HIGHWAY ENGINEERING

GEOMETRIC DESIGN

4 G

* Horizontal Alignment *

التخطيط الأفقي للطرق

مقدمة :-

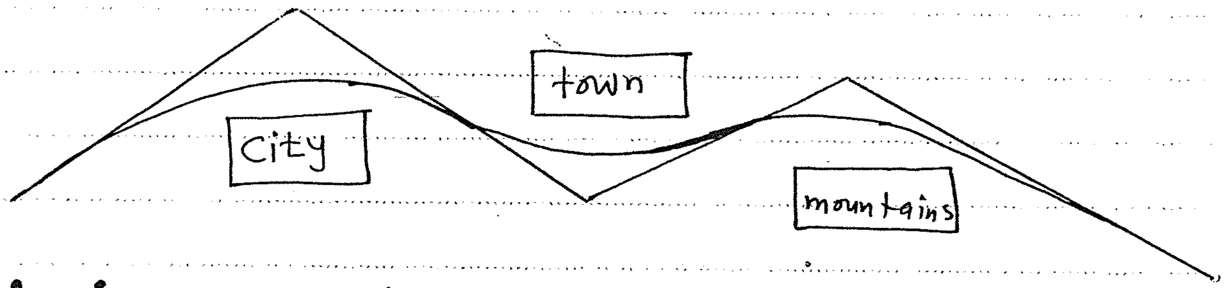
في كثير من الأحيان يواجه المصمم للطرق مهمة وصل الخطوط المستقيمة والمتقاطعة لمسار الطريق بمنحنيات عامة لتفادي التغير المفاجئ في الاتجاه وتسهيل الانتقال بين هذه الخطوط.

المنحنيات الأفقية هي المنحنيات التي تربط بين خطوط التقاطعات في المسارات الأفقية.

العوامل التي تؤثر في تصميم المنحنيات :-

* طبوغرافية الأرض
* النقاط الحاكمة لمسار الطريق (المدن والقرى التي يجب ان يمر بها الطريق)
* العوامل الاقتصادية
* العوائق الموجودة على المسار .
* السرعة التصميمية

لاحظ وجود المنحنيات الأفقية في الطريق تزيد من درجة انتباه السائق عن الطرق المستقيمة أثناء القيادة .

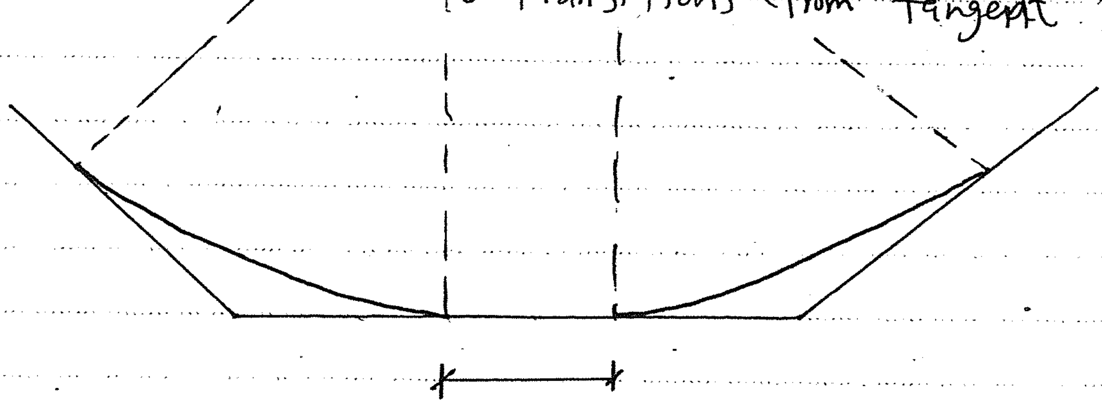


Horizontal Alignment

* Tangents
    - Straight Segments
    - Preferably not more than 20 V
    - " not less than 6 V
      (2 V for reverse Curves)

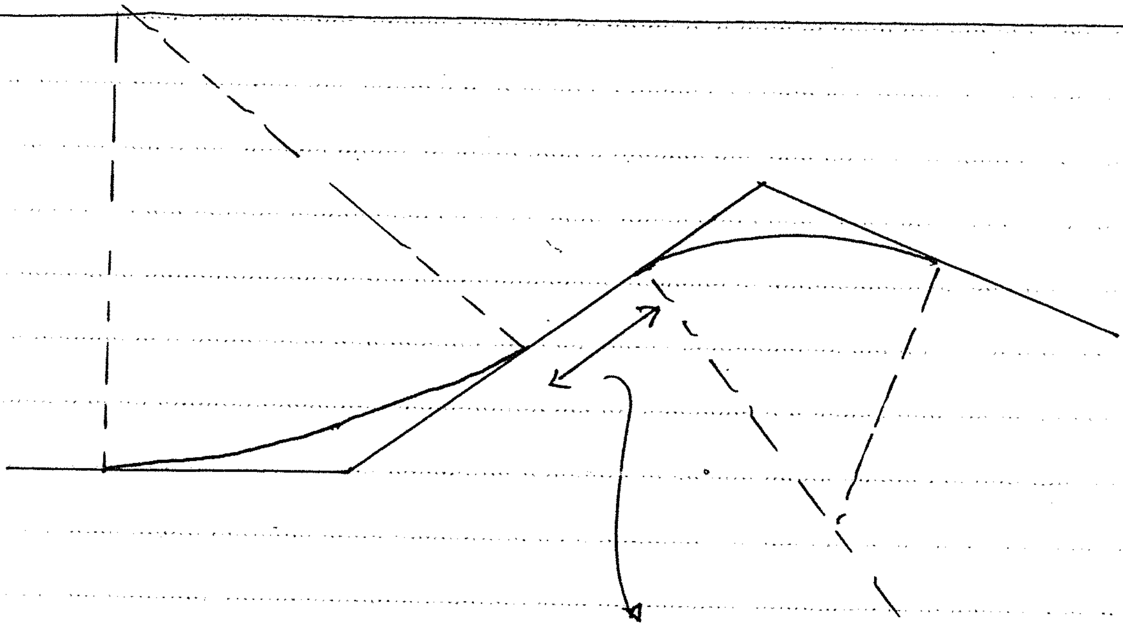
* Horizontal Curve
    - Usually circular
    - Simple, compound, reverse
    - full superelevation

* Transition Curve
    - Transitions from tangent to curve



min = 6 V   في حالة المركزين في نفس الاتجاه منفصلانه

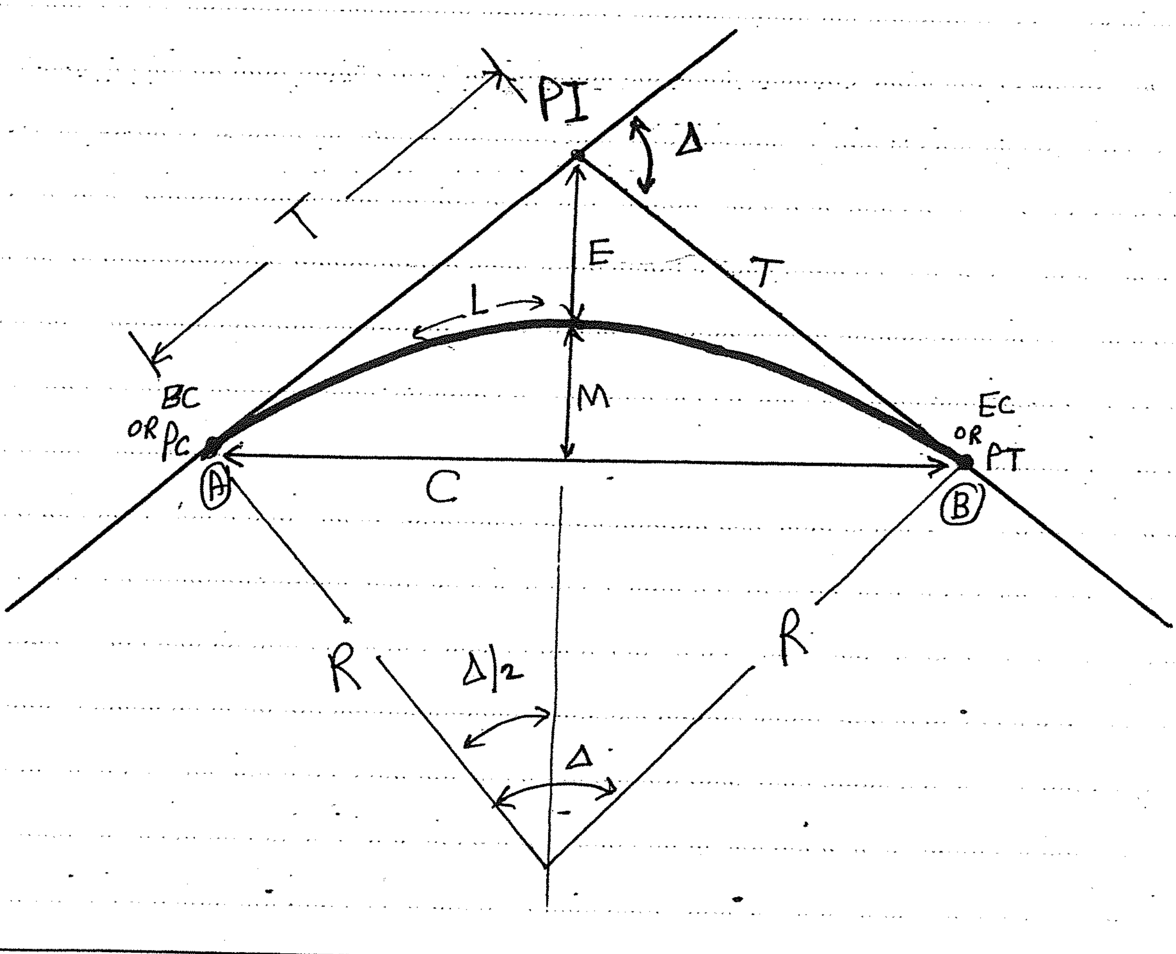
max = 20 V



في حالة المركزين في اتجاهين مختلفين

- min = 2 V
- max = 20 V

Layout of a simple horizontal Curve



- R :- Radius of Circular Curve
- BC :- Beginning of Curve (OR PC = Point of Curvature)
- EC :- End of Curve (OR PT = Point of Tangency)
- PI :- Point of Intersection
- T :- Tangent length
- L :- length of Curvature
- M :- Middle ordinate
- E :- External Distance
- C :- Chord length
- Δ :- Deflection Angle

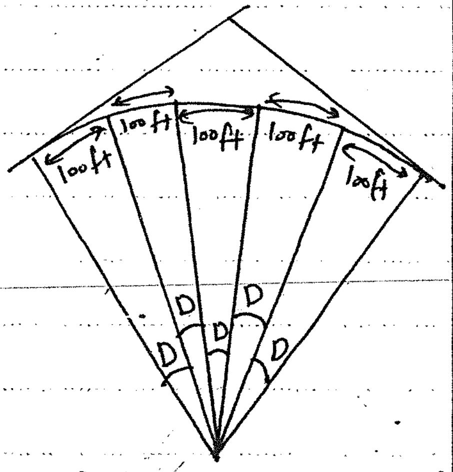
Properties of horizontal Curve

- A circular Curve is described either by its Radius (R) or by the Degree of the Curve (D)

- Degree of Curve is the angle in degrees subtended at the Center of a circular arc [100] ft

درجة المنحنى هي مقدار الزاوية المركزية بالدرجات التي تحصر
قوس من المنحنى طوله 100 قدم ≡ [30.48] m

$$L = R * D * \frac{\pi}{180}$$



$$30.48 = R * D * \frac{\pi}{180}$$

$$\boxed{R_c = \frac{1746}{D^\circ}}$$

Properties of Circular Curves

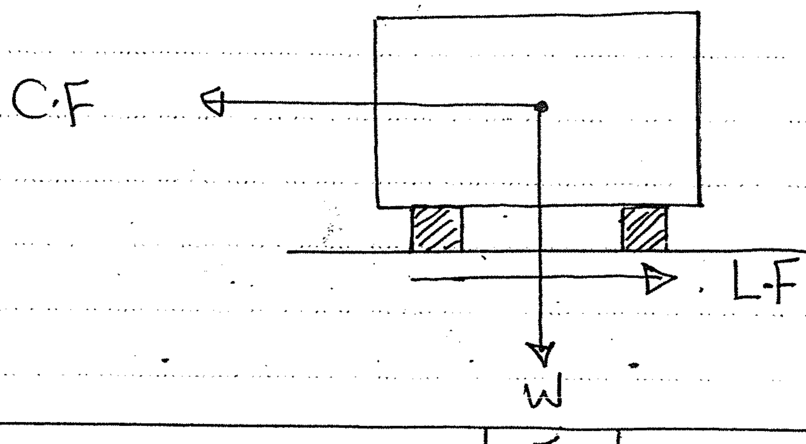
- length of Curve $L_c = R * \Delta_{Rad}$
- Tangent $T = R * \tan\left(\frac{\Delta}{2}\right)$
- Chord الوتر $C = 2R * \sin\left(\frac{\Delta}{2}\right)$
- Mid ordinate $M = R - R * \cos\left(\frac{\Delta}{2}\right)$
- External Distance $E = R * \sec\left(\frac{\Delta}{2}\right) - R$

$$= \frac{R}{\cos\left(\frac{\Delta}{2}\right)} - R$$

Forces Acting on Circular Curve

A vehicle moving on a circular curve will be influenced by Centrifugal force.

. عند سير المركبات على المنحنيات الأفقية فإنه تتولد قوة طاردة مركزية قد تتسبب في إنزلاق المركبة وأحياناً خروجها من المنحنى



$$C.F = \frac{W * U^2}{g * R} \quad \text{(centrifugal force)}$$

But This force is resisted by lateral friction (الاحتكاك الجانبي)

$$L.F = W * f$$

For Stability ولعمل الاتزان

$$L.F = C.F$$

$$W * f = \frac{W * U^2}{g * R}$$

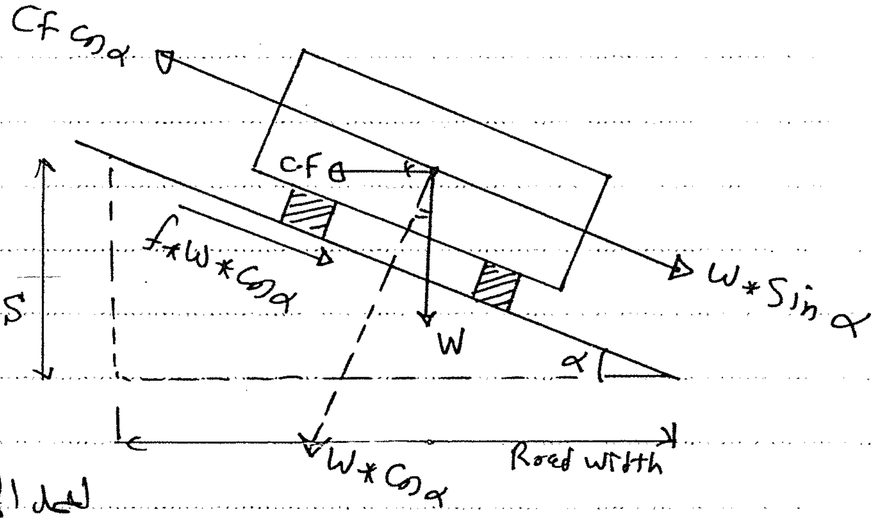
$$\therefore f = \frac{V^2}{g * R}$$

$V \rightarrow km/hr$ ، أخذ الـ $g = 9.81 \ m/sec^2$

$$f = \frac{(V/3.6)^2}{9.81 * R} = \frac{V^2}{127 R}$$

حيث (f) هي معامل الاحتكاك الجانبي .

ولكن في معظم الأحيان تكون قوة الطرد المركزي أكبر من مقاومة الاحتكاك الجانبي ولهذا نلجأ إلى عمل رفع الظهر للمنحنى



لحل الاتزان

$$W*\sin\alpha + f*W*\cos\alpha = CF*\cos\alpha$$

$$W*\sin\alpha + f*W*\cos\alpha = \frac{W*V^2}{g*R}*\cos\alpha$$

وبالقسمة على $(\cos\alpha)$

$$\tan\alpha + f = \frac{V^2}{127R}$$

حيث ← $\tan\alpha = \frac{S}{\text{عرض الطريق}}$ = ميل الطريق في منطقة المنحنى = ⓔ

معدل ارتفاع الظهر عن البطن

$$e+f = \frac{V^2}{127R}$$

$$R = \frac{V^2}{127(e+f)}$$

حيث

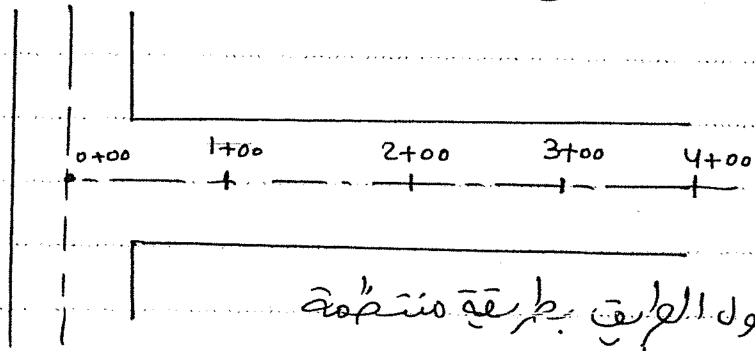
- **R** → Radius of circular curve in (m)
- **V** → design speed in km/hr
- **e** → Superelevation
- **f** → coefficient of lateral friction (0.1) → (0.2) depending on speed - typically 0.14 → 0.16

- إذا طلعت (e) قيمة سالبة فإننا لا نحتاج إلى تنفيذ superelevation حيث أن قوة الاحتكاك الجانبي في هذه الحالة وحدها تكفي لمقاومة قوة الطرد المركزية.

- Highest in common use = 10% for (e) Superelevation.
  12% with no ice and snow on low volume gravel - surfaced roads.

- 8% is the logical maximum to minimized slipping by stopped vehicles.

المحطات Stations



المحطات :- هي تقسيمات لطول الطريق بطريقة منتظمة بغرض تسهيل توقيعة في الطبيعة.
فمثلاً عندما يراد توقيع نقطة 4+10 مثلاً نذهب عند محطة رقم 4+00 ثم نقيس 10 متر بعدها

ما معنى محطة رقم 4+10

لاحظ ان الاجابة تتوقف على قيمة المحطة

فلو قال ان المحطة 1 sta = 100 m فده معناه ان النقطة المقصودة تبعد مسافة (4) محطات يعني 400 متر + 10 متر اي ان النقطة تبعد 410 متر من بداية الطريق

ولو قال في المسألة 1 sta. = 30 m فهذا يعني ان النقطة المقصودة تبعد مسافة (4) محطات يعني (4 * 30 = 120 متر) + 10 متر اي ان النقطة تبعد مسافة 130 متر من بداية الطريق

عندما نقول : (4+10)

4 رقم ده يسمى محطة

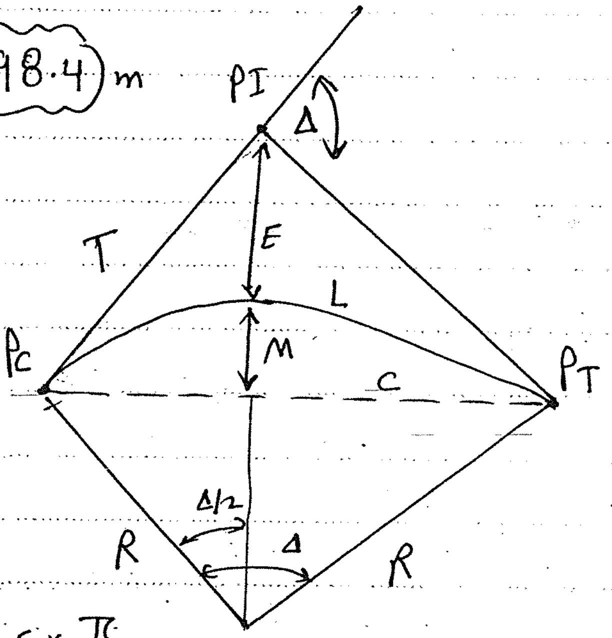
10 وده يسمى كسر محطة وعادة لا يزيد عن قيمة المحطة ويكون بالمتر

(Ex)

Road with horizontal Curve having an external angle of 22°30' & degree of the Curve = 2.5°
(PI) Station = 175 + 50 , Station = 100 m
- estimate the Station of Pc & PT
 then find E , M , C .

→ $R = \frac{1746}{D^\circ} = \frac{1746}{2.5} = 698.4$ m

→ $\tan\frac{\Delta}{2} = \frac{T}{R}$



$T = R * \tan(\frac{\Delta}{2})$

$= 698.4 * \tan(\frac{22.5}{2})$

$= \boxed{138.9}$ m

→ $L_c = R * \Delta_{Rad} = 698.4 * 22.5 * \frac{\pi}{180}$

$= \boxed{274.26}$ m

$= (2 + 74.26)$

→ Station of Pc

St (PI) − T = (175 + 50) − (1 + 38.9)
 = (174 + 11.1)

→ Station of PT

St (Pc) + Lc = (174 + 11.1) + (2 + 74.26)
 = (176 + 85.36)

$$C = 2 * R * \sin\frac{\Delta}{2} = 2 * 698.4 * \sin\frac{22.5}{2}$$
$$= 272.5\ m$$

$$M = R - R * \cos\left(\frac{\Delta}{2}\right) = 698.4\left(1 - \cos\frac{22.5}{2}\right) = 13.4\ m$$

$$E = R * \sec\left(\frac{\Delta}{2}\right) - R = \frac{698.4}{\cos\frac{22.5}{2}} - 698.4 = 13.7\ m$$

Ex

For a maximum Superelevation of 0.1, Compute the max degree of Curve for design Speeds of 50, 60, 70, 80 and 100 km/hr. Using the following Values for side friction

Design speed km/hr	50	60	70	80	100
max Safe Side friction	0.16	0.15	0.14	0.13	0.12

Sol

$$e + f = \frac{V^2}{127 R} \longrightarrow R = \frac{V^2}{127 * (e + f)}$$

$$D^\circ = \frac{1746}{R}, \quad e = 0.1 \text{ given}$$

V (km/hr)	50	60	70	80	100
e+f , e = 0.1	0.26	0.25	0.24	0.23	0.22
$R = \frac{V^2}{127 * (e+f)}$	75.71	113.38	160.76	219.1	357.91
$D^\circ = \frac{1746}{R}$	23.06°	15.4°	10.86°	7.97°	4.88°

EX

Vehicles performance is being tasted on a large flat area. for this situation :-

① → What coefficient of side friction must be developed to speed of 100 km/hr. ($D = 10°$)

② → What is the sharpest curve (stated in degree) that the vehicle travelling 100 km/hr can travel if the coefficient of side friction is 0.4 ?

*** Sol ***

1. at $v = 100$ km/hr , $D = 10°$, $f = ??$

$$R_c = \frac{1746}{D°} = \frac{1746}{10} = \boxed{174.6} \text{ m}$$

$$\therefore f = \frac{v^2}{127R} = \frac{(100)^2}{127 * 174.6} = 0.451$$

2. at $v = 100$ km/hr , $f = 0.4$, $D = ??$

$$f = \frac{v^2}{127R} \Rightarrow 0.4 = \frac{(100)^2}{127 * R}$$

$$R = 196.89 \text{ m}$$

$$\therefore R = 196.89 = \frac{1746}{D}$$

$$D = \boxed{8.87}°$$

Ex

An existing horizontal Curve on a highway has a radius of 150 m, which restricts the posted speed limit on this section of the road to only 59% of the design speed of the highway. If the curve is to be improved so that its posted speed will be the design speed of the highway, determine the minimum radius of the new curve. Assume that the rate of superelevation is 0.08 for both the existing curve and the new curve to be designed and the coefficient of lateral friction is 0.14 .

Sol.

Determination of existing speed

$$R = \frac{V^2}{127(e+f)} \qquad 150 = \frac{V^2}{127(0.08 + 0.14)}$$

$$V = 64.73 \text{ Km/hr}$$

Design Speed

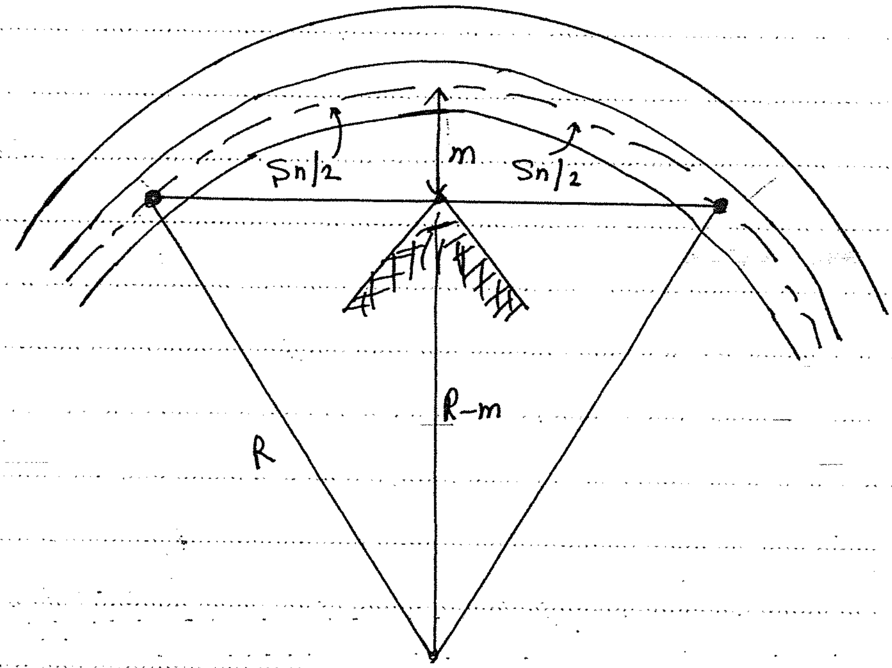
$$V = \frac{64.73}{0.59} = 110 \text{ Km/hr}$$

New Radius

$$R = \frac{(110)^2}{127(0.08 + 0.14)} = 433 \text{ m}$$

Sight Distance of Horizontal Curve

غير مسموح التخطي على المنحنيات الأفقية لذلك فإن المسافة المطلوب توافرها على المنحنيات الأفقية هي Sn



$$\left(\frac{Sn}{2}\right)^2 = m^2 + \left(R^2 - (R-m)^2\right)$$

$$= \cancel{m^2} + \cancel{R^2} - \cancel{R^2} + 2Rm - \cancel{m^2}$$

$$\left(\frac{Sn}{2}\right)^2 = 2Rm$$

$$Sn = \sqrt{8mR}$$

(Sn) → stopping sight distance

(m) → the lateral distance at the height of the deriver's eyes.

(R) → the radius at the center of the inner lane.

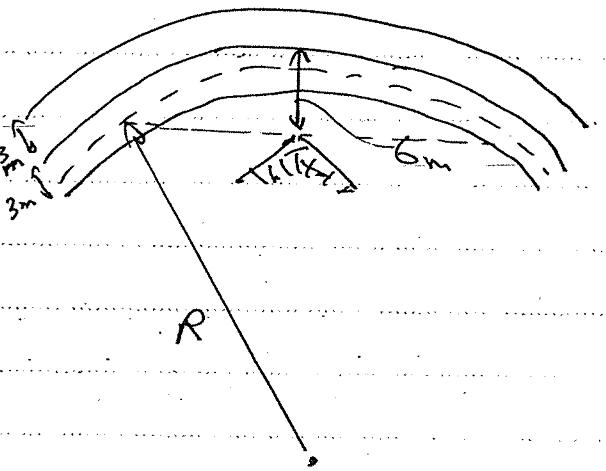
EX

A Corner of an existing obstruction is 6m from C.L on 12 degree Curved portion of 2 lane roadway having a lane width of 3 m :-

what is the horizontal sight distance along the centerline of the inside lane , what is the safe operating speed

SoL.

$$R_c = \frac{1746}{D^\circ} = \frac{1746}{12} = 145.5\,m$$



$$m = 6 - \frac{3}{2} = 4.5\,m$$

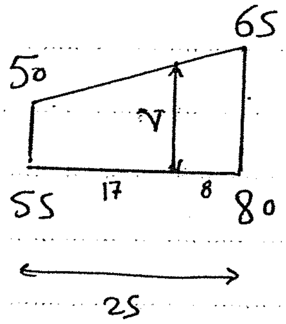
$$R = 145.5 - \frac{3}{2} = 144\,m$$

$$S_n = \sqrt{8mR} =$$

$$\sqrt{8 * 4.5 * 144} = 72\,m$$

From table # 4 Data Sheet

بالاستكمال



$$V_{max} = \frac{50 * 8 + 65 * 17}{25}$$

$$= 60.2\ km/hr$$

If the desired operating speed is 100 km/hr how far the obstruction should be set back to satisfy the stopping sight distance.

from table (4)

@ $v = 100$ km/hr

$$S_n = \frac{150 + 165}{2} = 157.5 \text{ m}$$

$$S_n = \sqrt{8mR}$$

$$\therefore m = \frac{S_n^2}{8 * R} = \frac{(157.5)^2}{8 * 144} = 21.53 \text{ m}$$

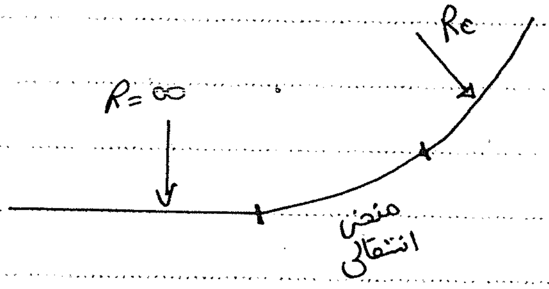
$\therefore$ obstruction distance $= 21.53 + 1.5 = 23.03$ m

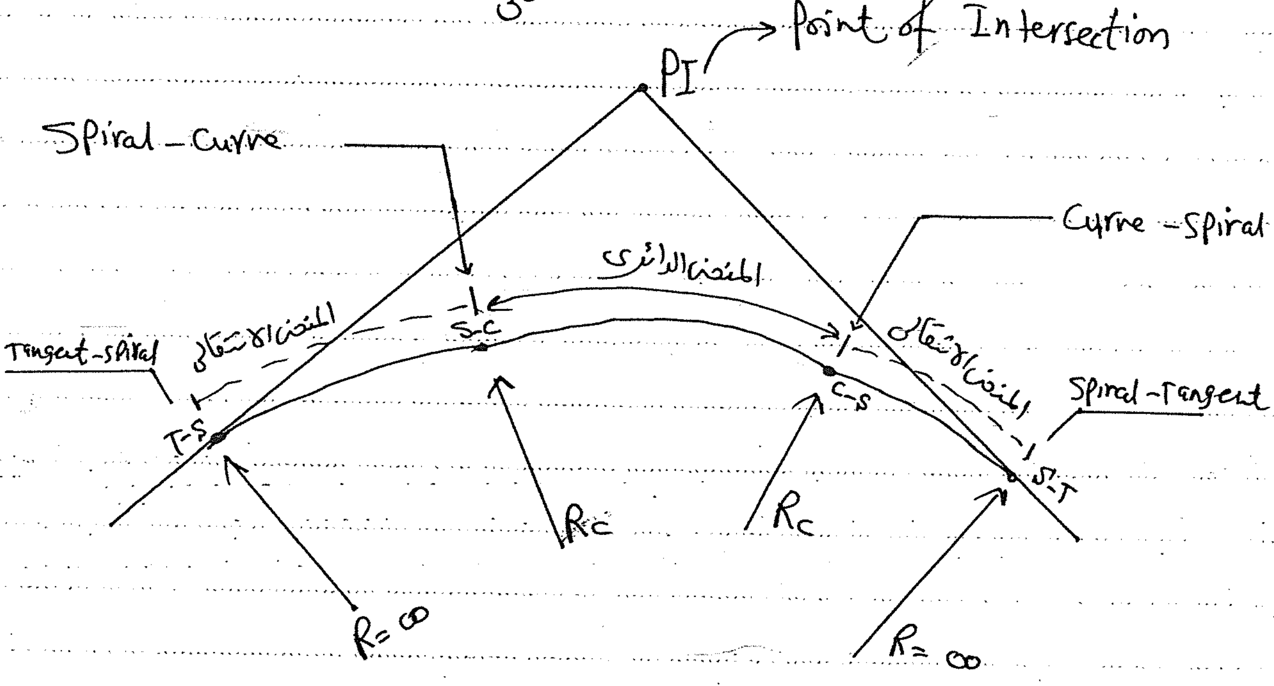
← $\frac{1}{2}$ عرض الطرق

Transition Curve (Spiral Curve)

المنحنى الانتقالى

هو منحنى نصف قطره يتغير تدريجياً





الغرض من استخدام المنحنى الانتقالى

1. لتفادى التغير المفاجئ من الحركة على خط مستقيم إلى الحركة على المنحنى الدائرى وبالتالى يحتفظ السائق بالسير فى حارته.
2. الشعور تدريجياً بالقوة الطاردة المركزية للمنحنى.
3. تنفيذ ارتفاع الظهر عن البطن Superelevation تدريجياً خلاله.
4. تنفيذ توسيع الطريق تدريجياً خلاله.

- Transition Curves are placed between tangents and circular curves.
- The transition curve provides the following:-
  - * A vehicle path that gradually increases or decreases the radial force.
  - * Gradual change in curvature – starts with zero at tangent and ends with a curvature D at circular curve.
  - * Gradual introduction of superelevation.
  - * 〃 〃 〃 lane widing.

- Euler Spiral Curve is the most widely used.
- An Euler spiral is a curve whose curvature changes linearly with its curve length.

Length of Spiral Curve:- طول المنحنى الانتقالي.

The maximum of the following

① $L_s = \frac{A^2}{R_c}$ (A) data sheet table (9)
دالة جوال رحم على المنحنى

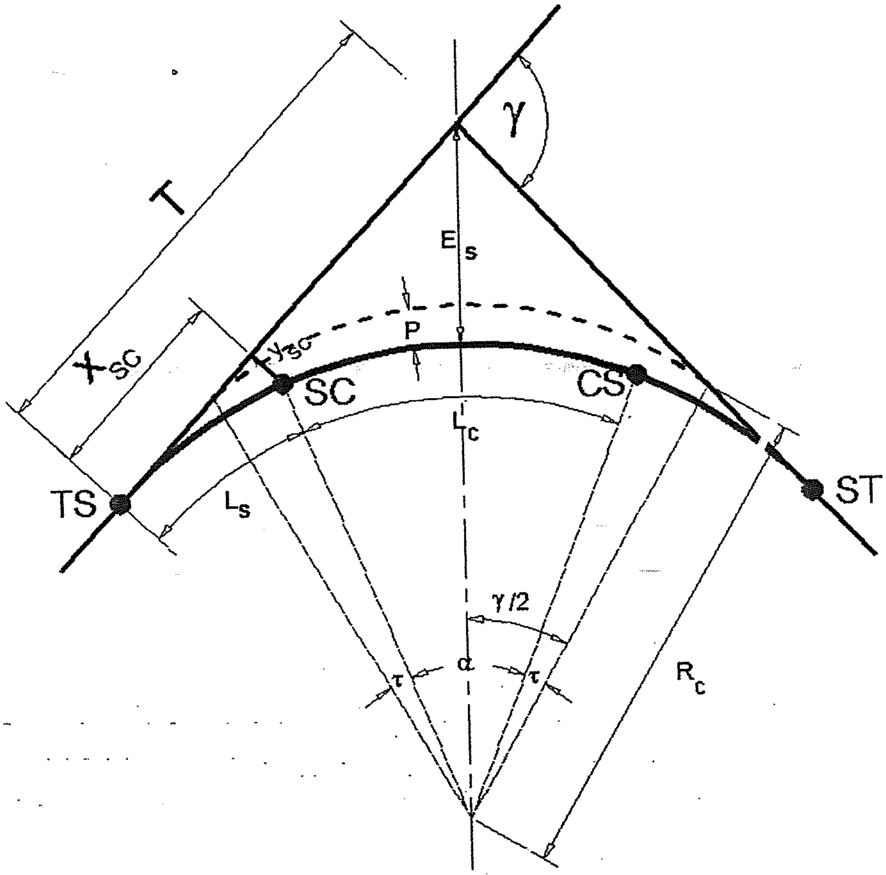
Where (A) is the curve constant [function of speed) and Rc is the Radius of the horizontal curve.

② $L_s = \frac{V^3}{28 * R_c}$

(Vc) km/hr	40	60	80	100	120	140
Amin	50	100	150	200	350	500

③ $L_s = 50$ m

Elements of circular and transition curves



- $L_s = 2\,\tau_{rad} \times R_c$
- $\gamma^o = 2\,\tau^o + \alpha^o$
- $L_c = \alpha_{rad} \times R_c$
- $P = Y_{sc} + R_c \times [\cos\tau^o - 1]$
- $T = X_{sc} + [P + R_c] \times \tan\left(\frac{\gamma^o}{2}\right) - R_c \times \sin\tau$
- $E_s = [P + R_c] \times \sec\left(\frac{\gamma^o}{2}\right) - R_c$

Coordinates of transition curve:

$$X = L \times [1 - \frac{L^4}{40 \times A^4}] \qquad Y = \frac{L^3}{6A^2} \times [1 - \frac{L^4}{56 \times A^4}]$$

ولتوقيع المنحنيات الأفقية :-

بالنسبة للجزء الدائري

① Find τ

$$L_s = 2 * \tau_{rad} * R_c \Rightarrow \tau = \checkmark \text{ Rad} = \checkmark^{\circ}$$

② Find α

$$\gamma^{\circ} = 2\tau^{\circ} + \alpha^{\circ} \Rightarrow \alpha = \checkmark^{\circ}$$

③ Find P

$$P = y_{\text{spiral curve}} + R_c * (\cos\tau^{\circ} - 1)$$

④ Find (L_c, T, E_s)

- $L_c = \alpha_{Rad} * R_c \quad , \alpha_{rad} = \alpha^{\circ} * \frac{\pi}{180}$
- $T = X_{s.c} + (P + R_c) * \tan\left(\frac{\gamma^{\circ}}{2}\right) - R_c * \sin\tau$
- $E_s = (P + R_c) * \sec\left(\frac{\gamma^{\circ}}{2}\right) - R_c$

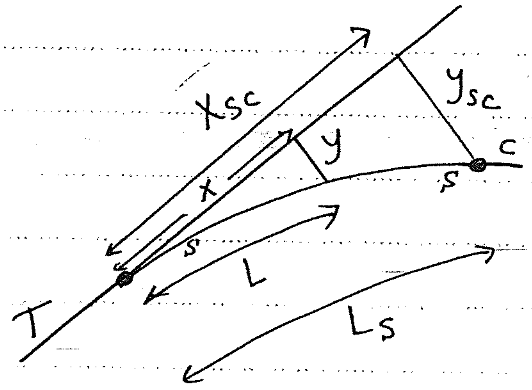
$$= (P + R_c) * \frac{1}{\cos\left(\frac{\gamma^{\circ}}{2}\right)} - R_c$$

وبالنسبة للمنحنى الانتقالي :-

لحساب اي احداثي (y) مقابل لأي مسافة (X) مقاسة على المماس نعوض في المعادلات :

$$X = L * \left(1 - \frac{L^4}{40 * A^4}\right)$$

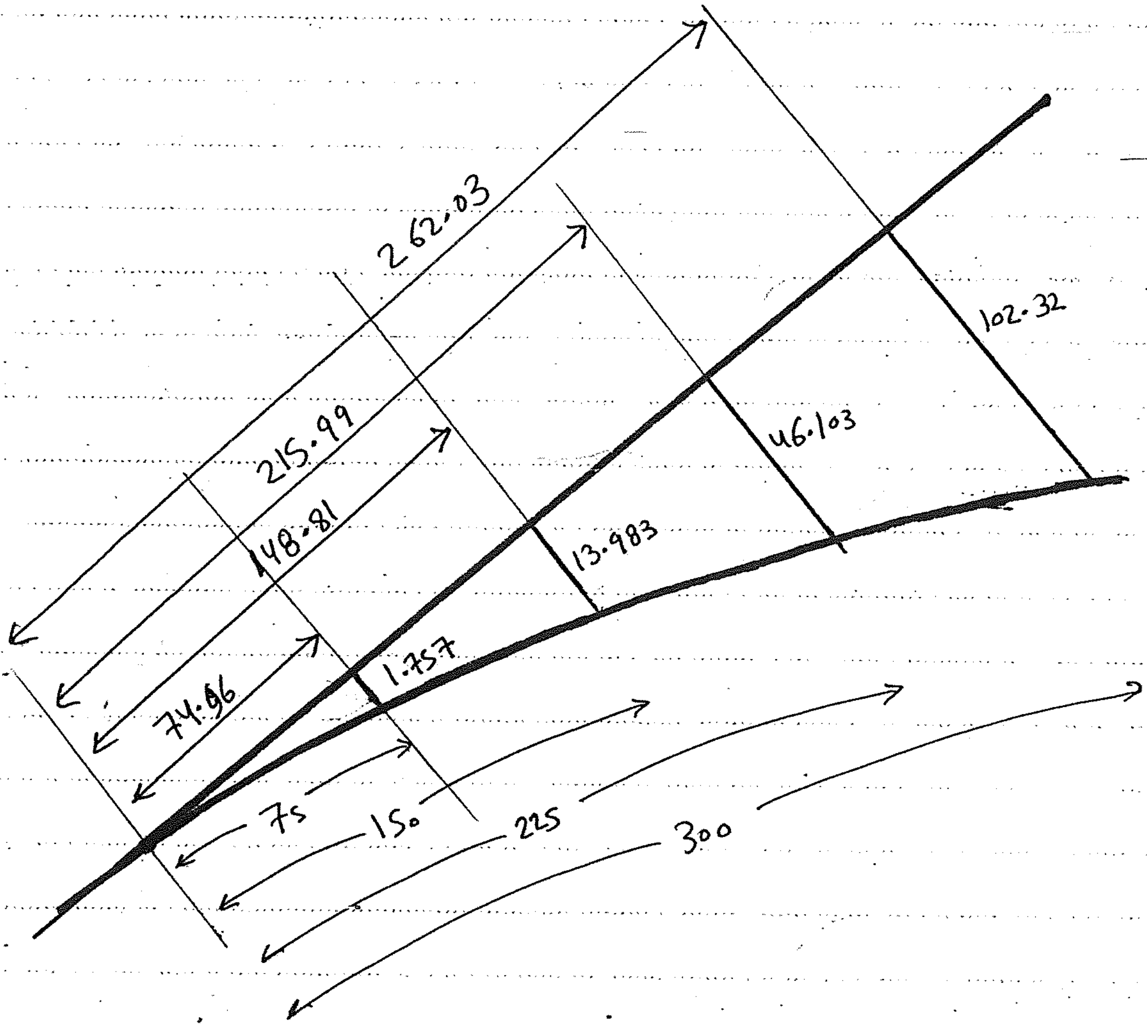
$$y = \frac{L^3}{6A^2} * \left(1 - \frac{L^4}{56 * A^4}\right)$$



Ex

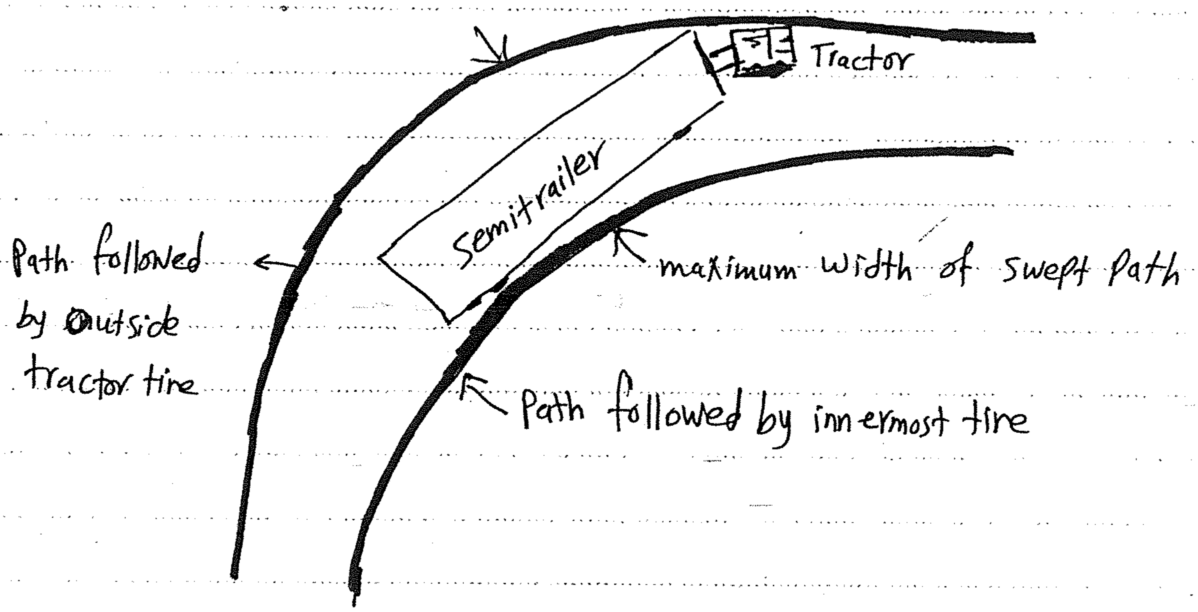
Calculate four coordinates on a spiral curve which length is 300 m long and $A = 200$

L	$\frac{1}{4} L_s = 75$	$\frac{1}{2} L_s = 150$	$\frac{3}{4} L_s = 225$	$L_s = 300$
$X = L * \left[1 - \frac{L^4}{40 A^4}\right]$	74.96	148.81	215.99	262.03
$y = \frac{L^3}{6 A^2} * \left[1 - \frac{L^4}{56 A^4}\right]$	1.757	13.983	46.103	102.32



Widening of Horizontal Curve

Widening is carried out because :-
- Rear wheels do not follow the path front wheels
- Drivers tend to weave towards the center of the curve



- هو تزويد عرض الطريق خلال المنحنى

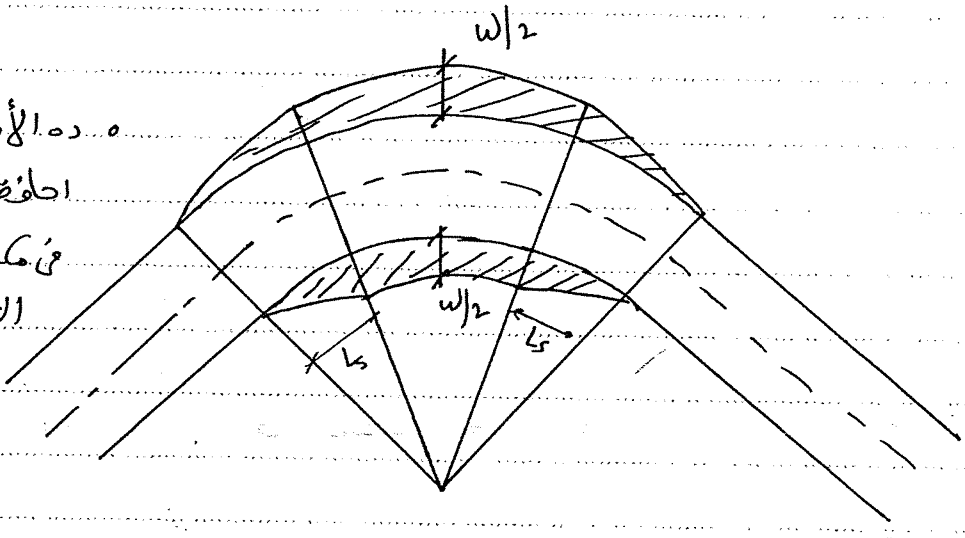
- يتم التوسيع خلال المنحنيات الأفقية للأسباب الآتية

① العجلة الخلفية لا تتبع حركة العجلة الأمامية في المنحنيات
② ميل السائقين إلى الابتعاد عن الحافة الداخلية للطريق

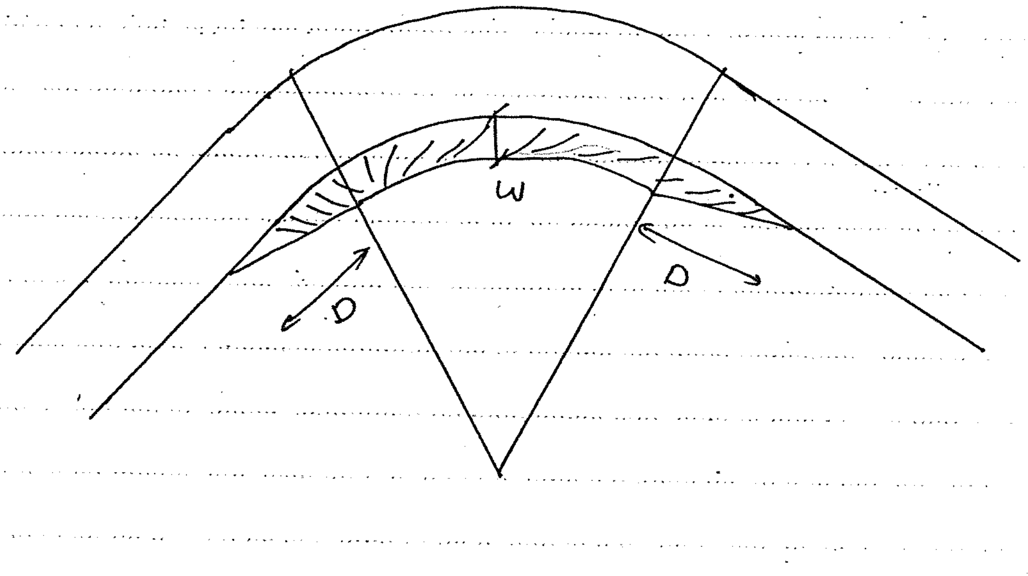
طرق تنفيذ التوسيع :-

① في حالة وجود منحنى انتقالى (توسعه من اتجاهين)

ده الأفضل حيث كلما احافظ على ماله (C.L) في مكانه كان أفضل في التنفيذ



② في حالة عدم وجود منحنى انتقالى (توسعه من ناحيه واحده)



Widening $(W) = W_1 + W_2$

- $(W_1) \rightarrow$ is the widening needed due to wheels shift

توسيع لعدم انطباق المسار الخلفي مع المسار الامامي

- $(n) \rightarrow$ is the number of lanes.

عدد الحارات

- $(R_c) \rightarrow$ the Radius of the horizontal Curve.

نصف قطر المنحنى الافقي

- $(L) \rightarrow$ the length of the design Vehicle.

طول المركبة التصميمية

$$W_1 = n * \left(R_c - \sqrt{R_c^2 - L^2}\right)$$

$$W_2 = \frac{0.105\ V}{\sqrt{R_c}}$$

- $(W_2) \rightarrow$ is the widening needed due for Driver perception

توسيع لمراعاة العامل النفسي للسائق

- $(V) \rightarrow$ The design speed.

$$\text{Widening } (W) = n * \left(R_c - \sqrt{R_c^2 - L^2}\right) + \frac{0.105 V}{\sqrt{R_c}}$$

EX

A two lane of 3.75 m traffic lane width, goes around a 8 degree curve, for a design speed of 100 Km/hr it is required:—

1. Compute the extra width required at the curve.
2. Compute the minimum length of transition curve.
3. Draw plan showing the development of widening.

L vehicle = 6 m

1 Widening W = ??

$$R_c = \frac{1746}{D^\circ} = \frac{1746}{8} = 218.25 \text{ m}$$

$$W = 2*\left(R_c - \sqrt{R_c^2 - L^2}\right) + \frac{0.105\,V}{\sqrt{R_c}}$$

$$= 2*\left(218.25 - \sqrt{218.25^2 - 6^2}\right) + \frac{0.105 * 100}{\sqrt{218.25}}$$

$$= 0.88 \text{ m} \simeq 0.9 \text{ m}$$

2 transition curve length →

For V = 100 A = 200

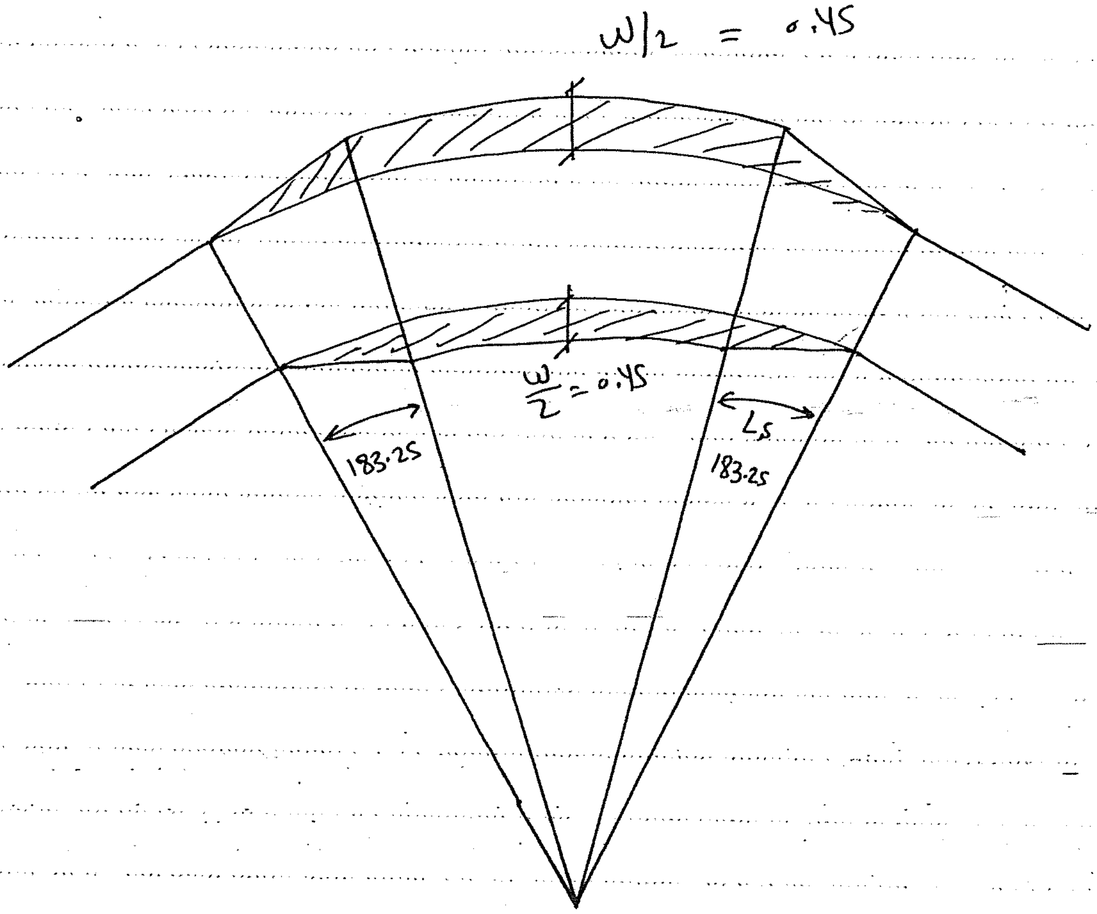
① $L_s = \frac{A^2}{R_c} = \frac{(200)^2}{218.25} = 183.28$ m

② $L_s = \frac{V^3}{28 * R_c} = \frac{(100)^3}{28 * 218.25} = 163.64$ m

③ $L_{s\,min} = 50$ m

$$(L_s) = 183.28 \text{ m}$$

يوجد منحنى انتقالي ← يتم تنفيذ التوسيع على الجانبين



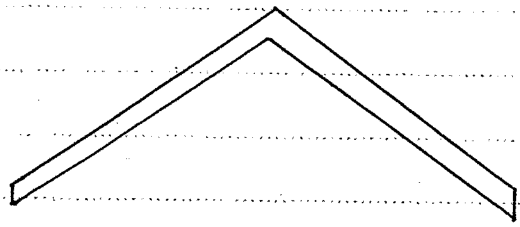
Home work

Draw a neat sketch showing the development about the Inner edge of 2-lane, 3.75 m, lane width, $D = 10^\circ$, cross slope 3%, long. slope = 4%, $V = 85$ km/hr, $f = 0.16$, compute four coordinates on spiral curve if $\gamma = 85^\circ$ $A = 200$, Draw sketches to show the application on extra widing.

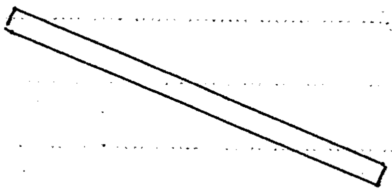
حيث:

يوجد انواع للطرق طبقاً للقطاع العرضي

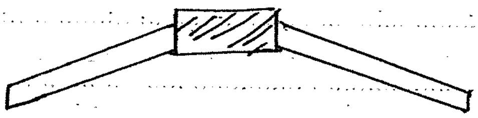
• Types of Roads according to their cross sections



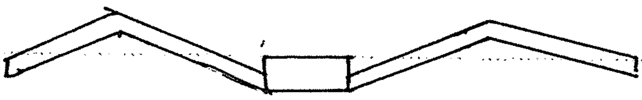
Crowned undevided



Planar undivided



Divided planar with median

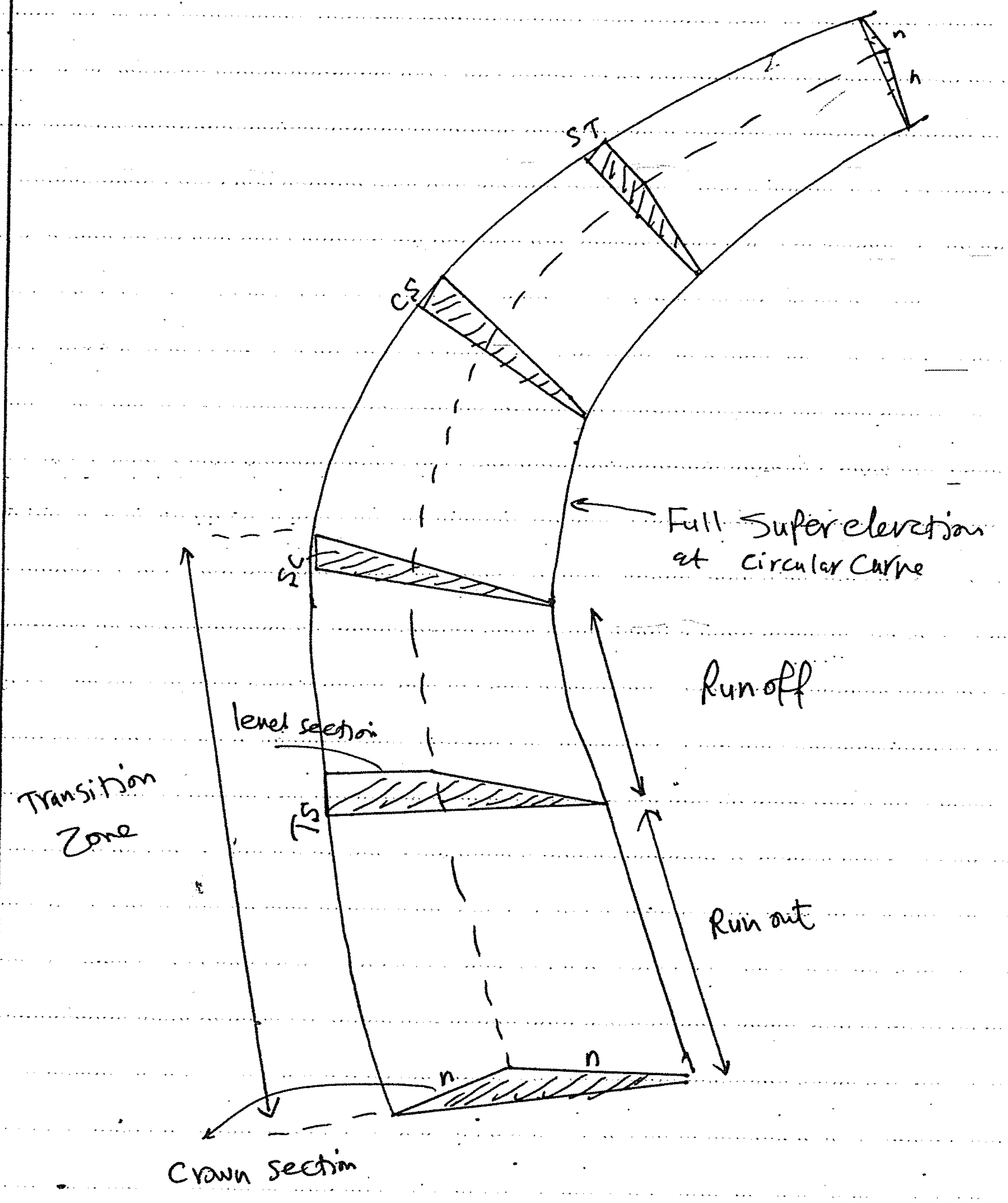


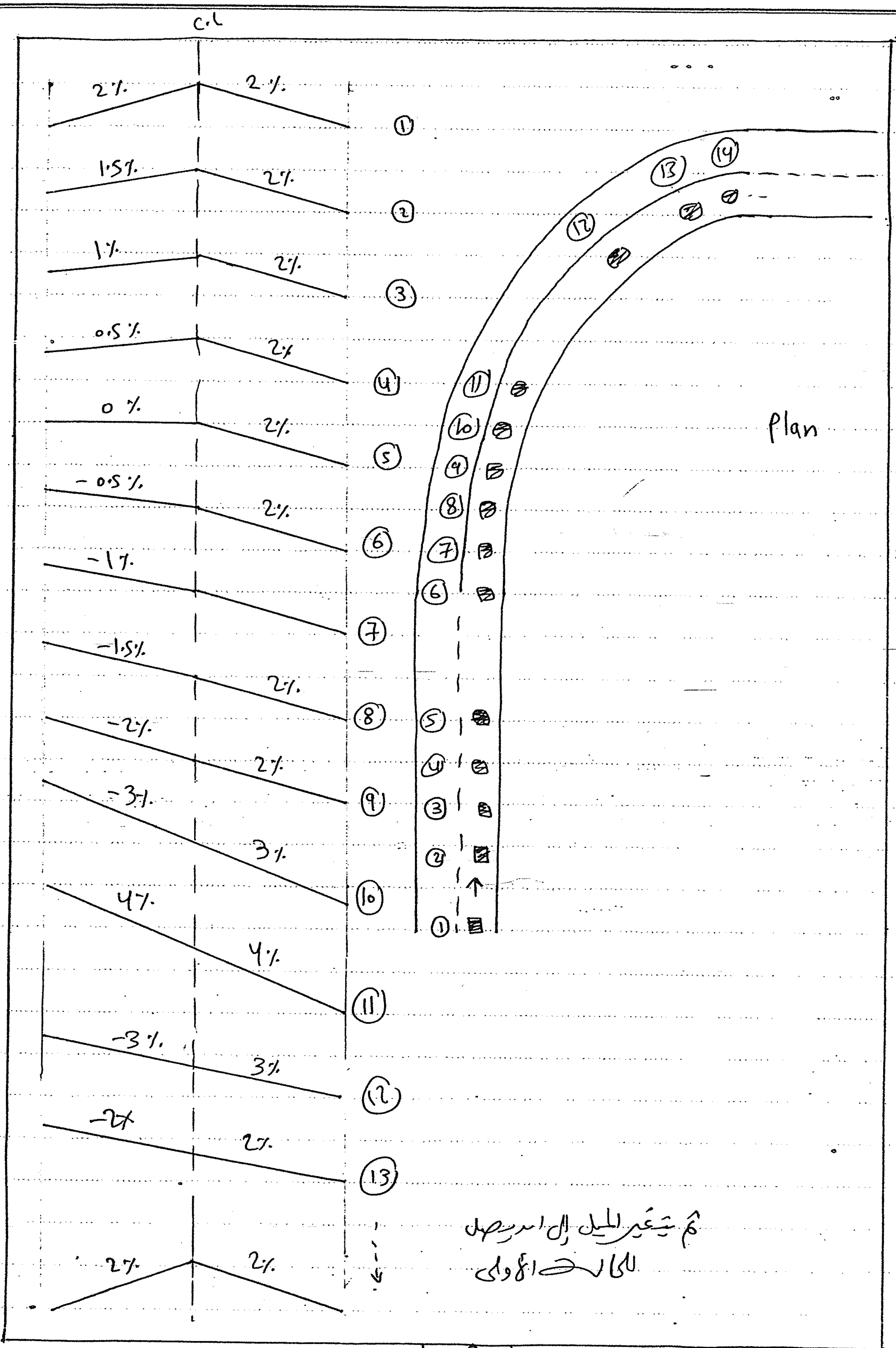
Divided crowned with median

خطوات تنفيذ ال Super elevation

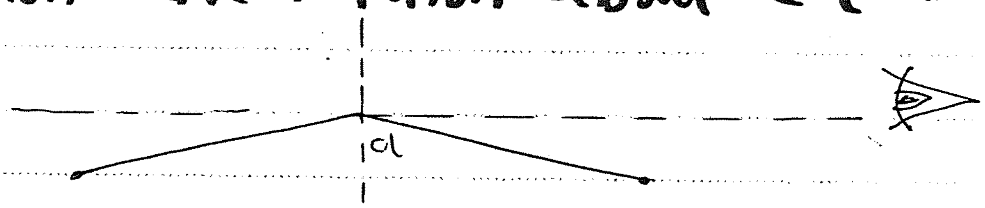
Rotation about centerline

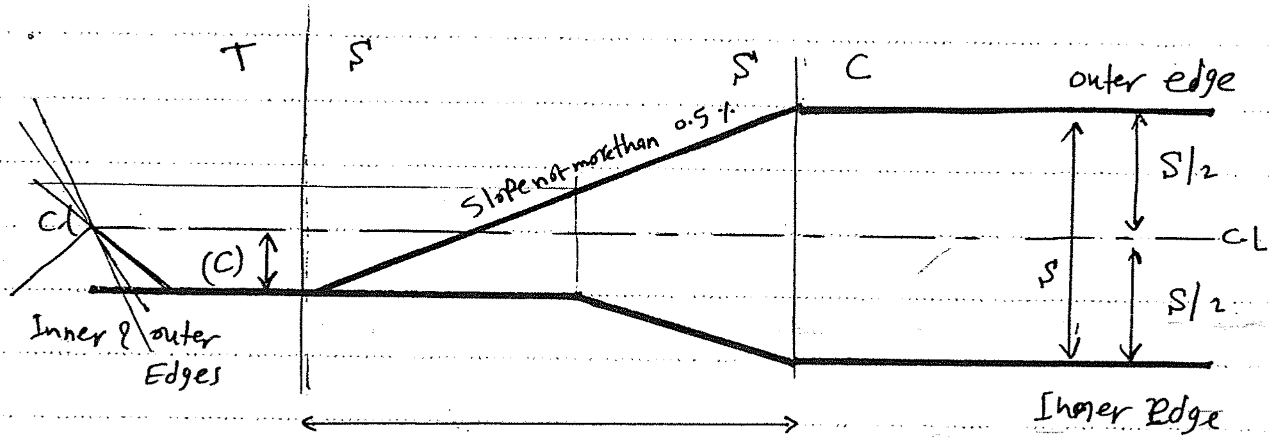
بدوران القطاع العرضي للطريق حول المحور الطولي



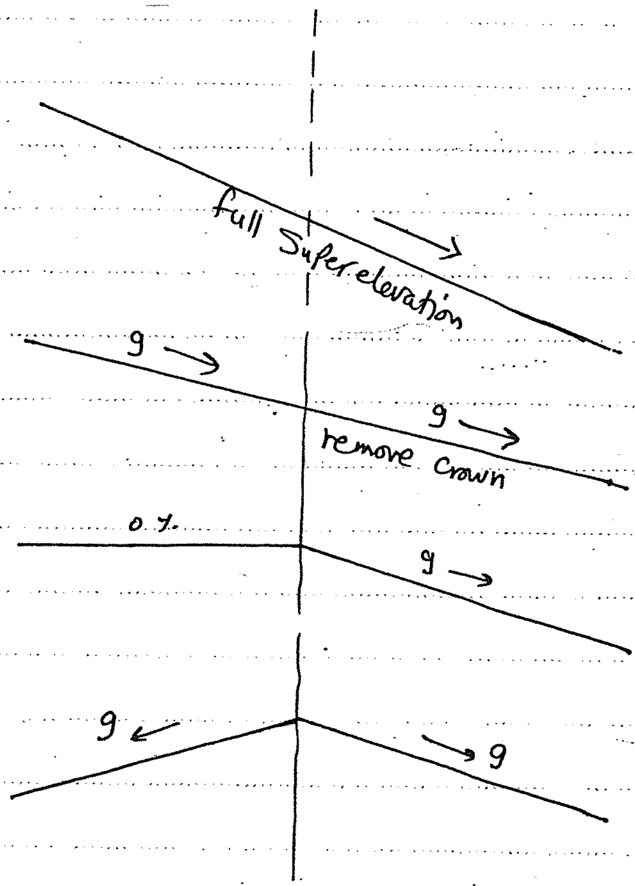

C.L
2% 2% ①
1.5% 2% ②
1% 2% ③
0.5% 2% ④
0% 2% ⑤
-0.5% 2% ⑥
-1% ⑦
-1.5% 2% ⑧
-2% 2% ⑨
-3% 3% ⑩
4% 4% ⑪
-3% 3% ⑫
-2% 2% ⑬
2% 2%
Plan
ثم يتغير الميل إلى ان يصل
للحالة الأولى

(a) Transition Curve Rotation about C.L

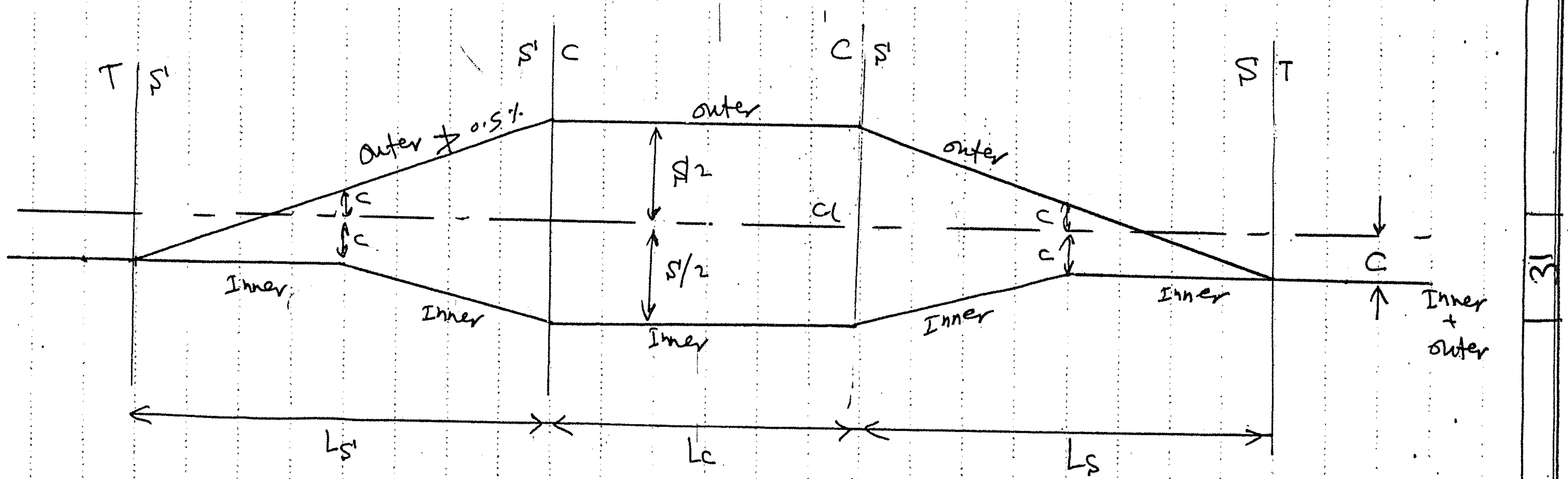




$$L_S = 200 * \left(\frac{S}{2} + C\right)$$



الرسم كاملاً لتنفيذ ال Super elevation خلال ال (Ls) بدوران القطاع العرضي للطريق
حول المحور الطولي له Transition Curve Rotation about C.L



L_s max of

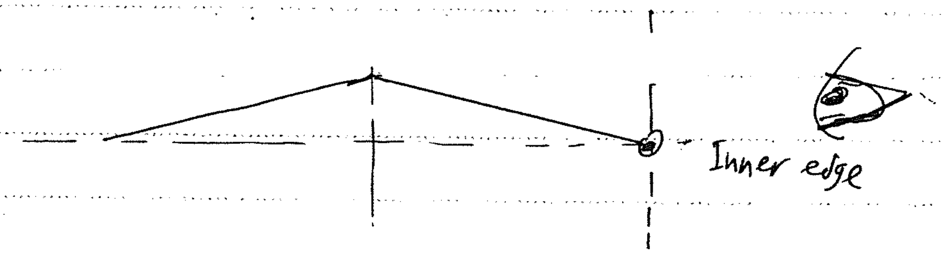
① $L_s = \frac{A^2}{R_c}$

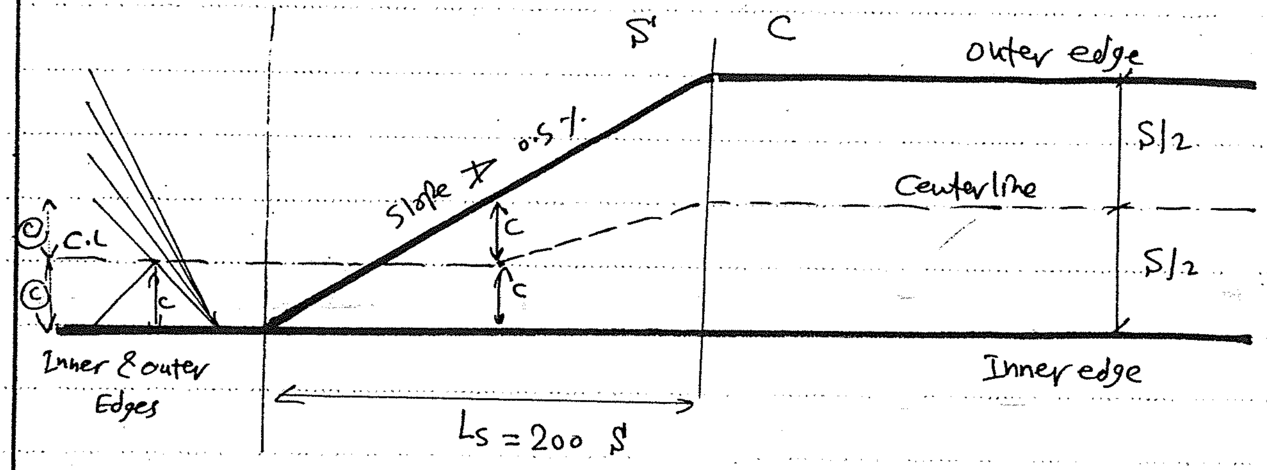
② $L_s = \frac{U^3}{28 R_c}$

③ $L_s = 50\ m$

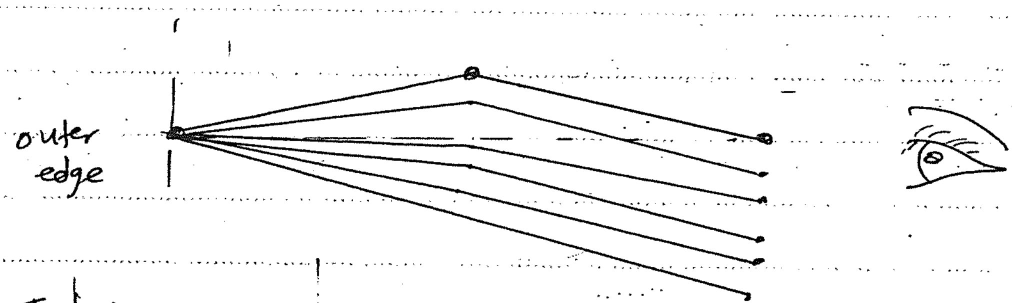
④ $L_s = 200\,e\left(\frac{S}{2} + C\right)$

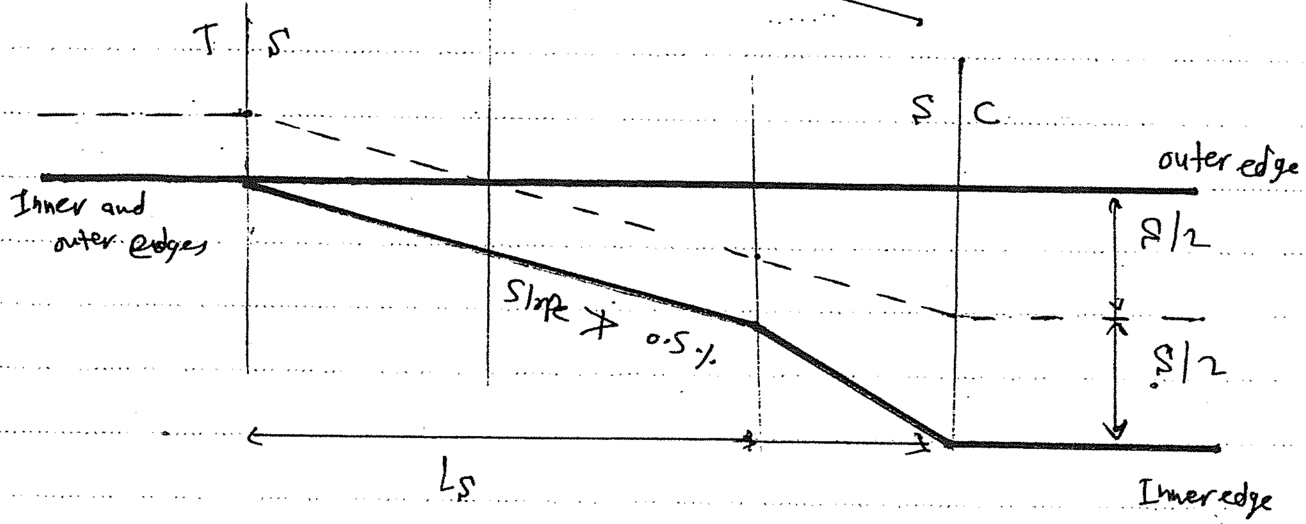
(B) Transition Curve Rotation about Inner Edge



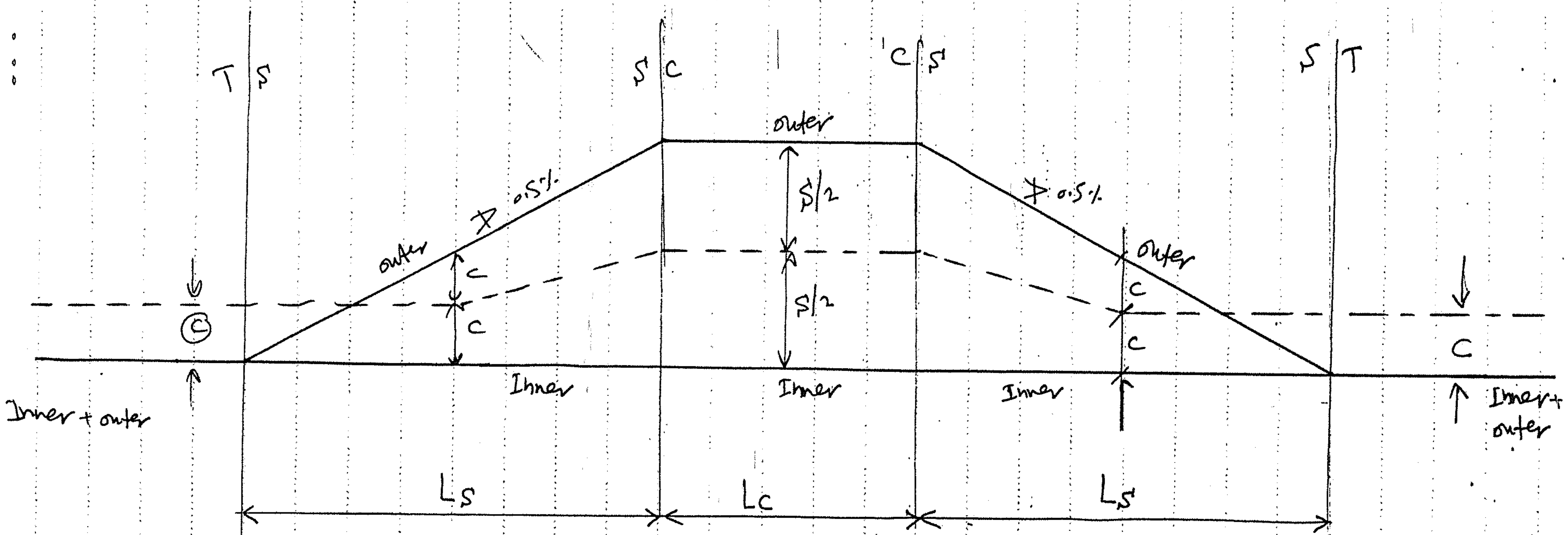


(C) Transition Curve Rotation about outer edge





الرسم كاملة لتنفيذ ال Super elevation خلال ال (Ls) بدوران القطاع العرضي للطريق حول الحافة الداخلية له (البطن) Transition curve Rotation about Inner Edge



(Ls) the max of

① $L_s = \frac{A^2}{R_c}$

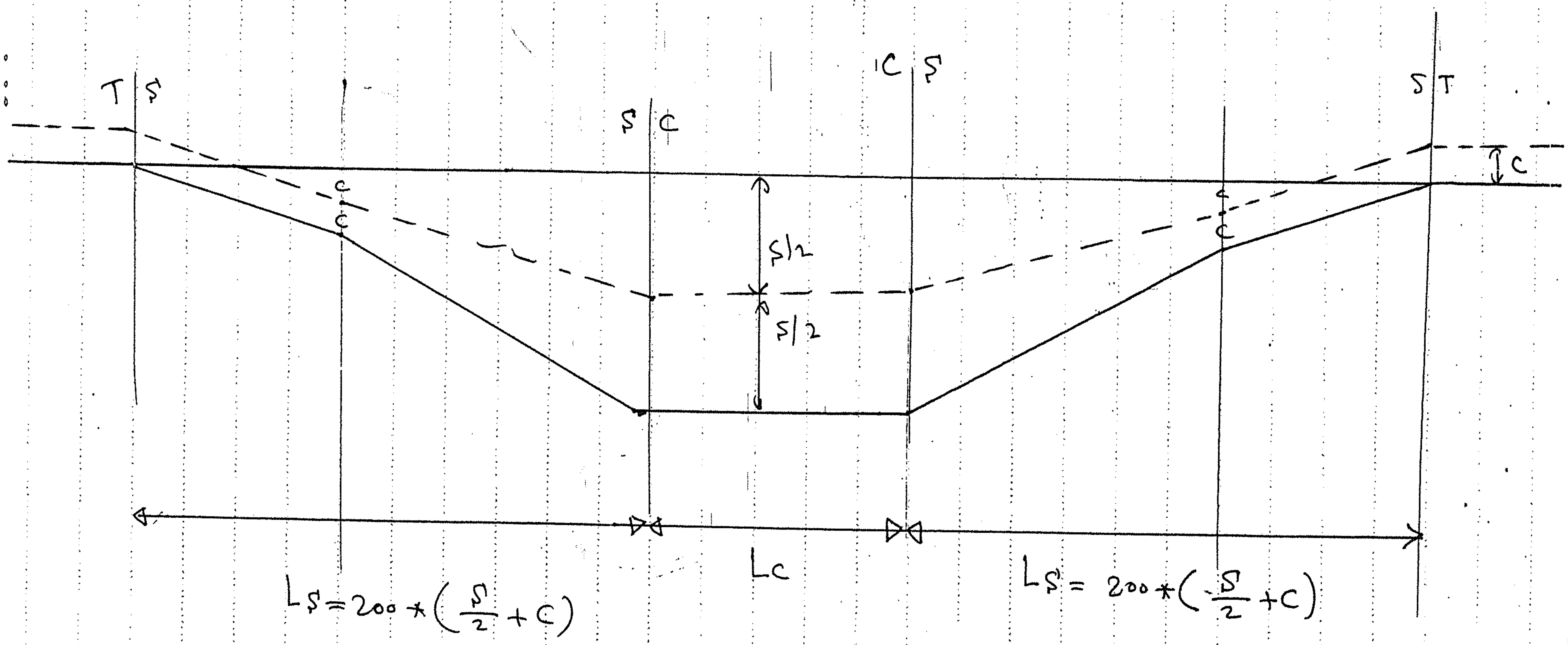
② $L_s = \frac{V^3}{28 R_c}$

③ $L_{s_{min}} = 50$ m

④ $L_s = 200 * S$

الرسم كاملة لتنفيذ ال Super elevation خلال ال (Ls) بدوران القطاع العرضي للطريق حول الحافة الخارجية له (الصفر)

Transition Curve Rotation about outer edge



Ex

The Center line of a 2lane Road 7.5 m wide with design Speed of 80 km/hr runs along a horizontal curve consisting of a circular curve and two transition curves. the road has a cross slope of 1.5 % and longitudinal slope − 1%. The tangent spiral point (T.S) has a station [215+00] and an elevation = 50 m along the centerline. The circular curve has a degree of curve = 8 degree and external angle 80 degree , fs = 0.17 , station = 100

① Determine the length of the transition curve and the length of the circular curve.

② Draw a neat sketch showing the attainment of superelevation along the curve by rotation about the inner edge.

③ Calculate the station and elevation of the controlling points of the horizontal curve TS , S.C , C.S and S.T at the centerline as well as the inside and outside edges of the pavement.

(1) $$R = \frac{1746}{D^\circ} = \frac{1746}{8} = \boxed{218.25}\ m$$

Superelevation

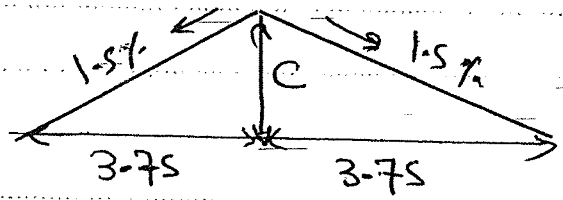
$$e + f_s = \frac{V^2}{127\ R_c}$$

$$e + 0.17 = \frac{(80)^2}{127 * 218.25}$$

$$e = \boxed{0.06}$$

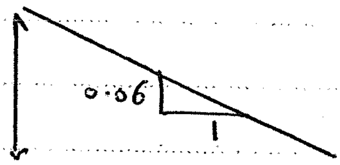
لحساب S و ال C

In Straight parts



$$C = \left(\frac{7.5}{2}\right) * 1.5/100 = \boxed{0.056}\ m$$

In Circular parts



$$S = 7.5 * 0.06 = \boxed{0.45}\ m$$

L_s the max of

$A = 150$ data sheet

(1) $$L_s = \frac{A^2}{R_c} = \frac{(150)^2}{218.25} = \boxed{103.09}\ m$$

(2) $$L_s = \frac{V^3}{28\ R_c} = \frac{80^3}{28 * 218.25} = \boxed{83.78}\ m$$

③ $L_s = 50$ m

④ $L_s = 200\,S' = 200 * 0.45 = 90$ m
(Rotation about Inner)

$L_s = \max = 103.09$ m

From data Sheet

* $L_s = 2\tau * R_c$

$103.09 = 2 * \tau * 218.25$

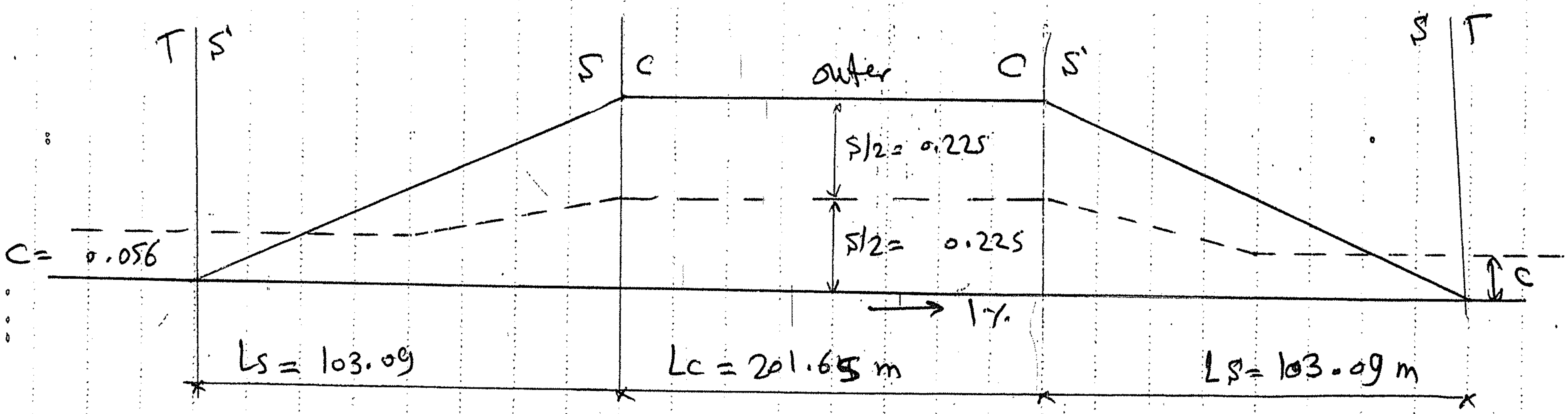
$\tau = 0.2362$ rad $= 0.2362 * \frac{180}{\pi}$
$= 13.53°$

* $\gamma = 2\tau + \alpha$

$80 = 2 * 13.53 + \alpha$ $\alpha = 52.94°$

* $L_c = \alpha_{rad} * R_c$

$= 52.94 * \frac{\pi}{180} * 218.25 = 201.65$ m



	Stations	215+00	216+03.09	218+04.74	219+07.82
Elevation	outer	50 − 0.056 = 49.944	49.363	47.347	45.866
	C.L	50	49.138	47.122	45.922
	Inner	49.944	$49.944 - \frac{1}{100} * 103.09 = 48.913$	$48.913 - \frac{1}{100} * 201.65 = 46.897$	$46.897 - \frac{1}{100} * 103.09 = 45.866$

Ex

A Curved 2-lane road 3.5 m lane width for a design speed of 100 km/hr and Superelevation of 0.09 which equals 2/3 the coefficient of Side friction. It is required

① Draw a neat sketch showing the development of superelevation about the Centerline if the road Cross slope is 2% and longitudinal slope of 2%

② the alignment of horizontal and transition Curve if you know that the external angle = 45 degrees. it is required four Coordinates.

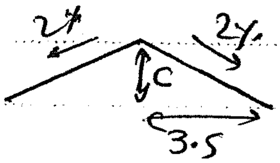
$$e = 0.09 = \frac{2}{3} f_s \quad \rightarrow f_s = 0.135$$

$$e + f_s = \frac{V^2}{127\, R_c}$$

$$0.09 + 0.135 = \frac{(100)^2}{127\, R_c}$$

$$R_c = 350\ m$$

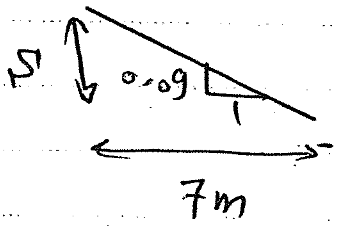
In straight paths



$$c = 3.5 * \frac{2}{100} = 0.07\ m$$

In Circular paths

$$S' = 7 * 0.09 = 0.63\ m$$



(Ls) = the max of

① $L_s = \frac{A^2}{R_c} = \frac{(200)^2}{350} = 114.286$ m

② $L_s = \frac{V^3}{28 R_c} = \frac{(100)^3}{28 * 350} = 102.04$ m

③ $L_s = 50$ m

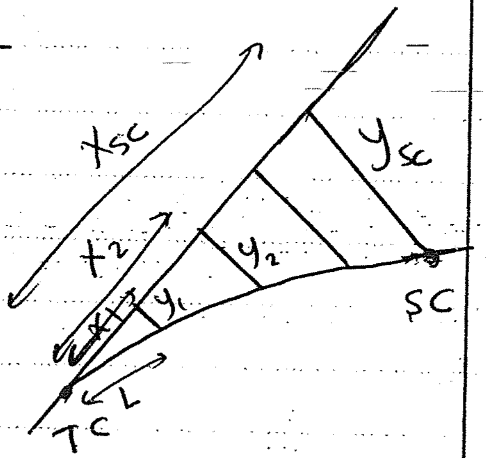
④ $L_s = 200 * \left(\frac{S}{2} + C\right)$ Rotation about CL

$= 200 * \left(\frac{0.63}{2} + 0.07\right) = 77$ m

$L_s = 114.28$ m

For transition curve

Required 4 points



$X = L * \left[1 - \frac{L^4}{40 * A^4}\right]$

$y = \frac{L^3}{6A^2} * \left(1 - \frac{L^4}{56 * A^4}\right)$

L	$\frac{114.286}{4} = 28.57$	57.14	85.71	114.286
X	28.569	57.13	85.637	113.97
y	0.097	0.777	2.621	6.208

for Circular Curve Data Sheet بارسەکام مراد

① (τ)

$L_s = 2\tau * R_c$

$114.28 = 2\tau * 350 \longrightarrow \tau = 0.163$ rad

$= 0.163 * \frac{180}{\pi} = 9.354^\circ$

② (α)

$\gamma = 2\tau + \alpha$

$45^\circ = 2 * 9.354 + \alpha$

$\alpha = 26.292^\circ$

③ (P)

$P = y_{sc} + R_c * (\cos\tau - 1)$

$= 6.21 + 350 * (\cos 9.354 - 1)$

$= 1.556$ m

④ (L_c, T, E_s)

$\alpha_{rad} = \alpha^\circ * \frac{\pi}{180} = 26.292 * \frac{\pi}{180} = 0.459$ rad

$L_c = \alpha_{rad} * R_c = 0.459 * 350 = 160.65$ m

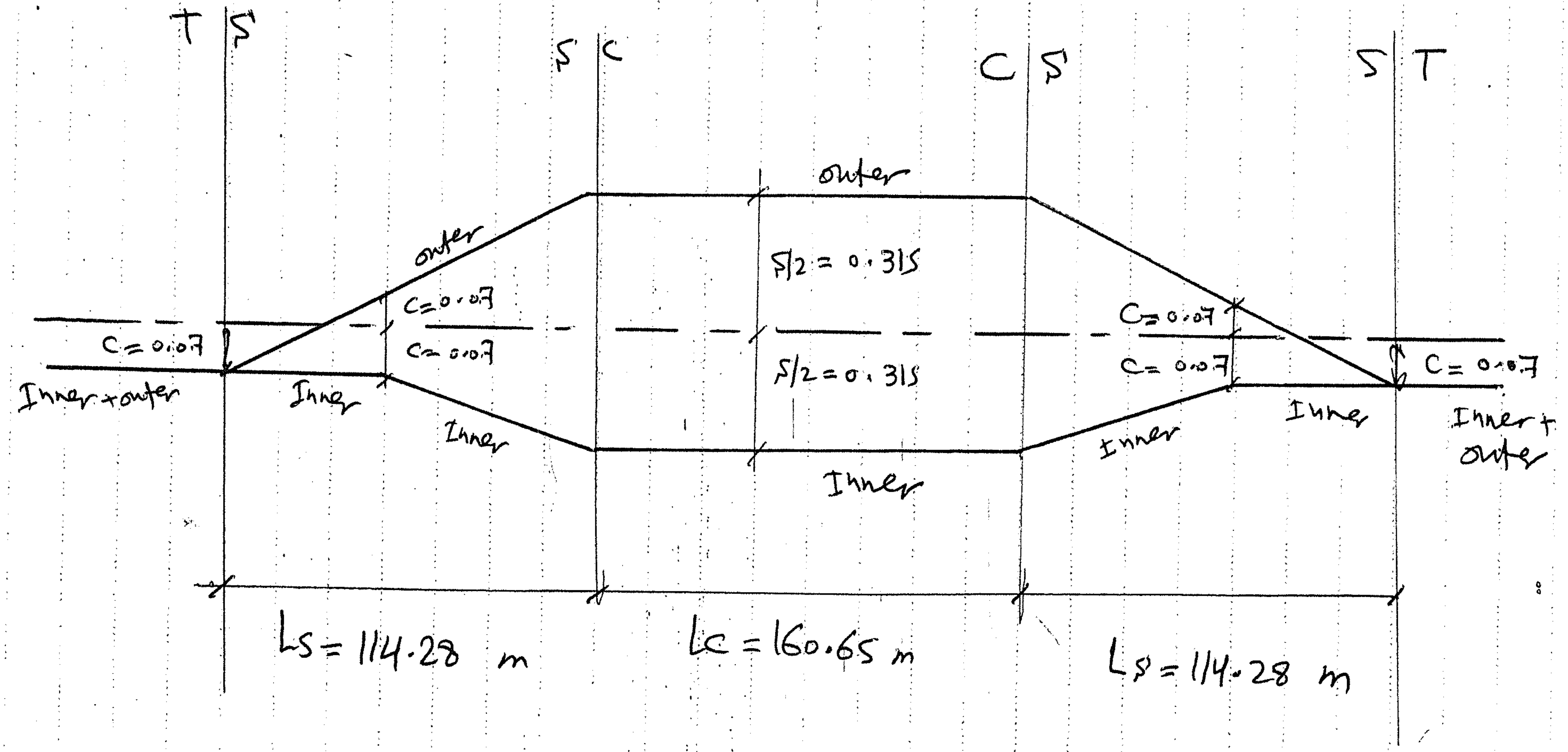
$T = X_{sc} + (P + R_c) * \tan\left(\frac{\gamma^\circ}{2}\right) - R_c * \sin\tau$

$= 113.97 + (1.556 + 350) * \tan\left(\frac{45}{2}\right) - 350 * \sin 9.354$

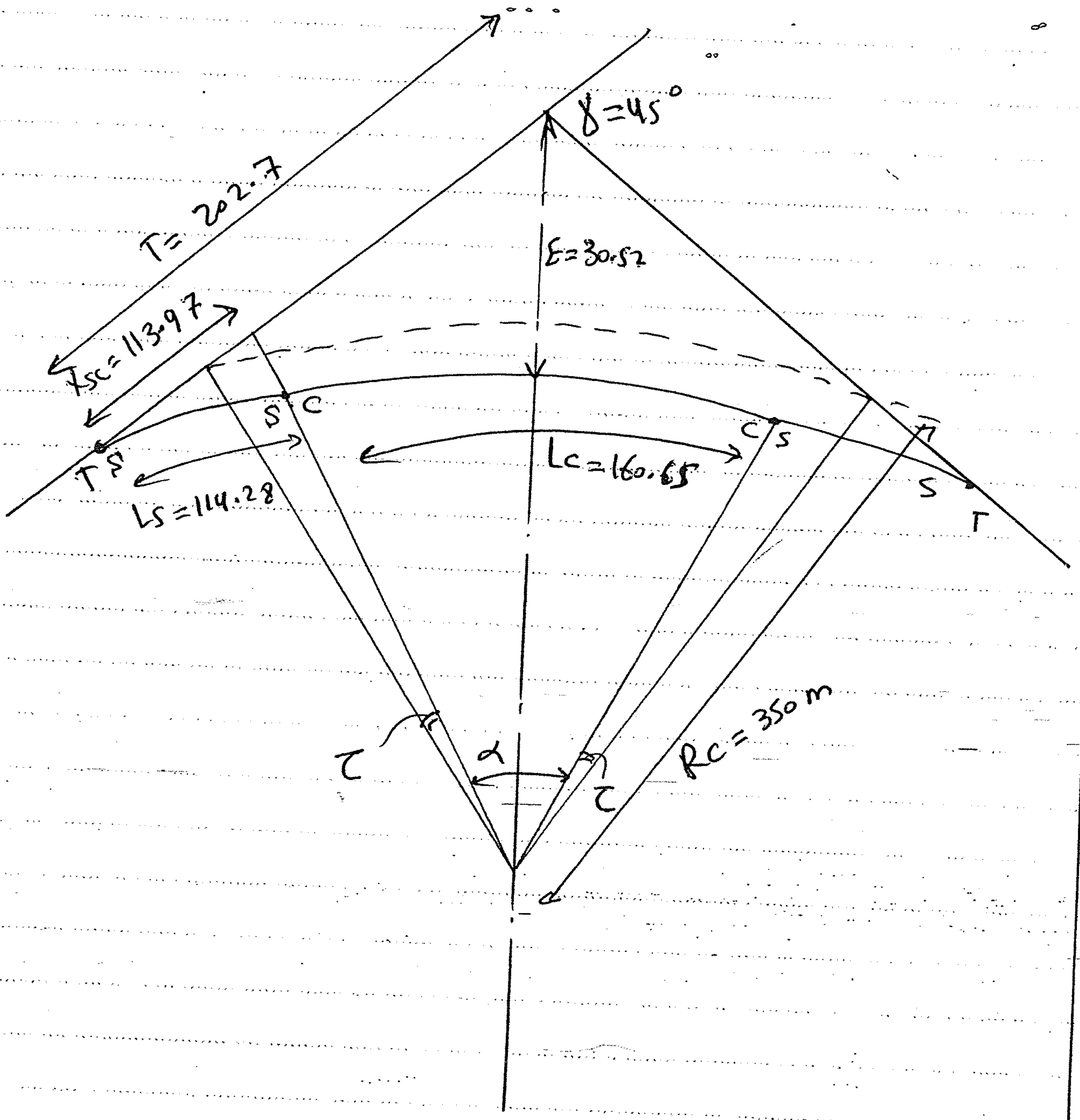
$= 202.7$ m

$E_s = (P + R_c) * \sec\left(\frac{\gamma}{2}\right) - R_c$

$= (1.556 + 350) * \frac{1}{\cos\left(\frac{45}{2}\right)} - 350 = 30.52$ m



T
S
S
C
C
S
S
T
outer
outer
S/2 = 0.315
S/2 = 0.315
C = 0.07
C = 0.07
C = 0.07
C = 0.07
C = 0.07
C = 0.07
Inner + outer
Inner
Inner
Inner
Inner
Inner
Inner + outer
Ls = 114.28 m
Lc = 160.65 m
Ls = 114.28 m



T= 202.7
γ=45°
E=30.52
Xsc=113.97
S C
C S
T S
S
T
Lc=160.65
Ls=114.28
τ
α
τ
Rc=350 m