TRANSPORTATION ENGINEERING-I

GVPCE(A)

B.Tech (Civil Engineering, V Semester)

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UNIT:-1

HIGHWAY DEVELOPMENT AND PLANNING

HIGHWAY DEVELOPMENT IN INDIA:

VARIOUS STAGES:

1. Roads in ancient India.

2. Roads in Mughal period.

3. Roads in nineteenth century.

ROAD DEVELOPMENT PLANS:

4. Jayakar committee and recommendations (1927)

    - Introduced central road fund, IRC, Motor vehicle act.

5. Nagpur conference (1943)

    - Formed CRRI, National highway act.

6. Second 20 yr road development plan (1961-81)

    - Formed Highway research board.

7. National transport policy committee.

8. Third 20yr road development plan (1981-2001)

NECCESITY OF HIGHWAY PLANNING:

Objectives:

1. To plan a road network for efficient and safe traffic operation.

2. To arrive maximum utility.

3. To fix date wise priorities development.

4. To plan for future requirements and improvements.

5. To work out financing system.

CLASSIFICATION OF ROADS:

1. Based on usage during different seasons.
    - All weather roads
    - Fair weather roads
2. Based on type of carriage way.
    - Paved roads (eg: bitumen, concrete roads)
    - Unpaved roads (eg: earthen, gravel roads)
3. Based on pavement surfacing.
    - Surfaced roads
    - Unsurfaced roads

CLASSIFICATION OF ROADS BY NAGPUR ROAD PLAN:

1. National highways.
    - Connects major ports, capitals of larger states, larger industrial and tourist centres.
    - Constructed by centre.

Eg: NH-1: Delhi-Ambala-Amritsar

NH-2: Mumbai-Agra

2. State Highways.
    - Connects district head quarters and important cities.
    - NH, SH are designed for same speeds.
3. Major district roads.
    - Connects production centres and markets.
    - Its speeds are lower than NH, SH.
4. Other district roads.

- Connects market centres, taluk head quarters.
- Lower design specifications than MDR.

5. Village roads.
    - Connects villages and group of villages.

MODIFIED CLASSIFICATIN BASEDE ON THIERD ROAD DEVELOPMENT PLAN:

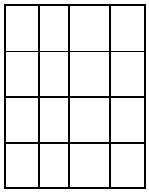
1. Primary system.
    - Express ways.
    - National highways (NH).
2. Secondary system.
    - State highways (SH).
    - Major district roads (MDR).
3. Tertiary system.
    - Other district roads (ODR).
    - Village roads (VR).

Classification of urban roads:-

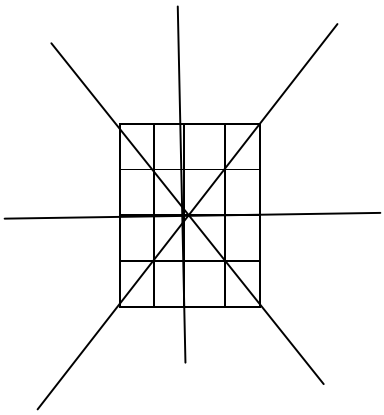
- Arterial.
- Sub-arterial.
- Collector streets.
- Local streets.

ROAD PATTERNS:

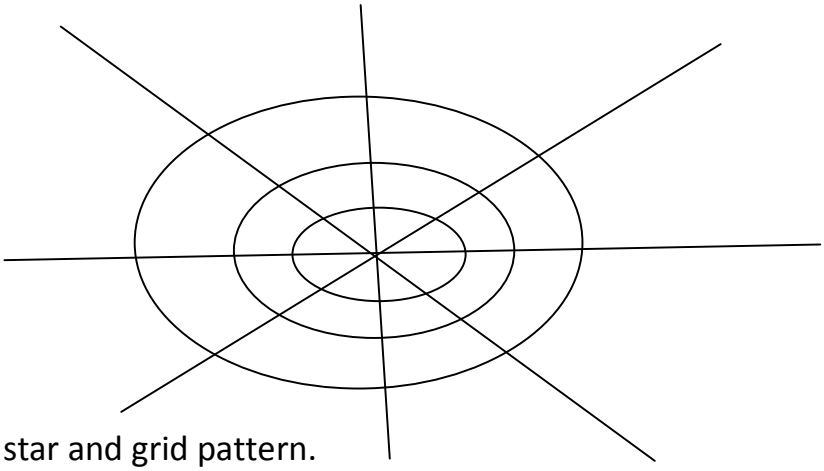
a. Rectangular or Block pattern.



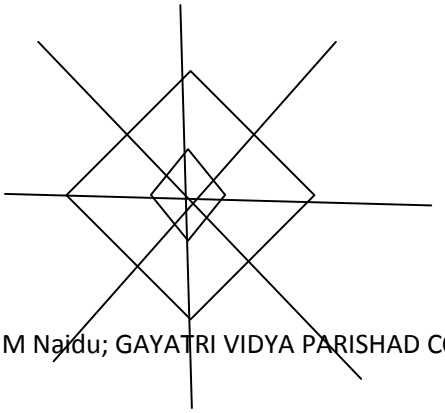
b. Radial or Star and Block pattern.



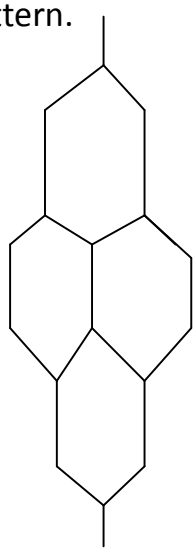
c. Radial or Star Circular pattern.



d. Radial or star and grid pattern.



e. Hexagonal pattern.



f. Minimum travel pattern

HIGHWAY ALIGNMENT:

Definition: The position or layout of the centre line of the highway line on the ground is called the alignment.

- Horizontal alignment includes straight path, horizontal deviations and curves.
- Vertical alignment includes gradients, vertical curves.

Improper alignment leads to

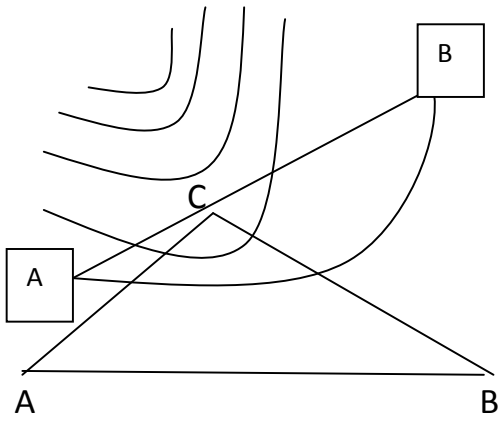
- Increase in construction cost.
- Increase in maintenance cost.
- Increase in vehicle operation rate.
- Increase in accident rate.

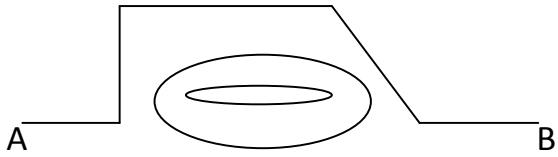
REQUIREMENTS OF ALIGNMENT:

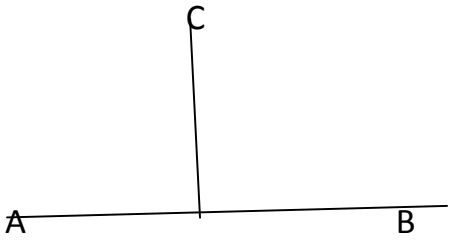
- Short
- Easy
- Safe
- Economical

FACTORS CONTROLLING ALIGNMENT:

a. Obligatory points







b. Traffic
    - Desire lines
c. Geometric Design
    - Geometric design factors such as gradient, radius of curvature and sight distance govern final alignment of highway.
d. Economy

- Finalized alignment should be economical.

e. Other considerations
    - Various other factors governs alignment are drainage considerations, hydrological factors and political considerations.

SPECIAL CONSIDERATIONS FOR HILLY AREAS

a) Stability

b) Drainage

c) Geometric standard of hill roads

ENGINEERING SURVEYS

a) Map study

-maps are available from survey of India.

- Alignment avoiding valleys, ponds or lakes.
- When the road has to cross a row of hills.
- Approximate location of bridge will be decided.

b) Reconnaissance

-details to be collected

- Valleys, ponds and lakes.
- Approximate values of gradient, length of gradient and radius of curvature.
- Number and type of cross drainage structures.
- Soil type along the routes.
- Sources of construction material, water.

c) Preliminary survey

Main objectives,

- To survey the various alternative alignments.
- To compare different proposals.
- To estimate quantity of earthwork materials.
- To finalize best alignment.

Surveys

1.) Preliminary traverse
2.) Topographical features
3.) Leveling work
4.) Drainage studies and hydrological data
5.) Soil survey
6.) Material survey
7.) Traffic survey
8.) Determination of final centre line

d.) Final location and detailed survey

DRAWINGS AND REPORT:

Drawings

- Key map
- Index map
- Preliminary survey plans
- Detailed plan and longitudinal section
- Detailed cross section
- Land acquisition plan
- Drawings of cross drainage
- Drawings of road intersection
- Land plan showing quarries

PROJECT REPORTS:

- General details of project
- Features of road

- Road design and specification
- Drainage facilities and cross drainage structure
- Material, labour and equipment
- Rates
- Construction programming
- miscellaneous

UNIT:-2

HIGHWAY MATERIALS

Highway materials:

- Bitumen
- Aggregate
- Soil

Soil is an integral part of the road pavement structure and it provides support to pavement from beneath

CHARACTERISTICS OF SOIL:

It is mainly of mineral matter formed by disintegration of rocks by action of water, frost, temperature and pressure

Based on grain size, soil is classified into

- Gravel
- Sand
- Silt
- Clay

DESIRABLE PROPERTIES OF SOIL:

- Stability
- Incompressibility
- Strength
- Minimum changes in volume
- Good drainage
- Easy of compaction

FACTORS AFFECTING SOIL STRENGTH

- Soil type
- Moisture content
- Dry density
- Internal structure of soil
- Type and mode of stress application

EVALUATION OF SOIL STRENGTHS

Tests are broadly divided into 3 groups

1) Shear tests
    - It is carried out on relatively small soil sample in laboratory.
    - No of samples need to be collected from different locations.
    - Some of the shear tests are direct shear test, tri-axial compression test, vane shear test etc.,
2) Bearing tests
    - These are loading tests carried out on sub-grade soils in-situ with load bearing area.

      Eg:- plate bearing test
3) Penetration tests
    - These are small scale bearing tests in which the size of the located area is relatively much smaller.

      (Penetration / size of loaded area) > (Penetration / size of loaded area)

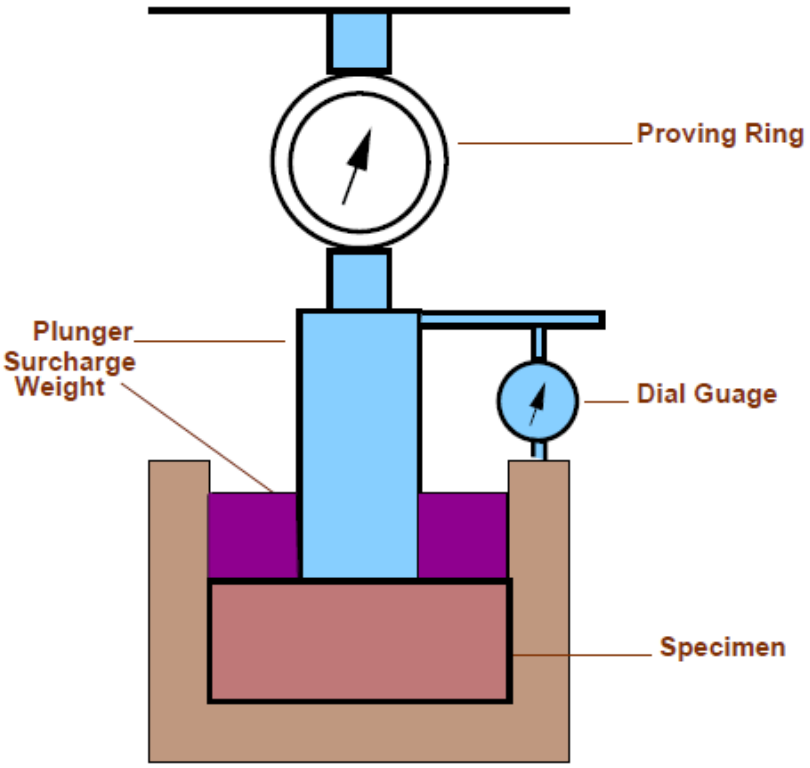
Penetration tests bearing tests

Eg:- California Bearing ratio test, cone penetration test

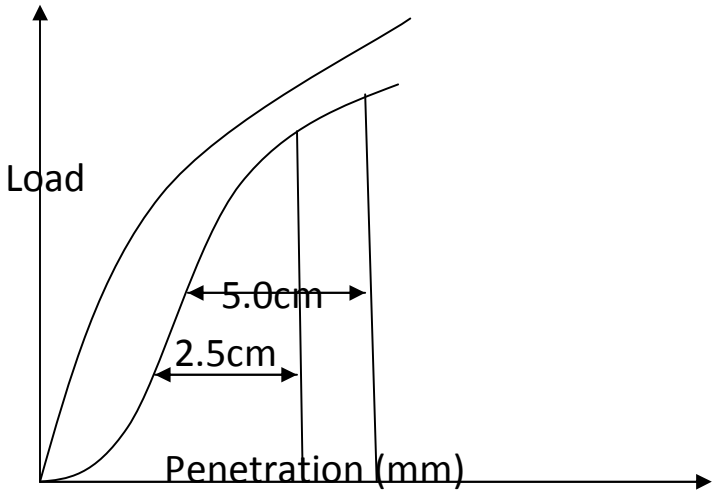
CBR test

CALIFORNIA BEARING RATIO TEST:

- It is developed by 12alifornia division of highways
- Penetration rate 1.25mm/min
- Local values are recorded at 2.5mm and 5.0mm
- Load values are noted of 0.0,0.5,1.0,1.5,2.0,2.5,3,4,5,7.5,10.0 and 12.5mm


Proving Ring
Plunger
Surcharge
Weight
Dial Guage
Specimen

CBR TEST


Load
5.0cm
2.5cm
Penetration (mm)

$$\text{CBR \%} = \frac{\text{load sustained by the specimen at 2.5 and 5.0mm}}{\text{Load sustained by standard aggregate at Corresponding penetration (1370kg at 2.5mm, 2055kg at 5.0mm)}}$$

STONE AGGREGATES:

- These form the major portion of pavement structure and prime material in pavement structure.
- Aggregate have to bear stresses occuring due to wheel loads.
- It also have to resist wear due to abrasive action of traffic
- These are used in pavement construction in cement concrete, bituminous concrete and other bituminous constructions.
- Properties of aggregate depends on properties of constitute material and nature of bond between them.

Aggregates

- Igneous
- Sedimentary
- Metamorphic

-Aggregates are specified based on grain size, shape, texture, and gradation.

DESIRABLE PROPERTIES OF ROAD AGGREGATE:

1) STRENGTH

- Aggregate should be sufficiently strong to withstand stresses due to traffic wheel load.
- It should resist wear and tear and to crushing

2) HARDNESS
   - The aggregates used in surface course are subjected to constant rubbing or abrasion due to moving traffic.
   - Abrasion is the rubbing of stones with other materials.
   - Attrition is the mutual rubbing of stones.
3) TOUGHNESS:
   - Aggregates are in the pavement are subjected to impact due to moving wheel loads. This resistance to impact is called toughness.
4) DURABILITY:
   - The stone used in pavement construction should be durable and should resist disintegration due to action of weather.
   - The property of the stones to withstand the adverse action os weather called soundness.
5) SHAPE OF AGGREGATES:-

Aggregates:

1) Rounded

2) Cubical

3) Angular or Flaky

4) Elongated

- Angular flaky and elongated particles will have less strength and durability compared with other

- Rounded aggregates are preferred than other due to low specific area.

6) ADHESION WITH BITUMEN:

- Aggregates should have less affinity to water than bitumen. Otherwise bituminous coating on aggregate will be stripped off.

TESTS FOR ROAD AGGREGATE:-

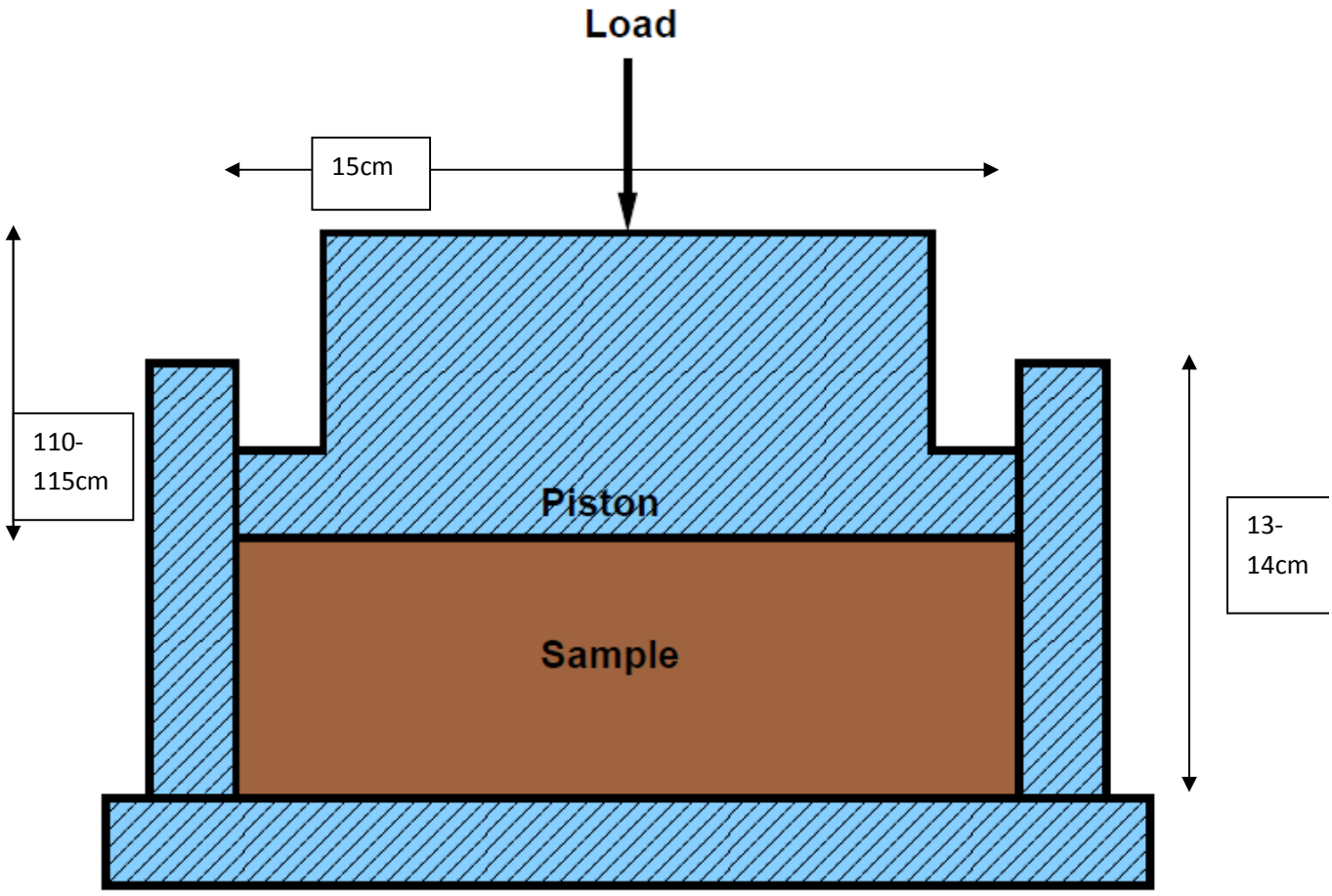
- Tests are required to know the suitability of aggregate for road construction. The following are the tests for aggregate.
  a) Crushing test
  b) Abrasion test
  c) Impact test
  d) Soundness
  e) Shape test
  f) Specific gravity and water absorption test
  g) Bitumen adhesion test

a) AGGREGATE CRUSHING TEST:-

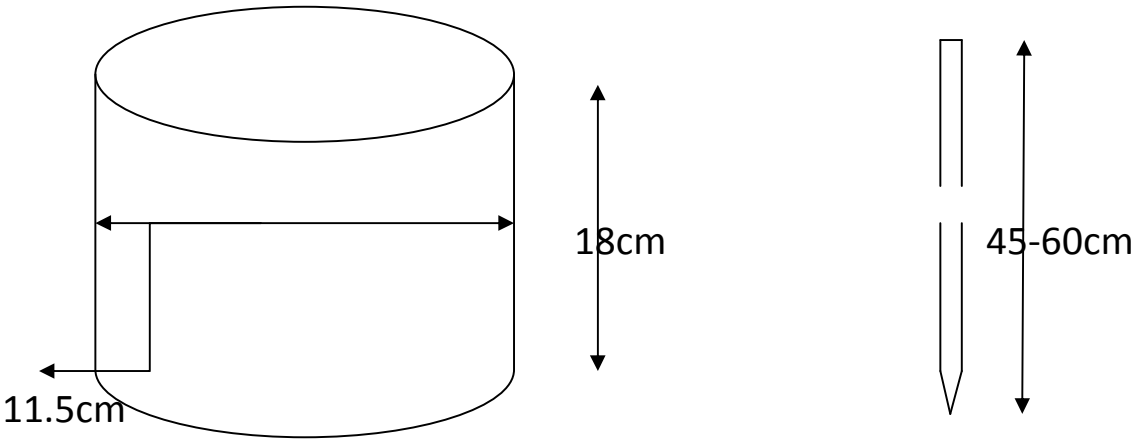
- Strength is assessed by this test.
- Aggregate crushing value provides relative measure of resistance to crushing under gradually applied compressive load.
- Low crushing value is preferred for construction.

Apparatus for standard test are:

Steel cylinder 15.2cm diameter with a base plate &plunger, compression testing machine, cylinder measure of diameter 11.5cm and height 18cm, tamping rods and sieves.



CRUSHING TEST APPARATUS



Cylindrical measure

Steel tamping rod

1) Aggregate size <12.5mm&>10mm is taken.

2) Aggregate filled in cylinder measure in 3 layers, each layer is ramped with 25 times by tamping rod.
3) The weighed, w1 (g) and placed in test cylinder in 3 layers with 25 blows each time.
4) Load is applied through plunger (40tonnes) at rate of 4tonnes/min by compression machine.
5) The crushed aggregate is sieved on 2.36mm sieve
6) The crushed material which passed through 2.36mm are weighed (w2 g).

   Aggregate crushing value = w2/w1*100

   For Base course <= 45%

   Surface course <=30%.

b) <u>ABRASION TESTS:-</u>

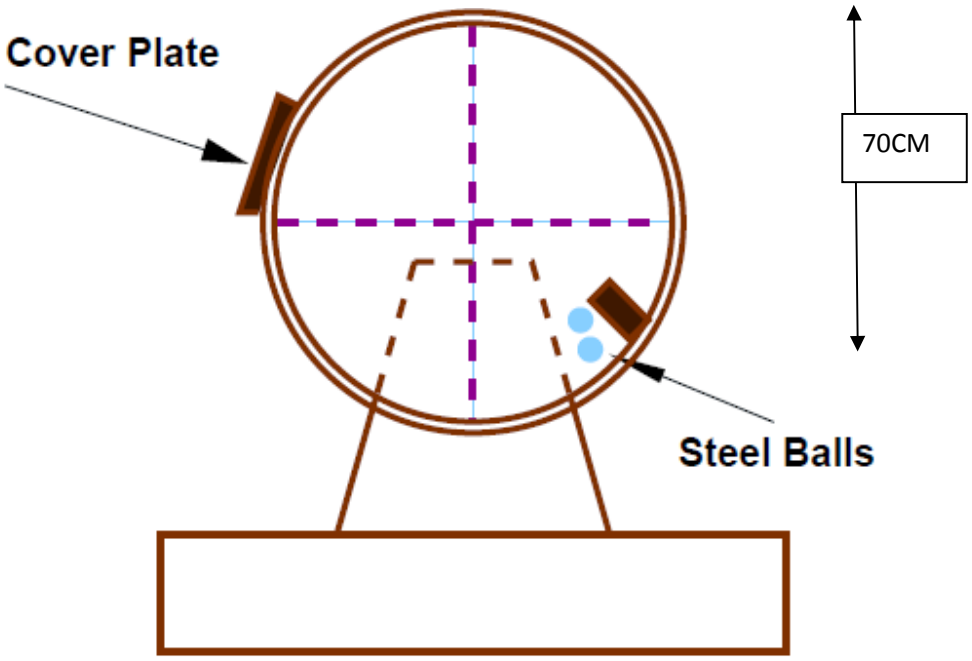
- Due to movement of traffic, the road stones in the surface course are subjected to wearing action.
- Road stones should be hard enough to resist abrasion action.

  Abrasion test can be carried out by following 3 tests:

  1) Los angeles abrasion test
  2) Deval abrasion test
  3) Dorry abrasion test

<u>LOS ANGELES ABRASION TEST:</u>

1) Steel balls are used as abrasive charge.
2) Machine consists of a hollow cylinder having 70cm diameter, length 50cm.



LOS ANGELES ABRASION TEST

3) Abrasive charge consists of cast iron spheres of approximates 4.8cm and each weight 390 to 445g.
4) 5-10 kg aggregate is taken and placed in cylinder w1 g.
5) Cylinder is rotated at a speed of 30-33 rpm for about 500-1000 revolutions.
6) Then the aggregate is sieve 1.7mm sieve.
7) Powder is weighed w2 g

Abrasion value = w2/w1*100

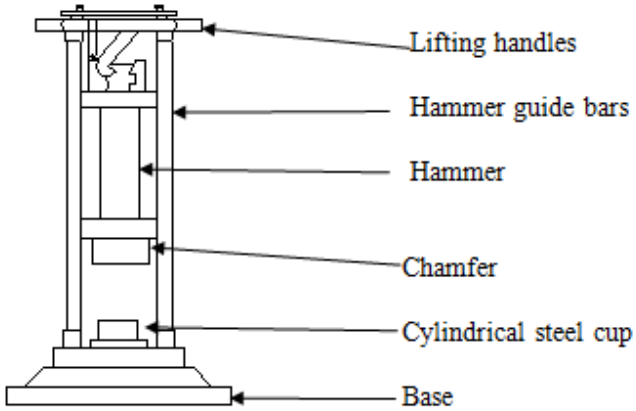
Base course <50%

DEVAL ABRASION TEST:

30-33 rpm, 10000 revolutions

IMPACT TEST:-

- It is a test designed to evaluate the toughness of stone
- It is the resistance of aggregate to fracture under repeated impacts.



IMPACT TEST APPARATUS

- Aggregate >10mm&<12.5mm
- 3 layers, each layer with 25 blows
- Test specimen is subjected to 15 blows
- Sieved through 2.36mm sieve

Impact value = [fines formed/total weight of sample]

<35% for bituminous macadam

<40% for water band macadam

SOUNDNESS TEST

- It is to study the resistance of aggregate to weathering action, by conducting accelerated weathering test cycles.

- It is the resistance to disintegration of aggregate by using saturated solution of sodium sulphate (or) magnesium sulphate
- Take clean, dry aggregate specimen of specified size range and is weighed and counted.
- It is immersed in sodium sulphate (or) magnesium sulphate for 16-18 hours.
- It is dried in oven at 105-110˚c.
- Again immerse in chemical solution & dry it.
- Repeat this for 10 cycles.
- Check the weights of aggregates
  Avg loss in weight ≤ 12% (for sodium sulphate)
  ≤ 18% (for magnesium sulphate)

SHAPE TESTS:

- This is conducted to determine percentage of flaky and elongated particles.
- The elevation of shape of the partical made in terms of flakiness index, elongation index and angularity number.

SPECIFIC GRAVITY AND WATER ABSORPTION TEST

- Specific gravity is considered to measure the quality and strength of material.
- Stones having low specific gravity are weaker.
- Stones having higher water absorption are weak.

STEP: 1 - Take about 2 kg of dry aggregate and is placed in wire bucket and is immersed in 24 hours.

STEP: 2- the sample is weighed in water and buoyant weight is found.

Aggregate is dried in oven for 24 hours at a temperature of 100-110˚c and then dry weight is determined.

- Specific gravity = [dry weight of aggregate/weight of equal volume of water]
  =2.6-2.9
- Water absorption = [water absorbed/oven dried weight of aggregate]
  ≤0.6%

BITUMEN MATERIALS:

- This is a binding material used in pavement construction.
- It is produced by distillation of petroleum crude where as tar is obtained by destructive distillation of coal or wood.
- Both bitumen, tar have similar appearance, bulk in color, but they have different characteristics.
- When the bitumen contains some inert material (or) mineral, it is called asphalt.
- The grades of bitumen used for pavement construction work for roads and airfields are called paving grades.
- The grades used for water proofing of structures and industrial floors etc., are called industrial grades.
  - Paving bitumen from assam petroleum, denoted as A-type and designed as grades A35, A90 etc.
  - Pavement bitumen from other sources denoted as S-type and designated as grades S35, S90 etc.

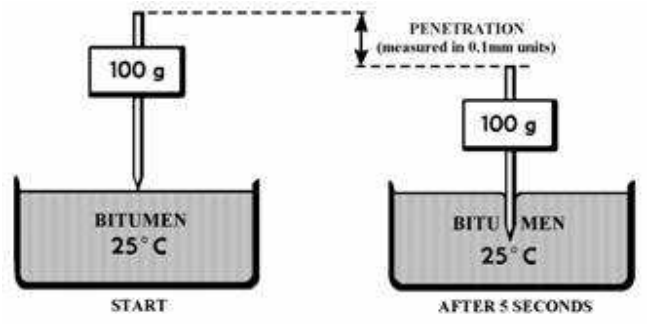
TESTS ON BITUMEN:

The various tests on bituminous material are

a) Penetration tests
b) Ductility tests
c) Viscosity tests
d) Float tests
e) Specific gravity test
f) Softening point test
g) Flash and fire point test
h) Solubility test
i) Spot test
j) Loss on heating test
k) Water content test

PENETRATION TEST:

- This test determines the hardness or softness of bitumen by measuring the depth in terms of millimeter vertically in 5 sec.



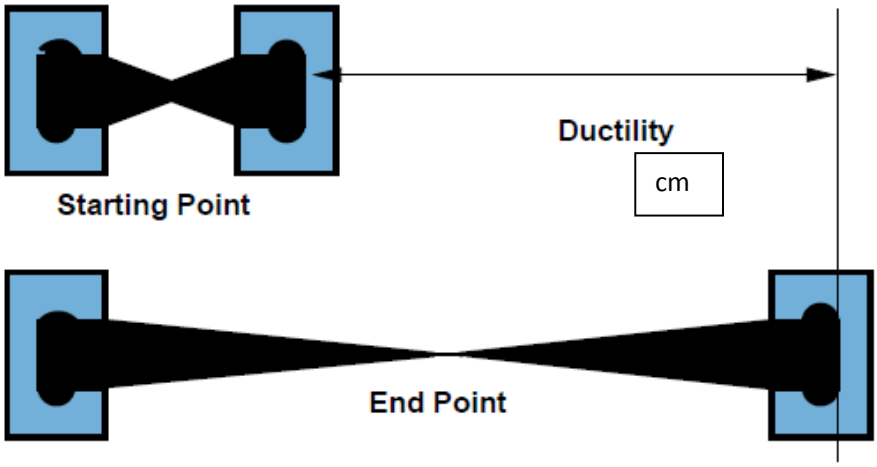
Sample is prepared and kept water at controlled temperature 25˚c

PENETRATION APPARATUS

- Keep dial gauge reading to zero (or) Note down the initial reading.
- Release weight for 5 sec.
- Note down final reading.
- Atleast three penetration values are need to be noted.
- After each penetration, needle should be cleaned with benzene and dried.
- The mean value of 3 measurements are taken as penetration value.
- The bitumen grade is specified in terms of penetration value. 80-100 (or) 80/100 grade bitumen means the penetration value of bitumen is in the range of 80-100 at standard conditions.

DUCTILTIY TEST:

DUCTILITY APPARATUS

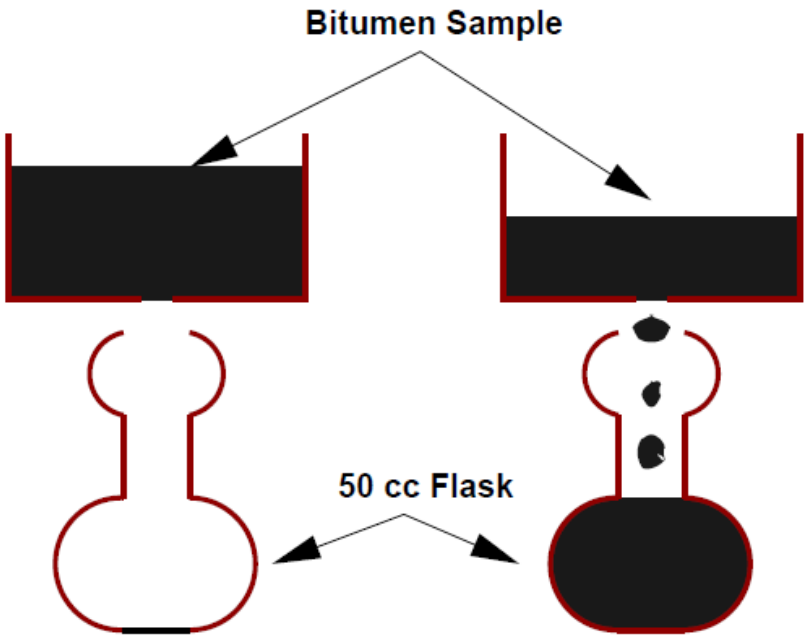


- Ductility is expressed as the distance in centimeter to which a standard briquette of bitumen can be stretched before the thread break.
- Test is conducted at 27˚c and at a rate of pull of 50m m per minute.
- The cross section at minimum width of the specimen is 10mm*10mm.

- The ductility machine functions as a constant temperature water bath with a pulling device at a pre-calibrated rate.
- Ductility values of bitumen vary from 5 to 100 for different grades.

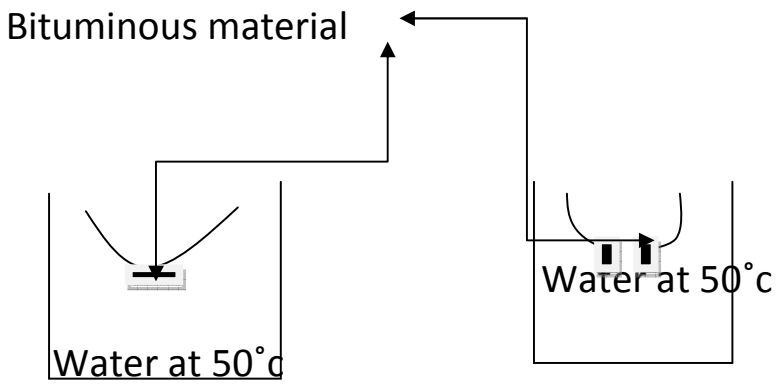
VISCOSITY TEST:

- Viscosity is defined as inverse of fluidity.



- It is fluid property of bituminous material
- It is measure of resistance of flow.
- Orifice type viscometer may be used to indirectly find the viscosity of liquid binder.
- Viscosity of tar is determined as the time taken in seconds for 50ml of the sample to flow through 10mm orifice.

FLOAT TEST:



Float test set up

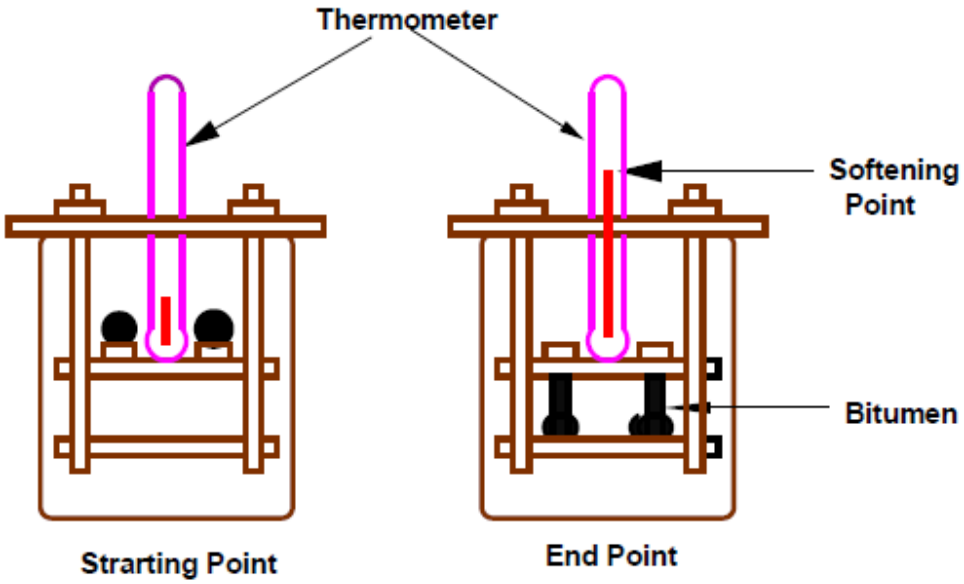
- The apparatus consists of a float material made of aluminium and a brass collar filled with specimen materials to be tested.
- The test specimen is filled in the collar, cooled to a temperature of 5˚c.
- The float assembly is floated in a water bath at 50˚c and the time required in seconds for water to force its way through the bitumen plug is noted as the float test value.
- Higher the float test value, the stiffer the material.

SPECIFIC GRAVITY TEST:

- The specific value of bitumen is useful in bituminous mix design.
- Increase amounts of aromatic type compounds (or) mineral impurities cause an increase in specific gravity.
- Specific gravity of bituminous materials is defined as the ratio of the mass of given value of substance to the same of an equal volume of water.
- Specific gravity is determined by pycnometer
- Generally, the specific gravity of pure bitumen is in range of 0.97 to 1.02.

SOFTENING POINT TEST:

- The softening is the temperature at which the substance attains a particular degree of softening under specified condition of test.
- This test is usually conducted by Ring and Ball apparatus.



SOFTENING POINT TEST

- Higher softening point indicates lower susceptibility.
- Softening point of various bitumen grades vary between 35˚c to 70˚c.

FLASH AND FIRE POINT TEST:

- Flash point of the material is the lowest temperature at which the vapour of substance momentarily takes fire in the form of flash.
- Fire point is the lowest temperature at which the material gets ignited and burns under specified conditions of test.

FLASH AND FIRE POINT APPARATUS

REQUIREMEMNTS OF BITUMEN MIXES:

- The mix design should aim at an economical blend, with proper gradation of aggregates and adequate proportion of bitumen so as to fulfill the desired properties of mix.
- The desirable properties of a good bituminous mix are stability, durability, flexibility, skid resistance and workability.
- Stability is defined as resistance of paving mix to deformation under load. It is the stress which causes specific strain.
- Stability is function of friction and cohesion
    - Friction: It is function of both inter particle friction and friction imparted by bituminous material.
    - Cohesion: It is mainly offered by factors that influence the mass viscosity of bitumen binder.
- Durability is defined as the resistance of mix against weathering and abrasive action.
- Flexibility is a property of the mix that measures the level bending strength.
- Skid resistance is defined as the resistance of the finished pavement against skidding and is a function of surface texture and bitumen content.
- Workability is the ease with which the mix can be laid and compacted. It is the function of grade, shape and texture of aggregate and bitumen content.

MIX DESIGN REQUIRES FOLLOWING PROPERTIES:

- Sufficient stability to satisfy service requirements of the pavement and traffic conditions, without undue displacements.
- Sufficient durability by coating aggregates and bonding them together and also by water-proofing the mix.
- Sufficient voids in the compacted mix.
- Sufficient flexibility even in the coldest season to prevent cracking due to repeated application of traffic load.
- Sufficient workability while placing and compacting the mix.
- The mix should be the most economical one that would produce a stable, durable, and skid resistant pavement.

Other tests on bitumen are:

(a) Solubility test(weight of insoluble material/weight of original sample)

(b) Spot test (to test over-heated bitumen)

(c) Loss on heating (loss in weight due to heating)

(d) Water content test.

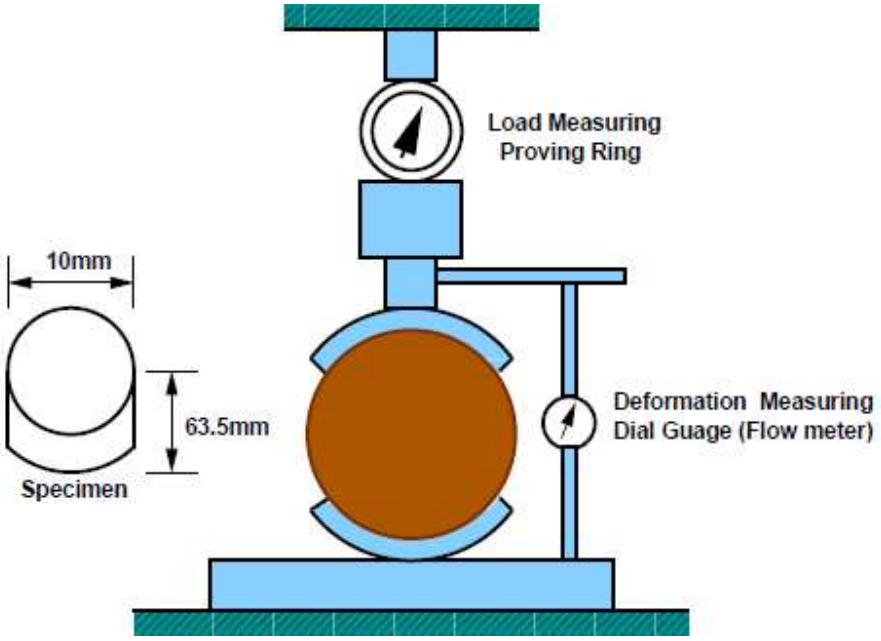
MARSHALL METHOD OF BITUMINOUS MIX DESIGN:

- Marshall, formerly bituminous engineer with Mississipi State Highway Department formulated this method.
- In this method, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measured

when the same loaded at the periphery at a rate of 5cm/min.

- There are two major features of Marshall method of designing mixes, namely:
  (1) Density void analysis, and
  (2) Stability flow test.
- Stability of the mix is defined as a maximum load carried by a compacted specimen at a standard test temperature 60˚c.
- Flow is measured as the deformation in units of 0.25mm between no load and maximum load carried by the specimen during stability test.
- Approximately 1200 g of mixed aggregates and the filler are taken and heated to a temperature of 175˚c to 190˚c.
- The bitumen is heated to a temperature of 121˚c to 145˚c and required quantity of the first trial percentage of bitumen (say 3.5% or 4% by weight of material aggregate) is added to the heated aggregates and thoroughly mixed at the desired temperature of 154˚c to 160˚c.
- Apparatus consists of 10.16cm diameter and 6.35 cm height, with a base plate and a collar.
- A compaction pedestal and hammer are used to compact a specimen by 4.54kg weight with 45.7cm height of fall.
- The mix is placed in preheated mould and compacted by rammer with 50 blows on either side.

- The compacted specimens are cooled to room temperature and then extracted from the mould with the help of specimen extractor.
- Three or four specimens may be prepared using each trial bitumen content.
- The diameter and mean height of specimen are measured and they are weighed in air and water.
- The specimen are kept immersed in water in thermostatically controlled water bath at 60˚c for 30-40 min.
- Specimens are taken one-by-one, placed in Marshall test head and tested to determine Marshall's Stability value and flow value.
- Load is applied on its periphery perpendicular to its axis in a loading machine of 5tonnes capacity at a rate of 5cm/min.
- Dial gauge fixed to the guide rods acts as a flow meter to measure the deformation of the specimen during loading.
-



- Correction factor should be applied to Marshall's Stability value, the average height of specimen is not exactly 63.5mm.
- Same above procedure is applied with other bitumen content with increment of 0.5%, upto about 7.5%-8% bitumen by weight of total mix.

Percentage of air voids, $V_v = (G_t - G_m)/G_m * 100$

Here G_m= bulk density (or) mass density of the specimen.

G_t= theoritical specific gravity of mixture.

$$G_t = 1000/ ((w1/g1) + (w2/g2) + (w3/g3) + (w4/g4))$$

Where

W1= percentage by weight of coarse aggregate in to total mix.

W2= percentage by weight of fine aggregate in total mix.

W3= percentage by weight of filler aggregate in total mix.

W4= percentage by weight of bitumen in total mix.

G1=apparent specific gravity of coarse aggregate.

G2=apparent specific gravity of fine aggregate.

G3=apparent specific gravity of filler aggregate.

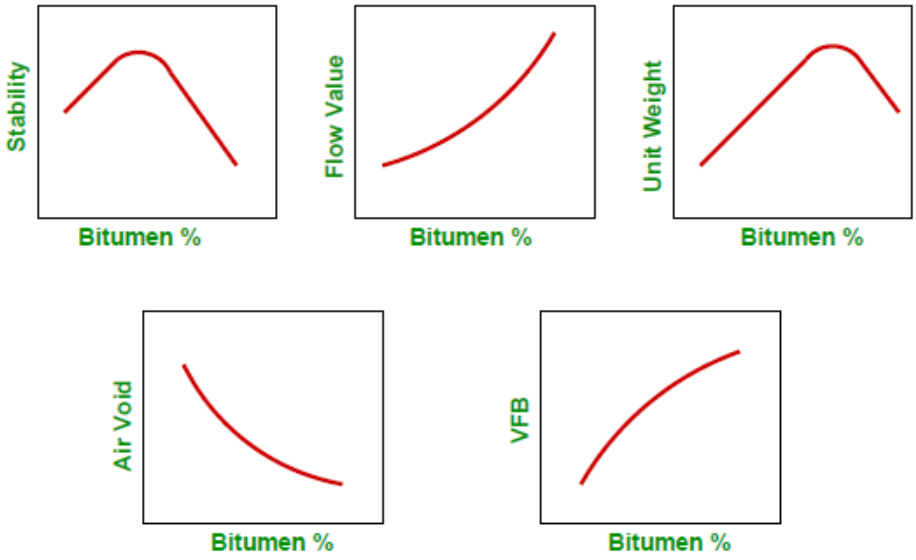
G4=apparent specific gravity of bitumen aggregate.

Percent voids in mineral aggregate (VMA)

$$VMA=V_V+V_B$$

Where volume bitumen $V_B= G_M* (W4/G4)*100$

$$VFB= (V_B/VMA)*100$$



Optimum bitumen content is prepared by following methods.

- Bitumen content corresponding to maximum stability.
- Bitumen content corresponding to maximum unit weight.
- Bitumen content corresponding to 4% Air voids in total mix.

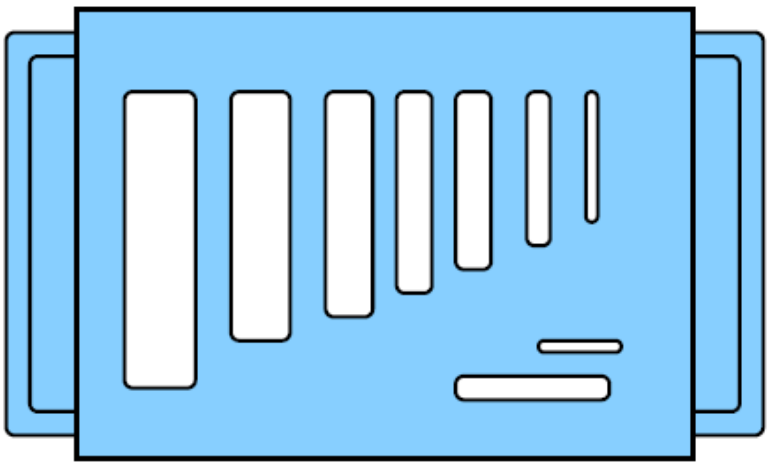
MARSHALL MIX DESIGN CRITERIA FOR BITUMINOUS CONCRETE:

Test property	Specific value
1) Marshall stability, kg	340 (minimum)
2) Flow value, 0.25mm units	8 to 16
3) Voids in total mix, V_v %	3 to5
4) Voids filled with bitumen, VFB %	75 to85

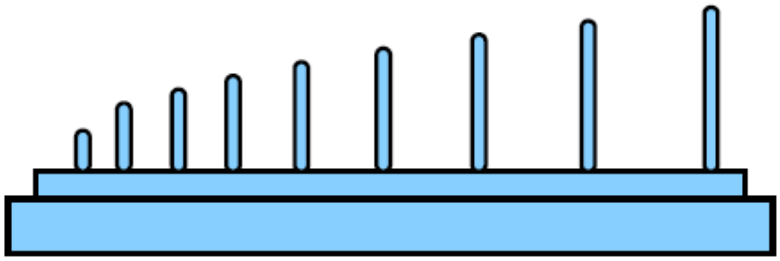
- Mixes with very heavy stability values and low flow values are not desirable as it develops cracks easily.

SHAPE TEST OF AGGREGATE:

- This test is performed to calculate flakiness index, elongation index.
- Flakiness index aggregates is the percentages by weight of particles whose least dimension is less than three-fifth (0.6) of their dimension.
- Elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four-fifth (1.8 times) their mean dimension.



FLAKINESS INDEX



ELONGATION INDEX

Size of aggregate		Weight of fraction consisting of atleast 200 pieces, g	Thickness gauge size mm (s1+s2)* (0.6/2)	Weight of aggregate passing thickness gauge, g	Length gauge size mm 1.8((s1+s2)/2)	Weight of aggregate retained on length gaug
Passing through IS sieve	Retained on IS sieve					
63	50	W1	33.9	w1	101.7	---
50	40	W2	27	W2	81	X1
40	25	W3	19.5	W3	58.5	X2
31.5	25	W4	16.95	W4	50.85	---
25	20	W5	13.5	W5	40.5	X3
20	16	W6	10.8	W6	32.4	X4
16	12.5	W7	8.55	W7	25.65	X5
12.5	10	W8	6.75	W8	20.25	X6
10	6.3	W9	4.89	W9	14.67	X7

Flakiness index = ((w1+w2+w3+……)/ (W1+W2+W3+……))*100

Elongation index = ((x1+x2+x3+….)/ (W1+W2+W3+……))*100

In pavement construction, flaky and elongated particles are to be avoided.

UNIT: 3

HIGHWAY GEOMETRIC DESIGN

Importance of geometric design:

- Geometric design of highway deals with dimensions and layout of visible features of highway such as sight distances and intersections.
- Geometrics are designed to provide optimum efficiency in traffic operations with maximum safety at reasonable cost.

Geometric design of highways deals with following elements:

1) Cross section elements.
2) Sight distance considerations.
3) Horizontal alignment.
4) Vertical alignment.
5) Intersection elements.

DESIGN CONTROLS AND CRITERIA:

- Geometric design of highway depends on several factors. The important of these factors are:
  a) Design speed.
  b) Topography.
  c) Traffic factors.
  d) Design hourly volume and capacity.

e) Environmental and other factors.

a) Design speed:

- It is the important factor which controls the geometric design.
- Design speed is decided based on the category of the road. i.e NH, SH, MDR, ODR and VR.
- Urban roads have different set of design speeds.
- Design of almost all the elements of the highway dependent on design speed.
- Width of the road, sight distance requirements, the horizontal alignment elements such as radius of curve, super elevation, transition curve length and vertical alignment elements such as valley, summit curve lengths-all these depend mainly on design speed.

b) Topography:

- Topography plays vital role in geometric design.
- Based on topography, the longitudinal slopes are provided.
- In hilly terrain, it is necessary to allow for steeper gradients and sharper horizontal curves.

c) Traffic factors:

- The factors associated with traffic are vehicle characteristics and human characteristics.
- The different vehicle classes such as bus, car, truck, motor cycles have different speeds and acceleration characteristics apart from having different dimensions and weights.

- Important human factors which affect traffic behavior include physical, mental and psychological characteristics of driver and pedestrian.

d) Design hourly volume and capacity:
   - Traffic keeps on changing in peak and in off-peak periods.
   - It experiences highest in peak and low in off-peak periods.
   - It is uneconomical to design roadway for peak period. So, a reasonable value of traffic volume is decided for design and this is called design hourly volume.
   - The ratio of volume to capacity reflects the level of service of road.

e) Environmental and other factors:
   - The environmental factors such as aesthetics, landscaping, air pollution, noise pollution should be considered while designing road geometrics.

HIGHWAY CROSS SECTION ELEMENTS:

PAVEMENT SURFACE CHARACTERISTICS:

- The important surface characteristics of the pavement are friction, unevenness, light reflecting characteristics and drainage of surface water.

Friction

- When a vehicle negotiates a horizontal curve, the lateral friction developed counteracts the centrifugal force and thus governs the safe operating speed.

- Skid: when the path travelled by the vehicle is more than circumferential movement, then it is called skid.
- Slip: when the wheel revolves more than the corresponding longitudinal movement along the road.

Factors affecting friction (or) skid resistance:

a) Type of pavement surface (C.C, WBM, Earth surface etc)
b) Macro-texture.
c) Condition of pavement(wet, dry)
d) Type and condition of tyre.
e) Speed of vehicle.
f) Brake efficiency.
g) Load and tyre pressure.
h) Temperature of tyre and pavement.
i) Type of skid.

PAVEMENT UNEVENNESS:

- Higher operating speeds are possible on even pavement surface than on uneven and poor surfaces.
- Bump integrater is commonly used to measure pavement surface condition in terms of unevenness index.
- Unevenness index is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of road.

  Good - 150cm/km.
  Satisfactory – 250cm/km
  Uncomfortable – 350cm/km

FACTORS CAUSING UNEVENNESS:

a) Inadequate compaction of sub aggregate.
b) Un-scientific construction practices.
c) Use of inferior material.
d) Use of improper machinery.
e) Improper surface drainage.
f) Poor maintenance practices.
g) Localized failures.

LIGHT REFLECTING CHARATERISTICS:

- Night visibility depend on light reflecting characteristics of pavement surface.
- Glare caused on wet pavement surface is more than dry surface.

CROSS SLOPE (or) CAMBER:

- It is the slope provided to the road surface in transverse direction to drain off rain water from road surface.

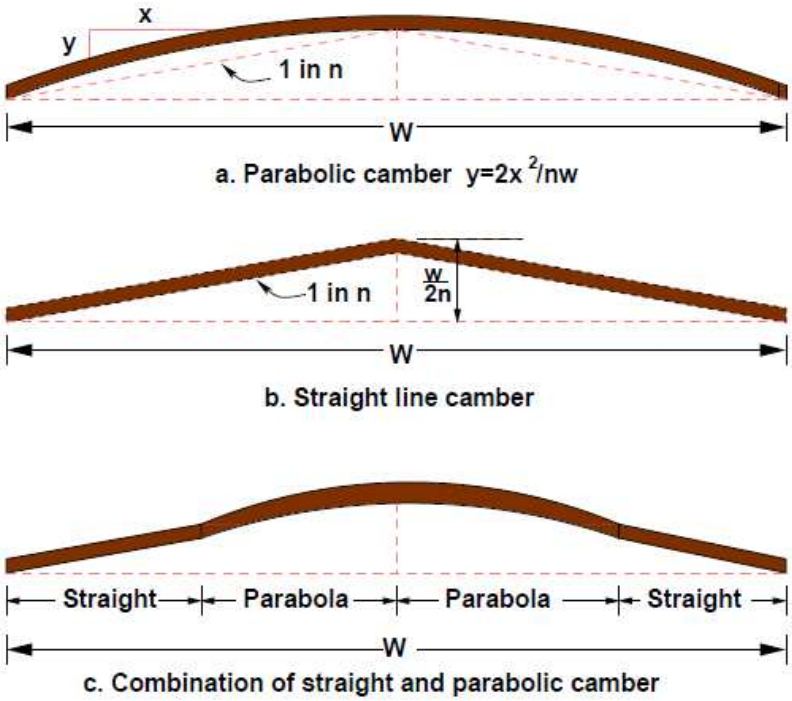
Cross slope is important due to following reasons:

- To prevent the entry of surface water into the sub-grade soil.
- To prevent entry of water in to bituminous pavement layers.
- To remove the rain water from pavement surface.
  - It is denoted in 1 in ‘n’ and x%.
  - Flat camber of 1.7 to 2.0% is sufficient.

Too steep cross slope in undesirable because of following reasons:-

1) Transverse tilt of vehicles causing uncomfortable side thrust.
2) Discomfort.
3) Problems of toppling.
4) Formation of cross ruts.

SHAPE OF CROSS SLOPE:



Different types of cambers

Type of road surface	Range of camber in areas of rainfall range	
	Heavy	Light
Cement concrete and high type of bituminous surface	2%	1.7%
Thin bituminous surface	2.5%	2%
Water bound macadam, and gravel pavement	3%	2.5%
Earth	4%	3%

Problem

Example:-

In a district where the rainfall is heavy, major district road of WBM pavement, 3.8m wide, and state highway of bituminous concrete pavement, 7.0m wide are to be constructed. What should be the height of crown with respect to the edges in these two cases?

Solution:

For WBM road, slope is 1 in 33

$Y= (2*x^2/nw)$

At x=w/2,

$Y= 2*(w^2/4nw) = w/2n= (38/66)= 0.058m$

For bituminous concrete road,

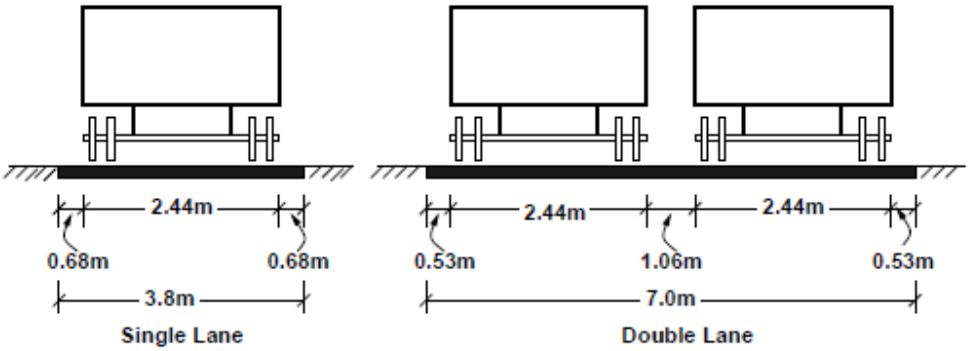
Slope is 1 in 50

$Y= (2*x^2/nw)= (w/2n) = (7/2*50)= 0.07m$

WIDTH OF PAVEMENT OR CARRIAGE WAY :-

- It depends on width of traffic lane and no. of lanes.
- The carriageway intended for one line of traffic movement is called as traffic lane.

Class of road	Width of carriage way
Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5



TRAFFIC SEPERATOR (OR) MEDIANS:-

- The main function of traffic separator is to prevent head-on collision between vehicles moving in opposite directions on adjacent lanes.

It may also helps to

1) Channelise traffic in to streams at intersection

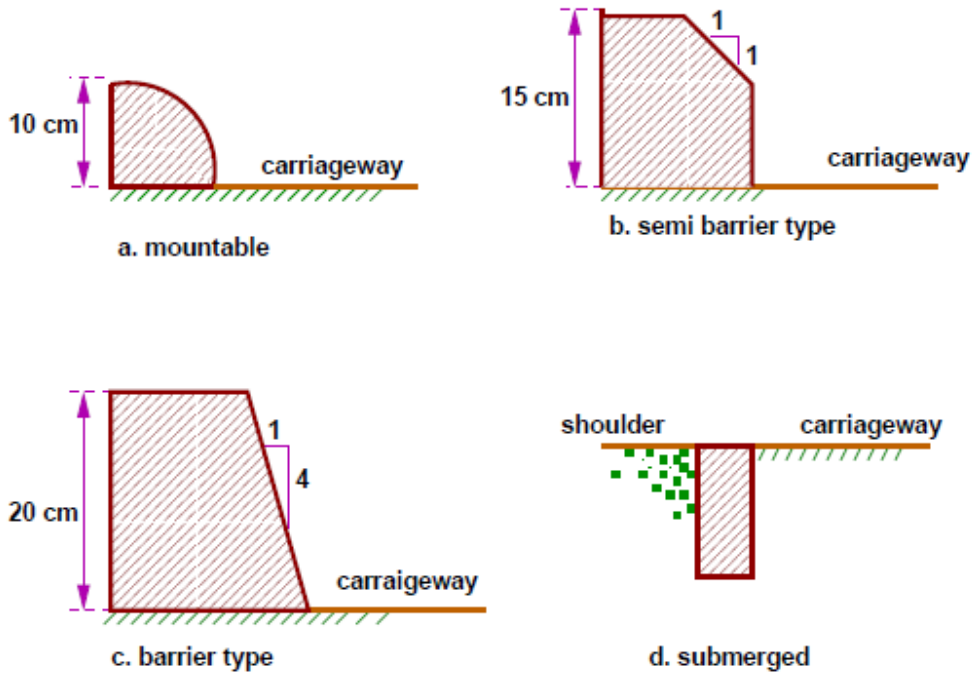
2) Shadow the crossing and turning traffic
3) Segregate slow traffic and to protect pedestrians.

IRC recommends a minimum desirable width of 5.0 m for medians of rural highways, which may be reduced to 3.0m where land is restricted.

On long bridges the width of the median may be reduced up to 1.2 to 1.5m

KERB:

- It indicates the boundary between the pavement and shoulder (or) island (or) footpath (or) kerb parking.



Different types of kerbs

1) low (or) mountable type kerbs

2) Semi-barrier type kerbs
3) Barrier type kerb
4) Submerged kerbs

Road margins:

The various elements included in the road margins aree shoulders, parking lane, frontage road, drive way, cycle track, footpath, guard rails.

Width of roadway (or) formation:

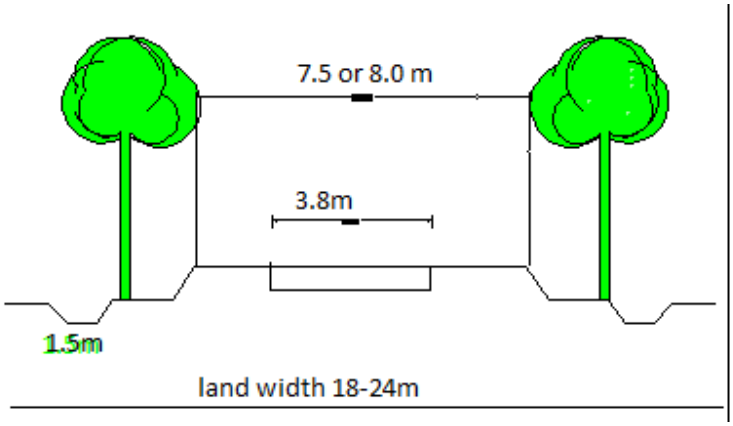
- it is the sum of widths of pavements (or) carriage way including separators and the shoulders.
- It is the top width of highway embankment (or) bottom width of highway cutting.

Right of way:

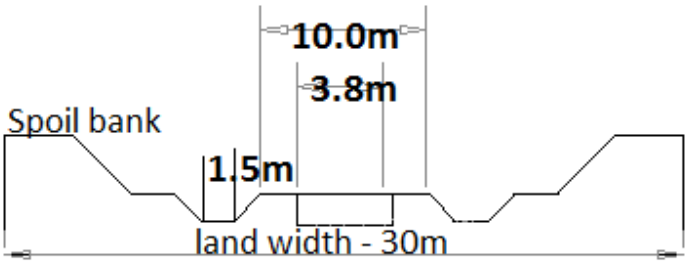
- It is the area of land acquired for the road, along its alignment.
- The recommended land widths for different classes for urban roads.

Arterial	50-60m
Sub arterial	30-40m
Collector	20-30m
Local streets	10-20m

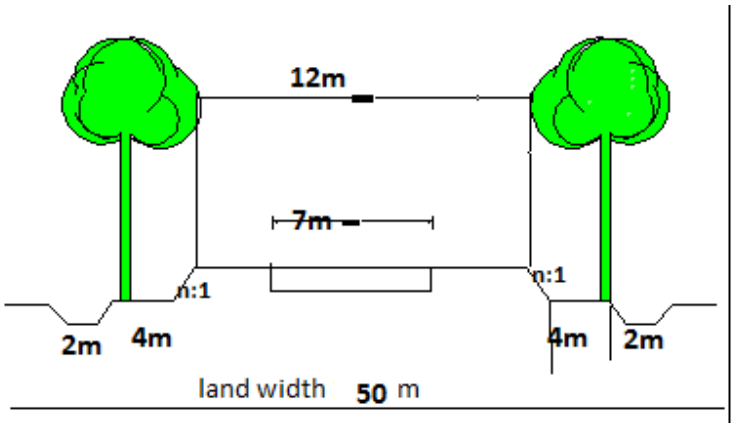
Cross sections:-



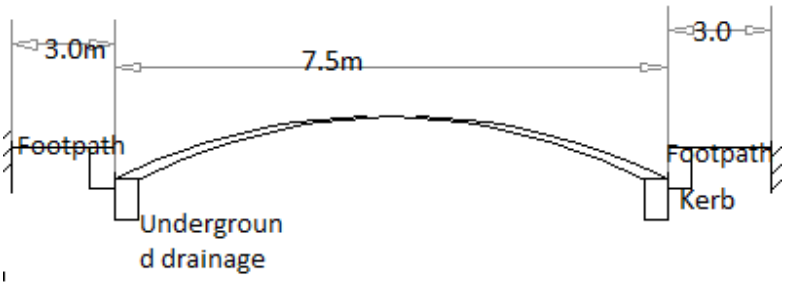
c/s of VR (or) ODR in embankment



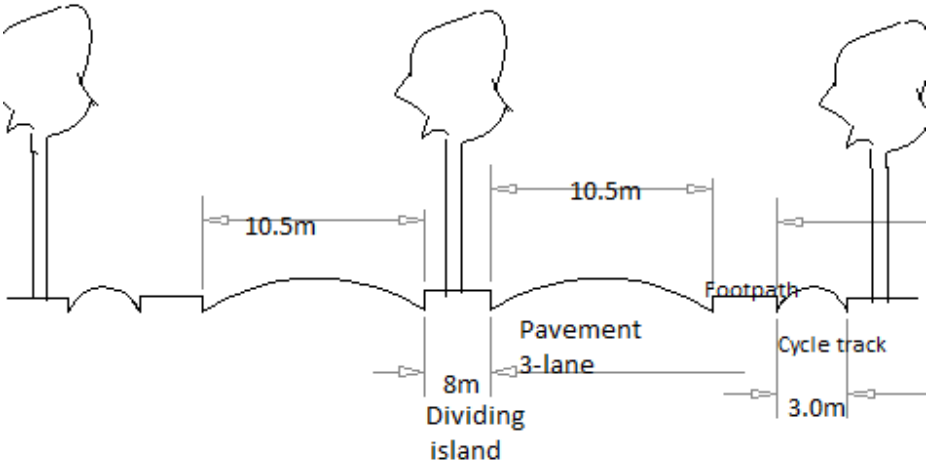
C/s of MDR in cutting



C/s of NH (or) SH in rural areas



C/s of two-lane city road



C/s of divided highway in Urban

Sight distance:

- It is the actual distance along the road surface, which a driver from a specified height above the carriage way has visibility of stationary (or) moving objects.
- It is the length of road visible ahead to driver at any instance.

In design, the following sight distances are considered

1) Stopping (or) absolute minimum sight distances are calculated.
2) Safe overtaking (or) passing sight distance.
3) Safe sight distance for entering in to uncontrolled intersections.

Intermediate sight distance:

- It is defined as twice the stopping sight distance
- When the overtaking sight distance cannot be provided, the intermediate sight distance is provided to give limited overtaking opportunities to fast vehicle.

Stopping sight distance:

- It is the length taken to stop a vehicle travelling at design speed, safely without collision with any other obstruction.

Sight distance depends on

- Feature of the road ahead.
- Height of driver's eye above the road surface.
- Height of object above road surface.

IRC has suggested the height of the eye level of driver as 1.2m and height of the object as 0.15m above road surface.

Stopping sight distance depends on factors:

- Total reaction time of the driver.
- Speed of the vehicle.
- Efficiency of breaks.

- Friction resistance between road and tyre.
- Gradient of the road.

PIEV THEORY:

Perception time:

It is the time required for sensations received by eye (or) ear to be transmitted to the brain.

Intellection time:

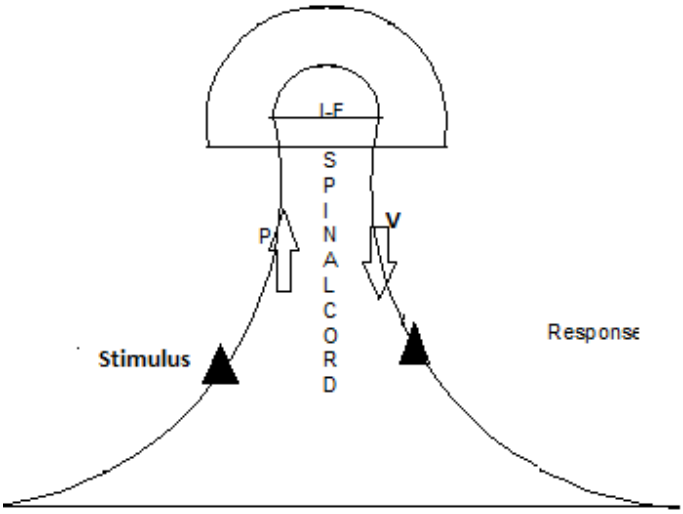
Time required to understand the situation.

Emotion time:

Time elapsed during emotional sensations and disturbance such as fear, anger.

Volition time:

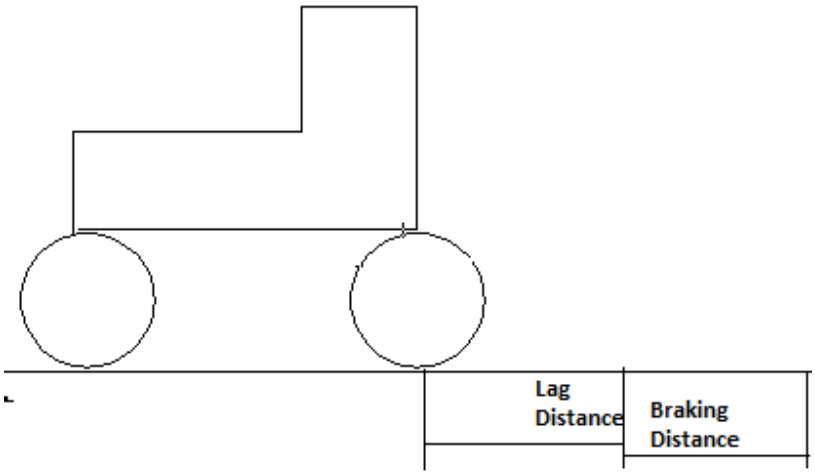
It is the time taken for final action.



Stopping distance:

It is the sum of

1) The distance travelled by the vehicle during the total reaction time (lag distance).
2) The distance travelled by the vehicle after the application of



brakes, to a dead stop position (braking distance).

Lag distance= $v*t$

$= v*(1000/(60*60))*t$

$= 0.278vt$ m

IRC recommended value of reaction time, t=2.5 sec

Breaking distance, work done = K.E

$Fwl= (wv^2)/(2g)$

$L= (v^2)/(2gf)$

Stopping distance = lag distance +braking distance

$= (vt) + (v^2/2gf)$ f= longitudinal friction

$= 0.278vt + (v^2/254f)$

Stopping distance at slopes,

Kinetic energy = work done

$(wv^2/2g) = fwl + (wxl/100)$

$(wv^2/2g) = w(f+(x/100))l$

$L = V^2/2g*(f+(x/100))$ (for ascending slope)

$L = V^2/2g*(f-(x/100))$ (for descending slope)

$SD = vt + V^2/2g*(f\pm(x/100))$

$SD = 0.278vt + V^2/254*(f\pm(x/100))$

Eg:-

Calculate the safe stopping for design speed of 50 kmph for (a)two-way traffic on a two lane road (b) two-way traffic on a single lane road.?

Sol: Assume coefficient of friction as 0.37 and reaction time of driver as 2.5 sec

$$SD = 0.278vt + (v^2/254f)$$

$$= 0.278*50*2.5 + (50^2/254*0.37)$$

$$=61.4m$$

Stopping sight distance when there are two lanes= stopping distance= 61.4m

Stopping sight distance with single lane= 2*64.1 =122.8m

Eg:-

Calculate the minimum sight distance required to avoid a head-on collision of two cars approaching from the opposite direction at 90 and 60 kmph. Assume a reaction time of 2.5 sec, coefficient of friction of 0.7 and brake efficiency 50%?

Sol: f= 0.5*0.7 = 0.35

Stopping sight distance for first car, $SD1= 0.278vt + (V^2/254f)$

$$= 0.278*90*2.5 +(90^2/(254*0.35))$$

$$=153.6m$$

For second car, $SD2= 0.278vt + (V^2/254f)$

$= 0.278*60*2.5 + (60^2/(254*0.35))$

$=82.2m$

Sight distance to avoid head-on collision of two approaching cars = SD1+SD2

$= 153.2+82.2$

$=235.4m$

Eg:-

Calculate the stopping sight distance on a highway at a descending gradient of 2% for a design speed of 80kmph. Assume other data as per IRC recommendations

Sol :- t=2.5s, f= 0.35

V=80kmph, x= -2%

$SSD = 0.278vt + (V^2/254*(f-0.02))$

$=0.278*80*2.5 + (80^2/(254*(0.35-0.02)))$

$=55.6 +76.4$

$=132m$

Eg:-

Calculate the values of a) Head light sight distance b) intermediate sight distance for a highway with speed 65kmph. Assume suitable data

Sol: v=65kmph, f= 0.35, t= 2.5 sec

a) Head light sight distance, SSD = $(0.278*vt) + (V^2/254f)$

$= (0.278*65*2.5) + (65^2/(254*0.35))$

$= 91.4m$

b) Intermediate sight distance = 2* SSD

= 2*91.4

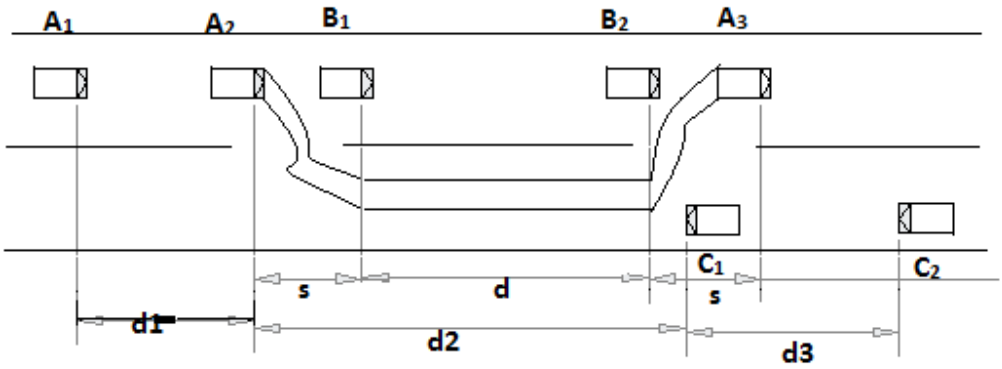
= 182.8m

Overtaking sight distance:-

- Different vehicles travels with different speeds.
- If all the vehicles travel with design speed, then there is no need of overtaking. But it is not possible.
- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as "OSD".

OSD depends on

a) Speeds of overtaking vehicle, overtaken vehicle and the vehicle coming from the opposite direction.
b) Distance between overtaking and overtaken vehicle
c) Skill and reaction time of driver.
d) Rate of acceleration of overtaking vehicle
e) Gradation of the road.



The overtaking process may be split uo into three operations, d1, d2, d3.

- d1 is the distance travelled by overtaking vehicle during the reaction time ‘t’ sec of the driver from position A1 to A2.
- d2 is the distance travelled by the vehicle A from A2 to A3 during actual overtaking operation in the ‘T’ sec.
- d3 is the distance travelled by on-coming vehicle C from C_1 to C_2 during overtaking operation of A i.e ‘T’ sec

$d1=V_b*t = 2V_bm$

$S= 0.7V_b+6$

$d2= b + (2*s)$

$b= V_b*T$ $\qquad$ $T= \sqrt{(4 * S)}/\sqrt{a}$

$d2= V_b*T + (2S)$

$d3= VT$

OSD = d1+d2+d3

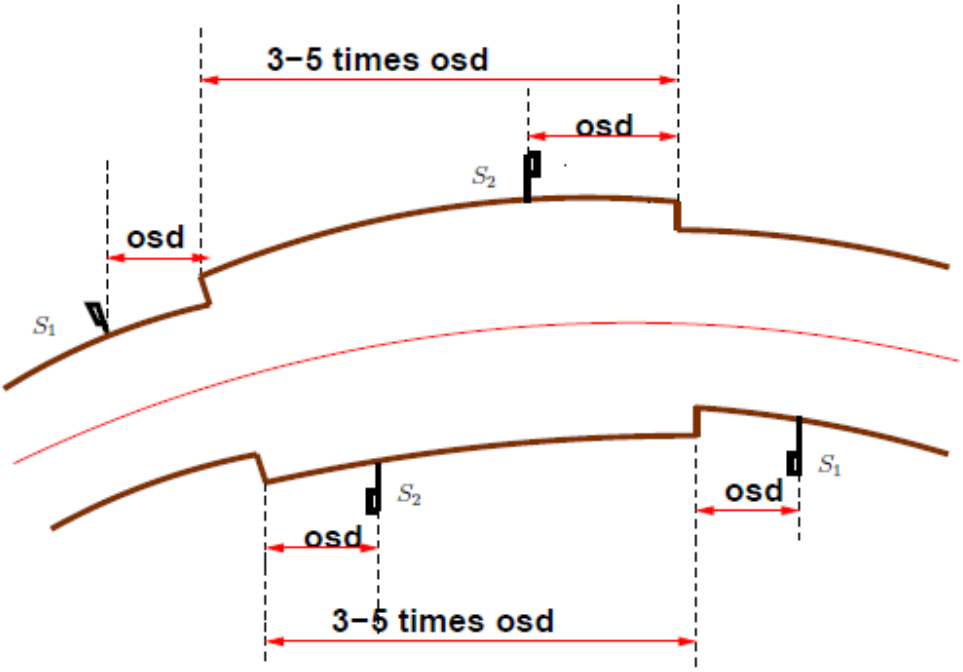
$= V_b t + V_b T + 2S + VT$

$OSD = 0.278V_b t + 0.278V_b T + 2S + 0.278VT$

Effect of grade in overtaking sight distance:-

Both descending as well as ascending, increase the sight distance required for safe overtaking.

Overtaking zones:



S_1– Overtaking zone begin

S_2–End of Overtaking zone

Overtaking zones

Minimum length of overtaking zone = 3*OSD

= 3*(d1+d2+d3) (two-way)

= 3*(d1+d2) (one-way)

Desirable length of overtaking zone = 5*OSD

= 5*(d1+d2+d3) (two-way)

= 5*(d1+d2) (one-way)

Eg:

The speed of overtaking and over-taken vehicles are 70 and 40 kmph respectively on a two-way road.If the acceleration of overtaking vehicle is 0.99 m/s².

a) Calculate safe overtaking sight distance.
b) Mention the minimum length of overtaking zone.
c) Draw a neat sketch of overtaking zone.

Sol: OSD= d1+d2+d3

V= 70 kmph = 70/3.6 = 19.4m/s

V_b= 40 kmph = 40/3.6 = 11.1m/s

Acceleration, A= 0.99m/s²

D1= V_bt

= 11.1*2 =22.2m

D2= V_bt +2S

S=0.7V_b+ 6 = (0.7*11.6) + 6 = 13.8m

T= $\sqrt{(4s/a)}$ =$\sqrt{(4 * 13.8/0.99)}$ = 7.47s

D2= (11.1*7.47) +(2*13.8)

= 110.5m

D3=VT= (19.4*7.47) = 144.9m

OSD = d1+d2+d3

= 22.2+110.5+144.9

= 277.6m = 278m

Minimum length of overtaking zone =3*OSD

= 3*278

=834m

Desirable length of overtaking zone = 5*OSD

= 5*278 = 1390m

SP1=overtaking zone ahead.

SP2=end of overtaking zone.

Eg:

Calculate the safe overtaking sight distance for a design speed of 96 kmph. Assume suitable data.

SOL:

OSD = d1+d2 (for one-way traffic)

= d1+d2+d3 (for two-way traffic)

V=96kmph

Assume V_b= V-16=80kmph

A = 2.5kmph/sec, t= 2sec

D1= $0.278V_bT$= 0.278*80*2 = 44.8m

D2= $0.278V_bT$+ 2s

S=$0.2V_b$+6

= (0.2*80)+6= 22m

T=$\sqrt{(14.4s/A)}$ = $\sqrt{(14.4 * 22/2.5)}$ =11.3sec

D2= (0.278*80*11.3) + (2*22)

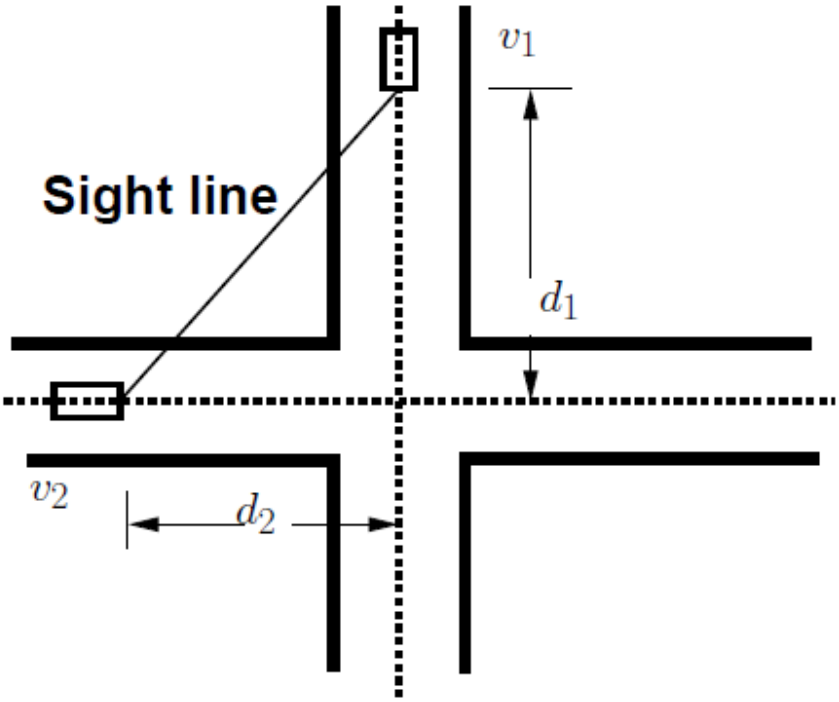
= 297m

D3= 0.278VT = 0.278*96*11.3 = 303.7m

$OSD_{0ne\text{-}way}$= d1+ d2 = 44.8+297 = 341.8= 342m

$OSD_{Two\text{-}way}$=d1+d2+d3= 44.8+297+303.7=645.5m

Sight distance at intersection:



Sight distance at intersections

UNIT-4

HIGHWAY GEOMETRIC DESIGN-2

Design of horizontal alignment:-

Factors to be considered are

a) Design speed.
b) Radius of circular curves.
c) Type of road and length of transition curves.
d) Super-elevation
e) Extra widening of pavement on curves

Design speed:

- Design speed of roads depends upon 1) class of the road. 2)terrain

Terrain classification	Cross slope of the country (%)
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	>60

Road classification	Plain		Rolling		Mountainous		Steep	
	Ruling	Min	Ruling	Min	Ruling	Min	Ruling	Min
NH&SH	100	80	80	65	50	40	40	30
MDR	80	65	65	50	40	30	30	20
ODR	65	50	50	40	30	25	25	20
VR	50	40	40	35	25	20	25	20

Recommended design speeds for different classes of urban roads.

a) For arterial roads 80 kmph
b) Sub-arterial roads 60 kmph
c) Collector streets 50 kmph
d) Local streets 30 kmph.

Horizontal curves,

Centrifugal force(P) = (WV^2/gR)

P= centrifugal force, kg

W= weight of vehicle, kg

R=Radius of circular curve, m

V= speed of vehicle.

g = acceleration due to gravity.

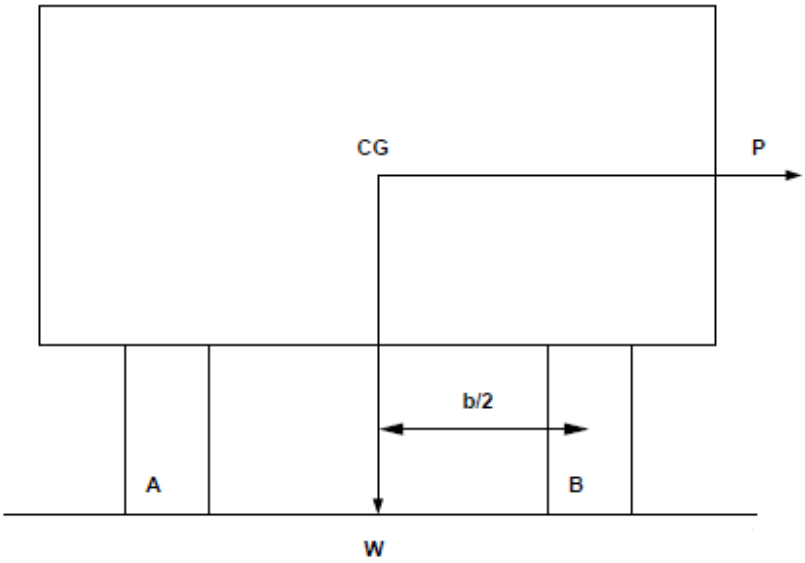
$P/W = V^2/gR$

(P/W) is known as centrifugal ratio (or) impact factor.

Centrifugal force acting on a vehicle negotiating a horizontal curve has two effects:

a) Tendency to overturn the vehicle outwards about the outer wheel.
b) Tendency to skid the vehicle laterally, outwards

Overturning effect:

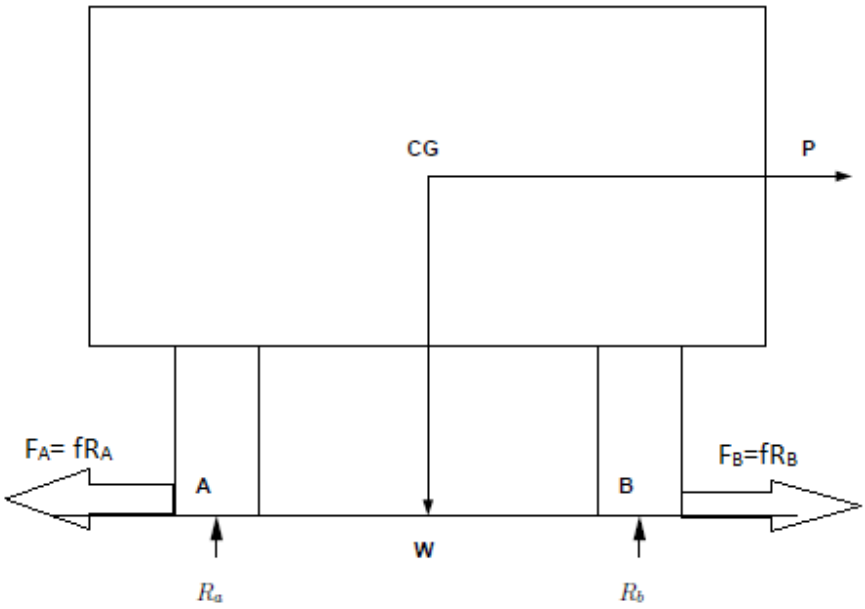


Ph= Wb/2

- P/W = b/2h

It means that there is danger of overturning when the centrifugal ratio attains a value of b/2h.

Transverse skidding effect:



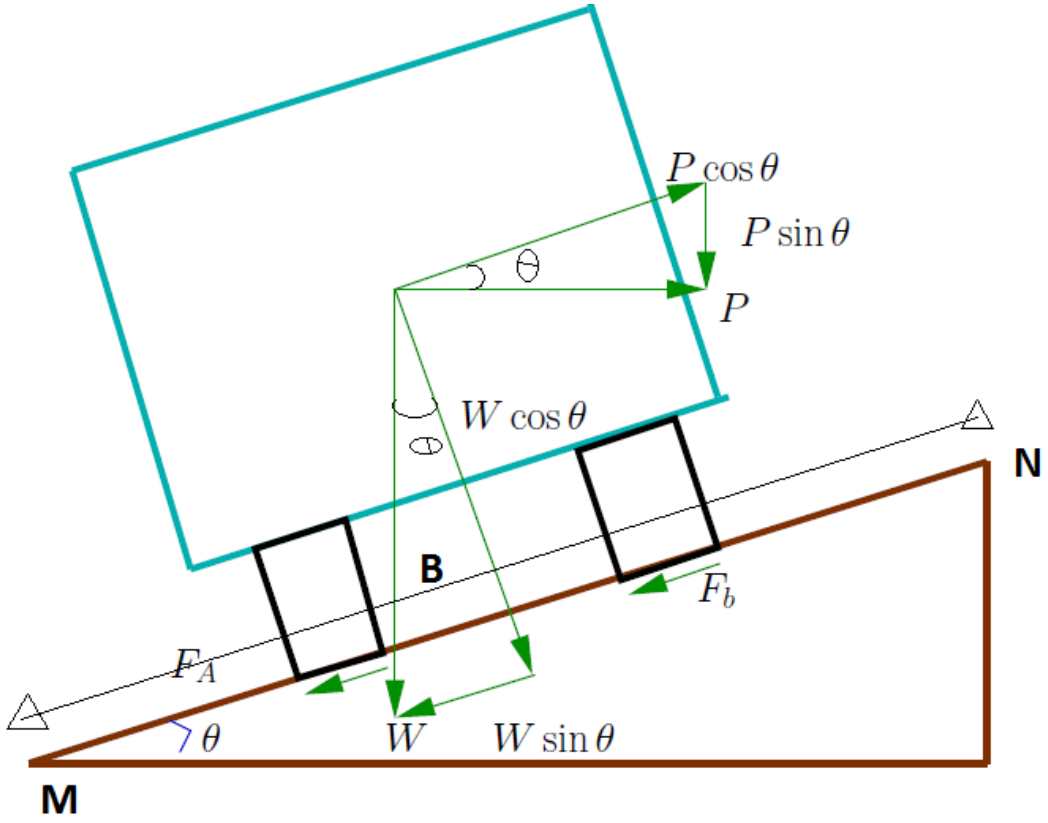
$P = fR_A + fR_B$

$= f(R_A+R_b)$

$= fW$

Super-elevation:-

- It is the transverse slope provided throughout length of horizontal curve.
- The purpose of super-elevation is to counteract the effect of centrifugal force and also to reduce overturn (or) skid of the vehicle.



tanθ = e= NL/ML

Tanθ = Sinθ= e= E/B

Pcosθ = WSinθ + F_A+ F_B

PCosθ = WSinθ + f(R_A+R_B)

= WSinθ + f(WCosθ+PSinθ)

P(Cosθ-fSinθ) = WSinθ+fWCosθ

Divide by WCosθ

(P/W)(1-fTanθ) = Tanθ + f

P/W = ((Tanθ+f)/(1-fTanθ))

As □ is small tan□=0

$$P/W = \tan\square + f$$

But $P/W = V^2/gR$ ($P= mV^2/R= WV^2/gR$)

$$e+f = V^2/gR$$

$$e+f = (0.278V)^2/9.8R$$

$$e+f= V^2/127R$$

If friction is neglected, f=0

$$e= V^2/127R$$

If super-elevation is not provide, the allowable speed,

$$e+f= V^2/127R$$

$$f= V^2/127R$$

$$V=\sqrt{127fR}$$

Eg:-

The radius of horizontal circular curve is 100m.the design speed is 50 kmph and design coefficient of lateral friction is 0.15

a) Calculate the super-elevation required for full lateral friction.
b) Calculate the coefficient of friction needed if no super-elevation is provided.
c) Calculate the equilibrium super-elevation if pressure on inner and outer wheels should be equal.

Sol:-

a) $e + f = V^2/127R$

$e + 0.15 = 50^2/ (127*100)$

$e = 0.047$

b) $e + f = V^2/127R$

$0+f = V^2/(127*100) = 0.197$

c) $e = V^2/127R = 50^2/(127*100) = 0.197$

Steps for super-elevation design:-

Step1:- $e = (0.75V)^2 /gR = V^2/225R$ (Super-elevation for 75% of design speed)

Step2:- Calculated 'e' <0.07 provide that 'e' value

If e> 0.07 provide e= 0.07 and proceed

Step3:- $f = (V^2/127R)-0.07$

If 'f' calculated <0.15 then e=0.07 is safe.

If 'f' calculated >0.15 then restrict speed.

Step 4:

$e + f = v^2/(127R)$

$0.07+ 0.15 = V_a^2/(127R)$

$V_a = \sqrt{(0.22 * 127R)}$

Allowable speed, $V_a = \sqrt{(27.94R)}$

Example: Design the rate of superposition for the horizontal highway curve of radius 500m and speed 100Kmph.

Sol:- $e = V^2/(225R)$

$= 100^2/(225*500) = 0.089 > 0.07$

$e+f = V^2/(127R)$

$0.07+f = 100^2/(127*500)$

$f = 0.087 < 0.15$

so the design is safe.

Example: The design speed of highway is 80Kmph and radius, R=200m.Check for safety.

Sol: $e = V^2/(225R)$

$= 80^2/(225*200) = 0.142 > 0.07$

$e+f = V^2/(127R)$

$0.07+f = 80^2/(127*200)$

$f = 0.18 > 0.15$

Therefore design not safe

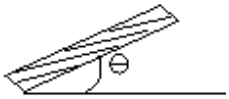
Therefore restrict the the speed

$0.07+0.15 = V_a/(127*200)$

$V_a = 74.75$Kmph.

ATTAINMENT OF SUPERELEVATION:-

a) Elimination of crown of cambered section
b) Rotation of pavement to attain full superelevation



RADIUS OF HORIZONTAL CURVE:-

$e+f = V^2/(127R)$

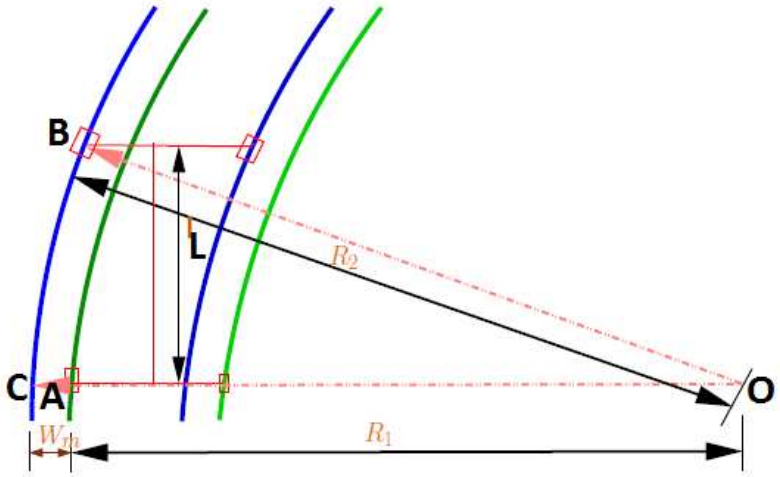
$R_{ruling} = V^2/((e+f)g)$ V –Ruling design speed

$R_{min} = (V)^2(127(e+f))$ V –Minimum design speed

WIDENING OF PAVEMENT ON HORIZONTAL CURVE:-

Mechanical widening:-

$W_m = OC-OA = OB-OA = R_2-R_1$



Extra-widening at a horizontal curve

ΔOAB, $OA^2 = OB^2 - BA^2$

$R_1^2 = R_2^2 - l^2$

But $R_1 = R_2 - w_m$

$(R_2 - w_m)^2 = R_2^2 - l^2$

$l^2 = w_m(2R_2 - w_m)$

$w_m = l^2/(2R_2 - w_m) \approx l^2/(2R)$; $w_m = nl^2/(2R)$ n-no.of lanes.

Psychological widening

As per IRC,

$w_{ps} = V/(9.5\sqrt{R})$

$w_e = w_m + w_{ps}$

$w_e = nl^2/(2R) + V/(9.5\sqrt{R})$

Example: Calculate the extra widening required for a pavement of within 7m on a horizontal curve of radius 250m if the longest wheel base of vehicle expected on the road is 7.0m, Design speed 70Kmph.

Sol: $w_e = w_m + w_{ps}$

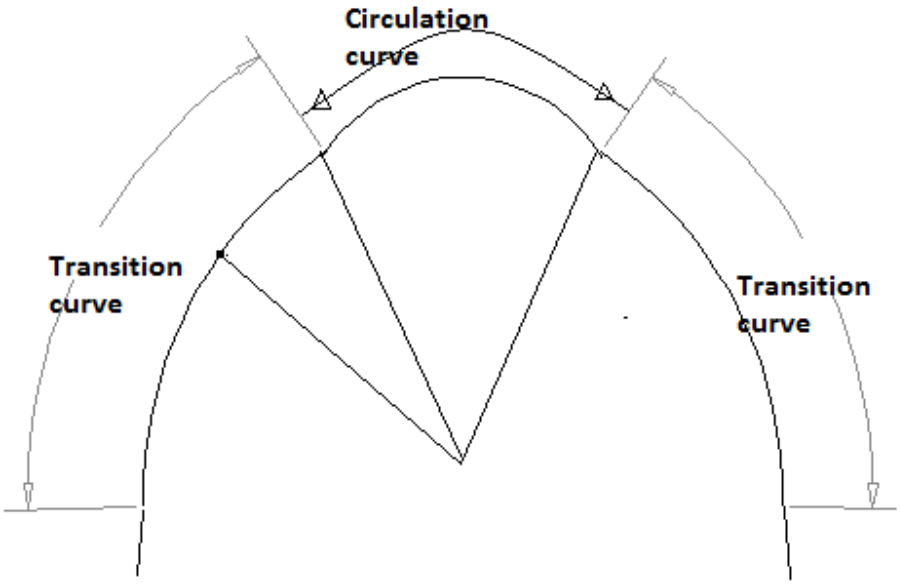
$= nl^2/(2R) + V/(9.5\sqrt{R})$

$= (2*7^2)/(2*250) + 70/(9.5\sqrt{250})$

$= 0.662m$

HORIZONTAL TRANSITION CURVE:-

- A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of circular curve.

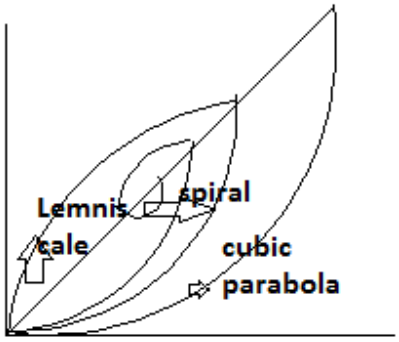


Functions of transition curve:-

a) To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve.
b) To enable the driver turn the steering gradually.
c) To enable the gradual introduction of the designed super elevation and the extra widening.
d) To improve the aesthetic appearance.

Different types of transition curves:

a) Spiral (also called clothoid)
b) Lemniscate



c) Cubic parabola

<u>IRC recommends due to the following reasons:</u>

I. Spiral curve satisfies the requirement of an ideal transition.
II. Geometric property of spiral is such that calculation and setting out the curve in the field is simple and easy.

Length of transition, $L_s = V^3/(CR) = 0.0215V^3/(CR)$,
V in kmph

Where, $C = 80/(75+V)$

$L_s = EN/2 = eN(w+w_e)/2$, (for pavement rotating about centre)

$L_s = EN = eN(w+w_e)$, (for pavement rotating about the inner edge)

Empirical formula:

For plane and rolling terrain:

$L_s = 2.7V^2/R$

For mountainous and steep terrain:

$L_s = V^2/R$

When transition is provided, parallel shift should be provided

$S = L_s^2/(24R)$

Example: Calculate the length of transition curve and shift using following data:

Design speed = 65Kmph

Radius of circular curve = 220m

Allowable rate of superelevation (about centre line) = 1 in 150 pavement width including extra widening = 7.5m.

Sol- $C = 80/(75+V) = 80/(75+65) = 0.57m/s^3$

$L_s = 0.0215V^3/(CR) = 0.021565^3/(0.57*220)=47.1m$.....**I**

$e + f = V^2/ (127R)$

$f = 65^2/ (127*220) – 0.07 = 0.08 < 0.15$

Therefore, e= 0.07 is safe

Raise of outer edge = E/2 = eB/2 = (0.07*7.5)/2 = 0.26m

$L_s = EN/2 = 0.26*150 =39m$.....**II**

$L_s = 2.7V^2/R = 2.7*65^2/220 = 51.9m$.....**III**

Adopt highest, i.e $L_s = 51.9 \approx 52m$

Shift, $S = L_s^2/ (24R) = 52^2/(24*220) = 0.51m$

DESIGN OF VATRICAL ALIGNMENTS:-

- The vertical alignment is the elevation (or) profile of the centre line of the road.
- Vertical alignment consists of grades and vertical curves.
- Vertical alignment influences the vehicle speed, acceleration, decelaration, sight distance and comfort.

Gradient:-

- Ruling gradient
- Limiting gradient
- Exceptional gradient
- Minimum gradient

- **Ruling gradient** is the maximum gradient within which the designer attempts to design the vertical profile of the road.
- **Limiting gradient** is the gradient where the topography of a place compels adopting steep gradient.
- **Exceptional gradient** is gradient still steeper than above and it should be adopted for short stretches.
- **Minimum gradation** is that gradation, which is provided in view of drainage and topography. It depends on rainfall, runoff, type of soil, topography.

GRADE COMPENSATION ON HORIZONTAL CURVES:-

When sharp horizontal curve is to be introduced on a road which has already the maximum permissible gradation. Then the gradient should be decreased to compensate for the loss tractive effort due to the curve.

This reduction n gradation at the horizontal curve is called grade compensation.

Grade compensation = 30+R/R %

Maximum value = 75/R 'R' is radius in m

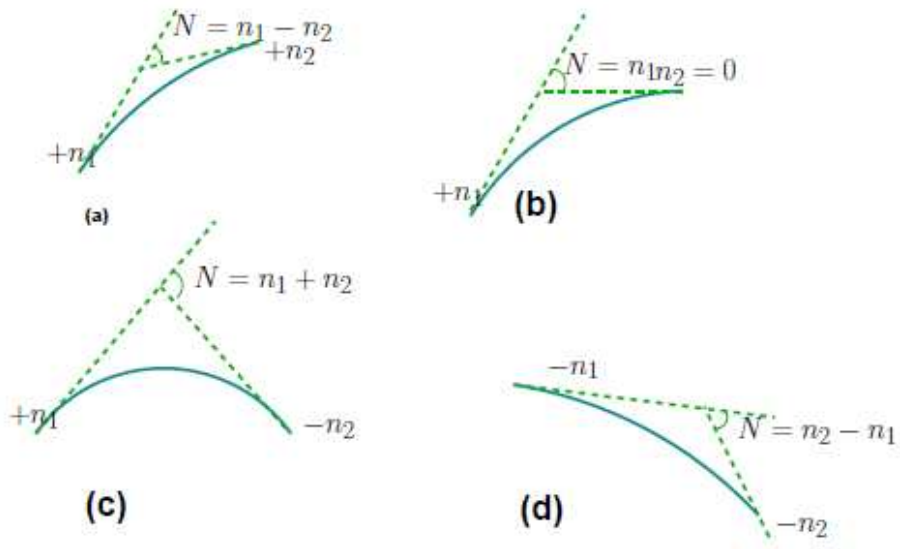
According to IRC, the grade compensation is not necessary for gradation flatter than 4.0%.

VERTICAL CURVES:-

Due to change in grade in the vertical alignment of highway, it is necessary to introduce vertical curves at the intersection of different grades.

Types of curves,

a) Summit curve (or) crest curves with convexity upwards.
b) Valley (or) Sag curves with concavity upwards.



Types of summit curves

Length of summit curve for stopping sight distance (SSD):-

I. L > SSD

$L = NS^2/(\sqrt{(2H)}+\sqrt{(2h)})^2$

H = 1.2 = height of eye level of driver

h = 0.15 = height of subject

S = Stopping sight distance

N = Deviation angle

$L = NS^2/4.4$

II. $L < SSD$

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

$L = 2S - 4.4/N$

LENGTH OF SUMIT CURVE FOR OVERTAKING SIGHT SIGHT DISTANCE (or) INTERMEDIATE SIGHT DIASTANCE:-

i. $L > OSD$

$L = NS^2/(8H)$

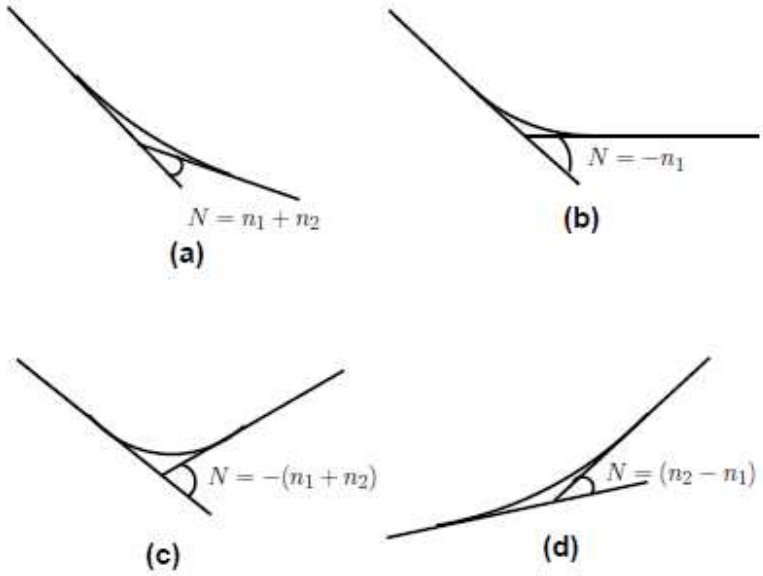
$L = NS^2/(9.6)$

ii. $L < OSD$

$L = 2S-8H/N$

$L = 2S-8H/N$

VALLEY CURVES:-



Types of valley curve

1) Comfort condition

$L = 2(NV^3/C)^{1/2}$ V is in m/s

2) Length of valley curve for head light sight distance

i. L > SSD

$L = NS^2/(2h_1+2S\tan\alpha)$

$L = NS^2/(1.5+0.035S)$

ii. L < SSD

$L = 2S-(2h_1+2S\tan\alpha)/N$

$L = 2S-(1.5+0.035S)/N$

Example: A vertical summit curve is formed at the intersection of gradients +3.0% and -5.0%. Design the length of summit curve to provide a stopping sight distance for a design speed of 80Kmph. Assume other data.

Sol:-

a) SSD = $0.278Vt + (V^2/254f)$ assume t= 2.5sec, f= 0.35

$= 0.278*80*2.5 + (80^2/(254*0.35)) = 128m$

b) Deviation angle = 0.03- (-0.05) = 0.08

Assume L> SSD

$L= (NS^2/4.4) = (0.08*128^2)/4.4 = 297.8$ (128m)

L= 298m

Ex:-

An ascending gradient of 1 in 100 meets a descending gradient of 1 in 120. A summit curve is to be designed for a speed of 80 kmph so as to have an overtaking sight distance of 470m.

Sol:-

$n_1= 1/100$, $n_2= -1/120$

$N= (1/100)-(-1/120)= 11/600$

Assume L> OSD

$L= (NS^2/9.6) = (11/600)*(470^2/9.6) = 422$ (<470)

L<OSD should be considered

$L=2S-(9.6/N)$

$= (2*470)-(9.6/(11/600))$

$= 416.4m$ ($<470m$)

Length of summit curve = 417m.

Ex:

A valley curve is formed by a descending grade of 1 in 25 meeting on ascending grade of 1 in 30.Design the length of valley curve to fulfill both comfort condition and head light sight distance requirements.

Assume $c=0.6m/S^3$, t= 2.5 sec; f= 0.35?

Sol:-

$N = - (1/25) - (1/30) = -11/150$

$V= 80$ kmph $= 80/3.6 = 22.2$ m/s

a) Comfort condition

$L= 2*(NV^3/C)^{1/2} = 2*(11*22.2^3/(150*0.6))^{1/2} = 73.1m$

b) Head light sight distance

T=2.5 sec, f=0.35

$SSD = Vt + (V^2/2gf) = 127.3m$

If L>SSD

$L= (NS^2/(1.5+0.0355)) = (11*127.3^2/(150(1.5+(0.0035*127.3))))$

$= 199.5$ (<127.3)

Length of valley curve

= 199.5m

= 200m

UNIT-5

TRAFFIC ENGINEERING

It is that branch of engineering which deals with deals with the improvement of traffic performance of road networks and terminals.

It is achieved by systematic traffic studies, scientific analysis and engineering application.

SCOPE OF TRAFFIC ENGINEERING:

The objective of traffic engineering is to achieve efficient, free and rapid flow of traffic with minimum number of accidents.

The study of traffic engineering is divided into following major sections:

1) Traffic characteristics.
2) Traffic studies and analysis.
3) Traffic operation-control and regulation.
4) Planning and analysis.
5) Geometric design
6) Administration and management.

TRAFFIC CHARACTERISTICS

Road user characteristics

a) Physical(vision, hearing)

b) Mental(knowledge, skill, intelligence)

Vehicular characteristics

a) Vehicle dimensions
b) Wt. of loaded vehicle.
c) Power of vehicle.

c) Psychological(fear, anger, maturity)
d) Environmental.
d) Speed of vehicle
e) Braking characteristics

Example:

In a braking test, a vehicle travelling at a speed of 30Kmph.Was stopped by applying brakes fully and the skid marks were 5.8m in length. Determine the average skid resistance of the pavement surface.

Sol:

Initial speed, U=30Kmph = (30/3.6)m/s = 8.33 m/s.

Braking distance, L= 5.8m = $(U^2/2gf)$

$$5.8 = (8.33^2/2*9.81*f)$$

$$f = (8.33^2/2*9.81*5.8)$$

Avg skid, f= 0.61

Example:

A vehicle travelling at 40Kmph was stopped within 1.8sec after the application of the brakes. Determine the average skid resistance.

Sol:

F=ma = fW

(W/g*a) = fW

f= (a/g)

a= (u/t) = (40/3.6/1.8) = 6.17m/s^2.

f= a/g = 6.17/9.81 = 0.63.

Example:

A vehicle was stopped in 1.4 sec by fully jamming the brakes and the skid marks measured 7.0m. Determine average skid resistance.

Sol:

V= u +at

0 = u + at => u= -at

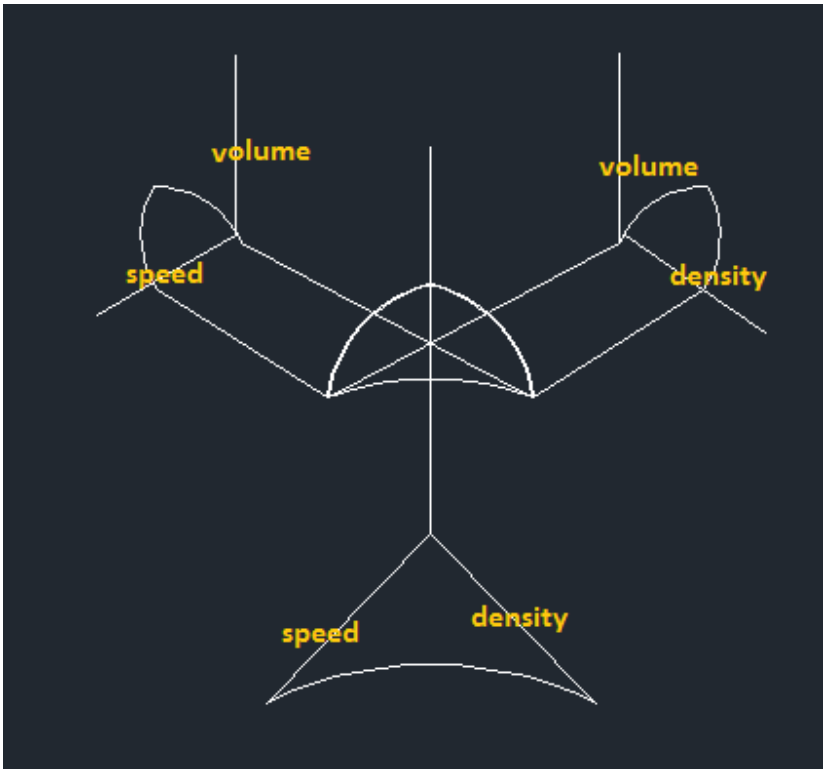
V^2-U^2 = 2as => 0 – U^2 = 2as => a^2t^2 = 2as

a = (2S/t^2) = 2(7/1.4^2)

f= a/g = (2*7/1.4^2*9.81) = 0.73

VOLUME-SPEED-DENSITY RELATION:

- Volume of traffic is the no. of vehicles passing a particular section in unit time.
- Speed is the distance travelled by the no. of vehicles in unit time.
- Density of traffic is the no. of vehicles plying in unit length of highway.



- As speed increased, volume increases upon maximum value and then decreases.
- Similarly, as the density of traffic plying on the road increases, volume increases upto maximum value and then decreases.
- The maximum speed value in the figure is called <u>free mean speed</u>, V_{sf}
- The maximum density at zero speed is called <u>jam density</u>, k_j
- The maximum flow or capacity flow, q_{max} occurs when the speed is $V_{sf}/2$ and density is $K_j/2$.
- $Q_{max} = (V_{sf}/2)*(K_j/2) = (V_{sf}K_j/4)$.

Example:

The free mean speed on roadway is found to be 80Kmph. Under stopped condition the average spacing between the vehicles is 6.9m. determine the capacity flow.

Sol:

Free mean speed, V_{sf} = 80Kmph

Jam velocity, K_j= 1000/6.9 = 145veh/km/lane

Max flow, q_{max}= (80*145/4)= 2900 vehicles/hr/lane.

TRAFFIC VOLUME STUDY:

- Traffic volume is the number of vehicles crossing a section of road per unit time at any selected period.
- A complete traffic volume study may include the classified volume study by recording the volume of various vehicle types.

Objects and uses of traffic volume studies:

- Traffic volume is generally accepted as a true measure of the relative importance of roads.
- Used in deciding properties for improvement and expansion.
- It is used in planning and designing of new facilities.
- It is used in analysis of traffic pattern and trends.
- Classified volume study is useful in structural design of pavements, in geometric design and in computing roadway capacity.
- It is used in planning one-way streets.

- Turning movement study is used in design of intersection.
- Pedestrian traffic study is used planning of side walk, cross walk and pedestrian signal.

Classified volume count format:-

Two wheeler	Car/ jeep/ van	Auto	Bus	LCV	2-Axle Truck	3-Axle Truck	Multi axle truck	Cycle	Others

Counting of traffic volume:-

Mechanical counters:-

- These are either fixed (permanent) type (or) portable type.
- These can automatically record the total number of vehicles crossing a section of road in desired period.
- Traffic count is recorded by electrically operated counters and recorders capable of recording the impulses.
- Examples of mechanical detectors are by photo-electric cells, magnetic detector and radar detectors.

- The main advantage of mechanical counter is that it can work throughout the day and night for the desired period. And, recording of hourly volume, is not predictable by manual counting.
- The main drawback of mechanical counter is that it is not possible to get the traffic volume of various classes and details of turning movement.

Manual counts:-

a) This method employs a field team to record traffic volume on the prescribed record sheets.
b) This method is useful where mechanical counting methods are not useful. For example, vehicle classification, turning movement details cannot be gathered by mechanical counters.

Presentation of traffic volume data:-

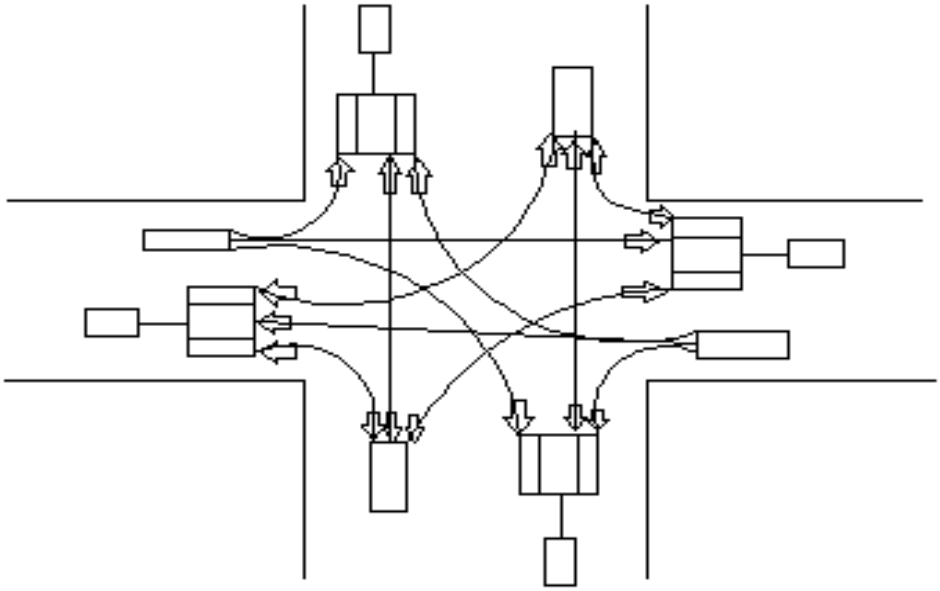
1) Annual average daily traffic (AADT or ADT) of the total traffic as well as classified traffic are calculated. In order to convert

different vehicle types to one class such as passenger car, conversion factors known as passenger car unit (PCU) are used.

Vehicle type	PCU
Two-wheeler	0.5
Auto	0.75
Car	1
BUS	3
LCV	2
2-Axle truck	3
3-Axle truck	4.5
Multi-axle	4.5
Animal drawn vehicle	6

2) Trend charts showing volume trends over period of years.
3) Variation charts showing hourly, daily and seasonal variations are also prepared. This help in deciding peak hours.

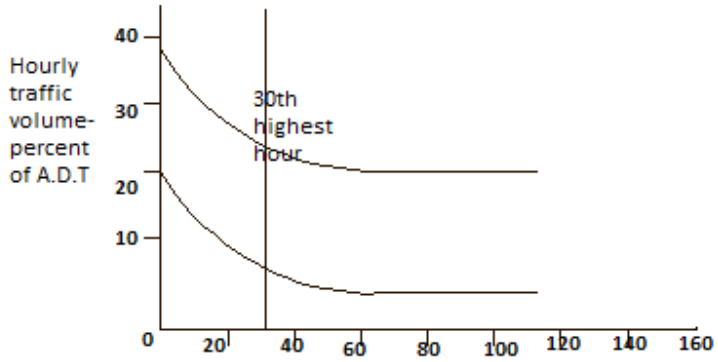
4) Traffic flow maps along the routes, (the thickness of the lines representing the traffic volume to any desired scale) are drawn.



These help to find the traffic volume distribution.

5) Volume floe diagram at intersections either drawn to a certain scale or indicating traffic volume.

6) Thirtieth highest hourly volume or design hourly volume is found



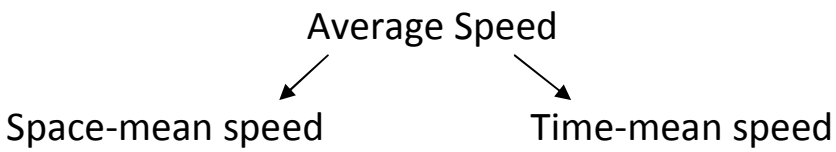
from the plot between hourly volume and the number of hours in a year that the traffic volume is exceeded.

7) The 30th highest hourly volume is the hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the year will be less than this value.
8) The high facilities designed with capacity for 30th highest hourly traffic volume.
9) Then, there will be congestion only during 29 hours in the year.

10) The 30th highest hourly volume is generally taken as the hourly volume for design.

Speed studies:-

- Actual speed of vehicle over a particular route may vary depending on several factors such as geometric features, traffic condition, time, place, environment and drive.
- Travel time is reciprocal of speed and it also gives operating condition of road network.
- Spot speed is the instantaneous speed of a vehicle at a specified section.
- Average speed is the average of the spot speeds of all vehicles passing a given point on the road.



- Space-mean speed represents the average speed of vehicles in a certain road length at any time.
- This (Space-mean speed) is obtained from the observed travel time of vehicles over relatively long stretch of the road.

Space-mean speed is calculated from:-

$$V_s = 3.6 d_n / \left(\frac{\sum_{i=1}^{n} Vi}{n}\right)$$

Where V_s= space-mean speed, Kmph

D= length of the road.

N= number of individual vehicle observations.

T_i= observed travel time(sec) for i^{th} vehicle to travel distanced, m

- The average travel time of all vehicles is obtained from the reciprocal of space-mean speed.
- Time-mean speed represents the speed distribution of vehicles at a point on roadway.

- Time-mean speed is the average of instantaneous speeds of observed vehicles at the spot.

Time-mean speed is calculated from:-

$$V_t = \left(\frac{\sum_{i=1}^{n} Vi}{n}\right)$$

Where V_t= time-mean speed.

V_i= observed instantaneous speed of i^{th} vehicles Kmph.

N= no. of observed vehicles.

- Under typical speed conditions.

$$V_s < V_t$$

- Running speed=(Distance covered/Running time)

Running time=total time-stopped delay

- Overall speed or travel speed is the effective speed with which a vehicle traverses a particular route between two terminals

Overall speed= (Total distance/Total time)

Total time (including all delays and stoppages)

- There two types of speed studies.

i. Spot speed study.

ii. Speed and delay study.

Spot speed study:-

It is useful in any of the following aspects of traffic engineering:

a) To use in planning traffic control.

b) To use in geometric design.

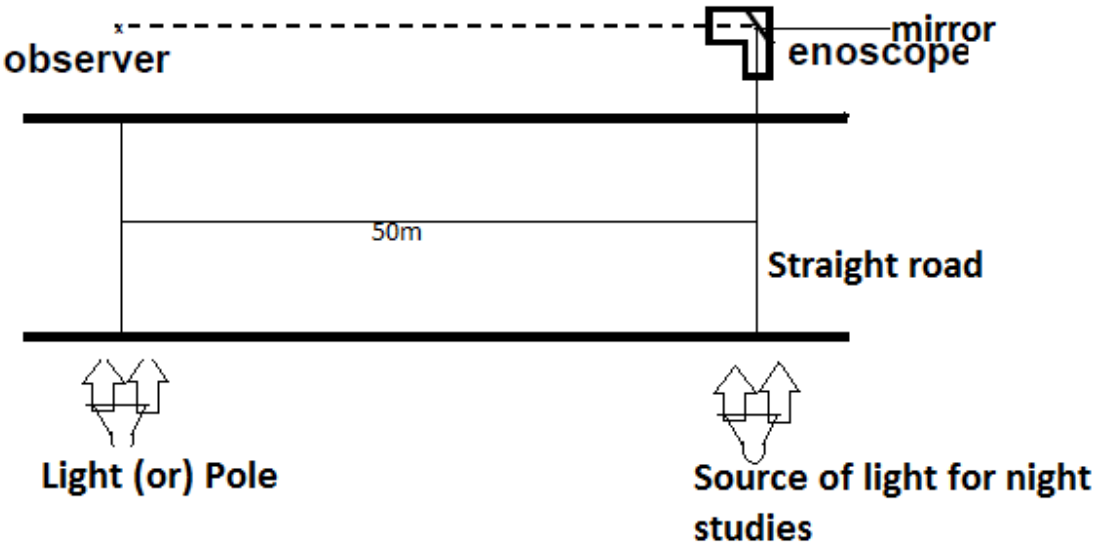
c) To use in accident studies.

d) To study traffic capacity.

e) To decide speed trends.

f) To compare diverse types of drivers.

- The spot speeds are affected by physical features of the road like pavement width, curve, sight distance, gradient, pavement unevenness, intersection and road side development.



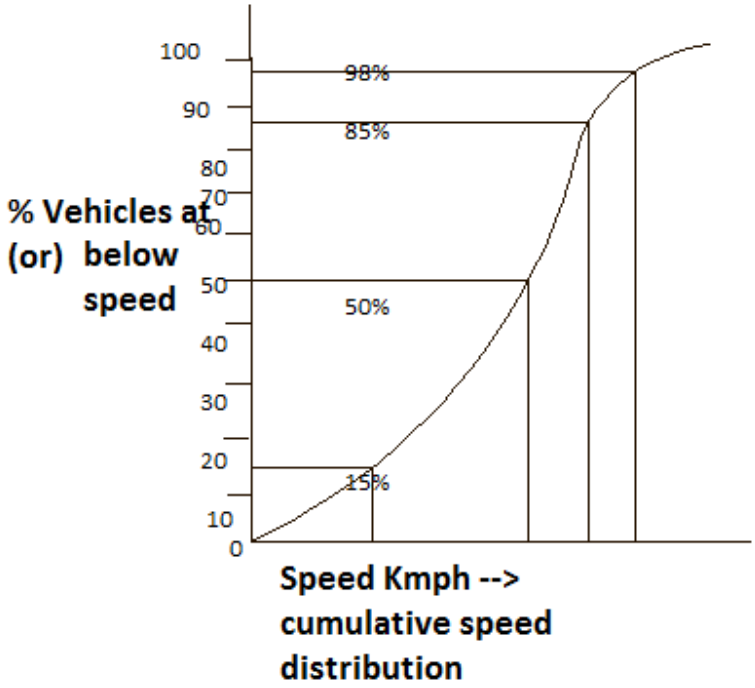
- Other factors affecting spot speeds are environment conditions, enforcement, traffic conditions.
- Enoscope is used to find the spot speeds of vehicles.
- Other equipment used for speed measurement are graphic recorder, electronic meter, photo electric meter, radar, speed meter and by photographic methods.]
- Out of all these, the radar speed meter method seems to be the most efficient one as it captures speeds instantaneously.

Presentation of spot speed data:-

a) Average speed of vehicles

- The arithmetic mean is taken as the average speed.

b) Cumulative speed of vehicles.



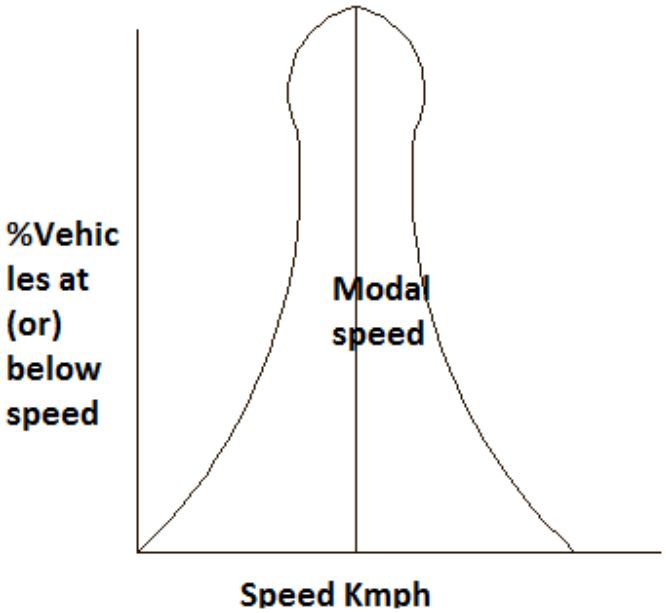
15% speed ---> lower limit speed.

50% speed -→ average speed.

85% speed -→ upper limit speed.

98% speed -→ design speed.

c) Modal average



Frequancy distribution curve of spot speeds

Problem:-

Sol:-

Speed range	Mid speed	Frequency	Frequency%	Cumulative frequency (%)
0-10	5	12	1.4	1.4
10-20	15	18	2.1	3.53
20-30	25	68	8.0	11.53
30-40	35	89	10.47	22.00
40-50	45	204	24	46.00
50-60	55	255	30	76.00
60-70	65	119	14	90.00
70-80	75	43	5	95.00
80-90	85	33	3.88	98.94
90-100	95	9	1.06	100.00

From graph

i. Upper speed limit for regulation=85 percentile speed= 60 Kmph
ii. Lower speed limit for regulation=15 percentile speed= 30 Kmph
iii. Speed to check design elements =95 percentile speed= 84 Kmph

Speed and delay study:-

- This study gives the running speeds, overall speeds, fluctuations in speed and the delay between stations.

There are various methods of carrying out speed and delay study, namely:-

a) Floating car method.
b) License plate method.

c) Interview technique.
d) Elevated observation.
e) Photographic technique.

The average journey time t (minute)

$$\bar{T}=t_w-n_y/q$$

$$Q= (n_a+n_y) / (t_a+t_w)$$

Where q= flow of vehicles (volume per min) in one direction of the stream.

N_a=average no. of vehicles counted in the direction of stream when the test vehicle travels in opposite direction.

N_y= {average no. of overtaking}-{no. of overtaken vehicles}

T_w=average journey time, in minutes, vehicle travelling against stream, q

T_a= average journey time, in minutes, vehicle travelling against stream, q

Problem:-

Stretch length= 3.5Km.

Trip no.	Direction of trip	Journey time Min.sec	Total stopped delay min.sec	No. of veh. overtaking	No. of vehicles overtaken	No. of veh. From opp. direction
1	N-S	6-32	1-40	4	7	268
2	S-N	7-14	1-50	5	3	186
3	N-S	6-50	1-30	5	3	280
4	S-N	7-40	2-00	2	1	200
5	N-S	6-10	1-10	3	5	250
6	S-N	8-00	2-22	2	2	170
7	N-S	6-28	1-40	2	5	290
8	S-N	7-30	1-40	3	2	160

Sol:-

Direction	Journey time	Stopped delay	Overtaking	Overtaken	In opp. Direction
N-S	6-32	1-40	4	7	268
	6-50	1-30	5	3	280
	6-10	1-10	3	5	250
	6-28	1-40	2	5	290
Total:	26-00	6-00	14	20	1088
Mean:	6-30	1-30	3.5	5.0	272
S-N	7-14	1-50	5	3	186
	7-40	2-00	2	1	200
	8-00	2-22	2	2	170
	7-30	1-40	3	2	160
Total:	30-24	7-12	12	8	716
Mean:	7-36	1-46	3	2	179

a) North-South direction:

N_y= overtaking-overtaken = 3.5-5.0=-1.5

Na=Avg. no of vehicle in opp. Direction= 179

T_w=avg. journey time= 6-30 =6.5min

T_a=avg. journey time against flow = 7-36=7.6min

Q= Average volume= $(n_a+n_y)/(t_a+t_w)$ = (179-1.5)/(7.6+6.5)= 12.59 veh/min

$\bar{T}$= Avg. journey time =t_w-n_y/q=6.5-(-1.5/12.59)=662min.

Journey speed= (distance/journey time) = 3.5/6.62= km/min

= 3.5/6.62=31.7Kmph

Avg. stopped delay=1-30=1.5min.

Avg. running time= Avg. journey time-delay

=6.62-1.5=5.12m

Avg. running speed= 3.5*60/5.12

b) South-North direction:-

N_y =3.0-2.0=1.0

T_w=7.6min

T_a=6.5min

N_a=from N-S strips=272

Q= (272+1.0)/(6.5+7.6)= 19.36veh/min

Journey time, $\bar{t}$ =7.6-1.0/19.36 = 7.55min

Journey speed = 3.5*60/7.55 = 27.8Kmph

Average stopped delay= 1.8min

Average running time = 7.55-1.80 = 5.75min

Average running speed=3.5*60/5.75= 36.5Kmph

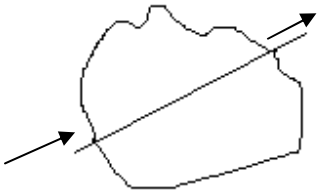
Parking studies:

- Parking space is one of the major problems in transportation.
- Parking demand is high in industrial, commercial and residential places.
- Parking studies are useful to evaluate the parking facilities.

Parking demand:-

- Parking demand may be evaluated by different methods.

  Method1:-



  Cordon counts are conducted to study parking accumulation in the study area.

  Method2:

  By noting the registration number of each parked vehicle at any desired time interval (such as 1/2hr, 1hr etc).

Parking characteristics:-

- The study is directed to note the present parking practices prevalent in study area and the general problems in parking.

Parking space inventory:-

- The study area is fully surveyed and a map is prepared showing kerb parking (on-street parking) and off-street parking to meet parking demands.

Accident studies:-

- Due to complex flow patterns, mixed traffic condition, the accident problems are increasing.
- Traffic accidents involves property damage, minor injury, fatal.
- With suitable traffic engineering, accident rate cannot be eliminated but can be decreased.

Objectives of accident studies:-

a) To study the causes of accidents.
b) To evaluate existing designs.
c) To support proposed designs.
d) To carry out before and after studies.
e) To make computations of financial loss.
f) To give economic justification for the improvements.

Causes of accidents:-

- Drivers.
- Pedestrians.
- Passengers.

- Vehicle defects.
- Road condition.
- Road design.
- Weather.
- Animals.

Preventive measures of road accidents;-

Accident rate can be reduced by following three groups. (3-E's)

a) Engineering.
b) Enforcement.
c) Education.

Engineering measures:-

a) Road design.
b) Maintenance of vehicle.
c) Before and after studies.
d) Road lighting.

Enforcement measures:-

a) Speed control.
b) Traffic control devices.
c) Training and supervision.
d) Medical check.
e) Special precautions for commercial vehicles.

Educational measures:-

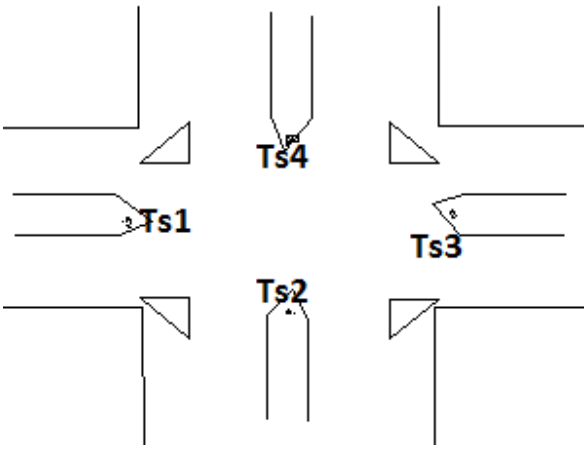
a) Education of road users.
b) Safety week.

Accident recording:-

- Collecting of accident data
    a) General (date, time, etc)
    b) Location.
    c) Details of vehicles involved.
    d) Nature of accident.
    e) Road and traffic conditions.
    f) Primary causes of accident.
- Accident report
- Accident records
    a) Location files.
    b) Spot maps.

Condition diagram:-

It is a scaled drawing showing all important physical conditions of an accident location.



The physical conditions are roadway limits, curves, bridges, culverts, trees, signs, signals etc.

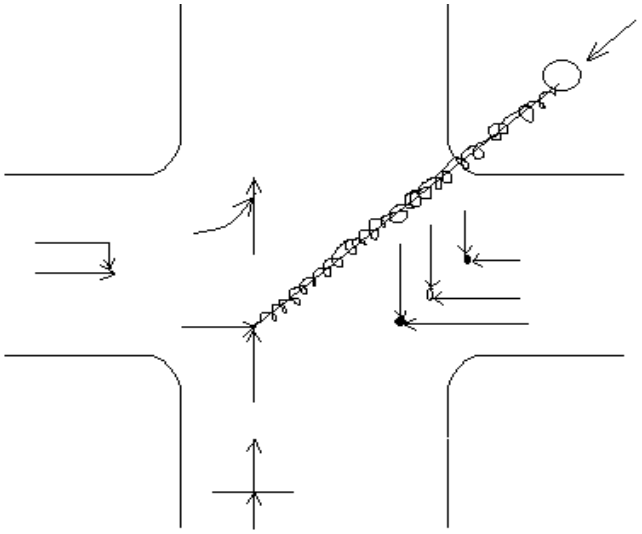
Condition diagram of 4-legged jn

Collision diagram:-

It is a drawing showing the paths of vehicles and pedestrians involved in the accidents.

It is useful to compare accident pattern before and after the remedial measures

Typical collision diagram and symbols:-



Symbols

Motor vehicle moving ahead

Motor vehicle moving ahead

Pedestrian

Parked vehicle

Fixed object

Rear end collision

Side swipe

Out of control

Fatal accident

Personal injury

Property damage

UNIT-6

TRAFFIC REGULATION AND MANAGEMENT

Traffic signs:-

__According to motor vehicle act, traffic signs are divided into three categories.

a) Regulatory signs.
b) Warning signs.
c) Informatory signs.

Placement of sign board:-

- Size, shape, colour code should be provided as per the IRC(Indian Road Congress)
- The reverse side of all the sign plates should be painted grey.

Regulatory signs:- (Mandatory signs)

- These are meant to inform the road users of certain laws, regulations and prohibitions.
- Violation of these signs are legal offence.
  Regulatory Signs
  1) Stop and give-away signs.
  2) Prohibitory signs.
  3) no parking and no stopping signs.
  4) Speed limit and vehicle control signs.
  5) Restriction end signs.
  6) Compulsory direction control.

Stop sign:-

- Stop sign is intended to stop the vehicles on a roadway.
- It is octagonal shape and red in colour with white border.
- This sign may be used in combination with a rectangular definition plate with the word ‘STOP’ written in English.

Giveway sign:-

Giveway

- It is used to control the vehicles on a road so as to assign right of way to traffic.
- This sign is triangular in shape with apex downwards and white in colour with red border.
- This sign may be used in combination with a definition plate.

Prohibitory signs:-

No Straight way

600mm

One-way

No Left

No right

- These are meant to prohibit certain traffic movements, use of horns (or) entry of certain vehicle type.
- These are circular in shape and white in colour with a red border.

No parking sign:-

- It is meant to prohibit parking of vehicles at that place.
- Definition plate may be indicated.
- It is circular shape with a blue back ground, a red border and an oblique red bar at an angle 45˚.

No stopping and Standing sign:-

- It is meant to prohibit stopping of vehicles at that place.
- It is circular in shape with blue back ground and two oblique red bars at 45˚ at right angle.

Speed limit sign:-

- It is meant to restrict the speed of all vehicle on that stretch.
- These are circular shape, white background, red border and black numerals.

Restriction end sign:-

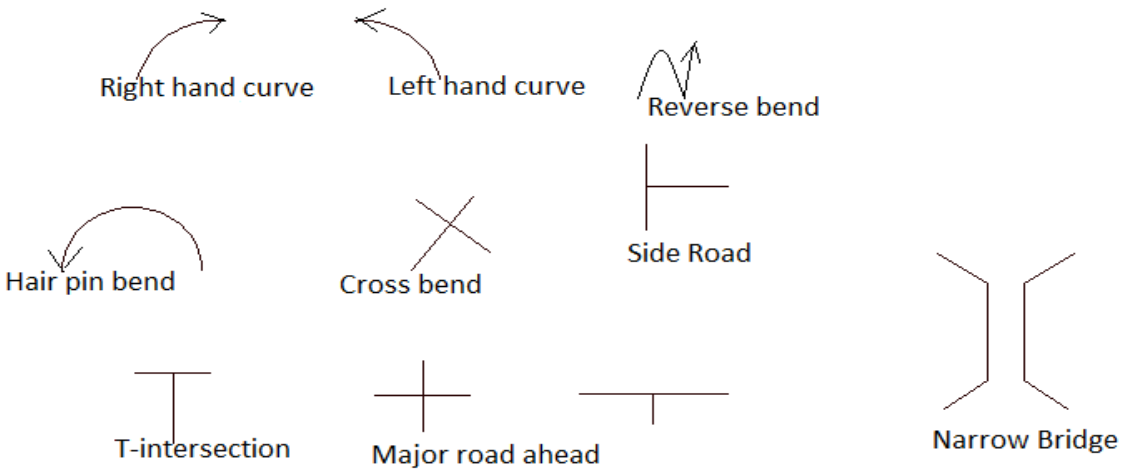
- Prohibitions notified is cease to apply after seeing it.
- These signs are also circular with a white back ground and a broad diagonal black bond at 45˚.

Warning signs:- (cautionary signs)

- These are used to warn the road users of certain hazardous conditions that exist on (or) adjacent to the roadway.
- The warning signs are in the shape of equilateral triangle with its apex pointing upwards.
- They are white background, red border and black symbols.
- These are located in advance at a distance of

120m ----> NH/SH
90m ----> MDR
60m ----> ODR
40m ----> VR

On urban roads, this distance is 50m



Informatory signs:-

- These are used to guide the road users along the route.
- It informs the destination, distance and provide travel easier, safe and pleasant.
- The direction and place identification signs are rectangular with white background, black border and black arrows and letters.
- Facility (i.e., Telephone, petrol pump, hospital) information signs are rectangular with blue back ground and white/black letters/symbols.

Traffic signal:-

- At intersection where there are large no. of crossings and right turn traffic, it requires traffic control.
- Earlier, traffic control is carried by traffic police.
- Traffic signal is alternative device to control traffic at intersections.

Advantages of traffic signals:-

1) They provide already movement of traffic and increase handling capacity.
2) They reduce certain type of accidents.
3) Pedestrian can cross road safely.
4) Heavy traffic flow cross intersection safely.
5) Reasonable speed can be maintained.
6) Works economically, when compared to manual control.
7) Quality of traffic flow improved by forming platoons.

Disadvantages of traffic signal:-

1) The rear-end collisions may increase.
2) Improper design and location leads to violations.
3) Failure of signal due to electric power failure cause confusion to the road user.

Terminology:-

→ Cycle:-

The period of time required for one complete sequence of signal indication is called cycle.

→ Phase:-

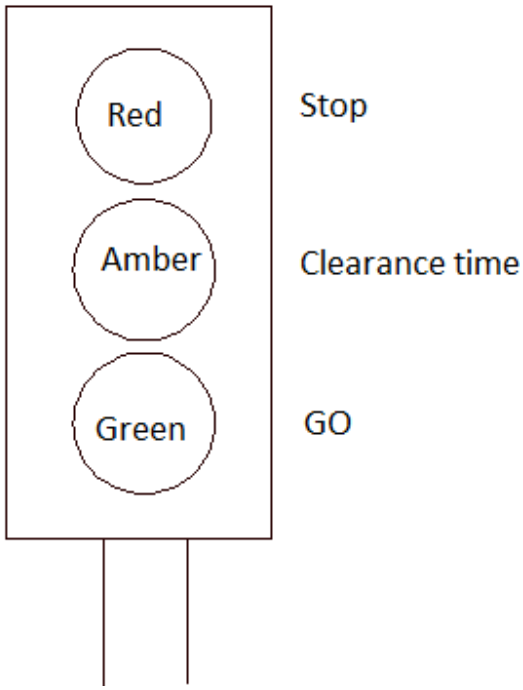
A part of the signal cycle allocated to a traffic movement (or) combination of traffic movements is called phase.

Types of traffic signals:-

a) Traffic control signals

i. Fixed time signal.
ii. Manually operate signal.
iii. Traffic actuated signal.

b) Pedestrian signal
c) Special traffic signal



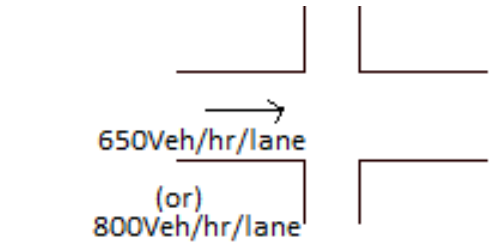
Type of traffic signal system:-

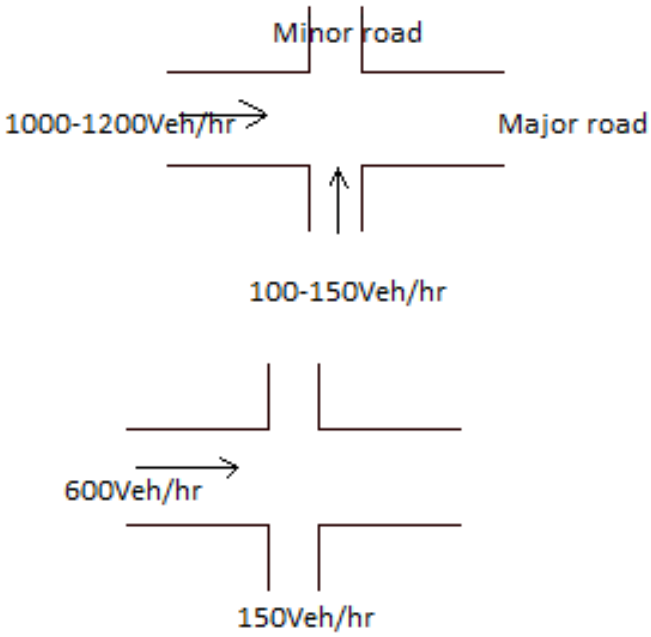
a) Simultaneous system.
b) Alternative system.
c) Simple progressive system.

d) Flexible progressive system.

Warrants for traffic control signal:-

Traffic signal should not be installed unless one (or) more of the following signal warrants are met.





- When 5 (or) more accidents occurred within 12 months period at a junction, the signal installation is preferred.

Webster's method:-

- This is the method used to design the traffic signal.

Ratio, $y_1=q_1/s_1$

$Y_2=q_2/s_2$

q_1, q_2 are normal flows veh/hr.

s_1, s_2 are saturation flow veh/hr.

The optimum signal cycle is given by:

$C_0= (1.5L+5) /1-Y$

$Y= y_1+y_2$; $L=2n+R$

N= no. of phases.

R= All red time.

Then, $G_1= y_1(C_0-L)/Y$ and $G_2= y_2(C_0-L)/Y$

Example:-

The average normal flow of traffic on cross roads A and B during design period are 400 and 250PCU/hr, the saturation flow values on these roads are estimated as 1250 and 1000 PCU/hr respectively. The all red time require for pedestrian crossing is 12 sec. design two phase traffic signal by webster's method.

Sol:-

$y_a= q_a/s_a$

$y_b= q_b/s_b$

$Y=y_a +y_b = 0.32+0.25=0.57$

$L=2n+R = 2*2+12 = 16$

Optimum cycle length,

C_0= (1.5L+5) /1-Y

= (1.5*16+5) /(1-0.57)

= 67.4sec = 67.5

G_a= y_a(C_0-L)/Y = 0.32(67.5-16)/0.57 = 29sec

G_b= y_b(C_0-L)/Y = 0.25(67.5-16)/0.57= 22.5sec

All red time =12sec.

Provide Amber time = 2 sec.

Total cycle time= 29+22.5+12+4 = 67.5sec

IRC METHOD:-

Step:-1 The pedestrian green time required for major and minor roads are calculate based on walking speed of 1.2m/s and initial walking time 7.0 sec.

Step:-2 The green time required for the vehicular traffic on the major road is increased in proportion to the traffic on two approach.

Step:-3 The cycle time is calculated after allowing amber time of 2.0secs each.

Step:-4 The minimum green time required for clearing vehicles during the cycle is determined for each lane of approach road assuming the first vehicle will take 60secs and subsequent vehicle of the queue will be cleared at the rate of 2.0secs.

Step:-5 The optimum signal cycle length/time is calculated using Webster formulae.

Road width	Saturation flow
3.0m	1850Pcu/hr
3.5m	1890
4.0m	1950
4.5m	2250
5.0m	2550
5.5m	2990

Step:-6 The signal cycle time and phases may be revised keeping in view the green time required for clearing the vehicles.

Road Marking:-

- Road marking are made of lines, patterns, words, symbols on the pavement, kerb, sides of island.
- These are to control, warn, guide (or) regulate the traffic.
- Light reflecting points are commonly used for traffic marking for night visibility.
- In order to ensure that the markings are seen by the road users, the longitudinal lines should be atleast 10cm thick.

The various types of markings may be classified as:

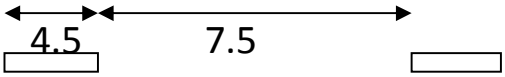
a) Pavement markings.
b) Kerb markings.
c) Object markings.
d) Reflector unit markings.

Pavement markings:-

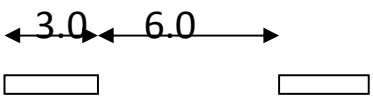
- It may be of white paint.
- Yellow colour markings are used to indicate parking restriction and for continuous centre line and barrier line.

1) Centre lines:-

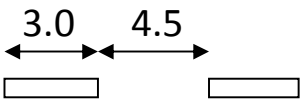
NH, SH



OTHER ROADS



URBAN ROADS



2) Lane lines:-
   - Lines are drawn to designate traffic lane.
   - These are used to guide the traffic and to properly utilize the carriageway.
3) No passing zone marking:-
   - These are marked to indicate that overtaking is not permitted.
4) Turn markings.
5) Stop lines.
6) Cross walk lines.
7) Approach to obstruction.
8) Parking space limits.
9) Border (or) edge lines.
10) Route direction arrows.
11) Bus stops.

Kerb marking:-

- These may indicate certain regulations like parking regulation.
- These are painted with alternate black and white line to increase the visibility from a long distance.

Object marking:-

- Physical obstruction on (or) near the roadway are hazardous and hence should be marked properly.
- Typical obstructions are supports for bridges, signs and signals, level crossing gate, traffic island, narrow bridge, culvert head walls etc.

Reflector unit markers:-

- These are used as hazard markers and guide markers for safe driving during night.
- Hazard markers reflecting yellow light should be visible from a long distance of about 150m.

UNIT-7
AT GRADE INTERSECTION DESIGN

- At the intersection, there are through, turning and crossing traffic and these traffic movements may be

handled in different ways depending on type of intersection and design.

- The efficiency, safety, speed, cost of operation and capacity of road system depend on intersection design.

Intersections are classified as:-

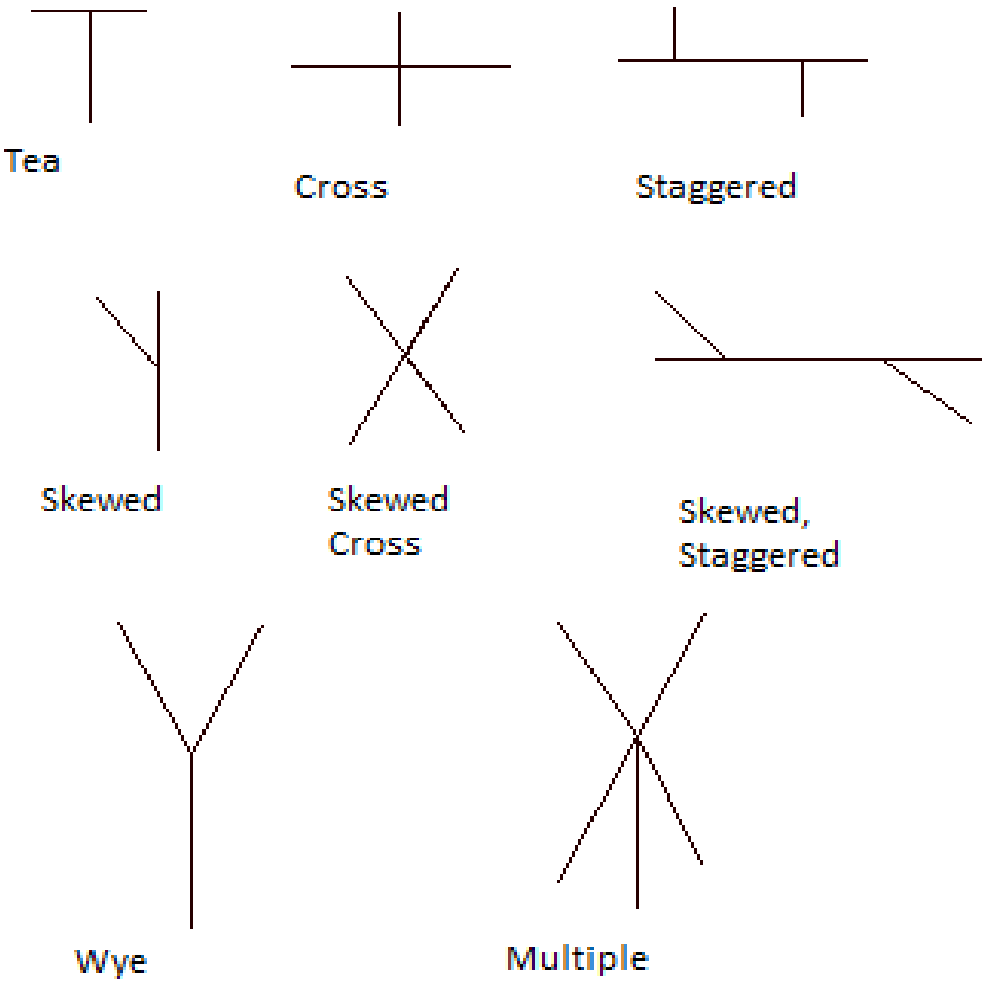
1) At grade intersection:-
   - These include all roads which meet at same level. The traffic manoeuvres like merging, diverging and crossing are involved in the intersections at grade.
2) Grade separated intersection :-
   - The intersecting roads are separated by difference in level, thus eliminating crossing manoeuvres.

Some of the traffic factors to be considered in intersection design are relative speed and manoeuvre areas.

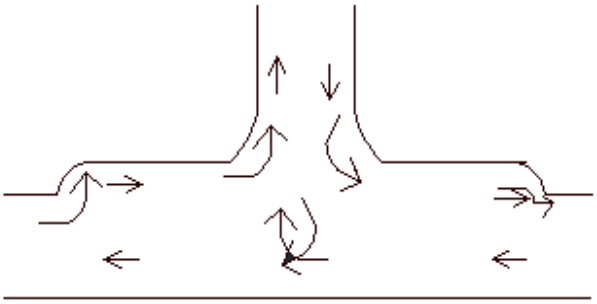
Basic requirements of at grade intersection are:-

a) At the intersection the area of conflict should be as small as possible.
b) The relative speed and particularly the angle of approach of vehicle should be small.
c) Adequate visibility should be available for vehicles approaching intersection.
d) Sudden change of path should be avoided.
e) Geometric features like turning radius and width of pavement should be adequately provided.
f) Proper signs should be provided on the road approaching intersection to warn the drivers.

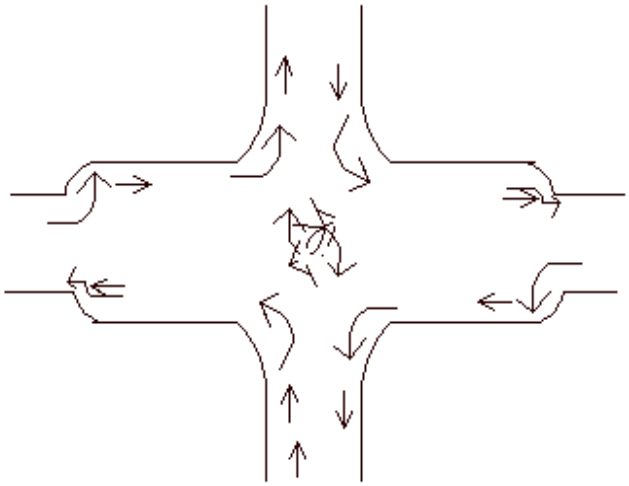
g) Good lighting at night is desirable.
h) If no. of pedestrians and cyclists are larger, separate provision should be made.



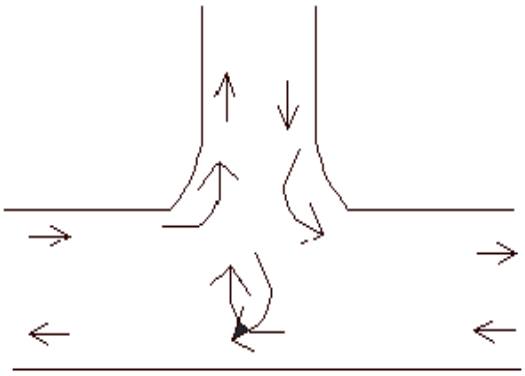
Unchannelised Intersections:



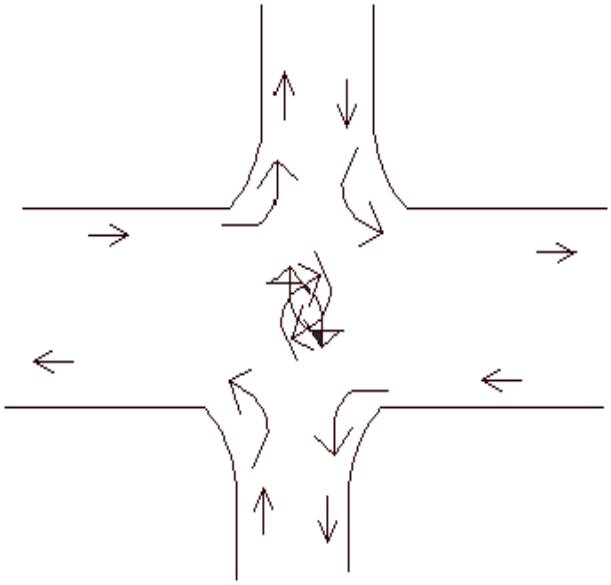
Tea(flared)



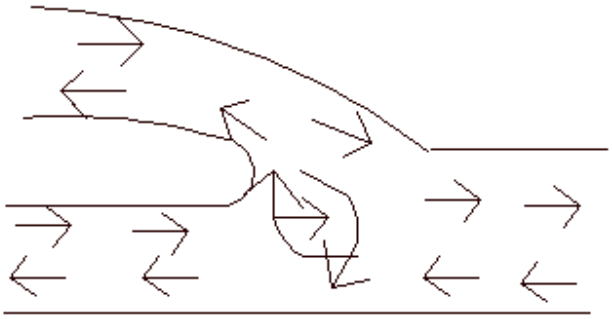
Cross(flared)



Tea(plain)



Cross(plain)



Skew(plain)

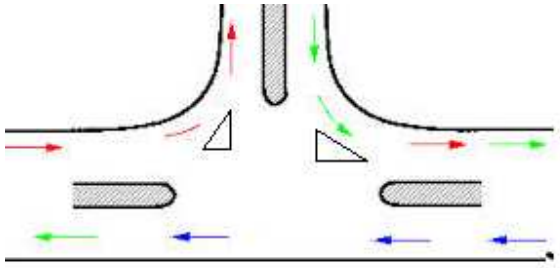
Channelized intersection:-

It is achieved by introducing islands into the intersectional area, thus reducing the total conflict area available.

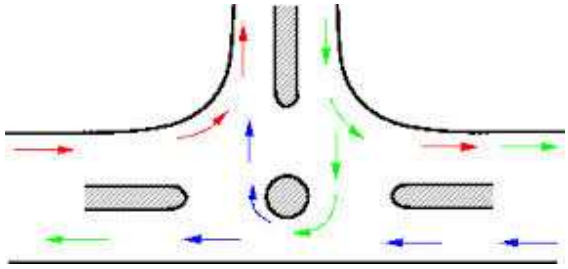
Advantages of channelized intersection:-

1) By channelization, vehicles can be confined to definite paths.
2) Angle of merging streams can be forced to be at flat angle so as to cause minimum disruption.
3) Both the major and minor conflict areas within the intersection can considerably be decreased.
4) Angle between intersecting streams of traffic may be kept as desired in a favourable way.
5) Speed control can be established over vehicles entering the intersection.
6) Refuse islands can be provided for pedestrians within the intersection area.
7) Points of conflicts can be separated.
8) The channelizing islands provide proper place for installation of signs and other traffic control devices.

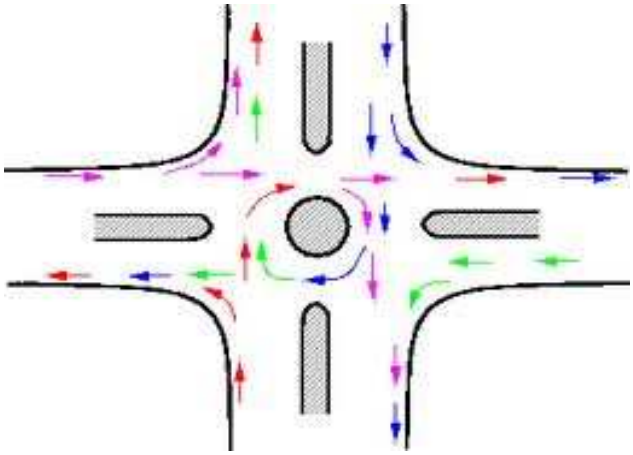
Channelised intersections:



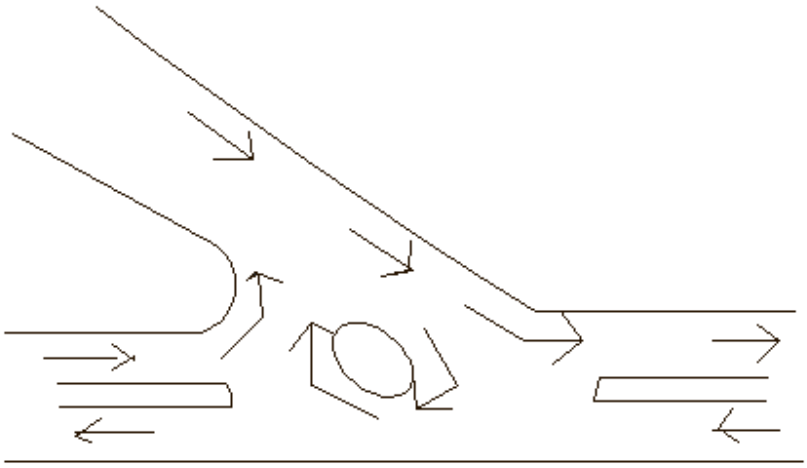
Tea (Partial Channelisation)



Tea (Complete Channelisation)



Cross(Complete Channelisation)



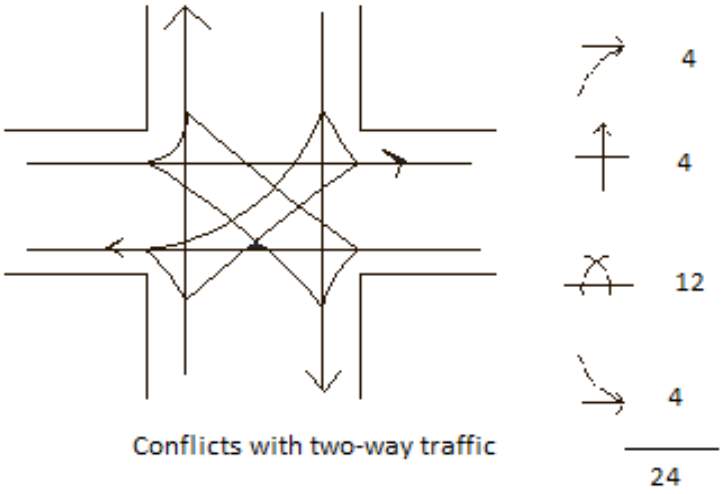
Skew(complete channnelisation)

Conflicts at intersection:-

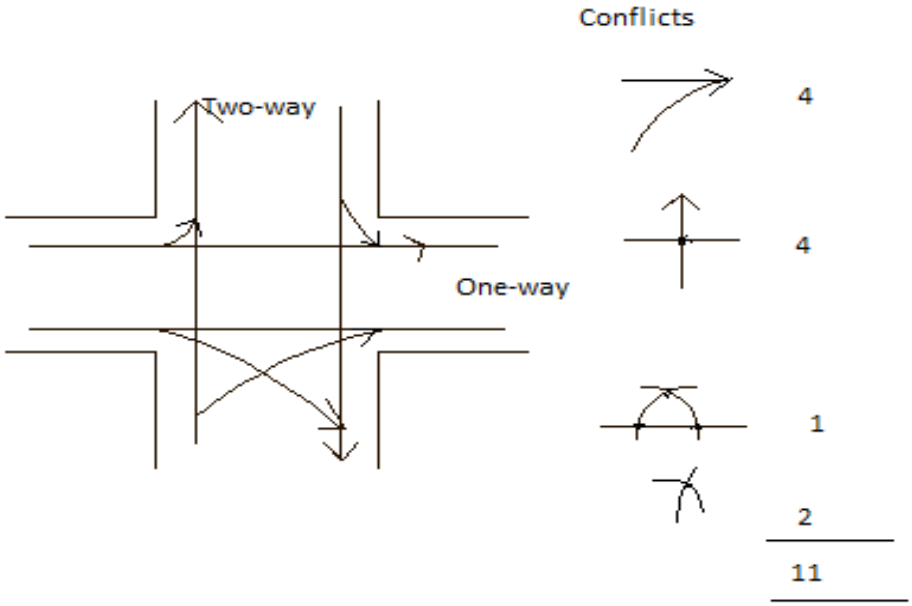
Types --> 1)Crossing conflicts

2)Merging conflicts

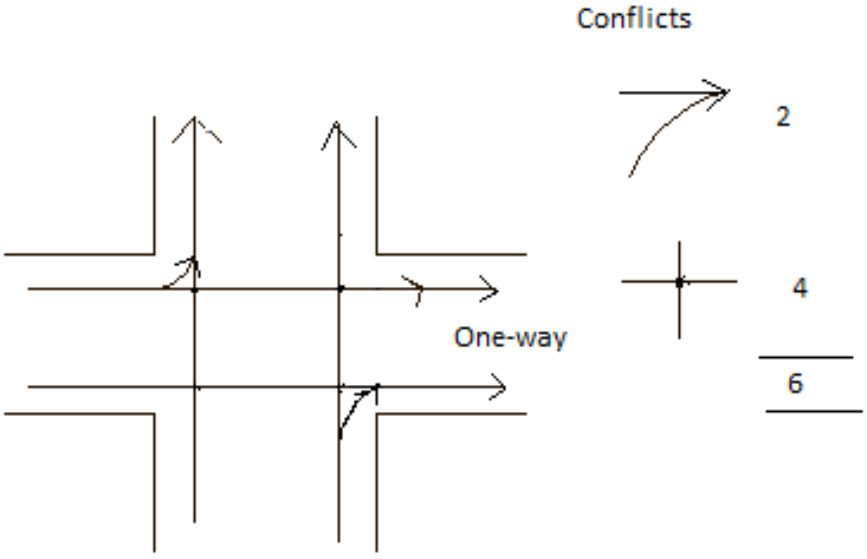
3)Divergin conflicts



Conflicts with two-way traffic



Conflicts with one-way regulation on one road



Conflicts with one-way regulation on both roads

w

Traffic island:-

- These are raised areas constructed within the roadway to establish physical channelization through which vehicular traffic may be guided.

The traffic island may be classified based on the function as:

1) Divisional island.
2) Channelizing island.
3) Pedestrian loading islands.
4) Rotary.

Divisional islands:-

- Divisional islands are intended to separate opposing flow of traffic on highway.
- By thus dividing the highway into two one-way roadways; head-on collisions are eliminated and other accidents are also reduced.

Channelized islands:-

- These are used to guide the traffic into proper channel through the intersection area.
- Traffic control devices can be installed on these areas.
- The size and shape of the channelizing islands will be very much depend up the layout and dimensions of the intersection.
- If the islands are not properly designed and placed, there is a possibility of violation of rules of the traffic resulting in greater hazards.

Uses of properly designed channelized islands:-

- The area of possible conflicts between traffic stream is reduced.
- They establish the desired angles of crossing and merging of traffic streams.
- They are useful when the direction of floe is to be changed.
- There serve as convenient locations for other traffic control devices.
- They serve as refuge island for pedestrians.

Pedestrian loading islands:-

- There are provided at regular bus stops and similar places for the protection of passengers.

Rotary island:-

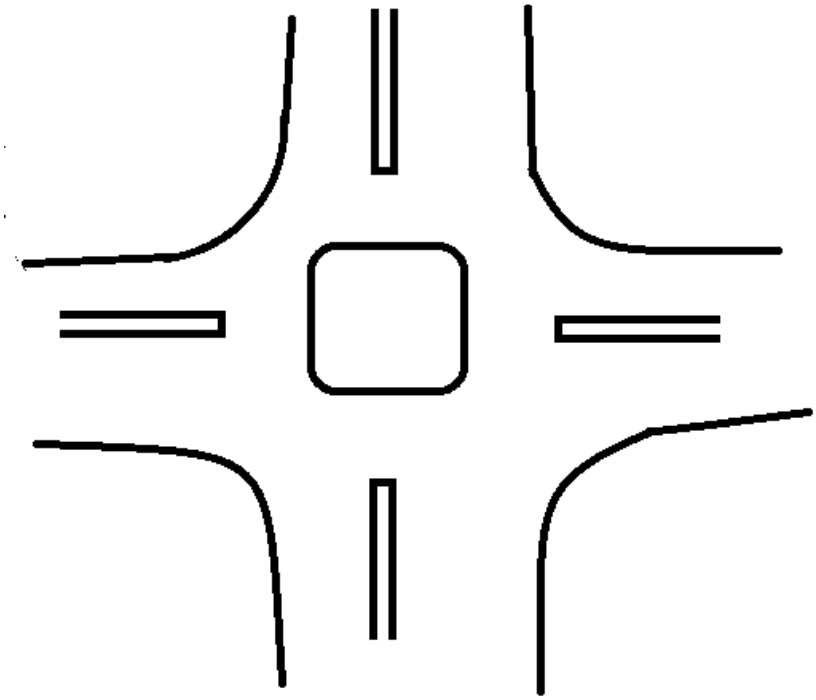
- It is the large control island of the rotary intersection.
- This island is much larger than the central island of channelized intersection.

ROTARY INTERSECTION:-

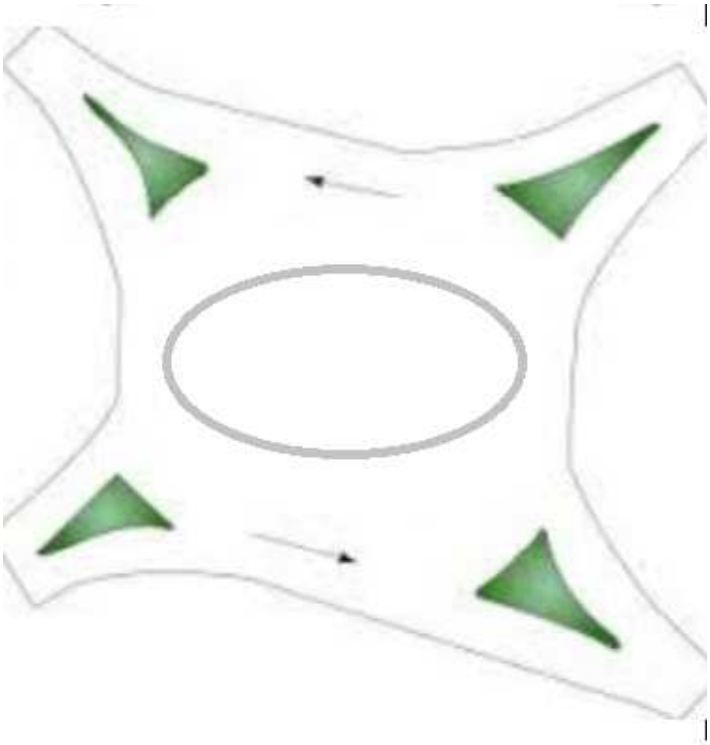
Definition:- It is specialised form of at grade intersection laid out for movement of traffic in one direction round a central island.

TYPES OF ROTARY INTERSECTIONS:-

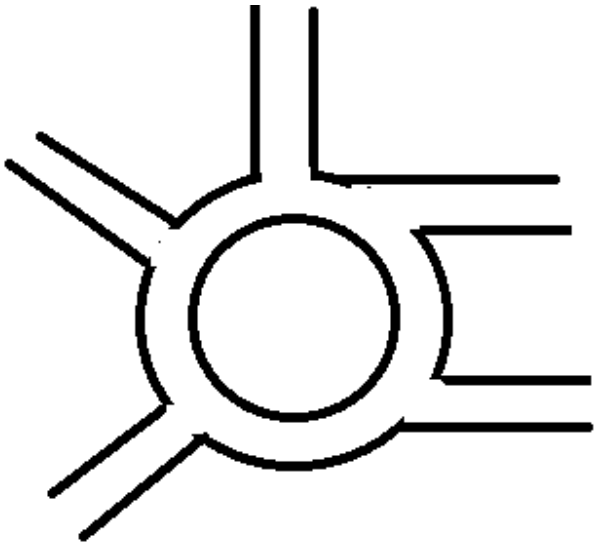
Circular



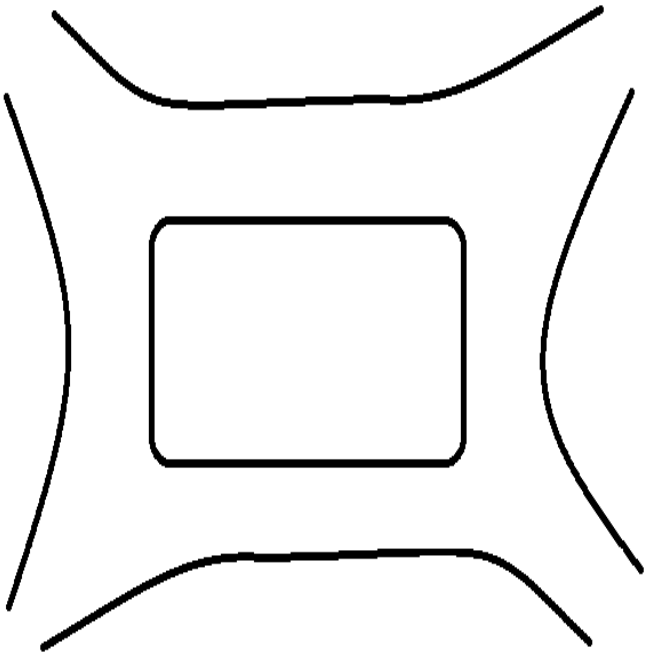
Squarish with rounded edges



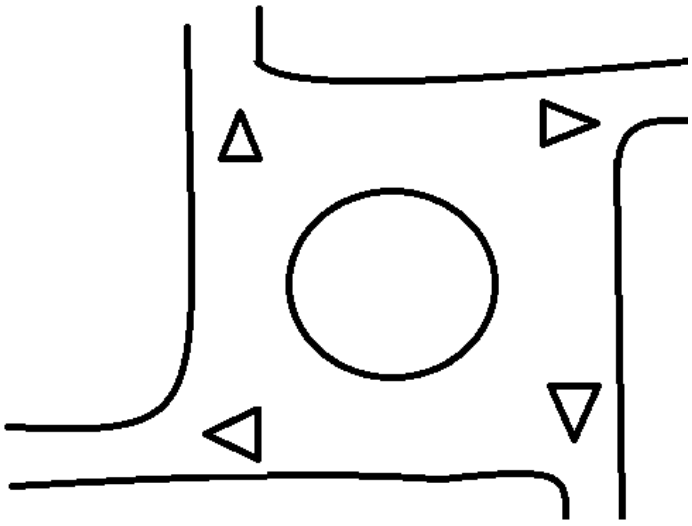
Elliptical



Irregular

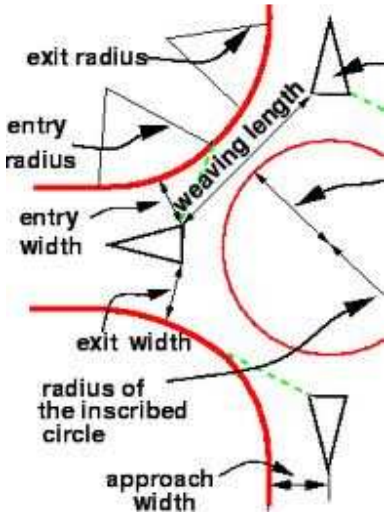


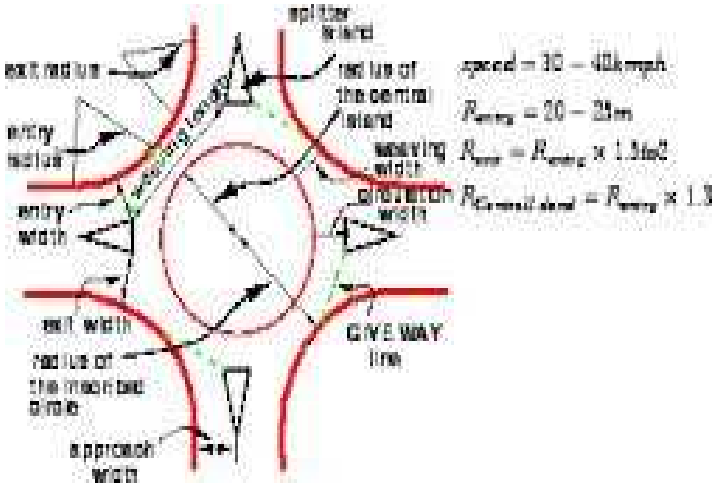
Rectangular with rounded edges



Turbine type

ROTARY DESIGN ELEMENTS:-





e_1 : width at entry

e_2 : width of non-weaving section

Diverging: The dividing of a single stream of traffic into separate streams

Merging: The converging of separate streams of traffic into single streams

Weaving: The combined movement of merging and diverging of traffic streams moving in the same direction

Weaving length: The length of the section of the rotary in which weaving occurs.

DESIGN SPEED:-

- The design speed of a rotary governs various elements such as radii and weaving lengths.
  - Rural areas 40Kmph
  - Urban areas 30Kmph

RADIUS AT ENTRY:-

- It is the determined by the speed, superelevation and coefficient and coefficient of friction.

  Rural areas 20-35m

  Urban areas 15-20m

RADIUS AT EXIST:-

R_{exit} = 1.5 to 2 times R_{entry}

- This will (Higher radius) enable the rotary to be cleared rapidly.

RADIUS OF CENTRAL ISLAND:-

$R_{central\ island} = 1.33 * R_{entry.}$

- Radius of Central Island may be kept slightly larger than that of curve at entry, this is to give a slight preference to the traffic already in the rotary.

WEAVING LENGTH:-

- The weaving length determines the ease with which the traffic can merge and diverge.
- The weaving is decided on the basis of factors such as width of wearing section, average width of the entry, total traffic and proportion of weaving traffic in it.

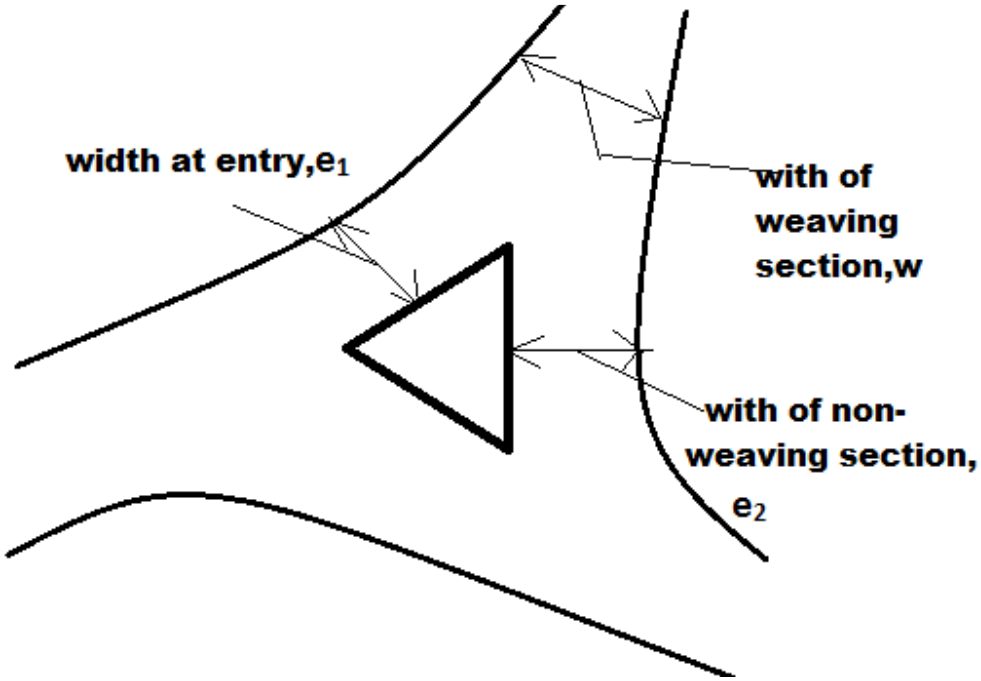
Design speed(Kmph)	**Minimum weaving length(m)**
40	45
30	30

WIDTH OF CARRIAGE WAY AT ENTRY AND EXIT:-

Carriageway width of approach road	**Radius at entry**	**Width of carriage at entry and exit(m)**
7m		6.5
10.5m		7.0

14m	25-35m	8.0
21m		13.0
7m	15-25m	7.0
10.5m		7.5
14m		10.0
21m		15.0

WIDTH OF ROTARY CARRIAGEWAY:-



$W = ((e_1+e_2)/2)+3.5$

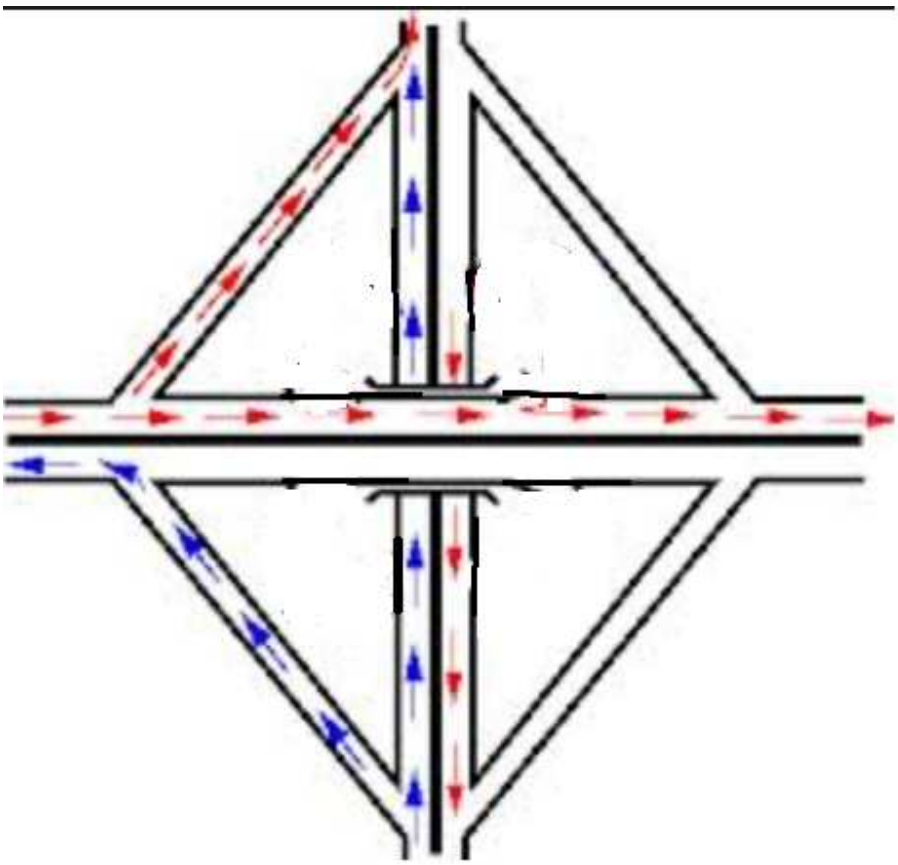
ENTRY AND EXIT ANGLES:-

$\theta_{entry} > \theta_{exit}$

$\theta_{entry} \approx 60^\circ$

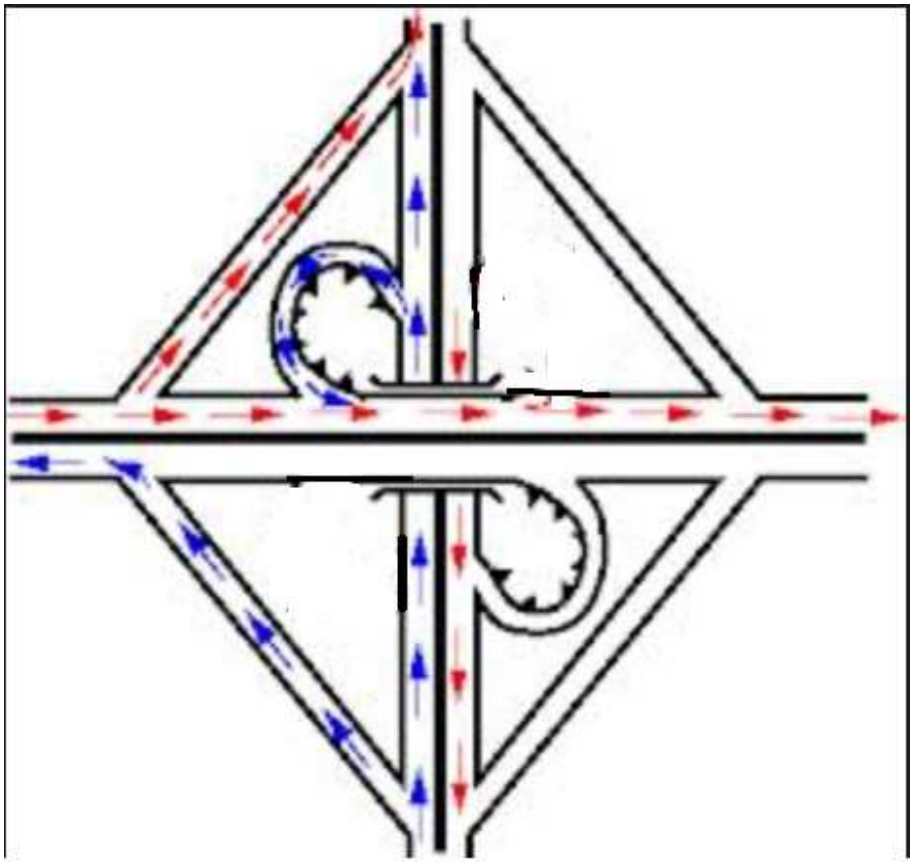
UNIT-VIII –GRADE SEPERATED INTERSECTION DESIGN

TYPES:-

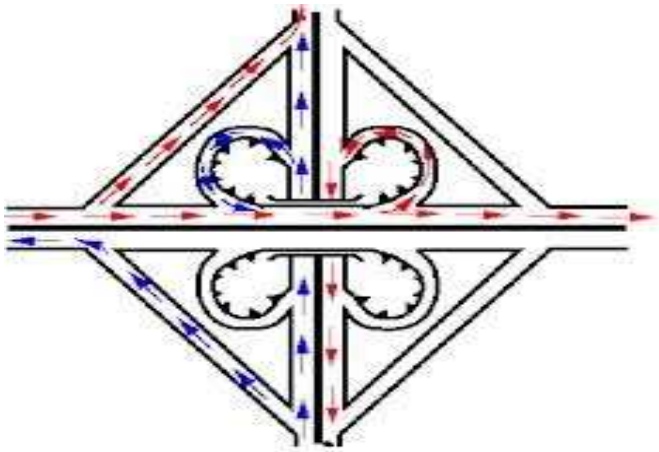


(a) Diamond type

(b)Rotary Interchange



(c) Partial clover leaf



(d)Full clover leaf

AVANTAGES OF GRADE SUPERATION:-

i. Maximum facility is given to the crossing traffic.
ii. There is increased safety for turning safety for turning traffic.
iii. There is overall in comfort and convenience to motorists and saving in travel time and vehicle operating cost.
iv. The capacity of grade operated intersection can practically that of two cross roads.
v. Grade separated is an essential part of controlled access highway like expressing.
vi. It is possible to adopt grade separation for all likely angles and layout.
vii. Stage construction of additional ramps is possible.

DISADVANTAGES OF GRADE SEPERATION:-

i. It is very costly.
ii. In urban/built up areas, grade separation is difficult.
iii. In flat (or) plain terrain, grade separation may introduce undesirable crests and sags in the vertical alignment.

ADVANTAGES OF OVERPASS:-

- When the wider road is taken above, the cost of the bridge structure will be less.

DISADVANTAGES OF OVERPASS:-

- There will be restrictions to sight distance useless long vertical are provided.

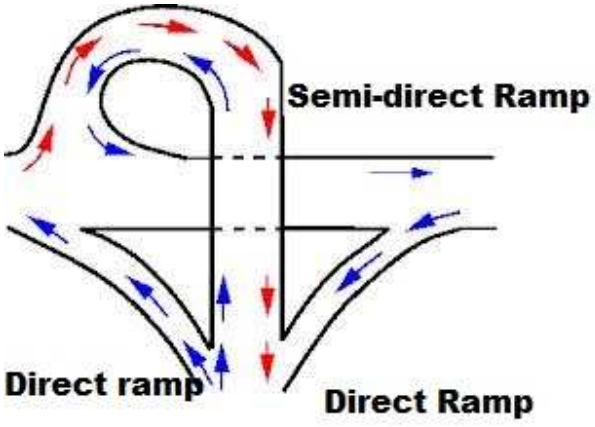
ADVANTAGES OF UNDERPASS:-

- It is advantageous, when the main highway is taken along the existing grade without alteration of vertical alignment and cross is depressed.

DISADVANTAGES OF UNDER PASS:-

- Drainage problems at the underpass.

TRUMPET:-



- Simple way to end one freeway at another.
- It requires one/two bridge.
- It will take up more land.

ADVANTAGES OF ROTARY:-

I. Crossing manoeuvre is converted to weaving (or) merging and diverging . Thereby, accident impact will be reduced.
II. All the turning movements gets equal opportunity.
III. Variable cost of operation of automobile is less at traffic rotary then signalled intersection.
IV. There is no necessity of traffic police.
V. The possible number of accidents and severity of accidents are quite low.

VI. Rotaries are advantages, when the intersecting roads is etween four and seven.
VII. Capacity of intersections is the highest of all other intersections.

LIMITATIONS OF ROTARY:-

I. Rotary requires comparatively a large area.
II. When there is no. of pedestrian traffic exist, traffic police control is necessary.
III. When pedestrian and cyclist is more, the design of rotary is complex.
IV. Where the angle of intersection of two roads is too acute (or) when there are more than seven roads intersecting, rotaries are unsuitable.
V. When the distance between intersections are less, rotaries become troublesome.
VI. When the traffic volume is very low in most of the rural areas in India, Rotary construction cannot be justified.

IRC Method of signal design:-

Step(i):-

The pedestrian green time required for major and minor roads are calculated based on walking for major and minor roads are calculated based on walking speed of 1.2m/s and initial walking of 7.0sec.

Step(ii):-

The green time required for the vehicular traffic on the major road is increased in proportion to the traffic on the approach roads.

Step(iii):-

The cycle is calculated after allowing amber time of 2.0sec each.

Step(iv):-

The minimum green time required for clearing vehicles arriving during a cycle is determined for each of approach assuming that the first vehicle will take 6.0secs. and the subsequent vehicles(PCV) of the queue will be cleared at a rate of 2.0sec.

Step(v):-

The optimum single cycle time is calculated using webster's formula. The saturation flow values may be as 1850, 1890, 1950, 2250, 2550, 2990, PCU/hr approach road widths 3.0, 3.5, 4.0, 4.5, 5.0,5.5m

For width above 5.5m, the saturation flow may be assumed as 525PCV/hr/mt.

The lost time is calculated from the amber time, intergreen time and initial delay of 4.0Sec

Step(vi):-

The single cycle time and phases may be revised keeping n view the green keeping in view the green time required for cleaning the vehicles.

Problem:

At a right angled intersection of two roads, road1 has 4 lanes with a total width of 12.0m and road2 has two lanes with a total width of 6.6m.The volume of traffic approaching. The intersection during design hour are 900 and 743PCU/hr on the two approaches of road 1 and 278 and 180PCU/hr on the two approaches of road2. Design the signal timing as per IRC guidelines.

Sol:

Design traffic on road1 = higher of the two approach volume per lane =900/2 =45PCU/hr

Design traffic on road 2 =278PCU/hr

(i) Pedestrian green time road1

Pedestrian green time for road 2 =(6.6/1.2)+7.0 = 12.5sec.

Green time for road2, G_2 = 17.0sec.

(ii) Green time for road1, G1 = 17*(450/278) = 27.5sec

(iii) Adding 2.0sec each towards clearance amber and 2.0sec inter-green period for each phase, total cycle time required = (2+17+2)+(2+27.5+2) = 52.5sec.

Signal cycle time may be conveniently set in multiplies of fire Secs and so the cycle time = 55sec.

The extra 2.5sec per cycle may be apportioned to green times of road1 and 2, as 1.5 and 1.0sec and so G1 =27.5+1.5 =29.0sec and G2=17.0 +1.0 = 18sec

(iv) Vehicle arrives per lane cycle on road1

450/55 = 8.2PCU

Minimum green time clearing vehicle on road1 = 6+(8.2-1.0)2= 20.4sec.

Vehicle arrives per cycle on road2 = 6+(5.1-1.0)2 = 14.2sec.

(v) Lost time per cycle =[amber time +inter-green + time lost for initial dealy of first vehicle] for 2 phases

=(2+2+4)*2 =168

Saturation flow for road1 = 525*6 =3150per/hr

Saturation flow for road2 = 1850+((40*3)/5) =1874per/hr

y_1 = 900/3150 = 0.286 y_2 = 278/1874 = 0.148

y = 0.286 = 0.148 = 0.434

Optimum cycle time

C_o = (1.5L+5)/1-Y = 1.5*16+5/(1-0.434) = 51.2sec

Therefore the cycle time of 55sec designed earlier is acceptable.

Road	Green	Amber	Red	Cycle
Road1	29	2	22+2	55
Road2	18	2	33+2	55