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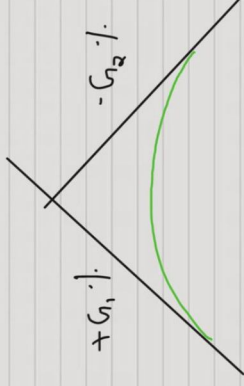
① Summit Curve $\Rightarrow$

$\rightarrow$ Upward Gradient is followed by Downward Gradient

Area and Volume - Part I

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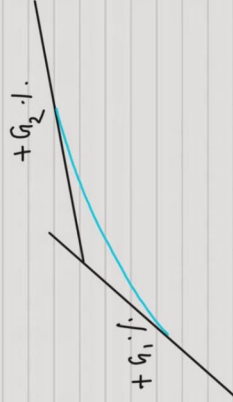


u/w Gr. = +ve
d/w Gr. = -ve

Net change in Gradient

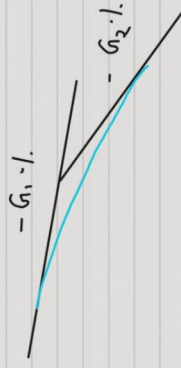
$$G = |G_1 - (-G_2)| \%$$

$\rightarrow$ Steeper u/w Gr. is followed by milder u/w Gr.



$$G = |(G_1 - G_2)| \%$$

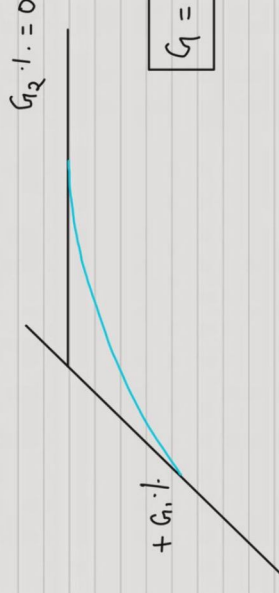
$\rightarrow$ Milder u/w Gr. is followed by steeper d/w Gr.



$$G = |-G_1 - (-G_2)| \%$$

$$G = |(G_2 - G_1)| \%$$

$\rightarrow$ u/w Gr. followed by Flat Ground profile $\Rightarrow$

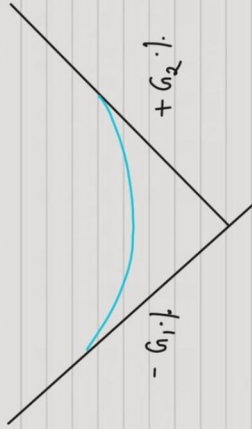


$$G = |G_1 - 0| \%$$

② Valley Curve (sag curve) $\Rightarrow$

$\rightarrow$ Downward Gradient is followed by Upward Gradient -

u/w Gr. = +ve
d/w Gr. = -ve

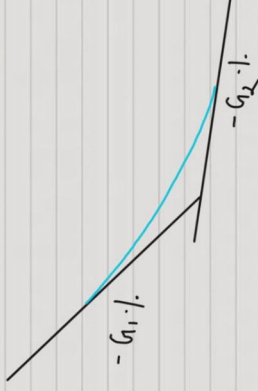


Net change in Gradient

$$G_1 = |-G_1 - (+G_2)| \%$$

$$G_1 = |-G_1 + G_2| \%$$

$\rightarrow$ Steeper d/w Gr. is followed by milder d/w Gr.



$$G_1 = |-G_1 - (-G_2)| \%$$

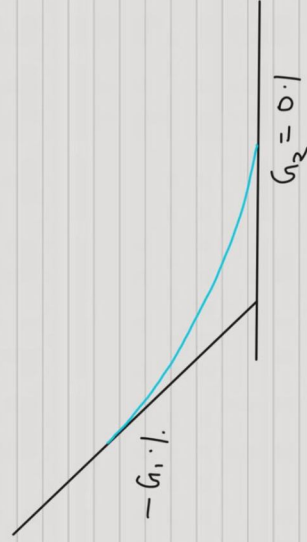
$$G_1 = |(G_2 - G_1)| \%$$

$\rightarrow$ Milder v/w Gr. is followed by steeper v/w Gr.



$$G_1 = |G_1 - G_2| \%$$

$\rightarrow$ d/w Gr. followed by Flat Ground profile $\Rightarrow$



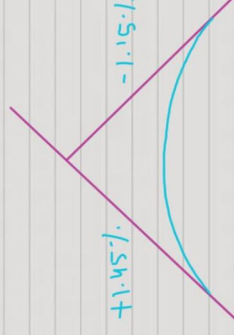
$$G_1 = |-G_1 - 0| \%$$

Q. A vertical curve has an u/w Gr. of +1.45%. which is followed by a down Gr. of -1.15%. The rate of change of Gradient is 0.35% per chain length of 20m. Determine length of vertical curve.

$$SOL \Rightarrow$$

$$G_1 = |1.45 - (-1.15)| \%$$

$$G_1 = 2.6 \%$$



0.35 % of change of Gradient — 20 m.

$$1 \% \rightarrow \frac{20}{0.35}$$

$$2.6 \% \rightarrow \frac{20}{0.35} \times 2.6$$

$$L = \frac{148.57 \text{ m.}}{}$$

Q. A vertical Curve has an upw Gr. of +1.45%. Which is followed by a down Gr. of -1.15%. The rate of Change of Gradient is 0.35% per Chain length. Determine length of vertical Curve.

Solⁿ ⇒

$$G_1 = |1.45 - (-1.15)| \%$$

$$G_1 = 2.6 \%$$

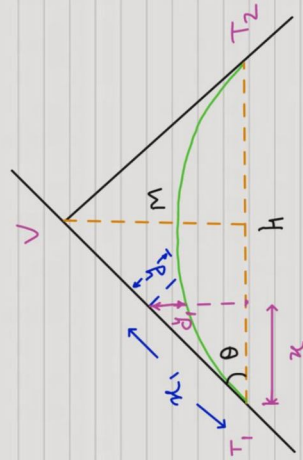
$$0.35 \% \rightarrow 1 \text{ chain length}$$

$$1 \% \rightarrow \frac{1 \text{ chain length}}{0.35}$$

$$2.6 \% \rightarrow \frac{1 \text{ chain length} \times 2.6}{0.35}$$

$$L = 7.428 \text{ chain}$$

Assumption on vertical Curve ⇒



$$① T_1 H = I_2 H$$

$$② VM = MH$$

$$③ T_1 V = T_1 M = T_1 H$$

④ offsets from tangent $T_1 V$ are proportional to Square of distance from T_1 .

$$y \propto x_1^2$$

Since Curve is flat so we can say

$$y_1 \propto x_1^2$$

$$y_1 \propto y$$

$$\cos \theta = \frac{x}{x_1}$$

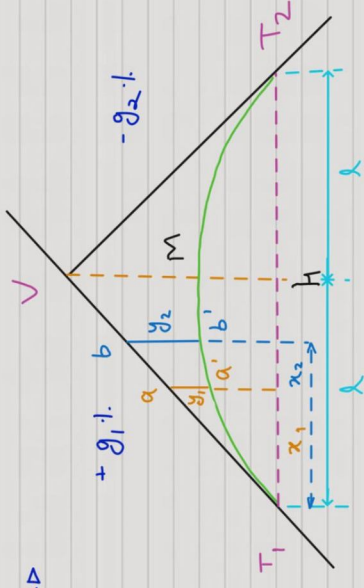
$$x_1 = x \sec \theta$$

$$y_1 \propto \kappa^2 \sec^2 \theta$$

$$y_1 \propto \kappa^2$$

Setting out Curve $\Rightarrow$

Method - I $\Rightarrow$



$$RL_{T_1} = RL_V - \frac{g_1}{100} \times l$$

$$RL_{T_2} = RL_V - \frac{g_2}{100} \times l$$

$$RL_H = \frac{RL_{T_1} + RL_{T_2}}{2}$$

$$VH = PL_V - RL_H$$

$$VM = \frac{VH}{2}$$

For the Calculation of offset of curve.

$$y_1 \propto \kappa_i^2$$

$$VM \propto \kappa^2$$

$$\frac{y_1}{VM} = \frac{\kappa_1^2}{\kappa^2}$$

$$y_1 = \left(\frac{\kappa_1^2}{\kappa} \right) VM$$

Similarly $y_2 = \left(\frac{\kappa_2^2}{\kappa} \right) VM$

$$y_3 = \left(\frac{\kappa_3^2}{\kappa} \right) VM$$

$$RL_{A'} = RL_A - y_1$$

$$RL_A = RL_{T_1} + \frac{g_1}{100} \times x_1$$

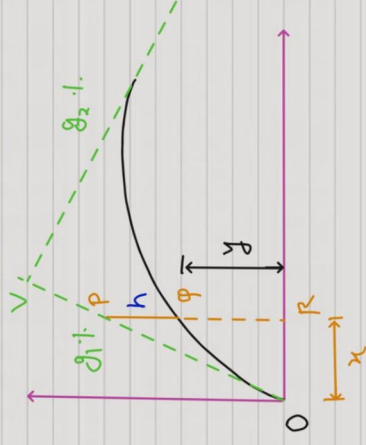
$$RL_{A'} = \left[RL_{T_1} + \frac{g_1}{100} \times x_1 \right] - \left[\left(\frac{x_1}{x} \right)^2 \times y_1 \right]$$

Similarly

$$RL_{B'} = RL_B - y_2$$

Method-II

Tangent Connection method $\Rightarrow$



$$h \propto x^2$$

$$h = Cx^2$$

Equation of Parabola

$$y = ax^2 + bx + c$$

$$x = 0, y = 0$$

$$C = 0$$

$$y = ax^2 + bx$$

$$\frac{dy}{dx} = 2ax + b$$

$$x = 0, \frac{dy}{dx} = g_1 \%$$

$$b = g_1$$

from eqⁿ of parabola

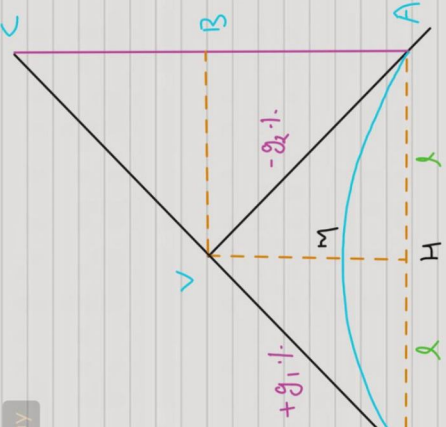
$$y \propto x^2$$

$$h \propto x^2$$

$$h = Cx^2 \longrightarrow \textcircled{1}$$

Difference in elevation betⁿ a vertical curve & tangent to it varies as a square of horizontal distance from the point of tangency/curve.

This difference in elevation is called tangent constⁿ.



Extend OV line to OC such that $OV = VC$
& it is observed that point C vertically above A.

$$AC = AB + BC \rightarrow (2)$$

$$BC = VH$$

$$g_1 \cdot l = \frac{VH}{l}$$

$$BC = VH = g_1 \cdot l$$

$$\text{Similarly } AB = -g_2 \cdot l$$

from eq. (2)

$$AC = (g_1 - g_2) l \rightarrow (3)$$

from eq. (1)

$$h = C n^2$$

$$AC = C (2l)^2$$

$$\frac{AC}{4l^2} = C$$

from eq. (3)

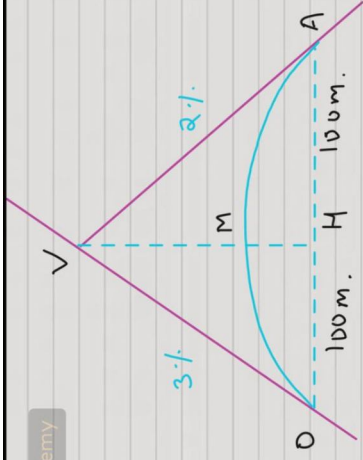
$$C = \frac{(g_1 - g_2) l}{4l^2}$$

$$C = \frac{(g_1 - g_2)}{4l}$$

A 3-l. Rising Gradient meets a 2-l. down Gradient. A vertical Curve 200m. long is to be used. The pegs are to be fixed at 20m. Interval. Calculate the elevation of Curve point by tangent connection method. RL of apex - 350m & chainage - 1000m.

Solⁿ =

$$\text{Curve length} = 200\text{m.}$$



$$OM = \frac{OA}{2} = \frac{200}{2} = 100m.$$

$$OH = OM = OV = 100m.$$

$$\text{Chainage of } O = 1000 - 100 = 900m.$$

$$\text{Chainage of } A = \text{Chainage of } O + \text{Curve length} \\ = 900 + 200 = 1100m.$$

$$\text{Peg Interval} = 20m.$$

$$\text{No. of Stations} = \frac{200}{20} = 10 \text{ stations}$$

$$\text{No. of Station on each side of apex} = 5$$

$$\text{RL of Station } O = RL_v - \frac{3}{100} \times 100$$

$$= 350 - 3 = 347m.$$

$$\text{RL of Station } A = RL_v - \frac{2}{100} \times 100$$

$$= 350 - 2 = 348m.$$

$$C = \frac{(g_1 - g_2)}{4L}$$

$$C = \frac{0.03 - (-0.02)}{4 \times 100} = 1.25 \times 10^{-4}$$

$$h = Cx^2$$

$$h_1 = 1.25 \times 10^{-4} \times 20^2 = 0.05m.$$

$$h_2 = 1.25 \times 10^{-4} \times 40^2 = 0.2m.$$

$$h_3 = 1.25 \times 10^{-4} \times 60^2 = 0.45m.$$

$$h_4 = 1.25 \times 10^{-4} \times 80^2 = 0.8$$

$$h_5 = 1.25 \times 10^{-4} \times 100^2 = 1.25$$

$$h_6 = 1.25 \times 10^{-4} \times 120^2 = 1.8$$

$$h_7 = 1.25 \times 10^{-4} \times 140^2 = 2.45$$

$$h_8 = 1.25 \times 10^{-4} \times 160^2 = 3.2$$

$$h_9 = 1.25 \times 10^{-4} \times 180^2 = 4.05$$

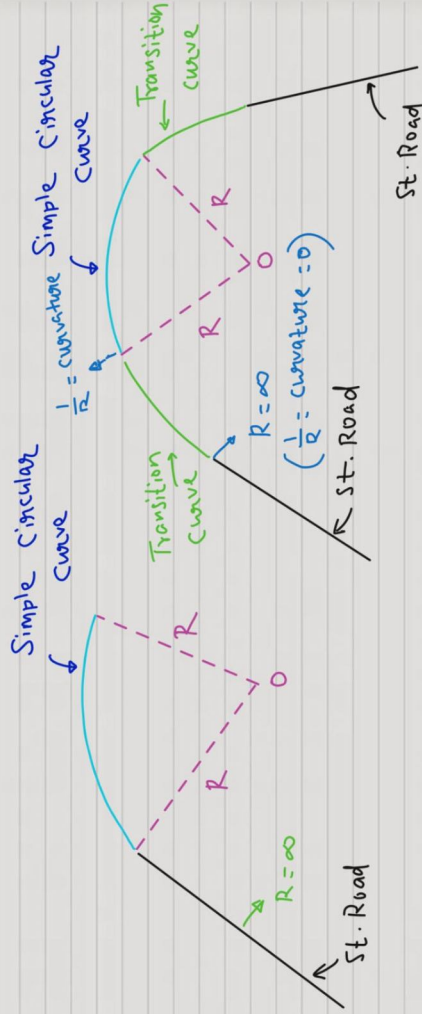
$$h_{10} = 1.25 \times 10^{-4} \times 200^2 = 5$$

Station	Chainage	Grade elevation	Tangent Connection	Curve elevation
0	900	347	0	347
1	920	347.6	0.05	347.55
2	940	348.2	0.2	348
3	960	348.8	0.45	348.35
4	980	349.4	0.8	348.6
5	1000	350	1.25	348.75
6	1020	350.6	1.8	348.8
7	1040	351.2	2.45	348.75
8	1060	351.8	3.2	348.6
9	1080	352.4	4.05	348.35
10	1100	353	5	348

Area and Volume - Part II

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Transition Curve $\Rightarrow$



unacademy Wave of variable gradients Introduce betⁿ a straight line and a simple circular curve.

- $\rightarrow$ Transition Curve provides a gradual change from st. line to circular curve & from circular curve to st. line.
- $\rightarrow$ It is tangential to st. line & also meets circular curve tangentially at the junction.
- $\rightarrow$ It's curvature is zero ($R = \infty$) at junction with straight line & curvature is $\frac{1}{R}$ at the junction with simple circular curve.

unacademy Rate of increase of curvature along the transition curve is equal to rate of increase of super-elevation.

$\rightarrow$ The length of transition curve should be such that full super-elevation is achieved at the junction with circular curve.

unacademy Derivation of Ideal Transition Curve $\Rightarrow$

Centrifugal force (P) should increase uniformly with distance from beginning of transition curve.

$$\boxed{P \propto l} \longrightarrow (1)$$

$P =$ Centrifugal force

$l =$ length of transition curve.

We know that

$$P = \frac{mv^2}{R}$$

for constant mass & velocity of vehicle

$$P \propto \frac{1}{R} \quad \longrightarrow \quad (2)$$

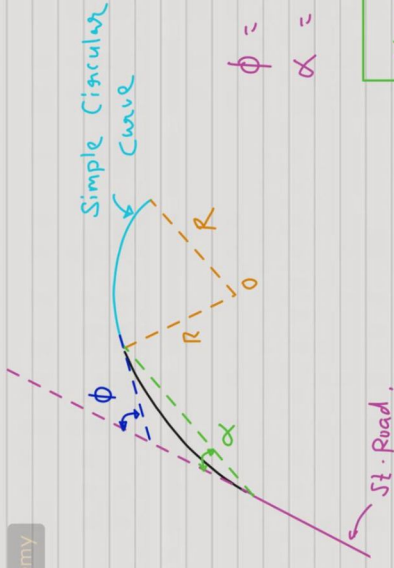
from eq. ① & ②

$$l \propto \frac{1}{R}$$

$$l = \frac{\text{Constant}}{R}$$

$$lR = \text{Constant}$$

This is fundamental condition of Ideal Transition curve,
Euler Spinal, Clothoid & Glover Spinal Curve.



ϕ = Spiral angle

α = polar Deflection angle

$$\alpha = \frac{\phi}{3}$$

property of Ideal Transition curve.

Equation of Curve in the form of Cartesian Coordinate.

① Euler Spinal

② Cubic Spinal

③ Cubic parabola

④ Lamniscate Curve

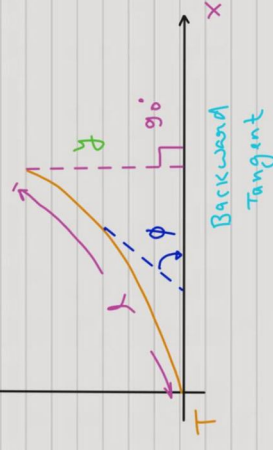
→ Cubic Spinal Curve $\Rightarrow$

Assumption

$$\sin \phi = \phi$$

$$y = \frac{l^3}{6RL} \quad \rightarrow \text{Equation of T.C.}$$

ϕ = Spinal angle.



L = Total length of T.C.

R = Radius of Simple Circular Curve

l = Distance of any point on T.C from Initial point (\$T\$)