HIGHWAY MATERIALS

Introduction

A wide variety of materials are used in the construction of roads these are soils (naturally occurring or processed), aggregates (fine aggregates or coarse aggregates obtained from rocks), binders like lime, bituminous materials, and cement, and miscellaneous materials used as admixtures for improved performance of roads under heavy loads and traffic.

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.

Soil constitutes the primary material for the foundation, subgrade, or even the pavement (for low-cost roads with low traffic in rural areas). When the highway is constructed on an embankment at the desired level, soil constitutes the primary embankment material; further, since all structures have to ultimately rest on and transmit loads to 'mother earth', soil and rock also serve as foundation materials. Soil is invariably used after some process of stabilization such as compaction and strengthening by adding suitable admixtures for improving the performance of the road. Mineral aggregates obtained from rocks form the major component of the sub-bases and bases of highway pavements of almost all types.

1. Soil:

Soils can be studied effectively if they are classified according to certain principles into a definite system. A system is an ordered grouping of certain elements in a discipline according to pre-defined principles. Just as classification or grouping is practised in scientific disciplines such as chemistry, zoology and botany, it is used in Geotechnical Engineering as well. A soil classification system may be defined as a fundamental division of the various types of soil into groups according to certain parameters such as its physical properties, constituents or texture, field performance under load, presence of water and so on. There are a few field identification tests have been developed for preliminary identification in the field.

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.

Need for Soil Classification:

Soil deposits in nature are never homogenous in character; wide variations are observed in their properties and behavior. Soils that exhibit similar average properties may be grouped as a class. Classification of soil is necessary to obtain an appropriate and fairly accurate idea of the properties and behavior of a soil type.

A classification system is usually evolved with a view to assessing the suitability of a soil for specific use as a construction material or as a foundation material. In view of the wide variations in engineering properties of several soils, it is inevitable that in any system of classification, there will be borderline cases which may fall into groups that appear to be radically different under different systems of classification.

Hence, classification is taken only as a preliminary requirement to study the engineering behavior of a soil; special tests may become necessary in any project of importance.

Requirements of a Soil Classification System:

The general requirements of an ideal soil classification system are:

i. It should have a scientific basis.
ii. It should be relatively simple and objective in approach.
iii. The number of groupings and properties used as the criteria should be limited.
iv. The properties considered should be relevant to the purpose of classification.
v. A generally accepted uniform soil terminology should be used.
vi. It should indicate the probable performance of the soil to a satisfactory degree of accuracy.
vii. Group boundaries should be drawn as closely as possible where significant changes in soil properties occur.
viii. It should be acceptable to all engineers.

Although several classification systems have been developed, some being relatively more elaborate and exhaustive than others, the following systems only will be considered:

(a) Grain size analysis
(b) Textural classification
(c) PRA system of classification (Group index method)
(d) Unified soil classification System
(e) Indian Standard Soil classification system

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.

Gravel	Sand			Silt			Clay		
	C	M	F	C	M	F	C	M	F
	0.6	0.2							
				0.02	0.006		0.006	0.002	

2.0mm 0.06mm 0.002mm

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 miscellaneous 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)

2. Stone Aggregates:

Stone aggregate, or mineral aggregate, as it is called, is the most important component of the materials used in the construction of roads. These aggregates are derived from rocks, which are formed by the cementation of minerals by the forces of nature.

Stone aggregates are invariably derived by breaking the naturally occurring rocks to the required sizes. They are used for granular bases, sub-bases, as part of bituminous mixes and cement concrete; they are also the primary component of a relatively cheaper road, called water-bound macadam.

A study of the types of aggregates, their properties, and the tests to determine their suitability for a specific purpose is of utmost importance to a highway engineer. Properties such as strength and durability of aggregates are generally influenced by their origin of occurrence, mineral constituents and the nature of the bond between the constituents.

Geological Classification of Rocks:

Geologically, rocks are classified into the following categories:

(a) Igneous Rocks:

These are formed by the cooling, solidification and crystallization of molten rock on the earth’s crust at different depths. The minerals, their proportions and the rate of cooling of the magma have a bearing on the strength characteristics of the rock.

Igneous rocks are, in general, stronger than the other two types. Granite, diorite and gabbro are intrusive rocks which form at deep layers in the earth’s crust. Basalt (or trap), andesite, rhyolite and dolerite are extrusive rocks which from at the top layers of the earth’s crust.

(b) Sedimentary Rocks:

Fine material or rock fragments and particles transported by water or wind and deposited in layers, get hardened in course of time to form sedimentary rocks (the time required is on geologic scale). They consist of a layered structure; the rock beds are stratified, they may be porous, and have relatively low strength. Examples of siliceous variety are sandstone and argillite; those of calcareous variety are limestone and dolomite.

(c) Metamorphic Rocks:

These are formed by the modification and re-crystallization of igneous rocks and sedimentary rocks by geological and natural agents such as temperature, pressure, moisture, humidity, and movement of rock beds. Major changes occur in geologic time and form foliations. This kind of foliated structure makes these rocks comparably weaker than igneous rocks. Popular examples of metamorphic rocks are gneiss (from granite), slate (from shale) and schist.

Examples of un-foliated types are marble (from limestone) and quartzite (from sandstone). (Marble and gneiss are used for flooring and face work in buildings).

Desirable Properties of Sand Aggregates:

The following properties are desirable in soil aggregates used the construction of roads:

(i) Strength:

It is the resistance to crushing which the aggregates used in road construction, especially in the top layers and wearing course, have to withstand the stresses due to wheel loads of the traffic in addition to wear and tear.

(ii) Hardness:

It is the resistance to abrasion of the aggregate at the surface. The constant rubbing or abrading action between the tyres of moving vehicles and the exposed aggregate at the road surface should be resisted adequately.

(iii) Toughness:

This is the resistance to impact due to moving traffic. Heavily loaded trucks and other vehicles cause heavy impact loads on the road surface while moving at high speeds, and while accelerating and decelerating. Even steel-typed vehicles, though moving slow, cause heavy impact on the aggregates exposed at the surface. Hence, resistance to such impact forces is a desirable quality.

(iv) Durability:

It is the resistance to the process of disintegration due to the weathering action of the forces of nature. The property by virtue of which the aggregate withstands weathering is called soundness. This is also a desirable property.

(v) Cementation:

It is the ability of the aggregate to form its own binding material under traffic, providing resistance to lateral displacement. Limestone and laterite are examples of stones with good cementing quality. This becomes important in the case of water-bound macadam roads.

(vi) Appropriate Shape:

Aggregates maybe either rounded, cubical, angular, flaky, or elongated. Each shape is appropriate for a certain use. Too flaky and too elongated aggregates have less strength and durability; so, they are not preferred in road construction. Rounded aggregates are good for cement concrete because of the workability such aggregates provide. Cubical or angular aggregates have good interlocking properties; since flexible pavements derive their stability due to interlocking, such aggregates are the preferred type for construction. Thus, the appropriate shape for a particular use is also a desirable property.

(vii) Adhesion with Bitumen:

The aggregates used in bituminous pavements should have less affinity to water than to bitumen; otherwise, the bituminous coating on the surface of the aggregate will get stripped off in the presence of water. So, hydrophobic characteristic is a desirable property for aggregates to be used in the construction of bituminous roads.

(viii) Attrition:

This is mutual rubbing of aggregates under traffic; adequate resistance to attrition is a desirable property.

(ix) Texture:

This is a measure of the degree of fineness or smoothness of the surface of the aggregate. Gravels from river beds are fairly smooth; as a rule, fine grained rock is highly resistant to wear and is preferred for surface courses.

3. Bituminous Materials:

Bitumen was used as a bonding and water-proofing agent thousands of years ago. However, the use of bitumen for road-making picked up only in the nineteenth century. As the quest for fuels like petroleum to run automobiles grew and the distillation of crude oil emerged as a major refining industry, the residues known as bitumen and tar found increasing use in constructing bituminous surfaces, which provided superior riding surface.

The definition for the term, bitumen, given by the American Society for Testing Materials (ASTM) runs thus:

"Bitumen is a hydrocarbon material of natural or pyrogenous origin, which is in a gaseous, liquid, semi-solid, or solid state, and which is completely soluble in carbon disulphide (CS_2)."

Of course, bitumen is found to be soluble to a large extent in carbon tetrachloride (CCl_4) also. Bitumen is a complex organic compound and occurs either as such in nature or can be obtained during the distillation of petroleum; it is generally non-volatile and resistant to most acids, alkalis and salts.

Bitumen occurring in nature as rock intrusions invariably contains inert inorganic materials or minerals; in such a case it is called asphalt. It is also found in lakes (as in Trinidad), in which case it is called lake asphalt. However, in American terminology, bitumen itself is termed asphalt, irrespective of whether it contains inorganic/mineral matter or not. In India, the British terminology is used for the terms bitumen and asphalt.

Important Properties of Bitumen:

1. Predominantly hydrocarbons, with small quantities of sulphur, nitrogen and metals.
2. Mostly (up to 99.9%) soluble in carbon disulphide (CS_2), and insoluble in water.
3. Softens on heating and gets hardened on cooling.
4. Highly impermeable to water.
5. Chemically inert and unaffected by most acids, alkalis and salts.
6. No specific boiling point, melting point or freezing point; a form of 'softening point' is used in their characterization.
7. Although generally hydrophobic (water repellent), they may be made hydrophilic (water liking) by the addition of a small quantity of surface-active agent.
8. Most bitumens are colloidal in nature.

Desirable Properties of Bitumen as a Road Material:

1. Workability – Bitumen should be fluid enough at the time of mixing so that the aggregates are fully coated by the binder. Fluidity is achieved either by heating or by cutting back with a thin flux or by emulsifying the bitumen.
2. Durability – There should be little change in viscosity within the usual range of temperatures in the locality.
3. Volatile constituents in bitumen should not be lost excessively at higher temperatures to ensure durability.
4. It should have enough ductility to avoid brittleness and cracking.
5. Strength and adhesion – The bitumen should have good affinity to the aggregates and should not be stripped off in the continued presence of water.
6. Cost-effectiveness.

A few more terms relating to bitumen/asphalt are:

Straight-Run Bitumen:

Bitumen derived from the refining of petroleum for which the viscosity has not been adjusted by blending with flux oil or by softening with any cut-back oil or by any other treatment. It generally has high viscosity.

Asphalt Cement:

A binder consisting of bitumen, or a mixture of lake asphalt and bitumen or flux oils, specially prepared as per prescribed quality and consistency for direct use in paving, usually in the hot condition.

Oxidised or Blown Bitumen:

Bitumen obtained by further treatment of straight-run bitumen by running it, while hot, into a vertical column and blowing air through it. In this process, it attains a rubbery consistency with a higher softening point than before.

Cut-Back Bitumen:

Asphalt/bitumen dissolved in naphtha or kerosene to lower the viscosity and increase the workability.

Emulsified Bitumen:

A mixture in which asphalt cement, in a finely dispersed state, is suspended in chemically treated water. Liquid Bitumen: Include cut-backs in naphtha and kerosene, as also emulsified asphalts.

Flux-Oil:

A bituminous material, generally liquid, used for softening other bituminous materials.

4. Cement, Cement Mortar and Cement Concrete:

Cement concrete is a versatile material which has revolutionized civil engineering construction during the twentieth century. A fresh cement concrete mix consists of cement, mineral aggregates (coarse aggregate and fine aggregate), and water.

A well-designed cement concrete mix sets and hardens due to the binding property of the cements, forms a mix with minimum void space and on curing with water, provides a strong, stable and durable pavement for a highway, resisting repetitive impact from wheel loads and also withstanding adverse environmental conditions.

Thus, a cement concrete pavement is the most superior highway construction primarily from the point of view of strength and durability. The ingredients of the concrete mix, viz., the coarse aggregate (broken stone) and fine aggregate (sand) have to be selected carefully to satisfy the desirable properties for concrete-making. Potable water is generally considered satisfactory making cement concrete.

Cement is used also as an additive to soil to produce soil-cement used as the primarily material in the construction of low-cost roads.

Cement:

Cement is the most important ingredient of cement concrete or cement mortar (cement mortar is a suitable mixture of cement and fine aggregate or sand in appropriate proportions).

Cement mixed with water becomes a paste and spreads over the aggregates forming a thin film; chemical reactions take place leading to the formation of silicates and aluminates. Subsequently, setting takes place and in the presence of water, hydration takes place leading to hardening of the concrete.

The most common cement is what is now known as the Ordinary Portland Cement (OPC). Calcareous and silicate compounds are blended and heated to high temperatures (1500°C) to form clinkers of new chemical compounds, which when ground to fine particles result in 'cement'.

The primary ingredients of cement are:

(i) Tricalcium silicate ($3CaO.SiO_2$) ≈ 50%

(ii) Dicalcium silicate ($2CaO.SiO_2$) ≈ 22%

(iii) Tricalcium aluminate ($3CaO.Al_2O_3$) ≈ 9%

(iv) Tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$) ≈ 9%

(v) Miscellaneous compounds ≈ 10%

The silicates contribute to the immediate strength gain while the other ingredients are responsible for the long-term strength gain. The properties of cement can be modified by blending it in different admixtures in the manufacturing process.

The following are the different types cements widely used for specific purposes in India:

i. Ordinary Portland cement (OPC)

ii. Rapid hardening cement

iii. High alumina cement

iv. Low heat cement

v. Portland blast furnace slag cement

vi. White cement

Function of soil as highway Subgrade

Soil is used for the construction of the bottom most layer of the pavement, i.e. sub-grade. Here is a short details of the sub-grade and its function.:

- Sub-grade is the layer of the pavement whose main function is to support the upper layers of the pavement and to provide the good drainage facility to the infiltrating rain water. It has to act as a single structure along with other layers of the pavement.
- Soil is compacted to its maximum dry density which can be achieved by using the optimum moisture content and the methods of compaction control. Strength has to be ensured which is required for the given design thickness of the pavement.
- Strength analysis and the thickness of pavement are inter linked because more thickness of the pavement is needed if the soil is weak but if the soil possess a good strength then less thickness is needed.

This is ensured by using the CBR (California Bearing Ratio) Test which is produced or was first used by the California State Highway Department. Using the CBR test and the empirical charts you can find out the thickness of the flexible pavement required above the sub-grade.

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 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 are direct shear test, triaxial compression test, and unconfined compression test.

Bearing tests are loading tests carried out on sub grade soils in-situ with a load bearing area. The results of the bearing tests are influenced by variations in the soil properties within the stressed soil mass underneath and hence the overall stability of the part of the soil mass stressed could be studied.

Penetration tests may be considered as small-scale bearing tests in which the size of the loaded area is relatively much smaller and ratio of the penetration to the size of the loaded area is much greater than the ratios in bearing tests. The penetration tests are carried out in the field or in the laboratory.

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. CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus. It is a penetration test wherein a standard piston, having an area of 3 in (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the CBR. 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.

In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired. The CBR test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

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.

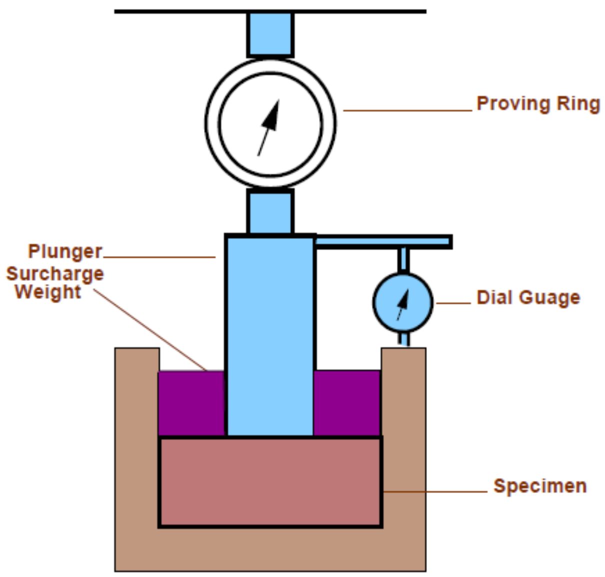
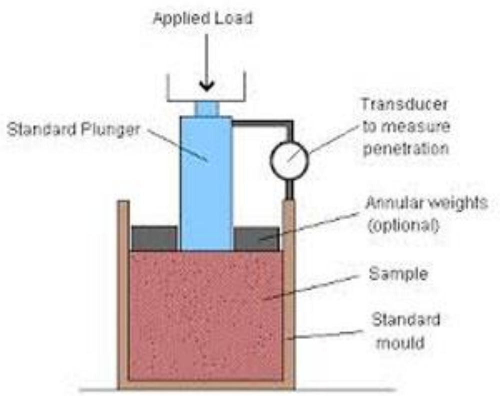


Figure: CBR test



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,

$$CBR = \frac{Load sustained by the specimen at\ 2.5\ or\ 5\ mm penetration}{Load sustained by standard specimen at corresponding penetration level} \times 100$$

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

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

Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.

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.

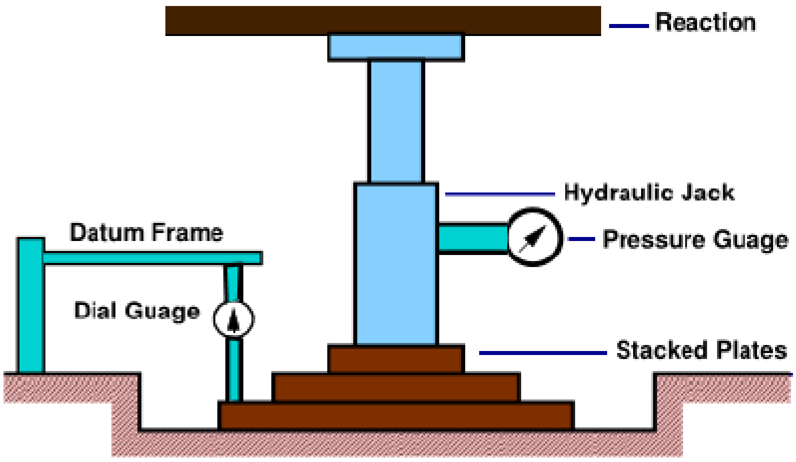
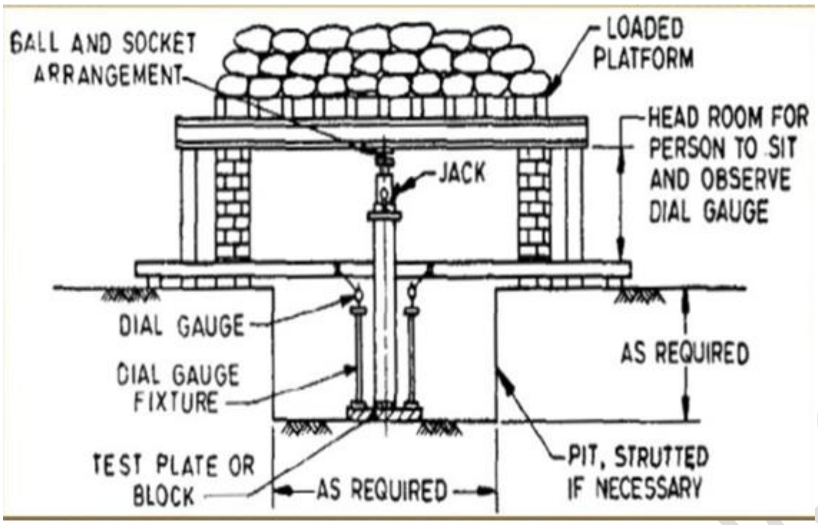
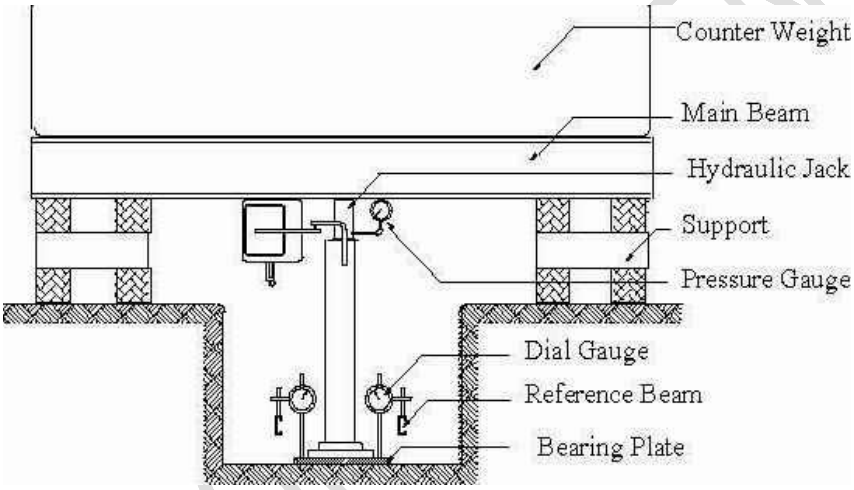


Figure: Plate load Test

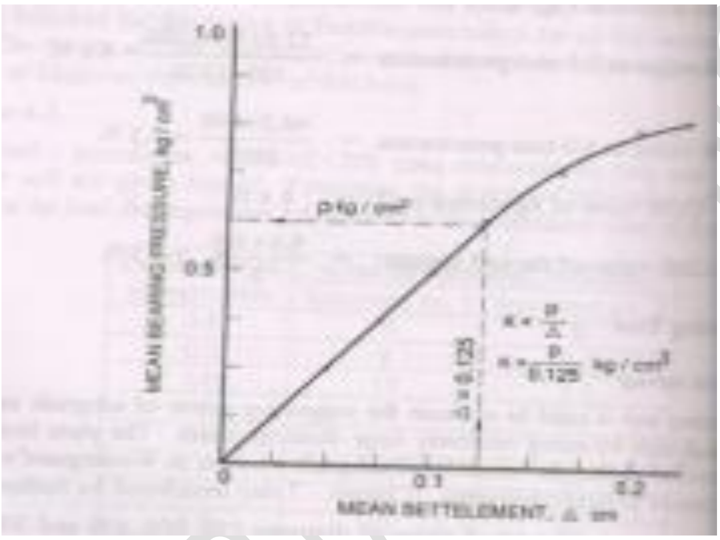




Procedure:

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

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. $Ka = K_1 a_1$

or $K = K_1 a_1 / a$

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

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

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

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

A= radius of plate

$K_1 a_1 = k_2 a_2$

A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter of 30 cm. The load values corresponding to the mean settlement dial readings are given below. Determine the modulus of subgrade reaction for the standard plate.

Mean settlement values, mm	0.0	0.24	0.52	0.76	1.02	1.23	1.53	1.76
Load values, kg	0.0	460	900	1180	1360	1480	1590	1640

Solution

The load-settlement curve is plotted on a graph paper (similar to the one shown in Fig. 6.13) and the load value p_1 corresponding mean settlement value of $\Delta = 0.125$ cm is determined = 1490 kg

For plate radius of a_1 = 15 cm, unit load, $p_1 = \frac{1490}{\pi 15^2}$ kg/cm^2

Modulus of subgrade reaction K_1 for 30 cm diameter plate

$$= \frac{p_1}{\Delta} = \frac{1490}{\pi 15^2 \times 0.125} = 16.86 \text{ kg/cm}^3$$

Modulus of subgrade reaction K for standard plate of diameter 75 cm

$$= \frac{K_1 a_1}{a} = \frac{16.86 \times 30}{75} = 6.75 \text{ kg/cm}^3$$

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 principal mechanical properties required in road stones are (i) Satisfactory resistance to crushing under the roller during construction and (ii) adequate resistance to surface abrasion under traffic. Also stresses under rigid tyre rims of heavily loaded animal drawn vehicles are high enough to consider the crushing strength of road aggregate as an essential requirement in India. Crushing strength of road aggregate may be determined either on aggregate or on cylindrical specimens cut out of rocks. These two tests are quite different is not only the approach but also is the expression of the results.

Aggregate used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the stability of the pavement stretches is likely to be adversely affected, the strength of coarse aggregate is assessed by aggregate crushing 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, aggregate possessing low aggregate value should be preferred.

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.

Testing Procedure:

i. Select clean and dry aggregate passing through IS 12.5 mm and retained on IS 10.0 mm sieve.

ii. Weight the empty cylindrical measure. Let the weight be ‘a’ g

iii. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod. Weigh the cylindrical measure with aggregate. Let the weight be ‘b’ grams. Thus, the weight of aggregate = W_1 g

iv. Transfer the aggregate into the steel cylinder again in three layers tamping each layer 25 times

v. Place the plunger in the steel cylinder such that the piston rests horizontally over the aggregate surface.

vi. Keep the assembly of steel cylinder with plunger in the compression testing machine.

vii. Set the pointer to read zero and apply the compressive load of 40 tonnes.

viii. Stop the machine. Take out the assembly.

ix. Sieve the crushed material on IS 2.36 mm sieve and find the weight of material passing this sieve. Let the weight be W_2 g.

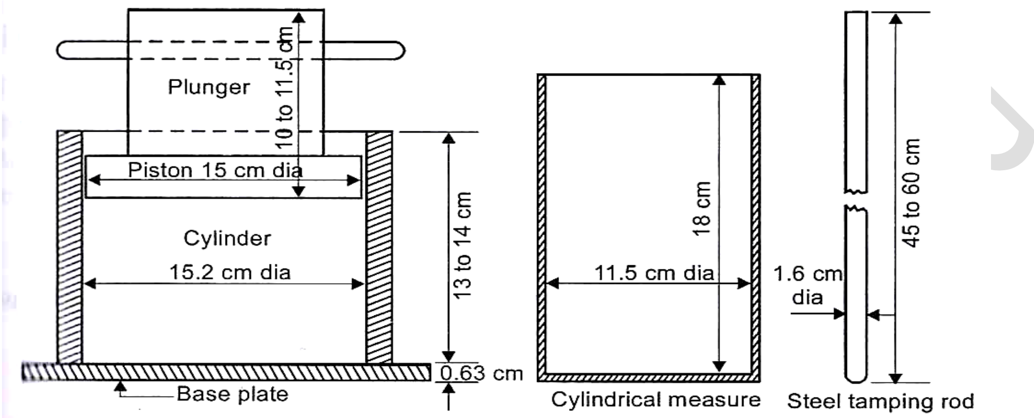
x. Then Aggregate crushing value=W_2 / W_1*100 %

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



Aggregate crushing test apparatus

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)

Due to the movement of traffic, the road stones used in the surfacing course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential property for road aggregates especially when used in wearing course. Thus road stones should be hard enough to resist the abrasion due to the traffic.

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.

Testing Procedure:

1) Take the clean and dried aggregates in an oven at 105-110° C.

2) Sieve the given aggregates in sieve size 20-12.5mm and weigh that aggregate in 2.5kg.

3) Again, sieve the aggregate in sieve size is 12.5-10mm and take that aggregates in 2.5 k. i.e., W_1 gm (2.5+2.5=5kg)

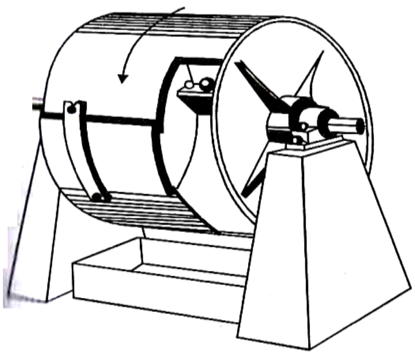
4) Pour the given taking aggregates into the los angles abrasion machine.

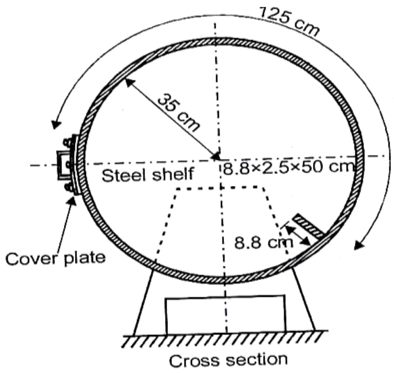
5) Put the steel balls into the abrasion machine after pouring the aggregates.

6) Start the machine and rotating the drum for 100 revolutions and stop the machine.

7) After stopping the machine, take out the aggregates and sieve the aggregates in 1.7mm sieve size and take the retained aggregates and note down its weight i.e, W_2 gm.

8) Then, Los Angles Abrasion value= $(W_1-W_2/W_1)X100$ %





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 = $20 - \frac{loss of weight in gm}{3}$

Impact value test

Toughness is the property of a material to resist impact. Due to traffic loads the road stones are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact.

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 value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregate differs from its resistance to a slow compressive load. The method of tests specifies the procedure for determining the aggregate impact value of coarse aggregate. 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.

Testing Procedure:

i. Take clean and dry aggregate and sieve on IS 12.5 mm and 10.00 mm sieve.

ii. Collect the aggregate passing IS 12.5mm sieve and retained on IS 10.0 mm Sieve.

iii. Find the weight of empty cylindrical measure. Let the weight be ‘a’ g.

iv. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod.

v. Roll the tamping rod over aggregate surface and remove excess aggregate, if any.

vi. Find the weight of the cylindrical measure with aggregate. Let the weight be ‘b’ g. Thus the weight of aggregate = W_1 = (b-a)

vii. Transfer all the aggregate from the cylindrical measure to the test cylinder in one layer and tamp the layer 25 times with the rounded end of the tamping rod.

viii. Fix the test cylinder firmly to the base of the impact tester.

ix. Adjust the height of fall of the plunger to 380+ 5mm and set the blow counter to zero.

x. Lift the plunger gently and allow it to drop. This is one blow. Give 15 such blows.

xi. Take out the test cylinder and sieve the crushed material on IS 2.36 mm sieve. Find the weight of material passing the sieve. Let weight be W_2 g.

xii. Find the weight of aggregate retained on this sieve. Let the weight be W_3 g.

Then, Aggregate impact value = W_2 / W_1 * 100 %

And percentage of dust = W_3 / W_1* 100 %

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.

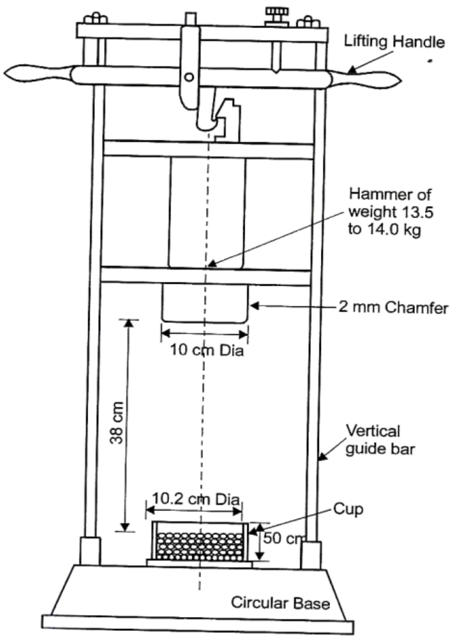
Aggregate impact value (AIV) = $\frac{W_2}{W_1}$ x 100

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.

Testing Procedure

1. In order, to quicken the effects of weathering due to alternate wet-dry or freeze-thaw cycles in the laboratory, the resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.

2. Clean, dry aggregates of specified size is weighed and counted. Then immersed in the saturated solution of sodium sulphate or magnesium sulphate for 16 to 18 hours.

3. Then the aggregates are dried in an oven at 105-110°C to a constant weight, thus making one cycle of immersion and drying.

4. The number of such cycles is decided by prior agreement and then the specimens are tested. After completing the final cycle, the sample is dried and each fraction of aggregate is examined visually to see if there is any evidence of excessive splitting, crumbling or disintegration of the grains.

5. Sieve analysis is carried out to note the variation in gradation from original. The coarse aggregate fraction of each size range is sieved on specified sieve sizes.

Desirable value

IRC has specified 12percent as the maximum permissible loss in soundness test after 5 cycles with sodium sulphate, for the aggregate to be used in bituminous surface dressing, penetration macadam and bituminous macadam constructions.

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

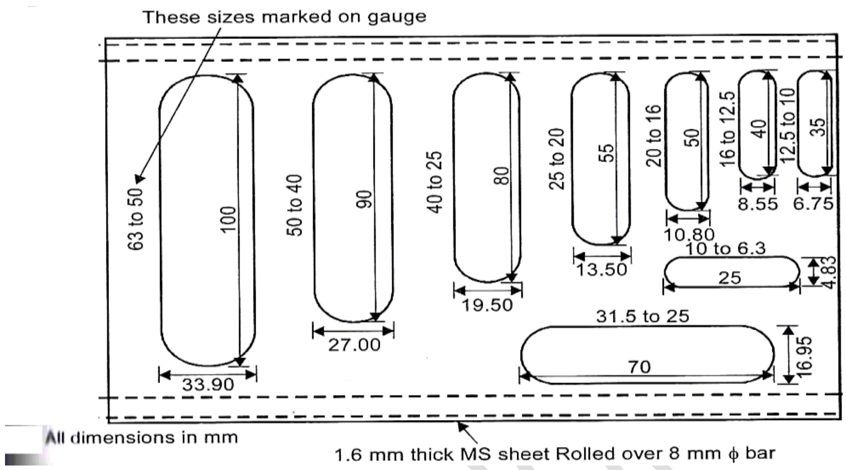
The flakiness index of aggregate is the percentage by weight of aggregate particles whose least dimensions /thickness is less than three fifths or 0.6 of their mean dimension. The test applicable to sizes larger than 6.3mm. Standard thickness gauge is used to cause the thickness of the sample.

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.

Flaky index = $\frac{w}{W}$ x 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 of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values. The specific gravity test helps in the identification of stone. Water absorption gives an idea of strength of rock stones having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness.

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.

Testing Procedure:

1. Take about 2kg of given aggregates passing IS 20mm sieve and retained on 10mm sieve.
2. Keep the aggregate in density basket and then keep the basket in water.
3. Allow the aggregate and basket to be in water for 24 hours.
4. After 24 hours find the suspended weight of basket with aggregate.
5. Remove the basket out of water and remove the aggregate.
6. Keep the empty basket back in water and find the suspended weight.
7. Wipe the surface of aggregate using a cotton cloth to make them surface dry.
8. Find the weight of surface dry aggregate in air.
9. Keep the aggregate in oven at 110° C for 24 hours.
10. Now find the weight of dried aggregate in air.
11. Then specific gravity and Water absorption is calculated from the relation:

$$\text{Specific gravity} = \frac{W4}{W3-(W1-W2)}$$

$$\text{Water absorption} = \frac{W3-W4}{W4} * 100\ \%$$

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.

A schematic flow-chart for petroleum refining is shown in Fig.

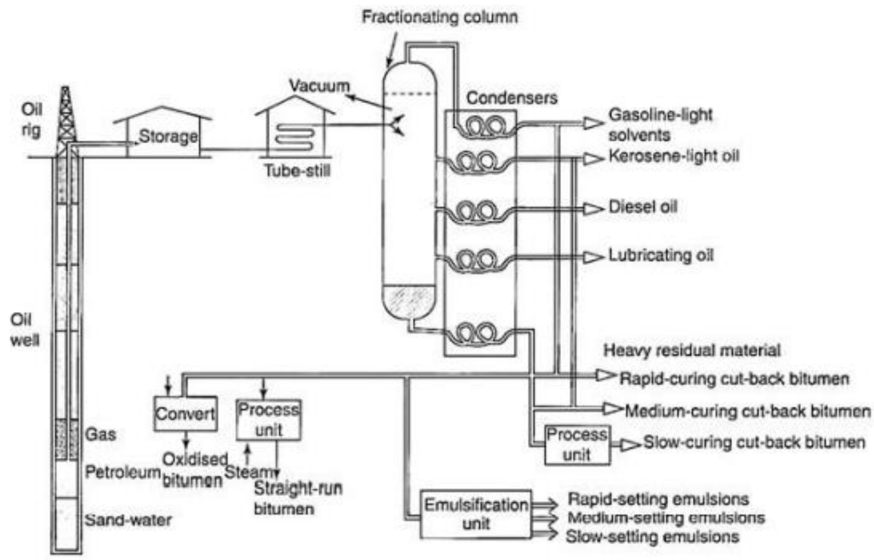


Fig. Schematic flow chat of petroleum refining

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:

Cut-back bitumen is one, the viscosity of which is reduced by adding a volatile diluent. Penetration grade bitumens require to be heated to a specified temperature to lower its viscosity before it is applied on a road to facilitate coating the pre-heated aggregate. To obviate the need for heating the aggregate, cut-backs come in handy. Upon application, the volatiles slowly evaporate, and leave behind the original bituminous binder.

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.

There are three types of cut-backs based on the diluent (dilutant or solvent) used:

1. Rapid-curing (RC) cutback – Bitumen blended with gasoline or naphtha, (highly volatile, low viscosity)
2. Medium-curing (MC) cutback – Bitumen blended with kerosene or coal tar creosote oil (medium viscosity)
3. Slow-curing (SC) cutback – Bitumen blended with gas oil (low viscosity, highly viscous)

Each of these has been categorized based on their initial kinematic viscosity values as follows:

1. RC 70, RC 250, RC 800, RC 3000
2. MC 30, MC 70, MC 250, MC 800, MC 3000
3. SC 70, SC 250, SC 800, SC 3000

Further details and specifications for these cutbacks are given in "IS: 217- 1988: Specification for cutback bitumen, Bureau of Indian Standards, New Delhi, 1993".

Since cutbacks contain volatile solvent, some of which may enter water bodies and air, they may cause environmental pollution. Also, since the solvent is inflammable, it may increase the possibility of fire hazard and cause concerns related to safety during handling and application. Therefore, cutbacks are being gradually replaced by emulsions.

Bitumen Emulsion:

A bitumen emulsion is obtained by blending bitumen with water and an additive called an emulsifier. The emulsified suspension contains dispersed minute particles of bitumen (that is, oil in water). In a bituminous emulsion, bitumen is the 'dispersed' phase (minutely subdivided particles), while water is the 'continuous' phase in which it is not soluble. The amount of bitumen to be mixed with water may range from 40 to 70% depending upon the intended use of the suspension.

Based on the type of emulsifier used, the bitumen particles can be negatively charged or positively charged. If they are negatively charged, 'anionic bitumen emulsions' are obtained, and if they are positively charged, 'cationic emulsions' are got.

Fatty acids derived from mineral, vegetable or wood sources saponified with sodium or potassium hydroxide are used as emulsifiers for producing anionic emulsion. For cationic emulsions, the emulsifiers are generally amine salts produced by the reaction of organic amine or diamine with acetic acid or hydrochloric acid.

The type of emulsion should be selected based on the mineral composition of the aggregate used for the bituminous mix. For example, for an aggregate rich in silica (SiO_2) which has a strong electronegative charge on the surface, cationic emulsions are suitable with electropositive charge on the suspended bitumen particles. The mix then becomes electrostatically stable and produces a strong layer when compacted.

Bitumen emulsions, like cutback bitumens, are also classified into three types based on their setting times:

1. Rapid-setting emulsions (RS)
2. Medium-setting emulsions (MS)
3. Slow-setting emulsions (SS)

Setting, in this context, means separation of the emulsion. When the water in the emulsion evaporates, the minute bitumen particles in the emulsion coat the surface of the aggregates; curing takes place, by which the compacted layer of the emulsion-aggregate mix hardens and attains strength. Therefore, rapid-setting emulsion sets and cures in a relatively quick manner.

"IS: 3117-2004: Anionic bitumen emulsions" covers anionic emulsions, while

"IS: 8887- 2004: Cationic bitumen emulsions" covers cationic emulsions.

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 possess 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.

Setting and curing of emulsion mixes are affected by the following factors:

I. Gradation, dust, dampness, water absorption and mineral composition and surface charge of/on the aggregates.

II. Ingredients and quantity of the emulsion used.

III. Meteorological conditions like climate, weather, temperature, humidity, wind velocity, etc.

IV. Drainage conditions of the construction site.

Advantages of Emulsions:

1. Emulsions can be used under cold and damp weather conditions.
2. Strength properties of bitumen are preserved as they do not need hot mixing.
3. Better coating of aggregates due to low viscosity of the emulsion.
4. Ideal for patch repair work and sealing of cracks as no heating is required and better penetration into even minute cracks is possible.
5. Water-based nature of the emulsions makes them environment-friendly.
6. A lot of energy is conserved as there is no need for intensive heating (only warming is needed, if at all.)

Limitations of Emulsions:

1. The nature of the aggregate has to be verified before choosing an appropriate emulsion.
2. Setting time varies not only with the type of emulsion, but also with atmospheric conditions at the time of application.
3. Based on the particular need, care should be exercised in choosing the type of emulsion and the quantity needed for the desired grade of bituminous mix.
4. Storage time is relatively restricted.
5. Bitumen emulsions are more expensive than hot-mix bitumen.
6. In general, emulsion-based bituminous pavements using emulsions are not as good as hot-mix constructions for heavy traffic loads.

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

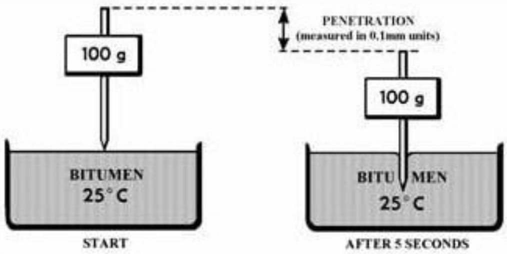
The penetration test determines the hardness and softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in five seconds. The sample is maintained at a temperature of 25^0C.

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^oC 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

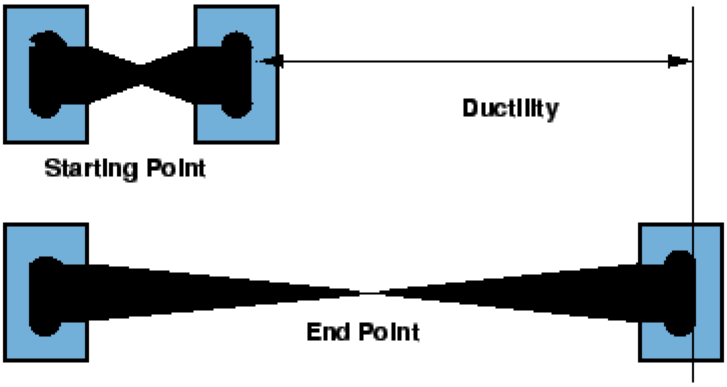
conditions or means penetration value lies between 8 to 10 mm. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred. Grade of bitumen is decided on the basis of penetration test. If grade of 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:

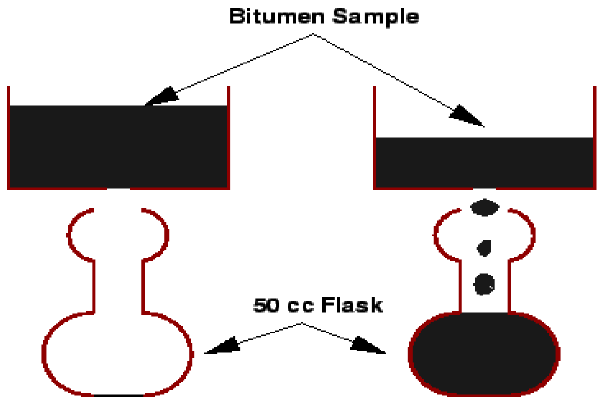
It is a measure of adhesiveness and elasticity of bitumen. Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension 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.

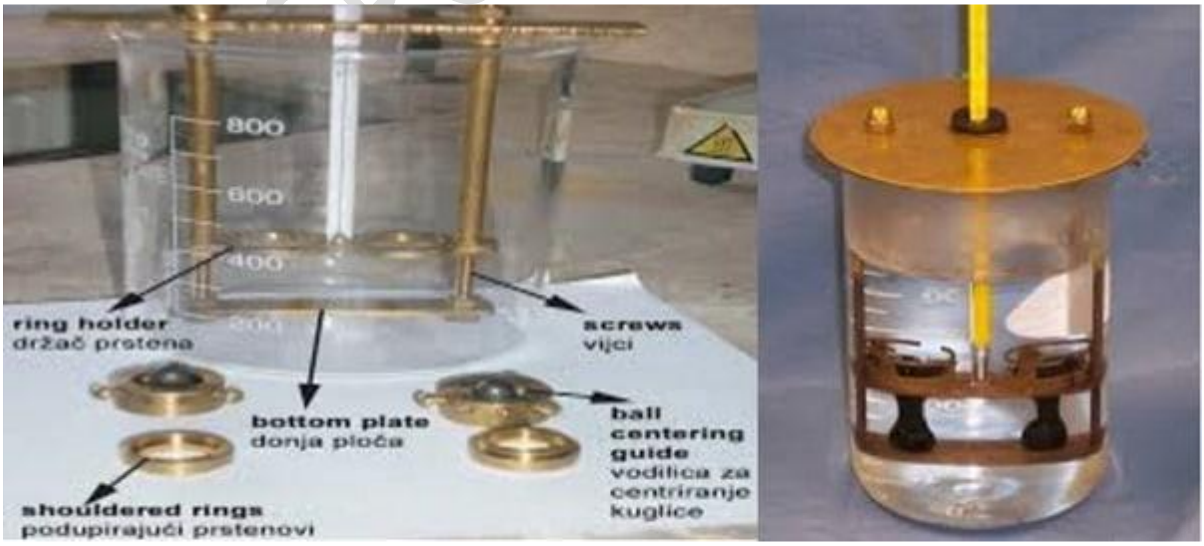


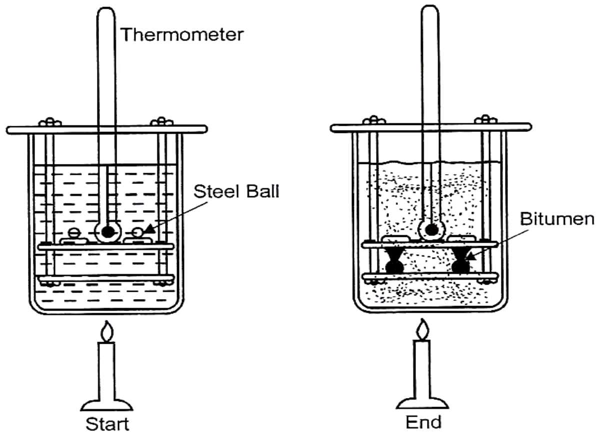
Softening point test:

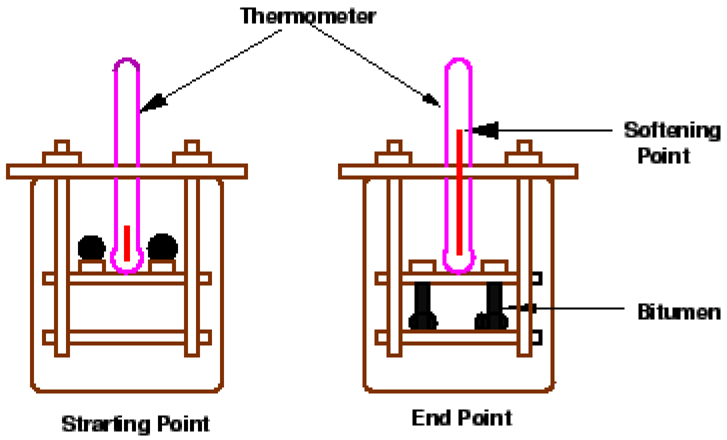
The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. The softening point of bitumen is usually determined by ring and ball test.

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.

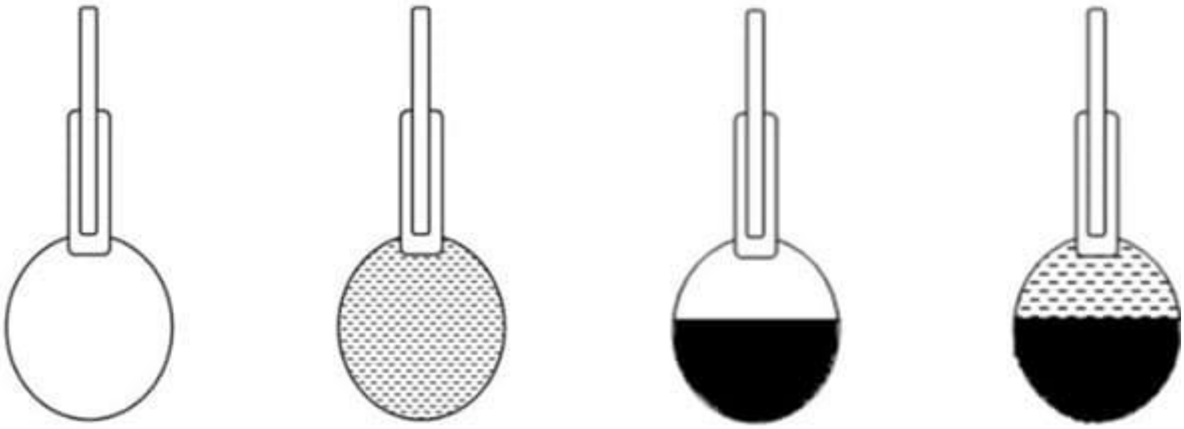
In this method, take clean and dry specific gravity bottle and take its weight(w_1).in the 2^{nd}case, fill the bottle with distilled water and dip it in water bath for 30 minutes and note down the weight(w_2). Next, fill half the bottle with bitumen sample and weigh (w_3).

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.

Specific Gravity Computation of Bituminous Material



Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catch 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^{0}C). The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

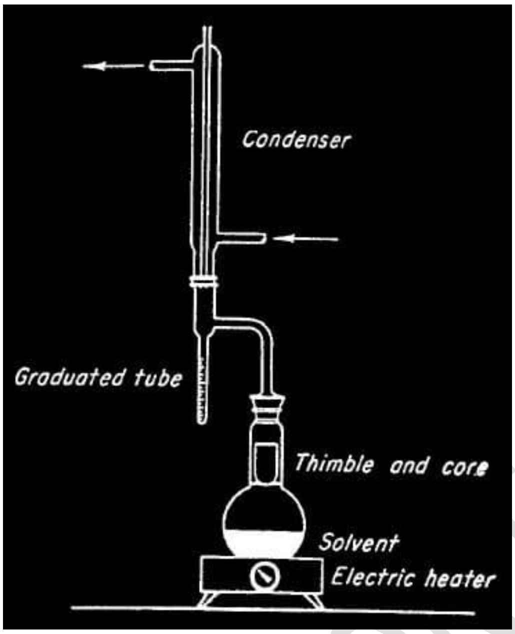
Apparatus use Pensky Nartin closed and open cup apparatus

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.

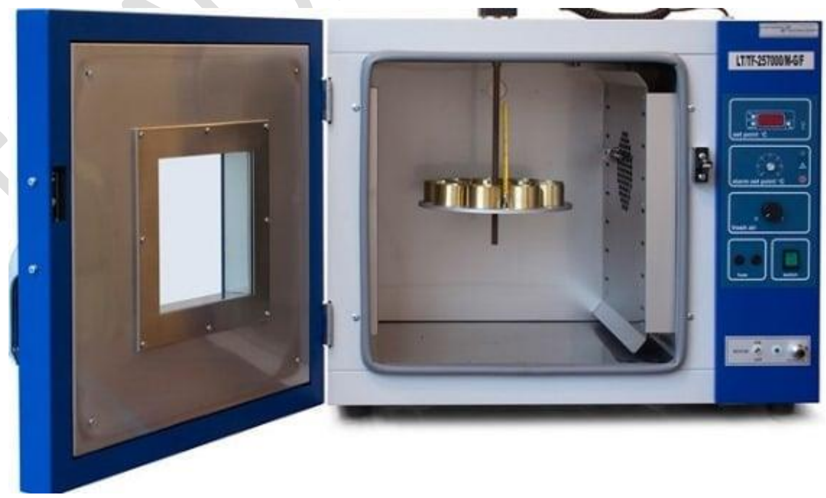
Water content test

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^{0}C 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 a black or brown to black, viscous, non-crystalline material having binding property. This is, therefore, the other category of bituminous materials.

Tar is obtained from the destructive distillation of organic materials such as coal, petroleum, oil, wood and peat, in the absence of air at about 1000°C. It is completely soluble in carbon tetrachloride (CCl_4). It contains more volatile constituents than bitumen and is therefore more susceptible to change in temperature. Generally, tar is used for surface dressing on the wearing course since it has good adhesion in damp conditions.

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.

Some more terms relating to tar are:

i. Coal tar – Tar produced by the destructive distillation of bituminous coal.

ii. Coke-oven tar – A variety of coal tar obtained as a by-product from the destructive distillation of coal in the production of coke.

iii. Oil-gas tar – A petroleum tar produced by cracking oils at high temperature in the production of oil-gas.

iv. Water-gas tar – A petroleum tar produced by cracking oils at high temperature in the production of carburetted water-gas.

v. Refined tar – Produced from crude tar by distillation to remove water and to produce a residue of desired consistency.

vi. Road tar – A tar refined in quality and consistency for use in paving of roads.

vii. Pitch – Black or dark brown solid cementitious residue which gradually liquefies when heated and which is produced by distilling off the volatile constituents from tar.

Specifications for Road Tars:

Indian Standards classify road tars for paving purposes into five grades — RT1, RT2, RT3, RT4, and RT5, meant for specific purposes. These are covered by "IS: 215-1995: Road tar: Specifications, Bureau of Indian Standards, New Delhi, 2000".

The grades and specific uses are given below in Table 6.12:

Table 6.12 (IS: 215-1995, 2000)

Grade	Specific uses
RT-1	Surface dressing for very cold weather conditions and at very high elevation on hill roads.
RT-2	Surface dressing under normal climatic conditions.
RT-3	(a) Surface dressing and renewal coats. (b) Pre-coating chippings; light chipping carpet.
RT-4	Premix tar macadam
RT-5	Grouting

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.

Low Temperature Tar:

The coal-tar produced in the manufacture of coking coal requires carbonation at high temperatures above 1000°C. In view of the increasing demand for road tars in recent years, a new technology known as low temperature carbonization has come into vogue.

In this, the carbonization of coal is carried out in the temperature range of 600°- 750°C in a smokeless fuel process. The crude tar thus produced is successfully used for making road tars; these are known as low temperature tars.

Bitumen versus Tar:

A comparison of bitumen and tar is given below:

I. Aggregates coated with tar exhibit lower stripping action than those coated with bitumen.

II. Tar is more susceptible to temperature than bitumen. It becomes liquid at relatively lower temperature.

III. Tar is not easily dissolved in petroleum solvents; so it can be preferred for paving parking areas, where oils might drip from vehicles.

IV. Since more setting time is required for tar, it may be processed at a mixing plant and carried to the construction site.

V. In view of the higher free carbon content, tar is more brittle than bitumen.

VI. As tars have more phenol content, they can get more easily oxidised than bitumen.

VII. At higher temperatures, tar may be more easily affected than bitumen.

VIII. As more time is required for tar to set, tar-paved roads need to be closed to traffic for a longer time.

IX. Both bitumen and tar appear black in colour in a large mass, but appear brown in thin films.

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	It binds aggregate more easily & retain it

the presence of water	better in the presence of water.

Tar-Bitumen Mixtures:

A mixture of tar and bitumen provides a binder of excellent quality as it has a decreased volume of insoluble benzene is decreased. Such mixtures have lower temperature susceptibility and reduced penetration value. Rheological properties of the binder also get altered. Generally, a mixture of tar and bitumen in equal proportions is considered to be an ideal binder.

Bituminous Mixes:

Bituminous mixes for paving purposes consist of coarse aggregate, fine aggregate, filler material, bitumen, and air voids, suitably proportional and blended to provide a strong, stable and durable pavement. The main aim of mix design is to determine the optimum bitumen content that will hold the mineral aggregates of suitable gradation together as a compact layer that resists the traffic loads. The mix should have a certain minimum air voids to allow volume changes during service either because of temperature changes or repeated loading from the traffic.

Requirements of Bituminous Mixes:

The following are the important requirements of bituminous mixes for pavements:

(i) Stability:

This is the resistance to deformation under traffic loads; it is a function of interparticle friction and cohesion offered by the bitumen binder. It is related to the density of the mix which is dependent on the voids content. The more the density, the more stable the mix; however, a minimum voids content is necessary to allow for volume changes which cannot be fully prevented.

(ii) Durability:

This is the resistance to weathering action and abrasion from traffic. Spalling, stripping and formation of pits, corrugations and potholes can result from weathering and traffic. Excessive strain may cause cracking or plastic failure.

(iii) Flexibility:

This is a measure of the resistance to long-term deformations and shapes of the road base, sub-base and subgrade; this depends on the flexural or bending strength of the pavement.

(iv) Skid Resistance:

The resistance of the surface of the pavement laid with the bituminous mix to skidding of the tyres of vehicles is called skid resistance. The surface texture should be such as to provide grip or friction even under wet conditions. This is important in the prevention of accidents.

(v) Workability:

This is the ease with which the mix can be placed in position and compacted. It depends on the aggregate characteristics like the size, shape texture and gradation, bitumen content and nature of the bituminous material.

(vi) Economy:

The overall cost in achieving the desired qualities of the mix and the pavement should be a minimum, consistent with quality.

The desired qualities of the bituminous mixes, therefore, have to be achieved by:

1. Using good quality aggregate, which is hydrophobic and has rough surface texture, with appropriate grading and voids content.

2. Using bituminous binder of the correct quality and consistency based on the specific purpose for which the pairing mix is intended.

3. Controlling the voids content and the bitumen content to achieve the desirable qualities listed above.

BITUMINOUS PAVING MIXES

Requirements of Bituminous Mixes

Bituminous mixes (sometimes called asphalt mixes) are used in the surface layer of road and airfield pavements. The mix is composed usually of aggregate and asphalt cements. Some types of bituminous mixes are also used in base coarse. The design of asphalt paving mix, as with the design of other engineering materials is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure.

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.

Desirable properties of Asphalt mixes

1. Resistance to permanent deformation: The mix should not distort or be displaced when subjected to traffic loads. The resistance to permanent deformation is more important at high temperatures.
2. Fatigue resistance: the mix should not crack when subjected to repeated loads over a period of time.
3. Resistance to low temperature cracking. This mix property is important in cold regions.
4. Durability: the mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process.
5. Resistance to moisture-induced damage.
6. Skid resistance.
7. Workability: the mix must be capable of being placed and compacted with reasonable effort.
8. Low noise and good drainage properties: If the mix is to be used for the surface (wearing) layer of the pavement structure.

Asphalt Mix Design is a very delicate engineering activity. It has to address many criteria: strength, stability, durability, impermeability, workability, surface skid resistance, resistance against fatigue cracking and rutting, appearance etc. But the fundamental performance properties are not measured in the design mix, those are indirectly assessed by some empirical parameters.

The parameters which have to be taken into account to achieve the desired criteria are:

- Sufficient asphalt or bitumen in the mix to ensure durable pavement.
- Sufficient voids in the compacted mix to allow as light amount of expansion of asphalt due to increase in temperature and also by the action of additional compaction under the effect of traffic movement specially in summer season when viscosity of the binder comes down a bit, without flushing, bleeding and loss of stability.
- Maximum void content in the mix to restrict the ingress of air and moisture causing early aging of the binder.
- Sufficient mix stability to satisfy the demand of traffic without distortion or displacement.
- Sufficient workability to permit efficient placement without segregation and without sacrificing stability and performance

- To provide sufficient skid resistance of the surface mix specially in unfavorable weather condition.
- To provide a good appearance of the pavement surface as well as to provide a noise-less smooth interaction with the pneumatic tyres of the vehicles.

Objective of the mix design

There are various objectives of mix design

- Sufficient bitumen to ensure a durable pavement.
- Sufficient strength to resist shear deformation under traffic at higher temperature.
- Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic.
- Sufficient workability to permit easy placement.
- Sufficient flexibility to avoid premature cracking and shrinkage cracks.
- Skid resistance.
- To determine a cost-effective blend of asphalt and mineral aggregate including filler, if any, with appropriate gradation which will yield a durable and serviceable pavement.

Methods of Mix Design

There are various methods of mix design

1. Marshall Method of mix design.
2. Haveems Method of mix design.
3. Superpave Method of mix design.

1. **Marshall Method:** Developed by Bruce Marshall, a former bituminous engineer with Mississippi State Highway Department and further improved by US army crops of Engineers. Guideline: ASTM D 1559, MS-2(Asphalt Institute, USA)

2. **Hveem Method:** Developed by Francis N Hveem, a former material and research engineer of California Department of transportation. Guideline: ASTM D 1561, MS-2 (Asphalt Institute, USA)

3. **Superior performing asphalt pavement (Superpave) method:** In USA, Strategic Highway Research Program(SHRP) developed a newer and improved asphalt mix design in 1987 as a five year,$ 150 million program which is the Superpave Mix Design Method. This method not only addresses the problem of better simulation of field compaction level under traffic effect to the laboratory samples but also differs from other mix design methods by

using performance-based and performance-related criteria to design the proper asphalt mix. Guideline: SP-2 (Asphalt Institute, USA).

Out of the three methods, Marshall Method is being used in India like most of the countries in the world. It was also in use in most of the states in USA, till Superpave has come in force.

Marshall method is popular because it's testing methods are simple, equipments are not costly. Since 2nd World war , Marshall Method has been successfully applied all over the world. Superpave is a superior method, but it's application outside USA is not extensive.

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 a mix: -

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

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

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

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

Types of mix:

(i) Well graded mix: Dense mix, bituminous concrete has good proportion of all constituents and are called dense bituminous macadam, offers good compressive strength and some tensile strength.

(ii) Gap graded mix: Some large coarse aggregates are missing and has good fatigue and tensile strength.

(iii) Open graded mix: Fine aggregate and filler are missing. It is porous and offers good friction, low strength and for high speed.

(iv) Unbounded: Binder is absent and behaves under loads as if its components were not linked together, though good interlocking exists. Very low tensile strength and needs kerb protection.

Different layers in a pavement:

(i) Bituminous Base course: It consists of mineral aggregates such as stone, gravel or sand bonded together by a bituminous material and used as a foundation upon which to place a binder or surface course.

(ii) Bituminous Binder course: A bituminous aggregate mixture used as an intermediate coarse between the base and surface courses or as the first bituminous layer in a two layer bituminous resurfacing. It is sometimes called as levelling course.

(iii) Asphaltic/Bituminous concrete: Bituminous concrete consists of a mixture of aggregates continuously graded from maximum size, typically less than 25 mm, through fine filler that is smaller than 0.075 mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties.

Steps in Mixed Design:

Various steps involved in the mix design are as follows:

1. Selection of aggregate and grading
2. Determination of specific gravity
3. Proportion of aggregate by triangular chart method
4. Preparation of specimen by adding bitumen
5. Determination of specific gravity on 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 Mix Design:

The mix design determines the optimum bitumen content for the evaluation of performance of bituminous mixed flow test and stability test are performed. The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method.

Stability is defined as maximum load carried by specimen at a standard temperature of 60^0 C and with the loading rate of 50.8 mm/minute. Stability is expressed in kg. Flow is measured as deformation in units of 0.25 mm between as load and maximum load during stability test. Thus, if deformation is 6 mm, flow value is 24.

Apparatus required

- Compaction mould, Cylindrical mould of diameter10.16cm and height of 7.5cm with collar, and a base plate.
- Compaction hammer, The compaction hammer has a flat circular plate of diameter 98.4mm and weight 4.5 kg lifted and released from a height of 45.7 cm
- Sample Extractor: for extruding the compacted specimen from the mould
- The compaction pedestal
- Loading machine
- Thermometers, oven, Dial gauges, Flow meter and water bath.

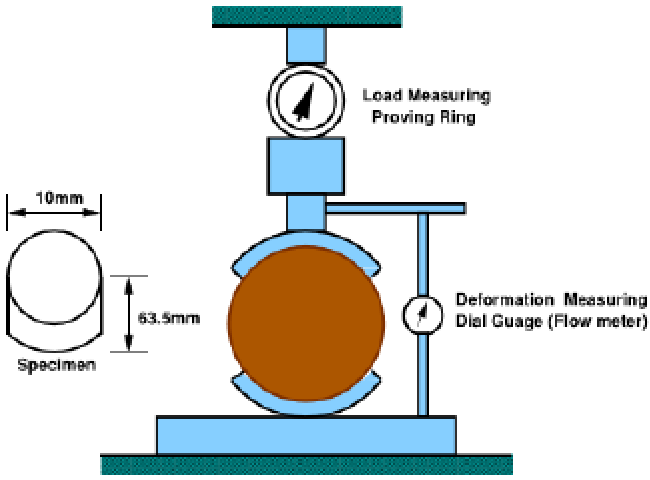


Figure: Marshall test setup

Steps involved in the Preparation of Specimen

(i) Coarse aggregates, fine aggregates and filler material should be proportioned and mixed in such a way that the final mix after blending has gradation within the specified range as given in table.

Table: Specified gradation of aggregates for bituminous concrete surface course

Sieve size (mm)	Percent Passing, by weight	
	Grade 1	Grade 2
20	-	100
12.5	100	80 - 100
10.0	80 - 100	70 - 90
4.75	55 - 75	50 - 70
2.36	35 - 50	35 - 50
0.600	18 - 29	18 - 29
0.300	13 - 23	13 - 23
0.150	8 - 16	8 - 16
0.075	4 - 10	4 - 10
Binder content	5 - 7.5	5 - 7.5

(ii) Approximately 1200gm of aggregates and filler is heated to a temperature of 175 - 190^oC.

(iii) Bitumen is heated to a temperature of 121 - 125^{o}C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates).

(iv) The heated aggregates and bitumen are thoroughly mixed at a temperature of 154 - 160^{o}C.

(v) The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138^{o}C to 149^{o}C.

(vi) The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm.

(vii) Vary the bitumen content in the next trial by +0.5% and repeat the above procedure. Number of trials are predetermined. The prepared mould is loaded in the Marshall test setup.

Different Properties of mix

The properties that are of interest include the theoretical specific gravity G_t, the bulk specific gravity of the mix G_m, percent air voids V_v, percent volume of bitumen V_b, percent void in mixed aggregate VMA and percent voids filled with bitumen VFB. These calculations are discussed next. To understand these calculation a phase diagram is given in Figure.

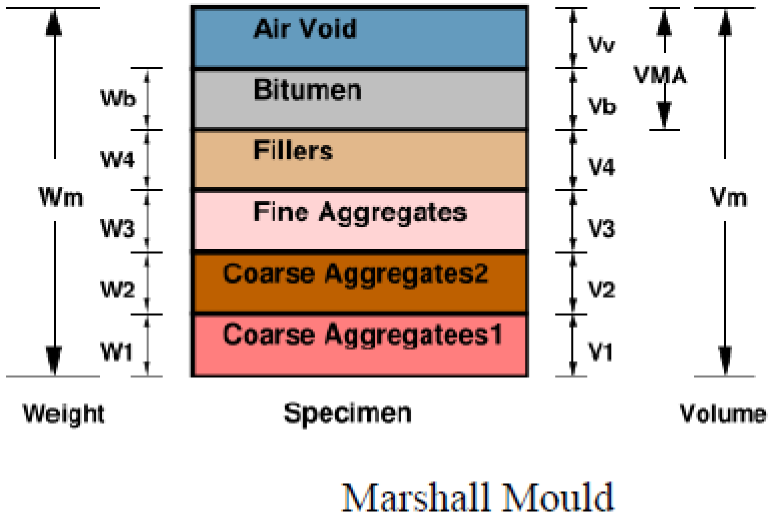


Figure: Phase diagram of a bituminous mix

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

Theoretical specific gravity G_t is the specific gravity without considering air voids, and is given by:

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

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

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

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

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

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

where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_1 is the apparent specific gravity of coarse aggregate, G_2 is the apparent specific gravity of fine aggregate, G_3 is the apparent specific gravity of filler and G_b is the apparent specific gravity of bitumen.

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

The bulk specific gravity or the actual specific gravity of the mix G_m is the specific gravity considering air voids and is found out by:

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

$$G_m = \frac{W_m}{W_m - W_w}$$

where, W_m is the weight of mix in air, W_w is the weight of mix in water, Note that W_m - W_w gives the volume of the mix. Sometimes to get accurate bulk specific gravity, the specimen is coated with thin film of paraffin wax, when weight is taken in the water. This, however requires to consider the weight and volume of wax in the calculations.

(3) Percent Air Void V_v:

Air voids V_v is the percent of air voids by volume in the specimen and is given by:

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

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

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

where G_t is the theoretical specific gravity of the mix, and G_m is the bulk or actual specific gravity of the mix.

(4) Percent Volume of bitumen V_b

The volume of bitumen V_b is the percent of volume of bitumen to the total volume and given by:

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

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

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

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

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

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

$$V_b = \frac{\frac{W_b}{G_b}}{\frac{W_1+W_2+W_3+W_b}{G_m}}$$

where, W_1 is the weight of coarse aggregate in the total mix, W_2 is the weight of fine aggregate in the total mix, W_3 is the weight of filler in the total mix, W_b is the weight of bitumen in the total mix, G_b is the apparent specific gravity of bitumen, and G_m is the bulk specific gravity of mix.

(5) Voids in mineral aggregate (VMA)

Voids in mineral aggregate VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from

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

$$VMA = V_v + V_b$$

where, V_v is the percent air voids in the mix and V_b is percent bitumen content in the mix.

(6) Void filled with bitumen VFB

Voids filled with bitumen VFB is the voids in the mineral aggregate frame work filled with the bitumen, and is calculated as:

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

$$VFB = \frac{V_b \times 100}{VMA}$$

where, V_b is percent bitumen content in the mix, and VMA is the percent voids in the mineral aggregate.

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).

While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall flow value of the specimen.

Apply stability correction

It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5 mm. Therefore, measured stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm. This is done by multiplying each measured stability value by an appropriated correlation factors as given in Table below.

Table: Correction factors for Marshall stability values

Volume of specimen (cm^3)	Thickness of specimen (mm)	Correction Factor
457 - 470	57.1	1.19
471 - 482	68.7	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 - 573	69.9	0.86

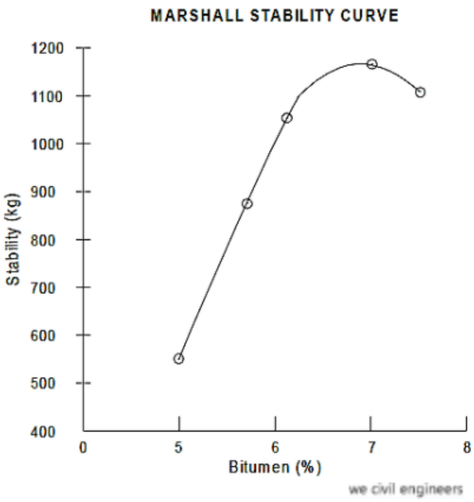
Prepare graphical plots

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

The average value of the above properties are found for each mix with the different bitumen contents. Graphs are plotted with the bitumen content on the x-axis and the following values on the y-axis.

1. Binder content versus corrected Marshall stability
2. Binder content versus Marshall flow
3. Binder content versus percentage of void (V_v) 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 (G_m)

A sample plot is given below



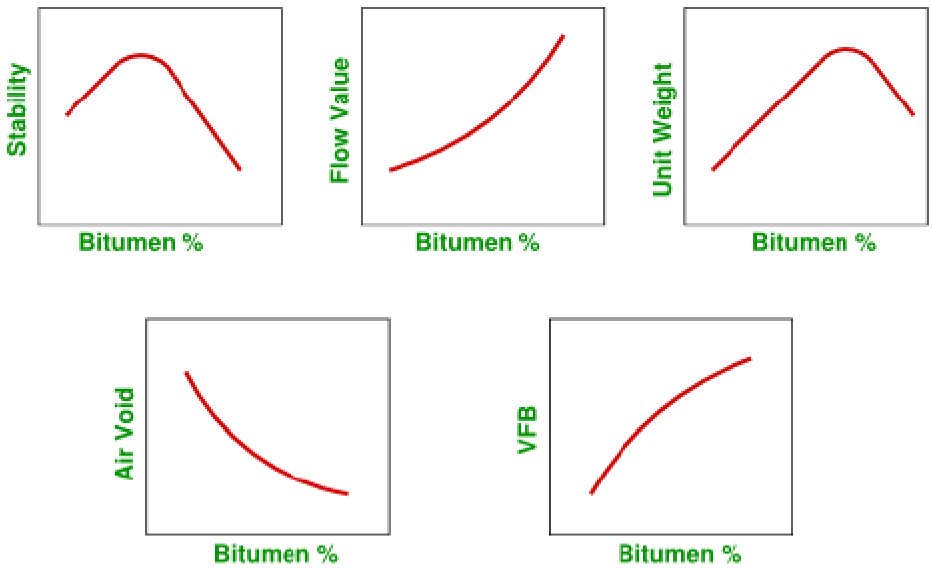


Figure: Marshal graphical plots

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%)

The stability value, flow value, and VFB are checked with Marshall mix design specification chart given in Table below. Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

Table: Marshall mix design specification

Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8 - 17
Percent air voids in the mix V_v%	3 - 5
Voids filled with bitumen VFB%	75 - 85

https://www.civil.iitb.ac.in/tvm/nptel/407_lnTse/web/web.html

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-surface water within the right way. This includes interception and diversion of water from the road surface and sub-grade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction.

During rain, part of the rain water flows on surface and part of it percolates through the soil mass as gravitational water until it reaches the ground water below the water table. Removal and diversion of surface water from the roadway and adjoining land is termed as surface drainage, while the removal of excess soil-water from the sub-grade is termed as sub-surface water.

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.

Necessity of road drainage work:

Highway drainage is important from various view points:

- Excess moisture in soil sub-grade causes instability under the road surface. The pavement may fail due to sub-grade failure. In some clayey soil variation in moisture content causes considerable variation in volume of sub-grade. This sometimes contributes to pavement failure.
- The waves and corrugations formed in case of flexible pavements also play an important role in pavement failure.
- Sustained contact of water with bituminous pavements causes failure due to stripping bitumen from the aggregates like loosening of some of the bituminous pavement layer and formation of pot holes.
- The prime cause of failures in rigid pavements by mud pumping is due to the presence of water in fine sub-grade soil.
- Excess water on shoulders and pavement edge causes considerable damage.
- Excess moisture causes increase in weight and thus increase in stress and simultaneous reduction in strength in soil mass. This is one of the main reasons of failure of earth slope and embankment foundations.
- In place where freezing temperatures are prevalent in winter, the presence of water in sub-grade and a continuous supply of water from the ground water can cause considerable damage to the pavement due to in frost action.
- Erosion of soil from top of un-surface roads and slopes of embankment, cut and hill side is also due to surface water.
- Failure due to hydraulic pressure and failure due to binder stripping can be avoided with the help of proper drainage on roads.

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.

Cross drainage works:

For streams crossing the runways, drainage needs to be provided. Also, often the water from the side drain is taken across by these cross drains in order to divert the water away from the road, to a water course or valley in the form of culverts or bridges. When a small stream crosses a road with linear water way less than amount six meter, the cross-drainage structure provided is called culvert; for higher value of linear waterway, the structure is called bridge.

Types of Cross-drainage Structures:

1. Culverts (waterway less than 6 m)
2. Minor bridges (waterway from 6-30 m)
3. Medium-sized bridges (waterway from 30-100 m)
4. Major bridges (waterway more than 100 m)
5. Causeways

Categories (2) and (3) may also be clubbed and called Minor bridges. Bridges are designed such that they are not submerged even under the highest flood expected in a design period of, say 50 years or 100 years, depending upon the importance of the highway and the bridge.

From the point of view of economy, a bridge may be designed to be submerged and cause interruption of traffic a limited number of days in a year. Such bridges are called submersible bridges.

Culverts:

The popular types of culverts are:

(i) Masonry arch culverts

(ii) Slab culverts (Stone slab or R.C.C. slab with abutments and piers)

(iii) Pipe culverts (Metal pipe, Stoneware pipe, or R.C.C. Hume pipe)

(iv) R.C.C. Box culverts

Bridges:

Bridge engineering is a specialised field. The following are types of bridges for spans in the increasing order:

(i) Masonry arch

(ii) R.C.C. slab (simply supported)

(iii) R.C.C. T-beam (simply supported)

(iv) Continuous T-beam and slab of R.C.C.

(v) R.C.C. balanced cantilever

(vi) Pre-stressed concrete

(vii) Suspension bridges.

Causeways:

Causeways allow water to flow over them when the stream or water course receives floods. These are provided on relatively unimportant roads with small volume of traffic.

The interruption to traffic on these structures should not be for more than 15 days in a year and not exceed 3 days at a stretch. Depending upon the degree of interruption, causeways may be called low-level causeways or high-level causeways.

SURFACE DRAINAGE

The surface water is to be collected and then disposed off. The water on the surface is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course. For the preparation of surface drainage, we should keep in mind various things like Seeing the amount of rainfall and slope a suitable camber is to be provided for collection of surface water. The shoulders of rural roads are constructed with suitable cross slopes so that the water is drained across the shoulders to the side drains. These side drains of rural roads are generally Open (kutcha) drains of trapezoidal shape, cut to suitable cross-section and longitudinal slopes. These sides are provided parallel to the road alignment and hence these are also known as longitudinal drains. In embankments the longitudinal drains are provided on one or both sides beyond the toe; in cutting, drains are installed on either side of the formation.

In urban roads because of the limitation of land width and also due to the presence of footpath, diving island and other road facilities, it is necessary to provide underground longitudinal drains. Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb and the pavement for short distances which may be collected in catch pits at suitable intervals and lead through underground pipes.

Drainage of surface water is all the more important in hill roads. In hill roads disposal of water is also very important. Certain maintenance problems may arise due to faulty hill road construction.

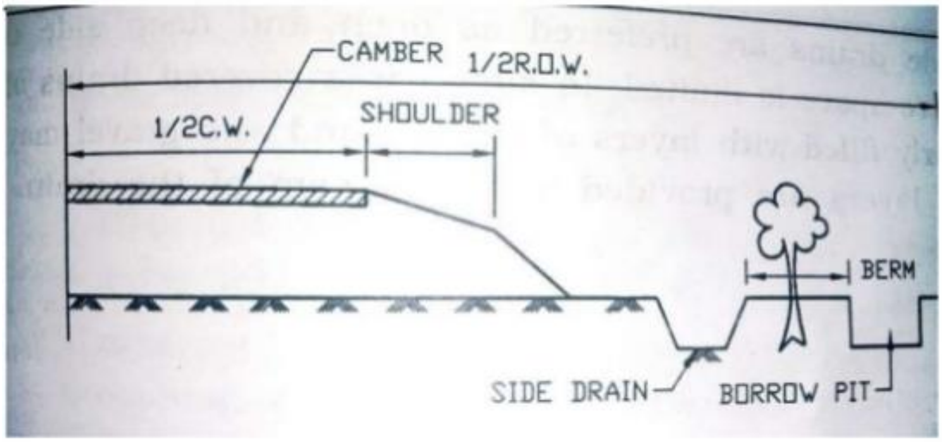
- During rains, part of the rain water flows on surface and part of it percolate through the soil mass as gravitational water until it reaches the ground water below water table.

- 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

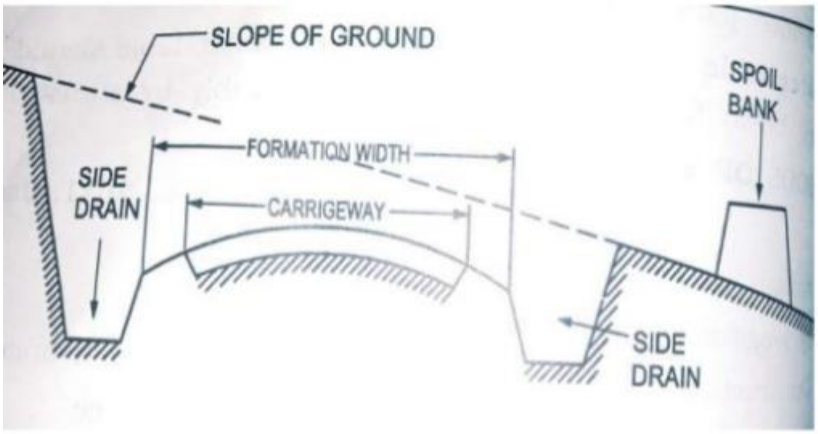
1. By Longitudinal side drains
2. Catch basins and inlets in urban areas
3. Providing damp proof course
4. Providing proper camber
5. Providing sufficient slope to the sides
6. Keeping the level of carriage way at least 60 cm above the HFL

Side drains for road in embankment –

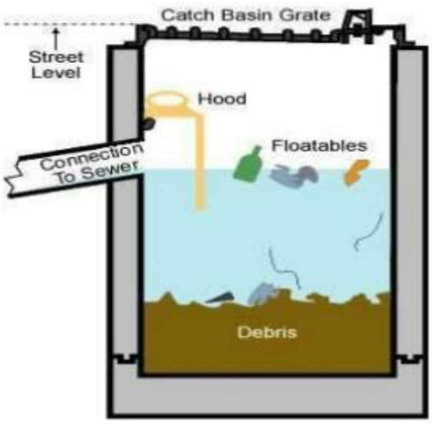


- It is necessary to provide side drain on one side or both sides, when road is constructed in embankment.
- Side drains should be at least 2.0 m away from bottom edge of an embankment.
- Depth of side drains is kept 1.0 to 1.5 m to prevent the entry of drain water into the embankment.

Side drains for road in cutting

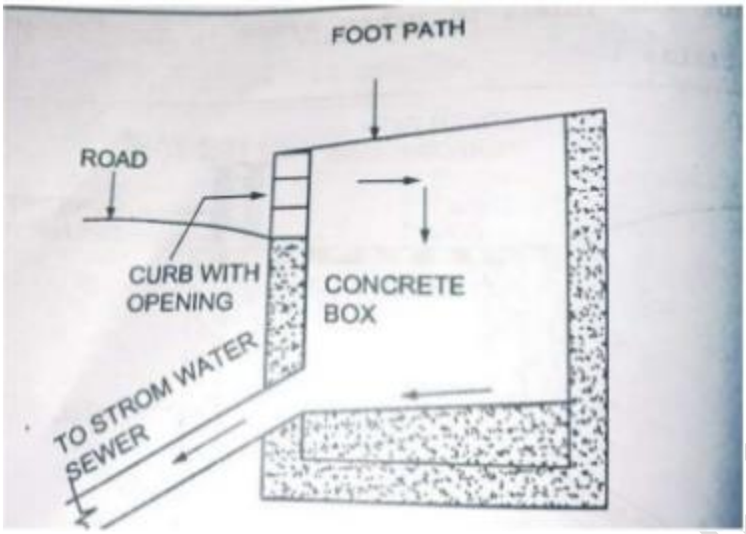


Catch basins



- 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.

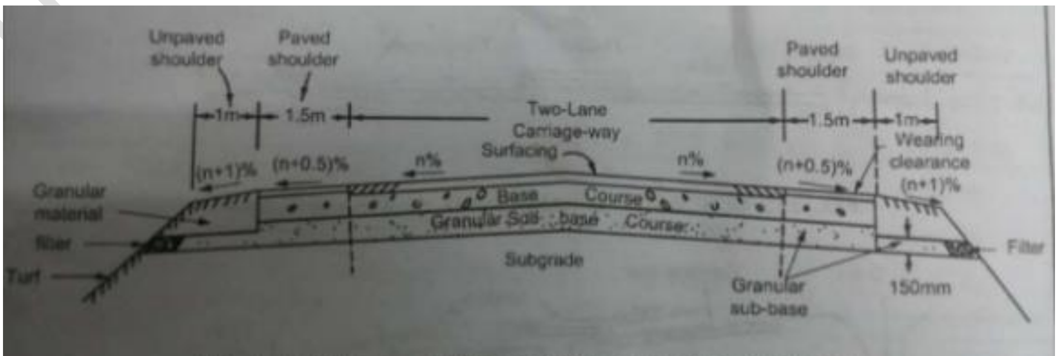


FIG. 8.15 TYPICAL CROSS-SECTION OF PAVED SHOULDER

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.

Procedure for Design of Open Drains:

The following are the steps for designing open drains:

1. For the known soil conditions, calculate the Manning's rugosity coefficient, side slopes, and the maximum permissible velocity.
2. Determine the slope of the drain from the topography.
3. For the runoff or discharge expected to be drained, calculate the hydraulic mean depth using Manning's formula.
4. Calculate the cross-sectional area from the discharge and the maximum permissible velocity.
5. From the result of (3) and (4), solve the two simultaneous equations to obtain the bottom width and depth.
6. Calculate the critical depth and determine whether the flow is streamlined or turbulent. If the flow is streamlined, add a free board to the depth and finalise the cross-section. If the flow is turbulent, it may be necessary to decrease the longitudinal slope, or line the channel.

Subsurface Drainage:

Moisture changes in the subgrade occur due to percolation of rain water and seepage flow, as also due to the phenomenon of capillary rise. The aim of subsurface drainage is to keep the ground water table (GWT) sufficiently below the level of the subgrade – at least 1.2 m.

When the water table is almost at the natural ground surface, the best option is to raise the formation of the roadway on an embankment, such that it is 1.2 m above the ground. If this is not possible for the reason of unfavorable topography, the only option is to lower the ground water table by means of subsurface drainage arrangements. It must, however, be remembered that only gravitational water in the soil can be drained, but not 'held water', which is made up of the moisture film around the grains.

A few drainage arrangements for different situations are discussed below: Subgrade Drain:

One option is to install a drain in the previous layer besides the road to intercept the ground water before it can reach the subgrade, as shown in Fig.

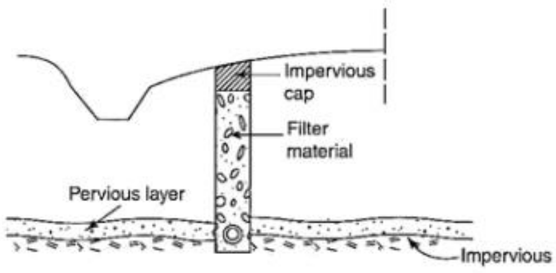


Fig. Subsurface drain to intercept drain water

Longitudinal Drain Trenches and Pipes:

If the soil is relatively pervious, longitudinal drainage trenches with drain pipe, backfilled with filter sand can be used. The depth of the trench depends on the extent of lowering required, soil type, and distance between the trenches. A typical arrangement is shown in Fig.

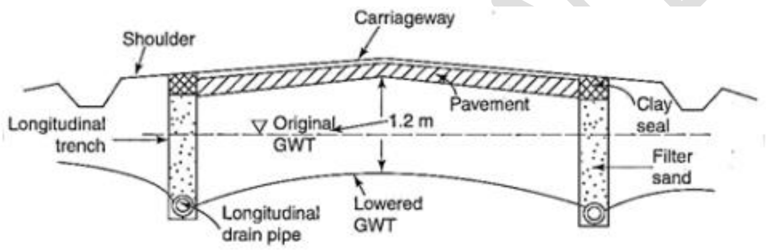


Fig. Lowering GWT in pervious soil by Subsurface drains

Longitudinal and Transverse Drains for Lowering GWT:

If the soil is relatively less permeable, longitudinal as well as transverse drains may be needed to lower the ground water table as shown in Fig.

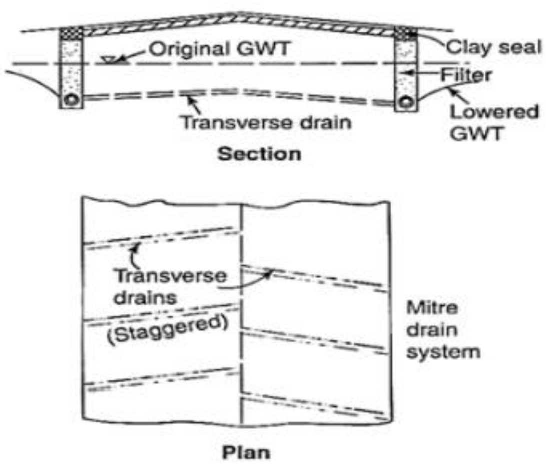


Fig. Longitudinal and transverse drain system for less permeable soil

Capillary Cut-Off for Clayey Subgrade:

If the subgrade is clayey, the system of sub-surface drains on either side will not be effective, in view of very low permeability of the subgrade. In such a case the subgrade has to be raised with a free-draining material, or a capillary cut-off has to be applied as shown in Fig.

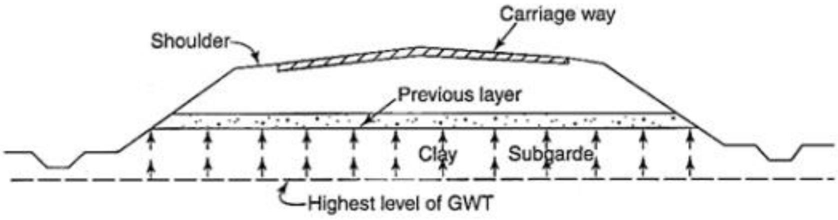


Fig. Capillary cut-off for a clayey subgrade

The capillary cut-off may even be an impermeable bituminous layer. The location of the cut-off should be above the level of capillary rise expected for the clayey subgrade.

Sub-Surface Drains to Control Seepage in Cut Slopes:

Sometimes, seepage water renders cut slopes unstable by reaching the face of the slope. This can be prevented by lowering the seepage line by providing a sub-surface longitudinal drain installed to a depth below the previous layer as shown in Fig.

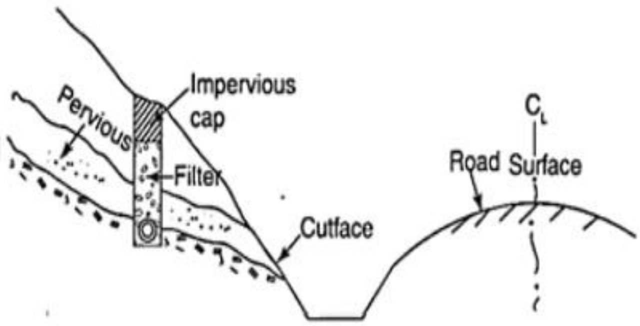


Fig. Subsurface drains at cut slope to control seepage

If the depth of pervious layer is more, horizontal drains comprising perforated metallic pipes or PVC pipes installed at a suitable slope may be provided to serve the same purpose.

Drain Pipes and Filter Media:

A subsurface drain may comprise of perforated pipe, a porous concrete pipe or solid pipe laid with open joints. Alternatively, a trench filled with a free draining material may be used to serve the purpose of a drain.

A perforated pipe or a porous pipe (of no fines concrete) with an impervious cap at the top, laid in a trench and backfilled with a granular, free-draining material top is considered to be a good choice.

If granular filter material with appropriate gradation has to be used, it has to be designed to satisfy certain criteria.

Design of a Filter Material:

The gradation requirements of the filter material are based on three criteria:

(i) Permeability of filter

(ii) Prevention of Piping (because of high seepage velocity)

(iii) Prevention of clogging of the drain pipe.

These requirements are:

(i) *Permeability ratio:* $\frac{D_{15}\text{(filter)}}{D_{15}\text{(soil to be drained)}} > 5$

(ii) *Piping ratio:* $\frac{D_{15}\text{(filter)}}{D_{85}\text{(soil to be drained)}} < 5$

(iii) $\frac{D_{85}\text{(filter)}}{(d_p\text{: diameter of the perforation in the drain pipe.})} > 2d_p$

Fig. shows an example of the selection of a suitable filter material based on the gradation of the soil to be drained.

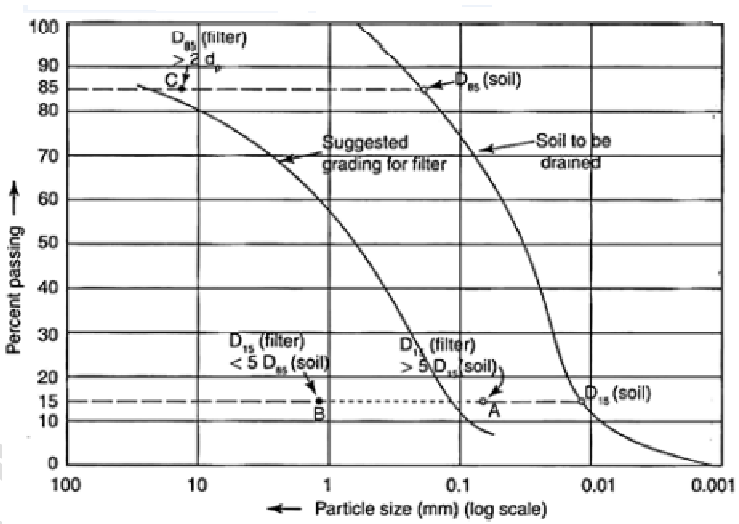


Fig. Filter design for subsurface drains

Set the grading of the soil to be drained be plotted as shown. Mark the D_{15} and D_{85} of the soil.

From permeability criterion, mark D_{15} of filter ($>5D_{15}$ of soil) as A.

From piping criterion, mark D_{15} of filter ($<5D_{85}$ of soil) as B.

On D_{85} line, mark point C, such that D_{85} (filter) is greater than $2d_p$ (d_p being the diameter of the perforation of the drain pipe).

A suggested grading of filter may be drawn smoothly such that it lies to the left of C and lies between A and B as shown.

The perforated pipe is usually 100 to 150 mm in diameter with holes in two or more lines towards the bottom of the pipe. The collector pipes of porous concrete, metal or PVC should be laid with a minimum of 100 mm of filter sand around them.

Usually, 5 mm diameter holes are considered adequate, if restricted to the lower 60° arc of the pipe. Solid pipes with open joints may be used, but care should be taken to see that silt and fine sand do not enter the pipe.

When the flow of water takes place through porous backfill of graded sand, it is likely to be clogged after some time. Hence, this involves maintenance, washing of the clogged backfill.

Geosynthetics in Subsurface Drains:

Geosynthetics or geotextiles are becoming popular as substitutes or alternatives to graded filters. They have high retention fine particles and permeability similar to graded material and good tensile strength. Installation is also easy. Geosynthetic products perform the functions of a filter as well as that of a separator.

Fig. shows an aggregate drain with a pipe encased in a geosynthetic.

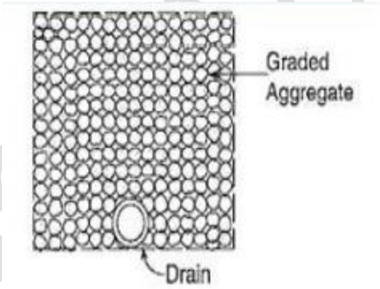


Fig. Geosynthetic-encased aggregate drain with a pipe

Shoulder Drainage:

For quick drainage of water from the roadway, the shoulder surface has to be properly sloped. A continuous drainage layer, 75 to 100 mm thick, can be laid under the shoulder at the bottom level of the sub-base or the bottom-most granular sub-base layer and extended up to the edge. A paved shoulder, if provided, should have a cross- slope of at least 0.5% more than the camber; the unpaved shoulder beyond this should be a further 0.5% steeper as shown in Fig.

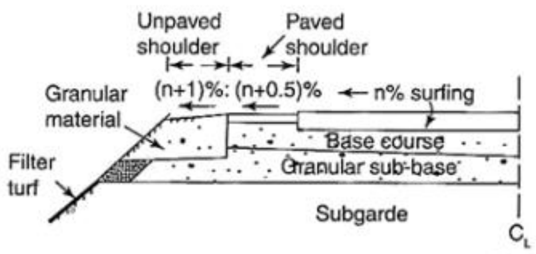


Fig. Shoulder Drainage

Median Drainage:

Narrow medians may be drained towards the pavement. Medians with a width of up to 1.8 m can be provided with kerbs and paved; those with width ranging from 1.8 to 5 m are usually turfed and crowned for the surface water to run towards the pavement (which may be with or without kerbs). For medians that are more than 5 m wide, there are no kerbs at the edge. If the carriageway drains towards the median, central drain may be made to carry the run off. At intervals, the drain may also be made to lead water to an outlet.

Drainage of High Embankment:

In the case of high embankments (more than 8 metres high) as with bridge approaches, slopes and shoulders may be eroded by surface run-off. To prevent or 78inimize this, longitudinal drains are to be provided at the edges of the roadway, from which the water may be led down the slopes by means of lined chutes with energy dissipation basins at the toe. The water thus collected at the toe can be led in an open toe drain at the bottom parallel to the road, and led to a natural outlet at an appropriate point. In between the chutes, the slope is to be turfed to protect it from surface erosion.

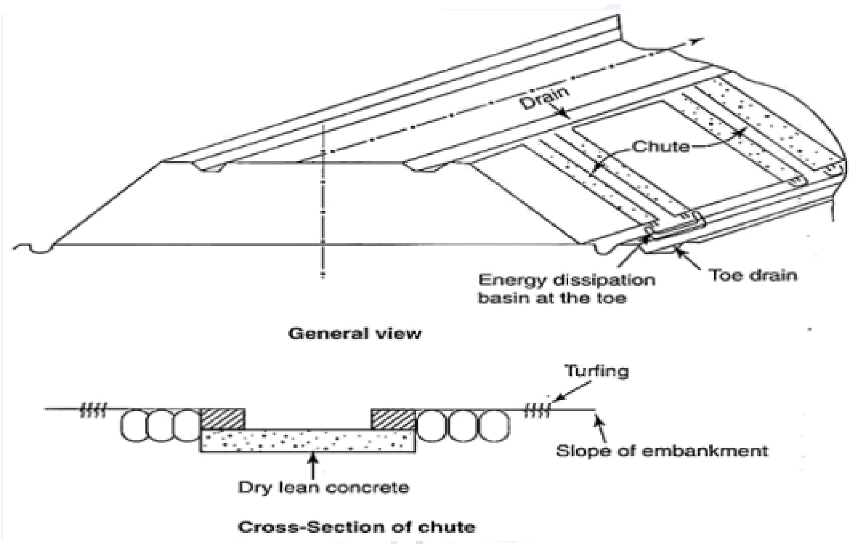


Fig. Drainage system for high Embankment

Drainage of Rotaries:

Water, from the large area around a rotary, flows towards the centre of the rotary, because of the super-elevated pavements. This has to be collected and led into the overall drainage system. A typical arrangement is shown in Fig.

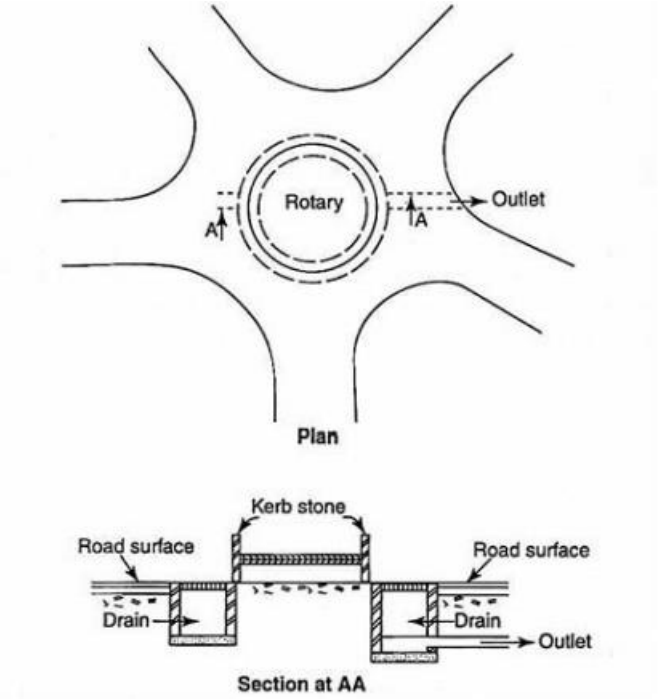


Fig. Typical drainage arrangement at a Rotary

Similar arrangements can be made at an intersection. At a flyover, the water collected in longitudinal drains on either side of the pavements can be led thorough the hollows of pillars of the supporting structure like a bridge and led away through a storm water drainage system.