UNIT 7

ROUTE SURVEYING

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Introduction

Route surveying is comprised of all survey operations required for design and construction of engineering works such as highways, pipelines, canals, or railroads. At Caltrans a route surveying system is generally associated with highway design and construction.

A route surveying system usually contains four separate but interrelated processes:

- Reconnaissance and planning
- Works design
- Right of way acquisition
- Construction of works

This video unit presents principles and techniques of route surveying and calculation operations related to these four processes.

Performance Expected on the Exams

Solve various exam problems related to principles, design and application of vertical curves.

Solve various exam problems related to principles, design and application of horizontal curves.

Compute and interpret grades for roads or streets from design information.

Compute and interpret grades, cuts and fills and positions for placement of slope stakes.

Key Terms

Arc

Arc definition

Centerline

Central angle

Chord

Chord definition

Circular curve

Construction

Contours

Deflection angle

Degree of curve

Direction of travel

Elevation

External distance

Grade

Horizontal curve

Length of arc

Mid-ordinate distance

Offset

Parabola

Percent of slope

Radian

Radius

Radius point

Rate of change

Right of way

Sag curve

Slope stakes

Stationing

Summit curve

Tangent

Tangent offsets

Vertical curves

Video Presentation Outline

The Route Surveying System

Linear Projects

- Highways
- Pipelines
- Canals
- Railroads

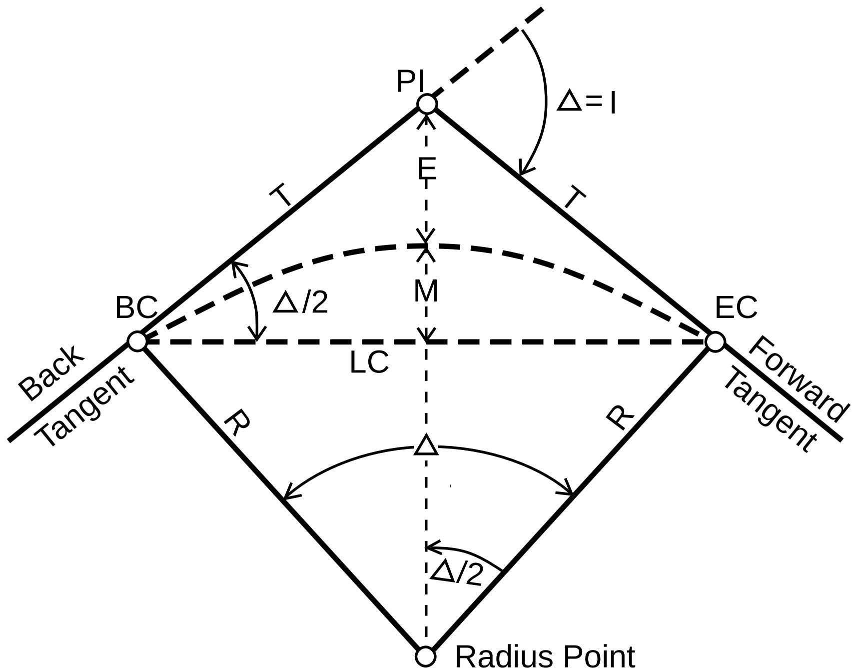
Major Elements of Route Surveying Systems

- Reconnaissance and planning
- Design
- Right-of-way acquisition
- Construction

Major Components of Route Surveying Systems

- Stationing
- Offset distance
- Profile grades (slope percentage)
- Horizontal curves
- Vertical curves
- Cross sections
- Slope staking

Components of Horizontal Circular Curves



Terminology for Horizontal Circular Curves

L = length of curve (arc)	Δ or I = central angle
LC = long chord	R = radius
T = tangent length	PI = intersection of tangents
E = external distance	M = middle ordinate distance

Formulae for Horizontal Circular Curves

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

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

$$LC = 2R \times \sin\frac{\Delta}{2}$$

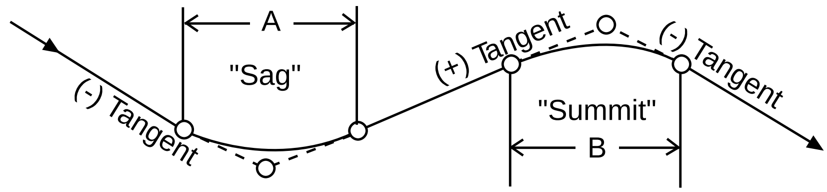
$$E = R\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right)$$

$$L = R \times \Delta \text{ (exp. in radians)}$$

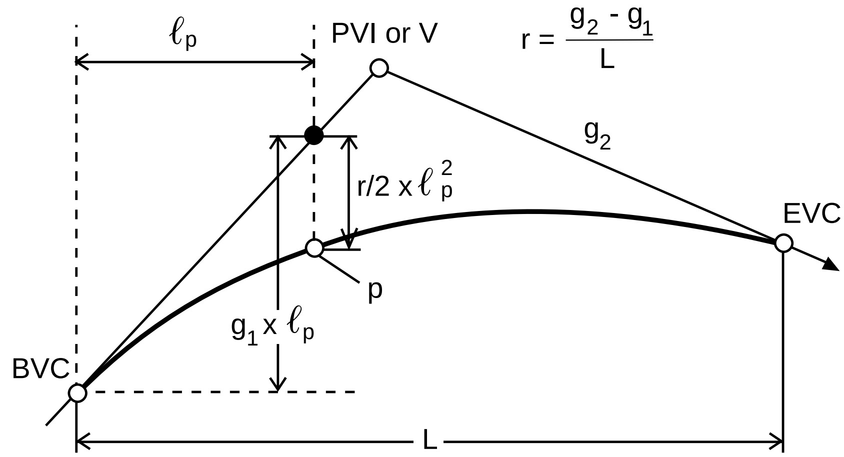
$$L = 2\pi R\left(\frac{\Delta}{360^\circ}\right)$$

Components of Vertical Parabolic Curves

Types of Vertical Curves



Components and Equations of Vertical Curves



Terminology for Vertical Parabolic Curves

BVC = beginning of vertical curve

PVI = point of intersection

g_1 = slope of back tangent (in %)

L = length of curve, in stations

EVC = end of vertical curve

r = rate of change

g_2 = slope of forward tangent (in %)

ℓ = length of sub-curve, in stations, to point on curve from BVC

$$\text{Elev.}_p = \left(\frac{r}{2}\right) \ell^2_p + g_1 (\ell_p) + \text{Elev}_{BVC}$$

$$\ell_{\text{high/low point}} = \left| \frac{g_1}{r} \right|$$

Example Problem

Problem B-5 1990 LS

You have been provided design criteria shown in the diagrams 1, 2, and 3, below and on the next page.

Answer the following questions using the information provided in the diagrams.

1. Determine the ground elevation of the back of the sidewalk at the following locations:
   A. Driveway centerline
   B. Southeasterly property corner
   C. Southwesterly property corner
2. Provide the grade percentage between Point C and the building pad. Show all calculations.
3. What is the slope ratio from Point A to the toe of slope?
4. Calculate the cut from the back of the sidewalk to the sewer lateral invert at the property line.
5. Calculate the distance from the north property line to the toe of slope at Point B.

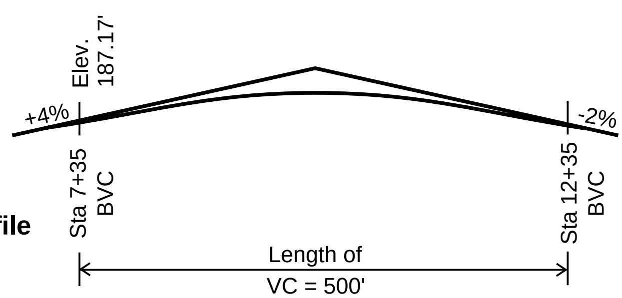


Diagram 1
Street ℄ Profile

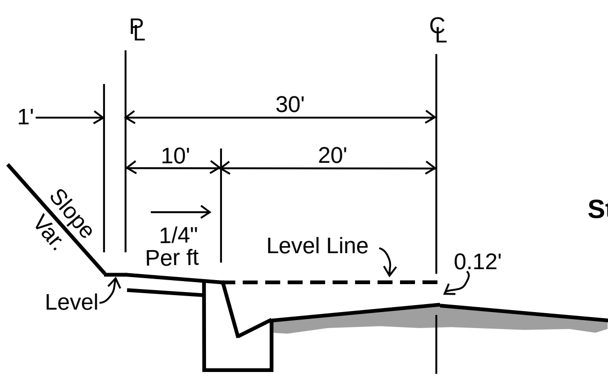


Diagram 2
Street Section

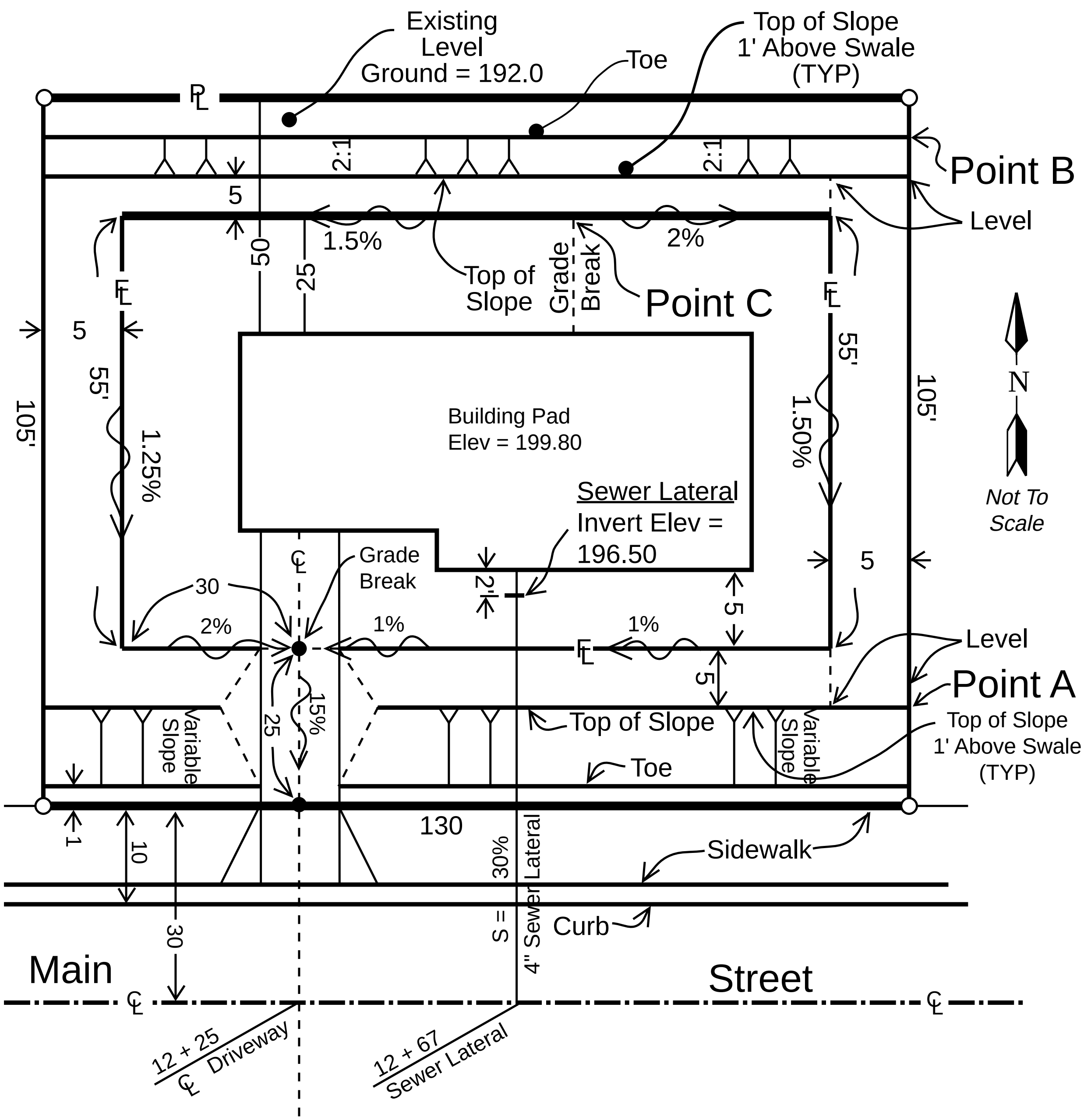


Diagram 3
Plan View
(all dimensions are in ft)

Solution of 1990 California LS Examination Problem B-5

NOTE: See video for solution methodology; ±0.02' is acceptable for all answers.

1. Calculation of the elevation of the back of sidewalk at the:

   A. Centerline of the driveway: **192.69'**
   B. Southeasterly property corner: **190.80'**
   C. Southwesterly property corner: **193.28'**

2. Grade percentage of the slope between Point C and the top of building pad: **3.40%**
3. Slope ratio from Point A to toe of slope opposite Point A: **39.68% or 2.52/1**
4. Cut from the back of sidewalk to the invert of sewer lateral at the property line: **C-3** $^{\underline{76}}$'
5. Distance from the north property line to toe of slope at point B: **5.66'**

Sample Test Questions

1. What is the "station" of the ending point of a surveyed line originating at "sta. 23+45.50" that has a measured length of 412.91 ft?

   A. Sta. 19+32.59
   B. Sta. 27+58.41
   C. Sta. 19+32.41
   D. Sta. 27+58.59

2. How far apart is survey point "G" (sta. 61+56.81) and survey point "H" (sta. 24+12.93)?

   A. 8,569.26
   B. 3,743.22
   C. 3,743.88 ft
   D. 8,569.74 ft

3. A section of road rises 18.50 ft in 435 ft (horizontal run). What is the percentage of slope for this section of the road (nearest two decimal places)?

   A. +4.25%
   B. -4.25%
   C. +4.05%
   D. -4.05%

4. The percentage of slope for a proposed ramp is -2.65%. What is the change in elevation of this ramp for a horizontal length of 412 ft?

   A. +10.92
   B. +100.92
   C. -10.92 ft
   D. -100.92

5. A distance measured perpendicularly from the center or base line of a survey project is called:

   A. agonic line
   B. an offset
   C. tangent correction line
   D. secant correction line

6. Stationing and offsets may define a ______________ system.

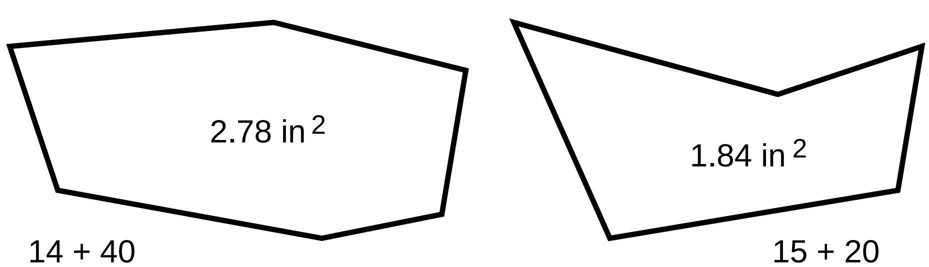
   A. solar correction
   B. plane coordinate
   C. cadastral
   D. construction

7. NGVD 1929 is one of the control systems that ___________ are referenced to.

   A. elevations
   B. solar positions
   C. horizontal positions
   D. GIS data bases

8. Two cross sections, plotted at a horizontal scale: 1 in=40 ft, and vertical scale: 1 in=10 ft, along with their areas are shown in the sketch below. Compute the volume (in cubic yards) contained between the two stations.

   A. 147,840
   B. 73,920
   C. 16,427
   D. 2,738

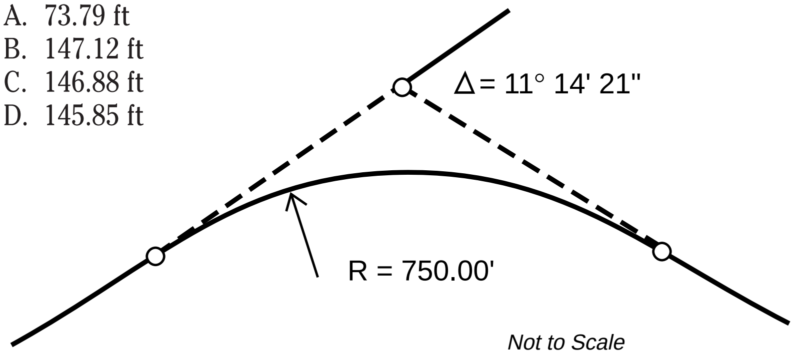


9. In laying out a highway for construction, slope stakes are needed. A fill is required at station 14+40; centerline elevation 48.75. The full width of the road from top of slope to top of slope is 36 ft and is level. The road design specifies side slopes of 2.5/1. A trial shot is taken 40.0 ft from the centerline at elevation 42.3. Assuming natural ground is fairly level, how far and in which direction from the trial shot should the "catch point" be located and staked?

   A. 19.4 ft toward centerline
   B. 5.9 ft away from centerline
   C. 5.9 ft toward centerline
   D. 19.4 ft away from centerline

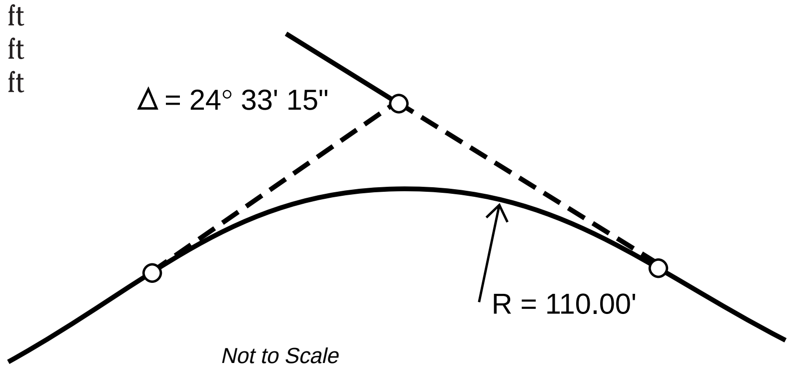
10. What is the length of arc for the horizontal curve shown in the sketch below?

   A. 73.79 ft
   B. 147.12 ft
   C. 146.88 ft
   D. 145.85 ft



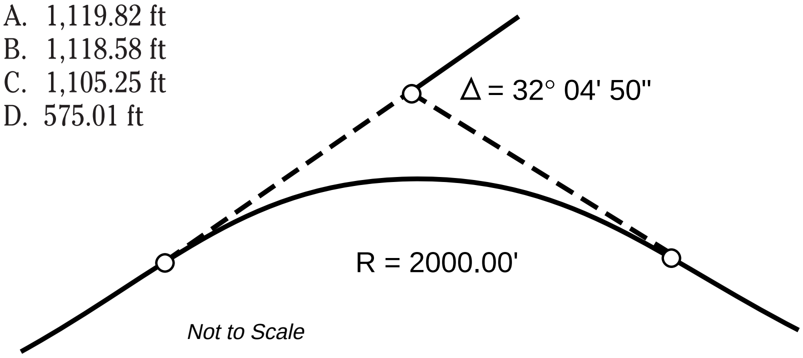
11. What is the length of tangent for the horizontal curve shown in the sketch below?

   A. 47.14 ft
   B. 46.78 ft
   C. 46.71 ft
   D. 23.94 ft



12. What is the length of long chord for the horizontal curve shown in the sketch below?

    A. 1,119.82 ft
    B. 1,118.58 ft
    C. 1,105.25 ft
    D. 575.01 ft



13. For a highway curve with a degree of curve of 06° 30', what is the length of chord between sta.16+32.09 and sta. 17+51.86?

    A. 119.65 ft
    B. 119.68 ft
    C. 119.77 ft
    D. 119.81 ft

14. From the given curve design data, calculate the stations of the BC and EC of this horizontal curve.

    R = 1270.00 ft

    Sta. @ PI = 34+21.89

    I = 26° 14' 11"

    A. BC = 31+25.93; EC = 37+17.85
    B. BC = 31+31.13; EC = 37+12.67
    C. BC = 31+26.42; EC = 37+10.48
    D. BC = 31+25.93; EC = 37+07.48

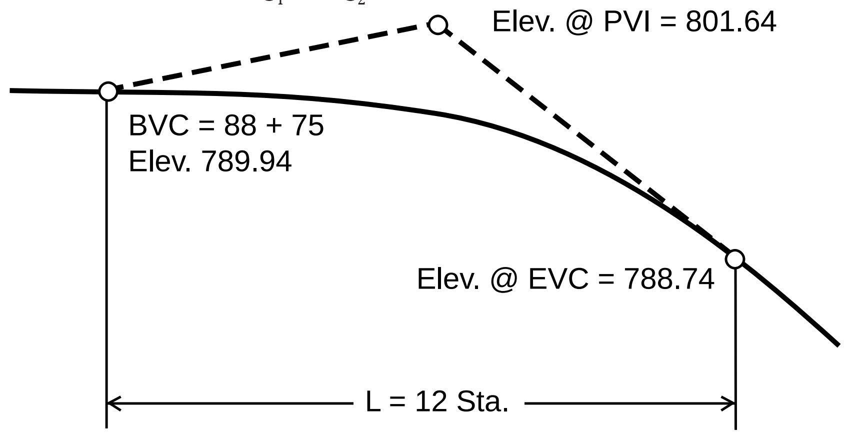
15. From the following design information for a circular curve:

    R = 760.00 ft; delta = 12° 04' 15"; Sta @ BC = 9+63.04

    What is the deflection angle (from the BC) to sta. 10+80?

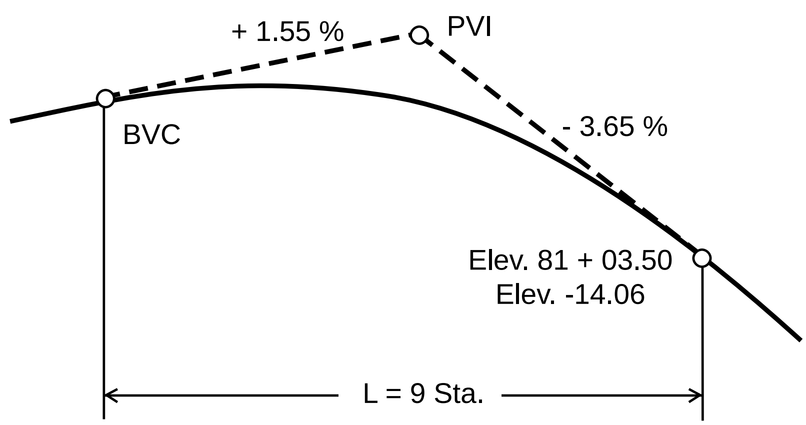
    A. Deflection angle = 04° 24' 32"
    B. Deflection angle = 04° 24' 03"
    C. Deflection angle = 08° 49' 06"
    D. Deflection angle = 08° 48' 06"

16. From the equal-tangent vertical curve data given in the sketch below, calculate the values of g_1 and g_2.



A. g_1 = -1.95%; g_2.= +2.15%
B. g_1 = +1.95%; g_2.= -2.15%
C. g_1 = -0.51%; g_2.= +0.46%
D. g_1 = +0.51%; g_2.= -0.46%

17. Using the equal-tangent vertical curve data given in the sketch below, calculate the station and elevation for the PVI and the BVC of the curve.



A. Sta. of BVC = 72+03.50; elev. = -9.34
Sta. of PVI = 21+45.50; elev. = -2.36

B. Sta. of BVC = 72+03.50; elev. = -4.62
Sta. of PVI = 76+53.50; elev. = 2.36

C. Sta. of BVC = 72+03.50; elev. = 4.62
Sta. of PVI = 21+45.50; elev. = 2.36

D. Sta. of BVC = 72+03.50; elev. = 9.34
Sta. of PVI = 21+45.50; elev. = 2.36

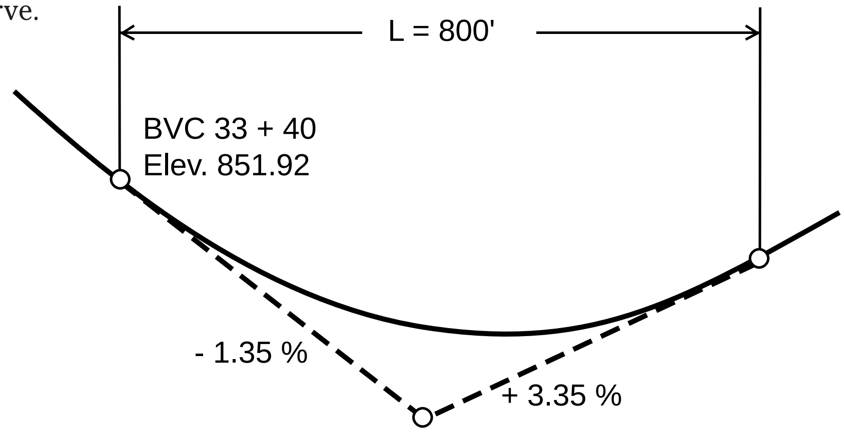
18. An equal-tangent vertical curve has the following design data:

g_1 = -3.65%; g_2 = -0.30%; L = 4 sta.

What is the rate of change for this curve?

A. +0.988% per full station
B. - 0.988% per full station
C. +0.838% per full station
D. - 0.838% per full station

19. Using the design data for the equal-tangent vertical curve shown in the sketch below, calculate the station and elevation for the low point of the curve.



A. Low point station = 35+65; elev. = 850.31
B. Low point station = 35+70; elev. = 850.37
C. Low point station = 35+70; elev. = 850.41
D. Low point station = 35+90; elev. = 850.37

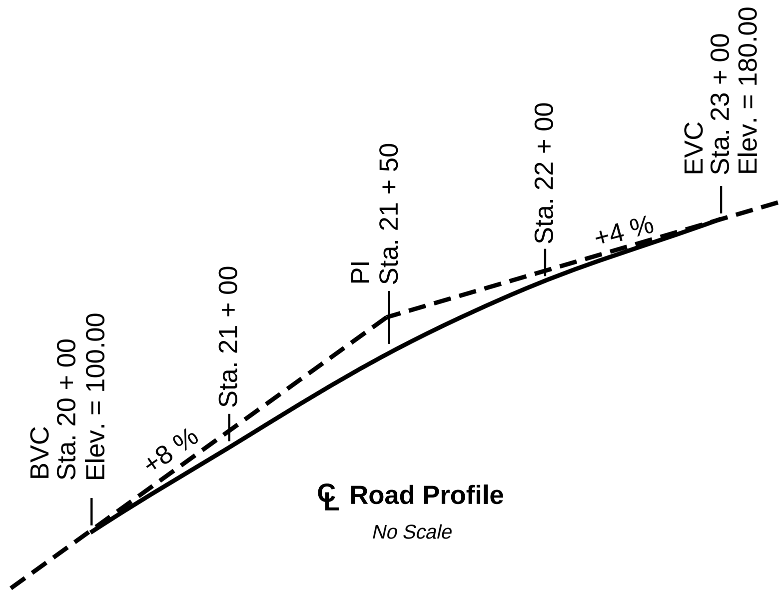
20. Problem A-6 1992 LS

A surveyor has been requested to set a slope stake at a five-ft offset as shown on the following data sheet. Place the slope stake for the daylight cut at Station 21+00. Assume the slope has a uniform grade between topo shots.

Requirements: Answer the following questions using the information provided on the data sheet.

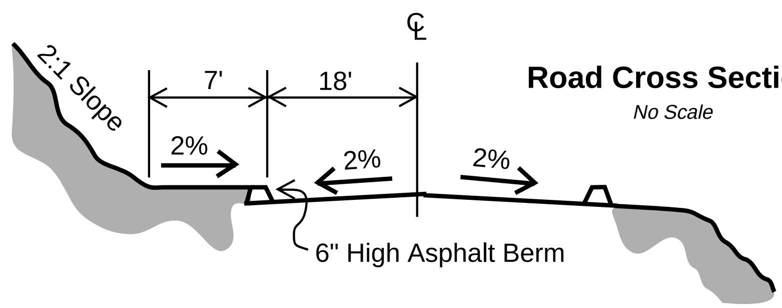
A. Determine the following for Station 21+00:
   1. Centerline elevation
   2. Hingepoint elevation (toe of 2:1 slope)
   3. Distance left from centerline for offset stake

B. What specific information should be put on the stake to construct the daylight cut and toe of slope as required above?



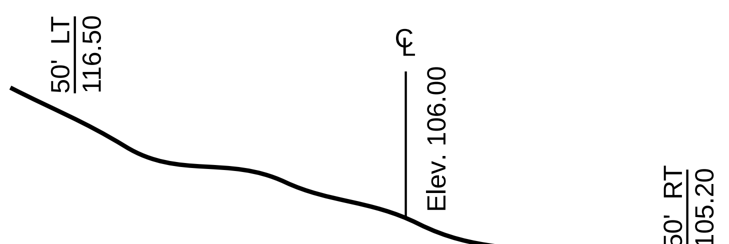
℄ Road Profile

No Scale



Road Cross Section

No Scale



Existing Ground at Staton 21+00

No Scale

NOTE: All units are in ft unless otherwise stated

21. Problem B-5 1991 LS

During the rough grading phase of construction, you discovered a 12-inch water pipe crossing the roadway at Station 18+50. The elevation on top of the pipe is 730.92 ft. You have communicated this information to the project engineer who has asked you to calculate and lay out an equal tangent vertical curve so that the top of pavement passes 36 in above the top of the water pipe with the following design elements:

Vertical curve beginning at Station 16+50 (Vertical Curve #2)

G_1 = +8.75%

G_2 = -1.50%

A drop inlet needs to be installed at the lowest possible elevation between the beginning and end of horizontal curve #1 along the flowline.

Required:
Show all work in completing the following requirements.

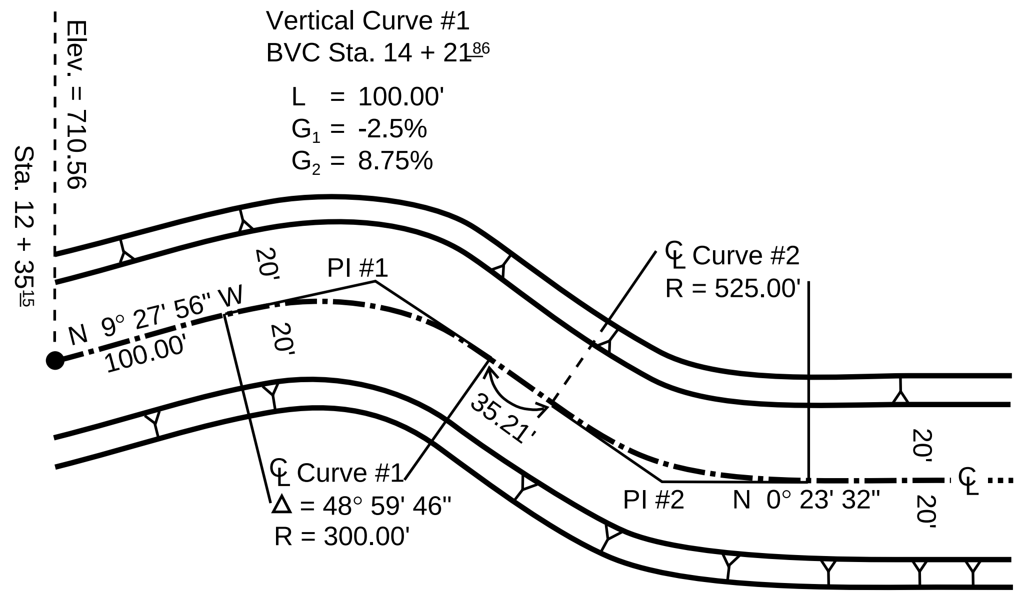
A. Calculate the following elements of horizontal curve #1:
   1. Tangent
   2. Length
   3. EC Station

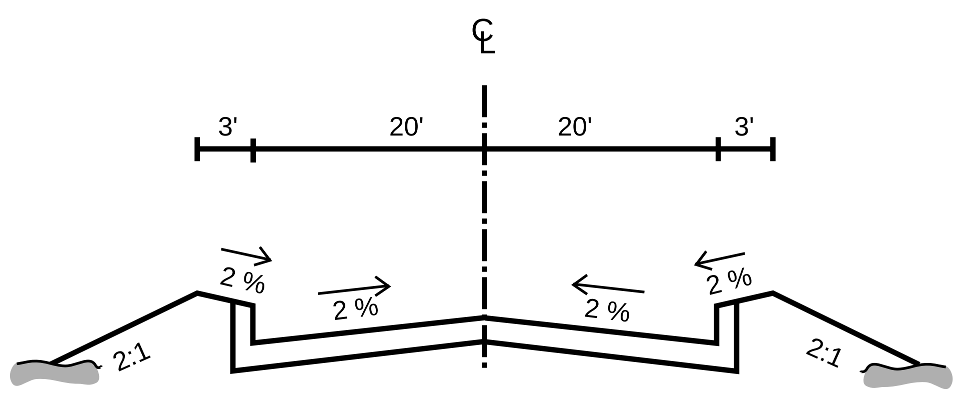
B. Calculate the delta of horizontal curve #2.

C. Calculate
   1. The station, and
   2. The elevation of the top of the drop inlet to be installedbetween the beginning and the end of horizontal curve #1.

D. Calculate the following elements of the equal tangent vertical curve #2:
   1. Total length
   2. Point of Vertical Intersection Station
   3. Pavement elevation at the intersection of the centerline and the water pipe

Plan View of Future Roadway





Typical Cross Section

Not to Scale

Answer Key

1. B. (sta. 27+58.41)
2. C. (3,743.88 ft)
3. A. (+4.25%)
4. C. (-10.92 ft)
5. B. (an offset)
6. B. (plane coordinate)
7. A. (elevations)
8. D. (2,738)
9. C. (5.9 ft towards the centerline)
10. B. (147.12 ft)
11. D. (23.94 ft)
12. C. (1,105.25 ft)
13. B. (119.68 ft)
14. D. (the sta. of BC is 31+25.93; the sta. of EC is 37+07.48)
15. A. (the deflection angle to sta. 10+80, is 04° 24' 32")
16. B. (G_1 = +1.95%; G_2 = -2.15%)
17. B. (Sta. @ BVC = 72+03.50; elev. = -4.62)
    (Sta. @ PVI = 76+53.50; elev. = 2.36)
18. C. (+0.838% per full station)
19. B. (sta. of “low point” = 35+70; elev. = 850.37)
20. NOTE: By using graph paper, the reader may solve or check certain elements of this problem by plotting and scaling.

20A. Calculation of the required elevations and offset distance:

1. Centerline grade of the road @ 21+00 by vertical curve computation: 107.33'
2. Elevation at hingepoint: 107.61'
3. Distance out from centerline for daylight stake: 42.6' ± 0.5'

20B.
1. Indicate that stake is set five ft offset from daylight at top of slope.
2. Indicate a $6^{\underline{3}'}$ from begin daylight or $7^{\underline{3}'}$ from offset stake.
3. Indicate that the design slope is 2:1
   OR a cut of $6^{\underline{3}}$ out $12^{\underline{5}}$ from daylight
   OR a cut of $7^{\underline{3}}$ out $17^{\underline{5}}$ from offset stake.

21A. Given: delta = 48° 59' 46", R = 300.00'

1. T = Rtan Δ/2 = (300.00) (tan 24° 29' 53") = 136.71
2. $L = 2\pi R\Delta/360° = \dfrac{2\pi\ (300)\ 48°\ 59'\ 46''}{360°} = 256.54$
3. Station 12+35.15 (Station given)

12+35.15	(Station given)
1+00.00	(Given tangent length to BC)
13+35.15	
2+56.54	(Length of arc)
15+91.69 EC	

21B.

First tangent	S 09° 27' 56" E
First delta	+ 48° 59' 46"
Second tangent	S 39° 31' 50" W
Second tangent	S 39° 31' 50" W
Last tangent	-S 00° 23' 32" W
Delta curve #2	39° 08' 18"

21C. 1.

$$\ell = \frac{g_1}{r}$$

$$r = \frac{g_2 - g_1}{L}$$

$$= \frac{8.75 - (-2.5)}{1}$$

$$= 11.25$$

$$\ell = \frac{-2.5}{11.25}$$

$$= 0.2222 \text{ station}$$

Given:	BVC station	14+21.86
		+ 22.22
station of lowest point		14+44.08

2.

$$\text{Elev. p} = \left(\frac{r}{2}\right) \ell^2 p + g_1 (\ell_p) + \text{Elev}_{BVC}$$

$$= \frac{11.25}{2} \quad (.222^2) \;= (-2.5)\,(.222) + 705.89$$

$$= 705.61$$

$$\text{Elev.}_{\text{top inlet}} = 705.61 - (.02)\,(20)$$

$$= 705.21$$

21D. 1. Data given for Vertical Curve #2

g_1 = +8.75% g_2 = -1.50% $BVC_{sta.}$ = 16+50

Compute BVC $\#2_{elev.}$:

$$PIVC\ \#1_{elev.} = (14{+}71.86 - 12{+}35.15)(-2.5\%)+710.56 = 704.64$$

$$BVC\ \#2_{elev.} = (16{+}50.00 - 14{+}71.86)(8.75\%)+784.64 = 720.23$$

Elev. required @ 18+50 = 730.92+3.00+0.40 = 734.32

$$r = \frac{g_2 - g_1}{L}$$

ℓ = 2 stations

$$elev._p = \left(\frac{r}{2}\right)\ell^2_p + g_1 l_p + elev_{BVC}$$

$$734.32 = \frac{1}{2}\left(\frac{-1.50 + 8.75}{L}\right)(2^2) + 8.75(2) + 720.23$$

L = 6.01 sta. or round to 600'

2. PIVC $\#2_{sta.}$ = 16+50 + 300' = 19+50

3.

Existing pipe elev.	730.92
Plus 3.00	3.00
Plus crown (gutter to centerline)	0.40
Pavement centerline over top of pipe	734.32

References

________________, *California Department of Transportation Surveys Manual.*

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