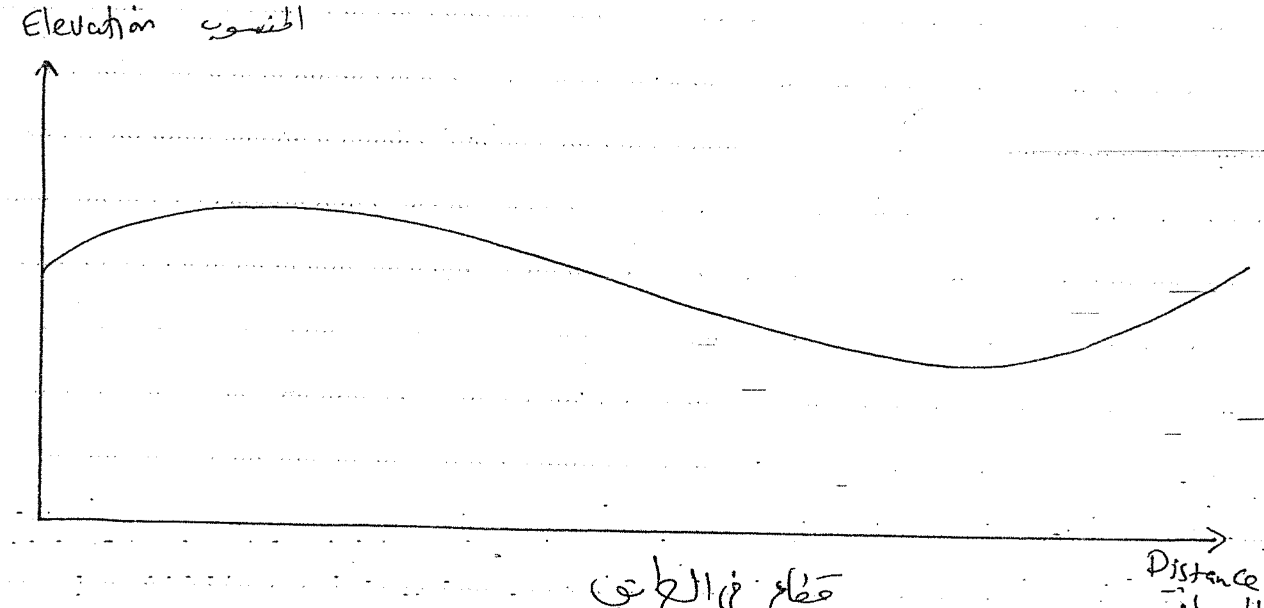
HIGHWAY ENGINEERING

GEOMETRIC DESIGN

GEO 5

Vertical Alignment of Highways

التخطيط الرأسي للطرق



قطاع في الطريق

* العوامل التي تؤثر على اختيار القطاع الطولي للطريق

1) يجب احترام مناسيب كافة العوائق التي تتقاطع مع الطريق من سكك حديدية أو مجاري مائية أو طرق قائمة.

2) في المناطق الصحراوية يجب أن يكون منسوب الطريق قدر الإمكان يساوي منسوب الأرض الطبيعية وذلك لتجنب النحر في حالة الارتفاع أو التغطية بالكثبان الرملية في حالة الحفر. كما يجب تقليل حركة الكثبان الرملية.

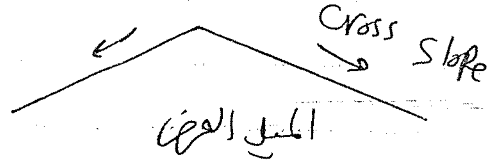
3) في حالة المناطق المستوية يجب أن يتبع خط الطريق المقترح الأرض الطبيعية مع رفعه بالقيمة التي تسمح بصرف المياه الطبيعية.

4) يجب أن تكون المماسات طويلة قدر الإمكان حتى لا يحدث تداخل بين المنحنيات الرأسية.

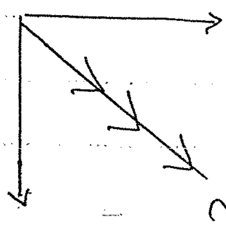
لاحظ انه

الطريق يكون له ميلين ← ميل طولي
← ميل عرضي

+ الميل الطولي في اتجاه السير



وعليه فإن المياه تتحرك في إتجاه محصلة الميلين



Factors affecting the choice of profile

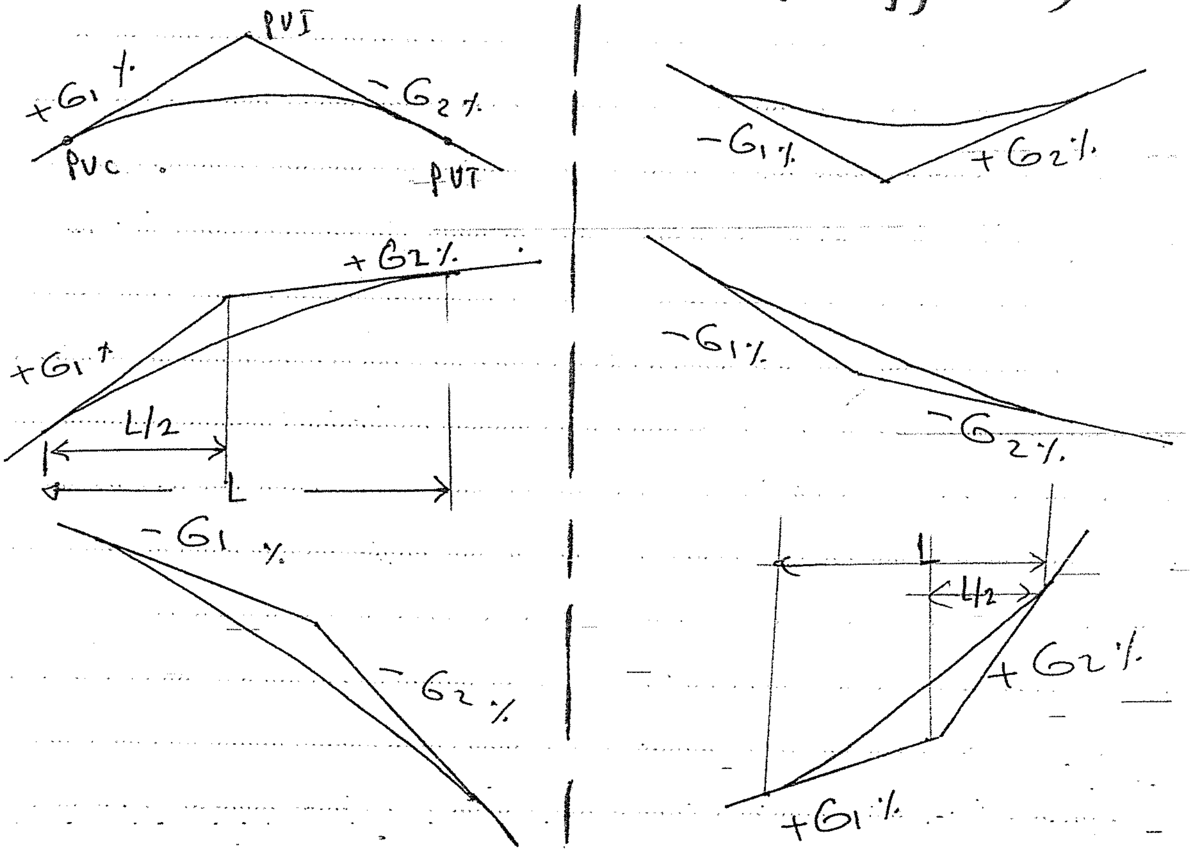
- Control points – Roads – waterways – bridges – etc.
- Natural topography – least costly
- Ground water level.
- Design standards – max grade, min curvature – etc.

المنحنى الرأسي

Crest	Sag
محدب	مقعر

Types of Vertical Curves

(Crest) محدب | (Sag) مقعر



نحسب

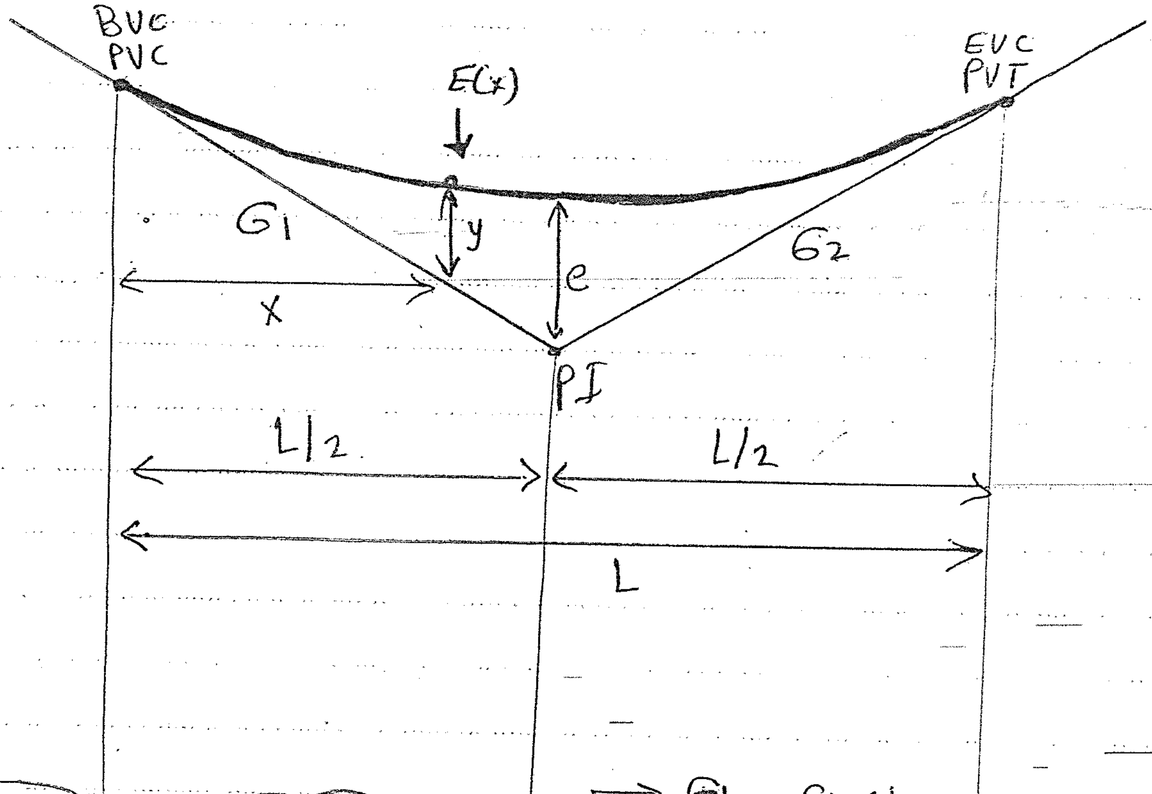
$$A = G_2 - G_1$$

(−) محدب Crest

(+) مقعر Sag

لاحظ ان (A) تستخدم من القوانين كقيمة مطلقة بدون إشارة

Properties of Vertical Curves



$$A = G_2 - G_1$$

→ ⊖ Crest محدب
→ ⊕ Sag مقعر

(A) → Change in grade , G = ✓ %

$$K = L/|A|$$

(k) → Rate of change of Curvature

. كلما زادت ال (K) كلما اصبح المنحنى مريح (منبسط)
gentler Smooth

. L = ✓ m

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

(r) → rate of change of grade
(g) → is expressed as a ratio (+ , −)
(L) → in meters

$$e = \frac{A * L}{800}$$

$$E(x) = y_0 + g_1 * X + \frac{1}{2} r x^2$$

$E(x) \rightarrow$ elevation at any point

$y_0 \rightarrow$ elevation at BVC

$g \rightarrow$ grade expressed as a ratio

$X \rightarrow$ horizontal distance from BVC

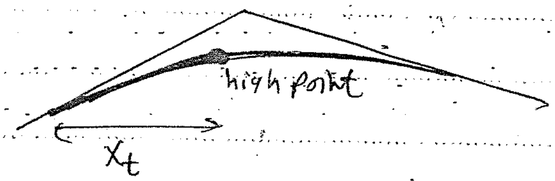
$r \rightarrow$ rate of change of grade expressed as ratio

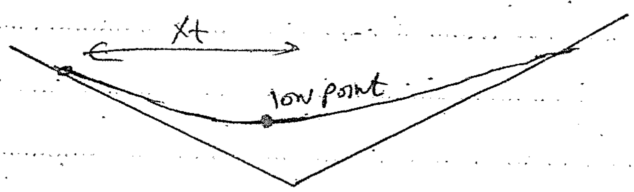
في هذا القانون لاحظ انك هتعوض بإشارات الـ ← (r)

← (g)

$$X_t = \frac{-g_1}{r}$$

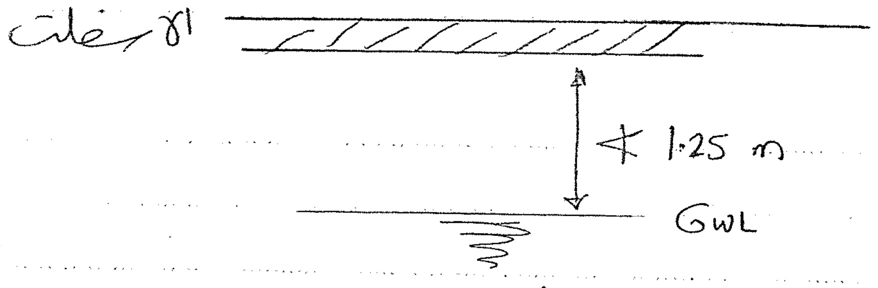
$(X_t) \rightarrow$ distance between BVC to the turning point (high/low point on curve)





ملاحظات

- تقع أعلى أو أوطى نقطة ناحية الميل الأقل في القيمة بغض النظر عن الإشارة.
- نقطة تقاطع المماسين (PI) تقسم طول المنحنى على الأفقي إلى نصفين متساويين L/2 دون النظر لاختلاف ميول المماسات.
- كافة الأبعاد الخاصة بالمسافات تقاس أفقياً تماماً وليس على المنحنى أو على المائل.
- كافة المناسيب والارتفاعات على المنحنى تقاس رأسياً تماماً وليس ⊥ على المائل



- يجب أن يكون منسوب الطريق أعلى من منسوب المياه الجوفية حتى لا تتعرض تربة تأسيس الطريق لمهاجمة المياه الجوفية

- يجب ألا يزيد الميل الطولي عن

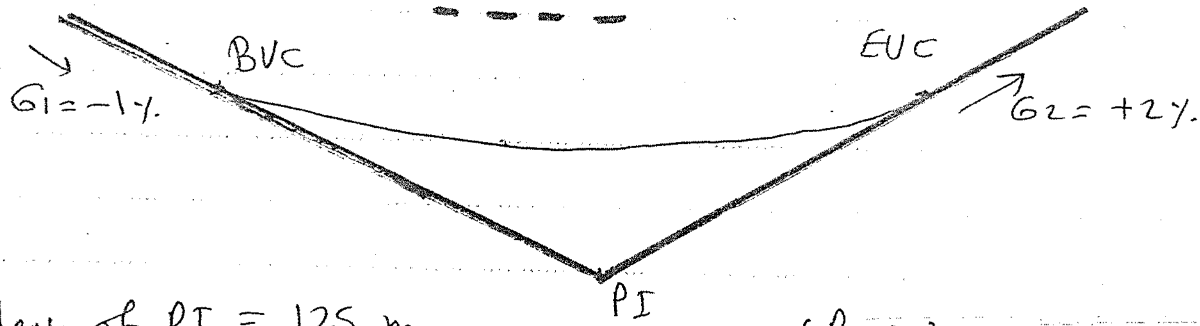
  . الطرق المستوية 3% ← المرور متوسط
  5% ← السيارات الخاصة

  . الطرق الجبلية 7%

- نقطة تقاطع المماسين تقسم المنحنى إلى نصفين متساويين كل منهما $= \frac{L}{2}$

- تتساوى الـ (Y) لكل (X) متساوية على جانبي المنحنى .

Ex



Elev. of PI = 125 m
Station of EVC = 25+00
Station of PI = 24+00
1 Sta = 100 m

(Req)

1. Length of Curve
2. r - Value
3. Station of low Point
4. Elevation at low point
5. Elevation at Station 23+50
6. Elevation at station 24+50

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① (L) →

$$L/2 = \text{Sta EVC} - \text{Sta PI}$$

$$= 2500 - 2400 = 100 \text{ m}$$

$$L = 2 * 100 = 200 \text{ m}$$

② (r) → $$\frac{g_2 - g_1}{L} = \frac{0.02 - (-0.01)}{200} = \boxed{0.00015} \ /m$$

③ (Station of low point) $$X_t = -\left(\frac{g_1}{r}\right) = -\left(\frac{-0.01}{0.00015}\right)$$

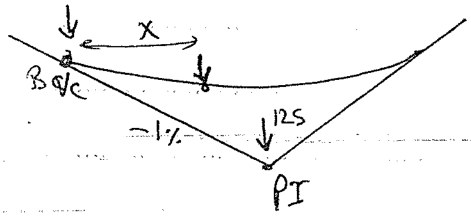
$$= 66.67 \text{ m}$$

$$\text{Station} = (23 + 00) + 66.67$$

$$= \boxed{23 + 67}$$

④ Elevation of low point

$$E(x) = y_0 + g_1 * x + \frac{1}{2} r * x^2$$



$y_0 \rightarrow$ Elev of BVC

$= \text{Elev of PI} - g_1 * \frac{L}{2}$

$= 125 - (-0.01) * 100 = \boxed{126}$ m

$= 126 + (-0.01) * 66.67 + \frac{1}{2} * (0.00015) * (66.67)^2$

$= \boxed{125.67}$ m

⑤ elev at station 23+50

$= 126 + (-0.01) * (50) + \frac{1}{2} * (0.00015) * (50)^2$

$= 125.69$ m

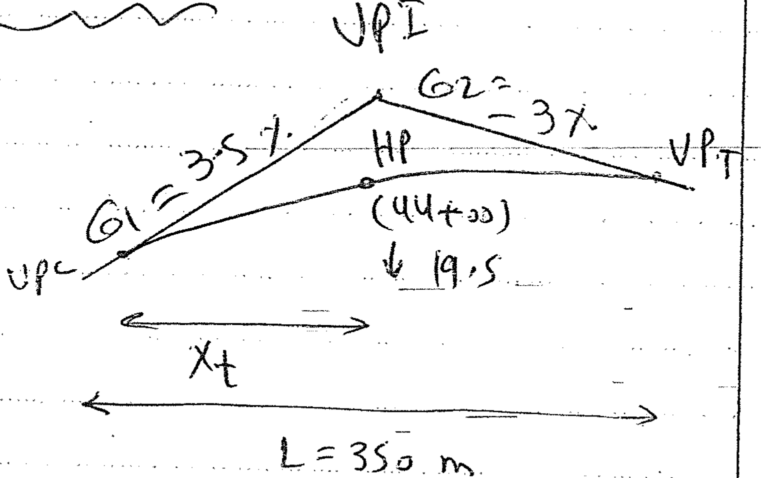
⑥ elev at station 24+50

$= 126 + (-0.01) * (150) + \frac{1}{2} * (0.00015) * (150)^2$

$= 126.19$ m

Ex

A 3.5 % grade meeting −3 % grade at a vertical curve of 350 m , if the highest point's elevation was 19.5 m and was located at station (44+00) find the station and elevation of VPC, consider 1 station = 30 m



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

$$= \frac{-0.03 - 0.035}{350}$$

$$= -1.857 * 10^{-4}$$

$$X_t = \frac{-g_1}{r} = \frac{-0.035}{-1.857 * 10^{-4}} = 188.46 \text{ m}$$

$$188.46 \doteq [6 + 8.46]$$ Station = 30 m

Station of (VPC)

$$= [44+00] - [6+8.46]$$

$$= [37 + 21.54]$$

$$\text{Elev (High point)} = \text{Elev (VPC)} + g_1 * X_t + \frac{1}{2} * r * X_t^2$$

$$19.5 = \text{Elev (VPC)} + \frac{3.5}{100} * 188.46 - \frac{1}{2} * 1.857*10^{-4} * 188.46^2$$

$$\text{Elev (VPC)} = 16.2 \text{ m}$$

Design of vertical curves

حساب طول المنحنى الرأسي المحدب :

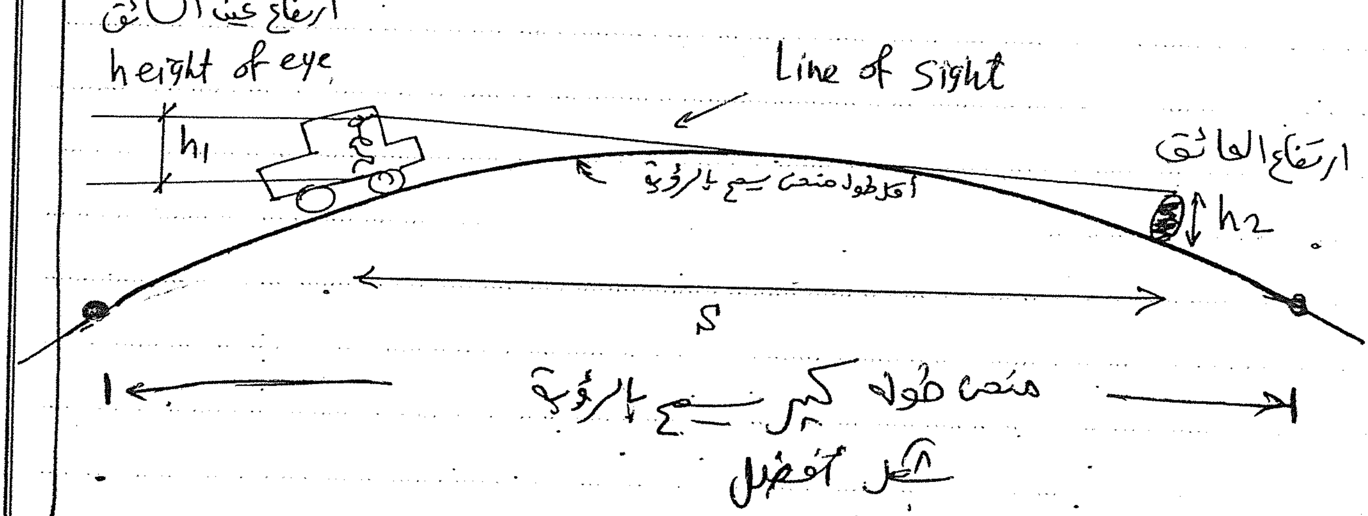
- The first step in the design is to determine the minimum length (or minimum k) for a given design speed.

- Factors affecting the minimum length include
  - Sufficient sight distance
  - Driver comfort
  - Appearance

- If sight distance requirements are satisfied then safety, comfort, and appearance requirements are also satisfied.

طرق حساب طول المنحنى الرأسي

هي ان يكون طول المنحنى يسمح بالرؤية للتخطي والايقاف

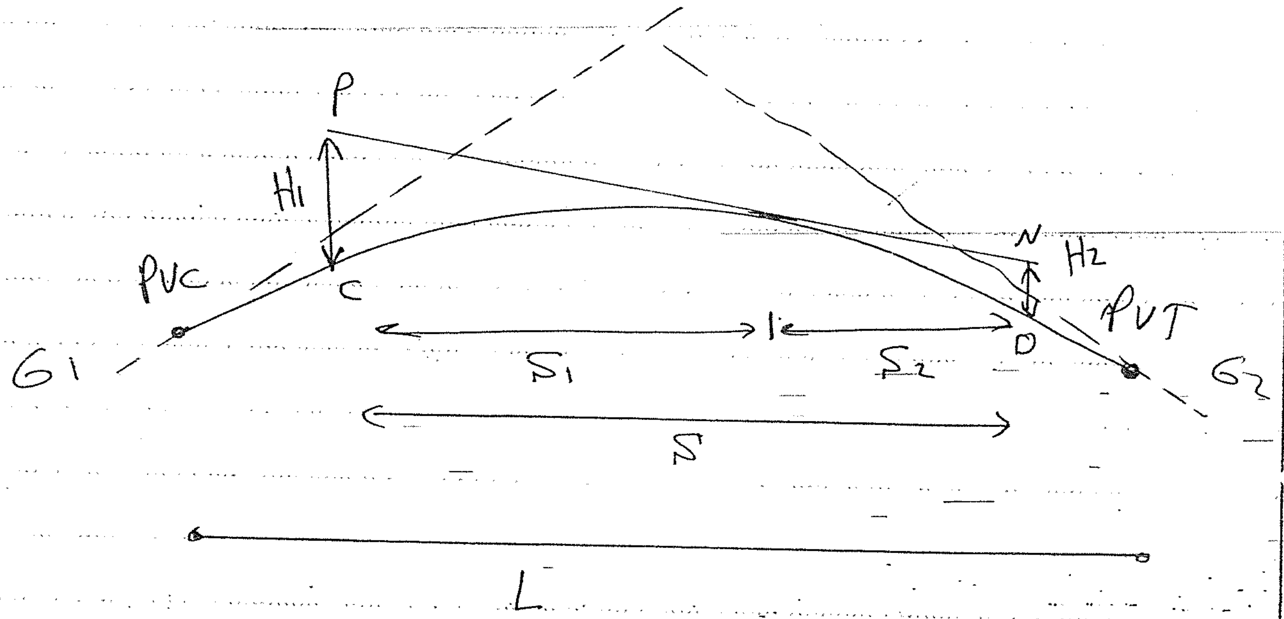


← من الممكن أن تكون مسافة الرؤية أقل من طول المنحنى

$$S < L$$

← وأحياناً أخرى تكون مسافة الرؤية أكبر من طول المنحنى

$$S > L$$



- L → length of vertical curve (ft)
- S → Sight distance (ft)
- H_1 → height of eye above roadway surface (ft)
- H_2 → " of object above roadway surface (ft)
- G_1, G_2 = grades of tangents (%)
- PVC = point of curve.
- PVT = point of vertical tangent.

Sight distance ≤ L curve .. في حالة

$$L_{min} = \frac{|A| * S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \quad \text{for } S \leq L$$

[From AASHTO]

$h_1 = 1.22$ m
$h_2 = 0.1$ m (stopping sight distance)
$h_3 = 1.37$ m (passing " ")

∴

For stopping sight distance

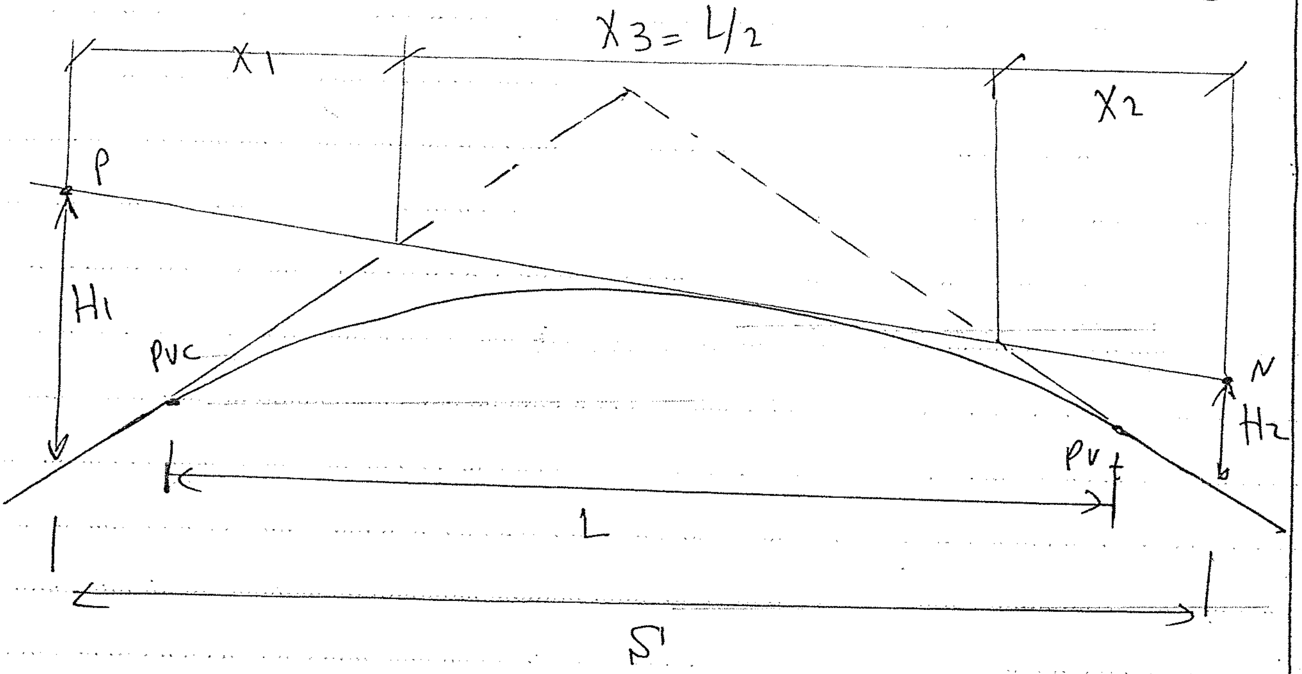
$$L_{min} \simeq \frac{|A| * S_n^2}{400}$$

For passing sight distance

$$L_{min} \simeq \frac{|A| * S^2}{1000}$$

لاحظ (A) هي نسبة % مثلاً 5%
لو خلتها (0.05) أكسر
خلي المقام مقسوم على 100 مثلاً (4 أو 10)

Sight distance > L curve ... في حالة



$$L_{min} = 2 * S - \frac{200(\sqrt{h_1}+\sqrt{h_2})^2}{|A|}$$

From AASHTO

→ $h_1 = 1.22$ m
→ $h_2 = 0.1$ m Stopping sight d.
→ $h_3 = 1.37$ m passing sight distance

∴ For stopping sight distance:-

$$L_{min} = 2S - \frac{400}{|A|}$$

for passing sight distance

$$L_{min} = 2S - \frac{1000}{|A|}$$

الملخص

① Calc. S_n (Stopping Sight distance)

لو كان معطى ال (f) وال (t)

$$S_n = \frac{V * t_1}{3.6} + \frac{V^2}{254 * (f \pm \frac{G_1}{100})}$$

لو غير معطى ال (f) وال (t) نحسب من
ال data sheet

Table 4: Minimum value for Stopping Sight Distance (S_n)

V (Km/hr.)	50	65	80	95	105	110	120
S_n (m)	55	80	115	150	165	185	205

Calc. S_p (Passing Sight distence) → لل 2lane crest بس

لو كان معطى الداتا الخاصة بالمعادلة المحفوظة

$$S_p = \frac{(V-m) * t_1}{3.6} + \frac{V * t_2}{3.6} + \frac{2 * V * t_3}{3.6} + \frac{2}{3} * \frac{V * t_2}{3.6}$$

وإذا لم تتوفر معلومات ندخل ع الداتا شيت

Table 5: Minimum value for Passing Sight Distance (S_p)

Number of lanes	2-lane					3-lane		
V (Km/hr.)	50	65	80	95	110	80	95	110
S_p (m)	245	385	510	620	700	360	440	500

لاحظ لتحديد طول المنحنى الرأسي

	2 lanes	multi-lanes
crest	Calculate L due to Sn Calculate L due to Sp } → max (L)	Calculate L due to Sn
Sag	Calculate L due to Sn	Calculate L due to Sn

(2) assume $S \leq L$

$$L = \frac{|A| * S^2}{200(\sqrt{h_1} + \sqrt{h_2})^2} \xrightarrow{\text{إذا لم يتحقق}} S > L$$

$$L = 2 * S - \frac{200(\sqrt{h_1} + \sqrt{h_2})^2}{|A|}$$

حيث عند الأخذ في الاعتبار مسافة الرؤية للتوقف (S_n) تكون

@ $S_n \leq L \rightarrow L_n = \frac{|A| S_n^2}{400}$

@ $S_n > L \rightarrow L_n = 2S_n - \frac{400}{A}$

} $h_1 = 1.22\,m$, $h_2 = 0.1\,m$

وعند الأخذ في الاعتبار مسافة رؤية التجاوز (S_p) تكون

@ $S_p \leq L \rightarrow L_p = \frac{|A| * S_p^2}{1000}$

@ $S_p > L \rightarrow L_p = 2S_p - \frac{1000}{|A|}$

} $h_1 = 1.22\,m$, $h_3 = 1.37\,m$

(EX)

Determine the minimum vertical curve length to provide

→ non passing and
→ passing sight distances in the following situat[ions]

Case	Speed	approaching PI Grade	leaving PI Gra[de]
1	50	+5%	−5%
2	65	+5%	−2%
3	80	+2%	−3%

— Sol. —

Case (1)

For $V = 50$ km/hr

data sheet → $S_n = 55$ m

→ $S_p = 245$ m

$A = G_2 - G_1 = -5 - 5 = -10$ %

Due to S_n

assume $S_n \leq L \Rightarrow L_n = \frac{|A| * S_n^2}{400} = \frac{10 * (55)^2}{400} = 75.63$ m

$> S_n$ OK

Due to Sp

assume $S_p \leq L \Rightarrow L_p = \frac{|A| * S_p^2}{1000} = \frac{10 * 245^2}{1000}$

$= 600.25$ m $> S_p$ OK

$L_{curve} = max = 600.25$ m

Case (2)

For $v = 65$ km/hr

$S_n = 80$ m

$S_p = 385$ m

$A = -2 - 5 = -7$ %

Due to Sn

assume $S_n \leq L_n \longrightarrow L_n = \frac{7 * (80)^2}{400} = 112$ m $> S_n$ OK

Due to Sp

assume $S_p \leq L_p \longrightarrow L_p = \frac{7 * (385)^2}{1000} = 1037.58$ m

$> S_p$ OK

$\therefore L_{max} = 1037.58$ m

Case (3) ط

تصميم المنحنى الرأسي المقعر

Design of Sag Vertical Curves

→ Passing is not allowed in Sag VC.

→ Design controls are one of the following :-

- headlight sight distance (Stopping sight distance)
- Rider comfort.
- Drainage.
- Appearance.
- Clearance below structures.

$$L_{min} = \frac{|A| S_n^2}{152.44 + 3.5 S} \quad \text{for } S \leq L$$

$$L_{min} = 2 S_n - \frac{152.44 + 3.5 S_n}{A} \quad \text{for } S > L$$

الملخص

assume $S_n \leq L_n$ إذا لم يتحقق → $S_n > L_n$

Determine the minimum vertical curve lengths to provide non passing in the following situations

Case	Speed	approaching PI grade	leaving PI Grade
1	50	−2 %	+5 %
2	80	−3 %	+1 %

Sol.

Case ①

For $V = 50 \longrightarrow S_n = 55$ m

$A = 5 - (-2) = 7\ \%$

assume $S_n < L_n$

$$L_n = \frac{|A| * S_n^2}{152.44 + 3.5 * S_n} = \frac{|7| * (55)^2}{152.44 + 3.5 * 55} = 61.39 \text{ m}$$

$> S_n$ OK

Case ②

For $V = 80$ km/hr $\longrightarrow S_n = 115$ m

$A = 1 - (-3) = 4\ \%$

assume $S < L$ $\quad L_n = \frac{4 * 115^2}{152.44 + 3.5 * 115} = 61.88$ m

$< S_n$ not ok

$\therefore S > L \quad L_n = 2 S_n - \frac{152.44 + 3.5 * S_n}{A}$

$$= 2 * 115 - \frac{152.44 + 3.5 * 115}{4} = 91.27 \text{ m}$$ #

مسافة التلاشي (?)

Ex

A Crest Vertical Curve is to be designed to join a 3% grade with a −2% grade at a section of a two-lane highway. Determine the minimum length of the curve if the design speed of the highway is 100 km/hr.

Sol

$A = 3 - (-2) = 5\%$

From tables

$SSD = 165\ m$

$PSD = 650\ m$

Assuming $S < L$

الدكتور قسمها على (100) فالمقام هيكون (4) وليس (400)

$$L_{min} = \frac{|A| * S_n^2}{4} \Rightarrow L_{min} = \frac{0.05 * 165^2}{4}$$

$$= 340.3\ m$$

مقسومة على (100) فالمقام هيكون (10) وليس 1000

$$L_{min} = \frac{|A| * S_p^2}{10} = \frac{0.05 * 650^2}{10} = 2112.5\ m$$

$S < L$ ok #

56. The superelvation required in horizontal alignment is equal to ______, where α is the angle of cross section

A. Cos α B. Sec α C. Sin α D. Tan α

57. A road is being redesigned to accommodate a 80 km/hr design speed. Part of this road has an existing curve with a degree 9° and zero superelevation. If the existing curve radius is kept unchanged, what superelevation is required for the curve to accommodate a 80 km/h design speed (use f_s = 0.17)

A. 7% B. 8 % C. 9% D. 10%

58. In the previous problem, if the lane width is 3-m, how far back from the edge of the road a building must be located to allow adequate sight distance for a 80 km/hr design speed?

A. 5m B. 6m C. 5.5m D. 7m

59. For a 2-lane road 3.75m lane width with 8° curve degree and 5% longitudinal slope, if the design speed is 80 km/hr, then the total superelevation (S) is ______

A. 0.68 m B. 0.70 m C. 0.75 D. 0.08 m

60. For the previous question, if a transition curve (A = 200) is to be used to implement a change in cross-section from a normally crowned section to a fully superelevated section around the outer edge. What is the suitable transition curve length?

A. 50 m B. 82 m C. 84 m D. 183 m

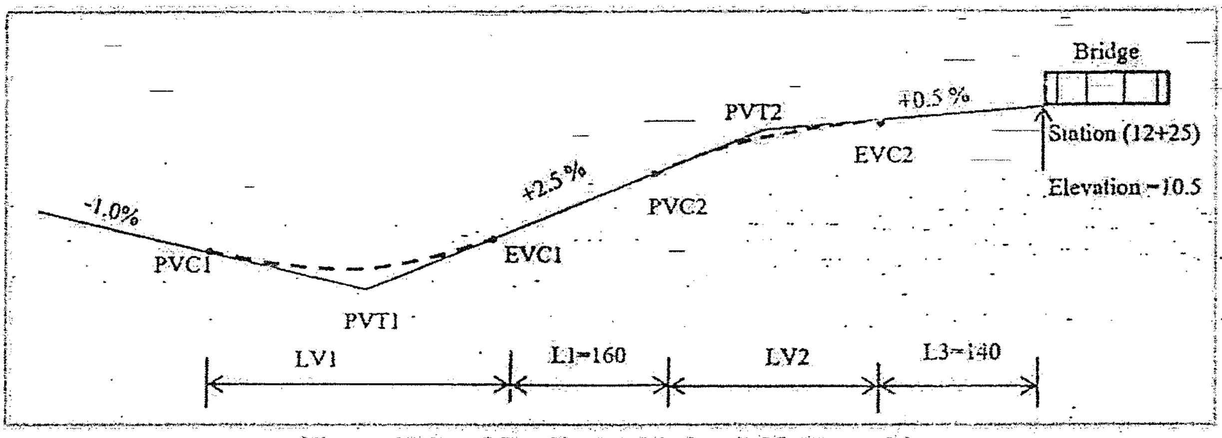


Figure (1) Road Profile (Multi –lane) (Not to scale)

Solve

Choose the correct answer according to the given road profile in Figure (1) for the next 8 questions

61. The station of point (EVC2) is:

A. (10+75) B. (10+85) C. (13+65) D. (11+60)

62. The elevation of point (EVC2) is:

A. 9.8 B. 9.5 C. 11.2 D. 11.5

63. If the K-value is 55 for the crest curve, what would be the safe operating speed that should be maintained along this curve?

A. 50 km/hr B. 65 km/hr C. 80 km/hr D. 95 km/hr

64. If the K-value is 20 for the sag curve, the lengths LV1 should be ______ m.

A. 50 B. 70 C. 125 D. 175

65. If the length LV1 = LV2= 120 m, the station of PVT1 is

A. (6+45) B. (6+85) C. (7+45) D. (10+40)

66. If the length LV1 = LV2= 120 m, the elevation of PVT1 is
    A. 2.2 B. 4 C. 2.5 D. 4.5

67. If the length LV1 = LV2= 120 m, the elevation of lowest point is
    A. 6.21 B. 3.95 C. 3.81 D. 3.61

68. If the length LV1 = LV2= 120 m, the elevation at station (10+ 00) equal to
    A. 8.0 B. 8.77 C. 9.52 D. 9.8

69. The extra width of pavement is provided on
    A. Horizontal curve B. Bridges C. Vertical curve D. None

70. The design speed on a rotary intersection is 45 km/hour, if the minimum radius is ___
    A. 52.5 m B. 63 m C. 90 m D. 114 m

71. In at grade crossroad intersection the total number of conflict points is:
    A. 3 B. 8 C. 32 D. none

72. Which of the following at grade intersections is not suitable for pedestrians?
    A. Channelized B. Non-flared C. Rotary D. Full clover leaf

73. _________intersection is suitable for locations where the volume of left turn traffic is relatively low
    A. Rotary B. Diamond C. Trumpet D. Full clover leaf

74. _________ramp is suitable for locations where the volume of left turn traffic is relatively high
    A. Direct B. Semi-direct C. Indirect D. None

75. The capacity of rotary in vehicle per hour for a proportion of weaving traffic 0.5 and the width of weaving section is 9.0m, average width of entry is 3.0m and length of the weaving section is 30m
    A. 1088 B. 2153 C. 2302 D. 2500

Best of Luck,,,,,,, The Exam Committee ,,,,,,,,,,,,,,,,,,,,,,,

Useful Formulae:

$Q = \frac{282w(1+\frac{e}{w})(1-\frac{p}{3})}{1+\frac{w}{l}}$	$L_{min} = \frac{\lvert A \rvert S^2}{152.44+3.5S}$ for $S \le L$	$L_{min} = 2S - \frac{152.44+3.5S}{A}$ for $S > L$

(22)