CHAPTER 5

Highway Materials

INTRODUCTION

Earthwork and pavement constitute a significant part of the cost of a road, hence it is desirable that thorough investigations be done about the availability of soil and other road materials of good quality at economical distance. Generally the main materials used in highway construction are soil, aggregate and bitumen. These materials, their associated properties and their interactions determine the properties of the resultant pavement.

5.1 Soil

Soil mainly consists of mineral matter formed by the disintegration of rocks. The characteristics of soil grains depend on the size, shape, surface texture, chemical composition and electrical surface charges. Moisture and dry density influence the engineering behaviour of a soil mass.

Desirable properties of soil as a highway materials are :

(*i*) Stability
(*ii*) Incompressibility
(*iii*) Permanency of strength
(*iv*) Minimum changes in volume and stability under adverse conditions of weather and ground water
(*v*) Good drainage and
(*vi*) Ease of compaction

5.2 Subgrade Soil

Subgrade 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 subgrade is to give adequate support to the pavement. Hence subgrade should have sufficient stability under the adverse conditions of climate and loading also.

5.2.1 Subgrade Soil Strength

Factors on which strength characteristics of soil depend are :

(*i*) Soil type
(*ii*) Moisture content
(*iii*) Dry density
(*iv*) Internal structure of soil
(*v*) Type and mode of stress application

5.2.2 Evaluation of Soil Strength

The tests used to evaluate the strength properties of soils may be broadly divided into three groups:

(i) Shear Test: Shear test is usually carried out on relatively small soil samples in the laboratory. A number of representative samples from different locations are tested to find the strength properties of soil. Commonly known shear tests are direct shear test, triaxial test and unconfined compression test.

(ii) Bearing Test: Bearing tests are loading tests carried out on subgrade soils 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.

(iii) Penetration Test: It 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 size of loaded area is much greater than the ratios in bearing tests. The California Bearing Ratio test and Cone Penetration test are commonly known penetration tests.

5.3 Plate Bearing Test

It is a loading test which is carried out on a subgrade soil in the field with load bearing area to find supporting power of subgrade which is represented by modulus of subgrade reaction (k). It consists of set of plates of diameter 75 cm, 60 cm, 45 cm and 30 cm, standard size of plate for plate bearing test is 75 cm.

5.3.1 Procedure of Plate Bearing Test

(*i*) Test site is prepared and loose material is removed. The 75 cm diameter plate is placed horizontally in full contact with subgrade soil and a seating load equivalent to a pressure of 0.07 kg/cm² is applied for few seconds. Now the settlement dial gauge is set corresponding to zero load.

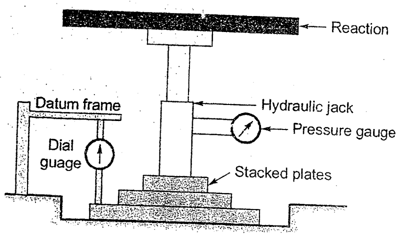


***Figure-5.1 :** Plate load test*

(*ii*) A load is applied by means of jack sufficient to cause an average settlement of about 0.25 mm. The load dial reading and settlement dial reading is noted when the rate of settlement is less than 0.025 mm per minute.

(*iii*) Average of three or four settlement dial gauge readings is taken as the settlement of the plate corresponding to the applied load.

(*iv*) Then the load is increased till the average settlement increase to a further amount of about 0.25 mm and the load and average settlement readings are noted.

(*v*) The procedure is repeated till the settlement reaches 0.175 cm.

(*vi*) A graph is plotted between mean settlement and mean bearing pressure, bearing pressure 'p' is noted corresponding to a settlement of 0.125 cm.

$$\text{Modulus of subgrade reaction } (k) = \frac{p}{0.125} \text{ kg/cm}^2\text{/cm}$$

5.3.2 Correction for Worst Sub-grade Moisture

For worst moisture condition of subgrade an unsoaked and a soaked sample of soil is taken and test is performed for both the samples. Hence

$$\frac{p_s}{k_s} = \frac{p}{k}$$

where, k_s = Modulus of subgrade reaction for soaked condition

k = Modulus of subgrade reaction for unsoaked condition

p_s = Pressure required to produce 0.125 cm settlement in soaked condition

p = Pressure required to produce 0.125 cm settlement in unsoaked condition

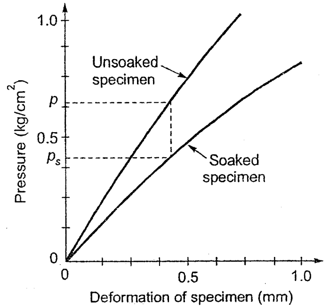


***Figure-5.2 :** Correction for soaking in plate bearing test*

5.3.3 Correction for Size of Plates

Assuming that subgrade is an elastic medium with modulus of elasticity E_s (kg/cm²), therefore

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

where, a = Radius of rigid place in cm

Δ = Deformation of plate in cm

$$\therefore \quad k = \frac{E_s}{1.18a}$$

Hence, $k_1 a_1 = k_2 a_2$

Example-5.1 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 (in mm)	0.0	0.24	0.52	0.76	1.02	1.23	1.53	1.76
Load values (in kg)	0.0	460	900	1180	1360	1480	1590	1640

Solution:

The load-settlement curve is plotted on a graph paper and the load value p_1 corresponding mean settlement value of Δ = 0.125 cm is 1490 kg.

$$\text{Unit load } p_1 = \frac{1490}{\pi(15)^2} \text{ kg/cm}^2$$

Modulus of subgrade reaction k_1 for 30 cm diameter plate

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

Modulus of subgrade reaction k for plate of diameter 75 cm

$$= \frac{k_1 a_1}{a} = \frac{16.86 \times 30}{75} = 6.75 \text{ kg/cm}^3$$

5.4 California Bearing Ratio Test

This is a penetration test developed by the California Division of Highways to evaluate the stability of soil subgrade and other flexible pavement. It consists a standard piston have a diameter of 50 mm which is used to penetrate the soil at the standard rate of 1.25 mm/min.

5.4.1 Test Procedure

(*i*) Laboratory CBR apparatus consists a mould of 150 mm diameter with a base plate and a collar, a loading frame and dial gauges to measure the penetration as shown in Figure 5.3.

(*ii*) The specimen of soil is soaked in water for 96 hours and the swelling and water absorption values are noted.

(*iii*) Load is applied on the sample by a standard plunger with diameter of 50 mm at the rate of 1.25 mm/min.

(*iv*) A graph is plotted between the load or pressure and penetration.

(*v*) Load values are noted corresponding to the 2.5 mm and 5.0 mm penetration.

(*vi*) Calculate the CBR value corresponding to 2.5 mm and 5.0 mm.

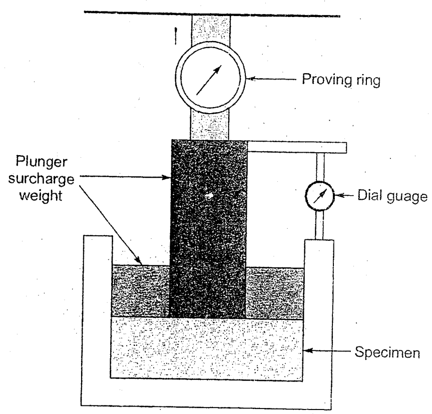


Figure-5.3 : *CBR test*

$$\text{CBR (\%)} = \frac{\text{Load carried by specimen at 2.5 or 5.0 mm penetration}}{\text{Load carried by standard aggregates at corresponding penetration level}} \times 100$$

NOTE If the CBR values of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value of 5.0 mm is greater than that of 2.5 mm penetration, the test is to be repeated for checking Standard load values for 2.5 mm and 5.0 mm penetration over standard aggregate.

Standard load values for 2.5 and 5.0 mm penetration over standard aggregated are given in Table 5.1.

Table-5.1 : Standard load values

Penetration (mm)	Load (kg)	Pressure (kg/cm^2)
2.5	1370	70
5.0	2055	105

(*vii*) Average CBR value of three test specimen is reported as the CBR value of the sample.

Table-5.2 : Typical CBR values of soils and their rating

Soil	Range of CBR values	Rating
Clay	2 - 5	Very poor subgrade
Silt	5 - 8	Poor subgrade
Sand	8 - 20	Fair to good subgrade
Gravel	20 - 30	Excellent subgrade

5.4.2 Correction in Load Penetration Curve

The normal curve of load penetration graph is with concavity downward. Sometimes a curve with initial upward concavity is obtained which required correction. In this case corrected origin is established by drawing a tangent AC from the steepest point A on the curve (Figure Ex. 5.2) and load values corresponding to 2.5 mm and 5.0 mm penetration are from the corrected origin.

The causes for the initial concavity of the load penetration curve are

(*i*) Bottom surface of plunger and the surface of soil specimen are not being in full contact with each other.

(*ii*) Top layer of the specimen being too soft or irregular.

CBR values are roughly correlated to modulus of subgrade reaction as given in Table 5.3.

Table-5.3 : Correction between CBR and *k* value

CBR	2	3	4	5	7	10	20	50	100
k value (MN/m^2)	20	27	34	41	48	54	68	136	218

5.5 Aggregates

Aggregates are one of the most important material used in pavement construction. They form the major portion of pavement structure. They are supposed to bear stresses occurring due to the wheel loads on the pavement and also have to resists wear due to abrasive action of traffic on the surface course. They are used with binding material such as portland cement, lime etc. to form compound materials.

5.5.1 Desirable Properties of Road Aggregates

(i) Strength: The aggregates to be used in road construction should be sufficiently strong enough to resist the stresses developed due to traffic load. The aggregates which are to be used in top layers of the pavement should withstand with high stresses in addition to wear and tear, hence they also have enough crushing strength.

(ii) Hardness: The aggregates used in surface course are subjected to wear due to abrasive action of moving traffic. They have to be hard enough to resists the wear land tear due to abrasive action of traffic.

NOTE: The mutual rubbing of stones is called attrition, wear in aggregates due to attrition is almost negligible.

(iii) Toughness: Aggregates in the pavement are also subjected to impact loading due to moving wheel loads. Hence aggregates should be tough enough to resists the action of impact loading

(iv) Durability or Soundness: Property of the stones to withstand the adverse action of weather is known as soundness. Stones used in pavement construction are subjected to the physical and chemical action of rain and ground water. Hence it is desirable that the road aggregates should be sound enough to withstand with weathering action.

(v) Shape of Aggregate: Aggregates which fall in a particular size range are classified as rounded, cubical angular, flaky and elongated shape of particles. Flaky and elongated. Particles have less strength and durability than other shapes of particles. Hence too flaky and too elongated aggregates should be avoided in the road construction.

(vi) Adhesive Property: The aggregates used in bituminous pavement construction should have more affinity to bitumen than the water otherwise bituminous coating on the aggregate will be stripped off by the action of water.

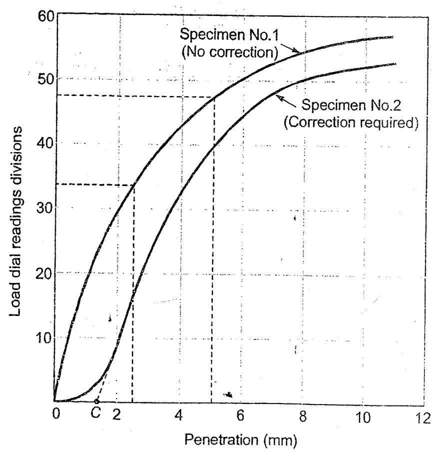
(vii) Freedom from Deleterious Particles: Aggregates used in bituminous mixes or cement concrete mixes should be clean, tough and durable in nature and free from excess amount of particles of dust, clayballs and other objectionable material.

Example-5.2 The load penetration values of CBR tests conducted on two specimens of a soil sample are given below. Determine the CBR value of the soil if 100 division of the load dial represents 190 kg load in the calibration chart of the proving ring.

Penetration of plunger (mm)	Load dial readings, divisions	
	Specimen No.1	Specimen No.2
0.0	0	0
0.5	8	0.5
1.0	15	1.5
1.5	23	2.5
2.0	29	6.0
2.5	34	13
3.0	37	20
4.0	43	30
5.0	48	38
7.5	57	50
10.0	63	58
12.5	67	63

Solution:

The penetration values are plotted against the load dial reading as shown in figure. (Instead, the load dial readings may also be converted either to load values in kg or load per unit area of cross section of the plunger in kg/cm^2 and plotted on the Y-axis.)



Specimen Number-1: The load penetration curve for specimen number 1 is consistently convex throughout and needs no correction.

Load dial reading at 2.5 mm penetration

= 34 divisions

Load at 2.5 mm penetration

$$= 34 \times \frac{190}{100} = 64.6 \text{ kg}$$

$$\text{CBR value at 2.5 mm penetration} = \frac{64.6 \times 100}{1370} = 4.7\%$$

$$\text{CBR value at 5.0 mm penetration} = \frac{48 \times 190 \times 100}{100 \times 2055} = 4.4\%$$

$\therefore$ CBR value of specimen number 1 = 4.7%

Specimen Number-2: As the curve has an initial concavity, correction is required. A tangent AC is drawn from the steepest portion *A* of the curve to intersect the X-axis at *C*, which is the corrected origin for this specimen. The penetration values are measured from this corrected origin *C*, as shown in figure.

$$\text{CBR value at 2.5 mm penetration} = \frac{32.5 \times 190 \times 100}{100 \times 1370} = 4.5\%$$

$$\text{CBR value at 5.0 mm penetration} = \frac{47 \times 190}{2055} = 4.3\%$$

CBR value of Specimen number 2 = 4.5%

$$\text{Therefore mean CBR value of the soil sample} = \frac{4.7 + 4.5}{2} = 4.6\%$$

Example-5.3 List-I below gives a list of physical properties of aggregates which should be determined to judge their suitability in road construction. List-II gives a list of laboratory tests which are conducted to determine these properties. Match List-I with List-II and select the correct answer from the codes given below the lists:

List-I	List-II
A. Hardness	1. Water adsorption
B. Porosity	2. Impact test
C. Toughness	3. Soundness test
D. Durability	4. Abrasion test

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	4	1	2	3
(c)	3	4	1	2
(d)	2	3	4	1

Ans. (b)

5.5.2 Test for Road Aggregates

To Decide a suitable aggregate for use in road construction, following tests are carried out.

(i) Crushing Test: The strength of coarse aggregate is determined by the aggregate crushing test.

Apparatus Used: A steel cylinder of diameter 15.2 cm with a base plate and a plunger, compression testing machine, cylindrical measures of diameter 11.5 cm and height 18 cm, tamping rod and sieves.

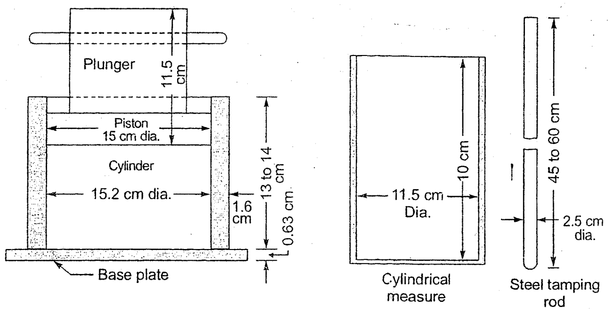


Figure-5.4 : *Aggregate crushing test apparatus*

Aggregates Used: Dry aggregates passing from 12.5 mm IS sieve and retained on 10 mm IS sieve. Aggregates are filled in cylindrical measure in three equal layers, each layer is ramped 25 times by the tamping rod and load is applied on the specimen through plunger. A load of 40 tonnes is applied at a rate of 5 tonnes per minute by the compression machine. The crushed aggregate is passed through 2.36 mm IS sieve and weighed equal to W_2 grams.

The aggregate crushing value (ACV) is given as

$$ACV = \frac{W_2}{W_1} \times 100$$

where, W_1 = Total weight of aggregate

W_2 = Weight of aggregate passing through 2.36 mm size sieve

ACV value less than 10% signifies a very strong aggregate while above 35% would normally regarded as weak aggregates.

NOTE: The aggregate crushing value for surface course should not exceed than 30% and should be less than 45% for base course.

(ii) Impact Test: This test is designed to evaluate the toughness of stone or resistance of aggregates under the repeated impact load.

Apparatus Used: Impact test machine which consists a metal base and a cylindrical steel cup of internal diameter 10.2 cm and depth 5 cm in which the aggregate specimen is placed, a metal hammer of weight 13.5 - 14.0 kg.

Aggregates Used: Dry aggregates passing through 12.5 mm IS sieve and retained on the 10.0 mm IS size sieve. Aggregates are filled in cylindrical measure in 3 layers by tamping each layer by 25 blows. The sample is transferred from the measure to the cup of aggregate impact testing machine and compacted by tamping 25 times. Hammer falls freely from the height of 38 cm

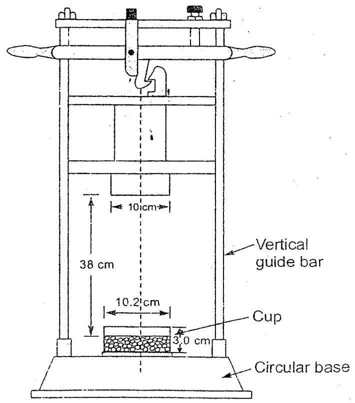


Figure-5.5 : *Aggregate impact testing machine*

above the upper surface of the aggregate in the cup. After the 15 blows on the specimen, the crushed aggregate is sieved on 2.36 mm IS sieve and weighted equal to W_2 grams.

$$\text{Aggregate Impact Value (AIV)} = \frac{W_2}{W_1} \times 100$$

where, W_1 = Total weight to the aggregate

W_2 = Weight of aggregate passing through 2.36 mm size sieve

For surface course aggregate impact value should not exceed 30%. For Bituminous Macadam maximum permissible value is 35% and 40% for Water Bound Macadam.

(iii) Abrasion Test: Abrasion test is carried out to test the hardness property of aggregates. It is the best test of aggregate which includes abrasion (rubbing between aggregate and steel balls), attrition (rubbing between aggregate and aggregate) and impact.

Different types of abrasion tests are:

(a) Los Angeles Abrasion Test

(b) Dorry Abrasion Test

(c) Dovel Abrasion Test

Los Angeles Abrasion Test:

(*i*) The principle of Los Angeles test is to find the percentage wear due to rubbing action between aggregate and steel balls.

(*ii*) It consists a circular drum of internal diameter 750 mm and length 520 mm rotating about a horizontal axis.

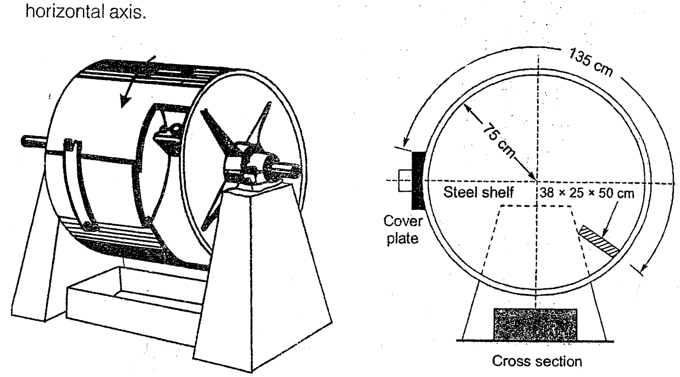


Figure-5.6 : *Los Angeles Abrasion Testing Machine*

(*iii*) An abrasive charge consisting of spherical cast iron balls of 48 mm diameters weigh 340 - 445 g is placed in the cylinder with aggregate

(*iv*) The cylinder is rotated at the speed of 30 - 33 rpm for a total of 500 - 1000 revolutions.

(*v*) After specified revolutions, the material is passed through 1.7 mm size sieve and weigh equal to W_2 grams.

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

where, W_1 = Total weight of aggregate

W_2 = Weight of aggregate passing through 1.7 mm size sieve (*vi*) For surface course abrasion value should not exceed 30% and should be less than 50% for base course.

NOTE: Coefficient of hardness $= 20 - \frac{\text{loss of weight in gm}}{3}$

(iv) Soundness Test: Soundness test is performed to study the resistance of aggregates against weathering action by conducting accelerated weathering test cycles.

Procedure of the test is as follows:

(a) Soak the aggregate in magnesium sulphate or sodium sulphate solution for 24 hours.

(b) Then heat the aggregate at 105°C - 110°C to a constant weight thus making one cycle of immersion and drying

(c) The number of cycles is decided by prior agreement and then the specimens are tested.

The average loss in weight of aggregates to be used in pavement construction after 10 cycles should not exceed 12% when tested with sodium sulphate and 18% when tested with magnesium sulphate.

(v) Shape Test: The particle shape of aggregate mass is determined by the percentages of flaky and elongated particles contained in it and by its angularity. The evaluation of shape of the particles made in terms of flakiness index, elongation index and angularity number.

(a) **Flakiness Index:** Flakiness index of aggregate is the percentage by weight of aggregate particles whose least dimension is less than 0.6 of their mean dimensions. This test is applicable to aggregate sizes larger than 6.3 mm.

$$\text{Flakiness index} = \frac{W_2}{W_1} \times 100$$

where, W_2 = Weight passed from $0.6 \times d_{mean}$ size

W_1 = Total weight of aggregates

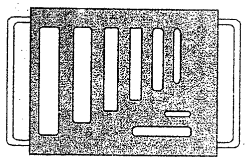


***Figure-5.7 :** Flakiness gauge*

NOTE: If the size range of aggregate in a group is 16 - 20 mm, then the width of the slot to be selected in flakiness gauge would be $18 \times 0.6 = 10.8$ mm

Flakiness Index of aggregates used in the road construction should be less than the 15% and normally does not exceed 25%

(b) **Elongation Index:** The elongation index of an aggregate is the percentage by weight of particles whose greatest dimensions is greater than 1.8 times their mean dimensions. This test is also applicable to aggregate sizes larger than 6.3 mm.

$$\text{Elongation Index} = \frac{W_2}{W_1} \times 100$$

where, W_2 = Weight pf aggregate passed from $1.8 \times d_{mean}$ size

W_1 = Total weight of aggregates

Elongation index of aggregates used in the road construction should be less than 15%.

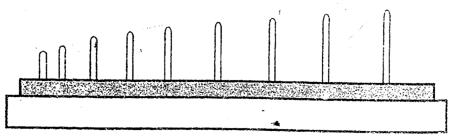


***Figure-5.8 :** Elongation gauge*

Example-5.4 If aggregate size of 50 - 40 mm is to be tested for finding out the portion of elongated aggregates using length gauge, the slot length of the gauge should be

(a) 81 mm (b) 45 mm

(c) 53 mm (d) 90 mm

Ans. (a)

Slot length for elongated aggregate $= 1.8 \times$ mean dimension $= 1.8 \times \left(\frac{50+40}{2}\right) = 81$ mm

For flakiness index, the slot size $= 0.6 \times \left(\frac{50+40}{2}\right) = 27$ mm

(c) **Angularity Number:** Based on the shape of the aggregate particles, they may be classified as rounded, irregular or partly rounded, angular and flaky. Angularity number shows degree of packing and measures voids in excess of 33%.

$$\text{Angularity number} = 67\ \% - \%\ \text{Solid Volume}$$

$$\therefore \quad \text{Angularity number} = 67\% - \left(\frac{W_a}{W_w G_a}\right) \times 100$$

where W_a = Weight of aggregate in cylinder

W_w = Weight of water in same cylinder

G_a = Specific gravity of aggregate

NOTE: 67% is the percentage solid volume of most rounded aggregate in well compacted state.

Example-5.5 The weight of coarse aggregate having specific gravity 2.65, which is completely filled into a cylinder of volume 0.003 m³ is 5247 gm. What is angularity number?

Solution:

W_a = 5247 gm or 5.247 kg

$W_w = \rho_w V_w = 1000 \times 0.003 = 3$ kg

G_a = 2.65

$$\text{Angularity Number} = 67\% - \frac{W_a}{W_w G_a} \times 100 = 67\% - \frac{5.247 \times 100}{3 \times 2.65} = 67\% - 66\%$$

$$\therefore \quad \text{Angularity Number} = 1\%$$

(vi) Water Absorption Test: The water absorption is expressed as the percent water absorbed in terms of oven dried weight of the aggregates. Water absorption should not be more than 0.6% of the weight of aggregate.

(vii) Specific Gravity Test: Specific gravity of a solid is the ratio of mass of solid to that of an equal volume of distilled water at a specified temperature. Specific gravity of aggregate lies between 2.6 and 2.9 and it is a measure of quality of strength of materials

5.6 Bitumen

Bitumen is a petroleum product obtained by the distillation of petroleum crude oil. Bitumen is hydrocarbon material of either natural of pyrogenous origin, found in gaseous, liquid semisolid or solid form. Bituminous materials are widely used in road construction and maintenance.

Bitumen is considered to be flexible from structural point of view. It is completely soluble in carbon disulphide (CS_2) and in carbon tetrachloride (CCl_4).

NOTE: When the bitumen contains some inert material or minerals, it is sometimes called asphalt.

Petroleum is also found as rock asphalt in some parts of Europe and as lake asphalt in Trinidad. In India good bitumen suitable for roadwork is obtained from Assam Petroleum.

Desirable Properties of bitumen required in construction of road are:

(*i*) The viscosity of the bitumen at the time of mixing and compaction should be adequate. This is archived by heating the bitumen and aggregate or by use of cutbacks or emulsion of suitable grade.

(*ii*) The bituminous material should not be highly temperature susceptible. The material should be durable.

(*iii*) In presence of water the bitumen should not stripoff from the aggregate.

5.6.1 Cutback Bitumen

Cutback Bitumen is a type of bitumen which is obtained when viscosity of bitumen is reduced by volatile diluent. It is generally used in colder regions.

Different types of cutback Bitumen are:

(i) Rapid Curing Cutback (RC): In this bitumen is fluxed with NAPTHA / GASOLINE.

(ii) Medium Curing Cutback (MC): In this bitumen is fluxed with KEROSENE.

(iii) Slow Curing Cutback (SC): In this bitumen is fluxed with high boiling point diluent.

NOTE: MC and SC cutback are used for priming and viscosity increases as the grade increases like RC-0, RC-1, RC-2.

5.6.2 Bitumen Emulsion

It is a condition in which bitumen is suspended in an aqueous medium. It is used for patch-up work. The biggest advantage of bitumen emulsion is that it can be used in rainy season also.

Different types of emulsions are:

(i) Rapid Setting (RS): It is used for surface painting.

(ii) Medium Setting (MS): It is used for premixing with coarse aggregate.

(iii) Slow Setting (SS): It is suitable for fine aggregate mixes.

5.6.3 Manufacturing of Bitumen

The refining of the petroleum crude in refineries is carried out on the principle of "fractional distillation". The crude oil is heated in a tube-still. The volatiles are separated in a fractionating column. Thus gasoline, kerosene, gas oil and heavy oil get separated. Steam is injected into the fractionating column to assist in the process and the residue is collected as bitumen.

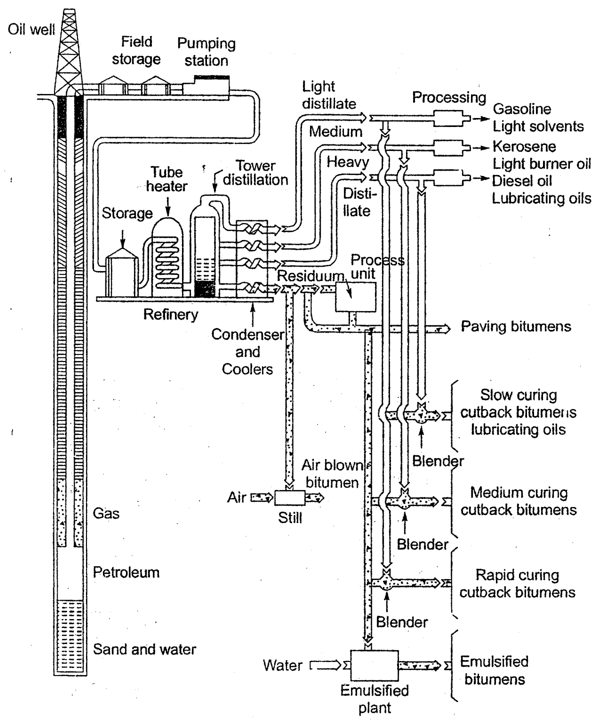


Figure-5.9 : *Petoleum bitumen flow chart*

5.6.4 Tests of Bitumen

(i) Penetration Test: Hardness of bitumen is obtained by the penetration test. It measures the distance a standard blunt pointed needle will vertically penetrate a sample of materials at 27°C, the load being 100g and time of application of load being 5 seconds.

The unit of penetration is 1/10 mm. Thus 80/100 grade bitumen mean 8 - 10 mm penetration. 30/40 and 80/100 grade bitumen are more commonly used, depending upon construction type and climatic conditions.

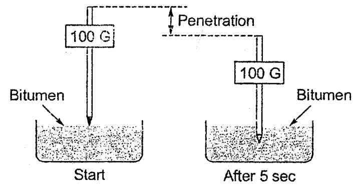


Figure-5.10 : *Penetration test concept*

NOTE: (*i*) In hot climates a lower penetration grade bitumen like 30/40 bitumen is preferred.

(*ii*) Tar is soft, hence Penetration Test is not used in case of tar.

Grade of bitumen is decided on the basis of penetration test. If the grade of bitumen is A-30 then it means this bitumen is manufactured from Assam Petroleum and Penetration value is 3 mm. If grade is S-30 then this bitumen is manufactured from other than Assam Petroleum.

(ii) Ductility Test: Bitumen should be sufficiently ductile and capable of being stretched without breaking. Ductility is measured as the distance in cm to which a standard briquette of size 10 × 10 mm can be stretched before the thread breaks at a standard temperature of 27°C and the rate of elongation is 50 mm per minute.

Ductility is a measure of adhesiveness and elasticity of bitumen. Minimum ductility value according to ISI is 75 cm for grade 45 and above.

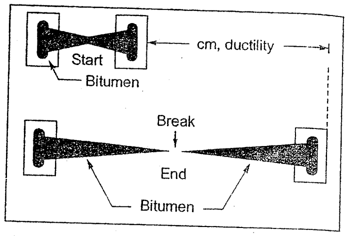


Figure-5.11 : Ductility test

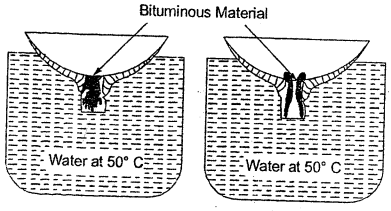


Figure-5.12 : Float test set-up

(iii) Float Test: This test is used to measure the consistency of bitumen for which penetration and viscosity test cannot be used. The apparatus consists of float made of aluminium and a brass collar filled with the specimen materials to be tested which is cooled to a temperature of 5°C and screwed into the float.

The float assembly is floated in a water bath at 50°C and the time required in seconds for water to force its way through the bitumen plug is noted as the float test value. Higher the float value, the stiffer is the bitumen.

(iv) Viscosity Test: Viscosity is the inverse of fluidity and it is a measure of resistance to flow. The viscosity of liquid bitumen is measured by efflux visconnecters. In this test, time taken in seconds by 50 m*l* of bitumen to flow from a container through a specified orifice of size 10 mm under standard test conditions and temperature of 25°C.

At low viscosity the bitumen binder simply lubricates the aggregate particle instead of providing a binder action while at high viscosity it will resist the compactive effort but mixture is heterogenous. Flurol Viscosity is a specific test which is used only to measure the viscosity of liquid bituminous materials.

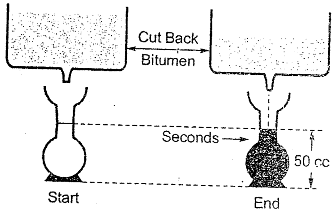


Figure-5.13 : Viscosity test

(v) Solubility Test: This test is used to measure the quantity of impurity present in the bitumen. Pure bitumen is soluble in solvents like carbon disulphide and carbon tetrachloride.

In this test 2g of bitumen is dissolved in 100 ml of solvent and insoluble material is washed, dried and weighted. Insoluble material is expressed in terms of percentage of original sample. The insoluble material should not be greater than 1.0 percent.

(vi) Specific Gravity Test: The specific gravity of bituminous materials is defined as 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°C. Pycnometer method is used to determine the specific gravity of bitumen. Specific gravity of pure bitumen is in the range of 0.97 to 1.02 where as tar has specific gravity ranging from 1.10 to 1.25.

(vii) Softening Point Test: The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. Apparatus used to determine softening point of bitumen is RING AND BALL assembly. A steel ball is placed over the bitumen sample and then liquid is heated at the rate of 5°C per minute.

The temperature at which a standard steel ball placed on a layer of bitumen kept in a standard ring passes through the bitumen layer and touches the bottom plate kept at a distance of 2.54 cm is the softening point. Softening point of various bitumen grades generally lies in between 35°C to 70°C.

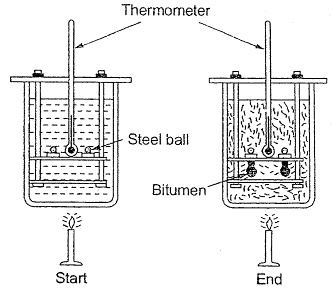


Figure-5.14 : Softening point test set-up

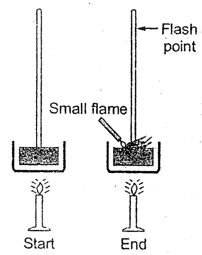


Figure-5.15 : Flash point test set-up

(viii) Flash and Fire Point Test: Flash point is the temperature at which bitumen vapours momentarily takes fire in the form of flash. Standard flash point according to Indian Standard Institute (ISI) is 175°C.

Fire point is the lowest temperature at which bitumen gets ignited and burn.

Pensky-Martens closed cup apparatus or open cup are used for conducting the tests. The safe limit for heating bitumen is normally 50°C below the flash point.

(ix) Spot Test: It is used to detect whether the bitumen is cracked or not. In this test 2g of bitumen is dissolved in 10 m*l* of naptha. A drop of this solution is taken on a filter paper. If the strain of the spot on the paper is uniform in colour, the bitumen is accepted as uncracked but if the spots form dark brown or black circle in the centre, the bitumen is considered to be over heated or cracked.

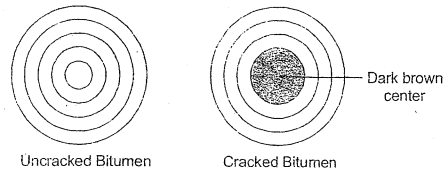


Figure-5.16 : Spot test

(x) Loss on Heating Test: When bitumen is heated, it loses the volatiles and gets hardened. The test is conducted by an accelerated heat test. 50 g of sample is heated at a temperature of 163°C for 5 hours in a special oven designed for this test. Not more than 1% loss in weight is desirable. Less the loss on heating, the better is the bitumen.

(xi) 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 maximum water content in bitumen should not exceed 0.2 percent by weight

5.7 TAR

Tar is also a bituminous material obtained by the destructive distillation of coal or wood. It has the same appearance as bitumen but both have different characteristics.

Table-5.4 : Difference between bitumen and tar

BITUMEN	TAR
1. Manufactured by fractional distillation of petroleum (In presence of air)	1. Manufactured by destructive distillation of coal and wood (In absence of air)
2. Soluble in CS_2 and CCl_4	2. Soluble in toluene
3. More resistant to water	3. Less resistant to water
4. Less temperature susceptibility	4. More temperature susceptibility
5. Free carbon content is less	5. More free carbon content

5.8 Mix Design

There are four popular methods of mix design:

(*i*) Marshall Method (Most Popular in India)
(*ii*) Hubbard - Field Method
(*iii*) Hveem Method
(*iv*) Smith Triaxial Method

5.8.1 Objective of Mix Design

There are various objectives of mix design:

(*i*) Sufficient bitumen to ensure a durable pavement
(*ii*) Sufficient strength to resist shear deformation under traffic at higher temperature
(*iii*) Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic
(*iv*) Sufficient workability to permit easy placement
(*v*) Sufficient flexibility to avoid premature cracking and shrinkage cracks
(*vi*) Skid resistance

5.8.2 Constituent of a Mix

(i) Coarse Aggregate: It offers compressive and shear strength and shows good interlocking properties. Example: Granite rocks etc.

(ii) Fine Aggregate: They fill the voids in the coarse aggregate and stiffens the binder. Example: Sand, Rockdust, etc.

(iii) Filler: It fills the void in fine aggregates, stiffens the binder and offers permeability. Example: Cement, Lime etc.

(iv) Binder: It fills the void, cause particle adhesion and offers impermeability. Example: Bitumen, Asphalt and Tar.

5.8.3 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.

5.8.4 Different Layers in a Pavement

(i) Bituminous Base Course: It consists of mineral aggregate 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 leveling 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.

5.8.5 Steps in Mix Design

Various steps involved in the mix design are as follows:

(*i*) Selection of aggregate and grading
(*ii*) Determination of specific gravity
(*iii*) Proportioning of aggregate by triangular chart method
(*iv*) Preparation of specimen by adding bitumen
(*v*) Determination of specific gravity on compacted specimen
(*vi*) Stability test on compacted specimen
(*vii*) Selection of optimum binder content

5.9 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°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.

5.9.1 Step 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 5.5**.

(*ii*) Approximately 1200 gm of aggregates and filler is heated to a temperature of 175 - 190°C.

(*iii*) Bitumen is heated upto a temperature of 121°C to 145°C with the first trial percentage of bitumen approximately 4% by weight of the mineral aggregate.

(*iv*) The heated aggregate and bitumen are thoroughly mixed at a temperature of 154 - 160°C.

(*v*) The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at the temperature of 138 - 149°C.

Table-5.5 : 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

(*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 upto 8% bitumen.

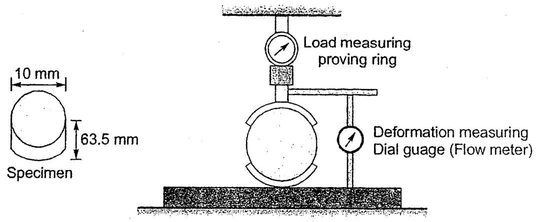


***Figure-5.17 :** Marshall test setup*

5.9.2 Different Properties of Mix

The properties that are being calculated are:

(i) Theoretical Specific Gravity or apparent specific gravity

It is the specific gravity without considering air voids and is given as

$$G_t = \frac{W_1 + W_2 + W_3 + W_4}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}}$$

or

$$\frac{W_T}{G_t} = \frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4} = \sum_{i=1}^{4} \frac{W_i}{G_i}$$

	Void	V_v
$W_b = W_4$	Bitumen	$V_4 = V_b$
W_3	Filler	V_3
W_2	Fine Aggregate	V_2
W_1	Coarse Aggregate	V_1

If weight of constituents are given in percent of total mix, then

$$G_t = \frac{100}{\frac{W_1(\%)}{G_1} + \frac{W_2(\%)}{G_2} + \frac{W_3(\%)}{G_3} + \frac{W_4(\%)}{G_4}}$$

Where,
W_1 = Weight of coarse aggregate in mix
W_2 = Weight of fine aggregate in mix
W_3 = Weight of filler in mix
W_4 = Weight of bitumen in mix
G_1 = Apparent specific gravity of coarse aggregates
G_2 = Apparent specific gravity of fine aggregates
G_3 = Apparent specific gravity of filler material
G_4 = Apparent specific gravity of bitumen

(ii) Bulk Specific Gravity of Unit Weight of Marshall Method

Bulk specific gravity is the specific gravity considering air voids and is calculated as

$$G_m = \frac{100}{\frac{W_1\%}{G_1} + \frac{W_2\%}{G_2} + \frac{W_3\%}{G_3} + \frac{W_4\%}{G_4} + V_v\gamma_w} = \frac{\frac{\text{Weight of Marshall mould}}{\text{Volume of Marshall mould}}}{\gamma_w}$$

(iii) Percent Air Void

Air voids is the percent of air voids by volume in the specimen which is given as

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

(iv) Percent Volume of Bitumen

It is the volume of bitumen to the total volume of the specimen which is formulated as

$$V_b(\%) = G_m \times \frac{W_4(\%)}{G_4} = \frac{G_m}{G_4} \times \left(\frac{W_4}{W_{mould}} \times 100\right)$$

(v) Voids in Mineral Aggregates

It is the volume of voids in the aggregates. It is also equals to volume of air voids and volume of bitumen

$$\text{VMA}(\%) = \frac{V_v + V_b}{V} \times 100 = V_v\% + V_b\%$$

(vi) Voids filled with Bitumen

Voids filled with bitumen is the voids in the mineral aggregate filled with the bitumen

$$\text{VFB} = \frac{V_b}{V_b + V_v} \times 100 = \frac{V_b\%}{V_b\% + V_v\%} \times 100 = \frac{V_b\%}{\text{VMA}\%} \times 100$$

Example-5.6 In a Marshall sample, the bulk specific gravity of mix and aggregates are 2.324 and 2.546 respectively. The sample includes 5% of bitumen (by total weight of mix) of specific gravity 1.10. The theoretical maximum specific gravity of mix is 2.441. The void filled with bitumen (VFB) in the Marshall sample (in %) is _______.

Solution:

$$V_v = \frac{G_t - G_m}{G_t} \times 100 = \frac{2.441 - 2.324}{2.441} \times 100 = 4.79\%$$

Void filled with bitumen, $$V_b = G_m \times \frac{W_b(\%)}{G_b} = 2.324 \times \frac{5}{1.1} = 10.56\%$$

$$\text{VMA} = V_v + V_b = 4.79 + 10.56 = 15.35\%$$

$$\therefore \quad \text{VFB} = \frac{V_b(\%)}{\text{VMA}} \times 100 = \frac{10.56}{15.35} \times 100 = 68.79\%$$

5.9.3 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). During the stability test 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.

5.9.4 Stability Correction

It is possible while making the specimen the thickness slightly vary from the standard specification of 63.5 mm. So measured stability value should be corrected to those which should have been obtained if the specimens hand been exactly 63.5 mm.

Correction is done by multiplying each measured stability value by an appropriate correlation factors as given in Table 5.6.

Table-5.6 : Correction factors for Marshal stability values

Volume of specimen(cm³)	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

5.9.5 Graphical Plots

The average value of each 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.

(*i*) Marshall Stability Value
(*ii*) Flow Value
(*iii*) Unit Weight
(*iv*) Percent Voids in Total Mix(V_v)
(*v*) Percent Voids Filled with Bitumen(VFB)

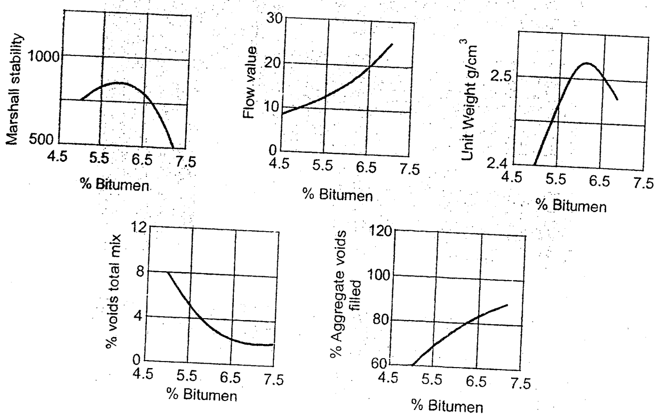


Figure-5.18 : *Bituminous mix design by Marshall test*

5.9.6 Optimum Bitumen Content

The optimum bitumen content for the mix design is found by taking the average value of the following three bitumen contents found from the graphs of the test results

(*i*) Bitumen content corresponding to maximum stability
(*ii*) Bitumen content corresponding to maximum unit weight
(*iii*) Bitumen content corresponding to the median of designed limits of percent air voids in total mix (i.e. 4%)

The stability value, flow value and VFB are checked with Marshall mix design specification chart given in Table 5.7.

Table-5.7 : 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

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.

Example-5.7 The specific gravities and weight proportions for aggregate bitumen are as under for the preparation of Marshall Mix design. The volume and weight of one marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero. Find V_v, V_b, VMA and VFB.

Item	Aggregate-1	Aggregate-2	Aggregate-3	Aggregate-4	Bitumen
Weight	825	1200	325	150	100
Specific Gravity	2.63	2.51	2.46	2.43	1.05

Solution:

Theoretical Specific Gravity,

$$G_t = \frac{W_1 + W_2 + W_3 + W_4}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_4}} = \frac{825 + 1200 + 325 + 150}{\frac{825}{2.63} + \frac{1200}{2.51} + \frac{325}{2.46} + \frac{150}{2.43}} = 2.406$$

Mass Specific Gravity, $G_m = \dfrac{\text{Weight of Marshall Specimen}}{\text{Volume of Marshall Specimen}} = \dfrac{1100}{475} = 2.316$

Percentage air void, $V_v = \dfrac{G_t - G_m}{G_t} \times 100 = \dfrac{2.406 - 2.316}{2.316} \times 100 = 3.741\%$

Percentage volume of bitumen,

$$V_b = \frac{G_m}{G_4} \times \frac{W}{W_{mould}} \times 100 = \frac{2.316}{1.05} \times \frac{100}{1100} \times 100 = 20.052\ \%$$

Voids in mineral aggregate,

$$\text{VMA} = V_v\% + V_b\% = 3.741 + 20.052 = 23.793\%$$

Voids filled with bitumen, $\text{VFB} = \dfrac{V_b\%}{VMA\%} \times 100 = \dfrac{20.052}{23.793} \times 100 = 84.277\%$

Hence, $G_t = 2.406$, $G_m = 2.316$, $V_v = 3.741\%$, $V_b = 20.052\%$, VMA = 23.793% and VFB = 84.277%.

Example-5.8 A specimen of bituminous concrete has a height of 5 cm and diameter of 10 cm. The weight of compacted specimen in water is 600 gm and in air is 1250 gm. Weight of specimen when coated with wax is 1280 gm in air and 590 gm in water. Specific gravity of wax is 0.90. The analysis of specimen gives the following data:

Material	Specific gravity	Mix composition (% by weight of total mix)	Aggregate composition (% by weight of total aggregate)
Bitumen	1.02	5.0	-
Coarse aggregate	2.60	50.0	56.0
Fine aggregate	2.65	39.0	35.0
Filler	2.68	6.0	9.0

Calculate the following:

(*i*) Bulk density of uncoated specimen by the immersion procedure
(*ii*) Bulk density of specimen from specimen dimension
(*iii*) Bulk density of specimen by wax coating procedure
(*iv*) Average specific gravity of aggregates
(*v*) Maximum theoretical density
(*vi*) Percent voids in compacted mix
(*vii*) Percent of volume occupied by bitumen, coarse aggregates and filler
(*viii*) Percent volume of voids in mineral aggregate
(*ix*) Percent voids in aggregates filled with bitumen

Solution:

(*i*) Bulk density of uncoated specimen by immersion procedure

$$= \frac{\text{Weight in air}}{\text{Volume}} = \frac{\text{Weight in air}}{\text{Loss of weight when immersed in water}} = \frac{1250}{1250-600} = \frac{1250}{650} = 1.92 \text{ g/cc}$$

(*ii*) Bulk density of specimen $= \dfrac{\text{Weight}}{\text{Volume}} = \dfrac{1250}{\pi(10)^2/4 \times 5} = 3.18$ g/cc

(*iii*) Bulk density of wax coating procedure

$$= \frac{\text{Weight of uncoated specimen in air}}{\text{Weight of wax coated specimen in air} - \text{Weight of wax coated specimen in water} - \dfrac{[\text{Weight of coated specimen} - \text{Weight of uncoated specimen}]}{\text{sp.gr.of wax}}}$$

$$= \frac{1250}{1280 - 590 - \left(\dfrac{1280-1250}{0.90}\right)} = \frac{1250}{690-33.33} = \frac{1250}{656.67} = 1.9 \text{ g/cc}$$

(*iv*) Average specific gravity of aggregate $= \dfrac{100}{\dfrac{56}{2.6}+\dfrac{35}{2.65}+\dfrac{9}{2.68}} = \dfrac{100}{38.10} = 2.62$ g/cc

(*v*) Maximum theoretical density

$$= \frac{\text{Weight of specimen in air}}{\text{Volume of bitumen} + \text{Volume of aggregates}}$$

$$= \frac{1250}{\dfrac{0.050 \times 1250}{1.02} + \dfrac{0.95 \times 1250}{2.62}} = \frac{1250}{514.52} = 2.43 \text{ g/cc}$$

(*vi*) Percent voids in compacted mix

$$= \frac{\text{Total volume} - \text{volume of ingredients}}{\text{Total volume}} \times 100$$

$$= \frac{\dfrac{1250}{3.18} - \dfrac{1250 \times 0.05}{1.02} - \dfrac{1250 \times 0.50}{2.60} - \dfrac{1250 \times 0.39}{2.65} - \dfrac{1250 \times 0.06}{2.68}}{\dfrac{1250}{3.18}} \times 100 = 10.43\%$$

(*vii*) Percent of volume occupied by bitumen, coarse aggregates, fine aggregates and filler.

$$\% \text{ Volume occupied by bitumen} = \frac{(5 \times 2.18)}{1.02} = 10.69\%$$

$$\% \text{Volume occupied by coarse aggregates} = \frac{(50 \times 2.18)}{2.60} = 41.92\ \%$$

$$\% \text{ Volume occupied by fine aggregates} = \frac{(39 \times 2.18)}{2.68} = 31.72\%$$

$$\% \text{ Volume occupied by filler} = \frac{(6.0 \times 2.18)}{2.68} = 4.88\%$$

(*viii*) Percent volume of voids in mineral aggregates

$$= 100 - \frac{\text{Percent weight of aggregate} \times 1250 \times 100}{\text{Average specific gravity of aggregates} \times (1250-600)}$$

$$= 100 - \frac{0.95 \times 1250 \times 100}{2.62 \times 650} = 30.27\ \%$$

(*ix*) Percent of voids filled with bitumen

$$= \frac{\text{Percent of bitumen in mix by volume}}{\text{Percent of voids in aggregates}} \times 100$$

$$= \frac{10.69 \times 100}{30.27} = 35.31\%$$

5.10 Modified Hubbard-Field Method of Bituminous Mix Design

Initially this method was intended to design sheet asphalt mix. Later the method was modified for the design of bituminous mixes having coarse aggregate upto 19 mm size. There is a testing assembly consisting of a ring of internal diameter 14.6 cm through which the specimen is extruded by applying load through the compression machine.

The specimen is placed in the test mould assembly over the test ring of internal diameter of 14.6 cm and the plunger is loaded on the top of the specimen. The whole assembly is placed in water bath at 60°C for atleast one hour. The compressive load is applied at a constant rate of deformation of 6.1 cm per minute and the maximum load in kg developed during the test is recorded as the stability value. The test is conducted with other bitumen contents as in Marshall method.

For each bitumen content the average value of specific gravity, percent voids in total mix and percent aggregate voids are calculated and following graphs are plotted:

(a) Stability vs bitumen content
(b) Unit weight vs bitumen content
(c) Percent voids in total mix vs bitumen content
(d) Percent aggregate voids vs bitumen content

The following criteria have been specified by the asphalt Institute for the design of bituminous mix.

Property	Medium and Light traffic	Heavy and Very heavy traffic
Stability (kg)	545 - 910	> 910
Voids (%)	2 - 5	2 - 6

5.11 Hveem Method of Bituminous Mix Design

Hveem method has certain advantages over the Marshall method such as the following:

(a) Kneading compaction is adopted in Hveem method which is close to the field compaction.

(b) Hveem stability gives an idea of the shear resistivity of the sample.

The hveem method of testing of bituminous mixtures involves three tests, namely the centrifuge kerosene equivalent test, the stabilometer test and the cohesiometer test.

To find the hveem stability, bituminous mixture is compacted in a kneading compactor according to the specified procedure and the sample is heated at 60°C and tested in the hveem stabilometer. The test result is expressed on the scale of 0 to 90.

NOTE: 0 value of Hveem stability represents the liquid sample while 90 means that the specimen is incompressible solid.

In the cohesiometer test vertical load is gradually applied from one side of a sample and at some stage it fails, the failure load is used to calculate the hveem cohesiometer.

Illustrative Examples

Example-5.9 Determine the percent voids in mineral aggregate, in compacted mix and filled with bitumen from the following data:

Bitumen content, W_b = 5.0 kg per 100 kg of aggregate
Specific gravity of bitumen, G_b = 1.002
Bulk specific gravity of mineral aggregate, G_a = 2.800
Bitumen absorption, weight percent = 0.56
Specific gravity of test specimen, G = 2.479

Solution:

Assume 100 ml of compacted mix

Weight mix per 100 ml = 100 × 2.479 = 247.9 gms

$$\text{Weight of aggregate, per 100 ml of mix} = \frac{2.749 \times 100}{105} = 236.1 \text{ gms}$$

$$\text{Volume of aggregate including pores} = \frac{236.1}{2.800} = 84.3 \text{ ml}$$

Voids in mineral aggregate = 100 − 84.3 = 15.7 ml

Weight of total bitumen = 247.9 − 236.1 = 11.8 gms

$$\text{Weight of absorbed bitumen} = \frac{236.1 \times 0.56}{100} = 1.3 \text{ gms}$$

Weight of unabsorbed bitumen = 11.8 − 1.3 = 10.5 gms

Volume of air voids = 15.7 − 10.5 = 5.2 ml

$$\text{Percent voids filled with bitumen} = \frac{15.7 - 5.2}{15.7} \times 100 = 66.9$$

Summary of results,

Percent of voids in mineral aggregate = 15.7
Percent voids in compacted mix = 5.2
Percent voids filled with bitumen = 66.9

Example-5.10 Determine the unit weight of a bituminous mix containing 70% coarse aggregate, 24% fine aggregate and 6% bitumen by weight of the mixture. The air voids after compaction are 8%. The specific gravities of the material are as under:

Sp. gravity of coarse aggregate = 2.80
Sp. gravity of fine aggregate = 2.66
Sp. gravity of bitumen = 1.00

Solution:

$$\frac{\text{Volume of voids}}{\text{Total volume}} = \frac{V_v}{V} = 0.08$$

∴ Volume of voids, $V_v = 0.08\,V$

Let, the total weight of mix = W

$$\text{Volume of coarse aggregate,} \quad V_c = \frac{0.70\,W}{2.8} = 0.25\,W$$

$$\text{Volume of fine aggregate,} \quad V_f = \frac{0.24\,W}{2.66} = 0.090\,W$$

$$\text{Volume of bitumen,} \quad V_b = \frac{0.06\,W}{1} = 0.06\,W$$

$$\therefore \quad V = 0.08\,V + 0.25\,W + 0.06\,W + 0.090\,W$$

$$\text{or} \quad V(1 - 0.08) = W(0.25 + 0.09 + 0.06)$$

$$\text{or} \quad \frac{W}{V} = \frac{0.92}{0.4} = 2.3$$

∴ Unit weight of mix = 2.3 g/cm³

Example-5.11 Determine the specific gravity of combined aggregate in a bituminous mix having maximum theoretical specific gravity of 2.4. The bitumen content is 8% by weight of the mix and its specific gravity is 1.00.

Solution:

Maximum theoretical specific gravity, G_t = 2.4
Bitumen content, W_b = 8%
Specific gravity of bitumen, G_b = 1

$$\text{The maximum theoretical specific gravity is given by, } G_t = \frac{100}{\frac{(100 - W_b)}{G_a} + \frac{W_b}{G_b}}$$

where, G_a is the specific gravity of the combined aggregate

$$2.4 = \frac{100}{\frac{(100-8)}{G_a} + \frac{8}{1}} \quad \text{or} \quad 2.4\left(\frac{92}{G_a} + 8\right) = 100 \quad \text{or} \quad \frac{92}{G_a} = \frac{100}{2.4} - 8 = 33.67$$

$$\therefore \quad G_a = \frac{92}{33.67} = 2.733$$

Summary

- Soil mainly consists of mineral matter formed by the disintegration of rocks.
- Sub-grade soil is an integral part of the road pavement structure and its main function is to give adequate support to the pavement.
- The tests used to evaluate the strength of soil are shear tests, bearing tests and penetration tests.
- **Plate bearing test** is used to find supporting power of sub-grade i.e. modulus of sub-grade reaction.
- **CBR value** is calculated corresponding to 2.5 mm and 5.0 mm generally CBR value at 2.5 mm is greater than the CBR value at 5.0 mm.
- Aggregates form the major portion of pavement structure and bear stresses occurring due to the wheel loads on the pavement.
- Property of aggregates in the pavement to withstand the adverse action of weather is known as **soundness**.
- In the crushing test and impact test, the crushed aggregate is passed through 2.36 mm IS sieve while in abrasion test 1.7 mm IS sieve is used.
- **Flaky aggregate** has its least dimension less than 0.6 times of their mean dimensions and **elongated aggregate** has its maximum dimension more than 1.8 times of its mean dimension.
- **Angularity number** shows degree of packing and measures voids in excess of 33%.
- Bitumen is obtained by the fractional distillation of petroleum crude oil while tar is manufactured by destructive distillation of coal and wood.
- Bitumen is soluble in CS_2 and CCl_4 and tar is soluble in toluene.
- The Marshall stability and flow test provides the performance prediction measure for the **Marshall mix design** method.
- Optimum bitumen content for the mix design is found by taking the average value of the bitumen content corresponding to maximum stability, bitumen content corresponding to maximum unit weight and bitumen content corresponding to the 4% air voids in total mix.
- Mixes with very high stability value and low flow value are not desirables for pavement construction.

Important Expressions

1. Modulus of sub-grade reaction, $k = \dfrac{p}{0.125}$ kg/cm²/cm
2. $\text{CBR}(\%) = \dfrac{\text{Load carried by specimen at 0.5 mm or 5.0 mm penetration}}{\text{Load carried by standard aggregates at corresponding penetration level}} \times 100$
3. Coefficient of hardness $= 20 - \dfrac{\text{Loss of weight in gm}}{3}$
4. Angularity number $= 67\% - \left(\dfrac{W_a}{W_W G_a}\right) \times 100$
5. Theoretical specific gravity, $G_t = \sum_{i=1}^{n} \dfrac{W_i}{G_i}$
6. Bulk specific gravity, $G_m = \dfrac{\left(\dfrac{\text{Weight of Marshall mould}}{\text{Volume of Marshall mould}}\right)}{\gamma_\omega}$
7. Percent air void, $V_v = \dfrac{G_t - G_m}{G_t} \times 100$
8. Percent volume of bitumen, $V_b = G_m \times \dfrac{W_u(\%)}{G_u}$
9. Voids in mineral aggregates, VMA $= V_v(\%) + V_b(\%)$
10. Voids filled with bitumen, $\text{VFB} = \dfrac{V_b(\%)}{\text{VMA}(\%)} \times 100$

Objective Brain Teasers

Q.1 As per revised method, the modulus of subgrade reaction corresponds to a pressure of

(a) 0.125 kg/cm² (b) 0.25 kg/cm²
(c) 0.7 kg/cm² (d) None of these

Q.2 The general range of angularity number for aggregates used in constructions is

(a) 0 to 11 (b) 11 to 20
(c) 20 to 30 (d) 30 to 45

Q.3 The grade of Bitumen generally preferred in hot climate is

(a) 30/40 (b) 80/100
(c) 100/40 (d) 100/20

Q.4 Pick-up the incorrect pair:

Test type
A. Ductility test
B. Spot test
C. Float test
D. Viscosity

Purpose
1. Adhesiveness and elasticity
2. Detecting cracked bitumen
3. Stiffness or consistency
4. Softening point

(a) A - 1 (b) B - 2
(c) C - 3 (d) D - 4

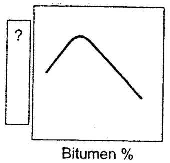
Q.5 Flash and fire point test is conducted using

(a) Ring and ball
(b) Benkelman test
(c) Pensky martens closed cup
(d) None of these

Q.6 Pick-up the incorrect statement:

(a) Tar is obtained from destructive distillation of wood or char cool where as Bitumen is obtained from fractional distillation of petroleum.
(b) Percentage of free carbon in Bitumen is less than that in tar.
(c) In presence of water tar coats aggregates better than Bitumen.
(d) Bitumen is more temperature susceptible than tar.

Q.7 A typical Marshal test graph is shown in the figure. The variable on y-axis is



(a) stability value
(b) flow value
(c) % of voids *d* unit weight
(d) none of the above

Q.8 In 500 gm sample of coarse aggregate, there are 100 gm flaky particles and 80 gm elongates particles. What are the flakiness and elongation indices (total) as per I.S.?
(a) 40% (b) 36%
(c) 18% (d) 4%

Q.9 What should be the relative magnitude of free carbon in bitumen over than in tar for road construction?
(a) More (b) Less
(c) Equal (d) Unrelative

Q.10 The Marshall flow value is expressed in units of
(a) 25 mm (b) 0.25 mm
(c) 5 mm (d) 3 mm

Q.11 Modulus of subgrade reaction using 30 cm diameter plate is obtained as 200 N/cm^3. The value of the same (in N/cm^3) using the standard plate will be
(a) 100 N/cm^3 (b) 200 N/cm^3
(c) 150 N/cm^3 (d) 80 N/cm^3

Q.12 The modulus of subgrade reaction is evaluated from which one of the following?
(a) Plate-bearing test (b) CBR test
(c) Direct shear test (d) Triaxial test

Q.13 Cutback bitumen is produced by diluting penetration grade bitumen with suitable petroleum distillate. Match **List-I (Type of cutback bitumen)** with **List-II (Solvent used)** and select the correct answer using codes given below:

List-I
A. Rapid curing
B. Medium curing
C. Slow curing

List-II
1. Kerosene
2. Naptha and Gasolene
3. High boiling point gas oil/Light oil
4. Vinegar

Codes:

	A	B	C
(a)	1	2	3
(b)	2	1	4
(c)	1	2	4
(d)	2	1	3

Q.14 The following data refers to observations taken for angularity number of aggregate
1. Size of aggregate = 20 mm – 16 mm (Passing through 20 mm and retained on 16 mm).
2. Specific gravity of aggregate = 2.856.
3. Weight of water required to fill the cylinder = 3000 gms.
4. Weight of aggregate required to fill the cylinder = 3880 gms.

The angularity number is
(a) 11.36 (b) 16.75
(c) 21.76 (d) 23.68

Q.15 Match **List-I** with **List-II** and select the correct answer using codes given below:

List-I
A. 80/100 grade bitumen
B. 30/40 grade bitumen
C. RT-1 (Road tar)
D. RT-5 (Road tar)

List-II
1. Suitable for cold climate region
2. Suitable for hot climate region
3. Is used for surface painting under cold weather
4. Is used for grouting purpose

Codes:

	A	B	C	D
(a)	1	2	4	3
(b)	2	1	4	3
(c)	1	2	3	4
(d)	2	1	3	4

Q.16 The bulk specific gravities of coarse aggregate fine aggregate and fines are found to be 2.5, 2.60 and 2.65 respectively. The specific gravity of bitumen is given as 1.10. For preparation of the Marshal sample, their relative proportions used are 55%, 30%, 10% and 5% by weight respectively. The mass of the sample measured in air is 1245.2 g, the mass of paraffin coated sample in air is 1295.8 g and the mass of the paraffin coated sample measured in water is measured as 703.7 g. The specific gravity of paraffin is 0.8 and the theoretical maximum specific gravity of the mixture obtained from Vacuum test is 2.441.
Match **List-I** with **List-II** and select the correct answer using codes given below:

List-I
A. VMA (% void in mineral aggregate)
B. VA (% air void)
C. VFB (% void filled with bitumen)
D. The percentage absorbed bitumen to the total weight of mixture

List-II
1. 2.5
2. 70.98
3. 12.13
4. 3.52

Codes:

	A	B	C	D
(a)	2	1	3	4
(b)	2	4	3	1
(c)	3	1	2	4
(d)	3	4	2	1

Q.17 The unit weight of a bituminous mixture containing 70 percent coarse aggregate, 24 percent fine aggregate and 6 percent bitumen by weight of the mixture is ________ gm/cm^3. The air voids after-compaction are 8 percent. Given the specific gravities of the materials as
Specific gravity of coarse aggregate = 2.80
Specific gravity of fine aggregate = 2.66
Specific gravity of bitumen = 1.00
(a) 2.30 (b) 2.80
(c) 3.10 (d) None of these

Q.18 In the Marshall method of mix design, the coarse aggregates, fine aggregates, filter and bitumen, having respective specific gravities of 2.56, 2.65, 2.70 and 1.10 are mixed in the ratio of 50, 38.2, 4.7 and 7.1 percent, respectively. The theoretical specific gravity of the mix would be
(a) 1.67 (b) 2.37
(c) 3.14 (d) 3.68

Q.19 A bituminous mix having maximum theoretical specific gravity of 2.5. The bitumen content is 7% by weight of the mix and its specific gravity is 1.00. What is the specific gravity of the combined aggregates?
(a) 2.65 (b) 2.82
(c) 2.95 (d) 3.10

Q.20 A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter of 30 cm. The load value corresponding to mean settlement value of 0.125 cm is 1490 kg. What is the modulus of subgrade reaction (in kg/cm^3) for the standard plate having 750 mm diameter?
(a) 6.75 (b) 4.02
(c) 3.57 (d) None of these

Q.21 A Marshall specimen is prepared for bituminous concrete with a bitumen content of 6 percent by weight of total mix. The theoretical and the measured unit weights of the mix are 2.54 g/cm^3 and 2.42 g/cm^3, respectively. The bitumen has a specific gravity of 1.03. The percent voids in mineral aggregate filled with bitumen (VFB) are
(a) 63.25 (b) 69.90
(c) 74.50 (d) 74.90

Answers

1. (c)	**2.** (a)	**3.** (a)	**4.** (d)	**5.** (c)
6. (c)	**7.** (a)	**8.** (b)	**9.** (b)	**10.** (b)
11. (d)	**12.** (a)	**13.** (d)	**14.** (c)	**15.** (c)
16. (d)	**17.** (a)	**18.** (b)	**19.** (b)	**20.** (a)
21. (d)				

Conventional Practice Question

Q.1 A specimen of asphaltic concrete has a height of 6.35 cm and a diameter of 10.16 cm. The weight of the compacted specimen (uncoated) in air is 1240.1 gms and in water the weight is 675.2 gms. When coated with paraffin, its weight in air is 1272.4 gms and its weight when immersed in water is 671.1 gms. The specific gravity of paraffin is 0.90. The analysis of the specimen yielded the following:

Material	Specific gravity	Mix composition (% by weight of total mix)	Aggregate composition (% by weight of total aggregates)
Bitumen	1.00	5.5	—
Coarse aggregates	2.61	54.0	56.0
Find aggregates	2.65	34.0	36.6
Mineral filler	2.68	6.5	7.4

Calculate:

(*i*) Bulk density of specimen by uncoated specimen procedure and immersion test.

(*ii*) Bulk density of specimen from dimensions.

(*iii*) Average specific gravity of the aggregates.

(*iv*) Maximum theoretical density.

(*v*) Bulk density as percent of maximum density.

(*vi*) Percent voids in compacted mix.

(*vii*) Percent volume occupied by bitumen, coarse aggregates, fine aggregates and mineral filler.

(*viii*) Percent volume of voids in mineral aggregate.

(*ix*) Percent aggregate voids filled with bitumen.

Ans. (*i*) 2.19 gm/cc
(*ii*) 2.41 gm/cc
(*iii*) 2.63 gm/cc
(*iv*) 2.41 gm/cc
(*v*) 90.9 gm/cc
(*vi*) 9.2%
(*vii*) 12.05, 45.31, 28.10 and 5.31
(*viii*) 21.3
(*ix*) 56.6

■■■■