Lecture 4
18/04/19

④ Vertical alignment

- Gradient
  - Ruling gradient
  - limiting gradient
  - exceptional gradient
  - min gradient
- Vertical curve
  - summit curve
  - valley curve

Gradient – Slope due to gradual rise or gradual fall in the dirⁿ of vehicle movement is called gradient

- If it is gradual rise there is a slope is called ascending gradient / rising gradient / positive gradient.

- If it is gradual fall then the slope is called descending gradient falling gradient and (-ve) gradient.

① R.G → this is the max gradient which designer want to provide to a vertical profile of road. it depend upon design speed and topography

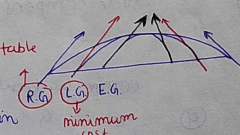
② L.G → this gradient is stepper than ruling gradient and it is provided only when cost of construction by L.G is less than the cost of construction by R.G.

③ E.G → this gradient is stepper than above other gradient and it is provided only when case is unavoidable

④ M.G → this gradient is provided for drainage point of view in order to provide gravity flow of water inside the drainage system

① min gradient = $\frac{1}{500}$ for cc drain

② = $\frac{1}{200}$ for open soil drain



EG > LG > RG > MG

Maximum gradient as per IRC →

		R.G	L.G	E.G
①	Plain & rolling terrain	3.3%	5%	6.7%
②	Mountaneous & steep terrain having elevation more than 3000m above MSL	5%	6%	7%
③	Mountaneous & steep terrain having elevation up to 3000m above MSL	6%	7%	8%

Note- {At higher elevation lesser gradient is provided bcoz availability of oxygen is less at higher elevation which may reduce pulling power of vehicle}

Grade compensation

When there is a Horizontal curve in addition to gradient there is a loss of traction due to curve and gradient both. In this case IRC suggest to compensate to grade so that pulling power of vehicle should not be compromise

***

Gradient − grade compensation = compensated grade

$$\text{Grade compensation} = \left(\frac{30+R}{R}\right)\% \text{ or } \left(\frac{75}{R}\right)\%_{min}$$

- As per IRC
  - Grade compensation is not require for a gradient flater than 4%.
  - Compensated gradient should not be less than 4%.

(Pb) (54) Grade compensation $= \left(\frac{30+R}{R}\right)\% = \left(\frac{30+60}{60}\right)\%$ or $\left(\frac{75}{R}\right)\%_{min}$

$= 1.5\%$ or $\frac{75}{60}\%$

$= 1.5\%$ or 1.25%

compe. Gradient $= G - GC$

(a) $GG = G - GC = 6 - 1.25 = 4.75 \nless 4\%$.

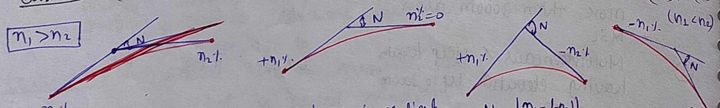
Actual Grade compensation $= 5 - 4 = 1\%$

(b) $CG = G - GC = 5 - 1.25 = 3.75 < 4\%$

(A) Vertical curve

- **summit curve**: are the vertical curve with convexity upward or concavity downward. It can be formed by 2 gradient in following way.

case ① (+ve) to (+ve) — case ② (+ve) to flate — case ③ (+ve) to (−ve) — case ④ (−ve) to (+ve)



change in gradient $N = |n_1 - n_2|$ — change in gradient $N = |n_1 - 0|$ — $N = |n_1 - (-n_2)|$, $N = |n_1 + n_2|$ — $N = |-n_2 - (-n_1)| = |n_2 - n_1|$

- **Some important Point**:

① convexity upward and concavity downward

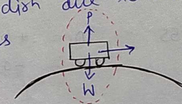
② Vertical point of intersection (VPI) always lies above the curve.

③ Summit curve and design only for sights distance criteria

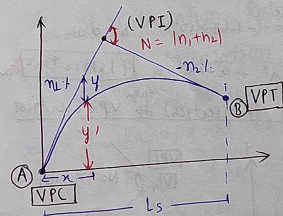
④ Summit curve are design with square Parabola shape due to best riding quality and due to simplisity of calculation.

⑤ Ideal shape of summit curve is circular.

⑥ Generally there is no discomfort in summit curve bcoz centrifugal force act in upward dir^n due to which effective weight of vehicle reduces



- **Derivation**



I) General eq^n of summit curve

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

At Point A $x = 0, y' = 0$

$0 = a \cdot 0^2 + b \cdot 0 + c$

c = 0

$\left[\frac{dy'}{dx} = 2ax + b\right]$ = Gradient

At Point A $\frac{dy'}{dx} = +n_1, x = 0$

$[+n_1 = 2a \cdot 0 + b]$ **b = +n_1**

At Point B $\frac{dy'}{dx} = -n_2, x = L_s$, $-n_2 = 2 \cdot a \cdot L_s + n_1$

$a = -\left[\frac{n_1 + n_2}{2L_s}\right] = \frac{-N}{2L_s}$

$$\boxed{a = \frac{-N}{2L_s}}$$

$$y' = \left[\frac{-N}{2L_s}\right]x^2 + n_1 x$$

② ** 2019 Position of summit Point / crest point / highest point from VPC

$\frac{dy'}{dx} = 0, \quad 2ax + b = 0, \quad x = \frac{-b}{2a} = \frac{-n_1}{2\left(\frac{-N}{2L_s}\right)}$

$$x = \frac{n_1}{N} \cdot L_s$$ ***

③ Apex eqn

tamp ⇒ $n_1 = \frac{y + y'}{x}$

⇒ $y + y' = n_1 x$

⇒ $y = n_1 x - y' = n_1 x - \left[\left(\frac{-N}{2L_s}\right)x^2 + n_1 x\right]$

$$y = \left[\frac{N}{2L_s}\right]x^2$$

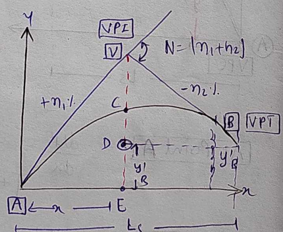
Pb- 55 $\left.\begin{aligned} n_1 &= +0.02 \\ n_2 &= -0.03 \end{aligned}\right\}$ $N = |n_1 + n_2| = |0.02 + 0.03| = |0.05|$

$x = \left(\frac{n_1}{N} \cdot L_s\right) = \frac{0.02}{0.05} \times 150 = 60m$

then $a = \frac{-N}{2L_s} = -\frac{0.05}{2 \times 150} = (-1.67 \times 10^{-4})$, $b = 0.02$

$y' = (-1.67 \times 10^{-4})x^2 + 0.02x = \boxed{(1.67 \times 10^{-4})x^2}$ Ans

Position of VPI (vertical point of intersection) from to VPC (vertical point of curve)



from ΔAVE

$n_1 = \frac{VE}{x} \Rightarrow VE = n_1 x$

from ΔVDB

$n_2 = \frac{VD}{L_s - x} \Rightarrow VD = n_2 L_s - n_2 x$

$\Rightarrow y'_{B\,at\,x = L_s} = DE = VE - VD$

$\left[\frac{-N}{2L_s}\right]L_s^2 + n_1 L_s = n_1 x - n_2 L_s + n_2 x$

$-\frac{NL_s}{2} + (n_1 L_s + n_2 L_s) = n_1 x + n_2 x$

$-\frac{NL_s}{2} + NL_s = Nx$

$\frac{NL_s}{2} = Nx$

$$x = \frac{L_s}{2}$$ *** 2019

Case-① When the curve is symmetrical → ($N_1 = N_2$)

① In this case vertical line passing VPI will bisect length of curve into equal half.

② This line is always pass through summit point of curve.

③ In this case RL of starting point and end point exactly same.

Case-② When the curve is not symmetrical ($N_1 \neq N_2$)

① In this case vertical line passing through VPI will bisect length of curve in two equal half. &

② this line will never pass through summit point of curve

③ In this case the curve will be tilted and RL of starting point and end point will be different.

RL of calculation (Reduce level)

5] R.L of calculation.

if RL of Ⓐ is known

a) RL of point just below (VPI)

$RL_C = RL_A + y'@x = \frac{L_s}{2}$

$= RL_A + \left(\frac{-N}{2L_s}\right)\left(\frac{L_s^2}{4}\right) + n_1 \frac{L_s}{2}$

$$RL_C = RL_A + n_1\left(\frac{L_s}{2}\right) - \frac{NL_s}{8}$$

b) RL of end point

$RL_B = RL_A + y' @ x = L_s$

$= RL_A + \left(\frac{-N}{2L_s}\right) \cdot L_s^2 + n_1 L_s$

$= RL_A + \left(\frac{-NL_s}{2}\right) + n_1 L_s$

$= RL_A + n_1 L_s - \frac{L_s}{2}(n_1 + n_2)$

$= RL_A + n_1 L_s - \frac{n_1 L_s}{2} - \frac{n_2 L_s}{2}$

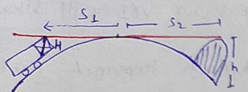
$= RL_A + n_1 \frac{L_s}{2} - n_2 \frac{L_s}{2}$

$RL_B = RL_A + \frac{L_s}{2}(n_1 - n_2)$

- If $n_1 = n_2$ ⇒ $RL_B = RL_A$
- If $n_1 > n_2$ ⇒ $RL_B > RL_A$
- If $n_1 < n_2$ ⇒ $RL_B < RL_A$

length of summit curve →

Case-① When $L_s > SD$



H = height of driver eye

h = Height of obstruction

$$L_s = \frac{NS^2}{2(\sqrt{H}+\sqrt{h})^2}$$

Standard Relation by IRC

For SSD H = 1.2m, h = 0.15m

$$L_s = \frac{NS^2}{2(\sqrt{1.2}+\sqrt{0.15})^2} = \frac{NS^2}{4.39}$$

$$L_s = \frac{NS^2}{4.4}$$

For OSD/ISD H = 1.2m, h = 1.2m

$$L_s = \frac{NS^2}{2(\sqrt{1.2}+\sqrt{1.2})^2} = \frac{NS^2}{9.6}$$

$$L_s = \frac{NS^2}{9.6}$$

Case-② when $L_s < SD$

$$L_s = 2S - \frac{2(\sqrt{H}+\sqrt{h})^2}{N}$$

IRC Relations

1] For SSD

$$L_s = 2S - \frac{4.4}{N}$$

2) for OSD/ISD

$$L_s = 2S - \frac{9.6}{N}$$

Note: for calcul. of sight distance in design of summit curve/ valley curve effect of gradient shoul nt be taken

$$S = 0.278 V t_R + \frac{V^2}{254 f}$$ ***

W.B. ***

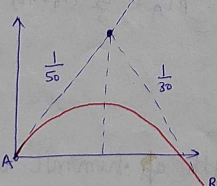
(40) $x = \frac{L_s}{2}$

$(200 = L_s)$

(57) Problem SSD = 180m

$n_1 = +\frac{1}{50}$, $n_2 = \frac{-1}{30}$ $n_1 < n_2$

$RL_A = 100m$



change in gradient

$$N = \left|\frac{1}{50} + \frac{1}{30}\right| = \frac{4}{75}$$

Assume $L_s > SD$ $L_s = \frac{NS^2}{4.4} = \left(\frac{\frac{4}{75}\times 180^2}{4.4}\right) = 392.72m > 180m$ (SSD)

Assumption was safe

(a) R.L of Point just below VPI

$$RL_C = RL_A + n_1 \frac{L_s}{2} - \frac{N L_s}{8}$$

$$= 100 + \frac{1}{50}\times\frac{392.72}{2} - \frac{4/75 \times 392.72}{8} = 101.31m$$

(b) R.L of summit point

$$x = \left(\frac{n_1}{N}\cdot L_s\right) = \left(\frac{\frac{1}{50}\times 392.72}{4/75}\right) = 147.27m$$

$y'@x =$ ~~147.27~~.

$$y'_{@x=147.27} = \left[\frac{-N}{2L_s}\right]x^2 + n_1 x$$

$$= -\left[\frac{\frac{4}{75}}{2\times 392.72}\right]\times 147.27^2 + \frac{1}{50}\times 147.27$$

$= 1.47m$

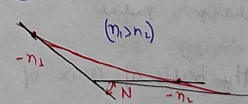
RL summit point $= RL_A + y'_{@x = summit}$

$= 100 + 1.47 = 101.47m$

Valley curve are vertical curve with concavity upward and convexity downward.

– It can be formed by 2 gradients in following ways

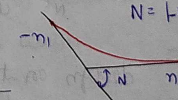
(a) (-ve) to (+ve)



$N = |-n_2 - (-n_1)|$

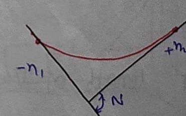
$= |n_2 - n_1|$

(b) (-ve) to flat



$N = |-n_1 - 0| = |n_1|$

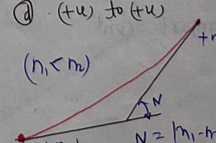
(c) (-ve) to (+ve)



$N = |-n_1 - n_2|$

$= |n_1 + n_2|$

(d) (+ve) to (+ve)



$N = |n_1 - n_2|$

Some important point

① concavity upward
② convexity downward
③ V.P.I always lies below the curve
④ valley curve are design taking following consideration into account.
⑤ ⓐ comfort to passenger
ⓑ Head-light sight distance***
⑥ Aesthatic (appearence) of valley curve

Note: HLSD (max. distance visible through head light of vehicle is called HSD)

generally HSD ≈ SSD

⑦ Valley curve are made fully transitional by adding 2 similar cubic parabola transition curve.
⑧ Centrifugal force act in downward dirn due to which effective wt of vehicle increases which may cause jerking/ discomfort to passengers
⑨ Position of lowest point of valley curve from (VPC)

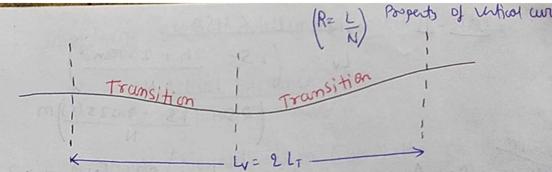
$$x = L_V\left(\frac{n_1}{2N}\right)^{\frac{1}{2}}$$ ESE 2015

L_V = length of valley curve
n_1 = 1st gradient
N = change in gradient

Length of valley curve- design on the basis of max. of following 2 criteria

criteria ① As per comfort condn

$\left(R = \frac{L}{N}\right)$ Property of vertical curve



Length of transition curve

$$L_T = \frac{V^3}{CR} = \frac{V^3}{C\cdot\left(\frac{L_T}{N}\right)} = \sqrt{\frac{NV^3}{C}}$$

$$L_T = \sqrt{\frac{NV^3}{C}}$$

Length of valley curve $L_V = 2L_T$

$$L_V = 2\sqrt{\frac{NV^3}{C}}$$

As per IRC

$C = 0.6\ m/s^3$ for cubic parabola T.C

Don't use formula $\left(C = \frac{80}{75+V}\right)$ It is valid for only spiral T.C

$$L_V = 2\sqrt{\frac{N(0.278V)^3}{0.6}}$$

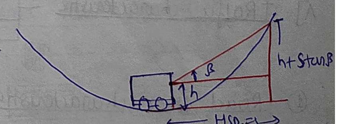
$$= 0.378\sqrt{NV^3}$$

As per IRC $L_V = 0.38\sqrt{NV^3}$ (m; V → kmph)

criteria ② As per HSD

case-① When L_V > HSD

h = Height of Headlight
β = Beam angle



$$L_V = \frac{NS^2}{2h + 2S\tan\alpha}\ (m)$$

$$L_V = \frac{NS^2}{1.5 + 0.035(S)}\ m \quad (h = 0.75\ m \text{ and } \alpha = 1°)$$

Case-II When $L_v < HSD$

$$L_v = \left(2S - \frac{2h + 2S\tan\beta}{N}\right)$$

$$= \left(2S - \frac{1.5 + 0.035(S)}{N}\right) m$$

(58) Problem

Criteria ① As per comfort $L_v = 0.38\sqrt{NV^3} = 0.38\sqrt{\frac{11}{50}\times 80^3}$

$= 73.63m$

Criteria ② As per HSD

Assume $L_v > HSD$

$$L_v = \frac{NS^2}{1.5 + 0.035(S)} = \frac{\frac{11}{150}\times(127.59)^2}{1.5 + 0.03\times 127.59} = 200.11m$$

$$HSD = SSD = \left(0.278\times 80\times 2.5 + \frac{(80)^2}{254\times 0.35}\right)$$

$= 127.59m$

$L_v = \max\begin{cases} 73.63 \\ 200.11 \end{cases}$

$L_v = 200.11m$

CHAPTER-③

TRAFFIC ENGINEERING

A] Traffic characteristic

B] traffic study and analysis

C] Traffic control devices and Regulation

A] Traffic characteristic →
- Road User characteristic
- Vehicular characteristic
- Braking characteristic

① Road user characteristic : Factor affecting road user charact.

① Physical : ⓐ vision ⓑ Hearing strength ⓒ strength ⓓ

② Psychological : ⓐ Attentiveness, ⓑ Fear ⓒ Anger ⓓ superstitions ⓔ impatience ⓕ Mutually

③ Mental → Knowledge, skill, intelligence, and literacy

Vision $= \frac{x}{y} = \left(\frac{\text{Actual Distance}}{\text{Required Distance}}\right)$

$\frac{6}{6}$ Vision / Normal vision (It is the ability of person vision due to which he can recognised a letter of size 8.5mm at a distance of 6m)

$\frac{6}{9}$ vision (this vision is poorer than the normal vision because he can recognized at a distance of 6m what a normal person can be recognise at a distance of 9m)

Vehicular characteristic →

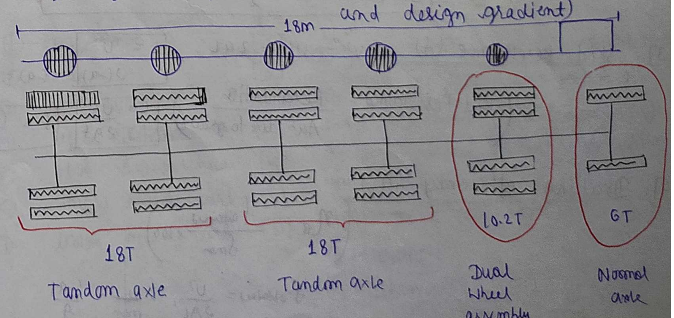
Dimension

① length of vehicle affect extra widening, turning radius, road capacity and parking design. (maximum length 18m)

② Width of vehicle affect lane width, Shoulder width, parking width (max- 2.44)

③ Height of vehicles height of vehicle affect height of bridge, height of electric, telephone, pole, etc. (maximum height 4.75m)

④ Weight of loaded vehicle (wt affect thickness of pavement and design gradient)



52.2T

① Power of Vehicle :- It effect limiting and permissible value of gradient

② Speed of vehicle It affect all geometrical element and traffic control device etc signal, rotary

Braking Test

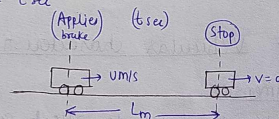
atleast two of the following 3 parameters are needed in breaking test to determine skid resistance of Pavement.

Initial speed U m/s, length (L_m) (Skid distance)

time of brake application = t sec

1] Retardation

$a = \frac{0 - U}{t} \Rightarrow (-a) = \frac{U}{t}$



$\text{Retardation} = \left(\frac{\text{Initial speed}}{\text{time}}\right)$

2] Skid distance

$L = Ut + \frac{1}{2} a t^2$

$= Ut + \frac{1}{2}\left(\frac{-U}{t}\right) t^2 = Ut - \frac{1}{2} Ut = \frac{1}{2} Ut$

$L = \frac{1}{2} Ut$

$\text{Skid distance} = \frac{1}{2} \times \text{initial speed} \times \text{time}$

3] Skid Resistance (f)

$v^2 = U^2 + 2aL$, $L = \frac{U^2}{2(-a)}$ $(-a) = gf$

$\left(\text{Skid Resistance} = \frac{\text{Retardation}}{\text{Acc}^n \text{ due to gravity}}\right)$ $L = \frac{U^2}{2gf}$ $f = \frac{(-a)}{g}$

4] Braking efficiency (η_B)

$\left(\eta_B = \frac{f_{obtained}}{f_{max}} \times 100\right)$

$f_{obtained} = \frac{U^2}{2gL}$, $f_{max} = \frac{(-a)}{g}$

① Pb W.B.

$V = 50 km/h$

$L = 16.5 m$

$f_{avg} = 0.687$

$\eta_B = ?$

$\eta_B = \frac{f_{obtain}}{f_{max}} \times 100 = \frac{0.596}{0.687} \times 100 = 86.75\%$

ⓐ (37) $L = 5.8m$, $U = 30 km/h$

$f = \frac{U^2}{2gL} = \left(\frac{0.278 \times 40}{1.8}\right) = 6.17 m/s^2$

$f = \frac{(-a)}{g} = \frac{6.17}{9.81} = 0.628$

ⓒ $1.7 m = L$

$t = 1.4 sec$

$L = \frac{1}{2} Ut$

$7 = \frac{1}{2} \times V \times 1.4 \Rightarrow$ $v = 10 m/s$ and $f = \frac{U^2}{2gL} = \frac{10^2}{(2 \times 9.81 \times 7)}$

$= 0.728$ Ans