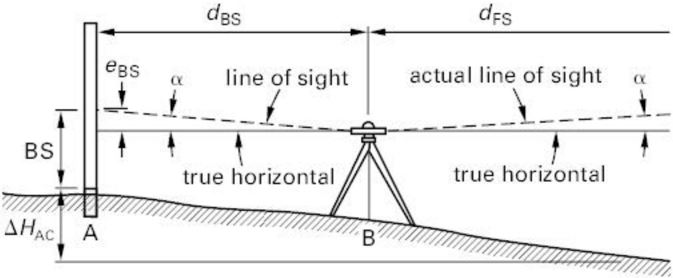
10. COLLIMATION ERROR

The most common cause of errors in leveling, other than reading blunders, is the imperfect adjustment of the level. Although almost all observed lines of sight will have a slight difference from a truly horizontal line, called the *collimation error* (see Fig. 14.11), this error can be eliminated by ensuring that the backsight and foresight distances are equal in length. By frequently performing collimation checks on the level and adjusting as needed, this error can be minimized even in unbalanced shots.

Figure 14.11 *Collimation Error*



Collimation checks may be made by setting two points about 200 feet apart. The level is first set up about 20 feet from the first point on a line between the two points. Rod readings for all three horizontal crosshairs are read and recorded with the rod on both the near and far points. The level is then moved along the same line to a location about 20 feet from the second point and rod readings for all three horizontal crosshairs read and recorded. The correction for the collimation error, c,[3] may then be calculated as the difference between the sum of the short readings, R_S, minus the sum of the long readings, R_L, divided by the difference between the long distances, d_L, and the short distances, d_S.

$$c = \frac{(R_{S,1} + R_{S,2}) - (R_{L,1} + R_{L,2})}{(d_{L,1} + d_{L,2}) - (d_{S,1} + d_{S,2})}$$

correction to compensate for the incident angle may be applied to the measurements.

Frequency drift is another source of error. Periodic calibration of the EDM instrument against a known distance ensures accurate and consistent results. Another frequent source of error in EDM is *tribrach error*. If the optical plummet on the tribrach supporting either the EDM instrument or the prism is misadjusted, this could result in the instrument or the prism being off the point. In this situation, the line being measured is not the line between occupied points.

E Chapter 15

An EDM has a standard error of ±(0.007 ft + 2 ppm). What is the expected error in measuring a 3000 ft line?

Solution

$$\begin{aligned}\text{standard error} &= \pm(0.007\text{ ft} + 2\text{ ppm}) \times (\text{measured distance})\\ &= \pm 0.007\text{ ft} + \left(\frac{2}{10^6} \times (3000\text{ ft})\right)\\ &= \pm 0.013\text{ ft}\end{aligned}$$

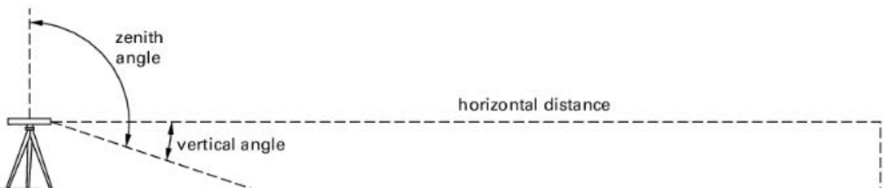
EDM Calibration

Periodic calibration of EDM instruments against a known distance is essential for obtaining consistent and accurate measurements. A calibration is best performed on a precise baseline established specifically for this purpose. Most states have a number of such baselines, typically established in cooperative programs with the National Geodetic Survey, and data for such sites are available on that agency's website. A typical baseline configuration includes four marks set at 0 m, 150 m, 800 m, and 1500 m. It is recommended that each mark be occupied and that redundant measurements be made to each of the other marks.

Slope Distance Reduction

Unlike taping, where the normal procedure is to make horizontal distance measurements, electronic measurements are typically made using slope distances. Figure 15.4 illustrates the need to reduce slope distance to horizontal distance.

Figure 15.4 *Slope Distance Correction*



$$= \pm(0.007 \text{ ft} + \frac{2}{10^6}) \times 3000 \text{ ft}$$

Return to Questions (/admin/questions/0?sfield=magento_id&stext=0000124997&sdka=&stype=&sdiff=)

Test Bank Question preview

Chapter 2, question 16

Question

An open rectangular concrete tank is 11 ft long, 6 ft wide, and 4 ft 6 in tall on the outside. The walls and floor of the tank are 6 in thick. How many gallons of water will the tank contain when three-quarters full?

Solution

Solve by writing a dimensional equation. The volume is

$$\begin{aligned} V &= \left(\frac{3}{4}\right)(11\ \text{ft})(5\ \text{ft})(4\ \text{ft})\left(7.5\ \frac{\text{gal}}{\text{ft}^3}\right) \\ &= 1125\ \text{gal} \end{aligned}$$

QUESTION DATA

Vendor

0000124997

Flashcard

✔

Solving Time

Difficulty

easy

Quantitative?

No

Status

Active

Created On

04/01/2019 06:50:15 PM

Published On

04/01/2019 06:50:15 PM

Modified On

07/07/2020 05:00:02 PM

OTHER VERSIONS

DISCIPLINES

KNOWLEDGE AREAS

PRODUCTS USED IN

Other useful equations for vertical curves are as follows:

$$E_{BVC} = E_{PI} - g_2\left(\frac{L}{2}\right) \quad 22.4$$

$$g_1 = \frac{E_{PI} - E_{BVC}}{\frac{L}{2}} \quad 22.5$$

$$g_2 = \frac{E_{PI} - E_{EVC}}{\frac{L}{2}} \quad 22.6$$

$$\text{sta BVC} = \text{sta PI} - \frac{L}{2} \quad 22.7$$

$$\text{sta EVC} = \text{sta PI} + \frac{L}{2} \quad 22.8$$

$$\text{sta EVC} = \text{sta BVC} + L \quad 22.9$$

Example 22.3

A −1.50% grade meets a +2.25% grade at sta 36+50, elev 452.00 ft. A vertical curve of length 600 ft (six stations) will be used. The elevation at the BVC is 456.50 ft. Calculate the finish elevations for each full station from the BVC to the EVC.

Solution

From the information provided, the station of the BVC is (36+50) − (3+00), or (33+50). The station of the EVC is (36+50) + (3+00), or (39+50).

Using Eq. 22.1,

$$r = \frac{g_2 - g_1}{L} = \frac{(2.25\% + 1.50\%)}{6 \text{ sta}} = 0.625$$

Using Eq. 22.3, for station 34+00,

$$\begin{aligned} y &= \left(\frac{r}{2}\right)x^2 + xg_1 + E_{BVC} \\ &= \left(\frac{0.625}{2}\right)(34.0 - 33.5)^2 + (34.0 - 33.5)(-1.50) + 456.50 \text{ ft} \\ &= 455.83 \text{ ft} \end{aligned}$$

Elevations for other stations can be calculated similarly.

point	station	finish elevation (ft)
PC	33+50	456.50
	34+00	455.83
	35+00	454.95
	36+00	454.70
PI	36+50	454.81
	37+00	455.07
	38+00	456.07
	39+00	457.70
PT	39+50	458.75

5. TURNING POINT ON VERTICAL CURVE

Unless the incoming and outgoing grades are the same, the highest or lowest point on a vertical parabolic curve is not vertically below (or above) the PI. Yet the location of that point is critical for drainage purposes. This point is called the *turning point*. The distance x from the PC to the turning point can be found from Eq. 22.10.

$$x = \frac{-g_1}{r} \quad 22.10$$

Example 22.4

A +1.500% grade meets a −2.500% grade at sta 12+50. Determine the distance from the PC to the turning point if a 600 ft vertical curve is used.

Solution

$$\begin{aligned} r &= \frac{g_2 - g_1}{L} \\ &= \frac{(-2.50\% - 1.50\%)}{6 \text{ sta}} \\ &= -0.66667 \ \%/\text{sta} \end{aligned}$$

$$\begin{aligned} x &= \frac{-g_1}{r} \\ &= \frac{-1.50\%}{-0.66667 \frac{\%}{\text{sta}}} \\ &= 2.25 \text{ sta} \quad (225 \text{ ft}) \end{aligned}$$

6. PRACTICE PROBLEMS

1. Determine the gradients between the points on the highway profiles shown.

Example:

PI = 5+50
E = 452.00 ft
PI = 8+50
E = 455.00 ft
PI = 11+00
E = 453.00 ft

Solution:

$$\begin{aligned} g_1 &= \frac{455.00 \text{ ft} - 452.00 \text{ ft}}{8.50 \text{ sta} - 5.50 \text{ sta}} \\ &= 1.00 \text{ ft/sta} \quad (+1.000\%) \end{aligned}$$

$$\begin{aligned} g_2 &= \frac{455.00 \text{ ft} - 453.00 \text{ ft}}{11.00 \text{ sta} - 8.50 \text{ sta}} \\ &= -0.800 \text{ ft/sta} \quad (-0.800\%) \end{aligned}$$

Plane Survey Calculations

19. PRACTICE PROBLEMS

1. How much does an Invar tape expand and contract due to change in temperature, compared to a standard steel tape under the same conditions?

(A) An Invar tape expands and contracts much more than a steel tape.

(B) An Invar tape expands and contracts slightly less than a steel tape.

(C) An Invar tape expands and contracts much less than a steel tape.

(D) The two tapes expand and contract about the same amount.

2. How many pins are in a set of chaining pins?

(A) 10

(B) 11

(C) 12

(D) 20

3. What features distinguish an add tape?

(A) The last foot of each end is graduated in tenths or hundredths of a foot.

(B) There is an extra graduated foot beyond the zero mark.

(C) There is an extra graduated foot at the 100 foot end of the tape.

(D) There is an extra graduated foot at both ends of the tape.

4. How long is a Gunter's chain?

(A) 30 ft

(B) 53 ft

(C) 66 ft

(D) 130 ft

5. The area of a square one Gunter's chain on a side is most nearly

(A) 250 ft^2

(B) 4400 ft^2

(C) 10,000 ft^2

(D) 44,000 ft^2

6. Most nearly, what is the area of a rectangle 6 Gunter's chains long by 5 Gunter's chains wide?

(A) 3 ac

(B) 7 ac

(C) 20 ac

(D) 30 ac

7. A distance of 100 ft is measured along a line where the difference in elevation from sta 0+00 to sta 10+00 is 11 ft. The measurement is taken at a temperature of 68°F, with a tape calibrated to be 100.0 ft in length. Most nearly, what is the corrected measurement?

(A) 98 ft

(B) 99 ft

(C) ~~101~~ ft

(D) ~~102~~ ft

8. A distance of 787.35 ft is measured on level ground with a steel tape 100 ft in length. The tape was calibrated for 68°F, and the temperature at the time of the measurement is 98°F. Most nearly, what is the corrected measurement?

(A) 787.0 ft

(B) 787.2 ft

(C) 787.5 ft

(D) 787.6 ft

9. A line is measured on level ground with a 100 ft tape and is found to be 582.32 ft long. Later, the tape is calibrated and found to be 100.03 ft in length. The temperature at the time of measurement was 68°F. Most nearly, what is the corrected length of the line?

(A) 582.1 ft

(B) 582.3 ft

(C) 582.5 ft

(D) 582.7 ft

10. Most nearly, what is the length of a standardized 100 ft steel tape at 28°F?

(A) 99.97 ft

(B) 99.99 ft

(C) 100.01 ft

(D) 100.03 ft

11. A tape that is 100.02 ft long at 68°F is used to measure a line along sloping ground when the temperature is 28°F. The difference in elevation from the beginning to the end of the line was 10 ft. The line is recorded as 196.44 ft. Most nearly, what is the corrected length of the line?

(A) 196.1 ft

(B) 196.3 ft

(C) 196.5 ft

(D) 196.7 ft

12. A 100 ft tape that was tested to be 99.97 ft long is used to measure a line when the temperature is 98°F. The length of the line is recorded as 713.19 ft. Most nearly, what is the corrected measurement?

(A) 712.9 ft

(B) 713.1 ft

(C) 713.3 ft

(D) 713.5 ft

SOLUTIONS

1. An Invar tape will expand and contract much less than a steel tape when exposed to the same change in temperature.

The answer is (C).

2. There are 11 pins in a set of chaining pins.

The answer is (B).

3. An add tape has an extra graduated foot beyond the zero mark.

The answer is (B).

4. A Gunter's chain is 66 ft long.

The answer is (C).

5. A square one Gunter's chain on a side has an area of

$$(66\ \text{ft})^2 = 4356\ \text{ft}^2 \quad (4400\ \text{ft}^2)$$

The answer is (B).

6. A Gunter's chain is 66 ft long. The length of the rectangle is

$$\frac{\big((6)(66\ \text{ft})\big)\big((5)(66\ \text{ft})\big)}{43{,}560\ \frac{\text{ft}^2}{\text{ac}}} = 3\ \text{ac}$$

The answer is (A).

7. From Eq. 13.3, the correction factor for the slope is

$$C \approx \frac{V^2}{2S} = \frac{(11\ \text{ft})^2}{(2)(100\ \text{ft})} = 0.6\ \text{ft}$$

The corrected length ~~is~~

$$L = 100\ \text{ft} - 0.6\ \text{ft} = 99.4\ \text{ft} \quad (99\ \text{ft})$$

The answer is (~~B~~).

8. From Eq. 13.7, the correction factor for the temperature is

$$\begin{aligned} C &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(T_{^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(98^\circ - 68^\circ)(787.35\ \text{ft}) \\ &= 0.152\ \text{ft} \end{aligned}$$

The corrected length is

$$L = 787.35\ \text{ft} + 0.152\ \text{ft} = 787.502\ \text{ft} \quad (787.5\ \text{ft})$$

The answer is (C).

Field Data Acquisition

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$$L = 100\ \text{ft} - \left(\frac{100}{1000} \times 0.06\right)$$
$$= 99.994\ \text{ft} \quad (100\ \text{ft})$$

9. From Eq. 13.8, the correction factor for the incorrect tape length is

$$\begin{aligned} C &= \left(L_{\text{tape measurement}} - 100 \text{ ft}\right)\left(\frac{L_{\text{line measurement}}}{100 \text{ ft}}\right) \\ &= (100.03 \text{ ft} - 100 \text{ ft})\left(\frac{582.32 \text{ ft}}{100 \text{ ft}}\right) \\ &= 0.17 \text{ ft} \end{aligned}$$

The corrected length is

$$L = 582.32 \text{ ft} + 0.17 \text{ ft} = 582.49 \text{ ft} \quad (582.5 \text{ ft})$$

The answer is (C).

10. From Eq. 13.7, the change in the length of the tape due to a temperature of 28°F is

$$\begin{aligned} C &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(T_{{}^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(28^\circ - 68^\circ)(100 \text{ ft}) \\ &= -0.03 \text{ ft} \end{aligned}$$

The corrected length of the tape is

$$L = 100 \text{ ft} - 0.03 \text{ ft} = 99.97 \text{ ft}$$

The answer is (A).

11. From Eq. 13.7, the correction factor for the temperature is

$$\begin{aligned} C &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(T_{{}^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(28^\circ - 68^\circ)(196.44 \text{ ft}) \\ &= -0.05 \text{ ft} \end{aligned}$$

From Eq. 13.3, the correction factor for the slope is

$$C \approx \frac{V^2}{2S} = \frac{(10 \text{ ft})^2}{(2)(196.44 \text{ ft})} = -0.25 \text{ ft}$$

insert on next page placed here.

The corrected measurement is

$$L = 196.44 \text{ ft} - 0.05 \text{ ft} - 0.25 \text{ ft} = 196.14 \text{ ft} \quad (196.1 \text{ ft})$$

The answer is (A).

12. From Eq. 13.7, the correction factor for the temperature is

$$\begin{aligned} C &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(T_{{}^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645 \ \frac{\text{ft}}{{}^\circ\text{F}}\right)(98^\circ - 68^\circ)(713.19 \text{ ft}) \\ &= 0.14 \text{ ft} \end{aligned}$$

From Eq. 13.8, the correction factor for the incorrect tape length is

$$\begin{aligned} C &= \left(L_{\text{tape measurement}} - 100 \text{ ft}\right)\left(\frac{L_{\text{line measurement}}}{100 \text{ ft}}\right) \\ &= (99.97 \text{ ft} - 100 \text{ ft})\left(\frac{713.19 \text{ ft}}{100 \text{ ft}}\right) \\ &= -0.21 \text{ ft} \end{aligned}$$

The corrected length is

$$L = 713.19 \text{ ft} + 0.14 \text{ ft} - 0.21 \text{ ft} = 713.12 \text{ ft} \quad (713.1 \text{ ft})$$

The answer is (B).

Solution

The correction due to change in temperature is

$$\begin{aligned} C &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(T_{^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(30^\circ - 68^\circ)(675.48\ \text{ft}) \\ &= -0.17\ \text{ft} \end{aligned}$$

The corrected length is

$$L = 675.48\ \text{ft} - 0.17\ \text{ft} = 675.31\ \text{ft}$$

16. CORRECTION FOR INCORRECT LENGTH OF TAPE

A standardized tape can be used to check other tapes. If a 100 ft tape is known to be of incorrect length, the correction factor for measurements that have been made with the incorrect tape is

$$C = \left(L_{\text{tape measurement}} - 100\ \text{ft}\right)\left(\frac{L_{\text{line measurement}}}{100\ \text{ft}}\right) \qquad 13.8$$

For Eq. 13.8, a line measured with a tape that is longer than 100 ft is actually longer than the measurement shown by the tape. A line measured with a tape that is shorter than 100 ft is actually shorter than the measurement shown by the tape. A rule to remember is "for a tape too long, add; for a tape too short, subtract." (This rule can also be applied to temperature correction.)

Example 13.4

A distance between two points is measured as 662.35 ft with a 100 ft tape. The 100 ft tape is later found to be 100.02 ft long. What is the actual distance between the two points?

Solution

From Eq. 13.8, the correction factor is

$$\begin{aligned} C &= \left(L_{\text{tape measurement}} - 100\ \text{ft}\right)\left(\frac{L_{\text{line measurement}}}{100\ \text{ft}}\right) \\ &= (100.02\ \text{ft} - 100\ \text{ft})\left(\frac{662.35\ \text{ft}}{100\ \text{ft}}\right) \\ &= 0.13\ \text{ft} \end{aligned}$$

The corrected measurement is 662.35 ft + 0.13 ft = 662.48 ft.

17. CORRECTION FOR IMPROPER ALIGNMENT

Improper alignment is probably the least important error in taping. Many instrument operators and persons handling the tape spend time aligning that is not justified by the effect of improper alignment. The linear error when one end of the tape is off-line can be found in the same way slope correction is found. For example, for a 100 ft tape with one end off-line by 1.0 ft, the correction is

$$C = \frac{V^2}{200\ \text{ft}} = \frac{1.0\ \text{ft}^2}{200\ \text{ft}} = 0.005\ \text{ft}$$

When the error in alignment is 0.5 ft, the linear error is 0.001 ft per tape length, or about 0.05 ft per mile.

18. COMBINED CORRECTIONS

Corrections for incorrect length of tape, temperature, and slope can be combined algebraically, as illustrated in Ex. 13.5.

Example 13.5

A line is measured with a 100 ft tape and found to be 1238.22 ft long. The tape is later measured when the temperature is 18°F and found to be 100.03 ft long. What is the corrected length of the line?

Solution

From Eq. 13.7, the correction factor for temperature is

$$\begin{aligned} C &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(T_{^\circ\text{F}} - 68^\circ)L \\ &= \left(0.00000645\ \frac{\text{ft}}{^\circ\text{F}}\right)(18^\circ - 68^\circ)(1238.22\ \text{ft}) \\ &= -0.40\ \text{ft} \end{aligned}$$

From Eq. 13.8, the correction factor for the length of the tape is

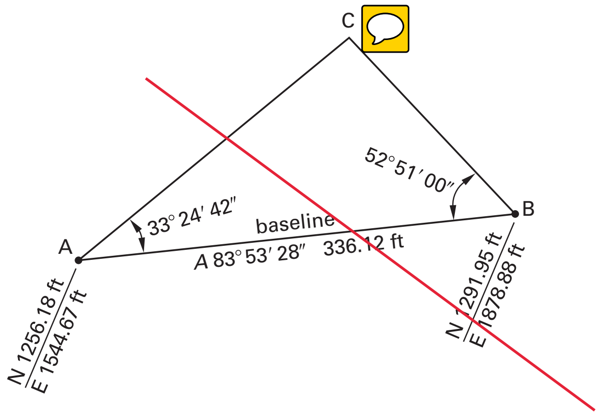
$$\begin{aligned} C &= \left(L_{\text{tape measurement}} - 100\ \text{ft}\right)\left(\frac{L_{\text{line measurement}}}{100\ \text{ft}}\right) \\ &= (100.02\ \text{ft} - 100\ \text{ft})\left(\frac{662.35\ \text{ft}}{100\ \text{ft}}\right) \\ &= 0.13\ \text{ft} \end{aligned}$$

The corrected measurement is

$$1238.22\ \text{ft} - 0.40\ \text{ft} + 0.13\ \text{ft} = 1237.95\ \text{ft}$$

Example 19.5

Find the coordinates of point C at the intersection of lines AC and BC in the illustration shown using the bearing-bearing method.



Solution

Find the azimuth AC.

$$\begin{aligned} A_{\mathrm{AC}} &= A_{\mathrm{AB}} - \theta_{\mathrm{A}} \\ &= 83°53'27'' - 33°24'42'' \\ &= 50°28'46'' \end{aligned}$$

Determine angle C.

$$\theta_{\mathrm{C}} = 180° - (\theta_{\mathrm{A}} + \theta_{\mathrm{B}}) = 93°44'18''$$

Find the distance AC using the law of sines, Eq. 19.12.

$$\frac{d_{\mathrm{AC}}}{\sin\theta_B} = \frac{d_{\mathrm{BC}}}{\sin\theta_A} = \frac{d_{\mathrm{AB}}}{\sin\theta_C}$$

$$\begin{aligned} d_{\mathrm{AC}} &= \frac{d_{\mathrm{AB}}\sin\theta_B}{\sin\theta_C} \\ &= \frac{(336.12\ \mathrm{ft})\sin 52°51'00''}{\sin 93°44'18''} \\ &= 268.48\ \mathrm{ft} \end{aligned}$$

Then find the northing and easting coordinate for Point C.

$$\begin{aligned} \mathrm{N_C} &= \mathrm{N_A} + d_{\mathrm{AC}}\cos A_{\mathrm{AC}} \\ &= 1256.18\ \mathrm{ft} + (268.48\ \mathrm{ft})\cos 50°28'46'' \\ &= 1427.03\ \mathrm{ft} \end{aligned}$$

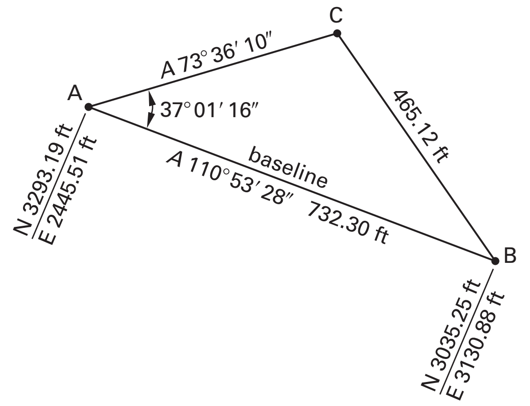
$$\begin{aligned} \mathrm{E_C} &= \mathrm{E_A} + d_{\mathrm{AC}}\sin A_{\mathrm{AC}} \\ &= 1544.67\ \mathrm{ft} + (268.48\ \mathrm{ft})\sin 50°28'46'' \\ &= 1751.77\ \mathrm{ft} \end{aligned}$$

Bearing-Distance Method

If the coordinates of the end points of one side of a triangle are known, and the bearing of one of the other two sides and the distance for the third side are known, the coordinates of the point of intersection of the other two sides can be found using the *bearing-distance method.*

Example 19.6

Find the coordinates of the point of intersection of lines AC and BC in the illustration shown using the bearing-distance method.



Solution

Determine angle C using the law of sines, Eq. 19.12.

$$\frac{d_{\mathrm{AC}}}{\sin\theta_B} = \frac{d_{\mathrm{BC}}}{\sin\theta_A} = \frac{d_{\mathrm{AB}}}{\sin\theta_C}$$

$$\begin{aligned} \theta_C &= \arcsin\frac{d_{\mathrm{AB}}\sin\theta_A}{d_{\mathrm{BC}}} \\ &= \arcsin\frac{(732.30\ \mathrm{ft})\sin 37°01'16''}{465.12\ \mathrm{ft}} \\ &= 71°26'17'' \end{aligned}$$

With a bearing-distance situation, two solutions are possible and are 180° apart. An arc with a radius of 465.12 ft swung from point B would intersect a line from point A with an azimuth of 73°36′10″ at two points. By inspection, angle C is greater than 71°. Therefore, the correct solution for angle C is $180° - 71°26'17'' = 108°33'43''$.

Determine angle B.

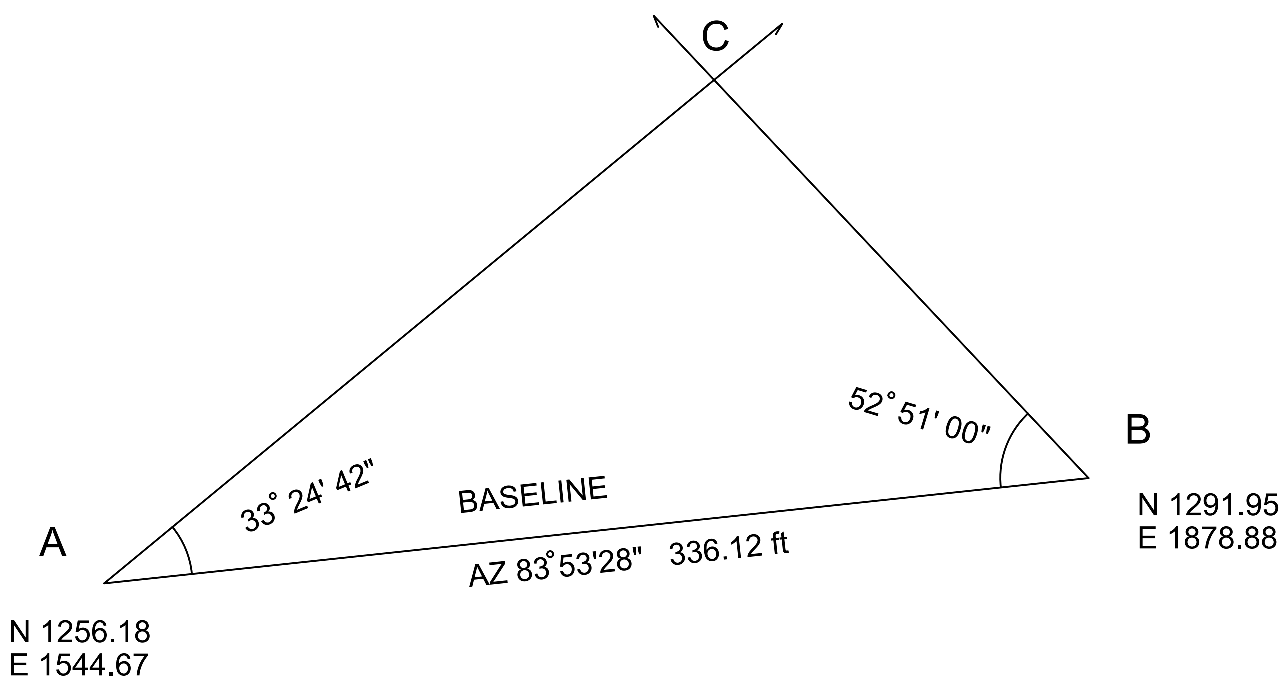
$$\begin{aligned} \theta_B &= 180° - \theta_A - \theta_C \\ &= 180° - 108°33'43'' - 37°01'16'' \\ &= 34°25'01'' \end{aligned}$$

Find the distance AC using the law of sines, Eq. 19.12.

$$\frac{d_{\mathrm{AC}}}{\sin\theta_B} = \frac{d_{\mathrm{BC}}}{\sin\theta_A} = \frac{d_{\mathrm{AB}}}{\sin\theta_C}$$

$$\begin{aligned} d_{\mathrm{AC}} &= \frac{d_{\mathrm{BC}}\sin\theta_B}{\sin\theta_A} \\ &= \frac{(465.12\ \mathrm{ft})\sin 34°25'01''}{\sin 37°01'16''} \\ &= 436.62\ \mathrm{ft} \end{aligned}$$

Figure in Example 19.8



Example 21.3

PC, PCC, and PT stations, deflection angles, and chord lengths are to be calculated from the following information.

$$\begin{aligned} \text{PI} &= \text{sta } 15{+}56.32 \\ I &= 68°00' \\ I_1 &= 35°00' \\ R_1 &= 600 \text{ ft} \\ R_2 &= 400 \text{ ft} \end{aligned}$$

Solution

$$\begin{aligned} I_2 &= I - I_1 = 68°00' - 35°00' \\ &= 33°00' \\ t_1 &= R_1 \tan\frac{I_1}{2} = (600 \text{ ft})(\tan 17°30') \\ &= 189.18 \text{ ft} \\ t_2 &= R_2 \tan\frac{I_2}{2} = (400 \text{ ft})(\tan 16°30') \\ &= 118.49 \text{ ft} \end{aligned}$$

$$\begin{aligned} \text{PI} - \text{PI}_1 &= \frac{\sin I_2(t_1 + t_2)}{\sin I} = \frac{(\sin 33°)\begin{pmatrix}189.18 \text{ ft} \\ +118.49 \text{ ft}\end{pmatrix}}{\sin 68°} \\ &= 180.73 \text{ ft} \end{aligned}$$

$$\begin{aligned} \text{PI} - \text{PI}_2 &= \frac{\sin I_1(t_1 + t_2)}{\sin I} = \frac{(\sin 35°)\begin{pmatrix}189.18 \text{ ft} \\ +118.49 \text{ ft}\end{pmatrix}}{\sin 68°} \\ &= 190.33 \text{ ft} \end{aligned}$$

$$\begin{aligned} T_1 &= t_1 + \text{PI} - \text{PI}_1 = 189.18 \text{ ft} + 180.73 \text{ ft} \\ &= 369.91 \text{ ft} \\ T_2 &= t_2 + \text{PI} - \text{PI}_2 = 118.49 \text{ ft} + 190.33 \text{ ft} \\ &= 308.82 \text{ ft} \end{aligned}$$

$$\begin{aligned} L_1 &= \frac{2\pi R_1 I_1}{360°} = \frac{2\pi(600 \text{ ft})(35°)}{360°} \\ &= 366.52 \text{ ft} \\ L_2 &= \frac{2\pi R_2 I_2}{360°} = \frac{2\pi(400 \text{ ft})(33°)}{360°} \\ &= 230.38 \text{ ft} \end{aligned}$$

PI = 15+56.32

T_1 = −3+69.91

PC = 11+86.41

L_1 = +3+66.52

PCC = 15+52.93

L_2 = +2+30.38

PT = 17+83.31

The deflection angles are

point	station	deflection angles
PC	11+86.41	
	12+00	$\left(\frac{13.59}{366.52}\right)\left(\frac{35}{2}\right) = 0.6489° = 0°39'$
	13+00	$\left(\frac{113.59}{366.52}\right)\left(\frac{35}{2}\right) = 5.4235° = 5°25'$
	14+00	$\left(\frac{213.59}{366.52}\right)\left(\frac{35}{2}\right) = 10.1981° = 10°12'$
	15+00	$\left(\frac{313.59}{366.52}\right)\left(\frac{35}{2}\right) = 14.9728° = 14°59'$
PCC	15+52.93	$\left(\frac{366.52}{366.52}\right)\left(\frac{35}{2}\right) = 17.5000° = 17°30'$
	16+00	$\left(\frac{47.07}{230.38}\right)\left(\frac{33}{2}\right) = 3.3712° = 3°22'$
	17+00	$\left(\frac{147.07}{230.38}\right)\left(\frac{33}{2}\right) = 10.5332° = 10°32'$
PT	17+83.31	$\left(\frac{230.38}{230.38}\right)\left(\frac{33}{2}\right) = 16.5000° = 16°30'$

The chord lengths are

$$C = (1200 \text{ ft}) \sin 0.6489° = 13.59 \text{ ft}$$

$$C = (1200 \text{ ft}) \sin 4.7746° = 99.88 \text{ ft}$$

$$C = (1200 \text{ ft}) \sin 2.5272° = 52.91 \text{ ft}$$

$$C = (800 \text{ ft}) \sin 3.3712° = 47.04 \text{ ft}$$

$$C = (800 \text{ ft}) \sin 7.1620° = 99.74 \text{ ft}$$

$$C = (800 \text{ ft}) \sin 5.9668° = 83.16 \text{ ft}$$

The field notes showing the results of these calculations are shown in *Solution for Example 21.3*.

Plane Survey Calculations

Plane Survey Calculations

Solution for Example 21.3

point	station	deflection angle	chord	calculated bearing	curve data
PT	17+83.31	16°30′			
			83.16′		
	17+00.00	10°32′			
			99.74′		
	16+00.00	3°22.3′			$I = 68°00'$
PI	15+56.32		47.04′		$R_1 = 600$ ft
PCC	15+52.93	17°30′			$I_1 = 35°00'$
			52.91′		$R_2 = 400$ ft
	15+00.00	14°58.7′			$I_2 = 33°00'$
			99.88′		$T_1 = 369.91$ ft
	14+00.00	10°12.1′			$T_2 = 308.82$ ft
			99.88′		$L_1 = 366.52$ ft
	13+00.00	5°25.5′	$L_2 = 230.38$ ft		
			99.88′		
	12+00.00	0°38.9′			
				13.59′	
	11+86.41	0°00′			

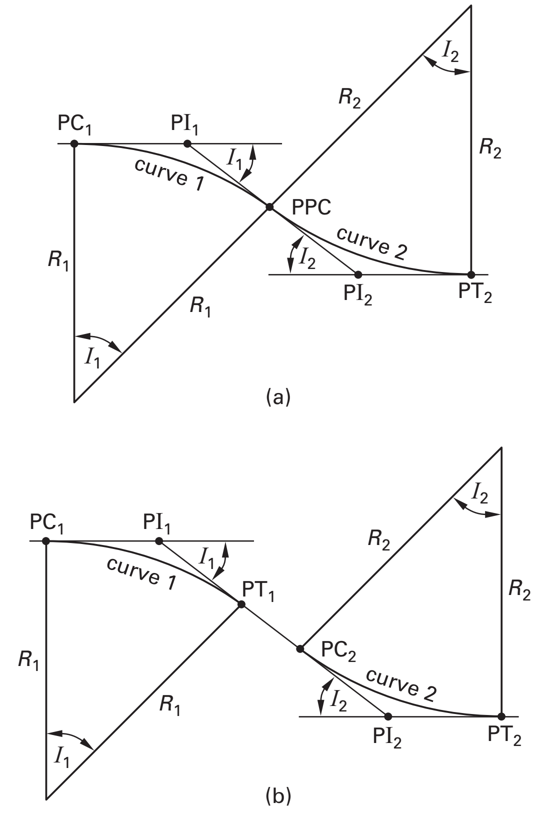
Insert new line: L_2 = 230.38 ft

15. REVERSE CURVES

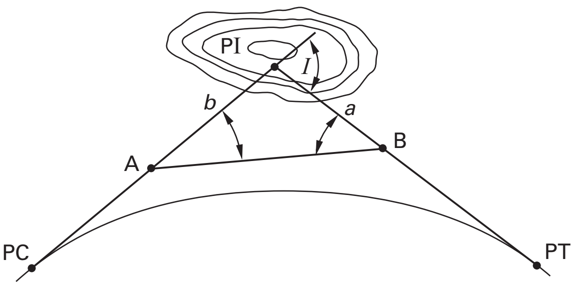
Reverse curves are compound curves with deflections in opposite directions (Fig. 21.8(a)). The curves may have equal or unequal radii and/or deflection angles. Each of the curves in a reverse curve is treated in a similar manner as a horizontal curve.

In some situations, good roadway design practice requires a short tangent section between reverse curves (Fig. 21.8(b)). This allows for a reversal of the superelevation of the roadway surface when transitioning between curves with opposite deflections.

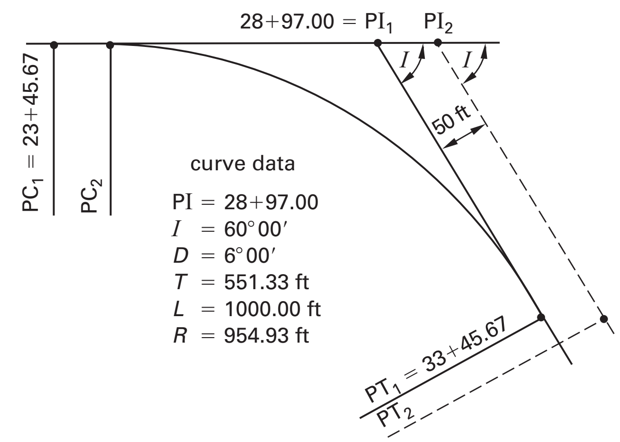
Figure 21.8 *Reverse Curves*



AB has been found to be 434.87 ft. Find the ~~deflection angle and the PC and PT~~ stations for a 3° curve.



8. The forward tangent of the highway curve shown is to be shifted outward so that it will be parallel to and 50 ft from the original tangent. Data for the original curve are shown in the figure. The degree of curve is to be unchanged. Find the PC and PT stations for the new curve.



9. Find L for the deflection angle and degree of curve indicated.

(a) $I = 32°18'$

$D = 2°30'$

(b) $I = 41°27'$

$D = 3°15'$

10. Find T for the deflection angle and degree of curve indicated.

(a) $I = 41°51'$

$D = 1°45'$

(b) $I = 39°14'$

$D = 2°15'$

11. Find E for the deflection angle and degree of curve indicated.

(a) $I = 31°30'$

$D = 1°30'$

(b) $I = 42°21'$

$D = 2°45'$

12. Find D for the nearest full degree for the deflection angle and approximate tangent distance indicated.

(a) $I = 32°56'$

$T = 600$ ft

(b) $I = 40°10'$

$T = 1000$ ft

13. Use trigonometric equations to solve the following problems.

(a) Find R for $D = 2°$.

(b) Find D for $R = 1909.86$ ft.

(c) Find T for $I = 34°44'$ and $R = 800$ ft.

(d) Find E for $I = 37°20'$ and $R = 650$ ft.

(e) Find M for $I = 42°51'$ and $R = 800$ ft.

(f) Find LC for $I = 32°55'$ and $R = 850$ ft.

(g) Find the chord length for $D = 8°$, $R = 716.20$ ft, and arc = 50 ft.

14. Calculate PC, PCC, and PT stations and deflection angles for full stations for the compound curve with the information given.

PI = sta 14+78.32

$I = 68°00'$

$I_1 = 36°00'$

$R_1 = 400$ ft

$R_2 = 300$ ft

15. Prepare field notes to be used in staking the centerline of the compound curve on full stations, given the data shown.

PI = sta 12+65.35

$I = 70°00'$

$I_1 = 36°00'$

$R_1 = 900$ ft

$R_2 = 600$ ft

16. PRACTICE PROBLEMS

1. Provide the missing word or words in each sentence.

(a) Highway curves are most often __________ arcs, known as simple curves.

(b) An inscribed angle is an angle that has its vertex on a __________ and that has __________ for its sides.

(c) An inscribed angle is measured by __________ its intercepted arc.

(d) An angle formed by a tangent and a chord is measured by __________ its intercepted arc.

(e) The radius of a circle is __________ to a tangent at the point of tangency.

(f) A perpendicular bisector of a chord passes through the __________ of the circle.

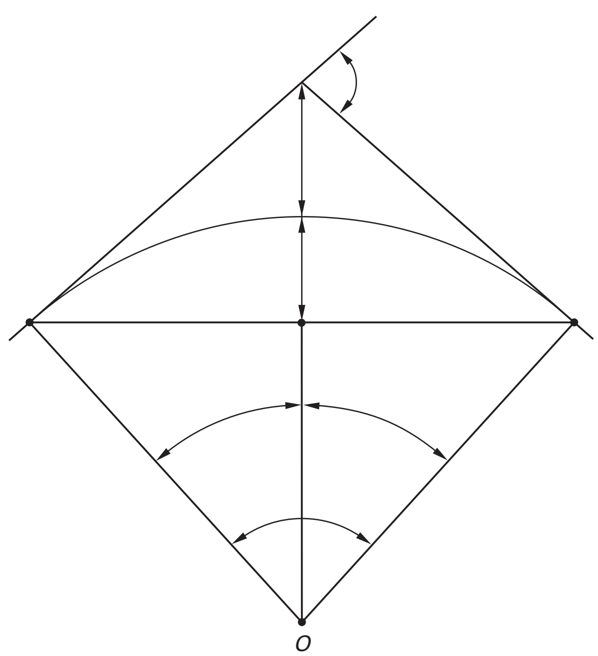
(g) By the arc definition, the degree of curve is the central angle that subtends a 100 ft __________.

(h) By the chord definition, the degree of curve is the central angle that subtends a 100 ft __________.

(i) By the arc definition, the radius of a 1° curve is ________ ft.

(j) The deflection angle for a full station for a 1° curve is ________.

2. Place all symbols pertinent to a circular curve on the figure shown.



3. Calculate the PC and PT stations and the deflection angles for each full station of the simple highway curve with the data given. Round the tangent distance to the nearest foot.

$$PI = \text{sta}\,25{+}01$$
$$I = 10^\circ$$
$$D = 1^\circ$$

4. Calculate the PC and PT stations and the deflection angles for each full station of the simple highway curve with the data given. Express the length to two decimal places.

$$PI = \text{sta}\,45{+}11.75$$
$$I = 30^\circ$$
$$D = 3^\circ$$

5. Prepare field notes to be used in staking the centerline of a simple horizontal curve for a highway with the data given.

PI = sta ~~45+11.75~~

I = change to: 40°21'

D = change to: 5°15'

back tangent bearing = N56°12′ W

6. A preliminary highway location has been made by locating tangents. Deflection angles have been measured at each PI, and the station number of each PI has been established by measuring along the tangents. Circular curves have not been located, but the degree of curve has been established for each curve. The beginning point is at sta 0+00. Using the data given, make necessary calculations to establish stations for PCs and PTs of the curves and for the end of the line.

PI	original station	I	D
1	10+35.27	13°34′	R 1°30′
2	36+15.44	15°18′	L 2°30′
3	52+98.40	18°05′	R 3°00′
end	61+32.77	end of line	

7. In locating a highway, the PI of two tangents falls in a lake and is inaccessible. Point A on the back tangent has been established at sta 26+52.61. Point B has been established on the forward tangent and is visible from point A. Angle A has been measured and found to be 23°13′; angle B has been measured and found to be 19°55′. The length of