Transportation System Engineering 1 , 10601360

Chapter 4
Highway Geometric Design (2)

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Outline: Chapter 2

4.1 Design of Cross-sectional Elements

4.2 Horizontal Alignments

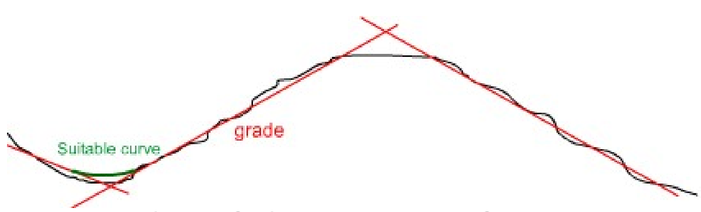
4.3 Vertical Alignments

4.4 Parking Facilities

4.3 Design of Vertical Alignments

Design of Vertical Alignments

- The vertical alignment of a highway consists of straight sections of the highway known as **grades**, or tangents, connected by **vertical curves**.
- The design of the vertical alignment contains:
  - selection of suitable grades for the tangent sections
  - and the design of the vertical curves



Topography of the area is of prime importance

Design of Vertical Alignments

- **Maximum grades** depend on:
  - design speed
  - design vehicle

  (**Table 15.4**)
- **Minimum grades** depend on the requirements for drainage of the highway in the longitudinal direction.
  - It is customary to use a minimum of 0.5 percent in such cases,
    - It may be reduced to 0.3 percent on high-type pavement constructed on suitably crowned firm ground.

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Table 15.4 Recommended Maximum Grades

Rural Collectors[a] — *Design Speed (mi/h)*, Grades (%)

Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
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)*, Grades (%)

Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
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)*, Grades (%)

Type of Terrain	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5

Rural and Urban Freeways[b] — *Design Speed (mi/h)*, Grades (%)

Type of Terrain	*50*	*55*	*60*	*65*	*70*	*75*	*80*
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)*, Grades (%)

Types of Terrain	*30*	*35*	*40*	*45*	*50*	*55*	*60*
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

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Design of Vertical Alignments

- Vertical curves are used to provide a gradual change from one tangent grade to another.
  - so that vehicles may run smoothly

- Main assumptions:
  - **Parabolic in shape.**
  - **X is measure in the horizontal direction**
  - **The curve is symmetrical around VPI**

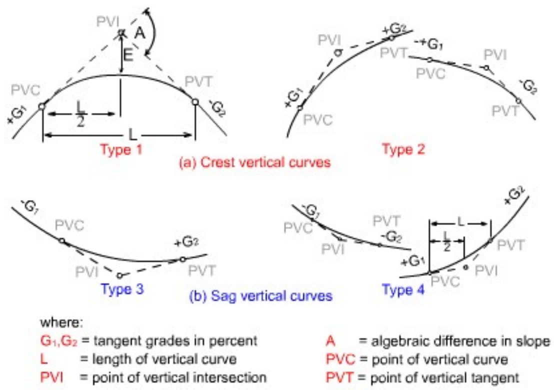
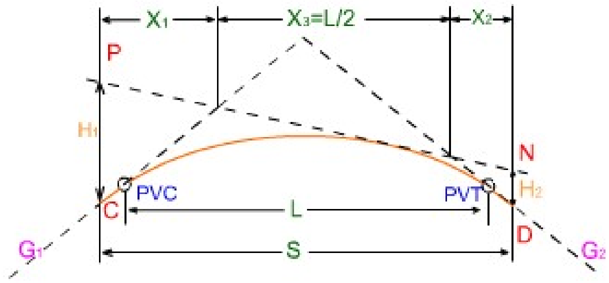


Figure 3.16 Types of Vertical Curves

Crest Vertical Curves

- Two conditions exist for the minimum length of crest vertical curves:
  1. the sight distance is greater than the length of the curve,
  2. the sight distance is less than the length of the curve.

Crest Vertical Curves



where:

- L = length of vertical curve (m)
- H_1 = height of eye above roadway surface (m)
- H_2 = height of object above roadway surface (m)
- PVC = point of vertical curve
- S = Sight distance (m)
- G_1 = slope of first tangent
- G_2 = slope of second tangent
- PVT = point of vertical tangent

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

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

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Crest Vertical Curves

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

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

Assuming

Previously
H1 = 3.75 ft (1.15m)
H2 = 0.5 ft (0.15m)

Recently
H1 = 3.5 ft (1.067m)
H2 = 2.0 ft (0.61m)

$$L_{min} = 2S - \frac{2158}{A} \text{ (for } S > L)$$

$$L_{min} = \frac{AS^2}{2158} \text{ (for } S < L)$$

ft

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Example 15.1

Example 15.1 Minimum Length of a Crest Vertical Curve

A crest vertical curve is to be designed to join a +3% grade with a −2% grade at a section of a two-lane highway. Determine the minimum length of the curve if the design speed of the highway is 60 mi/h, $S < L$, and a perception-reaction time of 2.5 sec. The deceleration rate for braking (a) is 11.2 ft/sec^2.

Solution:

- Use the equation derived in Chapter 3 to determine the SSD required for the design conditions. (Since the grade changes constantly on a vertical curve, the worst-case value for G of 3% is used to determine the braking distance.)

$$\text{SSD} = 1.47ut + \frac{u^2}{30\left\{\left(\frac{a}{32.2}\right) - G\right\}}$$

$$= 1.47 \times 60 \times 2.5 + \frac{60^2}{30\left\{\frac{11.2}{32.2} - 0.03\right\}}$$

$$= 220.50 + 377.56$$

$$= 598.1 \text{ ft}$$

- Use Eq. 15.5 to obtain the minimum length of vertical curve:

$$L_{\min} = \frac{AS^2}{2158}$$

$$= \frac{5 \times (598.1)^2}{2158}$$

$$= 828.8 \text{ ft}$$

Example

Example 3.2: Minimum Length of a Crest Vertical Curve

A crest vertical curve is to be designed to join a +2 percent grade with a -2 percent grade at a section of two-lane highway. Determine the minimum length of the curve if the design speed of the highway is 85 kph and S < L. Assume that f = 0.29 and that the perception reaction time is 2.5 sec.

$$\text{SSD} = u*t + \frac{u^2}{2g(f+G)}$$

$$= (85*\frac{1000}{3600})*2.5 + \frac{(85*\frac{1000}{3600})^2}{2*9.81(0.29-0.02)} = 164.1$$

To obtain the minimum length of the vertical curve

$$L_{\min} = \frac{AS^2}{404}$$

$$= \frac{4*164.1^2}{404} = 266.29 \text{ m}$$

interchange

interchange

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Sag Vertical Curves

- The main criteria used for designing sag vertical curves are:
  1. Provision of Minimum **S**topping **S**ight **D**istance
  2. Comfort Criterion
  3. Pleasant Appearance Criterion
  4. Adequate Drainage Criterion

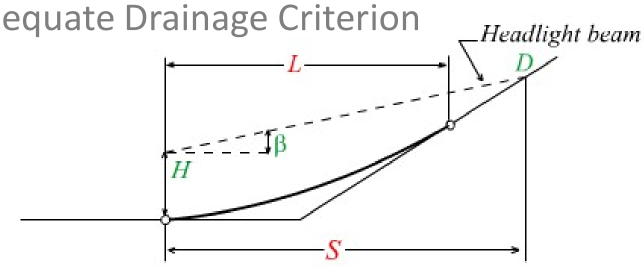

Figure 15.14 Headlight Sight Distance on Sag Vertical Curves ($S > L$)

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Sag Vertical Curves

1. Provision of Minimum Stopping Sight Distance

- The headlight SSD requirement is based on the fact that sight distance will be restricted during periods of darkness
  - Whereas during daylight periods, sight distance is unaffected by the sag curve.
- As a vehicle is driven on a sag vertical curve at night, the position of the headlight and the direction of the headlight beam will dictate the stretch of highway ahead that is lighted.
  - Therefore the distance that can be seen by the driver is controlled by the headlight beam.

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Sag Vertical Curves

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

AASHTO assumes H = 2 ft (0.6m) and β = 1 degree

ft

$$L_{min} = 2S - \frac{(400 + 3.5S)}{A} \quad (\text{for } S > L) \qquad L_{min} = \frac{AS^2}{400 + 3.5S} \quad (\text{for } S < L)$$

Metric units

$$L_{min} = 2S - \frac{(120 + 3.5S)}{A} \qquad L_{min} = \frac{AS^2}{120 + 3.5S}$$

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Sag Vertical Curves

2. Minimum Length based on Comfort Criterion

- When a vehicle travels on a sag vertical curve, both the gravitational and centrifugal forces act in combination, resulting in a greater effect on a crest vertical curve
  - where these forces act in opposition to each other.
- Several factors affect upon the comfort :
  - weight carried
  - body suspension of the vehicle
  - tire flexibility

It is generally accepted that a comfortable ride will be provided if the radial acceleration is not greater than 1 ft/sec^2 (0.3m/sec^2).

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Sag Vertical Curves

2. Minimum Length based on Comfort Criterion

- The following expression is used for comfort criterion:

ft

mi/hr

$$L_{min} = \frac{Au^2}{46.5}$$

Minimum Length for Comfort is typically about **75%** of that obtained from the headlight sight distance requirement.

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Sag Vertical Curves

3. Minimum Length of Curve based on Appearance Criterion

– The following expression is used:

$$L_{\text{min}} = 100A \text{ .... (ft)}$$

Longer curves are frequently necessary for major arterials if the general appearance is to be considered to be satisfactory.

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Sag Vertical Curves

4. Minimum Length based on Drainage Criterion

– It must be considered when the road is curbed.

– Actually there is a **maximum length** rather than minimum length

– The maximum length requirement: minimum slope of 0.35 percent be provided within 50 ft of the lowest point of the curve.

– The maximum length for this criterion is usually

- greater than the minimum length for the other criteria for speeds **up to 60 mi/h**
- usually equal for a speed of **70 mi/h**.

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Example

Example 3.3: Minimum Length of a Sag Vertical Curve

A sag vertical curve is to be designed to join a -3 percent grade with a +3 percent grade. If the design speed is 60kph, determine the minimum length of the curve that will satisfy minimum sight distance criteria. Assume that f = 0.32 and that the perception reaction time is 2.5 sec.

$$SSD = u*t + \frac{u^2}{2g(f+G)} = (60*\frac{1000}{3600})*2.5 + \frac{(60*\frac{1000}{3600})^2}{2*9.81(0.32-0.03)} = 90.5m$$

Determin L for the headlight sight distance criteria.
For S > L,

$$L=2S - \frac{(120+3.5S)}{A}$$

$$L=2*90.5 - \frac{(120+3.5*90.5)}{6} = 108.21m$$

This condition is not appropriate since 90.5<148.20 and therefore S<L.

For S<L then,

$$L= \frac{AS^2}{120+3.5S}$$

$$L= \frac{6*(90.5)^2}{120+3.5*90.5} = 112.51m$$

This Condition applies.

interchange

Example 15.3

Example 15.3 Minimum Length of a Sag Vertical Curve

A sag vertical curve is to be designed to join a −5% grade to a +2% grade. If the design speed is 40 mi/h, determine the minimum length of the curve that will satisfy all criteria. Assume $a = 11.2$ ft/sec² and perception-reaction time = 2.5 sec.

Solution:

- Find the stopping sight distance.

$$\begin{aligned} \text{SSD} &= 1.47\,ut + \frac{u^2}{30\left(\frac{11.2}{32.2} - G\right)} \\ &= 1.47 \times 40 \times 2.5 + \frac{40^2}{30(0.35 - .05)} = 147.0 + 177.78 \\ &= 324.78 \text{ ft} \end{aligned}$$

- Determine whether $S < L$ or $S > L$ for the headlight sight distance criterion.
  For $S > L$,

$$\begin{aligned} L_{min} &= 2S - \frac{(400 + 3.5S)}{A} \\ &= 2 \times 324.78 - \frac{400 + 3.5 \times 324.78}{7} \\ &= 430.03 \text{ ft} \end{aligned}$$

  (This condition is not appropriate since 324.78 < 430.03. Therefore $S \ngtr L$.)
  For $S < L$,

$$\begin{aligned} L_{min} &= \frac{AS^2}{400 + 3.5S} \\ &= \frac{7 \times (324.78)^2}{400 + 3.5 \times 324.78} \\ &= 480.48 \text{ ft} \end{aligned}$$

  This condition is satisfied since 324.78 < 480.48.
- Determine minimum length for the comfort criterion.

$$\begin{aligned} L_{min} &= \frac{Au^2}{46.5} \\ &= \frac{7 \times 40^2}{46.5} = 240.86 \text{ ft} \end{aligned}$$

- Determine minimum length for the general appearance criterion.

$$\begin{aligned} L_{min} &= 100\,A \\ &= 100 \times 7 = 700 \text{ ft} \end{aligned}$$

The minimum length to satisfy all criteria is 700 ft.
(*Note*: In order to check the maximum length drainage requirement, it is necessary to use procedures for calculating curve elevations that are discussed later in this chapter.)

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Length of Vertical Curves Based on *K Factors*

K Factors

- Crest and Sag curves:

Crest

$$L_{min} = \frac{AS^2}{2158} \text{ (for } S < L) \qquad L_{min} = 2S - \frac{2158}{A} \text{ (for } S > L)$$

Sag

$$L_{min} = \frac{AS^2}{400 + 3.5S} \text{ (for } S < L) \qquad L_{min} = 2S - \frac{(400 + 3.5S)}{A} \text{ (for } S > L)$$

$$L = KA$$

- **For Crest curves**: K values can be computed for the case where the **sight distance is less than the length of the vertical curve**.
- K factor is function of design speed.
- It is very convenient.

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Length of Vertical Curves Based on *K Factors*

- For Crest curves, It has been found that :
  - The minimum lengths when **S > L** do not produce practical design values
    - generally are not used.
- The common practice for this condition is:
  - Set minimum limits, ranging from 100 ft to 325 ft.
  - Use three times the design speed **(L = 3 V)**
  - **(L (ft) = 3 V (mi/hr))**

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K Factor Values (Crest Curves)

Table 15.5 Values of *K* for Crest Vertical Curves Based on Stopping Sight Distance

		Rate of Vertical Curvature, K[a]	
Design Speed (mi/h)	*Stopping Sight Distance (ft)*	*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: Adapted from *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

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K Factor Values (Sag Curves)

Table 15.6 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	*Rate of Vertical Curvature, K*[a] 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: Adapted from *A Policy on Geometric Design of Highways and Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used with permission.

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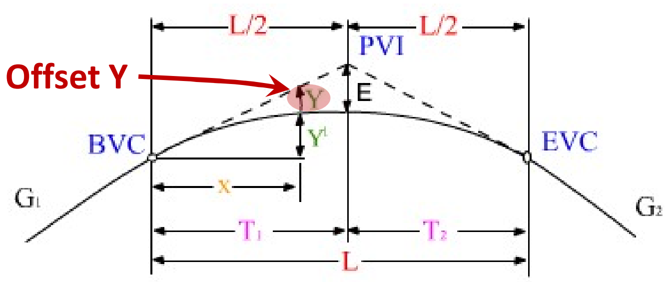
Elevation of Crest and Sag Vertical Curves

- Depending on the estimated curve length and the properties of parabola, elevations are determined.



where:
PVI = point of vertical intersection
BVC = begining of vertical curve (same point as PVC)
EVC = end of vertical curve (same as PVT)
E = external distance
G_1, G_2 = grades of tangents
L = length of curve
lgebraic difference of grades, (G_1-G_2)

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Derivation of the general equation

- *Y = a*x^2 *+ bx + c*
- *a is constant and b* and *c are 0*
- *Y = a*x^2
- *Slope (rate of change of the curve), Y' = 2ax*
- Rate of change of slope, Y'' = 2a
- 2a = grade change (A) divided by L
- A = $|G_1 - G_2|$
- 2a = (A / 100 L)
- a = (A / 200 L)
- Y = (A/200L) x^2

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Elevation of Crest and Sag Vertical Curves

- **The length of the vertical curve** is the horizontal projection of the curve and not the length along the curve.

Offset Y

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

The external distance E (when x = L/2)

$$E = \frac{A}{200L}\left(\frac{L}{2}\right)^2 = \frac{AL}{800}$$

$$Y = \left(\frac{x}{L/2}\right)^2 E$$

The location of the **high point of the crest vertical curve** is frequently of interest to the designer because of **drainage requirements**.

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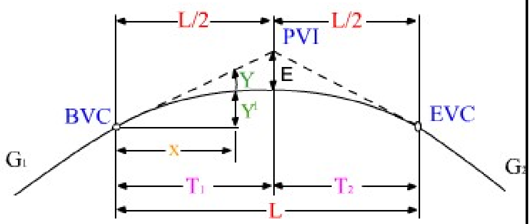
Derivation of the High/Low (maximum) Point

$$Y^1 = \frac{G_1 x}{100} - Y$$

$$= \frac{G_1 x}{100} - \frac{A}{200L}x^2$$

$$= \frac{G_1 x}{100} - \left(\frac{G_1 - G_2}{200L}\right)x^2$$



$$\frac{dY^1}{dx} = \frac{G_1}{100} - \left(\frac{G_1 - G_2}{100L}\right)x = 0$$

$$X_{\text{high}} = \frac{100L}{(G_1 - G_2)}\frac{G_1}{100} = \frac{LG_1}{(G_1 - G_2)}$$

X_{high} = distance in feet from BVC to the turning point

$$Y^1_{\text{high}} = \frac{LG_1^2}{200(G_1 - G_2)}$$

interchange

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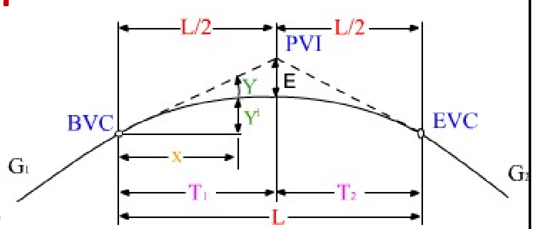
Elevation of Crest and Sag Vertical Curves

- **The elevation of any point at the curve of the vertical curve** is:



Y'

Elevation H (at x) =

$$\text{Elevation of BVC} + \frac{G_1 x}{100} - \left(\frac{G_1 - G_2}{200L}\right)x^2$$

$$X_{\text{high}} = \frac{LG_1}{(G_1 - G_2)}$$

$$Y_{1\text{high}} = \left(\frac{LG_1^2}{200(G_1 - G_2)}\right)$$

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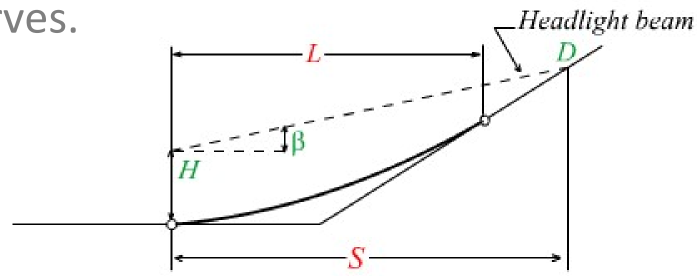
Elevation of Crest and Sag Vertical Curves

- For sag curves the equations are the same as crest curves.



- **The offset Y is added to the appropriate tangent elevation to obtain the curve elevation**

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Elevation of Crest and Sag Vertical Curves

- The following steps are followed to determine the elevations on vertical curves:

1. Determine the **minimum length of curve** to satisfy sight distance requirements (or other requirements).
2. Determine **the station and elevation of the PVI**.
3. Compute the **elevations** of the beginning of vertical curve (**BVC**) and end of vertical curve (**EVC**).
4. Compute **offsets Y** from the tangent to the curve at equal distances, usually 20m apart, beginning with the first whole station after BVC.
5. Compute elevations on the curve for each station as:

   elevation of the tangent ± offset from the tangent, Y.

   For **crest curves the offset is (-)** and for **sag curves the offset is (+).**
6. Compute the location and elevation of **the highest (crest) or lowest (sag) point on the curve.**

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Example 15.4

Example 15.4 Design of Crest Vertical Curve

A crest vertical curve joining a +3 percent and a −4 percent grade is to be designed for 75 mi/h. If the tangents intersect at station (345 + 60.00) at an elevation of 250 ft, determine the stations and elevations of the BVC and EVC. Also, calculate the elevations of intermediate points on the curve at the whole stations. A sketch of the curve is shown in Figure 15.16.

Solution: For a design speed of 75 mi/h, $K = 312$. From Table 15.5,

$$\text{Minimum length} = 312 \times [3 - (-4)] = 2184 \text{ ft}$$

$$\text{Station of BVC} = (345 + 60) - \left(\frac{21 + 84}{2}\right) = 334 + 68$$

$$\text{Station of EVC} = (334 + 68) + (21 + 84) = 356 + 52$$

$$\text{Elevation of BVC} = 250 - \left(0.03 \times \frac{2184}{2}\right) = 217.24 \text{ ft}$$

The remainder of the computation is efficiently done using the format shown in Table 15.7.

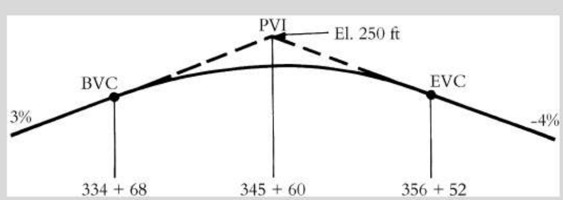

Figure 15.16 Layout of a Vertical Curve for Example 15.4

Example 15.4

Table 15.7 Elevation Computations for Example 15.4

Station	Distance from BVC (x) (ft)	Tangent Elevation (ft)	Offset $\left[y = \frac{Ax^2}{200L}\right]$ (ft)	Curve Elevation (Tangent Elevation – Offset) (ft)
BVC 334 + 68	0	217.24	0.01	217.24
BVC 335 + 00	32	$217.24 + \frac{32}{100} \times 3 = 218.20$	0.02	218.18
BVC 336 + 00	132	221.20	0.28	220.92
BVC 337 + 00	232	224.20	0.86	223.34
BVC 338 + 00	332	227.20	1.77	225.43
BVC 339 + 00	432	230.20	2.99	227.21
BVC 340 + 00	532	233.20	4.54	228.66
BVC 341 + 00	632	236.20	6.40	229.80
BVC 342 + 00	732	239.20	8.59	230.61
BVC 343 + 00	832	242.20	11.09	231.11
BVC 344 + 00	932	245.20	13.92	231.28
BVC 345 + 00	1032	248.20	17.07	231.13
BVC 346 + 00	1132	251.20	20.54	230.66
BVC 347 + 00	1232	254.20	24.32	229.88
BVC 348 + 00	1332	257.20	28.43	228.77
BVC 349 + 00	1432	260.20	32.86	227.34
BVC 350 + 00	1532	263.20	37.61	225.59
BVC 351 + 00	1632	266.20	42.68	223.52
BVC 352 + 00	1732	269.20	48.07	221.13
BVC 353 + 00	1832	272.20	53.79	218.41
BVC 354 + 00	1932	275.20	59.82	215.38
BVC 355 + 00	2032	278.20	66.17	212.03
BVC 356 + 00	2132	281.20	72.84	208.36
EVC 356 + 52	2184	282.76	76.44	206.32

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Example 15.5 Design of Sag Vertical Curve

A sag vertical curve joins a −3 percent grade and a +3 percent grade. If the PVI of the grades is at station (435 + 50) and has an elevation of 235 ft, determine the station and elevation of the BVC and EVC for a design speed of 70 mi/h. Also compute the elevation on the curve at 100-ft intervals. Figure 15.17 shows a layout of the curve.

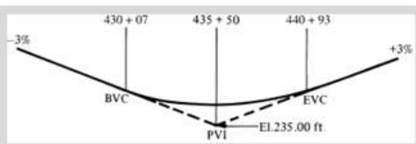

Figure 15.17 Layout for a Sag Vertical Curve for Example 15.5

Solution: For a design speed of 70 mi/h, $K = 181$, using the higher rounded value in Table 15.7.

$$\text{Length of curve} = 181 \times 6 = 1086 \text{ ft}$$
$$\text{Station of BVC} = (435 + 50) - (5 + 43) = 430 + 07$$
$$\text{Station of EVC} = (435 + 50) + (5 + 43) = 440 + 93$$
$$\text{Elevation of BVC} = 235 + 0.03 \times 543 = 251.29$$
$$\text{Elevation of EVC} = 235 + 0.03 \times 543 = 251.29$$

The computation of the elevations is shown in Table 15.8.

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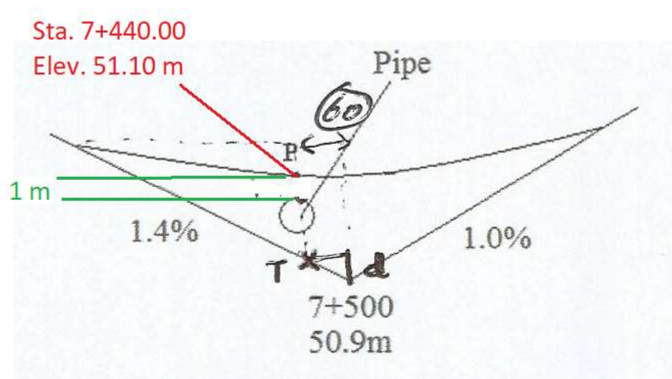
Table 15.8 Elevation Computations for Example 15.5

Station	Distance from BVC (x) (ft)	Tangent Elevation (ft)	Offset $\left[Y = \frac{Ax^2}{200L} \right]$ (ft)	Curve Elevation (Tangent Elevation + Offset) (ft)
BVC 430 + 07	0	251.29	0.28	251.29
BCV 431 + 00	93	248.50	0.24	248.74
BCV 432 + 00	193	245.50	1.03	246.53
BCV 433 + 00	293	242.50	2.37	244.87
BCV 434 + 00	393	239.50	4.27	243.77
BVC 435 + 00	493	236.50	6.71	243.21
BCV 436 + 00	593	233.50	9.71	243.21
BCV 437 + 00	693	230.50	13.27	243.77
BCV 438 + 00	793	227.50	17.37	244.87
BCV 439 + 00	893	224.50	22.03	246.53
BCV 440 + 00	993	221.50	27.24	248.74
EVC 440 + 93	1086	218.71	32.58	251.29

Example

Q3. (30 points) A vertical curve joins a -1.4% grade to +1.0% grade. The PVI is at station 7+500 and elevation 50.90 m above mean sea level. The centerline of the roadway must be at least 1.0 m above a pipe located at station 7+440, as shown in the sketch below. The elevation of the top of the pipe is 51.10 m above mean sea level.

What is the minimum length of the vertical curve that can be used?
If the length of the curve is 350m, what is the height of the lowest point on the curve?



$(7+500) - (7+440)$

$= \boxed{60\ m}$

* $d = \frac{60 \times 1.4}{100} = \boxed{0.84\ m}$

* Elevation for "P" $= 51.10 + 1 = \boxed{52.10\ m}$

* Elevation of "T" $= 50.9 + 0.84 = 51.74$

* $Y = 52.10 - 51.74 = 0.36\ m$

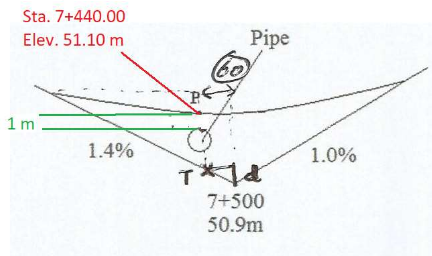
$$Y = \frac{A x^2}{200 L} = \frac{(2.4)(L/2 - 60)^2}{200\ L} = 0.36$$

$$\frac{72 L}{2.4} = \frac{L^2}{4} + 3600 - 60 L$$

$$\frac{L^2}{4} - 90 L + 3600 = 0$$

$$L = \frac{90 \pm \sqrt{90^2 - (4 \times 0.25 \times 3600)}}{2 \times 0.25} = \frac{90 \pm 67.08}{0.5}$$

$$= \boxed{314.16\ m}$$



Home work

- Problems:
  - 15-3
  - 15-7
  - 15-10 (15-11 fifth version)
  - 15-12 (15-14 fifth version)
  - 15-21 (15-22 fifth version)
  - 15-22 (15-23 fifth version)

4.4 Special Facilities and Parking Facilities

SPECIAL FACILITIES FOR HEAVY VEHICLES ON STEEP GRADES

- Statistics indicate a continual increase in the annual number of vehicle-miles of large trucks on highways.
  - as the grade of a highway section increases, the presence of trucks become more pronounced
- It becomes necessary to consider the provision of special facilities on highways with steep grades where high volumes of heavy vehicles exist.
  - Climbing lanes
  - Emergency escape ramps.

Climbing lanes

- **A climbing lane is an extra lane in the upgrade direction for use by heavy vehicles whose speeds are significantly reduced by the grade.**
- **Objective:** A climbing lane eliminates the need for drivers of light vehicles to reduce their speed when encountering heavy slow-moving vehicles.
- They become important because of:
  - The increasing rate of crashes which is directly associated with the reduction in heavy vehicles speed on steep sections of two-lane highways
  - The significant reduction of the capacity of these sections when heavy vehicles are present

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Climbing lanes

- The need for a climbing lane is evident when a grade is longer than its critical length,
  - Critical length is the length that will cause a speed reduction of the heavy vehicle by at least 10 mi/h.
- The amount by which a truck's speed is reduced when climbing a steep grade depends on the **length of the grade**.

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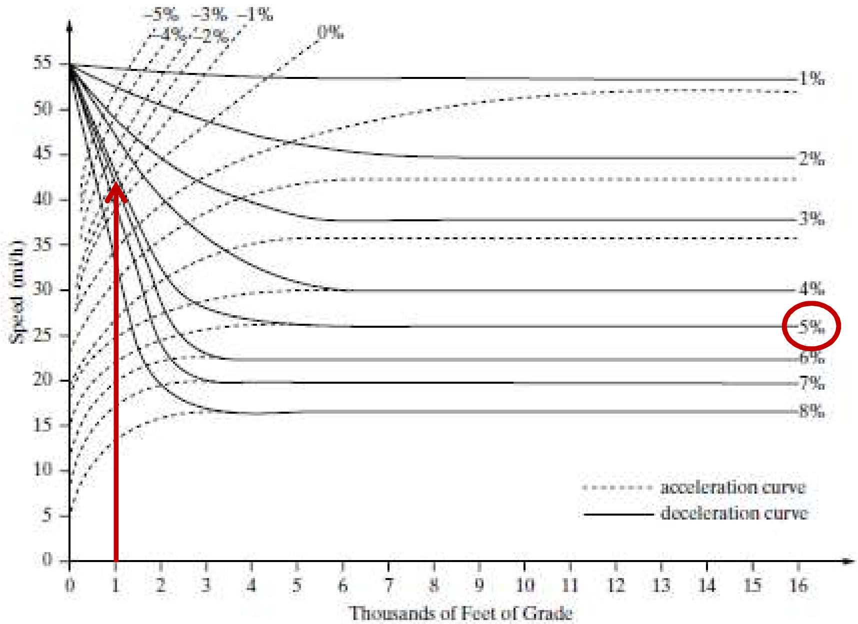
Climbing lanes



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Climbing lanes

- The length of the climbing lane depends on the physical characteristics of the grade, but
  - Climbing lane should be long enough to facilitate the heavy vehicle's rejoining the main traffic stream without causing a hazardous condition.
- A climbing lane is provided only if (in addition to the critical length requirement):
  - Upgrade traffic flow rate is greater than 200 veh/h
  - Upgrade truck flow is higher than 20 veh/h.
- Climbing lanes are not typically used on multilane highways.

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Emergency Escape Ramps

- An emergency escape ramp is 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.
- Common designs are:

1. **The sandpile**

(a) Sandpile

- It provides increased rolling resistance
- It is placed with an upgrade to assist stopping by gravity.
- Not greater than 400 ft in length.

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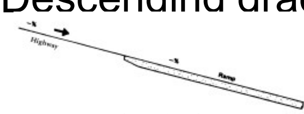
Emergency Escape Ramps

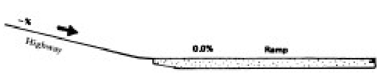
- Common designs are:

2. Descending grade



(b) Descending grade

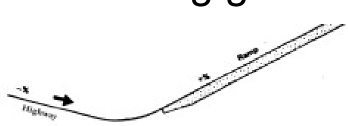
2. Horizontal grade



(c) Horizontal grade

- **Does not employ gravity in stopping the vehicle**
- **It utilizes the increased rolling resistance of the ramp surface.**

3. Ascending grade



(d) Ascending grade

- **combines the effect of gravity and the increased rolling resistance.**
- **This ramp design is the shortest of all types.**

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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.

1. **Design of On-Street Parking Facilities**
2. **Design of Off-Street Parking Facilities—Surface Car Parks (Parking Lots)**
3. **Design of Off-Street Parking Facilities—Garages**

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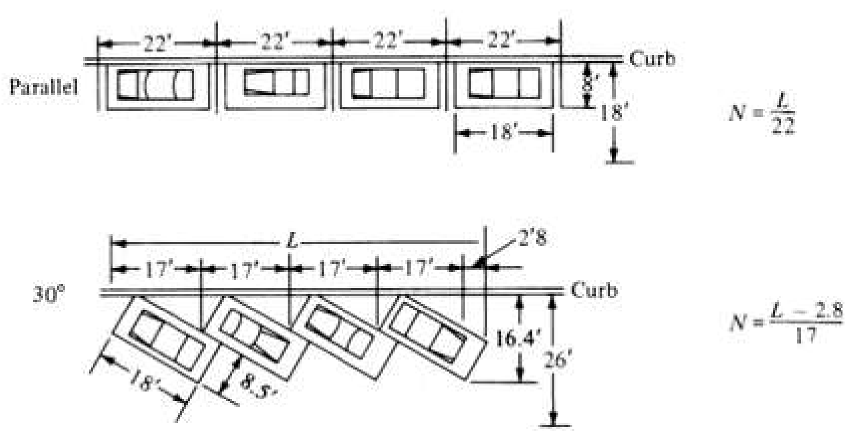
Parking Facilities

1. **Design of On-Street Parking Facilities**
   - On-street parking facilities may be designed with parking bays parallel or inclined to the curb.
   - The number of parking bays that can be fitted along a given length of curb increases as the angle of inclination increases
   - Parking bays that are inclined at angles to the curb interfere with the movement of traffic,
     - Crash rates tend to be higher
   - Dimension of the design vehicle has to be considered.

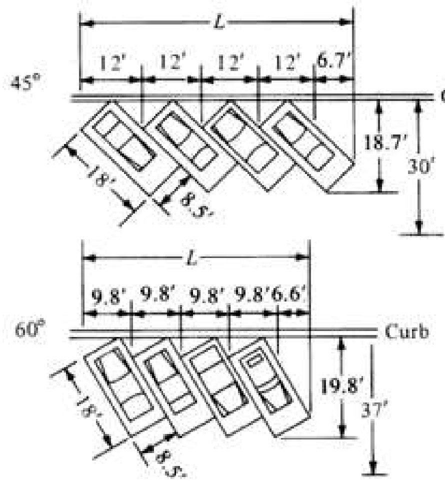
Parking Facilities

1. **Design of On-Street Parking Facilities**



Parking Facilities

1. **Design of On-Street Parking Facilities**



$$N = \frac{L - 6.7}{12}$$

A parking space is called **parking stall**

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

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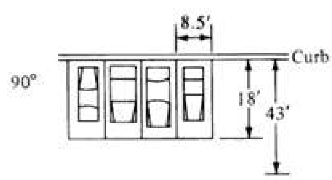

$$N = \frac{L}{8.5}$$

N = number of spaces
L = curb length

interchange

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Parking Facilities

2. **Design of Off-Street Parking Facilities—Surface Car Parks**
   - The primary aim in designing off-street parking facilities is to **obtain as many spaces as possible within the area provided**.
   - **Important consideration:** the layout should be such that parking a vehicle involves only one distinct maneuver, without the necessity to reverse.

- **Parking spaces are efficiently used when the parking bays are inclined at 90 degrees to the direction of traffic flow.**

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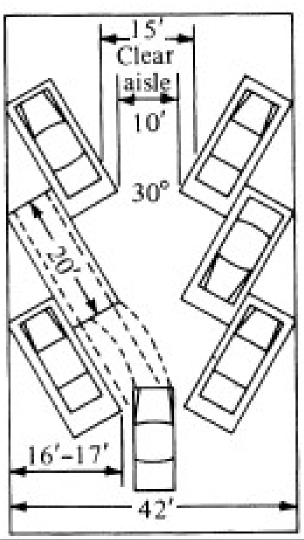
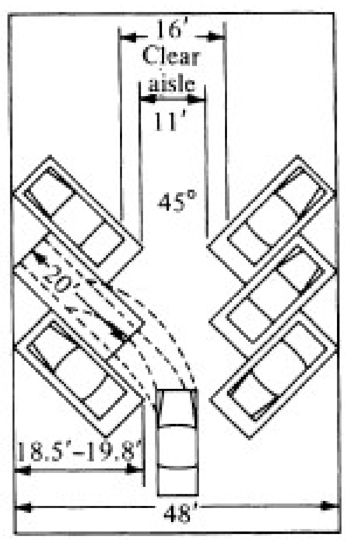
Parking Facilities

2. **Design of Off-Street Parking Facilities—Surface Car Parks**





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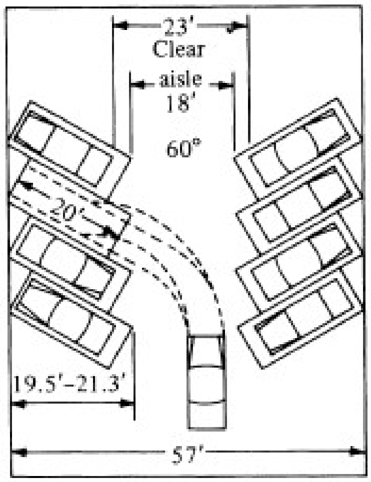
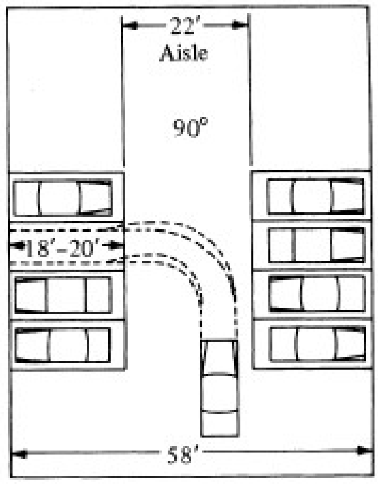
Parking Facilities

2. **Design of Off-Street Parking Facilities—Surface Car Parks**

Highest Capacity





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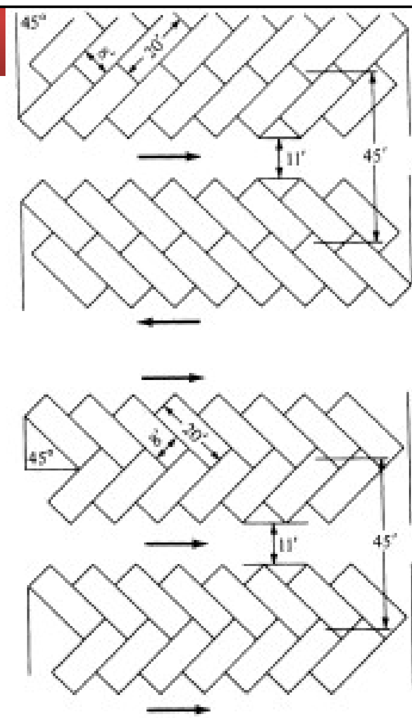
Parking Facilities

2. **Design of Off-Street Parking Facilities—Surface Car Parks**
   – The use of the **Herringbone** layout facilities traffic circulation because it provides for one-way flow of traffic on each aisle.

Best Trade-off between Circulation and capacity



Parking Facilities

3. Design of Off-Street Parking Facilities—Garages

- Parking garages consist of several platforms, supported by columns,
  - which are placed in such a way as to facilitate an efficient arrangement of parking bays and aisles.
- Access ramps connect each level with the one above.
  - The gradient usually is not greater than 1:10 on straight ramps and 1:12 on the centerline of curved ramps.
  - The radius measured to the end of the outer curve should not be less than 70 ft.
  - maximum superelevation should be 0.15 ft /ft.
  - Lane width should not be less than 16 ft for curved ramps and 9 ft for straight ramps.

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Parking Facilities

3. Design of Off-Street Parking Facilities—Garages

- Ramps can be one-way or two-way, with one-way ramps preferred.
  - In two-way ramps, the lanes must be clearly marked and where possible physically divided at curves and turning points to avoid head-on collisions.
- Platforms may be connected by elevators into which cars are driven or placed mechanically. Elevators then lift the car to the appropriate level for parking.

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Parking Facilities

3. Design of Off-Street Parking Facilities—Garages

– The size of the receiving area is an important factor in garage design and depends on whether the cars are **owner-parked (self-parking)** or **attendant-parked**.

– Attendant-parked: reservoir space must be provided that will accommodate temporary storage for entering vehicles.

– The size of reservoir space depends on the ratio of the rate of storage of vehicles to their rate of arrival.

- **Rate of storage** must consider the time required to transfer the vehicle from its driver to the attendant.

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Parking Facilities

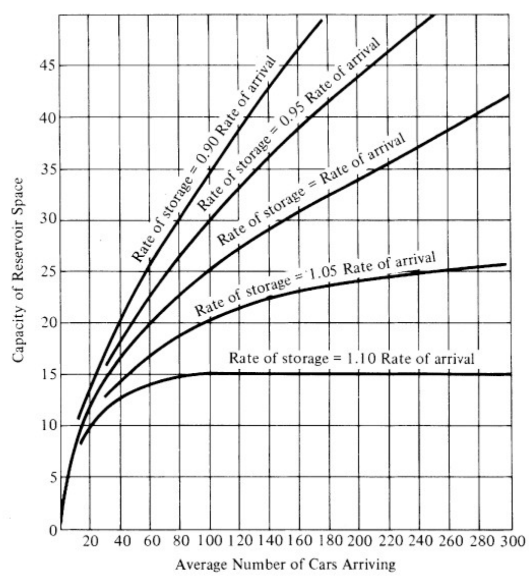

Figure 15.36 Reservoir Space Required If Facility Is Overloaded Less Than One Percent of Time

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Parking Facilities

3. Design of Off-Street Parking Facilities—Garages

– Automatic Parking Garage

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Consideration for off-street parking

- Size of the facility
- Entrance – Exit
- Circulation
- Access
- Corners and critical places
- End spaces

interchange

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Homework

- Problem 15-25 in the 4^{th} version (or 15-26 fifth version)
- Try at 90^{o}
- Try it at 45^{o}

interchange

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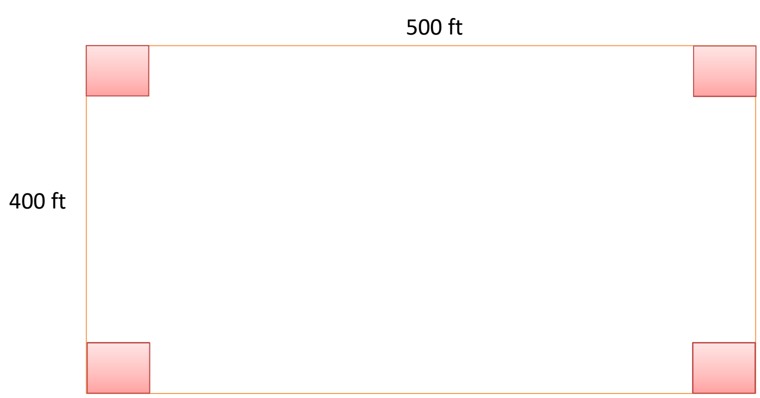
Sample

- Each isle is ≈ 58 ft
- 400 / 58 = 6.89 → 6 isles → 400 / 6 = 66.7 ft
- (500 – 24.5x2) / 8.5 = 53.05 ≈ 53 spaces
- 6 isles, each 53 x 2 spaces → = 636 spaces



interchange

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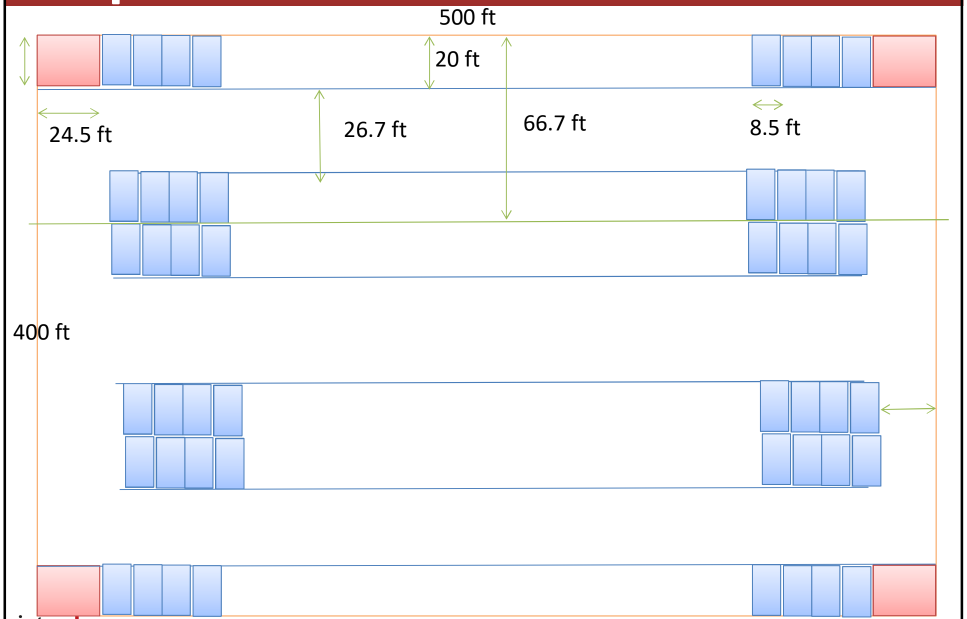
Sample



interchange

Highway Geometric Design

Thank You Very Much