UNIT-II
HIGHWAY MATERIALS AND CONSTRUCTION

Pavements

- **highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade**. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted
- stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade.
- **Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements.**

Pavements

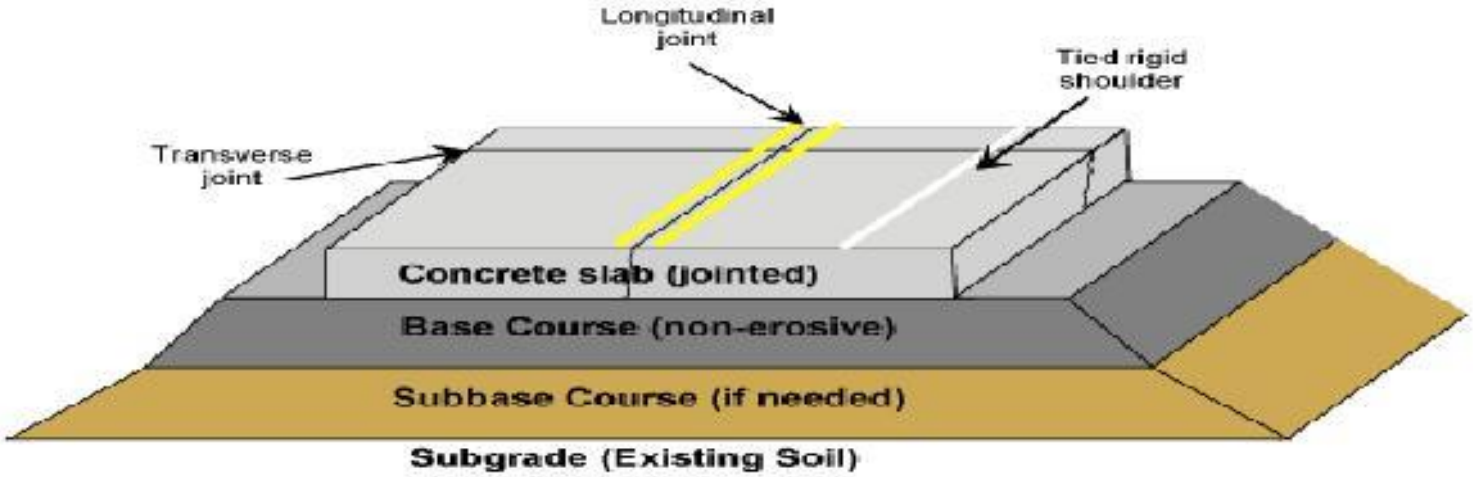
Requirements of a pavement

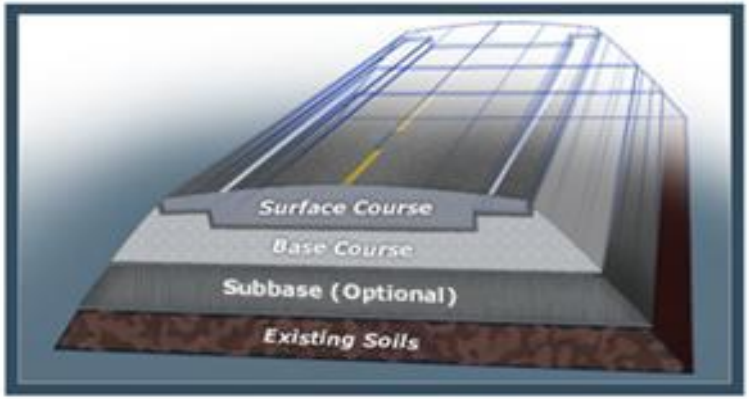
- **An ideal pavement should meet the following requirements:**
- Sufficiently thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that tract safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

Types of pavements

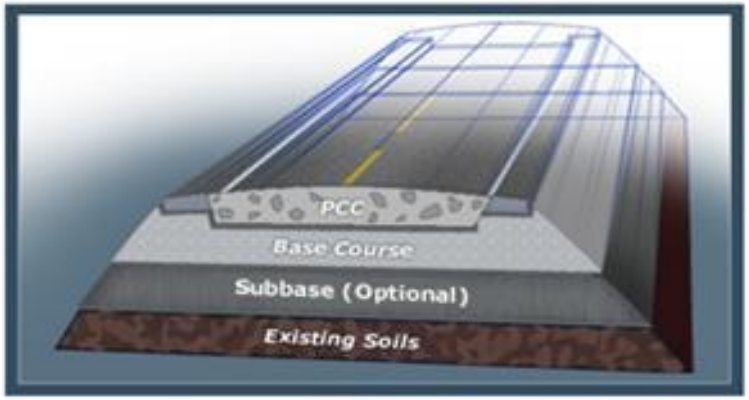
- The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through
- the granular structure

Types of pavements

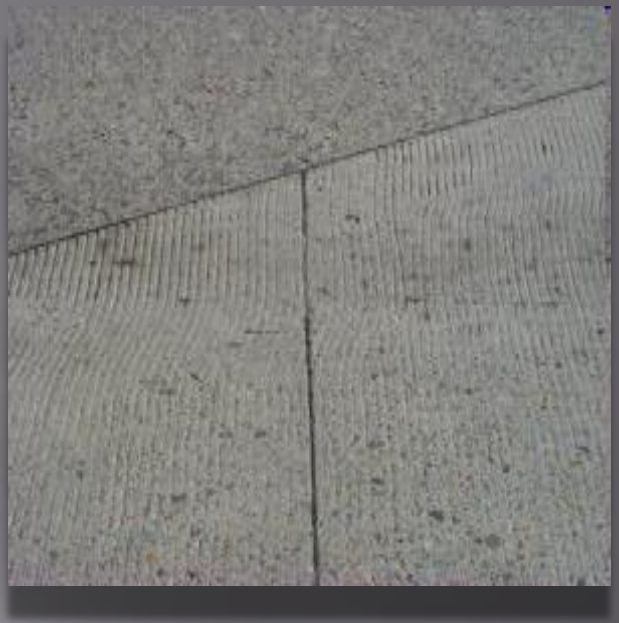




Typical Flexible Pavement



Typical Rigid Pavement



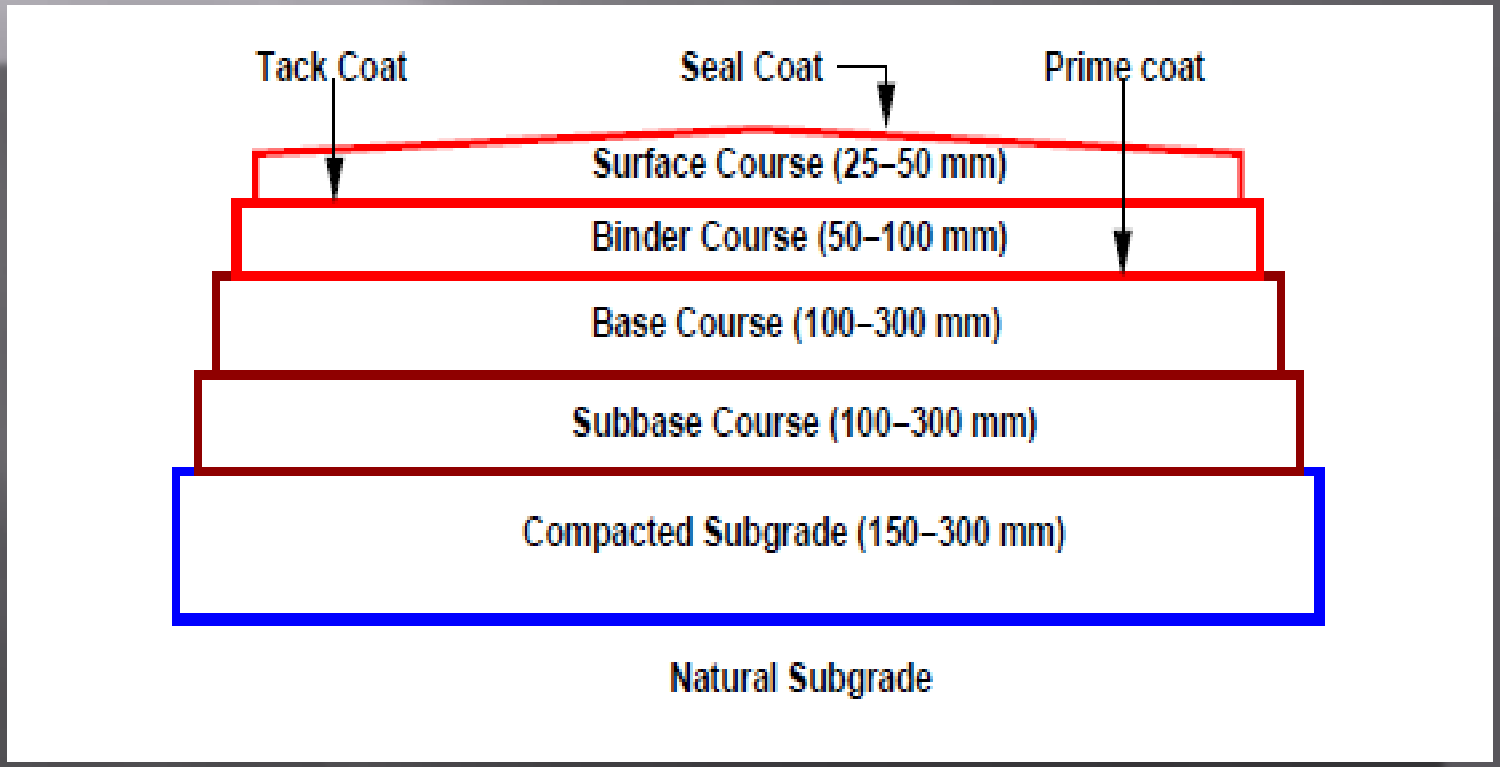
FLEXIBLE PAVEMENT

RIGID PAVEMENT

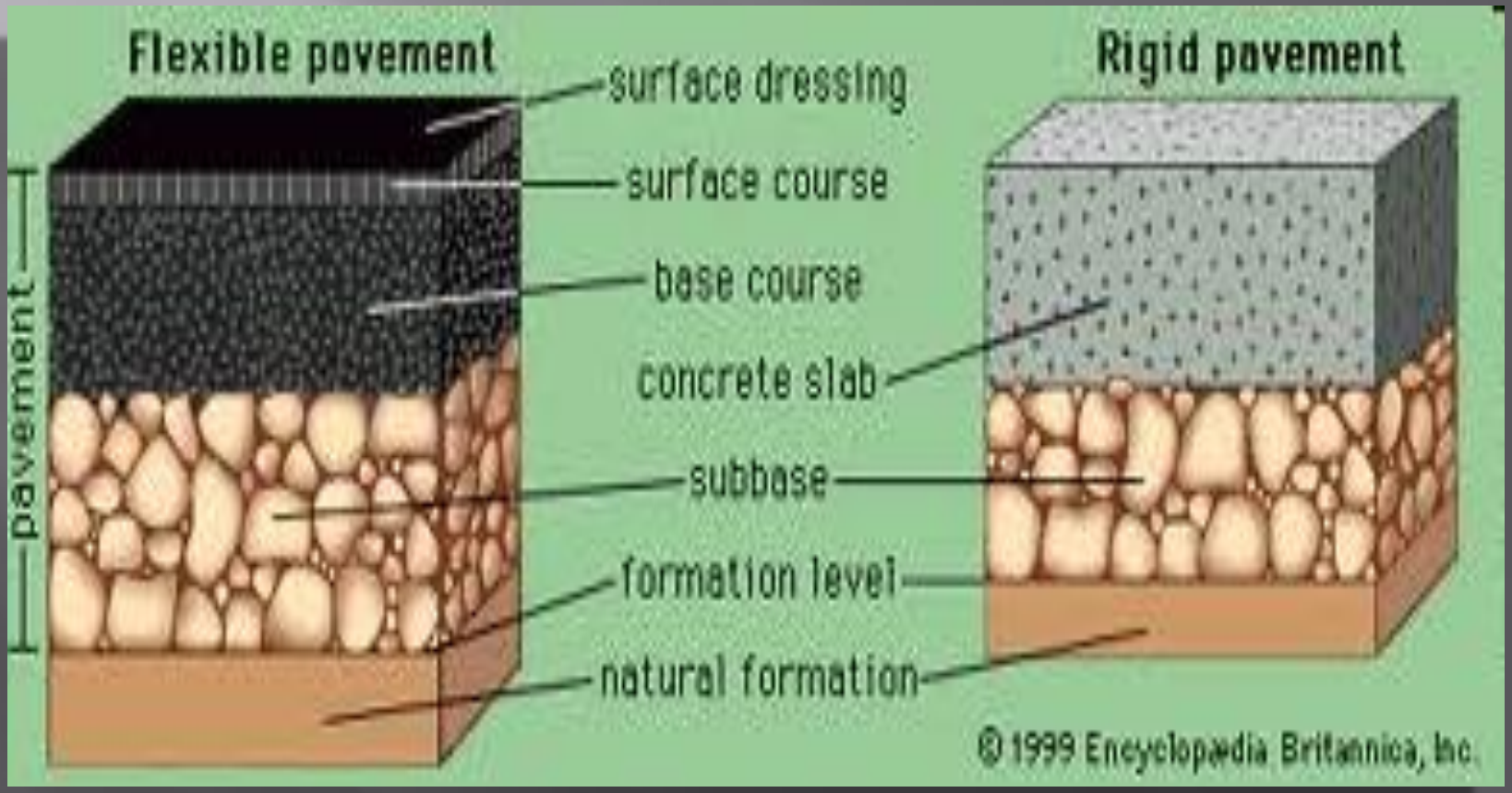
Flexible pavements

- **Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure**. The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this stress distribution characteristic, **flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system.**

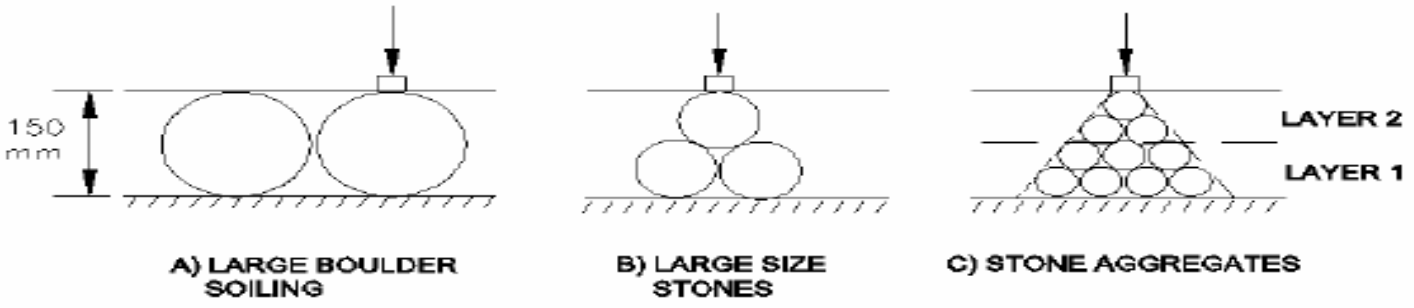
Flexible pavements



Types of Pavements



Layers in Flexible Pavement



Stress Distribution Through Granular Layers

Typical layers of a flexible pavement

- Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.
- **Tack Coat**: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Typical layers of a flexible pavement

- **Prime Coat:** Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.
- **Surface course**
- Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).

Typical layers of a flexible pavement

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade, It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface, It must be water proof to protect the entire base and sub-grade from the weakening effect of water.
- **Binder course**
- This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

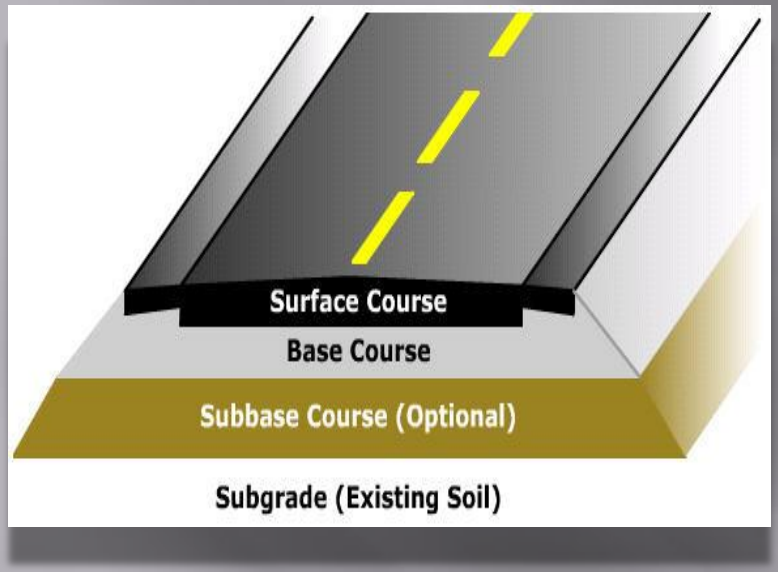
Typical layers of a flexible pavement

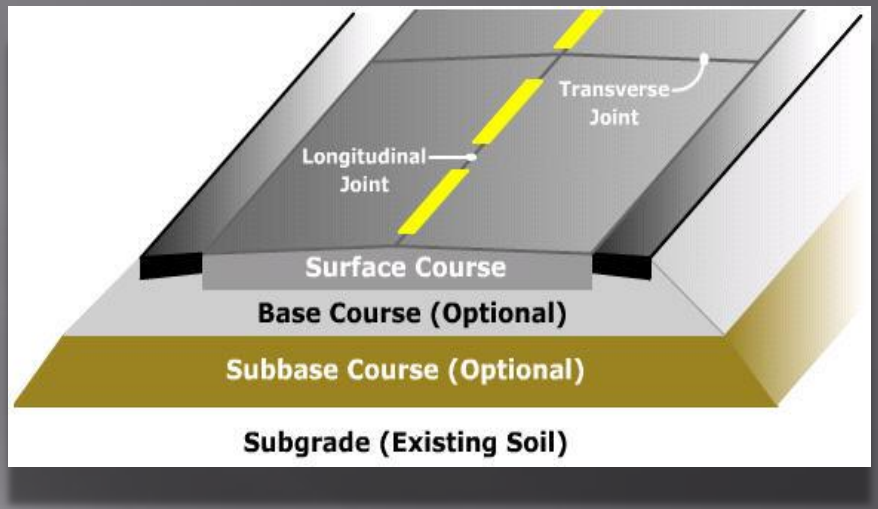
- **Base course**
- The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.
- **Sub-Base course**
- The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

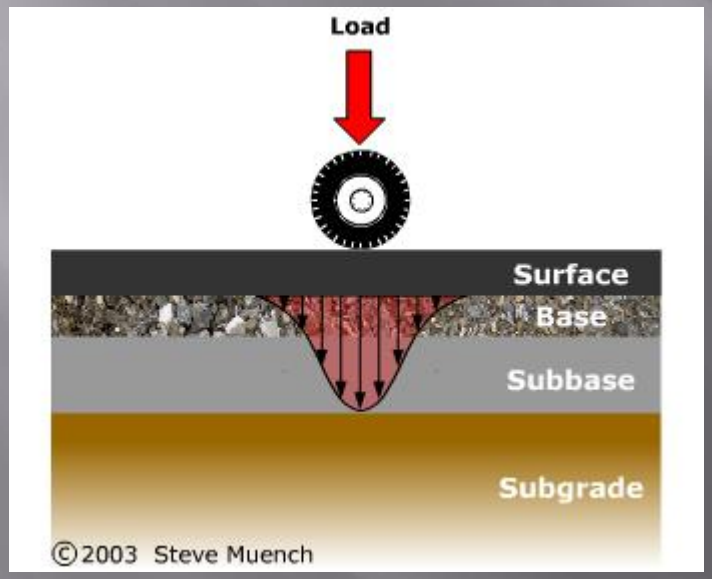
Typical layers of a flexible pavement

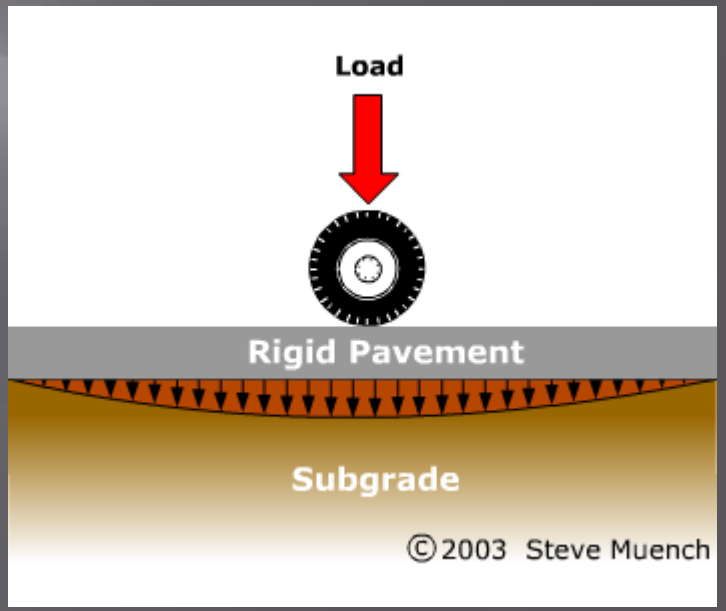
Sub-grade

- The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.









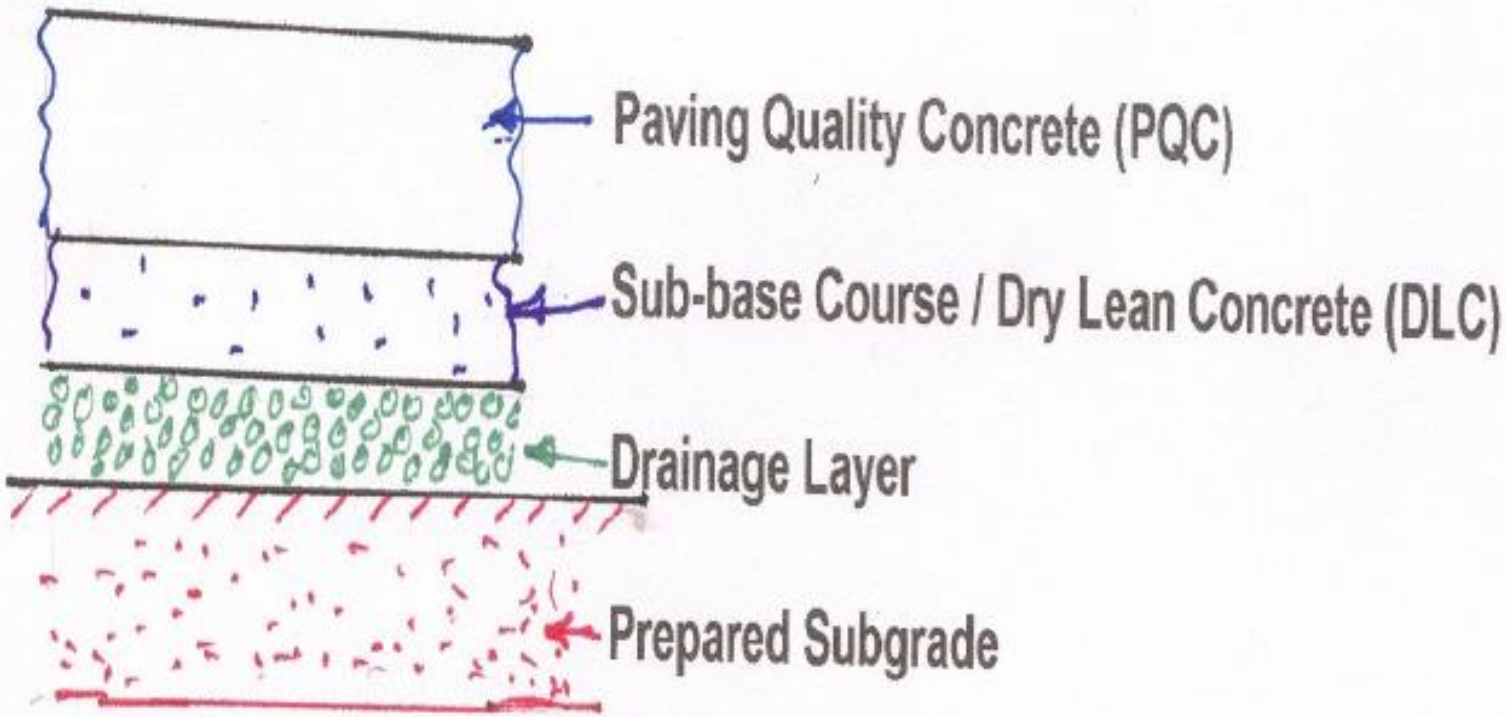
Flexible

Rigid

Rigid pavements

- Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below.
- Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

Rigid pavements



Components of Cement Concrete Pavement

Pavement materials

- **Soils-**

Pavements are a conglomeration of materials. These materials, their associated properties, and their interactions determine the properties of the resultant pavement. Thus, a good understanding of these materials, how they are characterized, and how they perform is fundamental to understanding pavement. The materials which are used in the construction of highway are of intense interest to the highway engineer.

Sub grade soil

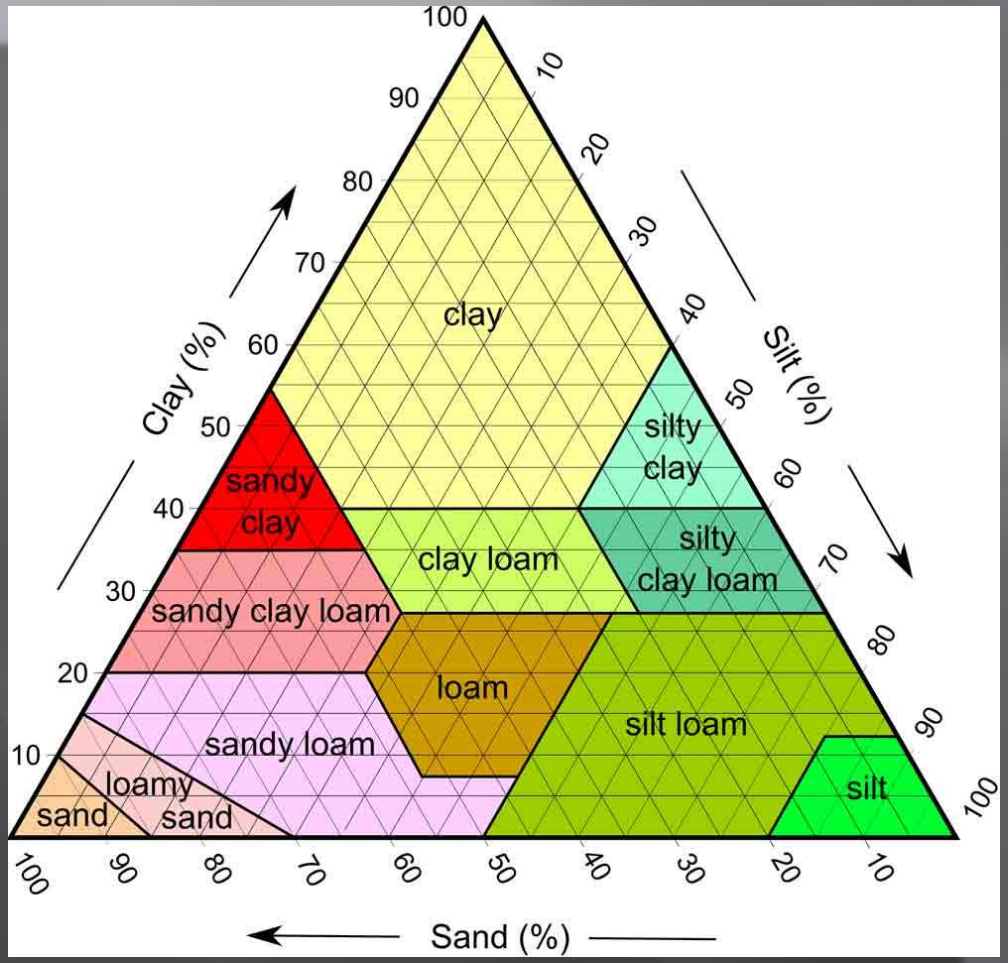
- **Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation, that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory**. The supporting **soil beneath pavement and its special under courses is called sub grade**. Undisturbed soil beneath the pavement is called natural sub grade**. Compacted sub grade is the soil compacted by controlled movement of heavy compactors.**

Sub grade soil

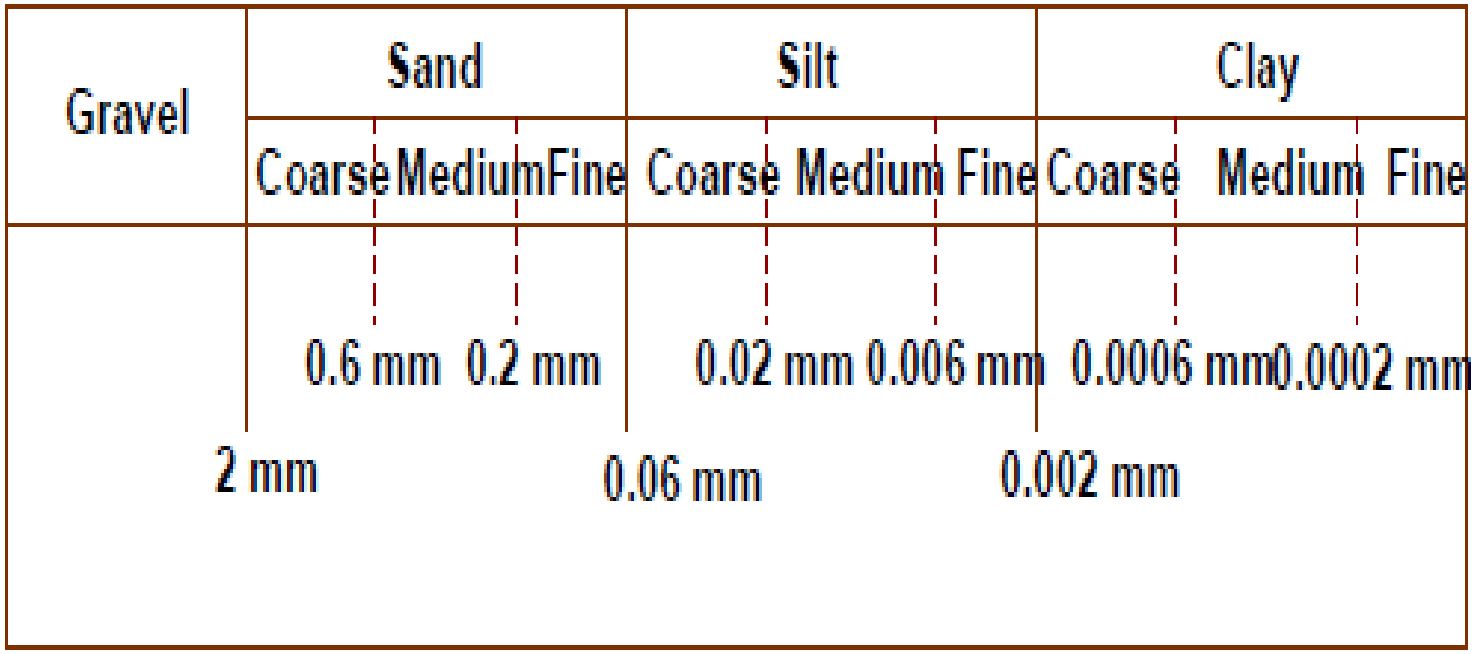
Soil Types

- The wide range of soil types available as highway construction materials have made it obligatory on the part of the highway engineer to identify and classify different soils.
- **Broadly, the soil types can be categorized as Laterite soil, Moorum / red soil, Desert sands, Alluvial soil, Clay including Black cotton soil.**

Soil Types


clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
silt loam
sandy loam
loamy sand
sand
silt
Clay (%)
Silt (%)
Sand (%)
100
90
80
70
60
50
40
30
20
10

Soil Types


Gravel
Sand
Silt
Clay
Coarse
Medium
Fine
Coarse
Medium
Fine
Coarse
Medium
Fine
0.6 mm
0.2 mm
0.02 mm
0.006 mm
0.0006 mm
0.0002 mm
2 mm
0.06 mm
0.002 mm

Soil Types

- **Gravel**: These are coarse materials with particle size under 2.36 mm with little or no fines contributing to cohesion of materials.
- **Moorum**: These are products of decomposition and weathering of the pavement rock. Visually these are similar to gravel except presence of higher content of fines.
- **Silts**: These are finer than sand, brighter in color as compared to clay, and exhibit little cohesion. When a lump of silty soil mixed with water, alternately squeezed and tapped a shiny surface makes its appearance, thus dilatancy is a specific property of such soil.
- **Clays**: These are finer than silts. Clayey soils exhibit stickiness, high strength when dry, and show no dilatancy. Black cotton soil and other expansive clays exhibit swelling and shrinkage properties. Paste of clay with water when rubbed in between fingers leaves stain, which is not observed for silts.

Tests on soil

- Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The sub grade soil and its properties are important in the design of pavement structure. 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:
- Shear tests
- Bearing tests
- Penetration tests

California Bearing Ratio Test

- **California Bearing Ratio (CBR) test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements**. 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 in2 (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. 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.**

California Bearing Ratio Test

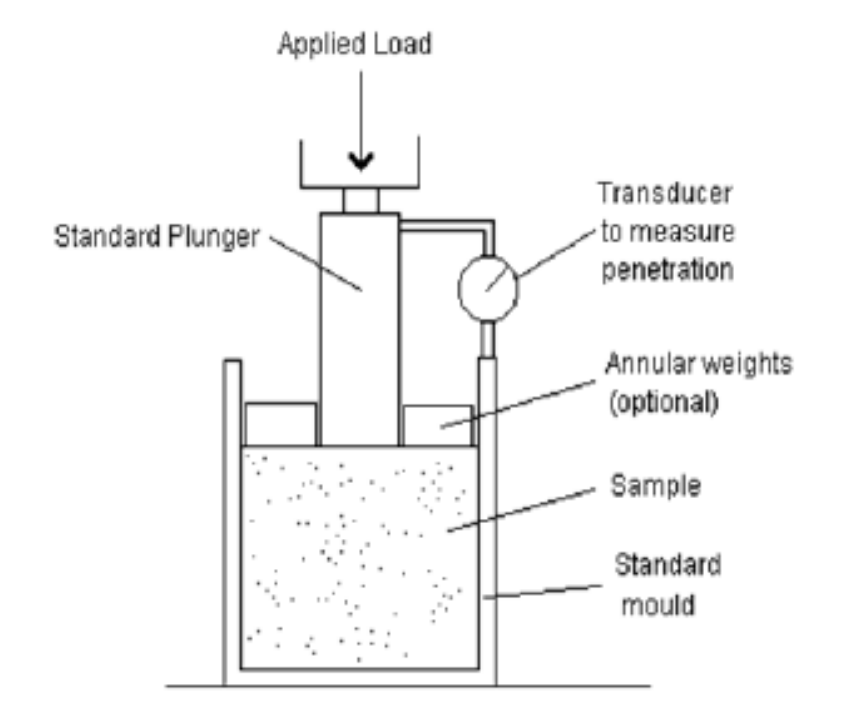


Plate Bearing Test

- **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. The deflection level is generally limited to a low value, in the order of 1.25 to 5 mm and so the deformation caused may be partly elastic and partly plastic due to compaction of the stressed mass with negligible plastic deformation. The plate-bearing test has been devised to evaluate the supporting power of sub grades or any other pavement layer by using plates of larger diameter.
- **The plate-bearing test was originally meant to find the modulus of sub grade reaction in the Westergaard's analysis for wheel load stresses in cement concrete pavements.**

Plate Bearing Test

Pavement materials

- **Aggregates**
- **Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.)** to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured.

Aggregates

Desirable properties

- **Strength**
- The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should posses high resistance to crushing, and to withstand the stresses due to traffic wheel load.
- **Hardness**
- The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.
- **Toughness**
- Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes severe impact on the aggregates

Desirable properties

- **Shape of aggregates**
- Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. 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 o in presence of water.
- **Durability**
- The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the
- weathering action

Aggregate tests

- In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out:
- Crushing test
- Abrasion test
- Impact test
- Soundness test
- Shape test
- Specific gravity and water absorption test
- Bitumen adhesion test

Aggregate tests

- **Crushing test**
- One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The

Crushing Test

Abrasion test

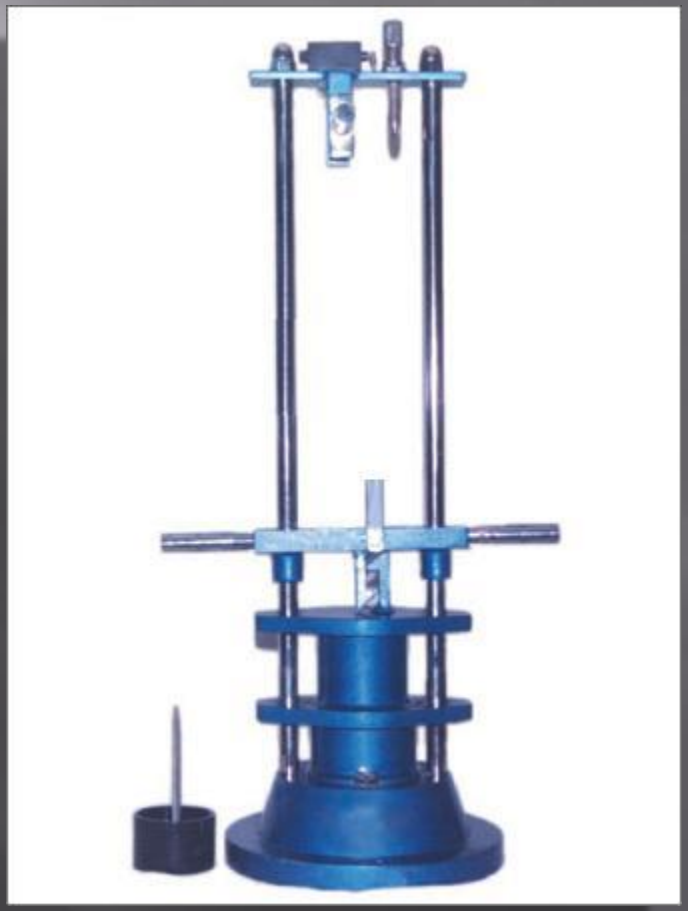
- Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS:2386 part-IV). The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

Abrasion Test

Aggregate tests

- Impact test
- The aggregate impact test is carried out to evaluate the resistance to impact of aggregates.
- Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent

Impact test



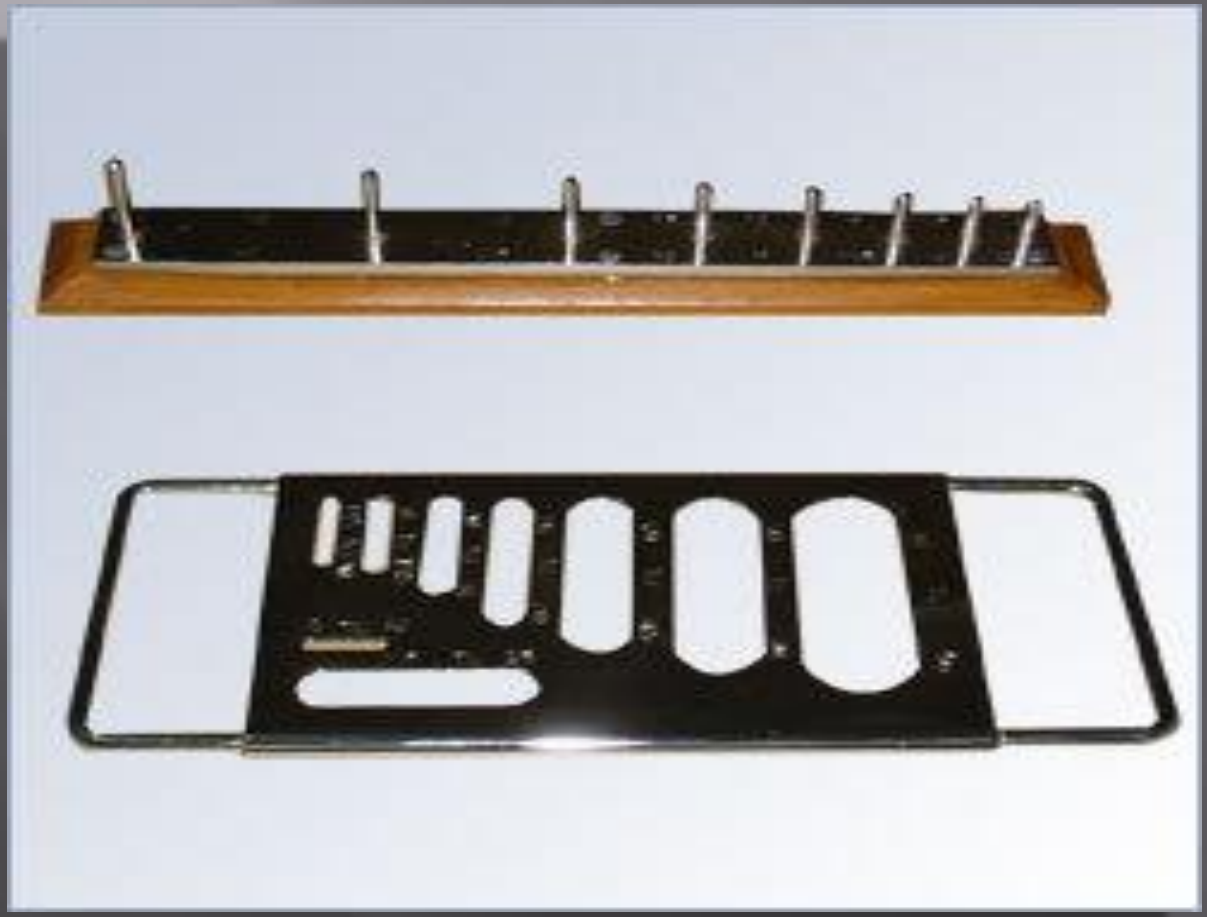
Aggregate tests

- 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 specied in IS:2386 part-V.

Aggregate tests

- Shape tests
- The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it.
- 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)

Shape tests



Aggregate tests

- 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) The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm.
- This test is also specified in (IS:2386 Part-I).

Aggregate tests

- Specific Gravity and water absorption
- The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes.

Aggregate tests

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

Table 22:1: Tests for Aggregates with IS codes

Pavement materials

- **Bitumen**
- **Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost**. Bituminous materials consists of bitumen which is a black or dark coloured solid or viscous cementations substances consists chiefly high molecular weight hydrocarbons derived from distillation of petroleum or natural asphalt, has adhesive properties, and is soluble in carbon disulphide**. Tars are residues from the destructive distillation of organic substances such as coal, wood, or petroleum and are temperature sensitive than bitumen. Bitumen will be dissolved in petroleum oils where unlike tar.**

Pavement materials

- **Production of Bitumen**
- **bitumen is the residue or by-product when the crude petroleum is refined**. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties. **Depending on the sources and characteristics of the crude oils and on the properties of bitumen required, more than one processing method may be employed.**

Different forms of bitumen

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

Cutback bitumen

Pavement materials

- **Bitumen Emulsion**
- Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilised by suitable material. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC).

Bitumen Emulsion

Pavement materials

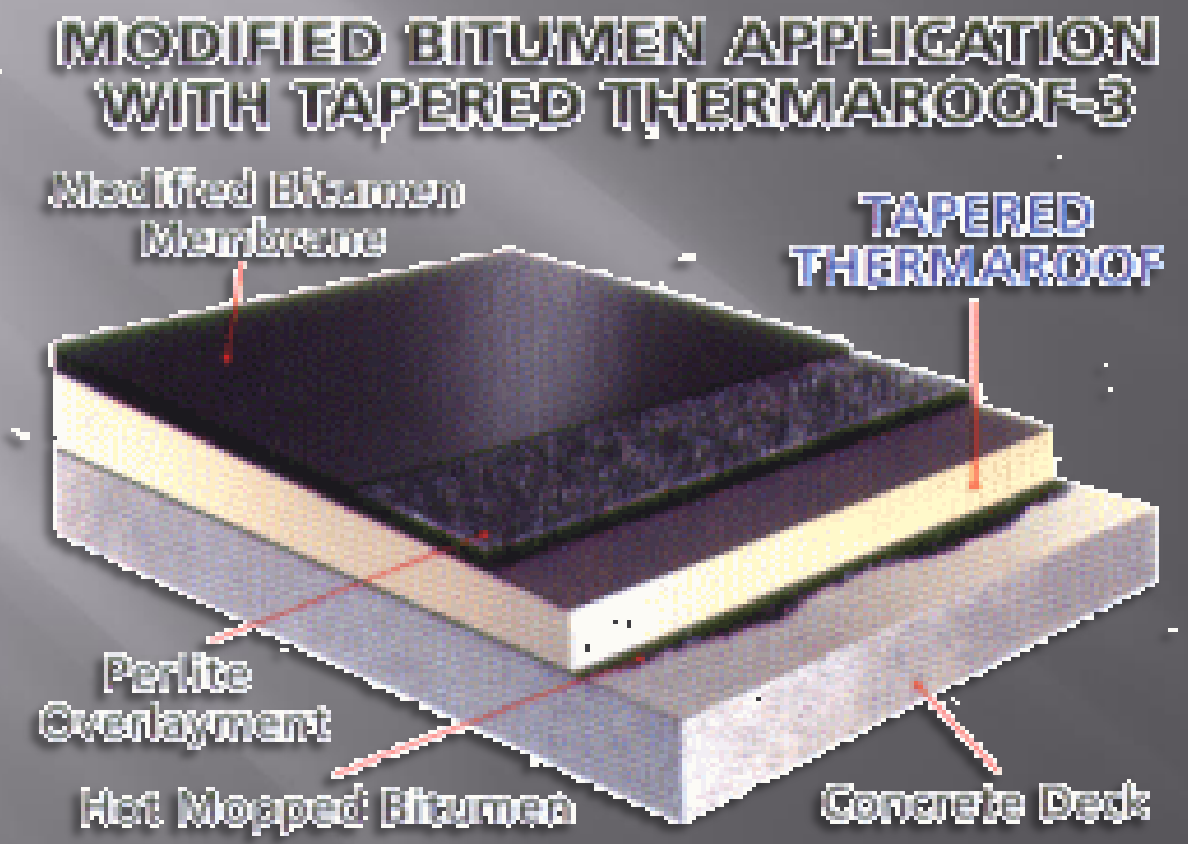
- **Bituminous primers**
- In bituminous primer the distillate is absorbed by the road surface on which it is spread. The absorption therefore depends on the porosity of the surface. Bitumen primers are useful on the stabilised surfaces and water bound macadam base courses. Bituminous primers are generally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

Bituminous primers

Pavement materials

- **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.

Modified Bitumen



Requirements of Bitumen

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

Tests on bitumen

- There are a number of tests to assess the properties of bituminous materials. The following tests are usually
- conducted to evaluate different properties of bituminous materials.
- 1. Penetration test
- 2. Ductility test
- 3. Softening point test
- 4. Specific gravity test
- 5. Viscosity test
- 6. Flash and Fire point test
- 7. Float test
- 8. Water content test
- 9. Loss on heating test

Penetration test

- It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimetre to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardised the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25^{o} C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature.
- 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.

Penetration test

Ductility test

- 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.
- 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.

Ductility test

Softening point test

- Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerine at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5^{o} C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below

Softening point test

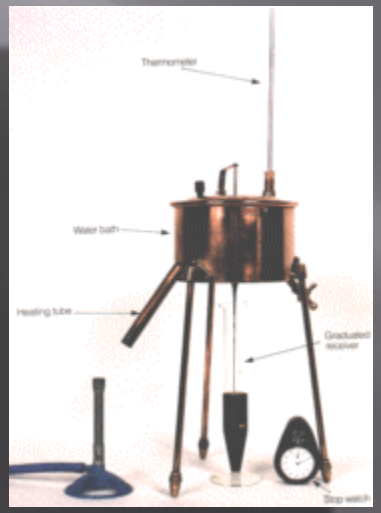
Specific gravity test

- In paving jobs, to classify a binder, density property is of great use. In most cases bitumen is weighed, but
- when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly inuenced by its chemical composition. Increase in aromatic type mineral impurities cause an increase in specific gravity.
- The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27o C. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi solid or solid state. The specific gravity of bitumen varies from 0.97 to 1.02.

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 comp active 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 25o C or 10 mm orifice at 25 or 40^{o} C.

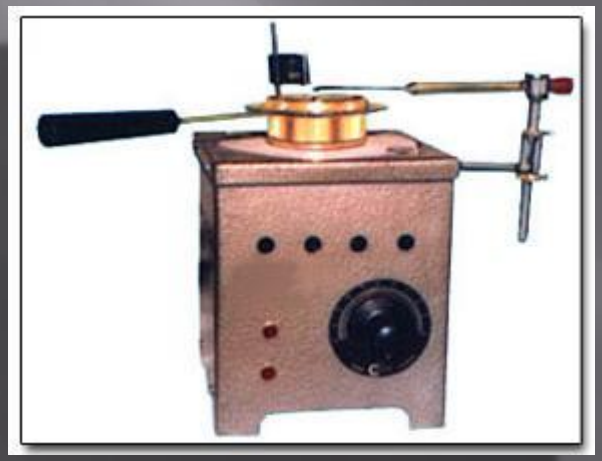
Viscosity test



Flash and fire point test

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

Flash and fire point test



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 aluminium float and a brass collar filled with bitumen to be tested. The specimen in the mould is cooled to a temperature of 5^{o}C and screwed in to float. The total test assembly is floated in the water bath at 50^{o}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.

Float test

Water content test

- It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water in a bitumen is determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling of the water. The weight of the water condensed and collected is expressed as percentage by weight of the original sample. The allowable maximum water content should not be more than 0.2% by weight.

Loss on heating test

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

Tests of Bitumen

Table 23:1: 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

References

Text Book

- **Khanna S.K. and C.E.G. Justo (2000),** "Highway Engineering", *Nem Chand & Bros., Roorkee*
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Thanks

Thanks..