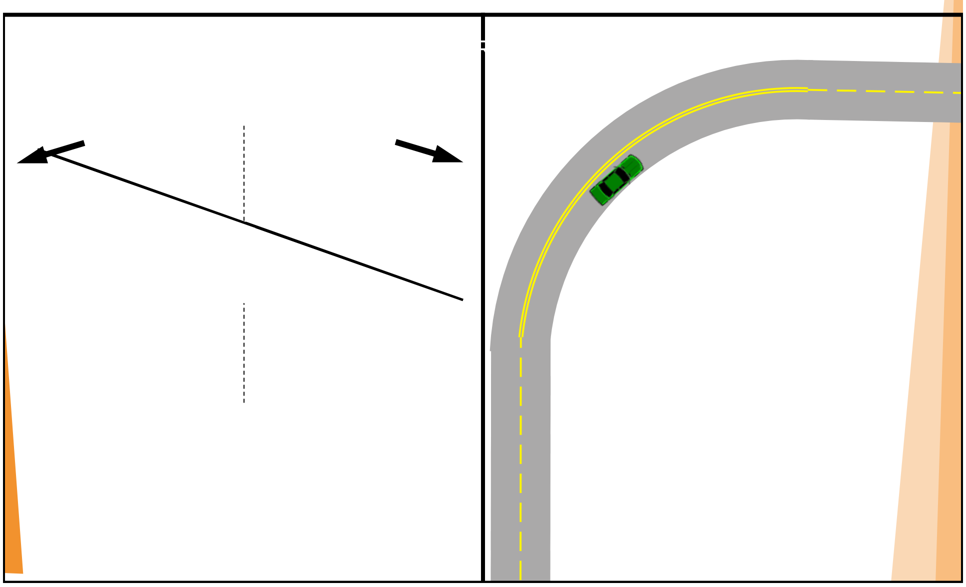
30

Concept of Super-elevation



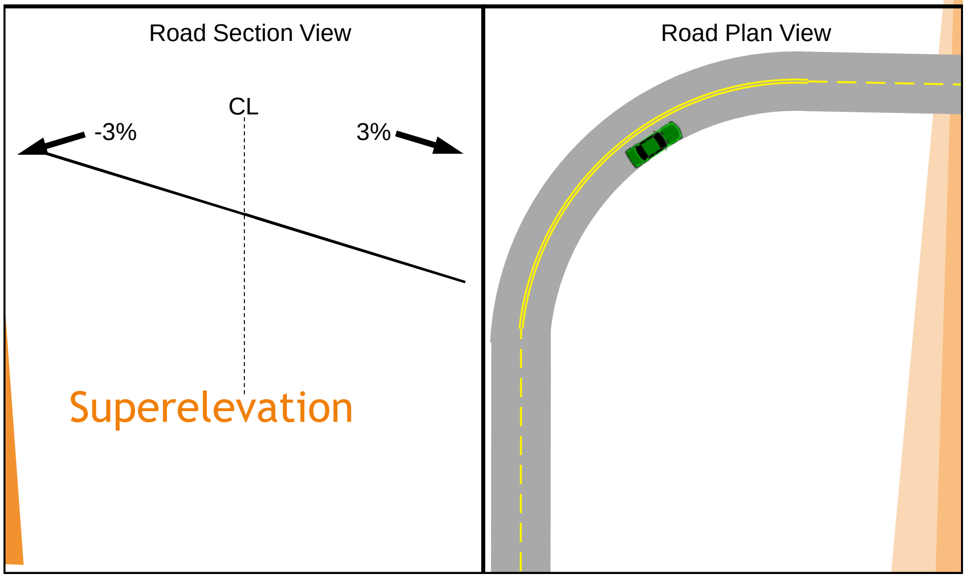
31

Concept of Super-elevation



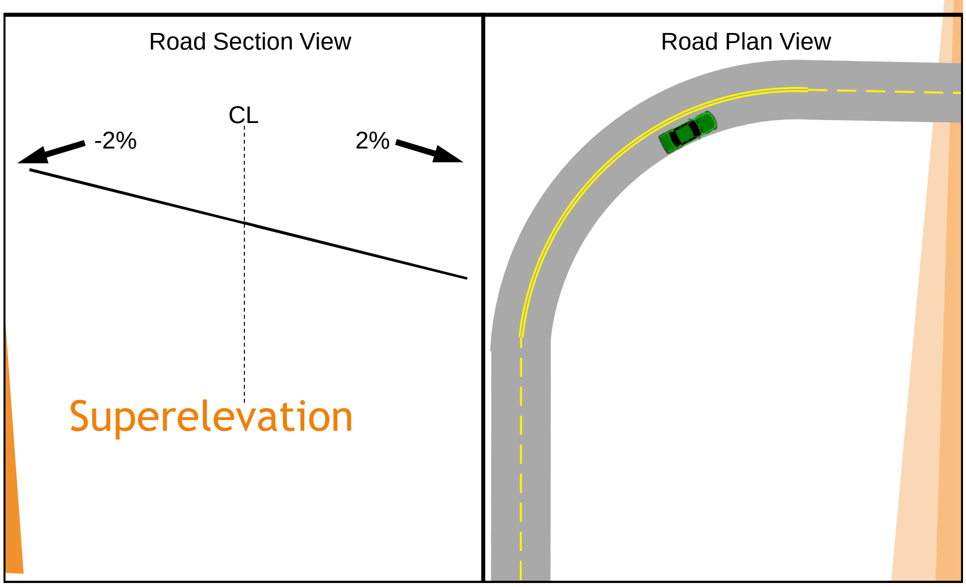
32

Concept of Super-elevation



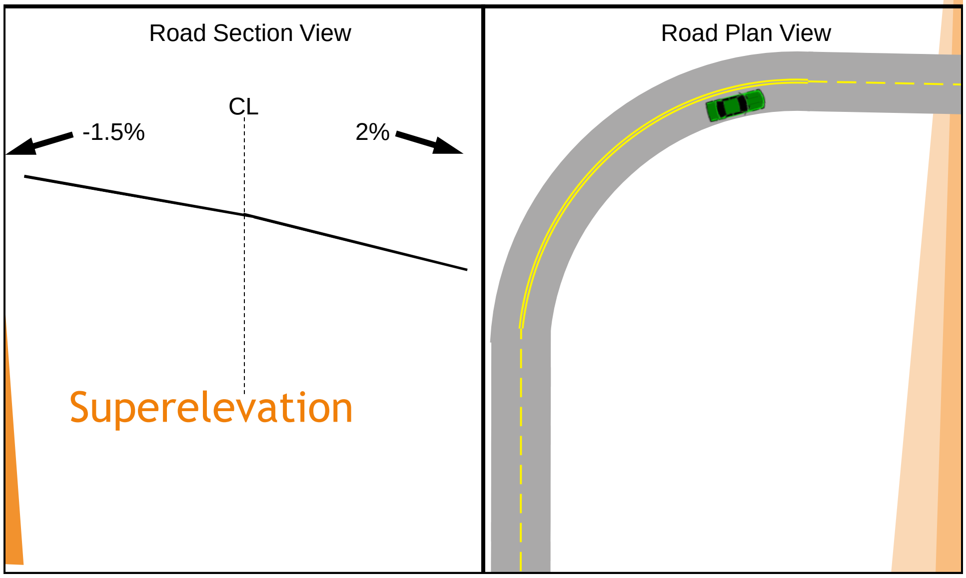
33

Concept of Super-elevation



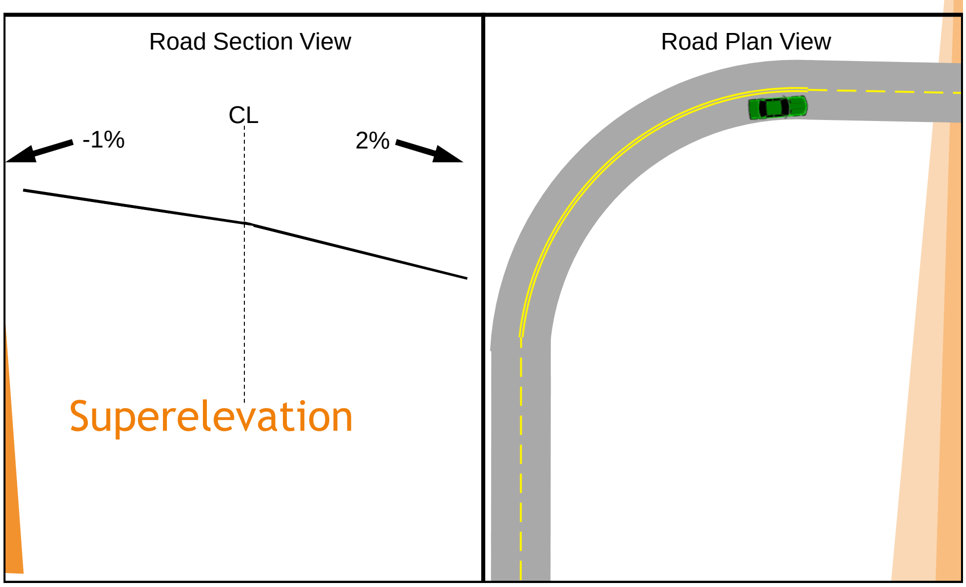
34

Concept of Super-elevation



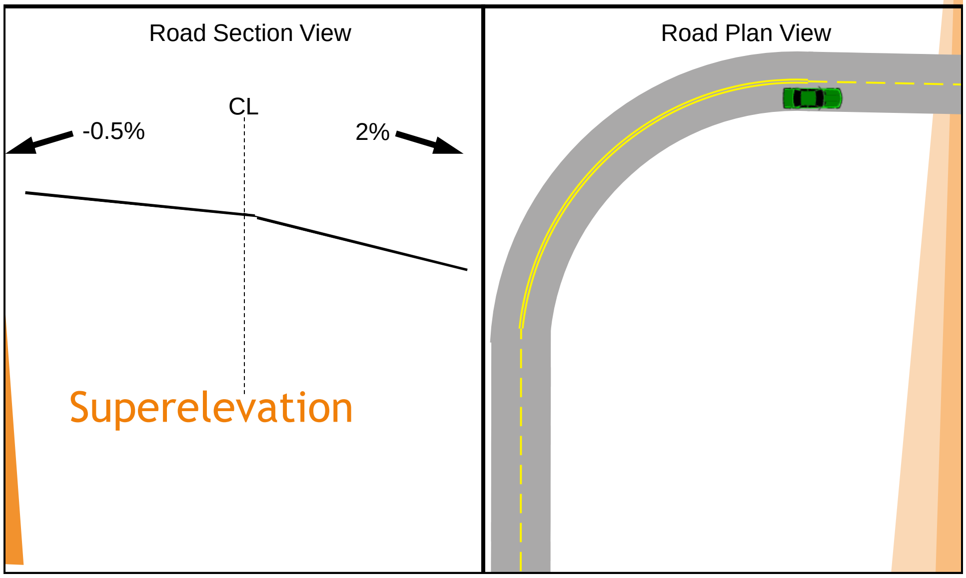
35

Concept of Super-elevation



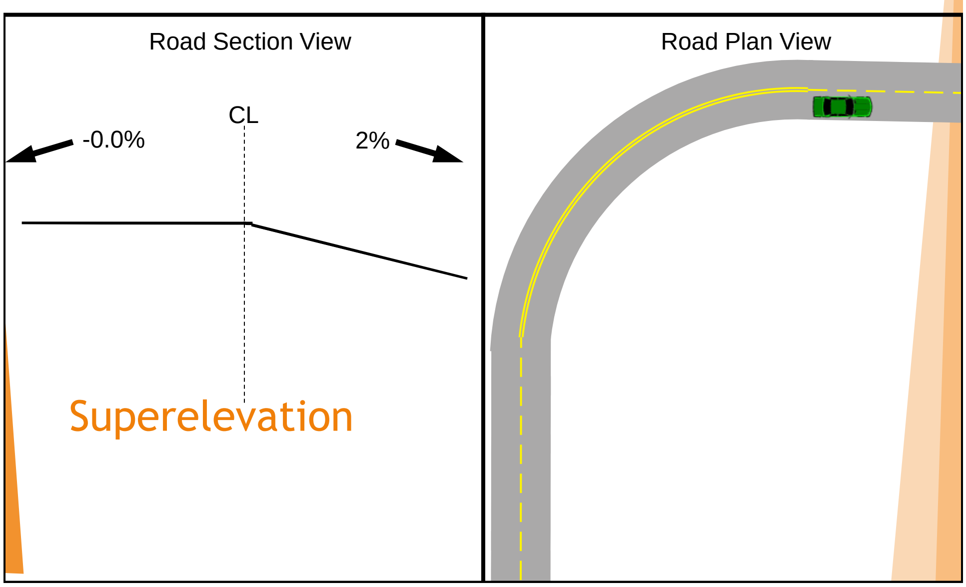
36

Concept of Super-elevation



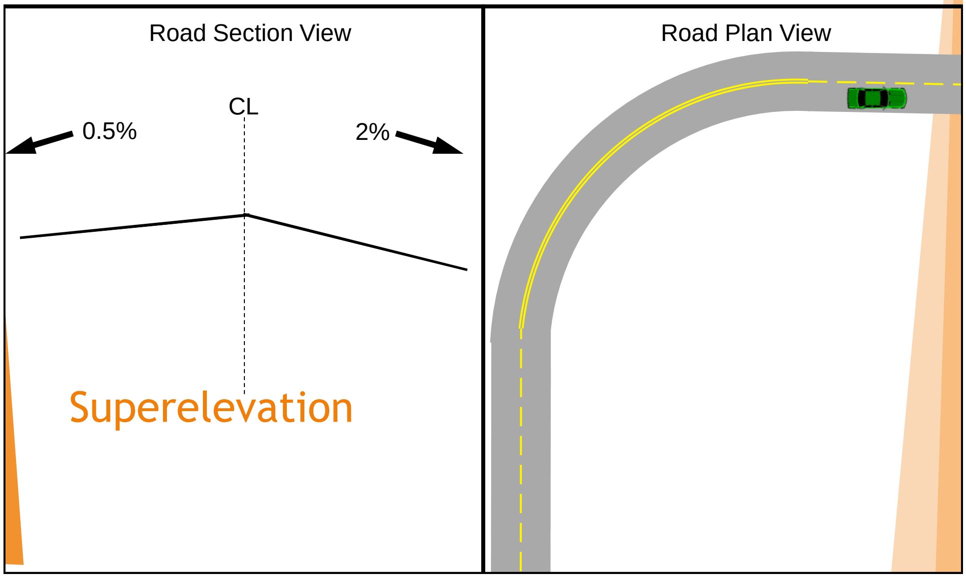
37

Concept of Super-elevation



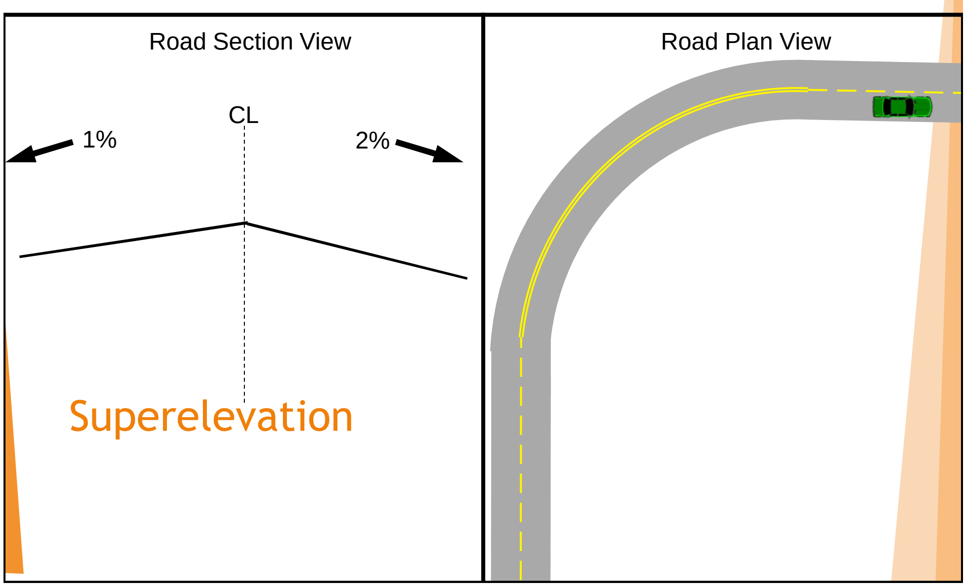
38

Concept of Super-elevation



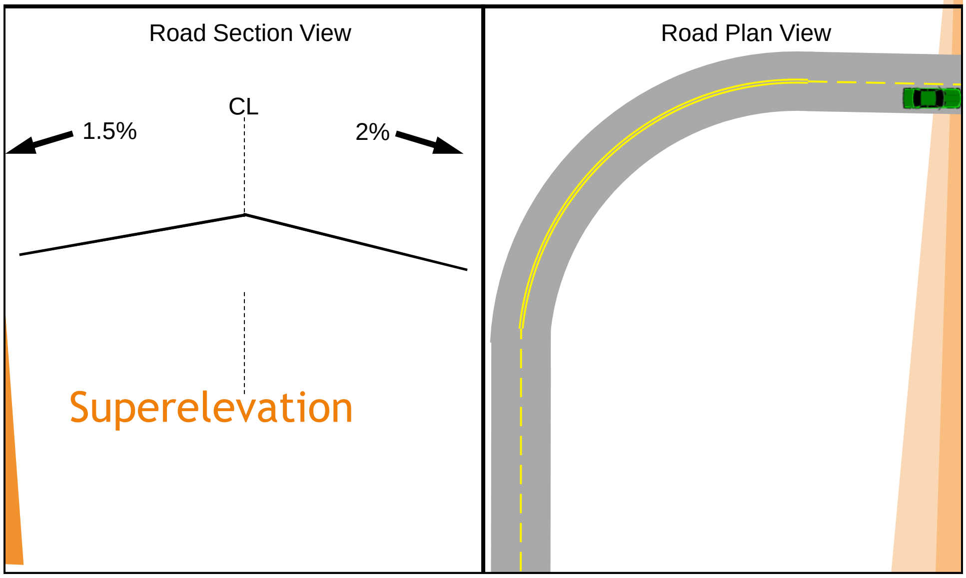
39

Concept of Super-elevation



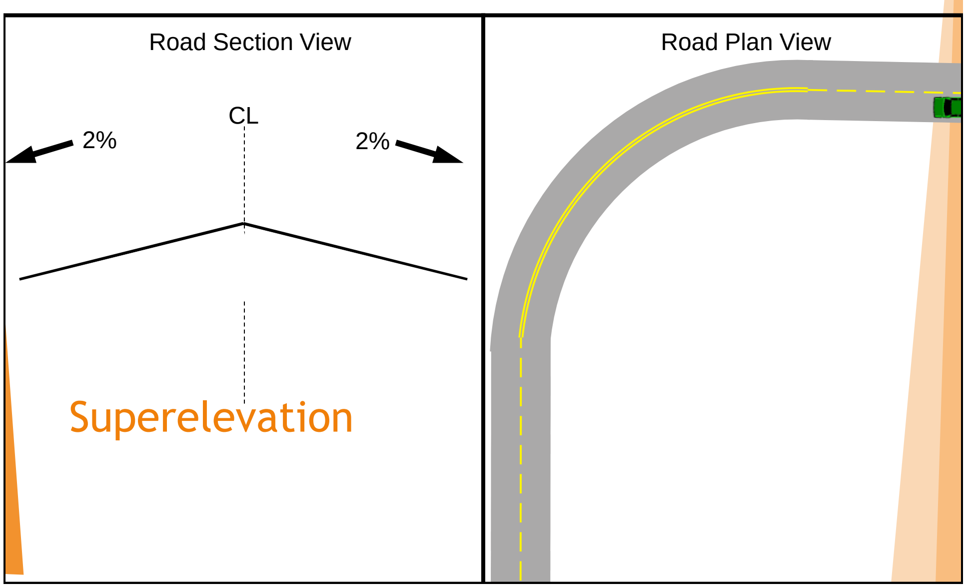
40

Concept of Super-elevation



41

Concept of Super-elevation



42

Max Superelevation (e)

- Controlled by 4 factors:
  - Climate conditions (amount of ice and snow).
  - Terrain Type (flat, rolling, mountainous).
  - Type of area (rural or urban).
  - Frequency of slow-moving vehicles.

Iraqi highway Design Manual:

- The highest superelevation rate for highways in common use is 10%, although 12% is used in low volume unpaved road to facilitate drainage.
- Generally, 8% is recognized as a reasonable maximum value for superelevation rate of highways. A maximum superelevation rate of 4-6% is applicable for urban design with traffic congestions,

43

Side Friction (f)

- The side friction factor is the friction force divided by the component of the weight perpendicular to the pavement surface.
- The upper limit of the side friction factor (f) is the point at which the tire would begin to skid, and the values used in curve design should be less than the coefficient of friction at impending skid.
- The recommended side friction factor, for use in horizontal curve design of highways, at different vehicle speeds(5-1/3) [1, p.3-25].
- The (f) values vary with the design speed from 0.40 (at 15 km/hr.), 0.15 (at 70 km/ hr.), to 0.075 (at 130 km/hr.).

44

Table 5-1/1: Minimum Radius Using Limiting Values of e and f [1, p.3-32]

Design Speed (km/hr.)	Maximum e (%)	Maximum f	Total (e/100+f)	Calculated Radius (m)	Rounded Radius (m)
15	4.0	0.40	0.44	4.0	4
20	4.0	0.35	0.39	8.1	8
30	4.0	0.28	0.32	22.1	22
40	4.0	0.23	0.27	46.7	47
50	4.0	0.19	0.23	85.6	86
60	4.0	0.17	0.21	135.0	135
70	4.0	0.15	0.19	203.1	203
80	4.0	0.14	0.18	280.0	280
90	4.0	0.13	0.17	375.2	375
100	4.0	0.12	0.16	492.1	492
15	6.0	0.40	0.46	3.9	4
20	6.0	0.35	0.41	7.7	8
30	6.0	0.28	0.34	20.8	21
40	6.0	0.23	0.29	43.4	43
50	6.0	0.19	0.25	78.7	79
60	6.0	0.17	0.23	123.2	123
70	6.0	0.15	0.21	183.7	184
80	6.0	0.14	0.20	252.0	252
90	6.0	0.13	0.19	335.7	336
100	6.0	0.12	0.18	437.4	437
110	6.0	0.11	0.17	560.4	560
120	6.0	0.09	0.15	755.9	756
130	6.0	0.08	0.14	950.5	951

Iraqi Highway Design Manual

45

15	6.0	0.40	0.46	3.9	4
20	6.0	0.35	0.41	7.7	8
30	6.0	0.28	0.34	20.8	21
40	6.0	0.23	0.29	43.4	43
50	6.0	0.19	0.25	78.7	79
60	6.0	0.17	0.23	123.2	123
70	6.0	0.15	0.21	183.7	184
80	6.0	0.14	0.20	252.0	252
90	6.0	0.13	0.19	335.7	336
100	6.0	0.12	0.18	437.4	437
110	6.0	0.11	0.17	560.4	560
120	6.0	0.09	0.15	755.9	756
130	6.0	0.08	0.14	950.5	951
15	8.0	0.40	0.48	3.7	4
20	8.0	0.35	0.43	7.3	7
30	8.0	0.28	0.36	19.7	20
40	8.0	0.23	0.31	40.6	41
50	8.0	0.19	0.27	72.9	73
60	8.0	0.17	0.25	113.4	113
70	8.0	0.15	0.23	167.8	168
80	8.0	0.14	0.22	229.1	229
90	8.0	0.13	0.21	303.7	304
100	8.0	0.12	0.20	393.7	394
110	8.0	0.11	0.19	501.5	501
120	8.0	0.09	0.17	667.0	667
130	8.0	0.08	0.16	831.7	832

Iraqi Highway Design Manual

46

15	10.0	0.40	0.50	3.5	4
20	10.0	0.35	0.45	7.0	7
30	10.0	0.28	0.38	18.6	19
40	10.0	0.23	0.33	38.2	38
50	10.0	0.19	0.29	67.9	68
60	10.0	0.17	0.27	105.0	105
70	10.0	0.15	0.25	154.3	154
80	10.0	0.14	0.24	210.0	210
90	10.0	0.13	0.23	277.3	277
100	10.0	0.12	0.22	357.9	358
110	10.0	0.11	0.21	453.7	454
120	10.0	0.09	0.19	596.8	597
130	10.0	0.08	0.18	739.3	739
15	12.0	0.40	0.52	3.4	3
20	12.0	0.35	0.47	6.7	7
30	12.0	0.28	0.40	17.7	18
40	12.0	0.23	0.35	36.0	36
50	12.0	0.19	0.31	63.5	64
60	12.0	0.17	0.29	97.7	98
70	12.0	0.15	0.27	142.9	143
80	12.0	0.14	0.26	193.8	194
90	12.0	0.13	0.25	255.1	255
100	12.0	0.12	0.24	328.1	328
110	12.0	0.11	0.23	414.2	414
120	12.0	0.09	0.21	539.9	540
130	12.0	0.08	0.20	665.4	665

Iraqi Highway Design Manual

Note: In recognition of safety considerations, use of e_{max}= 4.0% should be limited to urban conditions.

Table 3-7. Minimum Radius Using Limiting Values of *e* and *f*

Metric						U.S. Customary					
Design Speed (km/h)	Maximum *e* (%)	Maximum *f*	Total (*e*/100 + *f*)	Calculated Radius (m)	Rounded Radius (m)	Design Speed (mph)	Maximum *e* (%)	Maximum *f*	Total (*e*/100 + *f*)	Calculated Radius (ft)	Rounded Radius (ft)
15	4.0	0.40	0.44	4.0	4	10	4.0	0.38	0.42	15.9	16
20	4.0	0.35	0.39	8.1	8	15	4.0	0.32	0.36	41.7	42
30	4.0	0.28	0.32	22.1	22	20	4.0	0.27	0.31	86.0	86
40	4.0	0.23	0.27	46.7	47	25	4.0	0.23	0.27	154.3	154
50	4.0	0.19	0.23	85.6	86	30	4.0	0.20	0.24	250.0	250
60	4.0	0.17	0.21	135.0	135	35	4.0	0.18	0.22	371.2	371
70	4.0	0.15	0.19	203.1	203	40	4.0	0.16	0.20	533.3	533
80	4.0	0.14	0.18	280.0	280	45	4.0	0.15	0.19	710.5	711
90	4.0	0.13	0.17	375.2	375	50	4.0	0.14	0.18	925.9	926
100	4.0	0.12	0.16	492.1	492	55	4.0	0.13	0.17	1186.3	1190
						60	4.0	0.12	0.16	1500.0	1500
15	6.0	0.40	0.46	3.9	4	10	6.0	0.38	0.44	15.2	15
20	6.0	0.35	0.41	7.7	8	15	6.0	0.32	0.38	39.5	39
30	6.0	0.28	0.34	20.8	21	20	6.0	0.27	0.33	80.8	81
40	6.0	0.23	0.29	43.4	43	25	6.0	0.23	0.29	143.7	144
50	6.0	0.19	0.25	78.7	79	30	6.0	0.20	0.26	230.8	231
60	6.0	0.17	0.23	123.2	123	35	6.0	0.18	0.24	340.3	340
70	6.0	0.15	0.21	183.7	184	40	6.0	0.16	0.22	484.8	485
80	6.0	0.14	0.20	252.0	252	45	6.0	0.15	0.21	642.9	643
90	6.0	0.13	0.19	335.7	336	50	6.0	0.14	0.20	833.3	833
100	6.0	0.12	0.18	437.4	437	55	6.0	0.13	0.19	1061.4	1060
110	6.0	0.11	0.17	560.4	560	60	6.0	0.12	0.18	1333.3	1330
120	6.0	0.09	0.15	755.9	756	65	6.0	0.11	0.17	1656.9	1660
130	6.0	0.08	0.14	950.5	951	70	6.0	0.10	0.16	2041.7	2040
						75	6.0	0.09	0.15	2500.0	2500
						80	6.0	0.08	0.14	3047.6	3050

A Policy on Geometric Design of Highways and Streets, (The Green Book). Washington, DC. American Association of State Highway and Transportation Officials AASHTO, 2011, 6th Ed.

15	8.0	0.40	0.48	3.7	4	10	8.0	0.38	0.46	14.5	14
20	8.0	0.35	0.43	7.3	7	15	8.0	0.32	0.40	37.5	38
30	8.0	0.28	0.36	19.7	20	20	8.0	0.27	0.35	76.2	76
40	8.0	0.23	0.31	40.6	41	25	8.0	0.23	0.31	134.4	134
50	8.0	0.19	0.27	72.9	73	30	8.0	0.20	0.28	214.3	214
60	8.0	0.17	0.25	113.4	113	35	8.0	0.18	0.26	314.1	314
70	8.0	0.15	0.23	167.8	168	40	8.0	0.16	0.24	444.4	444
80	8.0	0.14	0.22	229.1	229	45	8.0	0.15	0.23	587.0	587
90	8.0	0.13	0.21	303.7	304	50	8.0	0.14	0.22	757.6	758
100	8.0	0.12	0.20	393.7	394	55	8.0	0.13	0.21	960.3	960
110	8.0	0.11	0.19	501.5	501	60	8.0	0.12	0.20	1200.0	1200
120	8.0	0.09	0.17	667.0	667	65	8.0	0.11	0.19	1482.5	1480
130	8.0	0.08	0.16	831.7	832	70	8.0	0.10	0.18	1814.8	1810
						75	8.0	0.09	0.17	2205.9	2210
						80	8.0	0.08	0.16	2666.7	2670
15	10.0	0.40	0.50	3.5	4	10	10.0	0.38	0.48	13.9	14
20	10.0	0.35	0.45	7.0	7	15	10.0	0.32	0.42	35.7	36
30	10.0	0.28	0.38	18.6	19	20	10.0	0.27	0.37	72.1	72
40	10.0	0.23	0.33	38.2	38	25	10.0	0.23	0.33	126.3	126
50	10.0	0.19	0.29	67.9	68	30	10.0	0.20	0.30	200.0	200
60	10.0	0.17	0.27	105.0	105	35	10.0	0.18	0.28	291.7	292
70	10.0	0.15	0.25	154.3	154	40	10.0	0.16	0.26	410.3	410
80	10.0	0.14	0.24	210.0	210	45	10.0	0.15	0.25	540.0	540
90	10.0	0.13	0.23	277.3	277	50	10.0	0.14	0.24	694.4	694
100	10.0	0.12	0.22	357.9	358	55	10.0	0.13	0.23	876.8	877
110	10.0	0.11	0.21	453.7	454	60	10.0	0.12	0.22	1090.9	1090
120	10.0	0.09	0.19	596.8	597	65	10.0	0.11	0.21	1341.3	1340
130	10.0	0.08	0.18	739.3	739	70	10.0	0.10	0.20	1633.3	1630
						75	10.0	0.09	0.19	1973.7	1970
						80	10.0	0.08	0.18	2370.4	2370
15	12.0	0.40	0.52	3.4	3	10	12.0	0.38	0.50	13.3	13
20	12.0	0.35	0.47	6.7	7	15	12.0	0.32	0.44	34.1	34
30	12.0	0.28	0.40	17.7	18	20	12.0	0.27	0.39	68.4	68
40	12.0	0.23	0.35	36.0	36	25	12.0	0.23	0.35	119.0	119
50	12.0	0.19	0.31	63.5	64	30	12.0	0.20	0.32	187.5	188
60	12.0	0.17	0.29	97.7	98	35	12.0	0.18	0.30	272.2	272
70	12.0	0.15	0.27	142.9	143	40	12.0	0.16	0.28	381.0	381
80	12.0	0.14	0.26	193.8	194	45	12.0	0.15	0.27	500.0	500
90	12.0	0.13	0.25	255.1	255	50	12.0	0.14	0.26	641.0	641
100	12.0	0.12	0.24	328.1	328	55	12.0	0.13	0.25	806.7	807
110	12.0	0.11	0.23	414.2	414	60	12.0	0.12	0.24	1000.0	1000
120	12.0	0.09	0.21	539.9	540	65	12.0	0.11	0.23	1224.6	1220
130	12.0	0.08	0.20	665.4	665	70	12.0	0.10	0.22	1484.8	1480
						75	12.0	0.09	0.21	1785.7	1790
						80	12.0	0.08	0.20	2133.3	2130

Note: In recognition of safety considerations, use of e_{max} = 4.0% should be limited to urban conditions.

A Policy on Geometric Design of Highways and Streets, (The Green Book). Washington, DC. American Association of State Highway and Transportation Officials AASHTO, 2011, 6th Ed.

49

Metric

$$R_{min} = \frac{V^2}{127(0.01e_{max} + f_{max})}$$

U.S. Customary

$$R_{min} = \frac{V^2}{15(0.01e_{max} + f_{max})}$$

50

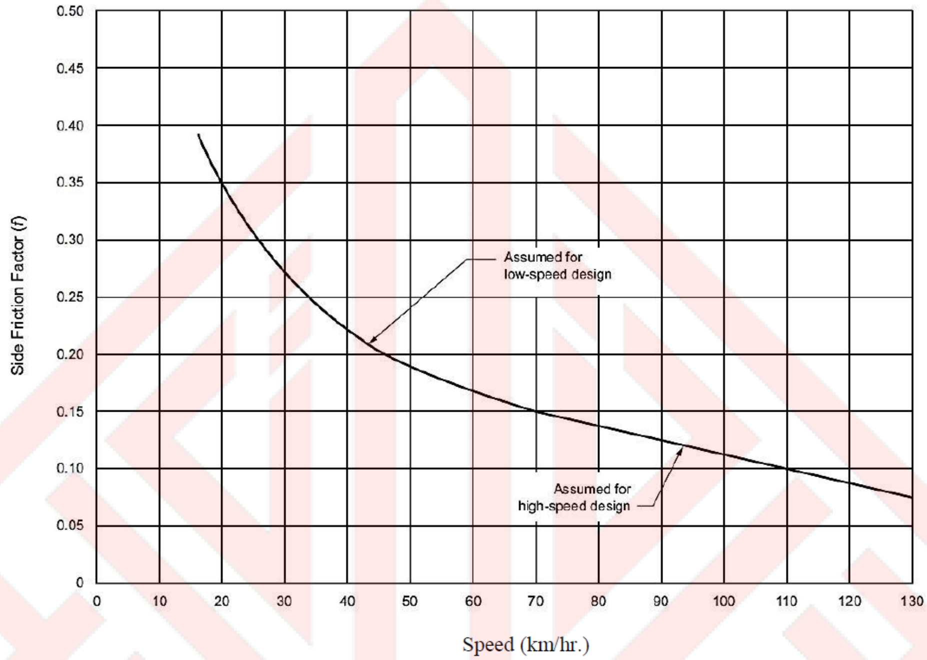


Figure 5-1/3: Side Friction Factors Assumed for Design [1, p.3-25]

51

Example -1-

Assume a maximum superelevation (e) of 8% and design speed of 60 mph, what is the minimum radius?

f_{max} = 0.12 (from Green Book)

$$R_{min} = \frac{60^2}{15(0.08 + 0.12)}$$

R_{min} = 1200 feet

52

Example cont'

1. For e_{max} = 4%? (urban situation)

$$R_{min} = \frac{60^2}{15(0.04 + 0.12)}$$

R_{min} = 1,500 feet

2. For e_{max} = 2%? (rotated crown)

$$R_{min} = \frac{60^2}{15(0.02 + 0.12)}$$

R_{min} = 1,714 feet

3. For e_{max} = -2%? (normal crown, adverse direction)

$$R_{min} = \frac{60^2}{15(-0.02 + 0.12)}$$

R_{min} = 2,400 feet

53

Example -2-

A curving roadway has a design speed of 110 km/hr. At one horizontal curve, the Super elevation has been set at 6.0% and the coefficient of side friction is found to be 0.10. Determine the minimum radius of the curve that will provide safe

Solution;

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

$R = 110^2 / 127(0.10+0.06)$

$= 595$ m

54

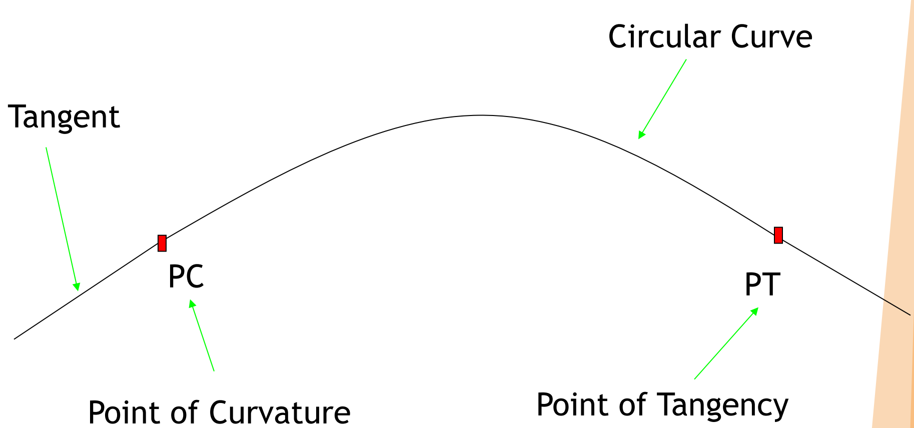
Example -3-

A roadway is designed for a speed of 70 mph (113 km/h). At one horizontal curve, it is known that the superelevation is 8%, and the coefficient of side friction is 0.10. Determine the minimum radius of the curve (measured to the traveled path) that will provide for safe vehicle operation.

$$R_{min} = \frac{70^2}{15(0.08 + 0.10)}$$

$$= 1814.8 \text{ ft}$$

Design of Simple Curve



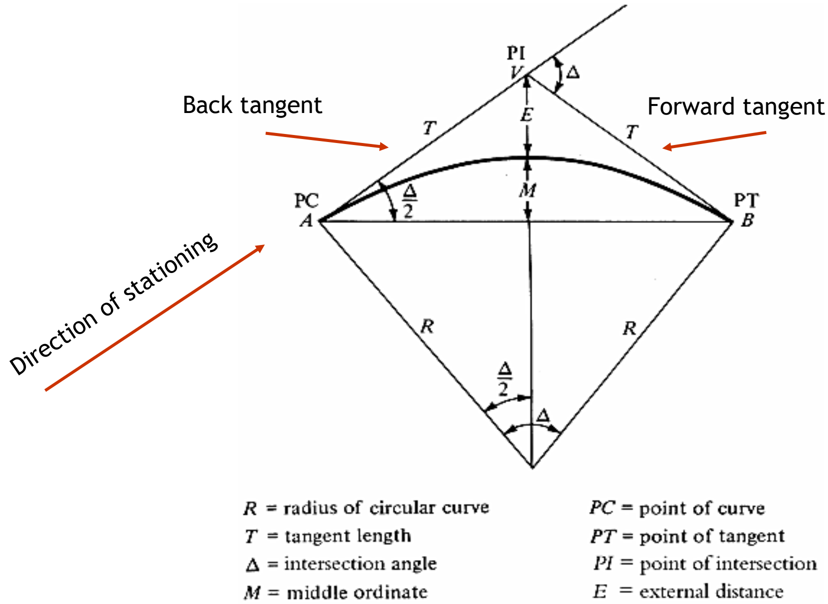


Figure 15.18 Layout of a Simple Horizontal Curve

57

- A simple circular curve is described either by its radius, for example, 200-ft-radius curve, or by the degree of the curve, for example, a 4-degree curve.
- There are two ways to define degree of the curve, which is based on 100 ft of arc length or on 100 ft of chord length.
- Highway practice (which is the focus of this chapter) uses arc definition whereas railroad practice uses chord definition.
- The angle subtended at the center of a circular arc 100 ft in length as shown in Figure 15.19(a) is the degree of curve as used in highway work.
- For example, a 2-degree curve subtends an arc of 100 ft if the central angle is 2 degree.

58

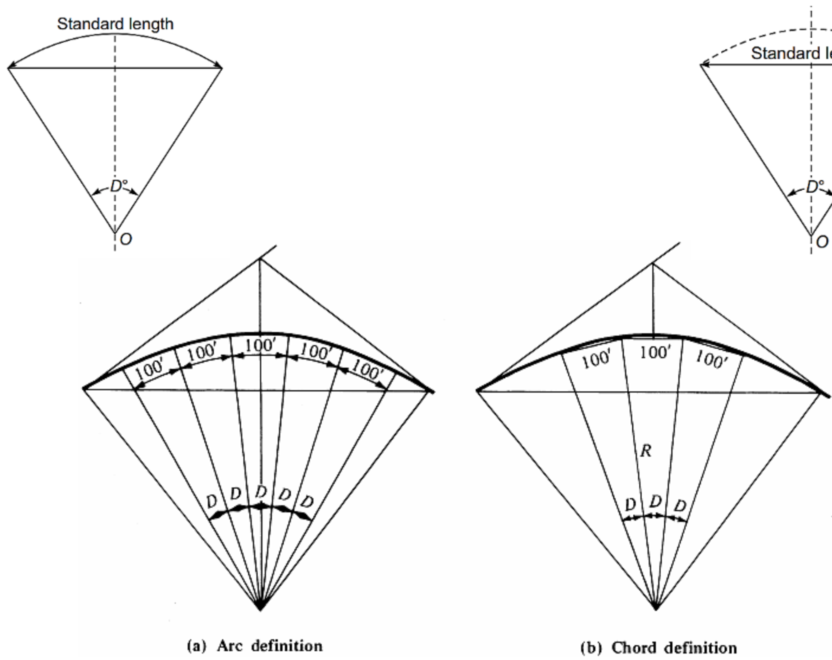
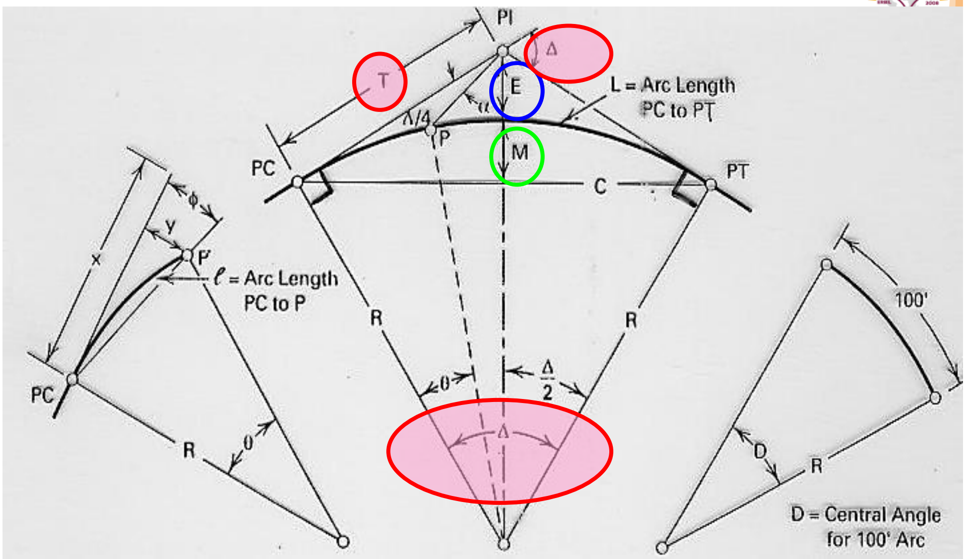


Figure 15.19 Arc and Chord Definitions for a Circular Curve

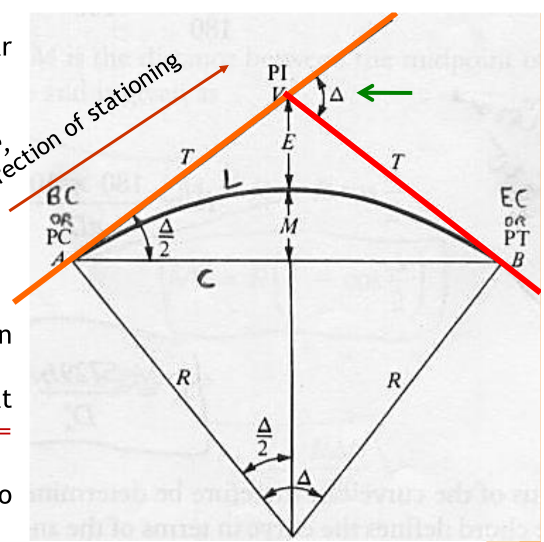
59

60



61

- R= Radius of the Circular (Simple) Curve
- L= Length of Curvature
- T= Semi Tangent Distance, (Tangent Length)
- M= Middle Ordinate
- E= External Distance
- C= Chord Length
- D= Degree of Curvature
- Δ= Central Angle, (Intersection Angle)
- TC= The curve begins at Tangent to Curve, (BC)= Beginning of Curve
- CT= The curve ends at Curve to Tangent, (EC) = End of Curve
- PI= The Point of Intersection
- POC= The point of Curve,
- POT= The point of Tangent,



$$1^\circ = \pi/180 radians = 0.0174532 \quad radians$$
$$1 radian = (180/\pi)^\circ = 57.2957^\circ$$

62

1. The Degree of curvature and Radius relationship:

$$R = \frac{5729.6}{D_a^\circ}$$ or R=1719/D (R in m) ------------- (1)

2. The Length of a circular curve is:

$$L = \frac{R\Delta\pi}{180}$$ or L = 2(π)R(Δ)/360 ------------- (2)

3. The Semi Tangent of a circular curve is:

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

4. The Middle Ordinate is:

$$M = R - R\cos\frac{\Delta}{2}$$ ------------------------------- (4)

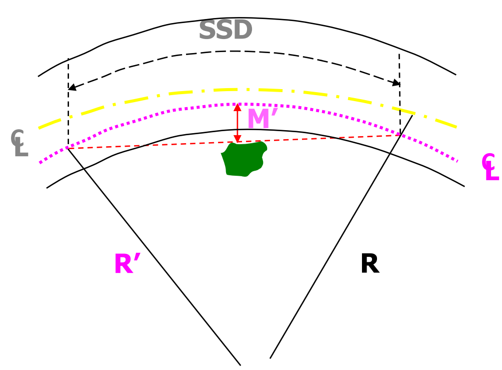
$$= R\left(1 - \cos\frac{\Delta}{2}\right)$$

Sight Distance on Horizontal Curves

The Middle Ordinate

- Clearance from roadside obstruction
  - M' measured from the CL of the inside lane

M' = R' {1 - cos[90 SSD/(πR')]}



5.The External Distance which is the distance from the point of intersection to the curve on a radial line is:

$$E = R\sec\frac{\Delta}{2} - R$$

$$E = R\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right) \qquad \text{-------------------------------} \qquad (5)$$

6.The Chord Length is:

$$C = 2R\sin\frac{\Delta}{2} \qquad \text{-------------------------------} \qquad (6)$$

7.The Point of the Curve is:

PC = PI - T ------------------------------- (7)

8.The Point of the Tangent is:

PT= PC +L ------------------------------- (8)

65

Figure 15.20 is a schematic of the procedure involved.

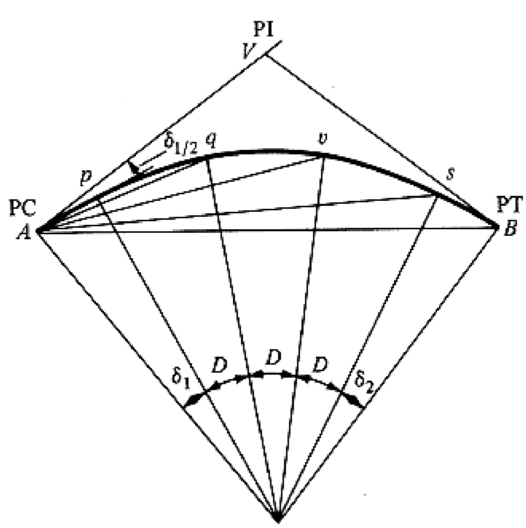


Figure 15.20 Deflection Angles on a Simple Circular Curve

66

The first deflection angle <u>*VAp*</u> to the first whole station on the curve, which is usually less than a station away from the PC, is equal to $\frac{\delta_1}{2}$ based on the properties of a circle.

The next deflection angle VAq is

$$\frac{\delta_1}{2} + \frac{D}{2} \qquad \text{------ (9)}$$

and the next deflection angle VAv is

$$\frac{\delta_1}{2} + \frac{D}{2} + \frac{D}{2} = \frac{\delta_1}{2} + D \qquad \text{------ (10)}$$

The next deflection angle VAs is

$$\frac{\delta_1}{2} + \frac{D}{2} + \frac{D}{2} + \frac{D}{2} = \frac{\delta}{2} + \frac{3D}{2} \qquad \text{------ (11)}$$

and the last deflection angle VAB is

$$\frac{\delta_1}{2} + \frac{D}{2} + \frac{D}{2} + \frac{D}{2} + \frac{\delta_2}{2} = \frac{\delta_1}{2} + \frac{\delta_2}{2} + \frac{3D}{2} = \frac{\Delta}{2} \qquad \text{------ (12)}$$

To set out the horizontal curve, it is necessary to determine δ_1 and δ_2.

The length of the first arc, l_1, is related to δ_1 as

$$l_1 = \frac{R\pi}{180}\delta_1 \qquad \text{------ (13)}$$

Solving for R provided the following expression.

$$R = \frac{l_1 \times 180}{\delta_1 \pi} \qquad \text{------ (14)}$$

Equating R from equation (13) and (14):

$$R = \frac{180L}{\Delta\pi} \qquad \text{------ (15)}$$

provides the relationship between the central angle that subtends the length of arc as follows,

$$\frac{l_1}{\delta_1} = \frac{L}{\Delta} = \frac{l_2}{\delta_2} \qquad \text{------ (16)}$$

- ✓ To locate points on a simple horizontal curve in the field, the PC (point of curve) and PT (point of tangent) are established and deflection angles between the tangent at the PC and the next whole station are measured using a transit set over the PC.
- ✓ Each whole station is located on the ground using the appropriate deflection angle and the chord distance measured from the preceding station.
- ✓ Lengths *l1* and *l2* are the actual distance along the curve. Thus, to locate end points of these curves, chord lengths corresponding to the arc length must be computed. The expression relating chord lengths to the corresponding arc length *l1* and *l2* and *100 ft*, are:

69

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

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

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

- ➢ **Where *C1*, *CD*, and *C2* are the first, intermediate, and last chords, respectively.**
- ➢ To summarize the relationships for deflection angles and chord lengths required to lay out a simple curve, refer to Figure 15.20 and the following formulas:

Chord: $Ap = 2R \sin\frac{\delta_1}{2}$ Deflection angle: $VAp = \frac{\delta_1}{2}$

Chord: $pq = 2R \sin\frac{D_a}{2}$ Deflection angle: $VAq = \frac{\delta_1 + D}{2}$

Chord: $sB = 2R \sin\frac{\delta_2}{2}$ Deflection angle: $VAB = \frac{\delta_1 + D + D + D + \delta_2}{2} = \frac{\Delta}{2}$

70

Example -4-

1. A highway has a design speed of 70mph and a superelevation rate of 0.01. If fs = 0.15, What should be the radius of the curve?

Solution;

$R = V^2/[15(fs+e)]$

$= 70^2/[15*(0.15+0.01)] =$ **2042 (ft)**

2. If the curve is fitted through two tangents with central angle Δ = 25°, How long should the curve be?

$L = \pi R\Delta/180 = \pi*2042*25/180 =$ **891 (ft)**

71

Example -5-

The intersection angle of a 4° curve is 55°25', and the PC is located at station 238+44.75. 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. Figure 15.21 illustrates a layout of the curve.

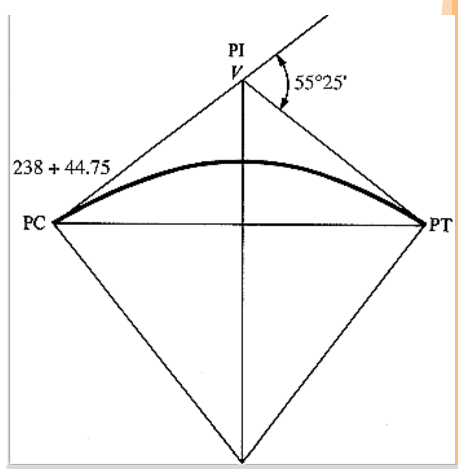


Figure 15.21 Layout of Curve for Example 15.6

72

Solution:

$$\text{Radius of curve} = \frac{5729.6}{D} = \frac{5729.6}{4}$$
$$\approx 1432.4 \text{ ft}$$
$$\text{Length of curve} = \frac{R\Delta\pi}{180} = \frac{1432.4 \times 55.4167\pi}{180}$$
$$= 1385.42 \text{ ft}$$

The station at PT is equal to station (238 + 44.75) + (13 + 85.42) = 252 + 30.17 stations. The distance between the PC and the first station is 239 − (238 + 44.75) = 55.25 ft.

$$\frac{\delta_1}{\Delta} = \frac{l_1}{L}$$
$$\frac{\delta_1}{55.4167} = \frac{55.25}{1385.42}$$

73

Therefore,

$$\delta_1 = 2.210°$$
$$C_1 = 2 \times 1432.4 \sin\left(\frac{2.210}{2}\right) = 55.25 \text{ ft}$$

The first deflection angle to station 239 is $\delta_1/2 = 1.105° = 1°6'18''$.

Similarly,

$$l_2 = (252 + 30.17) - (252) = 30.17 \text{ ft}$$
$$\frac{\delta_2}{2} = \frac{30.17}{1385.42} \times \frac{55.4167}{2} = 0.6034°$$
$$= 36'12''$$
$$C_2 = 2 \times 1432.4 \sin(0.6034°)$$
$$= 30.17 \text{ ft}$$
$$D = 4°$$
$$C_D = 2 \times 1432.42 \sin\left(\frac{4}{2}\right)$$
$$= 99.98 \text{ ft}$$

74

- Note that the deflection angle to PT is half the intersection angle Δ of the tangents.
- This relationship serves as a check of the computation.
- Since highway curves are relatively flat, the chord lengths are approximately equal to the arc lengths.
- The other deflection angles are computed in Table 15.9.

Table 15.9 Computations of Deflection Angles and Chord Lengths for Example 15.6

Station	*Deflection Angle*	*Chord Length (ft)*
PC 238 + 44.75	0	0
PC 239	1°6′18″	55.25
PC 240	3°6′18″	99.98
PC 241	5°6′18″	99.98
PC 242	7°6′18″	99.98
PC 243	9°6′18″	99.98
PC 244	11°6′18″	99.98
PC 245	13°6′18″	99.98
PC 246	15°6′18″	99.98
PC 247	17°6′18″	99.98
PC 248	19°6′18″	99.98
PC 249	21°6′18″	99.98
PC 250	23°6′18″	99.98
PC 251	25°6′18″	99.98
PC 252	27°6′18″	99.98
PT 252 + 30.17	27°42′30″	30.17

Example -6-

A circular curve has 300 m radius and 60° deflection angle.

a. What is its degree by arc definition.
b. Calculate length of curve,
c. Calculate tangent length,
d. Calculate length of long chord,
e. Calculate mid-ordinate and
f. Calculate apex distance.

Solution:

$$R = 300 \text{ m} \quad \Delta = 60°$$

(a) Arc definition:

$$s = 30 \text{ m},$$

$$R = \frac{s}{D_a} \times \frac{180}{\pi}$$

$$\therefore \quad 300 = \frac{30 \times 180}{D_a \pi} \quad \text{or} \quad D_a = 5.730 \qquad \textbf{Ans.}$$

(b) Chord definition:

$$R \sin \frac{D_c}{2} = \frac{s}{2}$$

$$300 \sin \frac{D_c}{2} = \frac{30}{2}$$

$$\therefore \quad DC = 5.732 \qquad \textbf{Ans.}$$

(i) Length of the curve:

$$l = R\Delta \frac{\pi}{180} = 300 \times 60 \times \frac{\pi}{180} = 314.16 \text{ m} \qquad \textbf{Ans.}$$

(ii) Tangent length:

$$T = R \tan\frac{\Delta}{2} = 300 \tan\frac{60}{2} = 173.21 \text{ m} \qquad \textbf{Ans.}$$

(iii) Length of long chord:

$$L = 2R\sin\frac{\Delta}{2} = 2 \times 300 \times \sin\frac{60}{2} = 300 \text{ m} \qquad \textbf{Ans.}$$

(iv) Mid-ordinate:

$$M = R\left(1 - \cos\frac{\Delta}{2}\right) = 300\left(1 - \cos\frac{60}{2}\right) = 40.19 \text{ m} \qquad \textbf{Ans.}$$

(v) Apex distance:

$$E = R\left(\sec\frac{\Delta}{2} - 1\right) = 300\left(\sec\frac{60}{2} - 1\right) = 46.41 \text{ m} \qquad \textbf{Ans.}$$

79

References

1. A Policy on Geometric Design of Highways and Streets, (The Green Book). Washington, DC. American Association of State Highway and Transportation Officials, 2011, 6th Ed.
2. Garber and Hoel - Traffic and Highway Engineering - 4th edition.
3. Iraqi Road Design Manual (Ministry of Construction & Housing, Iraq).
4. FHWA Highway Design Standards

80