HIGHWAY MATERIALS

Introduction

There are different highway materials, viz, soil, stone, bitumen, concrete. Each material has defined desirable properties for the purpose for which it is used. The desirable properties of soil as a highway material are:

- Short and long term stability of the subgrade and slopes of embankment.
- Compressibility within permissible limits.
- Adequate permeability
- Compaction should be ease and economical
- Minimum volume change at all conditions.

Subgrade soil

Subgrade soil is an integral part of the road pavement structure which directly receives the traffic load from the pavement layers. The subgrade soil and its properties are important in the design of pavement structure. The main function of the subgrade is to give adequate support to the pavement and for this the subgrade should possess sufficient stability under adverse climate and loading conditions. The formation of waves, corrugations, rutting and shoving in black top pavements and the phenomena of pumping, blowing and consequent cracking of cement concrete pavements are generally attributed due to the poor subgrade conditions.

Desirable Properties

The desirable properties of soil as a highway material are

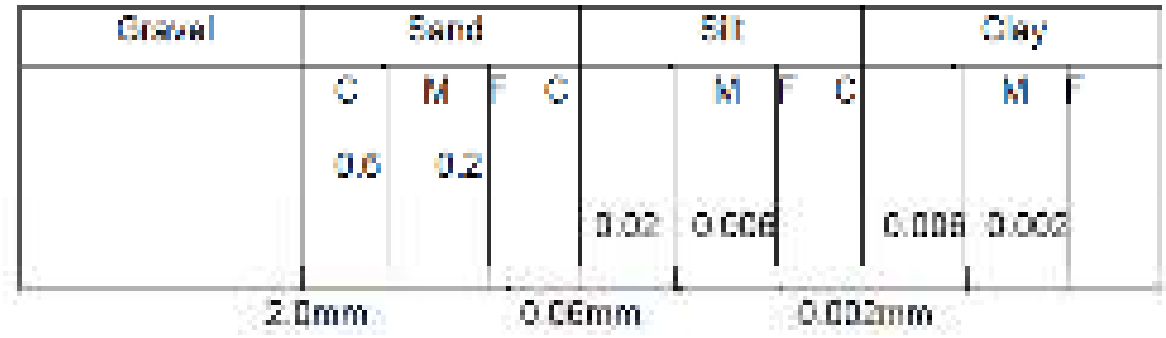
- Stability
- Incompressibility
- Permanency of strength
- Minimum changes in volume and stability under adverse conditions of weather and ground water
- Good drainage
- Ease of compaction

The soil should possess adequate stability or resistance to permanent deformation under loads, and should possess resistance to weathering, thus retaining the desired subgrade support.

Soil classification

1. Grain size analysis

According to size of grains soil is classified as gravel, sand, silt and clay. As per Indian standard classification the limits of grain size are as follows.



Fraction of soils

Larger than 2.00mm size Gravel

Between 2.00mm – 0.06 mm size Sand

Between 0.06mm – 0.002 mm size Silt

Smaller than 0.002 size Clay

2. Highway Research Board (HRB) classification of soils

This is also called American Association of State Highway Officials (AASHO) classification of Revised Public Roads Administration (PRA) soil classification system. Soils are divided into seven groups A-I to A-7. A-I, A-2 and A-3 soils are granular soils, percentage fines passing 0.074 mm sieve being less than 35. A-4, A-5, A-6 and A-7, soils are fine grained or silt-clay soils, passing 0.074 mm sieve being greater than 35 percent.

A-1 soils are well graded mixture of stone fragments, gravel coarse sand, fine sand and non-plastic or slightly plastic soil binder. The soils of this group are subdivided into two subgroups, A- 1-a, consisting predominantly of stone fragments or gravel and A-I-b consisting predominantly of coarse sand.

A-2 group of soils include a wide range of granular soils ranging from A- 1 to A-3 groups, consisting of granular soils and up to 35% fines of A-4, A-5, A-6 or A-7 groups. Based on the fines content, the soils of A-2 groups are subdivided into subgroups A-2-4, A-2-5, A-2-6 and A-2-7.

A-3 soils consist mainly, uniformly graded medium or fine sand similar to beach sand or desert blown sand. Stream-deposited mixtures of poorly graded fine sand with some coarse sand and gravel are also included in this group.

A-4 soils are generally silty soils, non-plastic or moderately plastic in nature with liquid limit and plasticity index values less than 40 and 10 respectively.

A-5 soils are also silty soils with plasticity index less than 10%, but with liquid limit values exceeding 40%. These include highly elastic or compressible, soils, usually of diatomaceous of miscialinious character.

A-6 group of soils are plastic clays, having high values of plasticity index exceeding 10% and low values of liquid limit below 40%; they have high volume change properties with variation in moisture content.

A-7 soils are also clayey soils as A-6 soils, but with high values of both liquid limit and plasticity index.

Group index is function of percentage material passing 200 mesh sieve (0.074mm) liquid limit and plasticity index of soil and is given by the equation.

$GI = 0.2\,a + 0.005ac + 0.01\,bd$

Where

a = that portion of material passing 0.074 mm sieve, greater than 35 and not exceeding 75 percent (expressed as a whole number from 0 to 40)

b = that portion of material passing 0.074 mm sieve, greater than 15 and not exceeding 35 percent (expressed as a whole number from 0 to 40)

c = that value of liquid limit in excess of 40 and less than 60 (expressed as a whole number from 0 to 20)

d = that value of plasticity index in excess of 10 and not more than 30 (expressed as a whole number from 0 to 20)

Test of Soil

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests. The tests used to evaluate the strength properties of soils may be broadly divided into three groups:

1. Shear tests
2. Bearing tests
3. Penetration tests

Shear tests

Shear tests are usually carried out on relatively small soil samples in the laboratory. In order to find out the strength properties of soil, a number of representative samples from different locations are tested. Some of the commonly known shear tests:

- Direct shear test,
- Tri-axial compression test,
- Unconfined compression test.

California Bearing Ratio (CBR) Test

This is a penetration test developed by the California division of highway. For evaluating the stability of soil subgrade and other pavement materials. The test results have been correlated with flexible pavement thickness requirement for highway and airfield. CBR test may be conducted in the laboratory on a prepared specimen in a mould or in situ in the field. The CBR test is an empirical test and not based on any theory or mathematical reasoning. However, it is one of the best penetration test to evaluate the sub grade strengths for roads and pavements. CBR values depend very much on moulding water content and density. CBR values are also used to identify the type of aircraft which can land a runway based on their CBR and load classification number relationship.

Laboratory CBR test

The laboratory CBR apparatus consists of

Cylindrical mould:

Mould 150mm dia, 175mm height with 50mm collar height, detachable perforated base with spacer disc of 148mm dia and 47.7mm thick is used to obtain a specimen of exactly 127.3mm height.

Loading Machine:

Compression machine operated at a constant rate of 1.25mm/min. Loading frame with cylindrical plunger 50mm dia & dial gauge for measuring the deformation due to application of load.

Compaction rammer

Type of compaction	No of layers	Wt of hammer (kg)	Fall (cm)	No of blows
Light compaction	3	2.6	31	56
Heavy compaction	5	4.89	45	56

Annular weight or surcharge weight

2.5 Kgs of surcharge weight of 147mm daimeter are placed on specimen both at the soaking and testing of prepared samples.

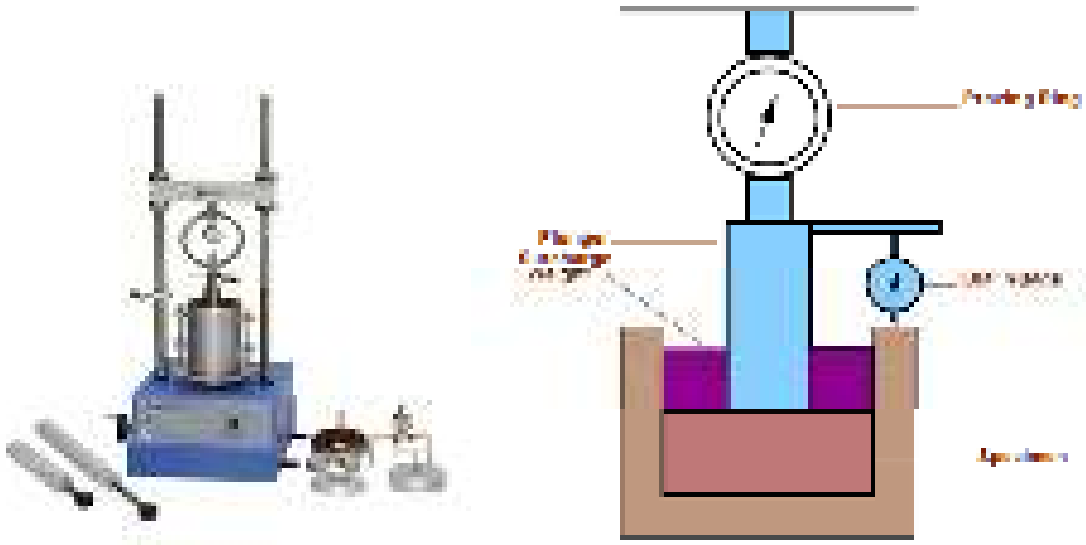
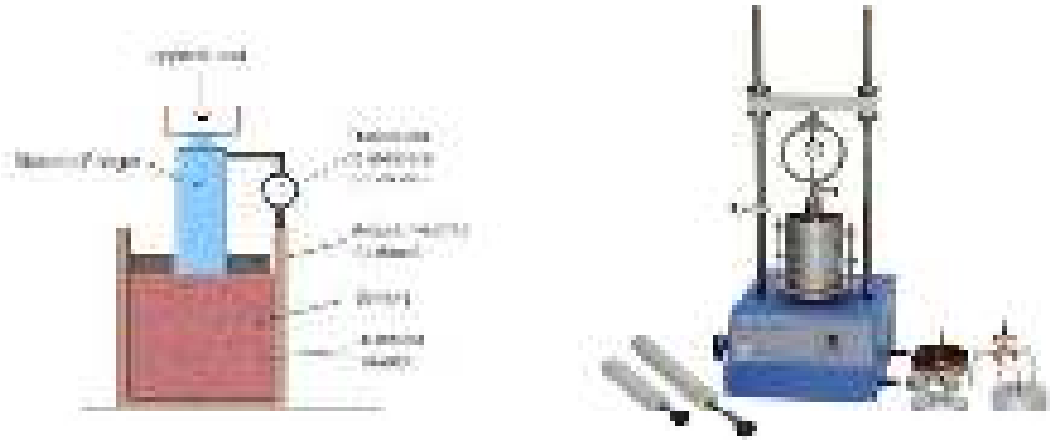


Figure: CBR test



Procedure:

CBR test may be performed on undisturbed soil specimens.

- About 5kgs of soil is taken passing though 20mm IS sieve and retained on 4.75mm IS sieve
- The soil is mixed with water up to OMC.

- The spacer disc is placed at the bottom of the mould over the base plate & a coarse filter paper is placed over the spacer disc. Then the moist soil sample is to be compacted over this in the mould by adopting either IS light compaction or IS heavy compaction.
- For IS heavy compaction 3 equal layers of compacted thickness about 44mm by applying 56 evenly distributed blows from 2.6kgs rammer.
- For IS heavy compaction 5 equal layers of compacted thickness about 26.5mm by applying 56 evenly distributed blows from 4.89 kg rammer.
- After compacting the last layer, The collar is removed and the excess soil above the top of the mould is evenly trimmed off by means of straight edge (of 5mm thickness).
- Clamps are removed ant the mould with compacted soil is lifted leaving below the perforated base plate & the spacer disc which is removed.
- Then the mould with compacted soil is weighed
- Filter paper is placed on the perforated base plate & the mould with compacted soil is inverted & placed in position over the base plate.
- Now the clamps of the base is tightened. Another filter paper is placed on the placed on the top surface of the sample & the perforated plate with adjustable stem is placed over it.
- Now surcharge weights of 2.5 or 5kgs are placed over the perforated plate & the whole mould with the weights is placed in a water tank for soaking such that water can enter the specimen both from the top & bottom.
- The initial dial gauge readings is recorded & the test set up is kept undisturbed in the water tank to allow soaking of the soil specimen for full 4 days or 96 hrs.
- The final dial gauge reading is noted to measure the expansion & swelling of the specimen due to soaking.
- The swell measurement assembly is removed, the mould is taken out of the water tank & the sample is allowed to drain in a perpendicular position for 15 min surcharge wweight, perforated plate with stem, filter paper are removed.
- The mould with the soil subgrade is removed from the base plate & is weighed again to determine the weight of water absorbed.
- Then the specimen is clamped over base plate surcharge weights are placed on specimens centrally such that the penetration test could be conducted.

- The mould with base plate is placed under the penetration plunger of loading machine.
- The penetration plunger is seated at the centre of the specimen & is brought in contact with the top surface of the soil sample by applying a seating load of 4kgs. The dial gauge for measuring the penetration values of the plunger is fitted in position.
- The dial gauge of proving ring & the penetration dial gauge are set to 0.
- The load is applied though the penetration plunger at a uniform rate of 1.5mm/min The load reading are recorded at penetration reading 0, 0.5, 1.0, 1.5, 2, 2.5, 3, 4, 5, 7.5, 10 & 12.5mm.
- In case the load reading starts decreasing before 12.5mm penetration, the maximum load & the corresponding penetration values are recorded.
- After the final reading the load is released & the mould from loading machine. The proving ring calibration factor is noted so that load dial gauge value can be converted into the load in kg.

Calculation :

Swelling or expansion ratio is calculated from the formula.

Expansion ratio = (100 (df – di))/h

Where, df = Final dial gauge after soaking in mm

di = Initial dial gauge before soaking in mm

h = initial height of the specimen in mm

Therefore,

$$\text{CBR} = \frac{Loadsustainedbythespecimenat2.5or5mmpenetration}{Loadsustainedbys\tan dardspecimenatcorrespondingpenetrationlevel} \text{ x}100$$

$$\text{CBR at 2.5mm} = \frac{P_1(kg)}{1370} \times 100\%$$

$$\text{CBR at 5mm} = \frac{P_2(kg)}{2055} \times 100\%$$

Generally CBR value @ 2.5mm penetration is higher & this value is adopted. The initial upward concavity of the load penetration is due to the piston surface not being fully in contact with top of the specimen. Top layer of soaked soil being too soft.

The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%.

Penetration of plunger (mm)	Standard load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

Modulus of subgrade reaction of soil

Plate bearing test

The plate bearing test has been devised to evaluate the supporting power of subgrade or any other pavement layer by using plates of larger diameter. Plate bearing test was originally meant to find the modulus of subgrade reaction in the westergaard's analysis for wheel load stresses in cement concrete pavement.

In the plate bearing test a compressive stress is applied to the soil or pavement layer through rigid plates of relatively large size & the deflection are measurement for various stress values. The deflection level is generally limited to a low value of 1.25mm to 5mm.

Modulus subgrade reaction (k)

K may be defined as the pressure sustained per unit deformation of subgrade at specified pressure level using specified plate size.

The standard plate size for finding K value is 75cm dia in same test a smaller plate of 30cm dia is also used (75, 60, 45, 30 & 22.5 cm dia).

Apparatus used:

Bearing plate: Mild steel of 75cm dia & 1.5 to 2.5 cm thickness.

Loading equipment: Reaction frame or dead load applied may be measured either by a proving ring or dial gauge assembly.

Settlement measurement:

It may be made by means of 3 or 4 dial gauge fixed on the periphery of the bearing plate from an independent datum frame. Datum frame should be supported from the loaded area.

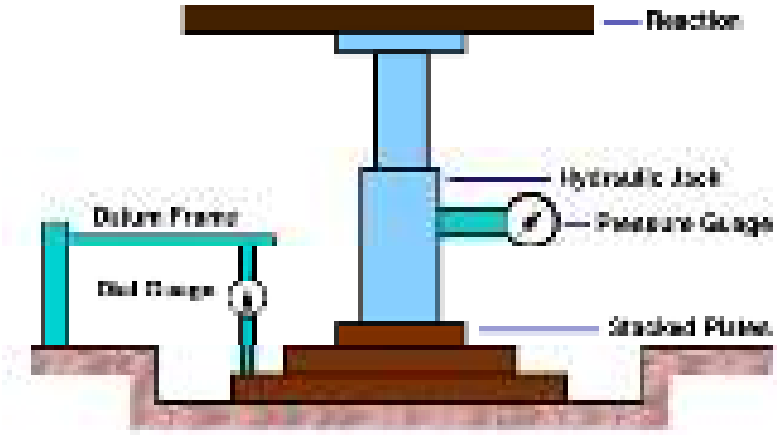
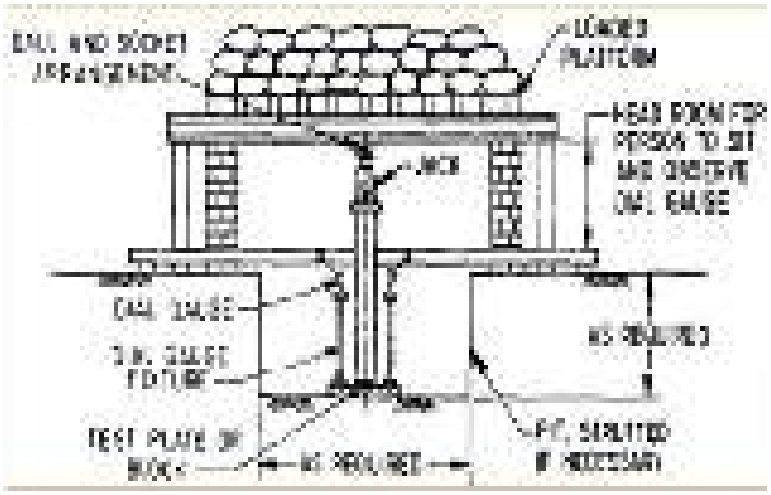
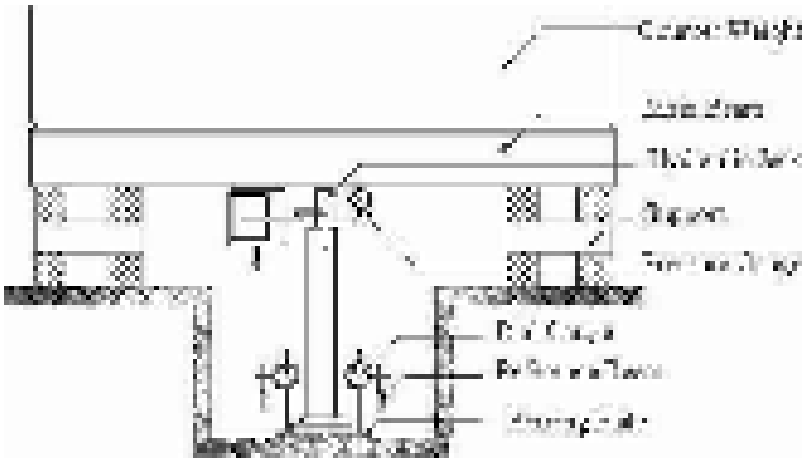


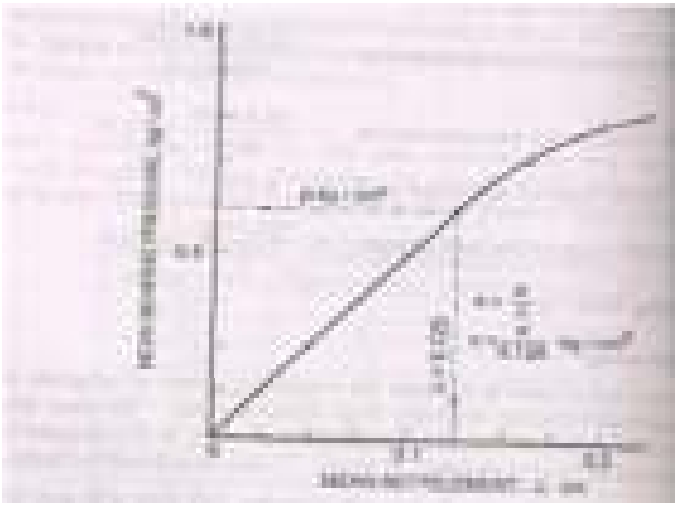
Figure: Plate load Test





Procedure:

- At the test site, about 20cm top soil is removed & the site is leveled & the plate is properly seated on the prepared surface.
- The stiffening plates of decreasing dia are placed & the jack & proving ring assembly are fitted to provide reaction against the frame.
- 3 or 4 dial gauges are fixed on the periphery of the palte from the independent datum frame for measuring settlement.
- A seating load of 0.07 kg/cm^2 (320 kgs for 75 dia) is applied & released after a few sec. The settlement dial gauges reading are now noted corresponding to zero load.
- A load is applied by means of jack sufficient to cause an average settlement of about 0.25mm.
- When there is no perception increase in settlement or when the rate of settlement is less than 0.025mm/min (case of clayey soil or wet soil), the reading of the settlement dial gauge are noted & the average settlement is found & the load is noted from the proving ring dial reading.
- The load is then increased till settlement increases to a further amount of about 0.25mm & the average settlement & load are found.
- The procedure is repeated till the settlement reaches 0.175cm. A graph is plotted with mean settlement versus mean bearing pressure (load/unit area) as shown in figure.



Bearing pressure settlement curve

The pressure p (kg/cm^2) corresponding to a settlement delta (Δ) = 0.125cm (obtained from the graph shown above). The modulus of subgrade reaction K is calculated from the relation.

K = $\frac{p}{0.125}\left(kg/cm^3\right)$

Correction for smaller plate size

In some cases the load capacity may not be adequate to cause 75cm dia plate to settle 0.175cm. In such a case a plate of smaller dia (say 30cm) may be used. Then K value should be found by applying a suitable correction for plate size. Assuming the subgrade to be an elastic medium with modulus of elasticity E (kg/cm^2), the theoretical relationship of deformation (cm) under a rigid plate of radius a (cm) is given by

Delta (Δ) = $\frac{1.18pa}{E}$

But, K = $\frac{P}{\Delta}$

Substitute the value of Δ in K

Therefore K = $\frac{p \times E}{1.18pa} = \frac{E}{1.18a}$

If the value of elastic modulus E is taken as constant for a soil, then K is inversely proportional to radius 'a' of the plate. Therefore Ka is constant.

i.e. Ka = K_1a_1

or K = K_1a_1/a

Therefore if the test is carried out with smaller plate of radius a_1 and the modulus of subgrade reaction K_1 is determined.

(i) Correction for moisture $\frac{p}{k} = \frac{p_s}{k_s}$

(ii) Correction for size of plate

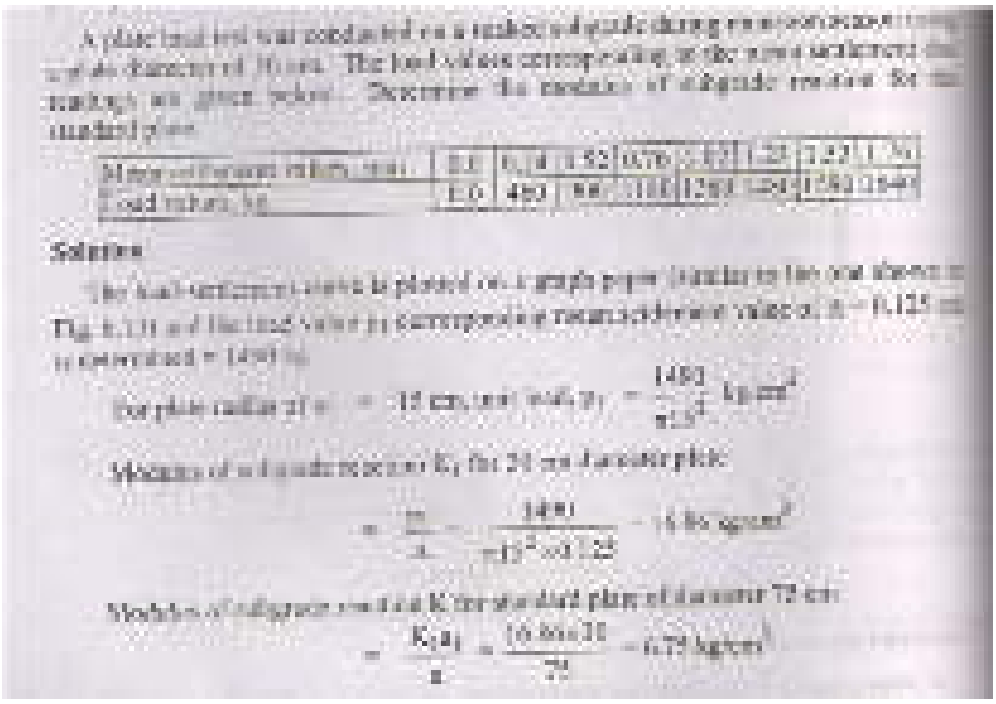
$$k = \frac{p}{\Delta}$$

$$\Delta = \frac{1.18pa}{E_s}$$

$$k = \frac{p}{\frac{1.18pa}{E_s}} = \frac{E_s}{1.18a}$$

A= radius of plate

$K_1a_1=k_2a_2$



AGGREGATES

Introduction

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic.

Strength:

The aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel load. The aggregates which are to be used in top layers of the pavements, particularly in the wearing course have to be capable of with 4jnhighs1csses in addition to wear and tear; hence they should possess sufficient strength resistance to crushing.

Toughness:

Aggregates in the pavements are also subjected to impact due to moving wheel loads. Sever impact like hammering is quite move on water bound macadam roads where stones protrude out especially after the monsoons. Resistance to impact (sudden load)

Durability: The stone used in pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may called soundness.

Shape of Aggregates:

The size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass, and not by the shape. Aggregates which happen to fall in a particular size range may have rounded, cubical, angular flaky or elongated shape of particles. It is e and donated particles will have less strength and durability when compared with cubical angular or rounded articles of the same Stone. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

Adhesion with Bitumen:

The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

Tests for Road Aggregate:

In order to decide the suitability of the road stones for use in construction, the following tests are carried out:

(a) Crushing test

(b) Abrasion test

(c) Impact test

(d) Soundness test

(e) Shape test

- Flakiness index
- Elongation index

(f) Specific gravity and water absorption test

(g) Bitumen adhesion test

Crushing strength test

The test is standardized by IS:2386 part-IV .The strength of course aggregate may be assessed by aggregate crushing strength test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement aggregates possessing high resistance to crushing or low aggregate crushing value are preferred.

The apparatus for standard test consists of a steel cylinder 15.2cm diameter with a base plate and plunger, compression testing machine, cylindrical measure of diameter 11.5cm and height 18cm, tamping rod and sieves.

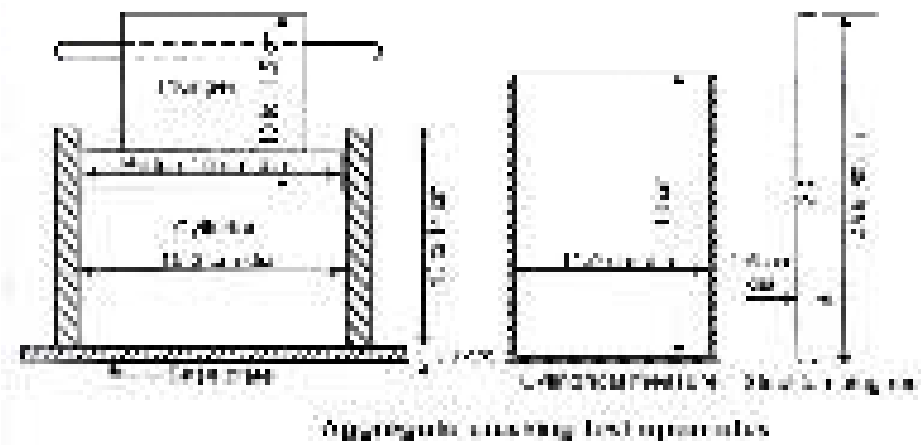
Dry aggregates passing 12.5mm IS sieve and retained on 10mm sieve is filled in the cylinder measure in three equal layers, each layer being ramped 25 times by the tamper. The test sample is weighed (equal to w1g) and placed in the test cylinder in compression machine.

The plunger is placed on the top of specimen and a load of 40 tones is applied at a rate of 4 tones per minute by the compression machine up to 10 minutes. The crushed aggregate is removed and sieved on 2.36mm IS sieve. The crushed material which passes this sieve is weighed equal to W_2 g. The aggregate crushing value is the percentage of the crushed material passing 2.36mm sieve in terms of original weight W_1 of the specimen.

Aggregate crushing value (ACV) = $\frac{W_2}{W_1}$ x 100

Where W_1 = Total weight of aggregate

W_2 = Weight of aggregate passing 2.36 mm sieve



A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.

ACV is not greater than 30 % for surface course

ACV is not greater than 45 % for base course

Abrasion test

Due to the movements of traffic the road stones used in the surface course are subjected to wearing action at the top. Hence road stones should be hard enough to resist the abrasion due to the traffic. Abrasion tests are carried out to test the hardness property of stones and to decide whether they are suitable for the different road construction works. The abrasion test on aggregate may be carried out using any one of the following three tests.

Los angles abrasion test

Deval abrasion test

Dorry abrasion test

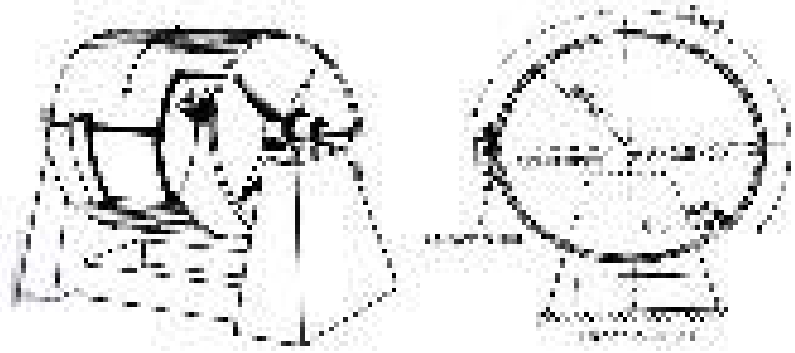
However los angles abrasion test is preferred as the result have been correlated with pavement performance and has been standardized in India (IS:2386 part-IV).

Los angles abrasion test : (Best test for aggregate)

The principle of los angles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregate and steel balls used as abrasive charge. Pounding action of these balls also exists during the test and hence the resistance to wear and impact is evaluated in this test. The los angles consists of a hollow cylinder closed at both ends, having inside diameter 70cm and length 50cm and mounted so as to rotate about its horizontal axis.

The abrasive charge consists of cast iron spheres of approximately diameter 4.8cm and each of weight 390-445 g. the number of spheres to be used as abrasive charge and their total weight have been specified based on grading of the aggregate sample.

The specified weight of aggregate specimen, (5 to 10 kg) is placed in the machine along with the abrasive charge. The machine is rotated at a speed of 30-33rpm for the specified number of revolutions(500-1000). The abraded aggregate is then sieved on 1.7mm IS sieve and the weight of powdered aggregate passing this sieve is found. The result of the abrasion test expressed as the percentage wear or the percentage of passing 1.7mm sieve expressed in terms of the original weight of the sample. The los angles abrasion value of good aggregate acceptable for cement concrete bituminous concrete and other high quality pavement materials should be less than 30 percent. Values up to 50 percent are allowed in base course like water bound and bituminous macadam road. This test is more dependable than other abrasion tests as rubbing and pounding action in the test simulate the field conditions better. Also correlation of los angles abrasion value with field performance and specifications of the test values have been established.



Abrasion value (AV) = $\frac{W_2}{W_1}$ x 100

AV is not greater than 30 % for surface course

AV is not greater than 50 % for base course

Coefficient of hardness = $20 - \frac{lossofweightingm}{3}$

Impact value test

A test designed to evaluate the toughness of stone or the resistance of the aggregates to fracture under repeated impacts is called impact test. The aggregate impact test is commonly carried out to evaluate the resistance to impact of aggregate and has been standardized by ISI. The aggregate impact value indicates a relative measure of resistance of aggregates to impact, which has a different effect then the resistance to gradually increasing compressive stress. The aggregate impact testing machine consists of a metal base and a cylindrical steel cup of internal diameter 10.2cm and depth 5cm in which the aggregate specimen is placed. A metal hammer of weight of 13.5-14.0 kg having a free fall from a height 38cm is arranged to drop through vertical guides.

Aggregate specimen passing 12.5mm sieve and retained on 10mm sieve is filled in cylinder measure in 3 layers by tamping each layer by 25 blows. The sample is transferred from the measure to the cup of the aggregates impact testing machine and compacted by tamping 25 times. The hammer is raised to a height of 38cm above the upper surface of the aggregate in the cup and is allowed to fall freely on the specimen. After subjecting the test specimen to 15 blows, the crushed aggregate is sieved on 2.36mm sieve. The aggregate impact value is expressed as the percentage of the fine formed in terms of the total weight of the sample.

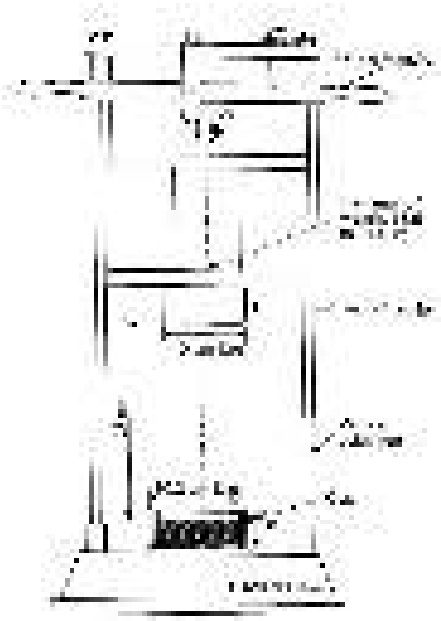
Aggregate impact value (AIV) = $\frac{W_2}{W_1}$ x 100

AV is not greater than 30 % for surface course

AV is not greater than 35 % for BM

AV is not greater than 40 % for WBM

The aggregate impact value should not normally exceed 30percent for the aggregate to be used in wearing course of pavements. The maximum permissible value is 35% for bituminous macadam and 40%for water bound macadam base courses.



Soundness test

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely. To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V. Aggregates of specified size are subjected to cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105^0 – 110^0 to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.

Shape tests

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which pass through the appropriate elongated slot of the thickness gauge are called flaky aggregates. Width of elongated slot would be 0.6 times the average of the size range. For example if the size range is 16to 20mm whose average size is 18mm,the width of the elongated slot is 10.8mm(0.6x18).hence in aggregates of 16to20mm size, the aggregates passing through 10.8mm are called flaky aggregate. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes.

The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. Test procedure had been standardized in India (IS:2386 part-I)

Flakiness index test

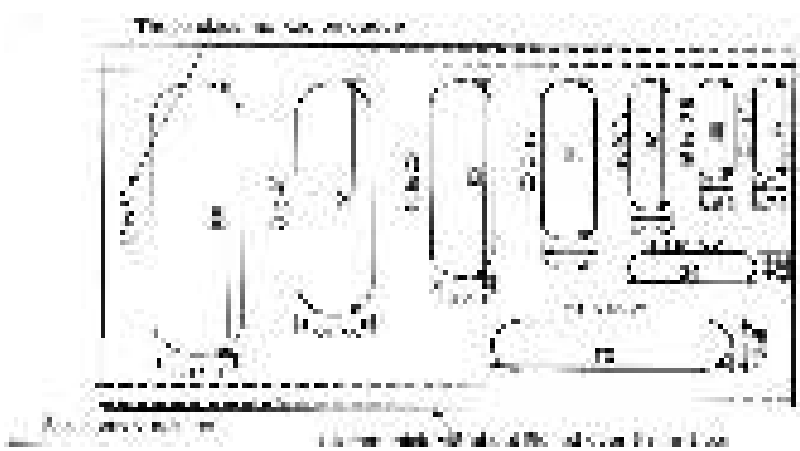
The flakiness index of aggregate is the percentage by weight of aggregate particles whose least dimensions /thickness is less than three fifths or 0.6 of their mean dimension. The test applicable to sizes larger than 6.3mm.standard thickness gauge is used to cause the thickness of the sample.

The sample of aggregates to be tested is sieved through a set of sieves and separated into specified size ranges. Now to separate the flaky material the aggregate which passes through the appropriate slot would be 0.6 of the average of the size range. If the size range of aggregate in a group is 16-20mm. The width of the slot too be selected in thickness gauge would be 18x0.6=10.8mm.

The flaky material passing the appropriate slot from each size range of test aggregates are added up and let this weigh be w. If the total weight of sample taken from the different sizes ranges is W.

$$\text{Flaky index} = \frac{w}{W} \times 100\ \%$$

In other words it is the percentage of flaky materials the width of which are less than 0.6 of the mean dimensions. It is desirable that the flakiness index of aggregates used in road construction is less than the 15 percent and normally does not exceed 25 percent.



Flakiness Index	**Elongation Index**	**Angularity number**
Size of aggregate is > 6.3 mm	Size of aggregate is > 6.3 mm	Angularity number lies between 0-11
$FI = \frac{W_2}{W_1} \times 100$ W_2 = Weight of aggregate passing 0.6d mean size strip	$EI = \frac{W_2}{W_1} \times 100$ W_2 = Weight of aggregate retained 1.8d mean size strip	It shows degree of packing AN = 67%- % solid volume = 67 - $\frac{w_a}{cG_a} \times 100$ 67% = represents volume of soild of rounded aggregate in a well compacted state which would have 33% voids. Angularity number measures void excess of 33%.
FI is not greater than15 %	EI is not greater than15 %	

$$G_a = \frac{\gamma_a}{\gamma_w} = \frac{w_a \cdot w_w}{v_a \cdot w_w}$$

$$\Rightarrow \frac{G_a \cdot w_w}{w_a} = \frac{v_a + v_v}{v_a}$$

$$\Rightarrow \frac{v_a}{v_a + v_v} = \frac{w_a}{G_a \cdot w_w}$$

$$\%soildvolume = \frac{w_a}{G_a \cdot w_w} \times 100$$

Specific Gravity and water absorption

The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. Because the aggregates may contain water-permeable voids, so two measures of specific gravity of aggregates are used: *apparent* specific gravity and *bulk* specific gravity.

- Apparent Specific Gravity (G_{app}), is computed on the basis of the net volume of aggregates i.e the volume excluding water-permeable voids. Thus

$$G_{app} = \frac{M_D / V_N}{W} \quad (1)$$

where, M_D is the dry mass of the aggregate, V_N is the net volume of the aggregates excluding the volume of the absorbed matter, W is the density of water.

- Bulk Specific Gravity (G_{bulk}), is computed on the basis of the total volume of aggregates including water permeable voids. Thus

$$G_{bulk} = \frac{M_D / V_B}{W} \quad (2)$$

where, V_B is the total volume of the aggregates including the volume of absorbed water.

- Water absorption, The difference between the apparent and bulk specific gravities is nothing but the water-permeable voids of the aggregates. We can measure the volume of such voids by weighing the aggregates dry and in a saturated, surface dry condition, with all permeable voids filled with water. The difference of the above two is M_W. M_W is the weight of dry aggregates minus weight of aggregates saturated surface dry condition. Thus

$$\text{water absorption} = \frac{M_W}{M_D} \times 100 \quad (3)$$

- The specific gravity of aggregates normally used in road construction ranges from about **2.5 to 2.9**. Water absorption values ranges from **0.1 to about 2.0 percent** for aggregates normally used in road surfacing. Water absorption should not be more than 0.6 % of the weight of aggregate.

Bitumen adhesion test

Test is known as static immersion test. Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold. This problem can be dealt with by removing moisture from the aggregate by drying and increasing the mixing temperature. Further, the presence of water causes stripping of binder from the coated aggregates. This problems occur when bitumen mixture is permeable to water. Several laboratory tests are conducted to arbitrarily determine the adhesion of bitumen binder to an aggregate in the presence of water. Static immersion test is one specified by IRC and is quite simple. The principle of the test is by immersing

aggregate fully coated with binder in water maintained at 40^0C temperature for 24 hours. IRC has specified maximum stripping value of aggregates should not exceed 5%.

Aggregate — Silica (Igneous)--- Electromagnetive----more prone to water -- Hydeophilic
— Limestone(sedimentary)–Electropositive--less prone to water-Hydrophobic

Tests for Aggregates with IS codes

Property of aggregate	**Type of Test**	**Test Method**
Crushing strength	Crushing test	IS : 2386 (part 4) - 1963
Hardness	Los Angeles abrasion test	IS : 2386 (Part 5)- 1963
Toughness	Aggregate impact test	IS : 2386 (Part 4)- 1963
Durability	Soundness test- accelerated durability test	IS : 2386 (Part 5)- 1963
Shape factors	Shape test	IS : 2386 (Part 1)- 1963
Specific gravity and porosity	Specific gravity test and water absorption test	IS : 2386 (Part 3)- 1963
Adhesion to bitumen	Stripping value of aggregate	IS : 6241-1971

BITUMINOUS MATERIALS

Introduction

Bituminous binders used in pavement construction works include both bitumen and tar. Bitumen is a petroleum product obtained by the distillation of petroleum crude where-as road tar is obtained by the destructive distillation of coal or wood. Both bitumen and tar have similar appearance, black in colour though they have different characteristics. Both these materials can be used for pavement works.

(i) paving bitumen from Assam petroleum, denoted as A-type and designated as grades A35, A 90, etc.

(ii) paving bitumen from other sources denoted as S-type and designated as grades S 35, S 90, etc.

Types of Bituminous Materials:

Asphalt: Bitumen containing inert material is asphalt.

Bituminous material used in highway construction may be broadly divided as

(i) Bitumen and

(ii) Tar

Bitumen may be further divided as petroleum asphalt or bitumen and native asphalt. There are different forms in which native asphalts are available. Native asphalts are those which occur in a pure or nearly pure state in nature. Native asphalts which are associated with a large proportion of mineral matter are called rock asphalts.

Bitumen:

Crude petroleum obtained from different places are quite different in their composition. The portion of bituminous material present in the petroleum's may widely differ depending on the source. Almost all the crude petroleum's contain considerable amounts of water along with crude oil. Hence the petroleum should be dehydrated first before carrying out the distillation. General types of distillation processes are fractional distillation. Bitumen is insoluble in water. It composes 87% carbon, 11% hydrogen and 2% oxygen by weight. It is obtained in solid or semi-solid state. It is generally used as surface coarse for roads, roof coverings etc.

Different forms of bitumen

Cutback bitumen: If the viscosity of bitumen is reduced by adding volatile diluent then it is known as cutback bitumen.

Normal practice is to heat bitumen to reduce its viscosity. In some situations preference is given to use liquid binders such as cutback bitumen. In cutback bitumen suitable solvent is used to lower the viscosity of the bitumen. From the environmental point of view also cutback bitumen is preferred. The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate. Cutback bitumen is used for cold weather bituminous road construction and maintenance. The distillates used for preparation of cutback bitumen are naphtha, kerosene, diesel oil, and furnace oil. There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC). RC is recommended for surface dressing and patchwork. MC is recommended for premix with less quantity of fine aggregates. SC is used for premix with appreciable quantity of fine aggregates. Generally used in colder region.

Bitumen Emulsion: It is a condition in which bitumen is suspended in an aqueous medium.

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilised by suitable material. Normally cationic type

emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC). Bitumen emulsions are ideal binders for hill road construction. Where heating of bitumen or aggregates are difficult. Rapid setting emulsions are used for surface dressing work. Medium setting emulsions are preferred for premix jobs and patch repairs work. Slow setting emulsions are preferred in rainy season.

It is used for patch up work and can be used in rainy season also.

Bituminous primers

In bituminous primer the distillate is absorbed by the road surface on which it is spread. The absorption therefore depends on the porosity of the surface. Bitumen primers are useful on the stabilised surfaces and water bound macadam base courses. Bituminous primers are generally prepared on road sites by mixing penetration bitumen with petroleum distillate.

Modified Bitumen

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999. It must be noted that the performance of PMB and CRMB is dependent on strict control on temperature during construction. The advantages of using modified bitumen are as follows

- Lower susceptibility to daily and seasonal temperature variations
- Higher resistance to deformation at high pavement temperature
- Better age resistance properties
- Higher fatigue life for mixes
- Better adhesion between aggregates and binder
- Prevention of cracking and reflective cracking

Requirements of Bitumen

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should posses following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

Tests on Bitumen:

Bitumen is available in a variety of types and grades. To judge the suitability of these binders various physical tests have been specified by agencies like ASTM, Asphalt Institute, British Standards Institution and the ISI. These tests include penetration test, ductility tests, softening point test and viscosity test. For classifying bitumen and studying the performance of bituminous pavements, the penetration and ductility tests are essential. The various tests on bituminous materials are

(a) Penetration tests

(b) Ductility tests

(c) Viscosity tests

(d) Float test

(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

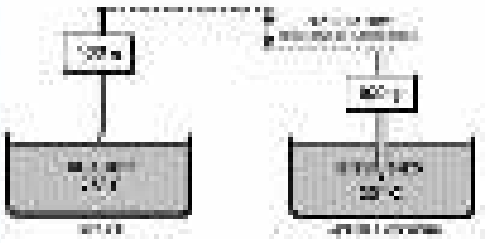
The penetration test determines the hardness and softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in five seconds. The sample is maintained at a temperature of 25^0C.

The penetrometer consists of a needle assembly with a total weight of 100g and device for releasing and locking any position. There is a graduated dial to read penetration values to 1/10th of a millimeter.

The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers to a depth at least 15mm in excess of the expected penetration. The sample containers are then placed in a temperature controlled water bath at temperature of 25°C for one hour. The sample with container is taken out and the needle is arranged to contact with the surface of the sample. The dial is set to zero or the initial reading is taken and the needle is released for 54 seconds. The final reading is taken on dial gauge. At least three penetration tests are made on this sample by testing at distances of at least 10mm apart. After each test the needle is disengaged and wiped with benzene and dried. The depth of penetration is reported in one tenth millimeter unit. The mean value of three measurements is reported as a penetration value. It may be noted that the penetration value is largely influenced by any inaccuracy as regards pouring temperature, size of needle weight placed on the needle and the test temperature.

The bitumen grade is specified in terms of penetration value 80-100 or 80/100 grade bitumen mean as that the penetration value of the bitumen is in the range 80 to 100 at standard test conditions or means penetration value lies between 8 to 10 mm. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred. Grade of bitumen is decided on the basis of penetration test. If grade of Bitumen is A-30 then that bitumen is manufactured from Assam petroleum and if grade is S-30 then other than Assam petroleum.

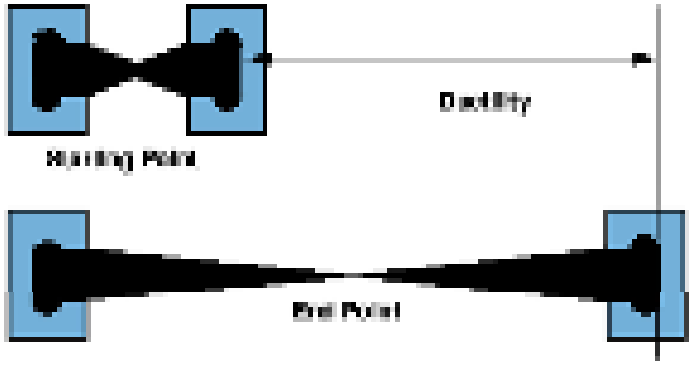
Tars are soft and hence penetration test is not used.



Ductility test:

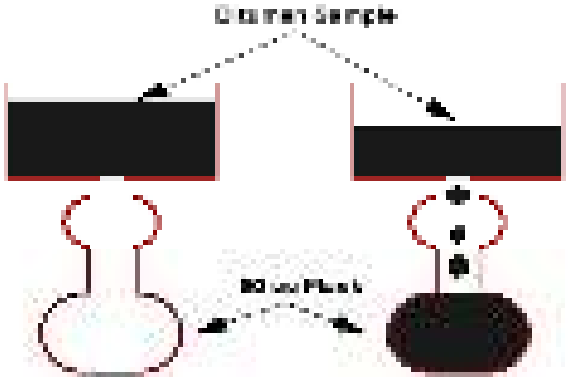
It is a measure of adhesiveness and elasticity of bitumen. Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27 C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc. A minimum ductility value of 75 cm has been specified by the BIS. Figure shows ductility moulds to be filled with bitumen.

It is a distance in cm to which a standard Briquette of size 10mmX10mm can be stretched before the thread breaks at a standard temperature of 27^0.



Viscosity test

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resist the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles. Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25 C or 10 mm orifice at 25 or 40 C.

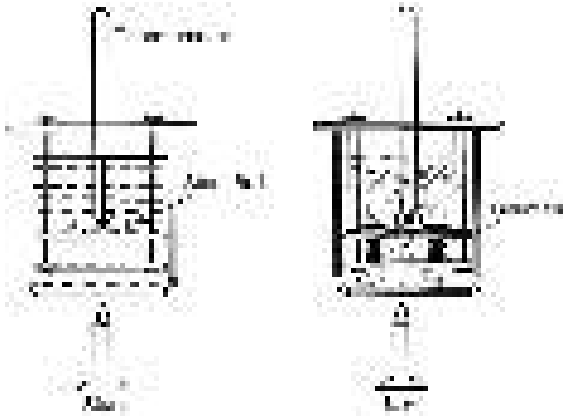


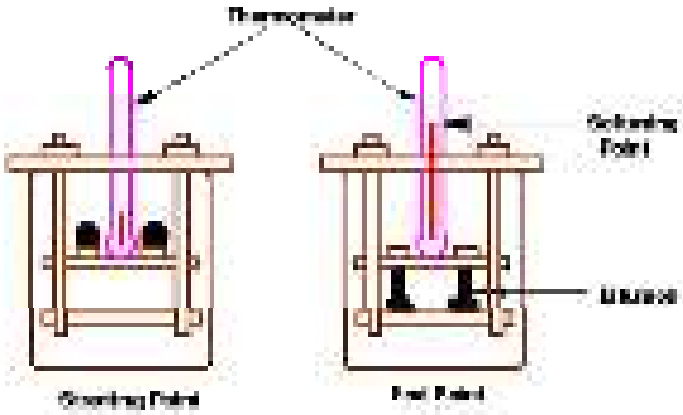
Softening point test:

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. The softening point of bitumen is usually determined by ring and ball test.

Generally higher softening point indicates lower temperature susceptibility and is preferred in warm climates brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature steel ball is placed upon the bitumen sample and the liquid medium is then heated at a rate of 5^0C per minute. The temperature at which the softened bitumen touches the metal placed at a specified distance below the ring is recorded as the softening point of bitumen. Hard grade bitumen posses higher softening point than soft grade bitumens.

The softening point of various bitumen grades used in paving jobs very between 35^0 to 70^0C.





Specific gravity of bitumen:

The density of the bitumen binder is a fundamental property frequently used as aid to classify the binders for use in paving jobs. In most applications, the bitumen is weighted but finally when used with aggregate system; the bitumen content is converted on volume basis using density values. The specific gravity value of bitumen is also useful in bituminous mix design.

The density of bitumen is greatly influenced by its chemical composition. Increased amounts of aromatic type compounds or mineral impurities cause an increase in specific gravity.

The specific gravity of bitumen material is the ratio of the mass of a given volume of the substance to the same of an equal volume of water, the temperature of both being 27^0C.the specific gravity is determined either by using a pycnometer or preparing a cube shape specimen in semi -solid or solid state and by weighing in water.

In this method, take clean and dry specific gravity bottle and take its weight(w_1).in the 2^{nd}case, fill the bottle with distilled water and dip it in water bath for 30 minutes and note down the weight(w_2). Next, fill half the bottle with bitumen sample and weigh (w_3).

Finally fill the bottle with half water and half portion with bitumen and weigh (w_4). Now we can find out specific gravity from the formulae.

$$\text{Specific gravity} = \frac{w3-w1}{[(w2-w1)-(w4-w3)]}$$

Generally the specific gravity of pure bitumen is in the range of 0.97-1.02. The specific gravity of cutback bitumen may be lower depending on the type and proportion of diluents used. Tars have specific gravity ranging from 1.10-1.25.

Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified

test conditions (175^0C). The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

Apparatus use Pensky Nartin closed and open cup apparatus

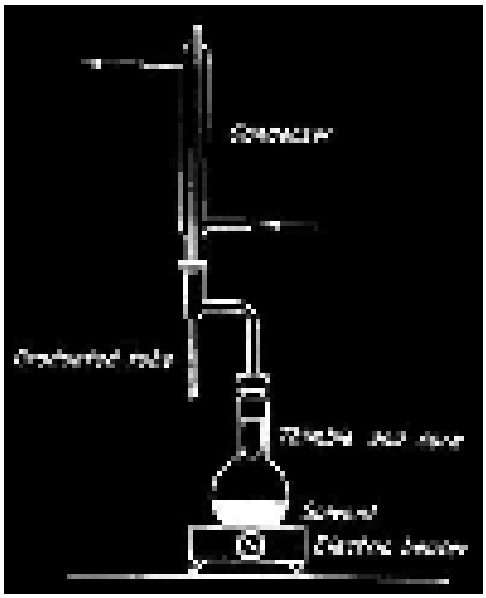
Float test

Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used. The apparatus consists of an aluminum float and a brass collar filled with bitumen to be tested. The specimen in the mould is cooled to a temperature of 5 °C and screwed in to float. The total test assembly is floated in the water bath at 50 °C and the time required for water to pass its way through the specimen plug is noted in seconds and is expressed as the float value.

Water content test

It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water in a bitumen is

determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling of the water. The weight of the water condensed and collected is expressed as percentage by weight of the original sample. The allowable maximum water content should not be more than 0.2% by weight.



Loss on heating test

When the bitumen is heated it loses the volatility and gets hardened. About 50gm of the sample is weighed and heated to a temperature of 163^0C for 5hours in a specified oven designed for this test. The sample specimen is weighed again after the heating period and loss in weight is expressed as percentage by weight of the original sample. Bitumen used in pavement mixes should not indicate more than 1% loss in weight, but for bitumen having penetration values 150-200 up to 2% loss in weight is allowed. The loss should be less than 5% of total weight otherwise it is not preferred for construction.

Tests for Bitumen with IS codes

Type of test	Test Method
Penetration Test	IS: 1203-1978
Ductility test	IS: 1208-1978
Softening Point test	IS: 1205-1978
Specific gravity test	IS: 1202-1978
Viscosity test	IS: 1206-1978
Flash and Fire Point test	IS: 1209-1978
Float Test	IS: 1210-1978
Determination of water content	IS: 1211-1978
Determination of Loss on heating	IS: 1212-1978

Cutback Bitumen

Cutback bitumen is defined as the bitumen, the viscosity of which has been reduced by a volatile dilutant. For use in surface dressings, some type of bitumen macadam and soil bitumen it is necessary to have a fluid binder which can be mixed relatively at low temperatures. Hence to increase fluidity of the bituminous binder at low temperatures the binder is blended with a volatile solvent. After the cutback mix in construction work, the volatile gets evaporated and the cutback develops the properties. The viscosity of the cutback and rate of which it hardens on the road depend on the characteristics and quantity of both bitumen and volatile oil used as the diluent. Cutback bitumens are available in three types, namely,

(i) Rapid Curing (RC) [Bitumen fluxed with Naptha/Gasoline]

(ii) Medium Curing (MC) [Bitumen fluxed with kerosene]

(iii) Slow Curing (SC) [Bitumen fluxed with high B.P. diluent]

This classification is based on the rate of curing or hardening after the application. The grade of cutback or its fluidity is designed by a figure which follows the initials; as an example RC-2 means that it is a rapid curing cutback of grade 2.The cutback with the lowest viscosity is designated by numeral 0, such as RC-0 and SC-0. Suffix numerals 0, 1, 2, 3, 4 and 5 designate progressively thicker or more viscous cutbacks as the numbers increase. This number indicates a definite viscosity irrespective of the type of cutback; in other words, RC-2, MC-2 all have the same initial viscosity at a specified temperature. The initial viscosity

values (in seconds, standard tar viscometer) of various grades of cutbacks as per ISI specifications are given in Table 6.7.

Thus lower grade cutbacks like RC-0, RC-l etc. would contain high prop solvent when compared with higher grades like RC-4 or RC-5, RC-0 and MC-0 may contain approximately 45 percent solvent and 55 percent bitumen, whereas, RC-5 and MC-5 may contain approximately 15 percent solvent and 85 percent bitumen. Rapid Curing Cutbacks are bitumens, fluxed or cutback with a petroleum Distillate such as naphta or gasoline which will rapidly evaporate after using in construction, leaving the bitumen binder. The grade of the R.C. cutback is governed by the proportion of the solvent used. The penetration value of residue from distillation up to 3600C of RC cutback bitumen is 80 to 120.

Medium curing cutbacks are bitumen fluxed to greater fluidity by blending with a intermediate-boiling-point solvent like kerosene or light diesel oil. MC cutbacks evaporate relatively at slow rate because the kerosene-range solvents will not evaporate rapidly as the gasoline-range solvents used in the manufacture of RC cutbacks. Hence the designation "medium curing" is given to this cutback type. MC products have good wetting properties and so satisfactory coating of fine grain aggregate and sandy soils is possible.

Slow curing cutbacks are obtained either by blending bitumen with high-boiling-point gas oil, or by controlling the rate of flow and temperature of the crude during the first cycle of refining. SC cutbacks or wood soils harden or set way slowly as it is a semi volatile material.

Various tests carried out on cut-backs bitumen are

(a) Viscosity tests at specified temperature using specified size of orifice.

(b) Distillation test to find distillation fractions, up to specified temperature and to find the residue from distillation up to 360°C

(c) Penetration test, ductility test and test for matter soluble in carbon disulphide on residue from distillation up to 360°C

(d) Flash point test on cutback using Pensky Martens closed type apparatus.

Bituminous Emulsion

A bitumen emulsion is liquid product in which a substantial amount of bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by means of one or more suitable materials. An emulsion is a two phase system consisting of two immiscible liquids; the one being dispersed as fine globules in the other.Usually, bitumen or refined tar is broken up into fine globules and kept in suspension in water. A small proportion of an emulsifier is used to facilitate the formation of dispersion and to keep the globules of dispersed binder in suspension.

Some of the general properties of road emulsions are judged by the following tests

(i) Residue on Sieving: It is desirable to see that not more than 0.25 percent by w of emulsion consists of particles greater than 0.15 mm diameter.

(ii) Stability to Mixing with Coarse Graded Aggregate: This test carried out to fit the emulsion breaks down and coats the aggregate with bitumen too early before mixing is complete.

(iii) Stability to Mixing with Cement : This test is carried out to assess the stability emulsions when the aggregate contains large proportions of fines.

(iv) Water Cement: To know the percentage water in the emulsion which depend the type of the emulsion.

(v) Sedimentation: Some sedimentation may occur when a drum of emulsion is standing before use, but on agitation, the emulsion redisperses and can be used.

(vi) Viscosity: The viscosity of emulsified bitumen should be low enough to be sprayed through jets or to coat the aggregates in simple mixing.

Three types of bituminous emulsion are prepared, viz., (i) Rapid Setting (RS), Medium Setting (MS) and (iii) Slow Setting (SS) types. Rapid Setting type emulsion is suitable for surface dressing and penetration macadam type of construction. Medium Setting type is used for premixing with coarse aggregates and Slow Setting type emulsion is suitable for fine aggregate mixes.

RS –Used for surface dressing

MS – Used for premixing with coarse aggregate

SS – Used for premixing with fine aggregate

Tar:

Tar is the viscous liquid obtained when natural organic materials such as wood and coal carbonized or destructively distilled in the absence of air. Based on the material from which tar is derived, it is referred to as wood tar or coal tar; the latter is more widely used for road work because it is superior. Three stages for the production of road tar are

(i) Carbonization of coal to produce crude tar

(ii) Refining or distillation of crude tar and

(iii) Blending of distillation residue with distillate oil fraction to give the desired road tar.

There are five grades of roads tars, viz., RT- I, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties. RT-l has the lowest viscosity and is used for surface painting under exceptionally cold weather as this has very low viscosity. RT-2 is recommended for standard surface painting under normal Indian climatic conditions. RT-3 may be used for

surface painting, renewal coats and premixing chips for top course and light carpets. RT-4 is generally used for premixing tar macadam in base course. For grouting purposes RT-5 may be adopted, which has the highest viscosity among the road tars.

Comparison between tar & bitumen

Bitumen	Tar
It has black to dark brown color	It also has black to dark brown in color
It is natural petroleum product	Tar is produced by the destructive distillation of coal or wool
It is soluble in carbon disulphide & in carbon tetrachloride	Tar is soluble only in toluene
It has better weather resisting property	It has inferior weather resisting property
Bitumen are less temp susceptible	Tar is more temp susceptible
Free carbon content is less	Free carbon content is More
It neither binds the aggregate well nor retains the presence of water	It binds aggregate more easily & retain it better in the presence of water.

BITUMINOUS PAVING MIXES

Requirements of Bituminous Mixes

The mix design should aim at an economical blend, with proper gradation of aggregates and adequate proportion of bitumen so as to fulfil the desired properties of the mix. Bituminous concrete or asphaltic concrete is one of the highest and costliest types of flexible pavement layers used in the surfacing course. The desirable properties of a good bituminous mix are stability, durability, flexibility, skid resistance and workability.

Mix design methods should aim at determining the properties of aggregates and bituminous material which would give a mix having the following properties.

(i) Sufficient stability to satisfy the service requirements of the pavement and the traffic conditions, without undue displacement

Marshal method of mix design:

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute.

Constitution of mix:-

(i) Coarse aggregate :- It offers compressive and shear strength an shows good interlocking property Ex: Granite

(ii) Fine aggregate : It fills the voids in the coarse aggregate stiffens the binder.
Example Sand, rockdust

(iii) Filler: It fill the voids, stiffens the binder and offers permeability.
Example: cement, lime

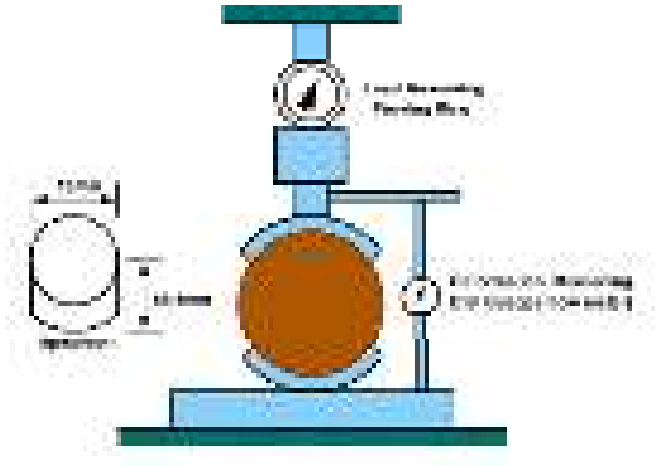
(iv) Binder: It fill the voids cause particle adhesion and offers impermeability.
Example: bitumen, asphalt

Steps of mixed design

1. Selection of aggregate
2. Determination of specific gravity
3. Proportion of aggregate
4. Preparation of specimen
5. Determination of specific gravity of compacted specimen
6. Stability test on compacted specimen
7. Selection of optimum binder content

Requirement of mix design:

1. Sufficient stability to carry load
2. Sufficient flexibility to prevent cracking
3. Durability/soundness
4. Sufficient voids in the specimen should be available for additional compaction due to traffic load
5. Skid resistance



Marshall Mould

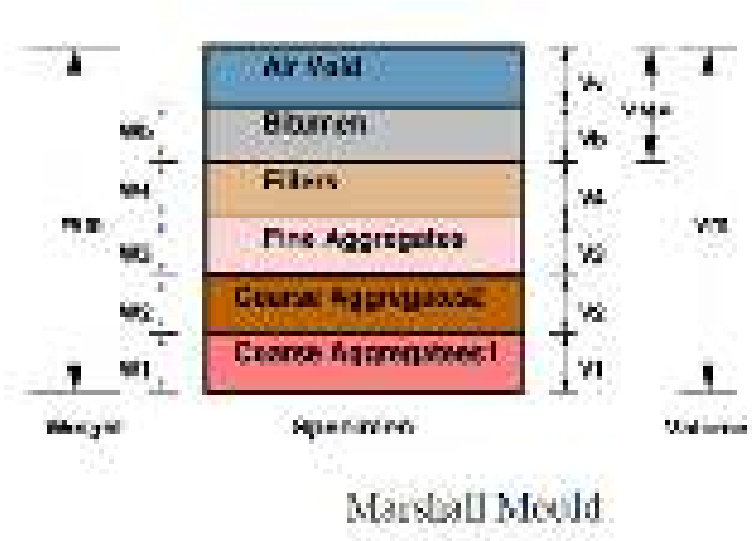


Figure: Phase diagram

(1) Theoretical specific gravity of the mix (without air voids) (G_t)

$$G_t = \frac{\gamma_t}{\gamma_w} = \frac{W_1 + W_2 + W_3 + W_b}{\dfrac{V_1 + V_2 + V_3 + V_b}{\gamma_w}}$$

$$= \frac{W_1 + W_2 + W_3 + W_b}{\dfrac{W_1}{G_1\gamma_w} + \dfrac{W_2}{G_2\gamma_w} + \dfrac{W_3}{G_3\gamma_w} + \dfrac{W_b}{G_b\gamma_b}}$$

$$G_1 = \frac{\gamma_1}{\gamma_w} = \frac{w_1}{V_1\gamma_w}$$

$$\therefore V_1 = \frac{w_1}{G_1\gamma_w}$$

$$G_t = \frac{W_1 + W_2 + W_3 + W_b}{\dfrac{w_1}{G_1} + \dfrac{w_2}{G_2} + \dfrac{w_3}{G_3} + \dfrac{w_b}{G_b}}$$

$$G_t = \frac{100}{\dfrac{w_1}{G_1} + \dfrac{w_2}{G_2} + \dfrac{w_3}{G_3} + \dfrac{w_b}{G_b}} \quad \text{(in \%)}$$

(2) Bulk specific gravity of a mix (with air voids)

$$G_m = \frac{weightofmix}{\frac{volumeofmix}{\gamma_w}} = \frac{weightofmould}{\frac{volumeofmould}{\gamma_w}}$$

(3) Volume of voids:

$$V_v(\%) = \frac{G_t - G_m}{G_t} \times 100$$

$$V_v(\%) = 100\% - \frac{G_m}{G_t} \times 100$$

(4) Void filled with bitumen

$$V.F.B. = \frac{V_b\%}{V_b\% + V_v\%} = \frac{V_b\%}{VMA}$$

(5) Voids in mineral aggregate

$$\%VMA = V_v\% + V_b\%$$

Volume of Bitumen (V_b):

$$\%V_b = \frac{V_b}{V} = \frac{W_b}{G_b \cdot \gamma_w \cdot V} = \frac{W_b}{G_b \times \gamma_w \times \frac{Wmould}{G_m \times \gamma_w}} = \frac{W_b}{G_b} \times \frac{G_m}{W_{mould}}$$

$$\because G_b = \frac{W_b}{\frac{V_b}{\gamma_w}}$$

$$\therefore V_b = \frac{W_b}{\gamma_w \times G_b}$$

$$\left[V = \frac{W_{mould}}{G_m \times \gamma_w} \right]$$

$$V_b = \frac{W_b}{W_{mould}} \times \frac{G_m}{G_b}$$

$$V_b = W_b\% \times \frac{G_m}{G_b}$$

Determine Marshall stability and flow

Marshall stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5 cm per minute).

Apply stability correction

Volume of specimen (cm^3)	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.13
471 - 482	58.7	1.14
483 - 495	60.3	1.09
496 - 508	61.9	1.04
509 - 522	63.5	1.00
523 - 535	65.1	0.96
536 - 546	66.7	0.93
547 - 559	68.3	0.89
560 - 572	69.9	0.85

Prepare graphical plots

The average value of the above properties are determined for each mix with different bitumen content and the following graphical plots are prepared:

1. Binder content versus corrected Marshall stability
2. Binder content versus Marshall flow
3. Binder content versus percentage of void in the total mix v
4. Binder content versus voids filled with bitumen (V F B) 5. Binder content versus unit weight or bulk specific gravity

Determine optimum bitumen content

Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found form the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity
3. Binder content corresponding to the median of designed limits of percent air voids in the total mix v (i.e. 4%)

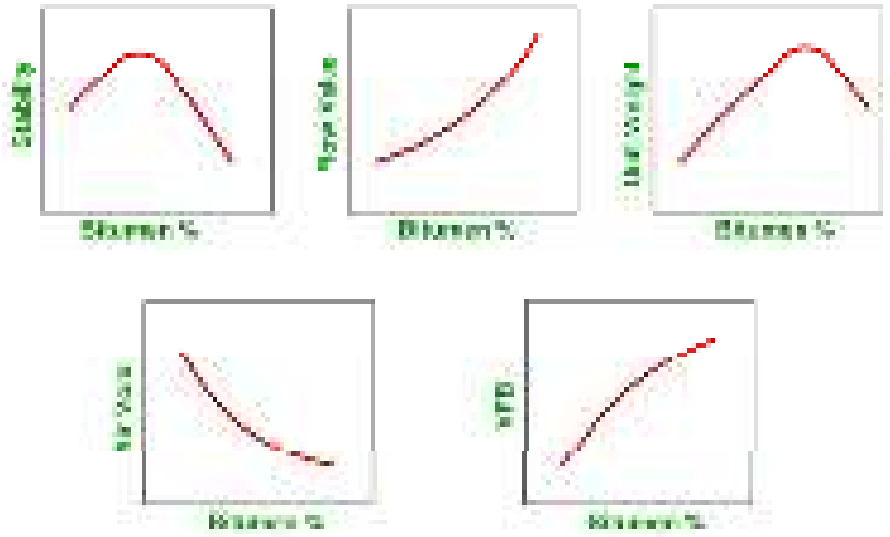


Figure: Marshal graphical plots

FUNCTIONS OF SUBGRADE, SUB-BASE, BASE AND WEARING COURSE

Subgrade:

- To receive the stress generation from the above layers
- To receive the materials of the above layers and act as a bedding layer.

Sub-base course:

- Act as a support for base and wearing course
- To improve drainage condition
- To remove heave
- To protect above layers from bad qualities from underlying soils

Base course:

- To horizontal shear stresses and vertical pressure produced by moving and standing wheel load
- To provide density and resistance to weathering
- Distribution of higher wheel load pressure

Wearing course:

- To provide resistance against wear and tear due to traffic movements
- To provide smooth and dense riding surface to resist the pressure exerted by vehicle and to resist surface water infiltration.

HIGHWAY DRAINAGE

INTRODUCTION

Highway drainage is the process of removing and controlling excess surface and sub-soil water within the right of way this includes interception and diversion of water from the road surface and subgrade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction.

Significance of Drainage

- Excess moisture in soil subgrade causes considerable lowering of its stability.
- Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.
- Sustained contact of water with bituminous pavements causes failure due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formations of pot holes.
- Excess water on shoulders and pavement edges causes considerable damage.
- In clayey soil variation in moisture content causes considerable variation in volume of subgrade.
- High moisture content causes increases in weight and thus increase in stress and simultaneous reduction in strength of soil mass.
- Erosion of soil from top of un-surfaced roads and slopes of embankment, cut and hill side is also due to surface water.
- In cold regions presence of water in the subgrade and a continuous supply of water from the ground water can cause considerable damage to the pavement due to frost action.

Requirements of Highway Drainage System

- The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to subgrade.
- Surface water from adjoining land should be prevented from entering the roadway.
- Side drain should have sufficient capacity and longitudinal slope to carry away all surface water collected.
- Flow of surface water across the road and shoulders and along slopes should not cause formation of cross ruts or erosion.

- Seepage and other sources of under-ground water should be drained off by the subsurface drainage system.
- Highest level of ground water table should be kept well below the level of subgrade, preferably by at least 1.2 m.
- In waterlogged areas special precautions should be taken, especially if detrimental salts are present or if flooring is likely to occur.

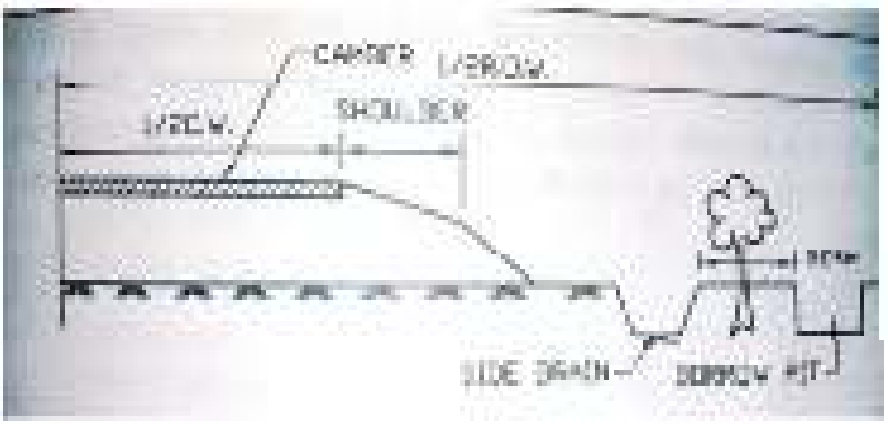
SURFACE DRAINAGE

- During rains, part of the rain water flows on surface and part of it percolate through the soil mass as gravitational water until it reaches the ground water below water table.
- Removal and diversion of surface water from the road way and adjoining land is termed as Surface drainage.
- Diversion and removal of excess soil water from the subgrade is termed as Surface drainage.

Methods of surface drainage

1. By Longitudinal side drains
2. Catch basins and inlets in urban areas
3. Providing damp proof course
4. Providing proper camber
5. Providing sufficient slope to the sides
6. Keeping the level of carriage way at least 60 cm above the HFL

Side drains for road in embankment –

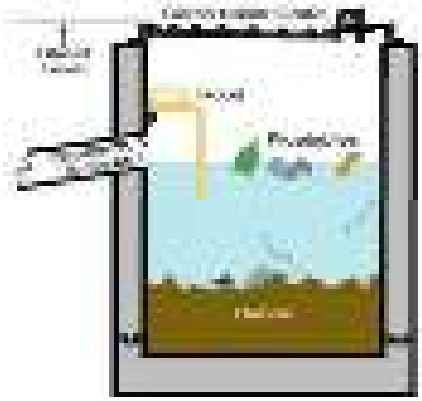


- It is necessary to provide side drain on one side or both sides, when road is constructed in embankment.

- Side drains should be at least 2.0 m away from bottom edge of an embankment.
- Depth of side drains is kept 1.0 to 1.5 m to prevent the entry of drain water into the embankment.

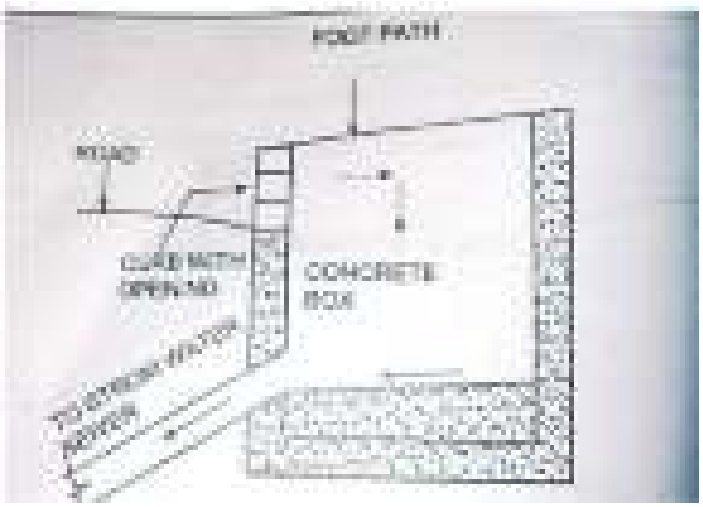
Side drains for road in cutting

Catch basins



- Catch basin is a structure like chamber constructed on a sewer line.
- Water from pavement surface is collected in catch basin and discharged to the sewer line.
- The catch basin (catch pit) is provided with grating to prevent the entry of rubbish into the drainage system.

Inlets: Inlets is a concrete box with grating either at the top or in the side.



Shoulder drainage

- For a quick drainage it is necessary to ensure that shoulder surface is properly sloped and free from irregularities and depressions.
- In impervious type, it is practiced to extend the sub-base course with drainage across the shoulder up to side drain.
- Alternatively we can provide continous layer of 75- 100 mm thick laid under the shoulder at the bottom layer of sub base about 150 mm thick extended up to the edge.
- The paved shoulder should be at least 0.5% steeper then camber subjected to min of 3%
- The unpaved shoulder should be further 0.5% steeper along the horizontal curve, Shoulder on inner side of the curve should have slope steeper than that of pavement.
- On the outer side, the shoulder should be made to drain away from the pavement, a low rate of superelevation are provided.
- On the other hand, where higher rate of super elevation, the outside shoulder are kept level or rounded.

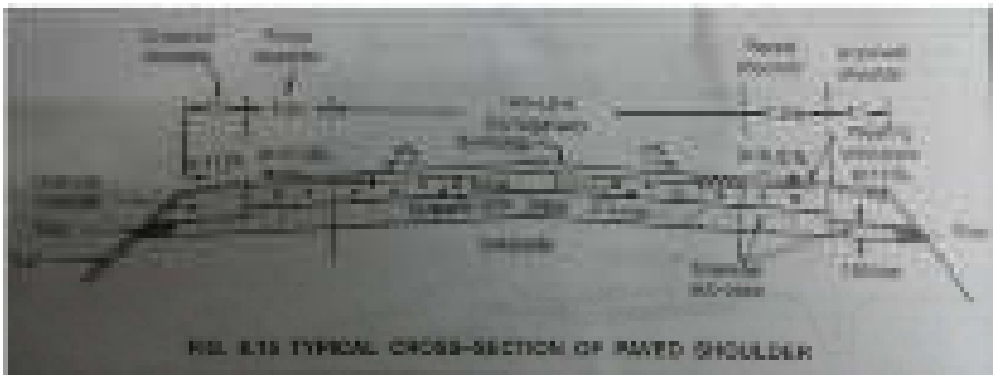


Plate bearing test is used to evaluate the support capability of sub-grades, bases and in some cases, complete pavement. Data from the tests are applicable for the design of both flexible and rigid pavements. In plate bearing test, a compressive stress is applied to the soil or pavement layer through rigid plates relatively large size and the deflections are measured for various stress values.

TRAFFIC ENGINEERING

Traffic engineering is a branch of civil engineering that uses engineering techniques to achieve the safe and efficient movement of people and goods on roadways.

General: Traffic engineering is the phase of engineering which deals with planning, geometric design, traffic operations of roads, streets and highways, their networks, terminals, abutting lands, relationship with other mode of transportation for the achievement of safe, efficient and convenient movement of person goods.

Traffic engineering pertains to the analysis of the behaviour of traffic and to design the facilities for a smooth, safe and economical operation of traffic. Traffic flow like the flow of water, has several parameters associate with it. The traffic stream parameters provide information regarding the nature of traffic flow, which helps the analyst in detecting any variation in flow characteristic. Understanding traffic behaviour requires a thorough knowledge of traffic stream parameters and their mutual relationships.

Objective of traffic engineering:

- Achieve efficient 'free and rapid' flow of traffic
- Reduce the no. of accidents.

Various phases of traffic engineering are: (3Es)

- Engineering (constructive i.e. geometric design of road)
- Enforcement (traffic laws, regulation and control)
- Education (publicity and through school and television)

Scope of traffic Engineering:

I. The basic object of the traffic is the achieve efficient free and rapid flow of traffic with least number of traffic accidents

II. The surface details sight distances requirements. Horizontal and vertical alignment. Intersections and parking facilities are to be suitably designed for better traffic performance.

III. The study of traffic of traffic engineering may be divide in to 6 major phases

- Traffic characteristics
- Traffic studies and analysis
- Traffic operation control and regulation
- Planning and analysis
- Geometric design
- Administration and management

IV. The various phases of traffic engineering are implemented with help of 3E

- ✓ Engineering
- ✓ Enforcement
- ✓ Education

Engineering: deals with the improvement of road geometric, providing additional road facilities and installation of suitable design traffic control devices.

Enforcement: is usually made through traffic laws, regulations and control.

Education: may be possible by sufficient publicity and through schools and television.

Functions of Traffic Engineering:

- **Planning and travel forecasting:** To manage the future requirements of safe, comfort and economic travel.
- **Collection of the factual information:** Collection analysis and interpretation of factual data's the main function of traffic engineering. The data collected from different types of field's survey.
- **Research:** To develop more efficient methods and techniques research is essential. The various areas if importance under this are read design factors, safety, economic impact etc.
- Traffic accident recording: If proper data recording and analysis is done on a scientific basis then accidents can be avoided.
- Design and placement of control and regulatory measures. The main object of control device and regulation is to control the road user, direct him in a better way.

•Traffic characteristics:-improvement of traffic facilities (vehicle, human [road user])

•Traffic studies and analysis

•Traffic operation-control and regulation:-laws of speed limit, installation of traffic control device

•Planning and analysis

•Geometric design:-Horizontal and vertical curve design

•Administration and management:-'3E'concept

Traffic characteristics:

•Road user characteristics

- ➢ Physical
- ➢ Mental
- ➢ Psychological

- Environmental

•Vehicular characteristics is two types (a) static (b) dynamic

Static

- Vehicle dimension
- Weight of loaded vehicle

Dynamic

- Power of vehicle
- Speed of vehicle
- Braking characteristics(braking test)
- Turning radius

Braking test to find skid resistance

At least 2 of the following 3 measurement are needed during the braking test to find 'skid resistance'

- Braking distance (skid mark)
- Initial speed
- Actual duration of brake application

TRAFFIC STUDIES AND ANALYSIS:

•Traffic studies are carried out to analyze the traffic characteristics. These studies helps in deciding the geometric design features traffic control for save and efficient traffic movement.

•The various traffic survey studies generally carried out are:

- Traffic volume study
- Speed study
- Spot speed study
- Speed and delay study
- Origin and destination study
- Traffic flow characteristics
- Traffic capacity study
- Parking study
- Accident studies

Fundamental parameters of traffic flow

Traffic stream parameters

The traffic stream includes a combination of driver and vehicle behaviour. The driver or human behaviour being non-uniform, traffic stream is also non-uniform in nature. It is

influenced not only by the individual characteristics of both vehicle and human but also by the way a group of such units interacts with each other. Thus a flow of traffic through a street of defined characteristics will vary both by location and time corresponding to the changes in the human behaviour.

The traffic engineer, but for the purpose of planning and design, assumes that these changes are within certain ranges which can be predicted. For example, if the maximum permissible speed of a highway is 60 kmph, the whole traffic stream can be assumed to move on an average speed of 40 kmph rather than 100 or 20 kmph. Thus the traffic stream itself is having some parameters on which the characteristics can be predicted. The parameters can be mainly classified as : measurements of quantity, which includes density and flow of traffic and measurements of quality which includes speed. The traffic stream parameters can be macroscopic which characterizes the traffic as a whole or microscopic which studies the behaviour of individual vehicle in the stream with respect to each other.

As far as the macroscopic characteristics are concerned, they can be grouped as measurement of quantity or quality as described above, i.e. flow, density, and speed. While the microscopic characteristics include the measures of separation, i.e. the headway or separation between vehicles which can be either time or space headway. The fundamental stream characteristics are speed, flow, and density and are discussed below.

The traffic stream includes a combination of driver and vehicle behavior.

1. Speed

Speed is considered as a quality measurement of travel as the drivers and passengers will be concerned more about the speed of the journey than the design aspects of the traffic. It is denoted as the rate of motion in distance per unit of time. Mathematically speed or velocity v is given by,

$$v = d/t \qquad (1)$$

where, v is the speed of the vehicle in m/s, d is distance travelled in m in time t seconds.

Speed of different vehicles will vary with respect to time and space. To represent these variation, several types of speed can be denoted. Important among them are spot speed, speed, journey speed, time mean speed and space mean speed. These are discussed below.

Travel time: It is the reciprocal of speed and it is a measure of efficiency of road.

1.1. Spot Speed

Spot speed is the instantaneous speed of a vehicle at a specified location. Spot speed can be used to design the geometry of road like horizontal and vertical curves, super elevation etc. Location and size of signs, design of signals, safe speed, and speed zone determination,

require the spot speed data. Accident analysis, road maintenance, and congestion are the modern field of traffic engineer, which uses spot speed data as the basic input. Spot speed can be measured using an enscope, pressure contact tubes or direct timing procedure or radar speedometer or by time-lapse photographic methods. It can be determined by speeds extracted from

video images by recording the distance traveling by all vehicles between a particular pair of frames.

Average speed: It is the average of spot speed of all vehicles passing at given points on the highway.

1.2. Running speed

Running speed is the average speed maintained over a particular course while the vehicle is moving and is found by dividing the length of the course by the time duration the vehicle was in motion. i.e. this speed doesn't consider the time during which the vehicle is brought to a stop, or has to wait till it has a clear road ahead. The running speed will always be more than or equal to the journey speed, as delays are not considered in calculating the running speed.

$$Runnigspeed = \frac{Totaldis\tan cetravelledbyvehicle}{Runningtime}$$

1.3. Journey speed/overall speed/travel speed

Journey speed is the effective speed of the vehicle on a journey between two points and is the distance between the two points divided by the total time taken for the vehicle to complete the journey including any stopped time. If the journey speed is less than running speed, it indicates that the journey follows a stop-go condition with enforced acceleration and deceleration. The spot speed here may vary from zero to some maximum in excess of the running speed. A uniformity between journey and running speeds denotes comfortable travel conditions.

$$Overallspeed = \frac{Totaldis\tan cetravelled}{Totaltimetaken(includingallstops\ \&\ delays)}$$

1.4. Time mean speed and space mean speed

Time mean speed is denoted as the average speed of all the vehicles passing a point on a highway over some specified time period. Space mean speed is denoted as the average speed of all the vehicles occupying a given section of a highway over some specified time period. Both mean speeds will always be different from each other except in the unlikely event that all vehicles are traveling at the same speed. Time mean speed is a point measurement while space mean speed is a measure relating to length of highway or lane, i.e. the mean speed of

vehicles over a period of time at a point in space is time mean speed and the mean speed over a space at a given instant is the space mean speed.

$$V_s = \frac{n}{\sum_{i=1}^{n} \frac{1}{V_i}}$$

Where V_s = space mean speed

n = no. of vehicles

V = speed of the vehicle

$$V_s = \frac{nL}{\sum_{i=1}^{n} t_i}$$

Time mean speed:-(arithmetic mean) Mean speed of vehicle at a point in space over a period of time or It is the average of instantaneous speeds of observed vehicles at the spot.

$$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

Where V_t = time mean speed

n = no. of vehicles

V = speed of the vehicle

Types of speed study

1. Spot speed study
2. Speed and delay study

Use of spot speed study

•To use in planning traffic control and in traffic regulation.

•To use in geometric design for redesigning the existing highway.

•To use in accident studies.

•To study the traffic capacity.

Speed and delay study

•The speed and delay studies give the running speeds, overall speeds, fluctuations in speeds and the delay between two stations of a road.

•It gives the information such as the amount, location, duration and cause of delay in the traffic stream.

•The result of the spot and delay studies are useful in detecting the spot of congestion.

•The delay or time lost traffic during the travel period may be either due to fixed delays or operational delays.

•Fixed delay occurs primarily at intersections due to traffic signals and at level crossings.

•Operational delays are caused by the interference of traffic movement, such as turning vehicles, parking vehicles, pedestrians etc.

Spot speed studies:

Methods:

i. Enoscope method/Mirror box method
ii. Photographic method
iii. Electronic method
iv. Radar method

Note: Best method for spot speed analysis is radar method

Presentation of spot speed data

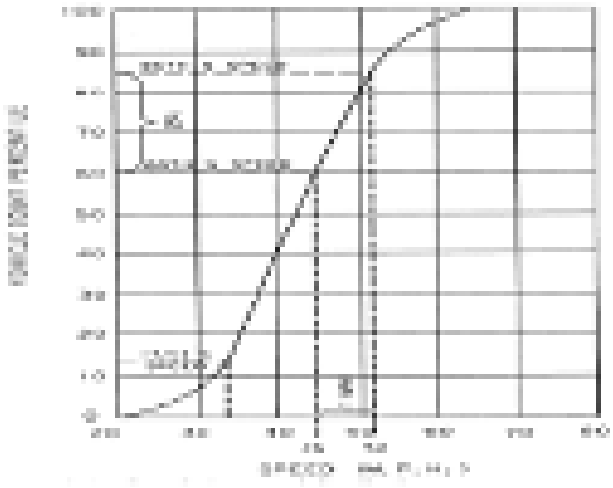
•A graph is plotted with the average value of each speed group on X-axis and the cumulative percent of vehicles travelled at or below the different speeds on Y-axis. From the graph (i.e. Cumulative frequency distribution curve) followings can be obtained.

- 98th percentile speed- Design speed
  Speed at or below which 98% of vehicles are moving and only 2 % crossing this limit.
- 85th percentile speed-Maximum speed
  Upper safe speed limit for regulation of traffic.
- 50th percentile speed-Median speed
- 15th percentile speed-Minimum speed
  Lower speed limit to avoid consgestion.

•Modal average speed (frequency distribution curve):

Speed at which maximum no. of vehicles are moving.

- A frequency curve of spot speed is plotted with average value of each speed group of vehicle in X-axis and the percentage of vehicle in that group on the Y-axis.
- The speed corresponding to peak value of curve is denoted as modal speed



METHODS OF SPEED AND DELAY STUDY:

This method is used to find travel time & to detect the spots of congestion.

a. Floating car or riding check method
b. License plate or vehicle number method
c. Interview method
d. Elevated observations
e. Photographic technique

a. Floating car or riding check method

•In the floating car method a test vehicle is driven over a given course of travel at approximately the average speed of the stream, thus trying to float with the traffic stream. A number of test runs are made along the study stretch and a group of observers record the various details. One observeris seated in the floating car with two stop watches. One of the stopwatch is used to record the time at various control point like intersections, bridges or any other fixed points in each trip.

•The other stop watch is used to find the duration of the individual delays. The time, location and cause of these delays are recorded by the second observer.

•the number of vehicle overtaking the test vehicle and the overtaken by the test vehicle are noted in each trip by third observer.

•The no. of vehicles travelling in the opposite direction in each trip is noted by fourth observer.

•In this method the detailed information is obtained concerning all phases of speed and delay including location, duration and causes of delay.

$$\bar{t} = t_w - \frac{n_y}{q}$$

$$q = \frac{n_a + n_y}{t_a + t_w}$$

where, $\bar{t}$= average journey time in minute

q= flow of vehicle(average volume) in one direction of the stream

$n_{a\ (against)}$ = average number of vehicles counted in the direction of the Stream when the test vehicle travels in the opposite directions

n_y= the average no. of vehicles overtaking the test vehicle minus the no. of vehicles overtaken when the test is in the direction of 'q'

t_w= average journey time, in minute when the test vehicle is travelling with the stream 'q'

t_a= average journey time, in minute when test vehicle is running against the stream 'q'

2. Traffic volume:

No. of vehicles per unit time. unit:- vehicle/hour

Method of measuring traffic volume:

1. Manual method
2. Mechanical method
    - Radar detector
    - Pneumatic hose
    - Magnetic detector

Traffic Flow:

There are practically two ways of counting the number of vehicles on a road. One is flow or volume, which is defined as the number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specific time interval.

The measurement is carried out by counting the number of vehicles, nt passing a particular point in one lane in a denoted period t. Then the flow q expressed in vehicles/hour is given by

$q = n_t / t$ (2)

Flow is expressed in planning and design field taking a day as the measurement of time.

2.1. Variations of Volume

The variation of volume with time, i.e. month to month, day to day, hour to hour and within a hour is also as important as volume calculation. Volume variations can also be observed from season to season. Volume will be above average in a pleasant motoring month of summer, but will be more pronounced in rural than in urban area. But this is the most consistent of all

the variations and affects the traffic stream characteristics the least. Weekdays, Saturdays and Sundays will also face difference in pattern. But comparing day with day, patterns for routes of a similar nature often show a marked similarity, which is useful in enabling predictions to be made. The most significant variation is from hour to hour. The peak hour observed during mornings and evenings of weekdays, which is usually 8 to 10 per cent of total daily ow or 2 to 3 times the average hourly volume. These trips are mainly the work trips, which are relatively stable with time and more or less constant from day to day.

2.2. Types of volume measurements

Since there is considerable variation in the volume of traffic, several types of measurements of volume are commonly adopted which will average these variations into a single volume count to be used in many design purposes.

Types of volume measurements

I. Average Annual Daily Traffic (AADT)

II. Average Annual Weekday Traffic (AAWT)

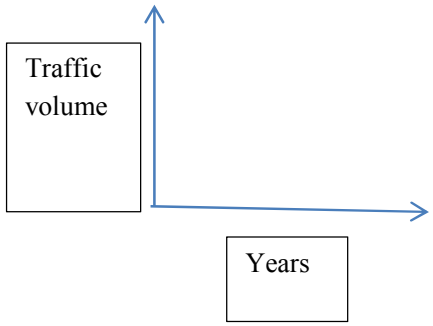
III. Average Daily Traffic (ADT)

IV. Average Weekday Traffic (AWT)

1. Average Annual Daily Traffic (AADT) : The average 24-hour traffic volume at a given location over a full 365-day year, i.e. the total number of vehicles passing the site in a year divided by 365.

$$AADT = \frac{No.ofvehicle\sin ayear}{365}$$

Trend chart =



Variation chart:

- Daily variation
- Seasonal variation
- Hourly variation

Volume flow diagram: No. of vehicles entering the traffic = No. of vehicles going out

30th highest hourly volume: It is that hourly volume which will be exceeded only 29 times in a year and all other volume will be lesser than this also known as design hourly volume.

2. Average Annual Weekday Traffic (AAWT) : The average 24-hour traffic volume occurring on weekdays over a full year. It is computed by dividing the total weekday traffic volume for the year by 260.

3. Average Daily Traffic (ADT): An average 24-hour traffic volume at a given location for some period of time less than a year. It may be measured for six months, a season, a month, a week, or as little as two days. An ADT is a valid number only for the period over which it was measured.

4. Average Weekday Traffic (AWT): An average 24-hour traffic volume occurring on weekdays for some period of time less than one year, such as for a month or a season.

3. Density

Density is defined as the number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per km/mile**.**

One can photograph a length of road x, count the number of vehicles, n_x, in one lane of the road at that point of time and derive the density k as,

$$k = \frac{n_x}{x}$$

This is illustrated in figure given below. From the figure, the density is the number of vehicles between the point A and B divided by the distance between A and B. Density is also equally important as flow but from a different angle as it is the measure most directly related to traffic demand. Again it measures the proximity of vehicles in the stream which in turn affects the freedom to maneuver and comfortable driving.

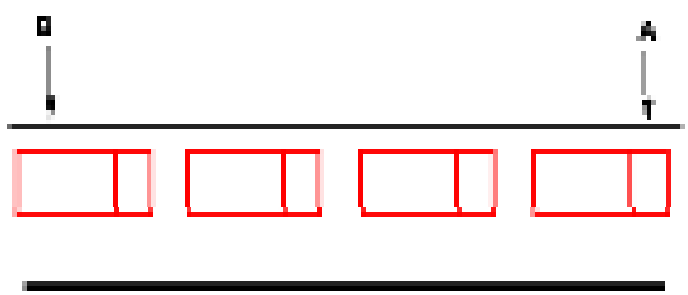


Figure : Illustration of density

4. Derived characteristics

From the fundamental traffic flow characteristics like flow, density, and speed, a few other parameters of traffic flow can be derived. Significant among them are the time headway, distance headway and travel time. They are discussed one by one below.

4.1 Time headway

The microscopic character related to volume is the time headway or simply headway. Time headway is denoted as the time difference between any two successive vehicles when they cross a given point. Practically, it involves the measurement of time between the passage of one rear bumper and the next past a given point. If all headways h in time period, t, over which flow has been measured are added then,

$$\sum_{1}^{n_t} h_i = t$$

But the flow is denoted n_t as the number of vehicles n_t measured in time interval t, that is,

$$q = \frac{n_t}{t} = \frac{n_t}{\sum_1^{n_t} h_i} = \frac{1}{h_{av}}$$

where, h_{av} is the average headway. Thus average headway is the inverse of flow. Time headway is often referred to as simply the headway.

4.2 Distance headway

Another related parameter is the distance headway. It is defined as the distance between corresponding points of two successive vehicles at any given time. It involves the measurement from a photograph, the distance from rear bumper of lead vehicle to rear bumper of following vehicle at a point of time. If all the space headways in distance x over which the density has been measured are added,

$$\sum_{1}^{n_x} x_i = x$$

But the density (k) is the number of vehicles n_x at a distance of x, that is

$$k = \frac{N_a}{L} = \frac{N_a}{\sum_{i=1}^{N_a} s_i} = \frac{1}{s_{av}}$$

Where, s_{av} is average distance headway. The average distance headway is the inverse of density and is sometimes called as spacing.

4.3. Travel time

Travel time is defined as the time taken to complete a journey. As the speed increases, travel time required to reach the destination also decreases and vice-versa. Thus travel time is inversely proportional to the speed. However, in practice, the speed of a vehicle fluctuates over time and the travel time represents an average measure.

5. Time-space diagram

Time space diagram is a convenient tool in understanding the movement of vehicles. It shows the trajectory of vehicles in the form of a two dimensional plot. Time space diagram can be plotted for a single vehicle as well as multiple vehicles. They are discussed below.

5.1. Single vehicle

Taking one vehicle at a time, analysis can be carried out on the position of the vehicle with respect to time. This analysis will generate a graph which gives the relation of its position on a road stretch relative to time.

This plot thus will be between distance x and time t and x will be a functions the position of the vehicle for every t along the road stretch. This graphical representation of x(t) in a (t; x) plane is a curve which is called as a trajectory. The trajectory provide an intuitive, clear, and complete summary of vehicular motion in one dimension.

In figure, the distance x goes on increasing with respect to the origin as time progresses. The vehicle is moving at a smooth condition along the road way. In figure 2(b), the vehicle at first moves with a smooth pace after reaching a position reverses its direction of movement. In figure 2(c), the vehicle in between becomes stationary and maintains the same position.

From the figure, steeply increasing section of x(t) denote a rapidly advancing vehicle and horizontal portions of x(t) denote a stopped vehicle while shallow sections show a slow moving vehicle. A straight line denotes constant speed motion and curving sections denote accelerated motion; and if the curve is concave downwards it denotes acceleration. But a curve which is convex upwards denotes deceleration.

Time space diagram

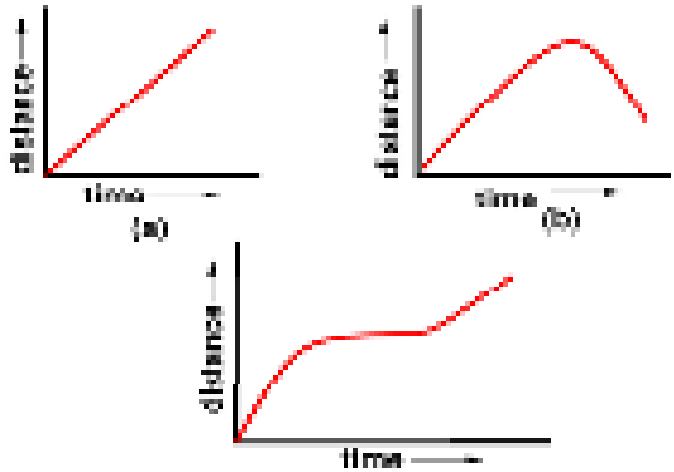


Figure: Single vehicle

5.2. Miultiple Vehicles

Time-space diagram can also be used to determine the fundamental parameters of traffic flow like speed, density and volume. It can also be used to find the derived characteristics like space headway and time headway. Figure below shows the time-space diagram for a set of vehicles traveling at constant speed. Density, by definition is the number of vehicles per unit length. From the figure, an observer looking into the stream can count 4 vehicles passing the stretch of road between x_1 and x_2 at time t . Hence, the density is given as

$$k = \frac{4 \text{ vehicles}}{x_2 - x_1}$$

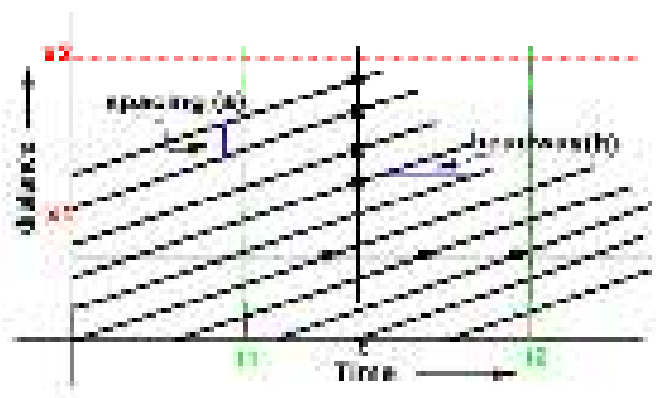


Figure: Many vehicle

We can also find volume from this time-space diagram. As per the definition, volume is the number of vehicles counted for a particular interval of time. From the figure above: we can see that 6 vehicles are present between the time t_1 and t_2. Therefore, the volume q is given as

$$q = \frac{8 \text{ vehicles}}{t_2 - t_1}$$

Again the averages taken at a specific location (i.e., time ranging over an interval) are called time means and those taken at an instant over a space interval are termed as space means.

Another related definition which can be given based on the time-space diagram is the headway. Space headway is denoted as the distance between corresponding points of two successive vehicles at any given time. Thus, the vertical gap between any two consecutive lines represents space headway. The reciprocal of density otherwise gives the space headway between vehicles at that time.
Similarly time headway is denoted as the time difference between any two successive vehicles when they cross a given point. Thus, the horizontal gap between the vehicles represented by the lines gives the time headway. The reciprocal of flow gives the average time headway between vehicles at that point.

ORIGIN AND DESTINATION STUDIES:

The object of this study is

- Plan the road network and other facilities for vehicular traffic
- Plan the schedule of different modes of transportation for the trip demand of commuters.

•It gives the information like the actual direction of travel, selection of routes and length of trip.

•Used in planning new highway facilities and in improving some of the existing system.

•To plan the transportation system and mass transit facilities in cities including route and schedules of operation

•To locate expressway or major routes along the desire lines.

•To locate terminals and to plan terminal facilities.

• To locate new bridge as per traffic demands.

•To locate intermediate stops of public transport.

Methods of 'O' and 'D' survey:

1. Road-side interview method

2. License plate method
3. Return post card method
4. Tag-on-car method
5. Home interview method
6. Work spot interview method

Note: O & D studies provides the basic data for determing the desire direction of flow or desire lines.

Desire line:

- It is a straight line connecting origin & destination
- Width of desire line is directly proportional to no. of trip in both direction.

Relation between traffic volume, density & speed:

FUNDAMENTAL RELATION OF TRAFFIC PARAMETER:

Fundamental diagrams of traffic flow

The flow and density varies with time and location. The relation between the density and the corresponding flow on a given stretch of road is referred to as one of the fundamental diagram of traffic flow. Some characteristics of an ideal flow-density relationship is listed below:

1. When the density is zero, flow will also be zero, since there is no vehicles on the road.
2. When the number of vehicles gradually increases the density as well as flow increases.
3. When more and more vehicles are added, it reaches a situation where vehicles can't move. This is referred to as the jam density or the maximum density. At jam density, flow will be zero because the vehicles are not moving.
4. There will be some density between zero density and jam density, when the flow is maximum.

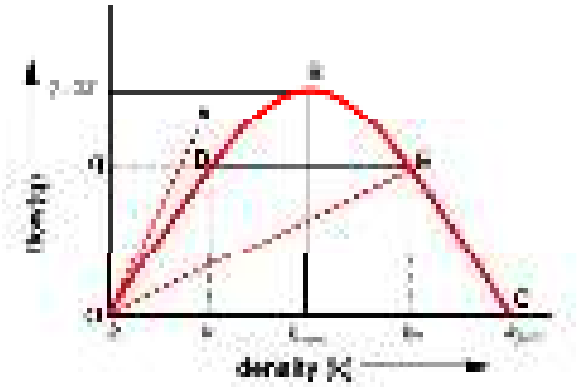


Figure: Flow density curve

Speed-density diagram

Similar to the flow-density relationship, speed will be maximum, referred to as the free flow speed, and when the density is maximum, the speed will be zero. The most simple assumption is that this variation of speed with density is linear

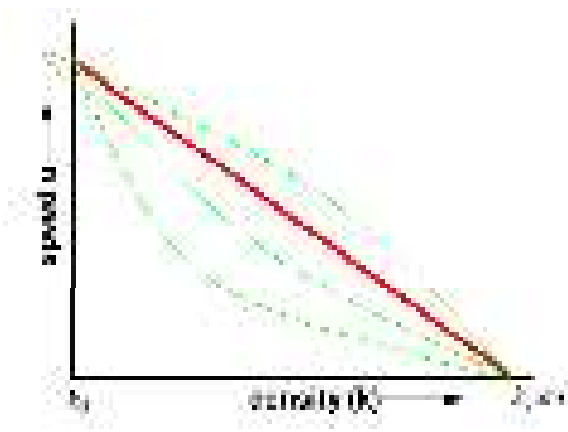


Figure: Speed-density diagram

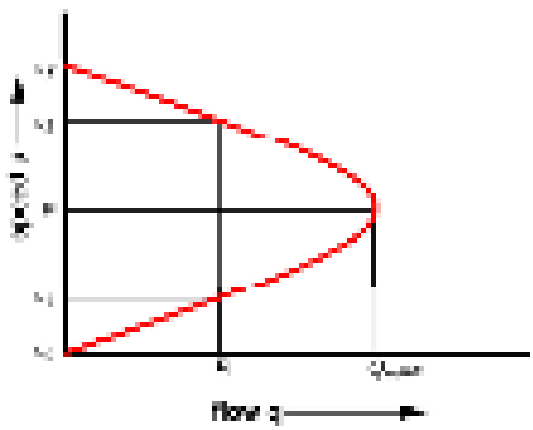


Figure: Speed-flow diagram

1. **Road-side interview method:**

   The vehicles are stopped at previously decided interview stations by a group of persons and answer to prescribed questionnaire are collected on the spot. The information collected include the place and time of origin and destination, route, location of stoppages, the purpose of trip, type of vehicle and numbers of passenger in each vehicle.

   In this method the data is collected quickly in short duration and the field organization is simple and the team can be trained quickly. The main drawback of

this method is that vehicles stopped for interview, and there is delay to the vehicular movement.

2. **License plate method:**

The entire area under study is cordoned out and the observers are simultaneously stationed at all points of entry and exit on all the routes leading to out of the area.

Each party at the observation station is given synchronized time pieces and they note the license plate numbers (registration numbers) of the vehicles entering and leaving the cordoned area and the time.

Separate recording sheets are maintained for each direction of movement for a specified time interval. After collecting the field data major work remains of the office computations and analysis, by tracking each vehicle number and its time of entering and leaving the cordon area.

This method is quite easy and quick as far as the field work concerned. The field organization can also be trained quickly. However, this method is quite advantageous when the area under consideration is small, like a large intersection or a small business center.

3. **Return post card method:**

Pre-paid reply post cards with return address are distributed to the road users at some selected points along the route or the cards are mailed to the owners of vehicles. The questionnaire to be filled by road user is printed on the card, along with a request for co-operation and purpose of the study. The distributing stations for the cards may be selected where vehicles have to stop as in case of a toll booth.

The method is suitable where the traffic is heavy. The personnel need not be skilled or trained just distributing the cards. The only a draw back of this methos is part of the road users may return the cards promptly after filling in the desire details properly and correctly.

4. **Tag-on-car method:**

In this method a pre-coded card stuck on the vehicles as its enters the area under study. When the car leaves cordon area the other observations are recorded on the tag. This method is useful where the traffic is heavy and moves continuously. But the method gives only information regarding the points of entry and exit and the time taken to traverse the area.

5. **Home interview method:**

A random sample of 0.5 to 10 percent of the population it selected and the residences are visited by trained personal who collect the travel data from each member of the household. The data collected may be useful either for planning the road network and other facilities for the vehicular traffic or for planning the mass transportation requirement of passengers.

6. **Work spot interview method:**

The transportation needs of work trip can be planned by collecting the O & D data at work spots like the offices, factories, educational institutions, etc. by personal interview.

Capacity and Level of Service

Capacity

Capacity is defined as the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under given conditions with a reasonable expectation of occurrence.

Traffic capacity:

•The ability of a roadway to accommodate traffic volume. It is expressed as the maximum number of vehicle in a lane or a road that can pass a given point in unit time, usually an hour.

•Volume represent an actual rate of flow whereas capacity indicates a maximum rate of flow with a certain level of service.

Basic capacity:

•It is the maximum no. of passenger car that can be pass a given point on a roadway during one hour under the most nearly ideal roadway and traffic conditions. It is otherwise known as theoretical capacity.

Possible capacity:

•It is the maximum no. vehicle that can pass a given point on a roadway during one hour under prevailing roadway and traffic conditions.

Practical capacity:

•It is the maximum no. of vehicle that can pass a given point on a roadway during one hour, without traffic density being so great as to cause unreasonable delay, hazard or restriction to the driver freedom to maneuver under the prevailing roadway and traffic conditions.

C= 1000 V/S

S = average spacing of vehicle in m, C is the capacity in vehicle per hour per lane.

Peak-Hour Factor

•It is basically represent the variation in traffic flow within an hour.

•Observations of traffic flow consistently indicate that the flow rates are found in the peak.

•A 15 minute period within an hour is not sustained throughout the entire period and that is why we need to use the peak-hour factor.

•Normally on freeways the peak-hour factor values range from 0.80 to 0.95.

Passenger Car Unit (PCU)

•The different vehicle classes have a wide range of statics characteristics and dynamic characteristics, apart from these the driver behavior of the different vehicle classes is also found to vary considerable. Therefore mixed traffic flow characteristics are very much complex when compare to homogeneous traffic and it is difficult to estimate the traffic volume, capacity of roadway under the mixed traffic flow, unless the different vehicle classes are converted to one common standard vehicle unit.

•Therefore it is a common practice to consider the passenger car as the standard vehicle unit to convert the other vehicle classes and this unit is called passenger car unit.

PCU value depends upon the several factors, such as:

•Vehicle characteristics

•Transverse and longitudinal gaps or clearance between moving vehicles.

•Speed distribution of the mixed traffic stream, volume to capacity ratio.

•Roadway characteristics.

•Regulation and control of traffic.

•Environmental and climatic conditions.

• As per IRC:9C-1993

Level of service

A term closely related to capacity and often confused with it is service volume. When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a qualitative measure.

Level of service (LOS)

It is define as a qualitative measure describing the operational condition within a traffic stream, and their perception by motorist and passengers. Or Rating of acceptable level of congestion.

LOS definitions

- A: Free flow, low traffic, high speed
- B:Stable flow, noticeable traffic
- C:Stable flow, traffic interactions,
- D:Unstable flow, High density, movement restrictions
- E:Unstable flow, lower speed, volume is nearly equal to capacity, little freedom
- F:Unstable flow, no freedom, traffic volume can drop to zero, stop & go

LOS-A

- Free-flow operation
- no restriction in maneuvering.

LOS-B

- Reasonably free flow
- Ability to maneuver is only slightly restricted
- Effects of minor incidents still easily absorbed

LOS-C

- Speeds at or near FFS
- Freedom to maneuver is noticeably restricted
- Queues may form behind any significant blockage.

LOS-D

- Speeds decline slightly with increasing flows
- Density increases more quickly
- Freedom to maneuver is more noticeably limited
- Minor incidents create queuing

LOS-E

- Operation near or at capacity
- No usable gaps in the traffic stream
- Operations extremely volatile

- Any disruption causes queuing

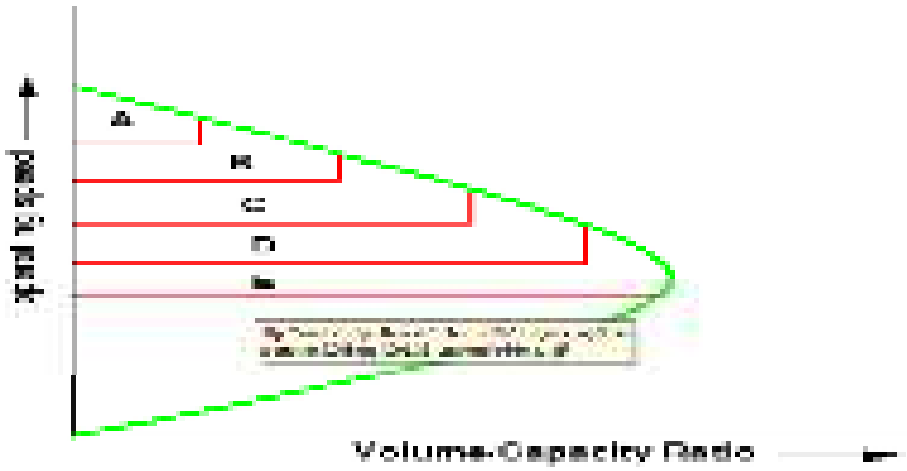
LOS-F

- Breakdown in flow
- Queues form behind breakdown points
- Demand > capacity

  In India, as per IRC

  LOS-B: for design of rural road

  LOS-C: for the design of urban roads



Highway capacity

Highway capacity is defined by the Highway Capacity Manual as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions.

- Traffic conditions:
- Road way characteristics:
- Control conditions:

Factors affecting level of service

Level of service one can derive from a road under different operating characteristics and traffic volumes. The factors affecting level of service (LOS) can be listed as follows:

- Speed and travel time
- Traffic interruptions/restrictions
- Freedom to travel with desired speed

- Driver comfort and convenience
- Operating cost.

TRAFFIC CONTROL DEVICES

Traffic control device is the medium used for communicating between traffic engineer and road users. Unlike other modes of transportation, there is no control on the drivers using the road. Here traffic control devices comes to the help of the traffic engineer.

The various aids and devices used to control, regulate and guide traffic may be called traffic control devices. The general requirements of traffic control devices are: attention, meaning, time for response and respect of road users. The most common among these are:

1. Traffic signs
2. Road markings
3. Traffic signals
4. Parking control.

In addition, road lights are useful in guiding traffic during night.

Requirements of traffic control devices

- The control device should fulfill a need
- It should command attention from the road users
- It should convey a clear, simple meaning
- Road users must respect the signs
- The control device should provide adequate time for proper response from the road users

Traffic signs have been divided in to three categories according to Indian motor vehicles act.

1) Regulatory signs
    a. Prohibitory signs
    b. Mandatory signs
2) Warning or danger signs
3) Informatory signs
    a. Indication signs
    b. Advance direction signs
    c. Place and route identification signs

Regulatory signs

These signs are also called mandatory signs because it is mandatory that the drivers must obey these signs. Regulatory or mandatory signs are meant to inform the road users of certain

laws, regulations and prohibitions. The violation of these signs is a legal offence. Regulatory signs are further subdivided into two types:

i) **Prohibitory signs**

These signs are part of the regulatory signs, which are intended to inform the highway users of traffic laws or regulation.

They may be of following types:

(a) Movement prohibition (such as prohibition of right turns, prohibition of overtaking, prohibition of entry, one-way streets, exclusion of certain types of vehicles)

(b) Waiting restriction signs,

(c) Speed limit and vehicle control signs

(d) No parking and no stopping signs

(e) Compulsory direction signs

Prohibitory signs are meant to prohibit certain traffic movements, use of horns or entry of certain vehicles class. These signs are circular traffic movements, use of horns or entry of certain vehicle class.

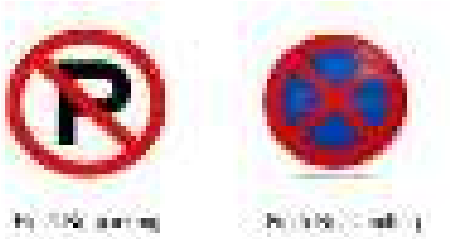
According to the IRC standards, the prohibitory signs are circular in shape and white in color with a red border and a diameter of 600 mm. The common prohibitory signs are, straight prohibited, no entry, one prohibited, bullock cart and hand cart prohibited, Tonga prohibited, hand cart prohibited, cycle prohibited, pedestrian prohibited, right/left turn prohibited, U turn prohibited, overtaking prohibited and horn prohibited.

If the driver fails to obey them, the control agency has the right to take legal action against the driver.

- Right of way series
- Speed series
- Movement series
- Parking series
- Pedestrian series
- Miscellaneous

No parking sign is meant to prohibit parking of vehicles at that place, the definition plate may indicate the parking restriction with respect to days, distance etc. The No parking sign is circular in shape with blue black ground, red border and an oblique red bar at an angle of 45 degrees.

No stopping/standing sign is meant to prohibit stopping of vehicles at the place; the scope of the scope of the prohibition may be indicated on a definition plate. The No stopping/standing sign is circular in shape with blue black ground, red border and two oblique red bars at 45 degree and right angle to each other.



Speed limit signs are meant to restrict the speed of all or certain classes of vehicles on a particular stretch of a road. These signs are circular in shape and have white back ground, red border and black numerals indicating the speed limit.

Restricted ends sign indicates the point at which all prohibitions notified by prohibitory signs for moving vehicles case to apply. Compulsory direction control signs indicate by arrows, the appropriate directions in which the vehicles are oblique to proceed, or the only directions in which they are permitted to proceed.

Some of the Compulsory direction controls are compulsory turn left, ahead only, ahead or turn left/right and keep left. Other compulsory signs are compulsory cycle track and compulsory sound horn; these are indicated by white symbols instead of white direction arrows of compulsory direction signs.

ii) Mandatory signs

Mandatory signs are part of regulatory signs and are intended to convey definite positive instructions when it is desires that motorist take some positive actions. The two most important mandatory signs are the (i) STOP sign and (ii) GIVE WAY sign.

Fig 7 Stop sign Fig 8 Give way sign

The stop sign requires all vehicles to come to a halt before stop line. According to IRC stop sign is octagonal in shape and red in color with a white border, the side of the octagon being 900 mm for the standard sized sign.

It is generally used at an intersection where the following conditiond exit:

i. Street entering a through highway or street
ii. Un signalized intersection in a signalized area

The stop sign should not be used:

i. On the through expressways
ii. For speed control
iii. At signalized intersections

The GIVE WAY sign is used to control the vehicles on a road so as to assign right of way to traffic on other roadways. According to the I.R.C. the shape of GIVE WAY sign is downward pointing equilateral triangle having a red border band with white back ground. It is used under the following conditions:

i. On a minor road at a entrance to an intersection where it is necessary to assign right of way to the major road.
ii. On the entrance ramp to an express way when acceleration lane is not provided.

The **GIVE WAY or YIELD** sign should not be used:

i. On the express ways
ii. To control the major flow of traffic at an intersection
iii. On the approach more than one of the intersection streets

Warning signs:

Warning or cautionary signs 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. According to I.R.C. warning signs are white back ground, red border and black symbols. The side of triangle is 900 mm.

The commonly used warning signs are, right hand/left hand curve, right/left hair pin bend, right/left reverse bend, steep ascent/descent, narrow bridge/road ahead, gap in median, slippery, cycle crossing, pedestrain crossing, school zone, men at work, ferry, cross road, side road, T-intersection, Y-intersection, major road ahead, round about, dangerous dip, hump or rough road, barrier ahead, unguarded railway crossing, graduated railway crossing and falling rock.

Informatory signs:

Informative signs also called guide signs, are provided to assist the drivers to reach their desired destinations. These are predominantly meant for the drivers who are unfamiliar to the place. The guide signs are redundant for the users who are accustomed to the location.

These signs are used to guide the road users along routes, inform them of destination and distance and provide with information to make travel easier, safe and pleasant. The information signs are

- Direction and place identification signs
- Facility information signs
- Other useful information signs
- Parking signs

- Flood gauge

The direction and place identification signs are rectangular with white background, black border and black arrows and letters. The signs of this group include destination signs, direction signs, Re-assurance signs, Route marker and place identifcation signs.

The facility information signs are rectangular signs are rectangular with blue background and white/black letters/symbols. Some of these signs indicate public telephone, petrol pump, hospital, First aid post, eating place and resting place. Other useful information signs include No through road, No through side road, etc.

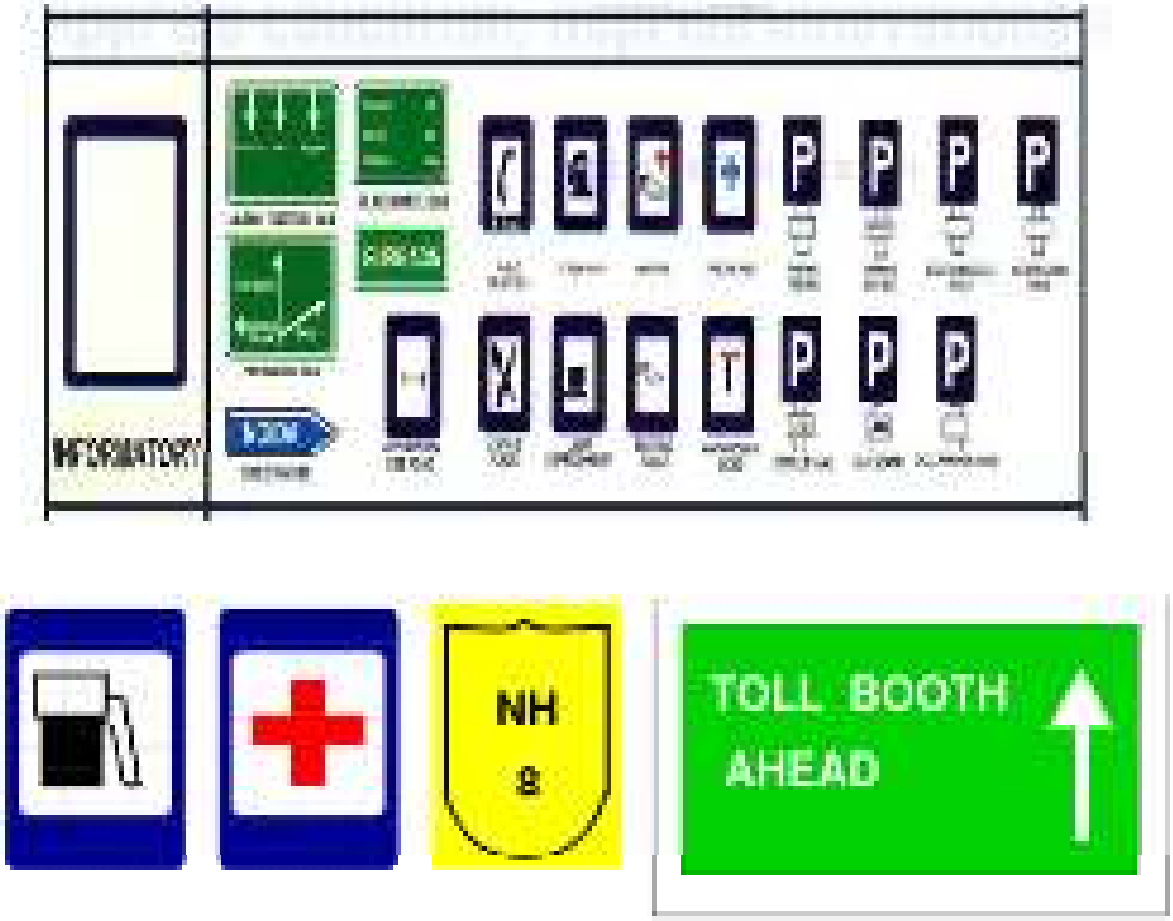


Figure: Examples of informative signs

TRAFFIC SIGNALS

Traffic signals are control devices which could alternately direct the traffic to stop and proceed at intersections using red and green traffic light signals automatically. The main requirements of traffic signals are to draw attention, provide meaning and time to respond and to have minimum waste of time.

Advantages of traffic signals:

Properly designed traffic signals have the following uses:

- They provide orderly movement of traffic and increase the traffic handling capacity of most of the intersections at grade.
- They reduce certain types of accidents, notably the right angled collisions.
- Pedestrians can cross the roads safely at the signalized intersection.
- The signals allow crossing of the heavy traffic flow with safely.
- Signals provide a chance to crossing traffic of minor road to cross the path of continuous flow of traffic stream at reasonable intervals of time.
- Automatic traffic signal may work out to be economical when compared to manual control.

Disadvantages of traffic signals:

- The rear end collisions may increase.
- Improper design and location of signals may lead to violations of the control system.
- Failure of the signal due to electric power failure or any other defect may cause confusion to the road users.

Type of traffic signal:

The signals are classified into the following types:

1. Traffic control signals
    a. Fixed –time signal
    b. Manually operated signal
    c. Traffic actuated (Automatic) signal
2. Pedestrian signal
3. Special traffic signal

The RED light is meant for STOP, the GREEN light is meant for GO and the AMBER or YELLOW light allows the CLEARABCE TIME for the vehicles which enter the intersection area by the end of green time, to clear off.

FIXED –TIME SIGNALS or pre-timed signals are set to repeat regularly a cycle of red, amber and green lights. The timing of each phase of the cycle is predetermined based on the traffic studies and they are the simplest types of automatic traffic signals which are electrically operated. The main drawback of the signal is that sometimes the traffic flow on one road may be almost nil and traffic on the cross road may be quite heavy.

TRAFFIC ACTUATED SIGNALS are those in which the timings of the phase and cycle are changed according to traffic demand.

1. **Vehicle actuated signal**

   In fully actuated traffic signals the detectors and a computer assigns the right of way for traffic movements on the basis of demand and pre-determined programming. But these are very costly to be installed at all intersections

2. **Semi-vehicle actuated signal**

In semi actuated traffic signals the normal green phase of an approach may be extended up to a certain period of time for allowing a few more vehicles approaching closely, to clear off the intersection with the help of detectors installed at the approaches.

MANUALLY OPERATED SIGNAL:

This type of signal operated manually. Normally traffic police can operate this type signal

Pedestrian signal

Pedestrian signals are meant to give the right of way to pedestrians to cross a road during the "walk period" when the vehicular traffic shall be stopped by red or stop signal on the traffic signal of the road.

TRAFFIC SIGNAL CO-ORDINATION

When there are series of signals on a city road at each intersection with crossroad, the signal system may be operated with only one controller. But it is desirable that a vehicle moving along a main road at normal speed should not have to stop at a very signalized intersection till getting the Go signal. Hence there should be proper co-ordination of the signal system to provide a through band.

Need for co-ordinated control

i. To pass maximum amount of traffic without enforced halts.
ii. To have minimum overall delay to traffic streams, both in main and side roads.
iii. To prevent the queue of vehicles at one intersection from extending and reaching the next intersection.

Type of traffic signal system:

There are four general types of co-ordination of signals for road network, as listed below

- Simultaneous system
- Alternate system
- Simple progressive system, and
- Flexible progressive system

SIMULTANEOUS SYSTEM:

In this system all the signals along a given road always show the same indication (green, red etc.) at the same time. As the division of cycle is also the same at all intersections, this system does not work satisfactorily.

The disadvantages of a simultaneous systems are:

i. The overall speed often reduced
ii. It encourages speeding of drivers between stops.
iii. It is not conductive to give continuous movements of all vehicles.

ALTERNATE SYSTEM:

In this system, alternate signals or groups of signals show opposite indications in a route at the same time. This system is also operated by a single controller, but by reversing the red and green indicator connections at successive signal systems. This system generally is considered to be more satisfactory than the simultaneous system.

The disadvantages of this system are:

i. The green time for the main and side streets have to be substantially equal, resulting inefficiency at most of the intersections.
ii. Adjustments are difficult for changing traffic conditions.

SIMPLE PROGRESSIVE SYSTEM:

A time schedule is made to permit, as nearly as possible, a continuous operation of groups of vehicles along the main at a reasonable speed. The signal phases controlling "GO" indications along this road is scheduled to work at the predetermined time schedule. The phases and intervals at each signal installation may be different; but signal unit works as fixed time signal, with equal signal cycle length.

FLEXIBLE PROGRESSIVE SYSTEM

This system is an improvement over the simple progressive system with the following provisions:

i. It is possible to introduce flashing or shut down during off-peak hours.
ii. It is possible to vary the cycle time and division at each signal depending upon the traffic.

Road Sign

The essential purpose of road markings is to guide and control traffic on a highway. They supplement the function of traffic signs. The markings serve as a psychological barrier and signify the delineation of traffic path and its lateral clearance from traffic hazards for the safe movement of traffic. Hence they are very important to ensure the safe, smooth and harmonious flow of traffic.

Classification of road markings

The road markings are defined as lines, patterns, words or other devices, except signs, set into applied or attached to the carriageway or kerbs or to objects within or adjacent to the carriageway, for controlling, warning, guiding and informing the users. The road markings are classified as

- Longitudinal markings
- Transverse markings
- Object markings
- Word messages
- Marking for parking
- Marking at hazardous locations

Longitudinal markings

Longitudinal markings are placed along the direction of traffic on the roadway surface, for the purpose of indicating to the driver, his proper position on the roadway.

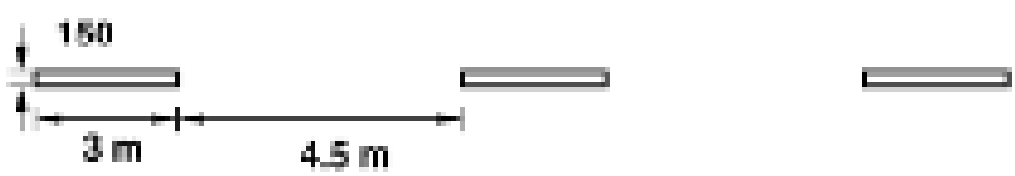


Figure Centre line marking for a two lane road

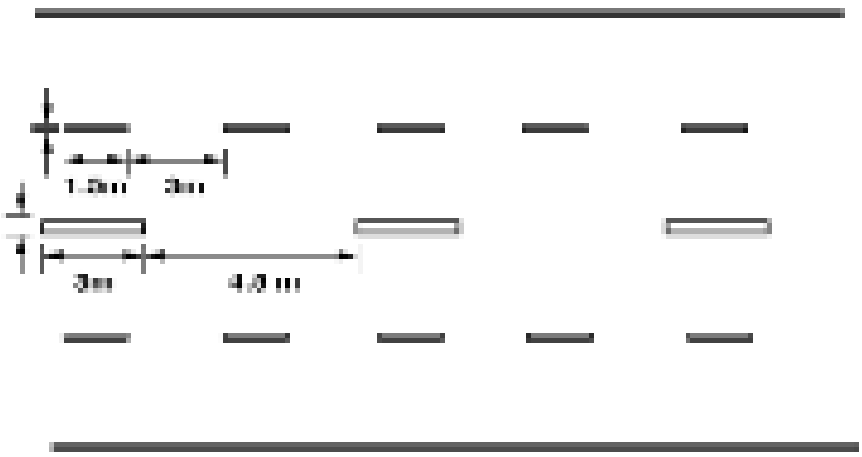


Figure Centre line and lane marking for a four lane road

Centre line

Centre line separates the opposing streams of traffic and facilitates their movements. Usually no centre line is provided for roads having width less than 5 m and for roads having more than four lanes. The centre line may be marked with either single broken line, single solid line, double broken line, or double solid line depending upon the road and traffic requirements.

Traffic lane lines

The subdivision of wide carriageways into separate lanes on either side of the carriage way helps the driver to go straight and also curbs the meandering tendency of the driver.

No passing zones

No passing zones are established on summit curves, horizontal curves, and on two lane and three lane highways where overtaking maneuvers are prohibited because of low sight distance. It may be marked by a solid yellow line along the centre or a double yellow line.

PARKING

Parking studies

Before taking any measures for the betterment of conditions, data regarding availability of parking space, extent of its usage and parking demand is essential. It is also required to estimate the parking fares also.

- Parking statistics
- Parking accumulation
- Parking volume
- Parking load

- Average parking duration
- Parking turnover
- Parking index

Parking surveys

o In-out survey

o Fixed period sampling

o License plate method of survey

On street parking

- Parallel parking
- 30 parking
- 45 parking
- 60 parking
- Right angle parking

Off street

Parking In many urban centres, some areas are exclusively allotted for parking which will be at some distance away from the main stream of traffic. Such a parking is referred to as off-street parking.

Traffic Signal Design

The conflicts arising from movements of traffic in different directions is solved by time sharing of the principle. The advantages of traffic signal includes an orderly movement of traffic, an increased capacity of the intersection and requires only simple geometric design. However the disadvantages of the signalized intersection are it affects larger stopped delays, and the design requires complex considerations.

Definitions and notations

- Cycle
- Cycle length
- Interval
- Green interval
- Red interval
- Phase
- Lost time

Phase design

The signal design procedure involves six major steps.

They include the

1. phase design
2. determination of amber time and clearance time
3. determination of cycle length
4. apportioning of green time
5. pedestrian crossing requirements,
6. the performance evaluation

Two phase signals

Two phase system is usually adopted if through traffic is significant compared to the turning movements.

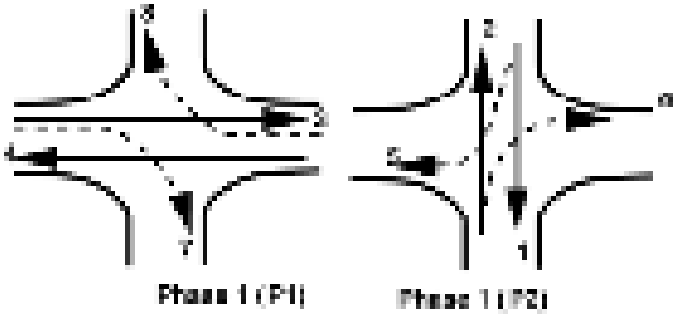


Figure Two phase signal

Four phase signals

There are at least three possible phasing options.

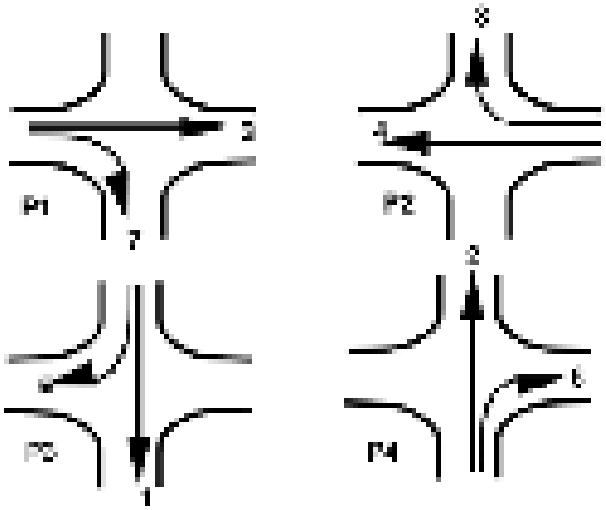


Figure One way of providing four phase signals

Cycle time

Cycle time is the time taken by a signal to complete one full cycle of iterations. i.e. one complete rotation through all signal indications. It is denoted by C.

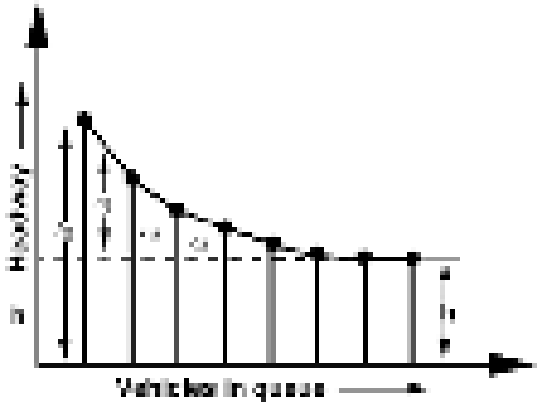


Figure Headways departing signal

ACCIDENT STUDIES:

The traffic accidents may involve property damages, personal injuries or even casualities. One of the main objective of traffic engineering is to provide safe traffic movements.

Road accident cannot be totally prevented, but suitable traffic engineering and management measures, the accident rate can be considerably decreases. Therefore the traffic engineer has to carryout systematic accident studies to investigate the causes of accidents and to take preventive measures in terms of design and control.

The objective of the accident studies may be listed below:

- To study the causes of accidents and to suggest corrective treatment at potential location
- To evaluate the exiting design
- To support the proposed designs
- To carry out the before and after studies and to demonstrate the improvement in the problem
- To make computations of financial loss

There are four basic elements ina traffic accident:

- The road users
- The vehicles
- The roads and its condition and
- Environmental factor – traffic, weather etc.

Types of accident:

- A moving vehicle hits a parked vehicle
- Two vehicle moving towards crossing collide at intersection
- A moving vehicle collide with an object

- Head on collision

Causes of accidents:

Road users: excessive speed and rash driving, careless, violation of rules and regulations, failure to see or understand the traffic situations, signs or signal, temporary effect du eto fatigue, sleep or alcohol.

Vehicles defects: Failure of brakes, steering system, and lighting system etc.

Road condition: Skidding road surface, pot holes, ruts and other damaged conditions of the road surfaces.

Road design: Defective geometric design like inadequate sight distance, inadequate width of shoulders, improper curve design, improper lighting and improper control devices.

Environmental factor:

Unfavorable weather condition like mist, fog, snow, dust, smoke and heavy rainfall which restrict the normal visibility and render driving unsafe.

TYPES OF ACCIDENTS:

- Fatal accident
- Grievous injury accidents
- Slightly injured accidents
- Minor injury accidents
- Non-injury accidents

Fatal accidents: An accident in which one or more persons were killed.

Grievous injury accident: Accidents in which persons were grievously injured. For example permanent disfigurement of head or face.

Slightly injured accidents: Persons who have sustained only minor injuries or bruises or sprains.

Minor injury accidents: Accidents in which persons received only minor injuries.

Non-injury accidents: Accidents in which no one was killed or injured.

COLLISION DIAGRAM:

A collision diagram is the schematic representation of all accidents occurring at a particular location.

Nature of collision:

Different types of collision are,

- Head on collision
- Rear end collision

- Side swipe collision
- Right angle collision
- Right turn collision
- Fixed object collision
- Out of control collision

GEOMETRIC DESIGN OF INTERSECTIONS

CHANNELIZATION:

The direction of traffic flow at intersections to definite path, by means of traffic markings, islands or other means is known as channelization.

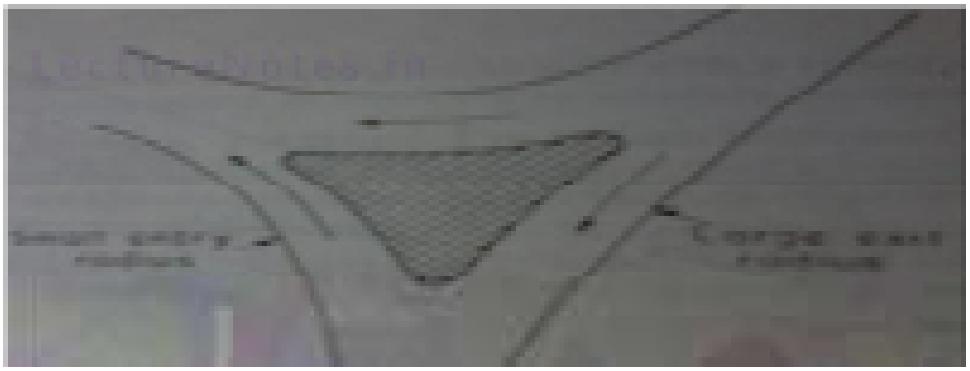
A channelized intersection is one which traffic is directed into definite paths by islands and markings.

An unchannelised intersection, on the other hand, is one without islands for directing traffic into definite paths. An unchannelised intersection is the most dangerous and inefficient.

1. Seperation of conflicts:
   To diminish the number of possible vehicle conflicts, to reduce the possible area of conflicts in the carriage way and to present drivers with only one decision at a time.

2. **Control of angle of conflicts:**
   Small angles of crossing cause severe accidents if they occur. Severity is reduced if the angle of conflict is controlled.
3. **Control of speed:**

To reduce the speed of traffic entering the intersection and increase the speed of traffic leaving the intersection, bending or funneling by suitable channelization techniques is resorted to, vide figs.



4. **Protection of traffic for leaving/crossing the main traffic stream**
   This is exemplified by the separate storage pockets for right turning traffic at an intersection and the adjacent island, vide fig.

5. **Protection of pedestrians:**
   To provide a haven or refuge for pedestrians b/w traffic flows. A channelizing island such as in fig serves as a refuge and makes the crossing much safer.
6. **Elimination of excessive intersectional areas:**
   Intersections with large corner radii & those at oblique angles have large paved areas, which permit & encourage hazardous uncontrolled vehicle movements. If these unused paved areas are converted into channelizing islands, orderly movement results and hazards are reduced vide fig.

7. **Blockage of prohibited movements:**

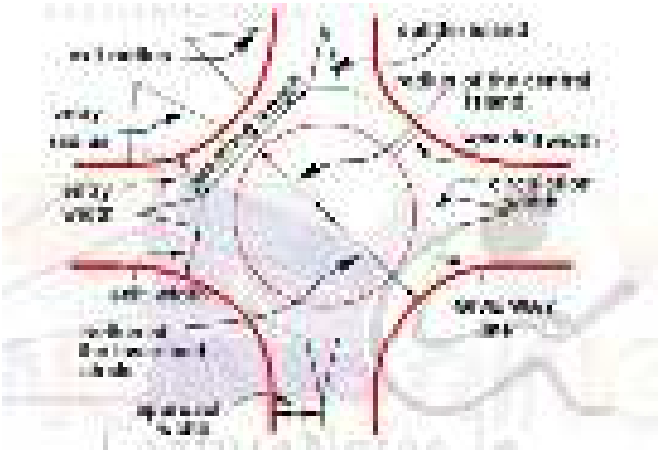
   To support regulations by making improper movements or encroachments impossible or inconvenient.

8. **Location of traffic control devices:**

   To provide space for traffic control devices such as direction indicators, reflectors, signs, etc.

ROTARY INTERSECTION (ROUND ABOUT):

A rotary intersection is an enlarged road intersection where all converging vehicles are forced to move round a large central island in one direction (clockwise direction).



ADVANTAGES OF ROTARY INTERSECTIONS

- The main objective of providing a rotary are eliminate the necessity of stopping even for cross streams of vehicles and to reduce the area of conflict.
- An orderly and regimented traffic flow is provided by rotary one way movement.
- Normally, all traffic proceeds simultaneously & continuously at fairly uniform, though low speed. Frequent stopping & starting are avoided.
- All turns can be made with ease, although little extra travel distance is required for all movements except left turns.

- A rotary is especially suited for intersections legs, and/or where there are right-turning movements.
- For moderate traffic, rotaries are self-governing & need no control by police or traffic signals.

DISADVANTAGES OF ROTARY INTERSECTIONS

- A rotary requires more land & may not be feasible in many built up locations.
- Where pedestrian traffic is large, a rotary by itself is not sufficient to control traffic & has to be supplemented by traffic police.
- When used on high speed roads, rotaries require extremely large size.
- Traffic turning right has to travel a little extra distance.
- A rotary requires many warning & directional signs for safety. The central island & entrances & exists must be well lighted at night. These tend to make it costly.

Guidelines for selecting a rotary Type of intersection

- A total volume of 3000 vehicles per hour entering from all the intersection legs appears to be maximum practical capacity of high type rotaries.
- A rotary design is most appropriate when the proportion of turning traffic is very high.
- A rotary is a good choice when there are more than four approaches to the junction.
- Rotaries are not generally warranted for intersections carrying very light traffic. Normally, the lowest traffic volume for which a rotary design should be considered is about 500 vehicles per hour.