The Hashemite University

Faculty of Engineering

The Department of Civil Engineering

Highway Engineering and Design

(110401368)

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(Fall 2013-2014)

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Highway Classification:

Highways are classified as follows:

(1) According to functions:-

(a) Freeways ⟵ (بين مدينة و مدينة (التقاطعات مفصولة
(b) Arterials
(c) Collectors (Distributers)
(d) Local Roads

(2) According to Responsibilities:-

(a) Rural Roads ⟵ وزارة الأشغال
(b) Urban Roads ⟵ البلديات

Urban	Rural
* Expensive land	* Cheap land
* Pedestrian Crossing is important	* Pedestrian Crossing is less important
* Speed is Low	* Speed is High
* Heavy vehicles are not allowed	* Heavy vehicles are important
* Access is more important than speed	* Speed is more important than access
* Drainage is important	* Drainage is Less important
* Street Lighting	* Less Street Lighting

* Loading and unloading	* No Loading and Unloading
* Lanes are not wide but have more Lanes	* Lanes are wide, but less # of lanes.
* Cycling	* No Cycling

Lanes width :-

max 3.6 m (12 feet)

min 2.7 m (9 feet)

☑ There are three types of Freeways :-

(1) Limited Access

(2) Partially Access

(3) Free Access

☑ Characteristics :-

(1) High Speed

(2) High Traffic flow

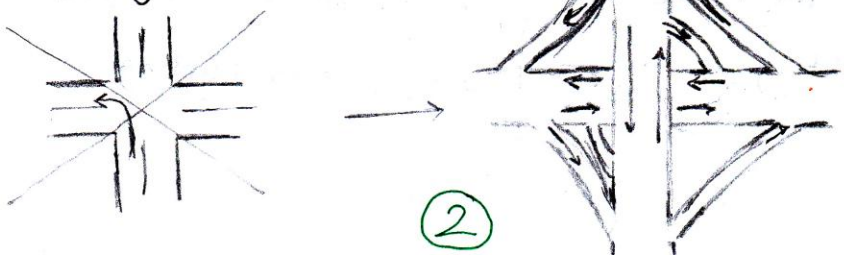
(3) Wide Curves ⟶ if Radius = ∞ ⟶ Straight Line

(4) Wide Lanes

(5) Barriers are located on bothsides to prevent entring the road

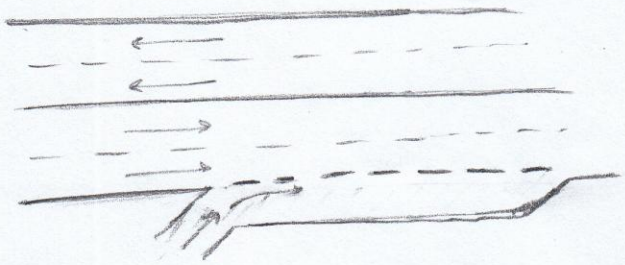
(6) Acceleration and Deceleration lanes are provided

(7) Exiting the Road is always from the Right.

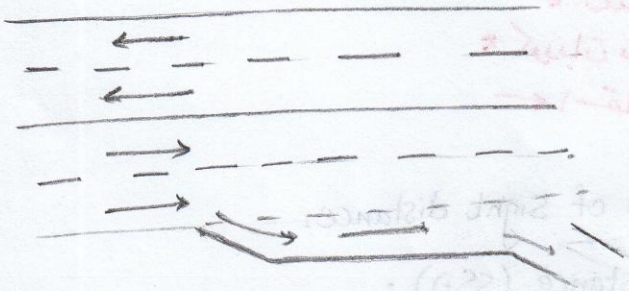


Types of Lanes:-

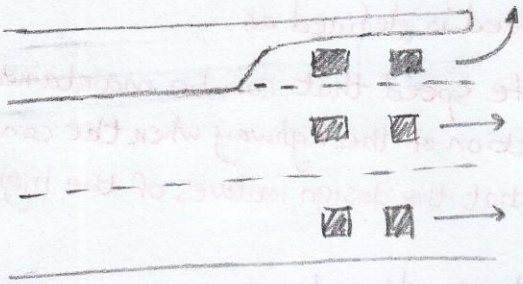
(1) Acceleration Lane:



(2) Deceleration Lane:



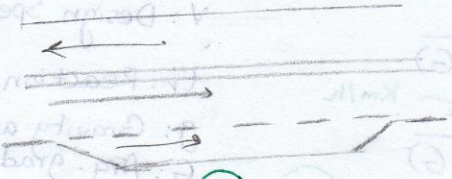
(3) Turning Lanes (Storage Lanes):-



(4) Overtaking Lanes

(5) Climbing Lanes : is an additional Lane for heavy trucks going on low speeds to allow other vehicles to overtake slow vehicles (For two-lane hwy uphill only) (Critical Length)

من بداية الطلوع حتى نهايته



(6) Escaping Lanes: عم النزول ويكون ميله عكس النزول (طلوع) ونهايته رمل وتستخدمه الشاحنات في حالات عدم السيطرة لتفادي حصول حوادث.

(7) Bus Lanes

(8) Cycle Lanes

Design Speed and Sight Distance:

زيادة السرعة التصميمية للشارع تزيد الكلفة ⊕ في حالات الطلوع يجب أن يكون الميل قليل ← cut أكثر
* كوبيات بأنصاف أقطار أكبر
← استملاك أراضي أكثر)

- There are two types of Sight distance:

(1) Stoping Sight Distance (SSD):

It is the distance required to see an object (0.15m) high on the roadway.

** The design Speed is defined as:-

The max. safe speed that can be maintained over a specified section of the highway when the conditions are so favorable that the design features of the highway governs

** Stoping Sight Distance depends on:-

(1) Reaction Time

(2) Breaking Distance

$$SSD = d_r + d_b$$

$$d_r = V * t_r$$

m → $$d_b = \frac{V^2}{2g(f \pm G)}$$ ← m/s

m → $$d_b = \frac{V^2}{254(f \pm G)}$$ ← Km/h

d_r: distance travelled during the reaction time

d_b: " " " " breaking "

V: Design Speed

t_r: Reaction time AASHTO Suggests 2.5 sec

g: Gravity acc.

G: Avg. grade

f: friction coeff. between tyres and pavement

Ex: Determine SSD on a (-3.5%) grade for a design speed of (110 Km/h).

$f = 0.28$

Sol.

$$SSD = d_r + d_b$$

$$d_r = V * t_r = 110 \frac{Km}{h} * \frac{1000}{3600} * 2.5\ sec = 76.4\ m$$

$$d_b = \frac{V^2}{2g(f \pm G)} = \frac{\left(110 * \frac{1000}{3600}\right)^2}{2*9.81\ (0.28 - 0.035)} = 194.4\ m$$

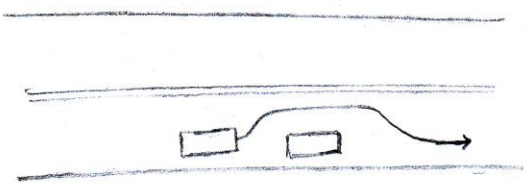
$$SSD = 76.4 + 194.4 = 270.8\ m$$

Table

Design Speed (Km/h)	f
30	0.4
40	0.38
60	0.33
80	0.3
100	0.28
120	0.28

Linear Interpolation

(2) Passing Sight Distance (Two-lane hwy only)



Table

Design Speed	Passing Sight Distance (m)
30	217
40	285
60	407
80	541
100	670
120	792

Geometric Design:

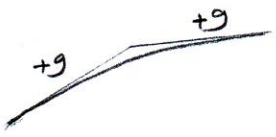
(1) Vertical Curves (alignment):-

Vertical curves are connecting profile grade tangents, they can be seen by drawing the hwy profile

** Vertical curves are provided to avoid abrupt changes in the rate of grades

Crest

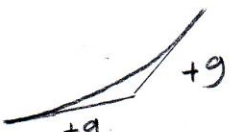
Crest



Crest

Sag

Sag



Sag

** The maximum grades recommended for various classes of roadway by AASHTO :-

3% Level Terrain

4% Hilly Areas

7% Mountainous Areas

** Max. grades depend on:-

(1) Topography (2) Design Speed

5% for 110 Km/h

(7-12)% for 50 Km/h

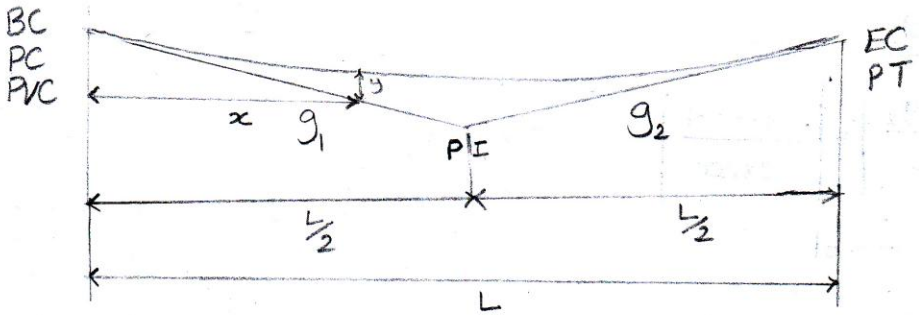
In urban areas the slope can reach up to 25% (Accessibility is more Important)

** For drainage there must be a minimum slope of 0.5%

** Critical Length:
each grade has a critical length

→ It is the maximum length that allows heavy vehicles to climb up without a significant drop in speed Climbing Lane لذلك نعمل

Vertical Curve Calculations:-



PVC : Point of Vertical Curve

PI : Point of Intersection

EC = PVT : Point of Vertical Tangent

x : Hor. Distance

y : Ver. Distance (offset)

g_1 : First grade

g_2 : Second grade

L : Length of curve

a : constant

* ال PI دائماً تكون على $\frac{L}{2}$

* في حالة تكون أعلى أو أخفض نقطة على ال PI

x_m : max. or min. point on the curve

$$a = \left| \frac{g_1 - g_2}{2L} \right|$$

$$y = ax^2$$

$$x_m = \left| \frac{g_1 L}{g_2 - g_1} \right|$$

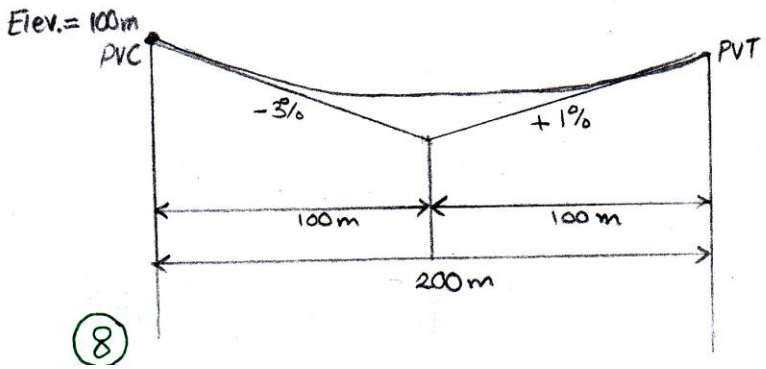
Ex: A (-3%) grade is connected to (1%) by means of (200m) V. Curve, if the elevation at the begining of the curve is (100m) Find the elevations of the curve at (20m) interval.

* العشرينات تُقسّم على L وليس على ال Curve

Sol:

$$a = \left| \frac{g_1 - g_2}{2L} \right| = \left| \frac{-0.03 - 0.01}{2 * 200} \right|$$

$$a = 0.0001$$



$y_0 = 0.0001*(0)^2 = 0$

$y_{20} = 0.0001*(20)^2 = 0.04$

$y_{40} = 0.0001*(40)^2 = 0.16$

$y_{60} = 0.0001*(60)^2 = 0.36$

$y_{80} = 0.0001*(80)^2 = 0.64$

$y_{100} = 0.0001*(100)^2 = 1$

→ $y_{120} = 0.0001*(200-120)^2 = 0.0001*(80)^2 = 0.64$

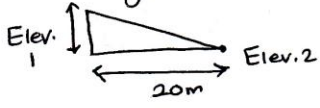
$y_{140} = 0.0001*(200-140)^2 = 0.0001*(60)^2 = 0.36$

⋮

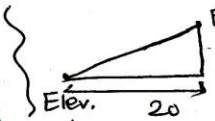
(mirror)

station	Grade	Tangent Elev.	offset	Profile Elev.
0+00		100	0	100
0+20		99.4	0.04	99.44
0+40	-3%	98.8	0.16	98.96
0+80		98.2	0.36	98.56
0+80		97.6	0.64	98.24
1+00		97.2	1.0	98
1+20		97.2	0.64	97.84
1+40		97.4	0.36	97.76
1+60	+1%	97.6	0.16	97.76
1+80		97.8	0.04	97.84
2+00		98	0	98

** Tangent Elev. (calc)



(before PI)



(After PI)

e.g : $\frac{3}{100} * 20 = 0.6 \longrightarrow 100 - 0.6 = 99.4\ m$

$$x_m = \left| \frac{g_1 L}{g_2 - g_1} \right| = \left| \frac{-0.03 * 200}{+0.01 - (-0.03)} \right| = 150\ m$$

$$y_{150} = 0.0001 * (50)^2 = 0.25$$

Tangent Elev. $\longrightarrow 97.0 + \frac{1}{100} * 50 = 97.5\ m$

Profile Elev. $\longrightarrow 97.5 + 0.25 = 97.75\ m$

OR

Tangent Elev. $\longrightarrow 98 - \frac{1}{100} * 50 = 97.5\ m$

▨ Lmin for Vertical Curves:-

↓ ** Crest Vertical Curves when (S ≤ L)

$$L_{min} = \frac{GS^2}{200\,(\sqrt{h_1} + \sqrt{h_2})^2} \quad \text{or} \quad L_{min} = \frac{GS^2}{404}$$

↓ ** Crest Vertical Curves when (S ≥ L)

$$L_{min} = 2S - \frac{200\,(\sqrt{h_1} + \sqrt{h_2})^2}{G} \quad \text{or} \quad L_{min} = 2S - \frac{404}{G}$$

↓ ** Sag Vertical Curves when (S ≤ L)

$$L_{min} = \frac{GS^2}{200\,[0.6 + S\tan 1^\circ]} \quad \text{or} \quad L_{min} = \frac{GS^2}{120 + 3.5S}$$

↓ ** Sag Vertical Curves when (S ≥ L)

$$L_{min} = 2S - \frac{200\,[0.6 + S\tan 1^\circ]}{G} \quad \text{or} \quad L_{min} = 2S - \frac{120 + 3.5S}{G}$$

* مسافة الضوء عن الشارع مع الزاوية

→ L : Length of the vertical curve (m)
S : Sight Distance (SSD) (m)
h_1 : Height of eye above road surface = 1.07m
h_2 : Height of object above road = 0.15m
G : Grades algebraic difference = الفرق الجبري بين الـ grades و هو رقم موجب و يُعوّض كرقم وليس كنسبة مئوية كما في قوانين الـ SSD (الأكبر - الأصغر)

** Longer Length of curve provides more SSD but is more costing to construct.

** In Calculating SSD we use the worst case (ie. the steepest slope)
النزول الأكبر

Ex: A Highway is being designed to AASHTO standards with (120 Km/h) design speed and at one section an equal tangent V. curve must be designed to connect grades of (1%) and (-3%). Determine the minimum length of the V. Curve. Take $f = 0.28$, $t_r = 2.5$ sec

Sol.

$$SSD = d_r + d_b$$

$$d_r = V t_r = 120 \frac{Km}{h} * \frac{1000}{3600} * 2.5$$

$$d_b = \frac{V^2}{2g(f \pm G)} = \frac{(120 * \frac{1000}{3600})^2}{2 * 9.81 (0.28 - 0.03)}$$

$$SSD \simeq 309 m$$

$$L_{min} = 2S - \frac{404}{G} \quad S > L$$

$$= 2 * (309) - \frac{404}{(1-(-3))} = 517 m \rightarrow \text{But } 309 \not> 517$$

$$S \not> L$$

$$L_{min} = \frac{GS^2}{404} \quad S < L$$

$$= \frac{(1-(-3))(309)^2}{404} = 945 m \rightarrow 309 < 945 \checkmark$$

For Passing Sight Distance

$$L_{min} = \frac{GS^2}{946} \quad S < L$$

$$L_{min} = 2S - \frac{946}{G} \quad S > L$$

Choosing Grade :-

(1) The ideal situation is one in which the cut is balanced against the fill without a great deal of borrow or an excess cut to be wasted

(2) Ideal grades should have long distance between intersections, with long V. Curves length between tangents to provide smooth (1) riding and good sight (2) distance

(3) The grade should follow the general terrain and rise and fall in the direction of existing drainage

(4) Change of grade from plus to minus (Crest) should be in cut, and Change of grade from minus to plus (Sag) should be in fill. (PI)

Horizontal Curves!

Seen in Plan View
NOT in Profile

* Curves are formed when the road changes direction
* The wider the curve (Bigger Radius) the better and safer
* Wide curves are in flat areas - more expensive
* Sharp Curves are in mountainous areas
* The higher the design speed the larger the radius is.

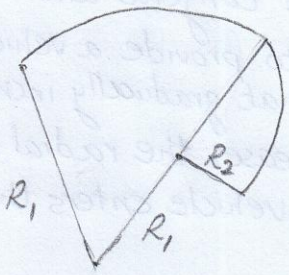
Types of Hor. Curves:

(1) Simple Circular Curve:-

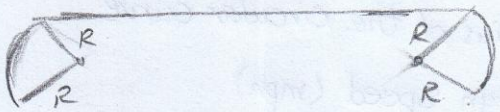
* It is a semi-circle between two tangents.

② Compound Curve :-

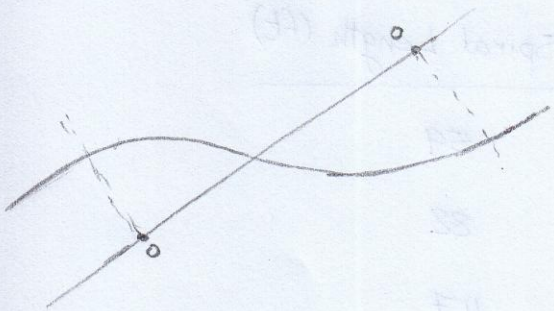
* It consists of two circles with different radii, this type is adopted when some obstruction is met with and it is not possible to use one curve with a single radius.



③ Broken-Back Curve :-



④ Reversed Curve :-



* It consists of two curves with different direction. it should be avoided

Because :-

① It's dangerous

② Difficult to provide superelevation
(*ميلان سطح الطريق باتجاه المركز لذا تجب توفير مسافة كافية (مستقيمة) لتغير اتجاه الميلان)

③ Sudden change in direction (*uncomfortable)

④ Sudden change in Superelevation
(* It is desirable to insert a straight line between the two curves)

⑤ Transition Curve (Spiral Curve)

* Transition curves are placed between tangent and circular curve to provide a vehicle path that gradually increases or decreases the radial force as the vehicle enters the curve

$$L = \frac{3.15\,V^3}{RC}$$ (mph)

L: min. Transition curve length (ft)

C: Rate of increase of radial acc (1-3) ft/sec^3

R: Radius of the circular curve

V: Design Speed (mph)

↝ Metric ↝ $L = \frac{0.214\,V^3}{RC}$

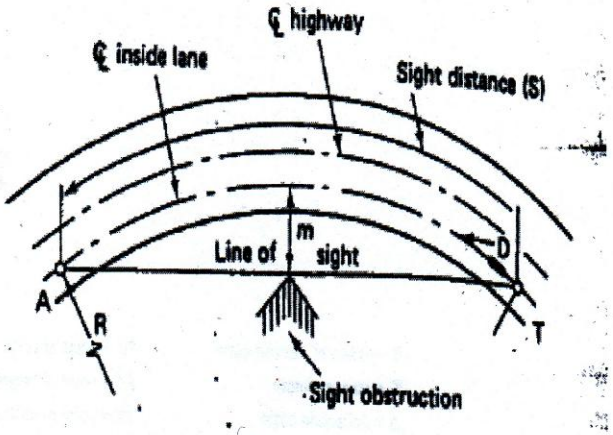
[V] = Km/h

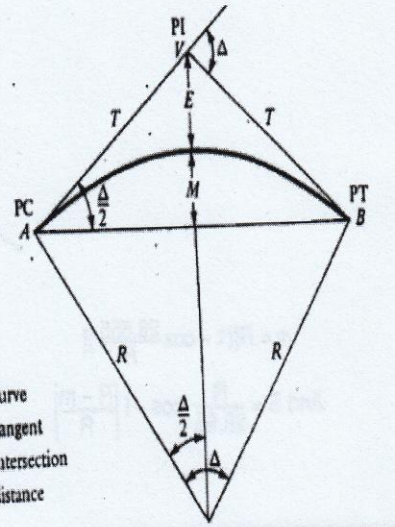
[C] = m/s^3 = 1.2 m/s^3

Design Speed (mph)	Spiral Length (ft)
20	59
30	88
40	117
50	147
60	176
70	205
80	235

$$m = R\left[\left(1 - \cos\frac{28.655}{R}\right)\right]$$

$$\text{And } S = \frac{R}{28.65}\cos^{-1}\left[\frac{R-m}{R}\right]$$





R = radius of circular curve
T = tangent length
Δ = deflection angle
M = middle ordinate

PC = point of curve
PT = point of tangent
PI = point of intersection
E = external distance

Figure 16.19 Layout of a Simple Horizontal Curve

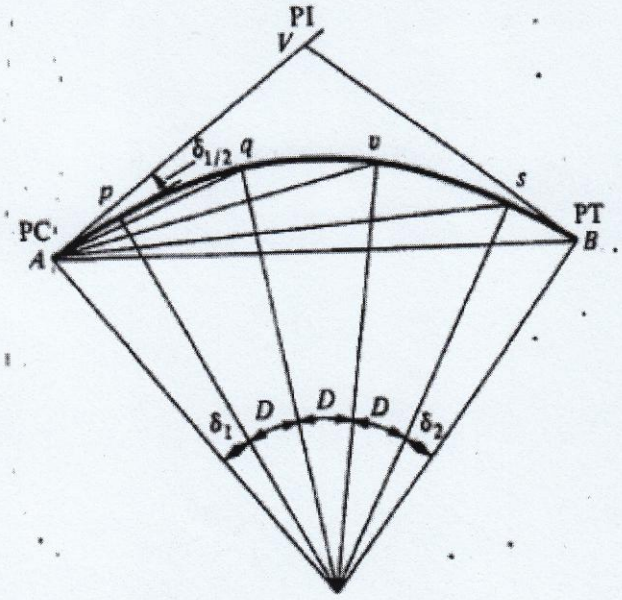


Figure 16.21 Deflection Angles on a Simple Circular Curve

Calculation of PI :-

- $L = R\,\Delta_{rad}$ → rad.
- $T = R \tan\left(\frac{\Delta}{2}\right)$
- $C = 2R \sin\left(\frac{\Delta}{2}\right)$
- $M = R - R\cos\left(\frac{\Delta}{2}\right)$
- $E = \frac{R}{\cos\left(\frac{\Delta}{2}\right)} - R$

→ deg.

L : Length of the Curve
T : Tangent
C : Chord
M : Middle Ordinate
E : External Ordinate

Example:

Given a Hor. Curve with a radius of (410m) and a deflection angle (Δ) of (32°), and the PI station of (1+120.744). Compute the curve data and the station of BC and EC. Compute the deflection angle at every (20m) station.

Sol:

$L = R\,\Delta_{rad} = 410 * 32^\circ * \frac{\pi}{180} = 229\ m$

$T = R \tan\left(\frac{\Delta}{2}\right) = 410 * \tan\left(\frac{32^\circ}{2}\right) = 117.56\ m$

Station of BC = Station of PI − T

= 1120.744 − 117.56 = 1003.184 → 1+003.184

Station of EC = Station of BC + L

= 1003.184 + 229 = 1232.184 → 1+232.184

$M = R - R\cos\left(\frac{\Delta}{2}\right) = 410 - 410 * \cos\left(\frac{32^\circ}{2}\right) = 15.88\ m$

$E = \frac{R}{\cos\left(\frac{\Delta}{2}\right)} - R = \frac{410}{\cos\left(\frac{32^\circ}{2}\right)} - 410 = 16.523\ m$

$C = 2R \sin\left(\frac{\Delta}{2}\right) = 2 * 410 * \sin\left(\frac{32^\circ}{2}\right) = 226.023\ m$

Station	x	dx → deg.	Cx
BC → 1+003.2	0	0	0
1+023.2	20	1.39°	19.89
1+043.2	40	2.79°	39.9
⋮	⋮	⋮	⋮
EC → 1+232	229	16°	226
	L	(Δ/2)	C

- $L = R\,\Delta_{rad} \longrightarrow x = R * 2dx \longrightarrow dx = \left(\frac{x}{2R}\right)_{rad}$
- $Cx = 2R \sin dx$ ← deg.

⇒ $x = 20$

$$dx = \left(\frac{x}{2R}\right)_{rad} = \left(\frac{20}{2*410}\right) = \frac{1}{41} \longrightarrow deg \longrightarrow \frac{1}{41} * \frac{180}{\pi} = 1.39^{\circ}$$

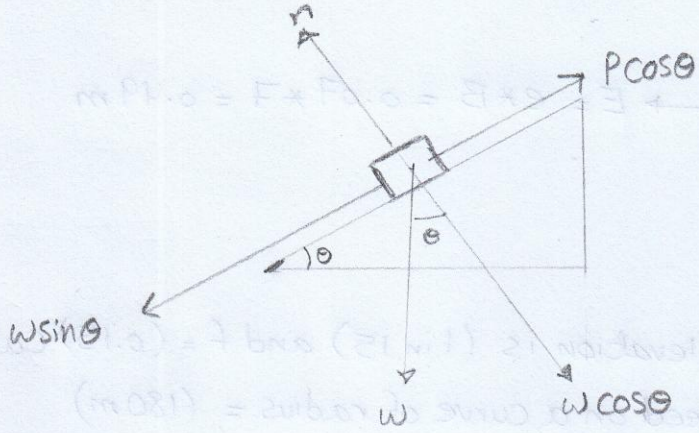
deg

$$Cx = 2R \sin dx = 2*410 * \sin(1.39^{\circ}) = 19.89\,m$$

** H. Curve شرح عن ال SSD لل **

Superelevation :-

The purpose of the superelevation curve is to counteract the centripetal force produced as a vehicle rounds a curve.



- $e+f = \frac{V^2}{127R}$ [V] = Km/h
  f = Coeff. of friction
  R = Radius of the H. Curve
- $e = \tan\theta$

* If e = 0 then the centripetal force is resisted by friction only
  → (The speed must be restricted)

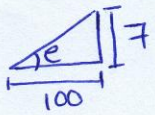
$$\rightarrow e+f = \frac{V^2}{127R} \xrightarrow{e=0} f = \frac{V^2}{127R} \rightarrow V = \sqrt{127Rf}$$ (The speed Limit)

Example:

① Find the rate of superelevation on a H. Curve having a radius of curveture of (90m). The design speed is (50 Km/h). Assume f = (0.15)

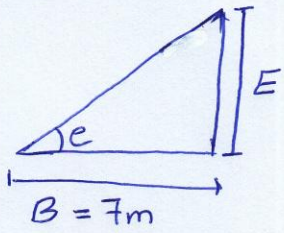
Sol.:-

$$e+f = \frac{V^2}{127R} \rightarrow e+0.15 = \frac{(50)^2}{127*90} \rightarrow e = 0.07 = 7\%$$



② If the road width is (7m) calculate the rise of banking due to the superelevation
or

Sol:



$\longrightarrow E = e * B = 0.07 * 7 = 0.49\ m$

③ If the max. superelevation is (1 in 15) and f = (0.15) calculate the permissible speed on a curve of radius = (180 m)

Sol:

$$e = \frac{1}{15} = 0.067$$

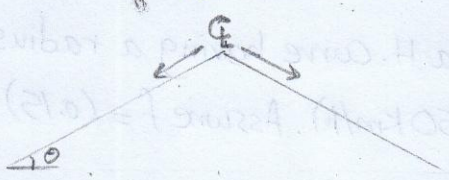
$$e + f = \frac{V^2}{127R} \longrightarrow 0.067 + 0.15 = \frac{V^2}{127 * 180} \longrightarrow V = 70.43\ km/h$$

Say

70 km/h ناخدها أقل عشان الـ Safety

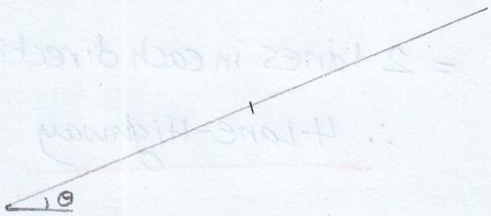
*Achieving superelevation by rotation around the center Line (℄)

① Normal drainage cross slope

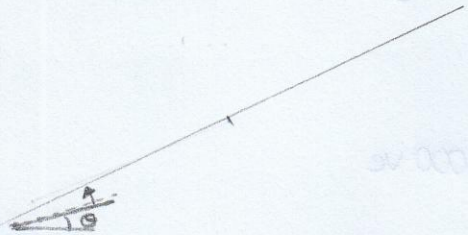


② Outside lane rotated to flat

(3) Outside lane rotated to normal the cross slope of the inner lane



(4) Full Superelevation



Estimation of the no. of lanes:-

* AADT = Annual Average Daily Traffic → [AADT] = Vehicles
* DDHV = Directional Design Hourly Volume → [DDHV] = ve/h

Example:

If the AADT = 10 000 vehicles and the percentage of the 30th hour is (20%) of the AADT for both directions. and the traffic volume in one direction is (60%). Find the no. of lanes if the lane capacity is (600 ve/h)

Sol:

- DDHV = D * K * AADT
  - = 60% * 20% * 10 000
  - = 1200 ve/h

D = Directional Distribution

K = % of the peak hour

- no. of lanes = $\frac{DDHV}{\text{Lane Capacity}}$

$= \frac{1200\ ve/h}{600\ ve/h} = 2$ lanes in each direction

$\therefore$ 4-Lane-Highway

Example:

Design Period = 20 years

If: ADT = 5000 ve/h in the 1st year

Normal growth = 50%

Generated traffic = 30%

Growth due to developing = 1000 ve

Find ADT after 20 years

Sol:

5000 ve * 50%

+

5000 ve * 30%

+

1000 ve

=

5000 ve

New ADT = 5000 ve + 5000 ve = 10000 ve/h

Recommended Design Speed: ليس للحفظ

Conditions	Design Speed (Km/h)	
Rural Freeway in Mountainous areas	80 - 100	Limited Access
Freeway in Urban areas	100 - 110	
Rural Freeway in Level Terrain	110	

* لا Free access سرعات أقل (تداخل أكثر)

Rural Arterial		
Flat Terrain	100 - 110	Unlimited Access
Rolling Terrain	80 - 100	
Mountainous Terrain	60 - 80	

Urban	
Arterial Streets	60 - 100
Central Bussiness District (CBD)	50 - 100

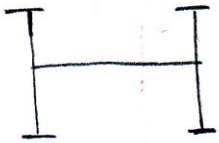
Objective For Providing H. Curves:

1. To keep the driver alert
2. To avoid any obstruction, buildings, weak soil
3. To avoid difficult topography
4. To avoid acquistion of land

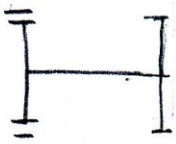
Design Standards :

Vehicles are classified by AASHTO into four main categories

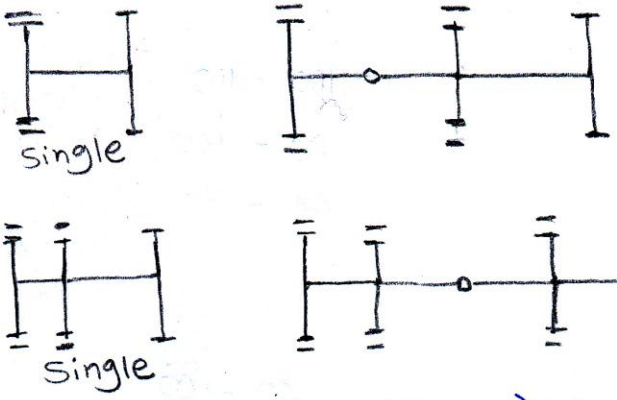
① Passenger Cars , Pickups , Vans



② Buses



③ Trucks , Single Unit Trucks , Truck Trailes , Semi-trailes



④ Recreational Vehicles (Boats & Caravans)

* There are some design standards that the engineer should be familliar with:-

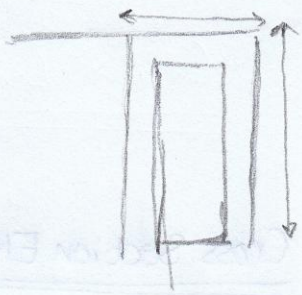
① Vehicle Characteristics (Design Vehicle)

It is a certain characteristics in the vehicle which is important for the geometric design.

a. Weight ⟶ structural design of surface (Pavement)
// // // Bridges

b. Height ⟶ Vertical Clearance (Bridges, Wires)

C. Vehicle's Length ⟶ Parking Stall Length
Platform length



D. Width ⟶ Lanes Width
⟶ Parking Stall's Width
⟶ Lateral Clearance

E. Wheel Base ⟶ Intersection's end radius.

Some Consideration Points When Designing Hor. & Ver. Curves:-

(1) Avoid short and sharp curves

(2) Straight roads with same slope should not be longer than (20*V)

(3) Short straight lines between curves should not be shorter than (6*V) and between reversed curves (2*V)

(4) It is preferred to be parallel to the contour lines rather than perpendicular

(5) You should avoid fill at sharp H. Curves.

(6) The BC and EC of two consecutive H. Curves should not coincide

(7) H. Curves and V. Curves should be avoided at intersection

Design Standards for Highways

a. Minimum Grade: Limited by the need to provide drainage

b. Minimum Length of V. Curves: It is limited by the stopping Sight Distance and the appearance

c. Maximum Superelevation: It is limited by side friction to prevent slow moving vehicles from sliding.

d. Maximum down grades: It is limited by Stopping Sight Distance

e. Minimum radius of H. Curves: It is limited by max Side friction which is based on max Superelevation.

Cross Section Element of Highways:

(1) Side Slopes:- (Fill)

H : V	
4 : 1	When Fill is about (3m) high
6 : 1	" " " " (1.8m) "

دبش وبطون

** In some cases when the Fill is high, side slopes are built with (Riprap)

(2) Back Slopes:- (Cut)

H : V
2 : 1

Shoulders:

داخل للدن نستخدم الرصيف بدلاً من الـ Shoulder

The are provided:-

(1) For Safe operation of traffic

(2) They increase sight distance on H. Curves

(3) They provide structural support for the pavement

(4) Improve Capacity

(5) Provide refuge for stalled vehicles or emergency

* Width should be $\geq 3m$
* In mountainous areas $\geq 1.2m$
* Slope 3%
* Surface should be rough compared to the main road

Guard Rails:

* A guard rail should be provided when:

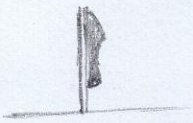
(1) Fill > 2.4 m high

(2) Sudden change in alignment (Sharp Curves)

(3) In locations near side ditches.

* Types of guard rails:-

(1) W-beam



Guard rails should be flexible to reduce damage if there is collision, also to absorb the energy produced.

(2) Cables

(3) Concrete

* In urban areas curb stones are used, They should be between (15 - 20 cm) high.

عشان نعرف نفتح باب السيارة.

Right of Way :-

* It is the land acquired along the road's alignment by the highway organization. وزارة الأشغال / البلدية

* The right of way depends on the importance of the road. Sufficient right of way should be acquired in order to:-
  (1) Avoid the expense of purchasing developed properties
  (2) For side slopes and cuttings.
  (3) Provide drainage systems
  (4) Visibility considerations on H.Curves
  (5) Width of land required for future development

* Recommended Values:-
  - (40-60) ft for 2-Lane collector
  - minimum (80) ft for arterial 2-Lane
  - 4-Lane undevided arterial (64-108) ft
  - divided from (120-300) ft depending on the no. of Lanes.

ليست للحفظ

Travel Lanes:

* The standard width is (3.6m) [12 ft] and the min. (2.7m) [9ft]
* Lanes are wider than (12 ft) are provided at curves to account for heavy vehicles.
* The width and number of lanes depends on :-
  (1) Volume of traffic
  (2) The design Speed

Categories of Highways:-

(1) Two-Lane hwy (width 7.2m) + Shoulders on each side.

(2) Three-Lane hwy:

* may be used in the following cases:-

a. Two lanes in one direction and one lane in the other

b. The third lane may be used alternately في الصباح باتجاه وفي المساء بالعكس

c. For climbing lanes

d. For left turns only (Urban Areas)

(3) Four or more lane hwys should be divided by median strip, median should be between (1.2m) to (18m)

Pavement Crown:

* Raising the centerline of the roadway above the pavement edge for drainage purposes.

* Recommended values (1.5-2%) slope proper drainage system at the edge should be provided.

* For oneway streets or divided roads (with median) may not have a Crown in the center of the road

* Sidewalk:- They are provided in urban roads on both sides also when pedestrian traffic is high. In urban or rural areas the max. width is (4ft) [1.2m] in residential areas, and range from (4-8ft) in Commercial areas.

* Medians:- It is the section of a divided hwy that seperates the lanes in opposing directions.

The function of a median include:-

(1) Seperate opposing traffic

(2) Providing storage areas for left-turning & U-turn vehicles.

(3) " refuge for pedestrians

(4) Reducing the effect of headlight glare.

* Medians can be: a. Raised
b. Flushed
c. Depressed

a. Raised medians are used in urban roads

b. Flushed medians are used in urban roads and freeways with median barriers

c. Depressed medians are used in freeways and they are more effective in draining surface water

Widening of curves:

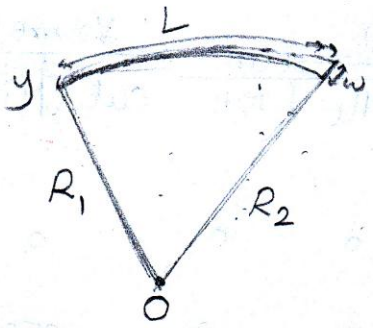
On a curved portion of a road the steering wheels turn sideways so the width of way occupied by a vehicle is more than the width of hwy occupied by a vehicle on a straight portion of the road, therefore it is a common practice to provide extra width of pavement. The amount of widening depends on:

(1) The design speed

(2) The design vehicle

(3) The radius of the H. Curve

(4) The width of the road



$w = R_2 - R_1 \rightarrow R_1 = R_2 - w$

for triangle Oxy :-

$R_2^2 = L^2 + R_1^2$

$R_1^2 = R_2^2 - L^2$

$(R_2 - w)^2 = R_2^2 - L^2$

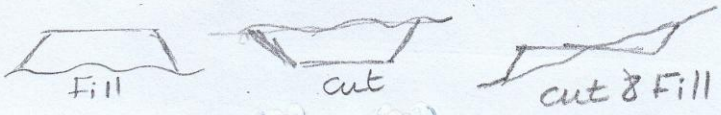
$R_2^2 - 2R_2 w + w^2 = R_2^2 - L^2$

$w = \frac{L^2}{2R - w} = \frac{L^2}{2R_2}$

Design Vehicle:

* When designing parking lots passenger car is used
* When designing intersections of local roads single unit truck is used
* When designing intersections of hwy city streets (collectors) buses are used
* When designing intersections of freeways' ramps semi-trailers are used

- Example on cut & Fill



Station	Area (m^2)		Volume (m^3)		Cumm.		Net
	Cut	Fill	Cut	Fill	Cut (+)	Fill (−)	
0	15	0	0	0	0	0	0
20	10	0	250	0	+250	0	+250
40	5	2	150	20 (23)	+400	-23	+377
60	0	5	50	70 (80)	+450	-103	+347
80	0	10	0	150 (172)	+450	-275	+175
100	0	5	0	150 (172)	+450	-447	+3
120	5	2	50	70 (80)	+500	-527	-27
140	10	0	150	20 (23)	+650	-550	+100
160	20	0	300	0 (0)	+950	-550	+400
180	10	0	300	100 (115)	+1250	-550	+700
200	0	10	100		+1350	-665	+685

Intersections' Design :

* The general term junction or intersection is where two or more roads meet or Cross one another at the same or different elevation

* Types of intersections

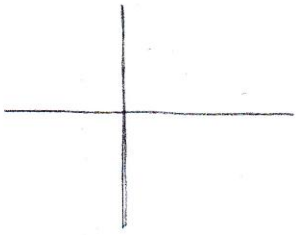
Intersections can be grouped in two categories:-

① At-grade Intersections

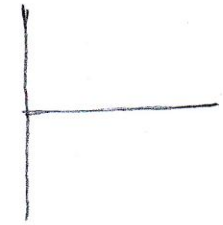
② Grade Seperation → With Ramps
→ Without Ramps

① At-grade Intersection

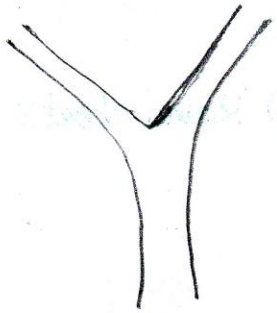
This is the most common type of intersections and it indicates the road junctions at the same elevation, traffic movement is at the same level.



Cross Int.

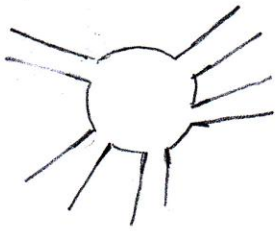


T- Int.

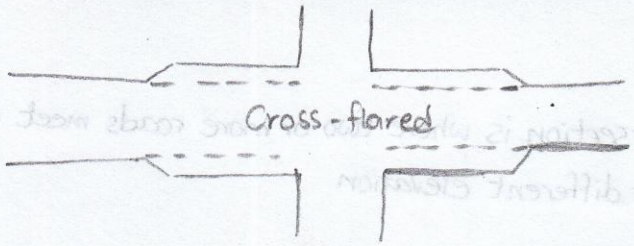


Y-Int.

Skewed Int. (مائل)

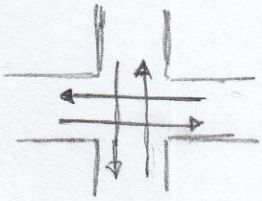


multi-leg Int
(4 أكثر من)

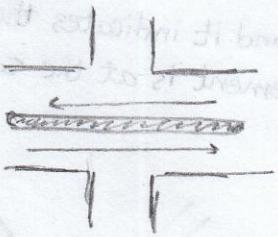


* There are 3 Types of at-grade intersections:

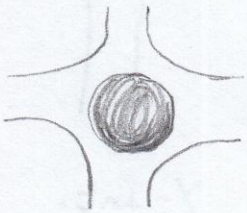
① All Paved Unchannelized Intersection



② Channelized Intersections



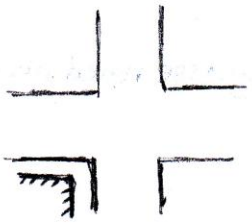
③ Round abouts



* The design of intersection (Curbline) depends on the following :-

(1) Sight Distance

If the sight distance is limited or short a STOP sign or giveway sign should be installed (on less important road)



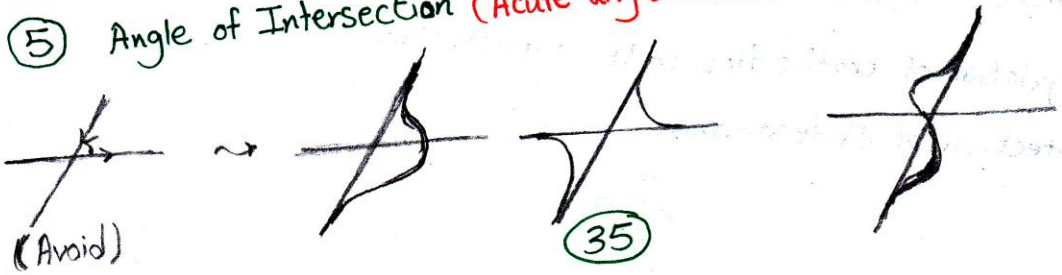
(2) Turning Radius of Intersection (Depends on the components of the traffic)

V. Type	Int. angle	R
PC	90	—
Bus		—
Truck		—
PC	60	—
Bus		—
Truck		—

(3) Pedestrian movement

(4) Reducing Accidents (Safety Consideration) [Reducing Conflict Points]

(5) Angle of Intersection (Acute angles should be avoided)



⑥ Type of intersecting roads (minor with major)

* If the traffic volume is low and the crossing roads are minor, simple or all paved intersection is used.

* If the volume increases flared crossing is used if not channelized intersection

* When the traffic flow (volume) increases and there is a delay, use round about provided there is enough area.

* If not then a traffic signal should be installed

* If all that failed then we should use grade seperated intersections

① All paved unchannelized intersections (flared is in all paved)

The unchannelized intersections are paved the whole area and as such there are no restrictions to vehicles to use any part of the Int. area. These intersections are of the lowest order, sometimes the width of the pavement is widened at the Int. and such junction is known as flared Int.

② Channelized Intersections:

In order to handle large volume of traffic at the Int. it becomes necessary to introduce traffic islands to channelize the turning traffic.

Islands in int. serve the following:-

(1) * Seperation of conflicts

(2) * Control of angle of conflicts and approach

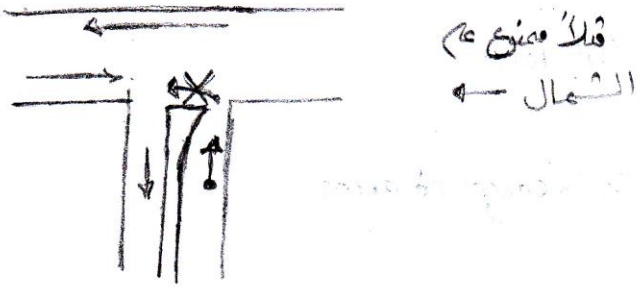
(3) * Reduction of excessive pavement areas

(4) * Regulation of traffic flow in the intersection

(5) * Protection of Pedestrians

(6)* Location of traffic control devices:

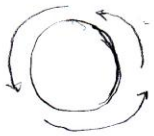
(7)* Preventing drivers from taking prohibited turning

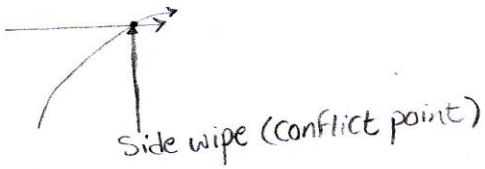


(8)* Increase Safety

③ Round abouts

A roundabout is the alternative to the conventional at grade intersection. It consists of a central Island where vehicles travel in one way counterclockwise direction.





- **Advantages of round abouts:-**

(1)* It provides simple solution for road junction where more than four roads meet, and it proves to be advantageous when the no. of intersecting roads are between (4-7).

(2)* It regulates traffic and there is a continous flow of traffic through the round about

(3)* Smooth and orderly flow of traffic with little delay (تأخير)

(4)* It is cheaper to construct than seperated intersections.

(5)* It is self controlled traffic avoiding the necessity of traffic police or signal

- Disadvantages of roundabouts :-

(1)* It doesn't function effectively if all approaches have similar traffic volume (major+major) (minor+minor)

(2)* It requires large area of flat land.

(3)* It is not possible to use it in congested areas.

(4)* Difficult for pedestrians

(5)* It requires the installation of complicated traffic signals

(6)* Not suitable for high-speed roads

* Space to draw junctions :-

Grade Seperations

A4

A grade seperation is the arrangement of taking one road over or under another. by means of a bridge. It is also known as a fly over junction.

* The grade seperation and interchanges may be ~~warranted~~ wanted :-

1) If it was decided to have limited access cross roads.

2) To eliminate bottle neck

3) To increase safety (to prevent accidents) if there was a high no. of accidents

4) If the topography is such that the other types of design are not feasible.

5) If there was a high traffic volume

---

* An Int. is a grade seperation in which vehicles moving in one direction.

* The Interchanges may be of various types, but the common types of Interchanges are:-

* Draw or see next page...

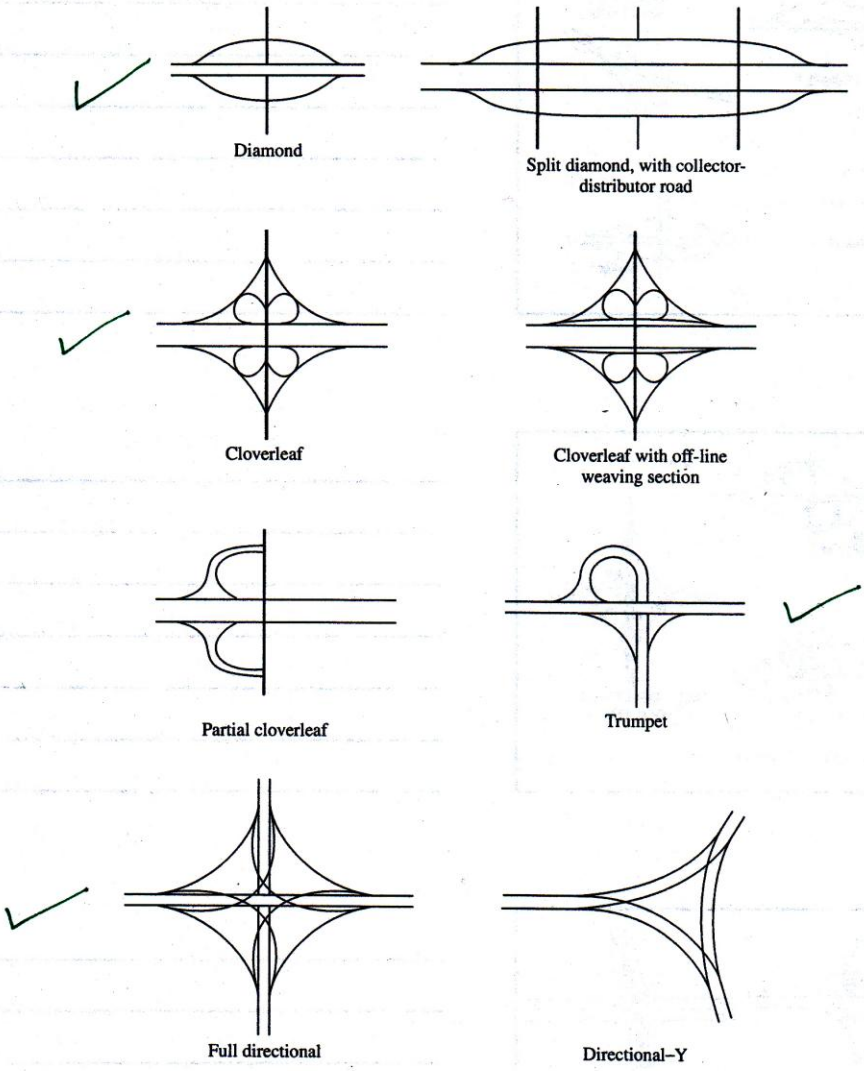
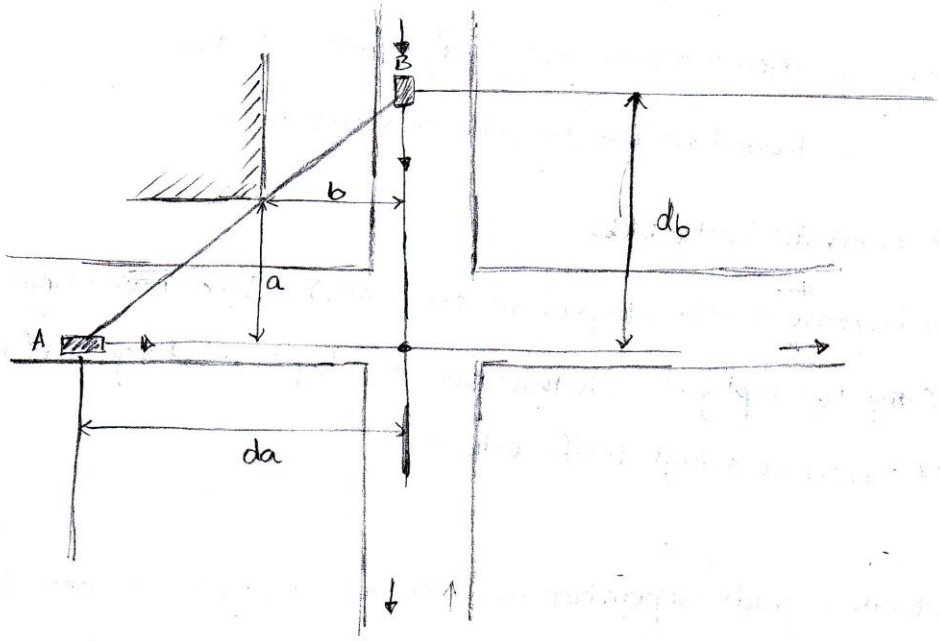


FIGURE 4.25
Interchange configurations.

Sight Distance of Intersection:-



$$\frac{d_b}{d_a} = \frac{a}{d_a - b} \rightsquigarrow d_b = a\left(\frac{d_a}{d_a - d_b}\right)$$

هنا نهمل مسافة الفرامل $SSD = d_r + d_b$ (breaking)

Example: A tall building is located (45) ft from the ℄ of the right lane of a local road (b in the figure), and (65) ft from the ℄ of the right lane (a in the fig) If the max. speed limit of the intersecting road is (35) mi/h. What should be the speed limit on the road to be such that the min sight distance is provided to allow the driver of approaching vehicles to avoide immenent collision by adjusting their speeds.

Sol: (see next page)

$a = 65\,ft$, $b = 45\,ft$

$$d_b = a\left(\frac{d_a}{d_a - b}\right) = 65\left(\frac{155}{155 - 45}\right) = 91.6\,ft$$

$$91.6 = 1.47 * V * 3 \rightarrow \frac{91.6}{3 * 1.42} = 20.8$$

Speed (mi/h)	Distance (ft)
10	45
15	70
20	90
25	110
30	130
35	155
40	180
50	220
60	260
70	310

$SSD = 1.47\ V\ t_r$

V: mi/h, t_r: assume 3sec

Drainage of city Streets:-

The surface of city streets is different from rural highways. Open drains cannot be used in city streets, they are ① unsightly, ② occupy more space, and ③ serve as a source of danger to the traffic, therefore underground drains ~~at~~ sewer are used

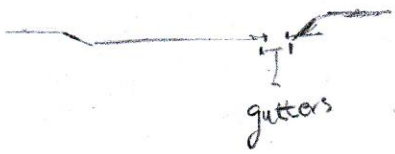
* The surface-water drainage system in a city is composed of the following:-

(1) Pavement Crown

(2) Curb & Gutters

(3) Inlets, Catch basins, and manholes

(4) Storm drains



① Pavement Crown:-

The crown should be as small as possible for appearance and safety.

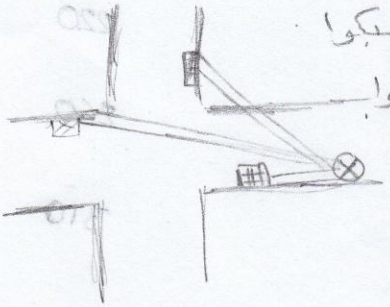
② Curbs & Gutters:-

Curbs and gutters are used in urban highways to protect pedestrians and facilitate drainage.

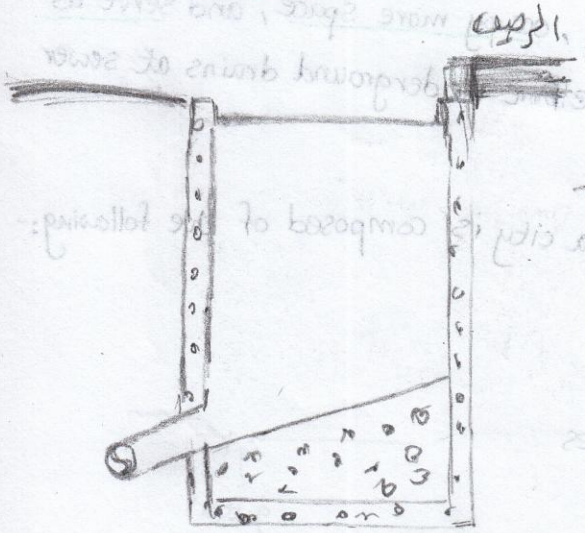
③ Inlets:-

Inlets are located by the sides of the road (30-60m) connected by manholes, the purpose of inlets is to collect storm-water in short period and there is no flooding.

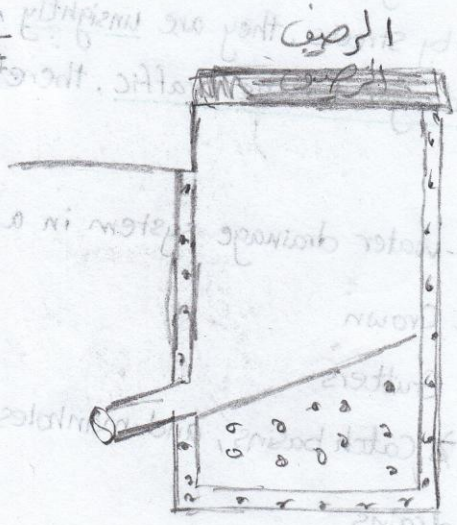
The Inlet is simply a concrete box, it may have an opening in the hor. direction, or in the ver. direction.



Horizontal



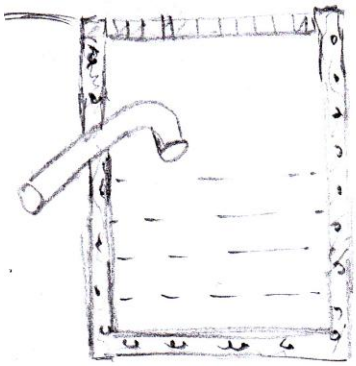
Vertical



* Inlets have only an outlet pipe (Circules) placed at the bottom (Flush) of the inlet. Inlets are subjected to clogging, the objects that cause trouble at the opening are sticks, waste, paper, leaves, depris, so they must be cleaned frequently.

(4) Catch basins:-

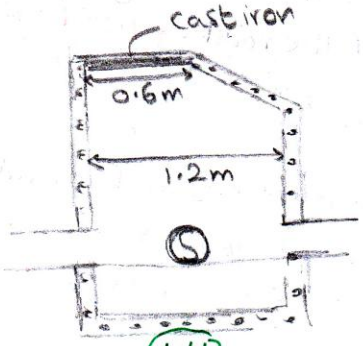
They are similar to inlets in their function and design, the difference is the outlet pipe is placed at some distance above the bottom of the chamber. The purpose of the catch basin is that debris flushed from the street is trapped at the bottom of the catch basin so that it doesn't enter the storm sewer. They need good maintenance. If silt built up and debris is not removed they function as inlets.



(5) Manholes:-

* Storm sewer systems are subjected to partial or complete clogging, and facilities must be provided for cleaning. Manholes are placed at points where the sewer changes grade, direction, where junctions are made and intermediate points (90-150m)

* The opening should be large enough to permit a man to enter the chamber and space in which he can work (1.2m) diameter. Manholes' covers are cast iron circular shaped (0.6m) diameter



Drainage and drainage structures:

Water is the major factor which contribute to the failure of hwys. Therefore adequate drainage is the most important consederation in locating and designing hwys and city streets.

* Highway structures that provide drainage are:

(1) Pavement Crown
(2) Inlets, Catch basins, Curbs } → Urban

(3) Shoulders & side slopes
(4) Bridges
(5) Longitudinal Ditches
(6) Culverts } → Rural

* **Side slopes and side ditches:-**

side ditches are provided along the hwy in rural roads (in cut sections). Avoid deep and narrow ditches (Dangerous). Grade for the ditch should be the same as the ℄ of the road → use Barriers.

* **Culverts:-**

The difference between a culvert and a bridge is the span's length

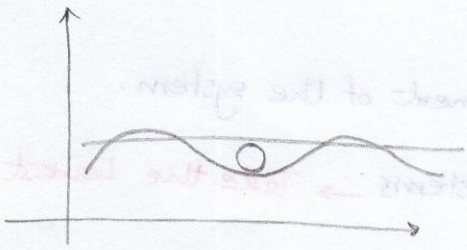
Span < 20 ft → is called culvert
Span > 20 ft → " " Bridge } → Rural Areas

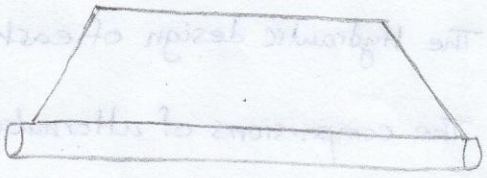
* Culverts are provided in three locations:-

(1) At the bottom of depression

(2) When natural streams intersect the roadway

(3) At location required for passing surface drainage carried in side ditches

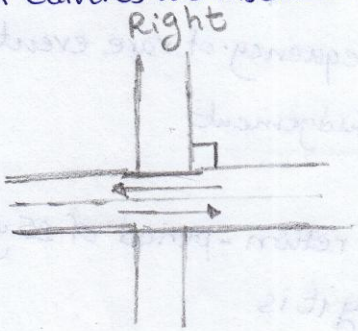


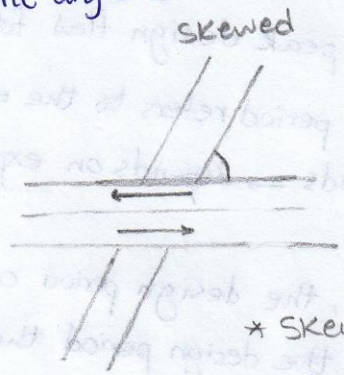


ممكن نعمل أحياناً أو
RipRap

* Shapes: Box, Circular, Arch, Pipearch

* Culverts are installed either at right angle or a skew





* skewed cost more *

* Culverts if possible should at right angle to reduce cost, the grade of culvert should conform to existing grade of the stream. If the grade is reduced this will cause sediment carried in the water deposited in the culvert and capacity will be reduced. Increasing the slope will increase the velocity hence it will cause errosion, protective measures are needed at the outlet.

* 2% for the culvert is the average

* The water speed is kept at resonable level. The speed of water should be between 1.5 m/s to 3 m/s

Design of Surface Drainage:

$Q = VA$

Q: Discharge

V: Flow speed

A: Cross sectional Area

* The design of surface system is divided into 3 phases:-

(1) An estimation of the quantity of water

(2) The Hydraulic design of each element of the system.

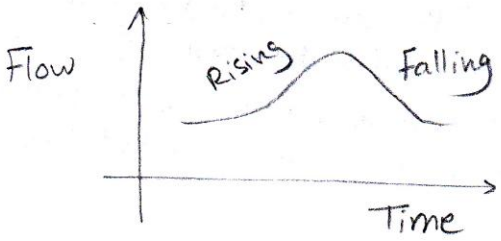
(3) The comparsions of alternative systems. → Take the Lowest Cost.

(1) Estimation of the quantity of water:-

- perform statistical analysis on the record stream flow to provide an estimated peak design flow for given - return period (الـ الـ الـ)

* The returned period refers to the estimated frequency of rare events such as floods → depends on experience & Judgement

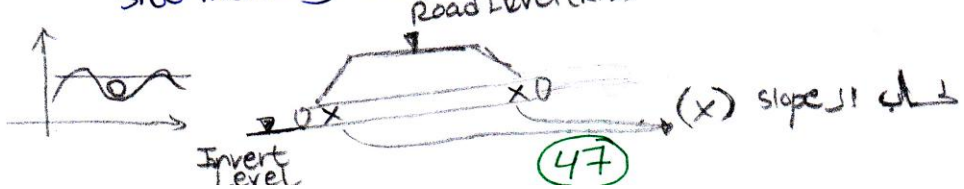
* for example, the design period could be for return - period of 25 years. The higher the design period the more costly it is



(2) The Hydraulic Design of Culvert:-

* The design procedure involves the following:-

(1) obtain all site data and plot a roadway cross section of the culvert site including the profile of the stream channel.



(2) Establish the culvert invert elevations at the inlet and outlet and determine the culvert's length and slope.

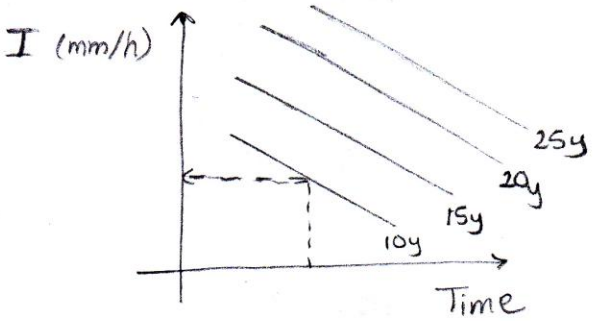
(3) Determine the allowable head water depth and the probable depth of tail water during the design flood

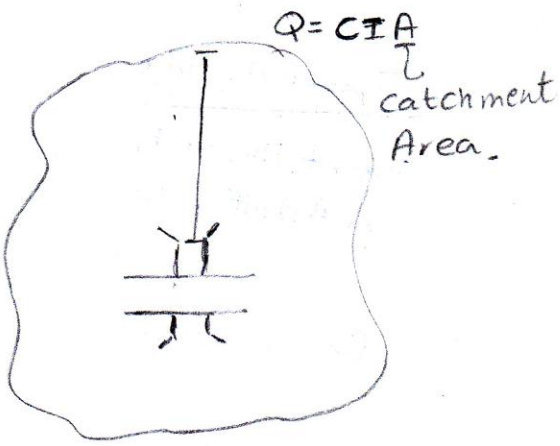
(4) Select a type and size of culvert and the design features.

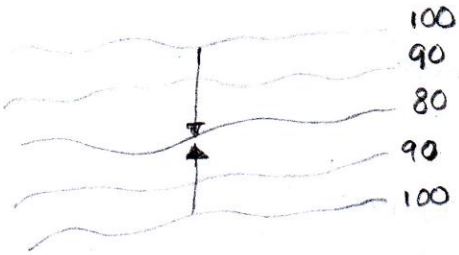
(5) Examine the need for energy dissipators and where needed provide protective devices → To prevent errosion (Wings, Rip Rap, ?)

Rainfall Intensity :-

The estimation of peak runoff for drainage design is accomplished by consediration of severe storms that occur at intervals which are greater than other times







In the design of hwy drainage system the duration chosen is the time of concentration, previous data is needed for estimation of intensity-frequency, and duration of rainfall to develop rainfall-intensity relationship.

- **Surface Runoff:**

The design of drainage must be provided for all rainfall that doesn't infiltrate the soil

The Infiltration depends on :-

(1) Type of soil

(2) Soil covers (الأشجار)

(3) M.C of the soil (Manning Coef.)

(4) Temperature of the air

(5) Slope of the surface

Type of drainage	Coeff. of runoff (C)
Cement, Pavement, or Asphalt surface	0.75 - 0.95
Gravel surface	0.25 - 0.6
Sandy Soil (Cultivated)	0.15 - 0.3
Clay Soil (Cultivated)	0.3 - 0.75
Urban Bussiness District	0.6 - 0.8
Urban Residential	0.5 - 0.7
Rural Residential	0.35 - 0.6

Surface Condition	Slope				
	0-3	4-7	8-10	11-15	16-20
Woodland	0.15 (m/s)	0.3	0.45	0.5	0.6
Pavement	1.5	3.65	4.7	5.5	—
Soil (Cultivated)	0.25	0.45	0.65	0.8	—

Average Runoff Water speed over Surface conditions for time concentration (m/s)

* The Rotational Method:-

The rotational method is used to estimate runoff from drainage area

$Q = CIA$

m^3/s ← Q, mm/h ← I, hectare ← A

Q = Run off (m^3/s)

C = Coeff. (The ratio of runoff to rainfall)

I = Intensity of rainfall

A = Drainage area in hectare

1 Hectare = 10 Donums = 10,000 m^2

A_1 C_1	A_2 C_2
A_3 C_3	A_4 C_4

$$\Sigma A = A_1 + A_2 + A_3 + A_4$$

$$C = \frac{C_1A_1 + C_2A_2 + C_3A_3 + C_4A_4}{\Sigma A}$$

* Design of culverts and Ditches:

$$Q = VA$$

$$V = \frac{R^{3/2} + S^{1/2}}{n} + - - -$$

Example: An Engineer plans to install a culvert under a collector type hwy to reduce flooding area. The drainage area is 9 hectares of soil cultivated in a rural residential area. Water in the drainage area flows on approximate 5% slope for 1215m before reaching the culvert. Estimate the discharge that can be expected at culvert. Use design period = 10 years

Sol:

From table $\longrightarrow$ speed = 0.45 m/s

$$T = \frac{1215\ m}{0.45\ m/s} = 2700\ sec = 45\ min$$

$Q = CIA$

$C = 0.6$ (From the table)

$I = 47\ mm/h$ (From the chart)

$$Q = \frac{0.6 * 47 * 9}{360} = 0.706\ m^3/s$$

* If the water flows at (1.5 m/s) in the pipe find the diameter of the pipe

Sol:

$Q = VA \longrightarrow 0.706 = 1.5 * A \longrightarrow A = 0.47 m^2$

dia $\rightarrow$ circular $\longrightarrow A = \pi r^2 \longrightarrow \frac{0.47}{\pi} = r^2 \longrightarrow r = 0.38\ m$

$\longrightarrow$ dia = 0.77 m.

The End