Exercises for Practice
(A) Short questions

2.29 Show the various elements of a simple circular curve on a neatly drawn sketch.
2.30 Explain the following terms for a simple circular curve: (i) Back and forward tangents, (ii) Point of intersection, curve and tangency, (iii) Deflection angle to any point, and (iv) Degree of curve
2.31 Show the various elements of a compound curve.
2.32 Draw a neat sketch of a reverse curve provided to join two parallel straights.
2.33 Draw the neat sketches to differentiate between simple. compound and reverse curves.
2.34 List the requirements to be satisfied in setting out a transition curve.
2.35 What is a transition curve and where is it used? What are its advantages?
2.36 What is the need of super-elevation and how it is determined?
2.37 Give any five general requirements of a transition curve.
2.38 State the conditions to be fulfilled by a transition curve introduced between the tangent and circular curve.
2.39 What are different types of vertical curves? What is the use of having a vertical curve as parabola and not a circle?
2.40 Why are parabolic curves not generally used for horizontal highway curves?
2.41 What is meant by rate of change of grade on vertical curves and why it is important?
2.42 Explain why the second differences of curve elevations are equal for a parabolic curve.

(B) Long answers
2.43 Derive the formulae to calculate various elements to set out a simple circular curve.
2.44 Establish the formulae to calculate various elements to set out the compound curve.
2.45 Derive the relationship between the several elements of the reverse curve.
2.46 Discuss varoious types of transition curves. Derive an expression for the super-elevation to be provided in a transition curve.

(C) Unsolved Numerical Problems

2.47 A 4.56° circular curve is to be designed to fit between two intersecting straights. What is the radius of this curve? *(Ans:1256.49 m)*

2.48 It was found, while setting a simple circular curve using offsets from the tangents, that for X =16 m, and Y = 0.28 m. Find the radius of the curve. *(Ans: R = 457.28 m)*

2.49 A right hand simple circular curve connects two straights AI and IB where A and B are the tangent points. The azimuth of each straight is 50^0 43' 12" and 88^0 22' 14", respectively. The curve passes through point C of coordinates (321.25, 178.1) m. If the coordinates of A are (240.40, 125.90) m, compute the radius of curve and degree of curve.

Neglecting the existence of point C above and assuming the radius of curve as 450 m and chainage of I as 2140 m, find the (i) chainage of tangents points A and B, (ii) the external distance E and mid-ordinate M, (iii) the length of various chords, and (iv) the corresponding deflection angles.
(Ans: R = 428.87 m, Degree of curvature = 04^0 00' 28", Chainage of A = 1986.59 m, Chainage of B = 2282.29 m, E = 25.43 m, M = 24.072 m, C = 20 m, C_1 = 13.10 m, C_2 = 2.296 m, Δ_1 = 00^0 51' 13.4", and Δ_2 = 00^0 08' 46.2")

2.50 There are two tangents XI and IY for a railroad circular curve where X and Y are the tangent points having coordinates (240.4E, 125.9N) and (253.8E, 218.65N), respectively, and the coordinates of the mod-[point on the curve is (60.13E, 195.89N). Compute the radius of curve, the deflection angle, and the length of the curve.

(Ans: $\Delta = 270^0\ 57'\ 56''$, R = 104.48 m, L = 494.11 m)

2.51 Two straights intersect at a chainage of 2500 m with an angle of deflection as 40^0. The straights are to be connected by a simple circular curve. If the coordinates of O and I are (400, 300) m and (680, 460) m, respectively, calculate the radius of curve, tangents lengths, curve length, and the length of long chord.

(Ans: R = 303.04 m, T = 110.3 m, L = 211.56 m, and L_c= 207.29 m)

2.52 A right hand circular curve connects two straights AB and BC intersected at point B which has a chainage of 2000 m. If the azimuth of line BC is 120^0, and the coordinates of PC and B are (100, 100) m and (200, 200) m, respectively, determine the intersection angle, radius of the curve, degree of curve, length of long chord, length of the circular curve, coordinates of the mid-point, and chainage of PT and O.

(Ans: Δ = 75 , R = 184.3 m, Degree of curvature = $09^0\ 19'\ 35.4''$, L_c = 224.39 m, L = 241.25 m, Coordinates of mid-point (X = 152.40 m, Y = 206.26 m), Coordinates of PT (X = 129.29 m, Y = 322.47 m), and Coordinates of centre of curve (X = -30.32 m, Y = 230.32 m))

2.53 A straight *BC* deflects 24° right from a straight *AB* which are to be joined by a circular curve passing through a point *P*, 200 m from *B* and 50 m from *AB*. Calculate the tangent length, length of curve and deflection angle for a 30 m chord.

(Ans: R = 3754 m, IT = 798 m, curve length = 1572 m, 0°14')

2.54 Two straights, which deflect through an angle of 60°00'00", are to be connected by a circular curve of radius 80 m. The curve is to be set out by offsets from its tangent lengths. Calculate the data required: (i) to set out the mid-point of the curve (ii) to set out pegs on the centre line of the curve by offsets taken at 10 m intervals along the tangent lengths.

(Ans: (i) 40 m, 10.72 m (ii) 0 m, 0 m; 10 m, 0.63 m; 20 m, 2.54 m; 30 m, 5.84 m)

2.55 Two straights, which meet at an intersection angle of 135°00'00", are to be connected by a circular curve of radius 60 m. The curve is to be set out by offsets from its long chord. Calculate the data required to set out the: (i) mid-point of the curve (ii) pegs on the centre line of the curve by offsets taken at 5 m intervals along its long chord.

(Ans: (i) 0 m, 4.57 m; (ii) 5 m, 4.36 m; 10 m, 3.73 m, 15 m, 2.66 m; 20 m, 1.14 m)

2.56 Two straights intersect making a deflection angle of 59°00'24", the chainage at the intersection point being 880 m. The straights are to be joined by a simple curve commencing from chainage 708 m. If the curve is to be set out using 30 m chords on chainage basis, by the method of offsets from the chord produced, determine the first three offsets. Also, find also the chainage of the second tangent point.

(Ans: 0.066, 1.806, 2.985 m, 864.3 m)

2.57 A circular curve of radius 900 m is to be constructed between two straights of a proposed highway. The deflection angle between the straights is 14°28'06" and the curve is to be set out by the tangential angles method using a theodolite and a tape. The chainage of the intersection point is 1345.82 m and pegs are inserted at the centre line at 20 m multiples. Tabulate the data required to set out the curve and compute the (i) tangent lengths (ii) length of the circular curve (iii) chainages of the two tangent points.

(Ans: Chainage (m), chord length (m), cumulative tangential angle: 1231.58 (T), 0.00, 00° 00' 00; 1240.00, 8.42, 00° 16' 05"; 1260.00, 20.00, 00° 54' 17"; 1280. 00, 20.00, 01° 32' 29"; 1300.00, 20.00, 02° 10' 41"; 1320.00, 20.00, 02° 48' 53"; 1340.00, 20.00, 03° 27' 05"; 1360.00, 20.00, 04° 05' 17"; 1380.00, 20.00, 04° 43' 29"; 1400.00, 20.00, 05° 21' 41"; 1420.00, 20.00, 05° 59' 53"; 1440.00, 20.00, 06° 38' 05"; 1458.85 (U), 18.85, 07° 14' 05").

2.58 The bearings of three successive intersecting straights AB, BC and CD along the centre line of a proposed highway are 103°29'24", 125°43'22" and 116°12'54", respectively. The horizontal distance BC is 708.32 m. It is proposed to connect AB and BC by a 1500 m radius curve and BC and CD by a 900 m radius curve such that there is an intervening straight on BC between the end of one curve and the start of the other. The through chainage of intersection point B is 1097.65 m and chainage increases from A to D. Calculate the through chainages of the four tangent points on the two curves.

(Ans: 802.52 m, 1384.57 m, 1723.31 m, 1872.66 m)

2.59 A circular curve has to pass through a point *P* which is 70.23 m from *I*, the intersection point and on the bisector of the internal angle of the two straights *AI*, *IB*. Transition curves 200 m long are to be designed at each end and one of these must pass through a point whose coordinates are 167 m from the first tangent point along *AI* and 3.2 m at right angles from this straight. *IB* deflects 37°54' right from *AI* produced. Calculate the radius and tabulate the data for setting out a complete curve.

(Ans: R = 1200 m, AI = IB = 512.5 m, setting-out angles or offsets calculated in usual way)

2.60 A reverse curve is to start at a point *A* and end at *C* with a change of curvature at *B*. The chord lengths *AB* and *BC* are respectively 661.54 m and 725.76 m and the radii as 1200 and 1500 m. Due to irregular topography of the ground, the curves are to be set out using two theodolites method. Calculate the data for setting out the curve.

(Ans: Tangent lengths: 344.09 m, 373.99 m; curve length: 670.2, 733, per 30 m chords: Δ_1 = 0°42'54", Δ_2 = 0°34' 30")

2.61 A circular curve of 1800 m radius leaves a straight at through chainage 2468 m, joins a second circular curve of 1500 m radius at chainage 3976.5 m, and terminates on a second straight at chainage 4553 m. This compound curve is to be replaced by 2200 m radius transition curves 100 m long at each end. Calculate the chainages of the two new tangent points and the quarter point offsets of the transition curves.

(Ans: 2114.3 m, 4803.54 m; 0.012, 0.095, 0.32, 0.758 m)

2.62 A composite curve consisting of two equal length transition curves and a central circular arc is to be used to connect two intersecting straights TI and IU, which have a deflection angle of 12°24'46". The design speed of the road is to be 70 kmph, the rate of change of radial acceleration 0.30 m/s^3 and the radius of curvature of the circular arc 450 m. The transition curves are to be set out by offsets taken at exact 20 m intervals along the tangent lengths from T and U. The central circular curve is to be set out by offsets taken at exact 20 m intervals from the mid-point of its long chord. Tabulate the data required to set out the three curves.

(Ans: Entry and exit transition curves (starting at T and U, respectively): y = 0.00 m, x = 0.00 m; y = 20.00 m, x = 0.05 m; y = 40.00 m, x = 0.44 m; y = 54.46 m, x = 1.10 m, Central circular arc (measuring along the long chord from its mid-point in both directions): y = 0.00 m, x = 0.51 m; y = 20.00 m, x = 0.07 m; y = 21.505 m, x = 0.00 m)

2.63 A composite curve consisting of entry and exit transition curves of equal length and a central circular arc is to connect two straights on a new road. The design speed for the road is 100 kmph, the radius of the circular arc is 800 m and the rate of change of radial acceleration is 0.30 m/s^3. The through chainage of the intersection point is 3246.28 m and the deflection angle is 15°16'48". (i) Prepare tables for setting out all three curves by the tangential angles method if pegs are required at each 20 m multiples of through chainage (ii) Describe the procedure necessary to establish the common tangent between the entry transition curve and the central circular arc giving the values of any angles required

(Ans: Entry transition curve (chainage, chord, tangential angle from TI): 3094.26 m (T), 0.00 m, 00°00'00"; 3100.00 m, 5.74 m, 00°00'16"; 3120.00 m, 20 m, 00°05'19"; 3140.00 m, 20.00 m, 00°16'47"; 3160.00 m, 20.00 m, 00°34'39"; 3180.00 m, 20.00 m, 00°58'57"; 3183.57 m (T1), 3.57 m, 01°03'58" Central circular arc (chainage, chord, tangential angle from common tangent): 3183.57 m (T1), 0.00 m, 00°00'00"; 3200.00 m, 16.43 m, 00°35'18"; 3220.00 m, 20.00 m, 01°18'16"; 3240.00 m, 20.00 m, 02°01'14"; 3260.00 m, 20.00 m, 02°44'12"; 3280.00 m, 20.00 m, 03°27'10"; 3300.00 m, 20.00 m, 04°10'08"; 3307.61 m (T2), 7.61 m, 04°26'29" Exit transition curve (chainage, chord, tangential angle from UI): 3396.92 m (U), 0.00 m, 360°00'00"; 3380.00 m, 16.92 m, 359°57'42"; 3360.00 m, 20. 00 m, 359°49'04"; 3340.00 m, 20.00 m, 359°34'01"; 3320.00 m, 20.00 m, 359°12'33"; 3307.61 m (T2), 12.39 m, 358°56'02").

2.64 A road 7.30 m wide deflects through an angle of 18°47'26", the through chainage of the intersection point being 1659.47 m. A circular arc of radius 600 m and two equal length transition curves are to be designed for a speed of 85 kph with a rate of change of radial acceleration of 0.30 m/s^3. Calculate: (i) The through chainages of the four tangent points (ii) The theoretical and actual values for the maximum super-elevation on the circular arc, taking g as 9.81 m/s^2 (iii) The data required to set out the entry transition curve and the exit transition curve by the tangential angles method if pegs are to be placed on the centre line at exact 50 m multiples of through chainage.

(Ans: (i) T = 1523.57 m T1 = 1596.70 m T2 = 1720.34 m U = 1793.47 m (ii) Theoretical = 0.69 m; maximum allowable = 0.31 m (iii) Entry transition curve (chainage, chord, tangential angle from TI): 1523.57 m (T), 0.00 m, 00°00'00"; 1550.00 m, 26.43 m, 00°09'07"; 1596. 70 m (T1), 46.70 m, 01°09'50" Exit transition curve (chainage, chord, tangential angle from UI): 1793.47 m (U), 0.00 m, 360°00'00"; 1750.00 m, 43.47 m, 359°35'20"; 1720.34 (T2), 29.66 m, 358°50'10")

2.65 A wholly transitional curve having equal tangent lengths is be designed to connect two intersecting straights which meet at a deflection angle of 07°34'56". If each tangent length is to be 95.38 m and the design speed for the road is 100 kmph, calculate: (i) The minimum radius of curvature (ii) The total length of the curve (iii) The maximum rate of change of radial acceleration

(Ans: (i) R = 719.96 m (ii) Total length of the curve = 190.55 m (iii) Maximum rate of change of radial acceleration = 0.31 m/s^3)

2.66 A 10 m wide road is to be deflected through an angle of 35° 30′. A transition curve is to be used at each end of the circular curve of 500 m radius. It has to be designed for a rate of gain of radial acceleration of 0.2 m/sec^2 /sec and a speed of 60 km/hr. Calculate the suitable length of the transition curve and super-elevation.

(Ans: 46.32 m, 56.6 cm)

2.67 A circular curve of 610 m radius deflects through an angle of 40°30', which is to be replaced by smaller radius transition curves 107 m long at each end. The deviation of this new curve from the old at their mid-points is 0.46 m towards the intersection point. Determine the revised radius assuming that the shift can be calculated with sufficient accuracy on the old radius. Calculate the lengths of track to be lifted and of new track to be laid.

(Ans: R = 590 m, new track = 521 m, old track = 524 m)

2.68 The centre-line of a new road is to be set out through built up area. The two straights of the road T_1I (237.23 m) and T_2I meet giving a deflection angle of 45°, and are to be joined by a circular arc of 572 m with spiral transitions 100 m long at each end. The spiral from T_1 must pass between two buildings, the position of the pass point being 70 m along the spiral from T1 and 1 m from the straight measured at right angles. Calculate all the necessary data for setting out the first spiral transition curve at 30-m intervals; and find the (a) first three angles for setting out the circular arc, if it is to be set out by 10 equal chords, (b) design speed and rate of change of centripetal acceleration, given a centrifugal ratio of 0.1, and (c) maximum super-elevation for a road width of 10 m. Given that θ_1 = 9'1", θ_2 = 36'37", θ_3 = 1°40'10").

(Ans: (a) 1°44'53", 3°29'46", 5°14'39", (b) 85 km/h, 0.23 m/s^3, (c) 1 m)

2.69 A parabolic vertical curve is to connect a +3.1% gradient to a –2.3% gradient on a single carriageway road having a design speed of 70 kmph. With reference to the current UK Department of Transport design standards, calculate the minimum required length of curve if: (i) The curve is to be designed for overtaking (ii) The curve is to be designed for stopping only.

(Ans: (i) 1080 m (ii) If possible use 162 m; if not, use 91.8 m)

2.70 A parabolic vertical curve is to connect a –2.2% gradient to a +1.9% gradient on a road having a design speed of 85 kmph. Using the current design standards, calculate the minimum required length of the vertical curve.

(Ans: 14.2 82 m)

2.71 A road having an up-gradient of 1 in 15 is to be connected to a down-gradient of 1 in 20 by a vertical parabolic curve 120 m in length. Determine the visibility distance afforded by this curve for two approaching drivers whose eyes are 1.05 m above the road surface. If a new vertical parabolic curve is set out to replace the original curve so that the visibility distance is increased to 210 m for the same height of driver's eye. Determine the (a) length of new curve, (b) horizontal distance between the old and new tangent points on the 1 in 5 gradient, and (c) horizontal distance between the summits of the two curves.

(Ans: 92.94 m, (a) 612 m, (b) 246 m, (c) 35.7 m)

2.72 A vertical parabolic sag curve is to be designed to connect a down-gradient of 1 in 20 with an up-gradient of 1 in 15. The chainage and reduced level of the intersection point of the two gradients is 797.7 m and 83.544 m, respectively. In order to allow for necessary headroom, the reduced level of the curve at chainage 788.7 m on the down-gradient side of the intersection point is to be kept as 85.044 m. Compute the (a) reduced levels and chainages of the tangent points and the lowest point on the curve, and (b) reduced levels of the first two pegs on the curve, the pegs being set at the 30 m chainage.

(Ans: T_1 = 745.24 m, 86.166 m, T_2 = 850.16 m, 87.042 m, lowest point = 790.21 m, 85.041 m, (b) 85.941 m, 85.104 m)

2.73 A proposed road consists of a rising gradient of 2% followed by a falling gradient of 4% with the two gradients joined by a vertical parabolic summit curve of 120 m in length. The two gradients produced meet a reduced level of 28.5 m. Compute the reduced levels of the curve at the ends, at 30-m intervals and at the highest point. What is the minimum distance at which a driver, whose eyes are 1.125 m above the road surface, would be unable to see an obstruction 100 mm high?

(Answer: 27.300, 27.675, 27.600, 27.075, 26.100 m; highest point, 27.699 m, 87 m)

References and Suggested Readings

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