Chapter 2

Highway Materials

CHAPTER HIGHLIGHTS

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- *Bituminous mix design by Marshall stability test*

Introduction

Highway construction is done with different types of materials like soil, stone aggregate, bitumen and cement concrete. The settlement of road or resistance of the pavement depends on the quality of all the materials. Therefore different properties of all materials are required to lay the pavement.

Subgrade

It is a natural foundation or fill which forms the integral part of road pavement and directly receive loads from it.

Functions

1. It should provide support to the pavement from beneath.
2. It should be stable and support the pavement even under adverse climate and loading conditions.

Materials Used for Pavements

1. Soil
2. Stone aggregates
3. Bituminous binders
4. Bituminous mixes
5. Portland cement and cement concrete

Desirable Properties of Soil

1. Stability
2. Incompressibility
3. Permanency of strength
4. Minimum changes in volume and stability under adverse conditions of weather
5. Good drainage
6. Ease of compaction

Evaluation of Soil Strength

1. **Shear tests:** On relatively small soil samples.

   Example: Direct shear test, tri-axial compression test, unconfined compression test.
2. **Bearing tests:** On soil subgrade or at foundation level in-situ.

$$\frac{\text{Deformation}}{\text{Diameter of loaded area}}$$

(= low value is preferable).

3. **Penetration tests:** On small loaded area and can be done in field or in laboratory

$$\frac{\text{Deformation}}{\text{Diameter of loaded area}} = \text{High}$$

Example: CBR test and cone penetration test.

California Bearing Ratio Test (CBR)

- To find the strength of subgrade soil and other pavement materials for the design and construction of flexible pavements.
- This test denotes the measure of resistance to penetration of a soil with standard plunger under controlled test conditions.
- Material passing 20 mm sieve is only used in testing.

Apparatus

Cylindrical mould (150 mm diameter), Base plate, cylindrical plunger (50 mm diameter), surcharge weight and compression testing machine.

Test Procedure

- Specimen in mould is compacted to a dry density (practically possible).
  For heavy compaction—high trafficked roads (Expressway NH and SH); for light compaction—Low volume roads
- Specimen is soaked for four days and surcharge weight is placed on it.
- This setup is placed under the plunger of loading frame where penetration rate is 1.25 mm per minute.
- The loads for 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm penetration are recorded and curves are plotted.
- If the curve is initially concave upward due to surface irregularities correction is applied by drawing a tangent to the curve at the steepest point and the point where tangent meets the horizontal axis is taken as corrected origin.
- The test load for 2.5 mm and 5.0 mm are recorded.

$$\text{CBR}(\%) = \frac{P_{(2.5 \text{ or } 5 \text{ mm})}}{P_{\text{std}(2.5 \text{ or } 5 \text{ mm})}} \times 100$$

- Higher of the two values is recorded as CBR value.
- Usually $\text{CBR}_{2.5\text{ mm}} > \text{CBR}_{5\text{ mm}}$. If $\text{CBR}_{5\text{ mm}} > \text{CBR}_{2.5\text{ mm}}$ test is repeated and if it gives the same result, higher value is reported as CBR value.

SOLVED EXAMPLES

Example 1

In a CBR test, the load sustained by a remoulded soil specimen at 5 mm penetration is 120 kg. The CBR value of the soil will be

(A) 9.2% (B) 7.3%
(C) 5.84% (D) 2.4%

Solution

$$(\text{CBR})_{5\text{ mm}} = \frac{P_{5\text{mm}}}{(P_{5\text{mm}})_{\text{standard}}} \times 100$$

$$= \frac{120}{2055} \times 100$$

$$= 5.84\%$$

Hence, the correct answer is option (C).

Plate Bearing Test

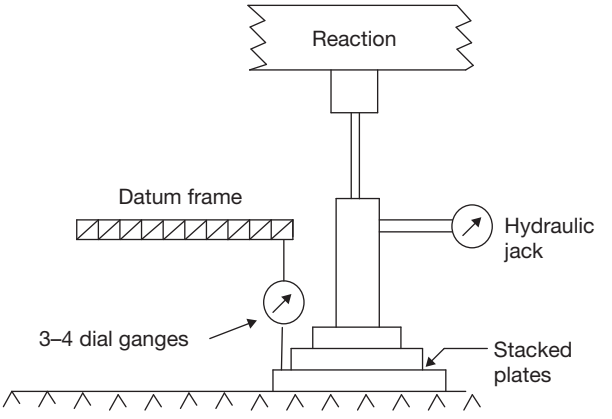
- To evaluate strength of subgrade in-situ to resist loads from pavement using relatively larger diameter plates.
- To find Modulus of subgrade reaction of soils (K).
- To find modulus of elasticity of soils (E_s).

Standard Values on Crushed Stones

Penetration (mm)	Standard Load (kg)	Standard Stress (kg/cm²)
2.5	1370	70
5.0	2055	105

Apparatus

- Plates of diameter 30, 45, 60, 75 cm are used.
- Loading device with jack and proving ring and a reaction frame to give thrust through jack to plates.
- A datum frame resting far from loaded area and dial gauges are used to measure the settlement of the loaded plate.



Test set up for plate bearing test

A seating load to cause a pressure of 0.07 kg/cm² is applied and released. A load sufficient to cause 0.25 mm settlement is applied at every loading. When the rate of settlement is less than 0.025 mm/minute, settlement and loads are recorded. Graph is plotted for bearing pressure (kg/cm²) and mean settlement (cm).

- Standard plate used for test is 75 cm diameter. Commonly used plate is 30 cm diameter (on highway pavements).

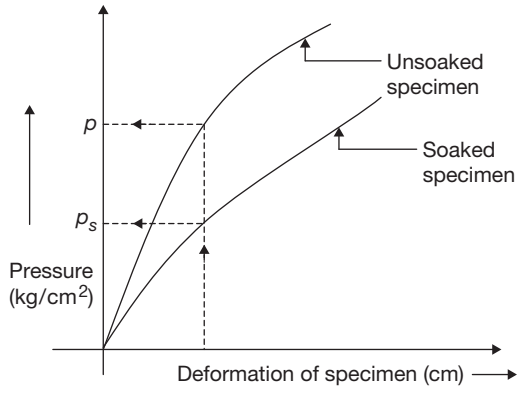
Modulus of Subgrade Reaction (K)

K is defined as the pressure sustained per unit deformation of subgrade at specified pressure level.

Pressure (P) corresponding to settlement of 0.125 cm is noted.

$$K = \frac{p}{0.125} \text{ kg/cm}^3$$

Correction of Soaked Sample



Correction for soaking in plate bearing test

Modulus of subgrade reaction for the soaked condition K_s

$$K_s = \frac{Kp_s}{p}$$

Where

p_s = Pressure on soaked sample

p = Pressure on unsoaked sample

K_s and K = Modulus of subgrade reaction of soaked and unsoaked sample.

Correction for Smaller Plate Size

- Assuming the subgrade to be an elastic medium with modulus of elasticity E(kg/cm^2) the theoretical relationship of deformation, Δ (cm) under a rigid plate of radius, 'a' cm is (as per Boussinessq)

$$\Delta = \frac{1.18pa}{E} \quad K = \frac{p}{\Delta} = \frac{pE}{1.18pa} = \frac{E}{1.18a}$$

If E is constant (for a soil) $Ka = K_1a_1$

- For flexible plate $\Delta = \dfrac{1.5\,pa}{E}$

Example 2

A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter 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. (in kg/m^3)

Mean Settlement Value (mm)	0.0	0.23	0.51	0.75	1.02	1.25	1.55	1.8
Load Value (kg)	0.0	470	910	1180	1360	1480	1590	1630

(A) 19.34 (B) 18.57

(C) 16.75 (D) 16.7

Solution

For Δ = 1.25 mm = 0.125 cm

Pressure $p = \dfrac{1480}{\pi \times 15^2}$ kg/cm^2

Modulus of subgrade reaction for 30 cm diameter plate,

$$K_1 = \frac{p_1}{\Delta} = \frac{1480}{\pi \times 15^2 \times 0.125} = 16.75 \text{ kg/cm}^2$$

Modulus of subgrade reaction for standard plate of diameter 75 cm, $K = \dfrac{K_1a_1}{a}$

$$= \frac{16.75 \times \left(\frac{30}{2}\right)}{\left(\frac{75}{2}\right)} = 6.7 \text{ kg/cm}^2$$

Hence, the correct answer is option (D).

NOTE

As the plate load test was conducted under soaked condition during monsoon season, there is no need to apply correction for subsequent soaking.

Stone Aggregate

- These form the major part of pavement surface and the strength of the pavement depends upon strength of aggregate.
- Aggregates of pavement surface have to resist:
  - (a) The wear due to abrasive action of traffic.
  - (b) Deterioration due to weathering.
  - (c) The highest magnitude of wheel load stresses.

Tests on Aggregate

Aggregate Impact Test (Toughness)

- Toughness is defined as resistance to impact of aggregates.
- Cylindrical steel cup of 102 mm diameter and 50 mm depth is used to fill the specimen.
- Cylindrical metal hammer of 13.5–14 kg free fall from 38 cm (15 blows).
- Aggregate passing 12.5 mm and retaining on 10 mm sieve is used.

- It is filled in steel up in 3 layers by tamping each layer with tamping rod for 25 times.

$$\text{Aggregate impact value (AIV)} = \frac{\text{Weight of fines passing 2.36 mm sieve}}{\text{Total weight of the sample}} \times 100$$

Specification:

- For wearing course AIV ⩽30%
- For bituminous macadam AIV ⩽35%
- For water bound macadam AIV ⩽ 40%
- If AIV > 35, the aggregate is weak for pavement surface.

Resistance to Abrasion (Hardness)

Abrasion tests are:

1. Los Angeles abrasion test
2. Deval abrasion test
3. Dorry abrasion test

Los Angeles Abrasion Tests It is commonly used as the test values of aggregates have been correlated with pavement performance.

This gives both abrasion and impact values (practical/similar to field condition)

- 5–10 kg aggregate specimen and abrasive charge consisting of cast iron spheres of diameter 48 mm (390–445 g each) is placed in machine rotated at 30–33 rpm—500 to 1000 revolutions depending on the grading of specimen.

$$\text{Abrasion value} = \frac{\text{Weight of aggregate passing 1.7 mm sieve}}{\text{Total weight of sample}} \times 100$$

Specifications for abrasion value:

- Bituminous concrete or high quality pavement ⩽30%
- For cement concrete and Dense Bituminous macadam ⩽35%
- For granular base course and bituminous bound macadam ⩽ 40%

Aggregate Crushing Value Strength

- To find resistance to crushing of the aggregates to gradual load.
- Aggregates passing 12.5 mm and retained on 10 mm sieve are used. Three layers with 25 blows each by tamper rod 1.6 cm, 45 cm–60 cm fall—40 tonnes load is applied at a rate of 4 tonnes/minutes.

$$\text{Aggregate crushing value} = \frac{\text{Weight of crushed material passing 2.36 mm}}{\text{Total weight of sample}} \times 100$$

Specifications:

- Strong aggregates give low aggregate crushing value.
- For base course ⩽45%
- For surface course and cement concretion pavement ⩽30%

Soundness Test

- Resistance to weathering action.
- As per BIS, saturated solution of sodium sulphate or magnesium sulphate are used for testing.
- Aggregate is immersed in solution for 16–18 hours and dried in oven at 105–110°C to constant weight and cycle is repeated as desired.

Specifications (as per IRC):

- Average loss in weight after 10 cycles (for pavement construction) 5 cycles (for bituminous binder and surface course)
- When tested with sodium sulphate ⩽12%
- When tested with Magnesium sulphate ⩽18%

Specific Gravity (2.6–2.9)

- Considered as a measure of strength or quality of material.
- The higher is the specific gravity, higher is the quality/strength.
- Used for making weight volume conversions and for calculating the void content in compacted bitumen mixes.
- Preferably specific gravity between 2.6–2.9

Water Absorption Test (⩽0.6%)

- Aggregate is immersed in water for 24 hours and weight is found and oven dried at 110°C for 24 hours

$$\text{Water absorption } (w) = \frac{W_1 - W_2}{W_2} \times 100$$

Where

W_1 = Weight of aggregate after immersing in water.

W_2 = Weight of oven dried sample.

Shape Tests

Angular shapes of particles are desirable for granular base course and in bituminous mixes due to increased stability derived from better interlocking.

Flakiness Index (FI) Percentage by weight of aggregate whose least dimension or thickness is less than $\frac{3}{5}$ or 0.6 (times their mean dimension).

Specifications (for FI):

- For bituminous concrete and surface dressing ⩽25%
- For water bound and bituminous macadam ⩽15%

Elongation Index (EI) EI is the percentage by weight of particles whose greatest dimension/length is greater than $1\frac{4}{5}$ or 1.8 (times their mean dimension).

Specifications:

- Generally EI or FI > 15%
- Elongated and flaky aggregates are less workable.

- The above tests (EI and FI) are applicable for sizes larger than 6.3 mm.

Combined Index (CI)

- This is combined flaky and elongation index.
- First FI test is conducted on the selected sample and on non-flaky aggregate elongation index test is conducted.

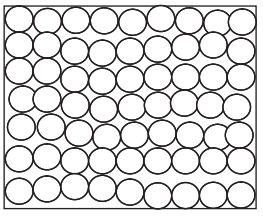
$$CI = FI + EI$$

Specification:

$$CI \not> 30\%$$

Angularity Number (AN)

- In case of gravel, shape may be expressed in terms of angularity number.
- The degree of packing of single sized aggregates depends on shape and angularity of the aggregate.
- Round well compacted, single sized aggregate would have solid volume = 67% (Void volume = 33%)
- Angularity number is defined as the voids in excess of 33%.



- Angularity Number (AN) = 67 – (% solid volume of aggregate)

$$AN = 67 - \frac{100W}{CG_a}$$

Where

W = Weight of aggregate in cylinder
C = Weight of water in cylinder
G_a = Specific gravity of aggregate

- AN is expressed as the neared whole number.
- AN of aggregates used in construction ranges from 0 to 11.
- AN does not apply to any aggregate which breaks down during test (weaker aggregate).

Example 3

An aggregate sample of 250 gm passing through 12.5 mm and retaining on 10 mm sieve. When filled into a cylinder the void percentage = 40%, find the angularity number.

(A) 3 (B) 5
(C) 7 (D) 11

Solution

Angularity number = Voids in excess of 33% = 40 – 33

$$AN = 7$$

Hence, the correct answer is option (C).

Bitumen Adhesion Test

- Static immersion test is commonly used to find adhering capacity of bitumen with aggregate as it is quite easy and simple.
- The aggregate and binder mixer taken into a beaker (500 ml) and cooled for 2 hours, distilled water added to the aggregate binder and kept in water both at 40°C for 24 hours.
- Stripping value

$$= \frac{\text{Average uncovered area}}{\text{Total area of aggregate}}$$

Specifications:

Stripping value $\not>$ 25% [or surface dressing/bituminous macadam]

$\not>$10% [For open graded premix carpet]

Bituminous Materials

1. **Bitumen:** It is hydrocarbon/complex organic material of either natural or artificially obtained during fractional distillation of petroleum.
2. **Tar:** Viscous liquid obtained when natural organic materials (wood/coal) are destructively distilled in the absence of air.
3. **Asphalt:** It is bitumen with inert materials of minerals.
4. **Cutback:** If viscosity of bitumen is reduced by volatile diluents like kerosene or oil it is called cutback.
5. **Emulsion:** It is the bitumen which is suspended in a finely divided condition in water and stabilized with an emulsifier.

Tests on Bitumen

Penetration Test

- To determine hardness or softness of bitumen. It is indirect measurement of consistency. Grading of bitumen is also done.
- Basic principle of the test is the measurement of penetration (in $\frac{1}{10}$ mm) of a standard needle in bitumen sample at standard temperature of 25°C in 5 seconds, where the total weight of needle assembly is 100 gm.
- Penetration grades are represented as $\frac{80}{100}, \frac{60}{70}, \frac{30}{40}$.
- $\frac{80}{100}$ means the penetration value ranges between 80 and 100.
- As road tars are soft, penetration tests cannot be carried out on these.
- In hot climate 30/40, grade is used due to its low penetration value.

Viscosity Test (Using Orifice Type Viscometer)

- It is a measure of resistance to flow.
- It is a general term for consistency.
- Viscosity is defined as the time (in seconds) required for 50 ml of binder in fluid state to flow through an orifice of standard size at standard temperature.
- Used for measuring viscosity of bitumen emulsion, cut-back bitumen and tar.

Ductility Test

- Used to test the adhesive property of material and its ability to stretch (elasticity).
- Standard briquette specimen having minimum 10 × 10 mm cross-section is used.
- Ductility is expressed as the distance in centimetre to which the bitumen specimen of standard size stretches before the thread breaks.
- Test is conducted at 27°C and rate of pull is 50 mm/minute.

Factors affecting ductility: Pouring temperature, dimensions of briquette, level of briquette in water bath, presence of air pockets, test temperature and rate of pulling.

Desired value: 50 cm

Specific Gravity Test (G)

G is used in bituminous mix design and to convert bitumen content on volume basis.

Specified values:

- For pure bitumen, $G = 0.97–1.02$
- For tar, $G = 1.1–1.25$
- Cutback bitumen has lower value depending on proportion.

Flash and Fire Point Tests

- On heating bitumen, volatile vapours arise and those vapours catch fire causing flash which is very hazardous. So, these are called safety tests (to avoid hazardous environment).

Flash point: It is defined as the lowest temperature at which application of a test flame causes vapours of the binder to catch an instant fire in the form of flash under specified test conditions.

- Pensky–Martens closed or open-cup tester is used for testing.

Specified value:

- Using Pensky–Martens open-cup test
- Minimum value of flash point = 175°C
- Closed-cup test = 175°C

Fire point: The lowest temperature at which the material gets ignited and burns under specified conditions atleast for 5 seconds.

- Pensky–Martens open-cup tester is used to find fire point.

Loss on Heating Test

- Percentage loss of weight after heating for 163°C for 5 hours

  Loss $\not>$ 1% (in general)

  $\not>$ 2% (if penetration value = 150–200)

Solubility Test

- Pure bitumen is completely soluble in solvents like carbon disulphide and carbon tetrachloride.
- Minimum proportion of bitumen soluble in carbon disulphide is specified as 99%
- If solubility test is with carbon tetrachloride and black carbonaceous residue > 0.5%, it is considered as cracked.

Spot Test

- This test is for detecting 'over heated' or 'cracked bitumen'.
- Naptha solution is used in the test to mix with bitumen.
- Drop of the mix is put on filter paper (one drop 1 hour after preparation, another 24 hour after preparation)
- If stain of spot color is uniform, it is considered as uncracked else considered as overheated/cracked.

Water Content Test

- Maximum water content in bitumen ≤ 0.2% (weight of bitumen original)

Softening Point Test

- Determined by ring and ball test.
- It is the temperature at which the substance attains a particular degree of softening under specified conditions of test.
- If softening point < 80°C (water is used in bath) > 80°C (glycerin is used in bath)
- Softening point usually varies 35°C–70°C
- Higher the softening point, the lower will be the temperature susceptibility and is preferred in warm climates.
- Hard grade bitumen—higher softening point
- Soft grade bitumen—lower softening point

Float Test (also Measures Consistency)

- This is used for those bituminous materials for which neither orifice viscometer nor penetration test could be used to define consistency.
- Time taken (in seconds) by water to force its way into the float through the bitumen plug is noted as the float test value.
- Higher the test value, stiffer is the material.

Cutback Bitumen

Used in surface dressing, soil bitumen stabilizations particular at low temperatures (as cutback reduces viscosity).

Types of Cutbacks

Based on rate of curing/hardening after application, these can be classified as follows:

1. **Rapid curing (RC):** Bitumen fluxed with a petroleum distillate such as naptha or gasoline which evaporate rapidly.
2. **Medium curing (MC):** Fluxed with kerosene or light diesel oil.
3. **Slow curing (SC):** Blending with high boiling point gas oil.
   - Fluidity or grade of cutback is expressed by a number (say 0 to 5)

     Example: RC-2 ⇒ Rapid curing cutback of grade 2.

The ascending order 0, 1, 2, 3, 4, 5 indicates increase in viscosity of the cutback.

Bitumen Emulsion

These have a wide range of applications in road construction and maintenance works.

Advantages:

- Can be used without heating.
- Can be used even when surface is wet/raining.

Types of Bitumen Emulsion

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

Uses

- RS are used in spray applications like tack coat, for surface treatments, surface dressing and penetration macadam.
- MS used in cold bituminous mixes and also for surface dressing and penetration macadam.
- SS used for prime coat, slurry seal treatments, recycling works and in soil stabilization.

Tar

Obtained by destructive distillation of wood or charcoal.

- Five grades of tar are RT-1, RT-2, RT-3, RT-4, RT-5 in the increasing order of viscosity.

Uses

- **RT-1:** Used for surface painting under exceptionally cold weather as this has very low viscosity.
- **RT-2:** Used for standard surface painting under Normal Indian Climatic conditions.
- **RT-3:** For surface pointing, renewal coats and premixing chips for top course and light carpets.
- **RT-4:** For premixing tar macadam in base course.
- **RT-5:** Used for grouting purposes.

Bituminous Mix Design by Marshall Stability Test

- Conducted on a compacted cylindrical specimen of 10 cm diameter and 6.3 cm height is compressed radially at constant rate of strain 5 cm per minute at standard temperature of 60°C.
- It is a type of unconfined compressive strength test
  - 'Marshall stability' is the maximum load (in kg) carried by the specimen at standard conditions.
  - It indicates resistance to deformation.
  - 'Flow value' is the total deformation the specimen undergoes at the maximum load. It indicates the extent of deformation it undergoes due to loading or its 'flexibility'.
- Marshall test is applicable to hot mix—paving mixture design using penetrating grade bitumen and using maximum aggregate size as 2.5 cm.
- Not suitable for open graded mixes and is doubtful for coarse graded mixes.
- Prior to stability flow test, density void analysis is done on test specimen.
- Optimum binder content for aggregate mixture and anticipated traffic conditions is a compromise value which meets specified requirements for stability flow value and voids content.

Air Voids Percentage (V_a)

$$V_a = \frac{G_t - G_m}{G_t} \times 100$$

Where

G_m = Bulk density/or mass density/field density (with voids)

G_t = Theoretical density (No air voids)

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

Where

W_1 = Percentage by weight of **coarse aggregate** in total mix

W_2 = Percentage by weight of **fine aggregate** in total mix

W_3 = Percentage by weight of **filler** in total mix

W_4 = Percentage by weight of **bitumen** in total mix

G_1, G_2, G_3, G_4 = Respective specific gravities

Percentage Voids in Mineral Aggregate

$$\% \text{ VMA} = V_a + V_b$$

Where

V_a = Air voids in mix per cent

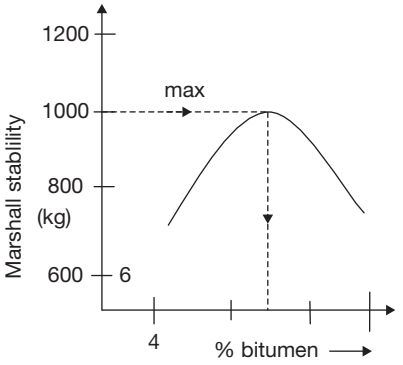
V_b = Percentage volume of bitumen $\Rightarrow V_b = G_m \times \dfrac{W_b}{G_b}$

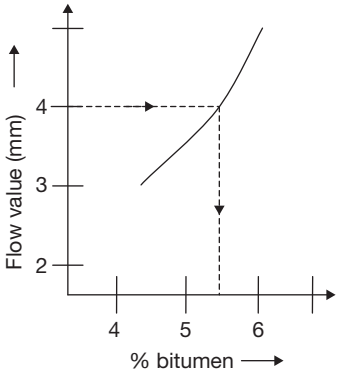
W_b and G_b = Weight and specific gravity of bitumen

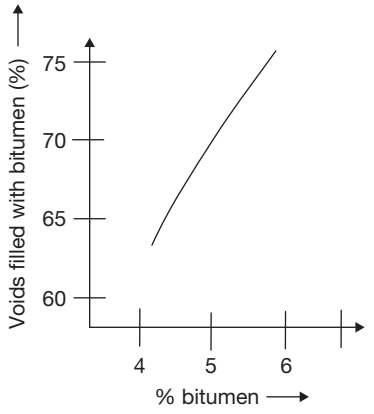
Percentage Voids Filled in Bitumen (VFB)

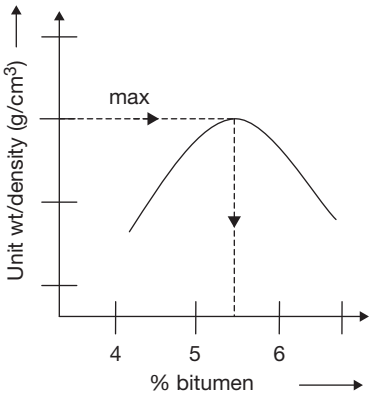
$$\text{VFB} = \frac{V_b}{V_a + V_b} \times 100 = \frac{V_b}{VMA} \times 100$$

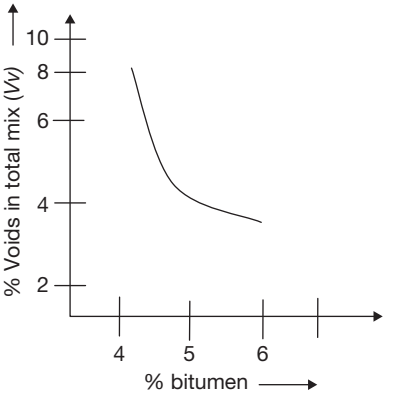
Marshall Test Graphs











Marshall Design Specifications (MORTH)

1. Marshall stability value, (kg) (minimum) = 900
2. Marshall flow value (in mm) = 2–4
3. Percentage air voids (V_v%) = 3–6
4. Voids filled with bitumen (VFB%) = 65–75%

Example 4

The bulk specific gravity of bituminous mix is 2.4 and theoretical specific gravity is 2.53. The percentage of bitumen in the mix is 4.5% by weight with specific gravity 1. The percentage voids filled in bitumen will be

(A) 58% (B) 62%

(C) 68% (D) 76%

Solution

$$\text{Air voids } V_a = \frac{G_t - G_m}{G_t} \times 100$$

$$= \frac{2.53 - 2.4}{2.53} \times 100 = 5.14\%$$

$$\text{Percentage volume of bitumen } V_b = G_m \times \frac{W_b}{G_b}$$

$$= 2.4 \times \frac{4.5}{1}$$

$$= 10.8\%$$

Percentage voids in mineral aggregate

$$VMA = V_a + V_b = (5.14 + 10.8)\% = 15.94\%$$

Percentage voids filled in bitumen, $VFB = \frac{V_b}{VMA} \times 100$

$$= \frac{10.8}{15.94} \times 100 = 67.75\% \approx 68\%$$

Hence, the correct answer is option (C).

Exercises

1. Rapid curing cut back bitumen is produced by blending bitumen with
(A) kerosene.
(B) benzene.
(C) diesel.
(D) petrol.

2. Bituminous materials are commonly used in highway construction because of their good
(A) tensile and compressive properties.
(B) binding and water proofing properties.
(C) shear strength and tensile properties.
(D) bond and tensile properties.

3. Bitumen is derived from
(A) destructive distillation of coal tar.
(B) destructive distillation of petroleum.
(C) fractional distillation of petroleum.
(D) naturally occurring ores.

4. List I contains some properties of bitumen. List II gives a list of laboratory tests conducted on bitumen to determine the properties. Match the property with the corresponding test and select the correct answer using the codes given:

	List I		List II
a.	Resistance to flow	1.	Ductility test
b.	Ability to deform under load	2.	Penetration test
c.	Safety	3.	Flash and fire point test

Codes:

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

5. 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:

	List I		List II
a.	Hardness	1.	Water absorption
b.	Porosity	2.	Impact test
c.	Toughness	3.	Soundness test
d.	Durability	4.	Abrasion test

Codes:

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

6. A Marshall specimen is prepared for bituminous material with a bitumen content of 5% by weight of total mix. The theoretical and measured unit weights of the mix are 2.442 gm/cc and 2.345 gm/cc respectively. The bitumen has a specific gravity of 1.02. The percentage voids in mineral aggregate filled with bitumen (VFB) are
(A) 34.55 (B) 39.9
(C) 73.55 (D) 74.3

7. In the Marshall method of mix design, the coarse aggregates, fine aggregates, filler material and bitumen, having respective specific gravities of 2.62, 2.72, 2.70 and 1.02 are mixed in the ratio of 55, 34.6, 4.8 and 5.6 per cent, respectively. The theoretical specific gravity of the mix would be
(A) 2.36 (B) 2.40
(C) 2.44 (D) 2.50

8. A plate load test conducted with a 75 cm diameter plate on soil sub grade yielded a deflection of 2.5 mm under a stress of 800 N/cm^2. The modulus of elasticity of the subgrade soil in kN/cm^2
(A) 141.6 (B) 154.6
(C) 160.0 (D) 185.4

9. If aggregate size of 50–40 mm is to be tested for finding out the proportion 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

10. The specific gravities and weight proportions for aggregates and bitumen are as under for the preparation of Marshall moulds:

	Weight (gm)	Specific Gravity
Aggregate 1	825	2.63
Aggregate 2	1200	2.51
Aggregate 3	325	2.46
Aggregate 4	150	2.43
Bitumen	100	1.05

The volume and weight of one Marshall mould was found to be 475 cc and 1100 gm assuming absorption of bitumen in aggregate is zero. Find

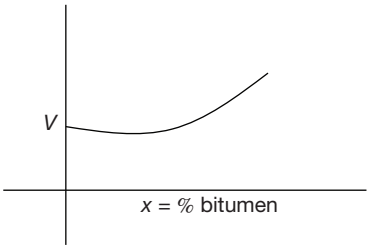
(A) percentage air voids (V_v)
(B) percentage bitumen by volume (V_b)
(C) percentage of voids in mineral aggregate (VMA)
(D) percentage of voids filled bitumen (VFB)

11. The mean weight of aggregates in the cylinder is 100 and weight of water required to fill the cylinder is 60 g and specific gravity of aggregate is 2.6. Then the angularity number is _____.

12. The grade of tar which is generally used for surface pointing and renewal coats of road is
(A) $RT-1$ (B) $RT-2$
(C) $RT-3$ (D) $RT-4$

13. The lowest point temperature at which a material gets ignited and burns under specified conditions of test
(A) fire point (B) flash point
(C) triple point (D) None of these

14.



In the above graph v = ?
(A) Marshal stability
(B) Unit weight
(C) Flow value
(D) Percentage voids of total mix

15. Match the following:

	Types of Test		Property
a.	Impact	**1.**	Resistance to weather
b.	Soundness	**2.**	Hardness
c.	Crushing	**3.**	Toughness
d.	Abrasion	**4.**	Strength

Codes:

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

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

16. A bitumen concrete mix has average specific gravity of 2.325 and theoretical specific gravity as 2.41. The density of bitumen is 1.03 g/cc with 4.5% bitumen content by weight in mix. The VFB of mix is
(A) 32.8% (B) 30.8%
(C) 20.73% (D) 10.15%

17. A subgrade soil sample was tested using standard CBR apparatus and the observations are given below:

Load, kg	Penetration, mm
40.8	2.5
60.5	5.0

The CBR value of the sample is
(A) 3.9% (B) 2.9%
(C) 4.8% (D) 12.2%

18. In Marshall method of mix design, the coarse aggregates, fine aggregates, filler material and bitumen, having respective specific gravities of 2.82, 2.42, 2.68, and 1.02 are mixed in ratio of 52, 34.8, 4.2 and 5.4 per cent respectively. The theoretical specific gravity of the mix would be _____.

19. Match the following:
Type of test property

	Types of Cut Backs		Materials
1.	Rapid curing (RC)	**a.**	Bitumen fluxed with kerosene
2.	Medium curing (MC)	**b.**	Bitumen blended with high boiling point gas oil
3.	Slow curing (BC)	**c.**	Bitumen fluxed with naphtha (or) gasoline

Codes:

	1	2	3
(A)	c	a	b
(C)	a	b	c

	1	2	3
(B)	b	c	a
(D)	c	a	b

20. A combined value of flakiness and elongation index are to be determined for a sample of aggregates. The sequence in which two tests are conducted is
(A) elongation index test followed by flakiness index test.
(B) flakiness index test followed by elongation index test.
(C) flakiness index test followed by elongation index on non flaxy aggregates.
(D) elongation index test followed by flakiness index test on non elongated aggregates.

21. Match the following:

	Type of Test		Purpose
a.	Penetration test	**1.**	Design of bitumen concrete mix
b.	Marshal test	**2.**	Overlay design
c.	Ring and ball test	**3.**	Gradation of Asphalts
d.	Benkelman beam test	**4.**	Determination of softening point

Codes:

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

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

22. In the revised CBR design method recommended by IRC for design of flexible pavement total thickness depends upon
(A) CBR value of soil only.
(B) CBR value of soil and magnitude of wheel load.
(C) CBR value of soil and number of commercial vehicle per day.
(D) CBR value of soil and cumulative standard axle loads.

23. The material obtained by the destructive distillation of wood is _____.
(A) bitumen (B) cutback
(C) emulsion (D) tar

24. The mix design of concrete pavement is based on
(A) flexural strength.
(B) compressive strength.
(C) shear strength.
(D) bond strength.

25. Which one of the following is the set of physical requirements of coarse aggregates for construction of WBM roads as per IRC recommendation?

	LAV (%)	AIV (%)	FI (%)
(A)	< 50	< 40	< 15
(B)	< 50	< 30	< 15
(C)	< 40	< 30	< 20
(D)	< 40	< 30	< 15

26. In 500 gm sample of course aggregate are 100 gm of flaky particles and 80 gm elongated particles. What are the flakiness and elongation particles as per IS?
(A) 40% (B) 3.6%
(C) 18% (D) 4%

27. In Marshall method of mix design, the courseaggregates, fine aggregates, filler material and bitumen, having respective specific gravities of 2.62, 2.72, 2.70 and 1.02 are mixed in the ratio of 55, 34.6, 4.8 and 5.6 per cent respectively. The theoretical specific gravity of mix would be
(A) 2.36 (B) 2.4
(C) 2.44 (D) 2.5

28. The weight of aggregate filled in cylinder is 20 gm. The weight of water filling the cylinder = 15 gm. The specific gravity of aggregate is 2.86. The angularity number is
(A) 20.86 (B) 20.42
(C) 20.34 (D) 20.67

29. The weight of test sample is 30 gm and the weight of crushed material which passes through this sieve is 20 g. The aggregate crushing value is
(A) 62.23% (B) 66.67%
(C) 63.26% (D) 64.67%

30. A pate load test is conducted with 85 cm diameter plate on soil subgrade yielded a deflection of 2 mm under a stress of 600 N/cm^2. The modulus of elasticity of subgrade soil in kN/cm^2 is
(A) 123.26 kN/cm^2.
(B) 120.3 kN/cm^2.
(C) 125.3 kN/cm^2.
(D) 126.23 kN/cm^2.

31. A Marshall specimen is prepared for a bituminous material with a bitumen content of 5% by weight of total mix. The theoretical and measured unit weights of the mix are 2.244 g/cc and 2.582 g/cc respectively. The bitumen has specific gravity of 1.02. The present voids in mineral aggregate filled with bitumen (VFB) is
(A) 43.08% (B) 41.23%
(C) 42.23% (D) 42.16%

32. The sub grade soil sample was tested using CBR and the observations

Load (kgs)	Penetrations (mm)
60.5	2.5
70.5	5.0

Assuming that the load-penetration curve is convex throughout, the CBR value (%) of sample is
(A) 5.6% (B) 5.2%
(C) 4.9% (D) 5.8%

33. In Marshall testing of bitumen mixes, as the bitumen content decreases the flow value
(A) remains constant.
(B) decreases first and then increases.
(C) decreases monotonically.
(D) increases first and then decreases.

34. A plate load test was conducted on a soaked sub grade during monsoon season using plate diameter of 40 cm. the load values corresponding to mean settlement are as given below.

Mean Settlement (mm)	Load Values (kg)
0	0
0.24	340
0.52	250
0.76	1130
1.02	1480
1.23	1524
1.53	1632
1.76	1748

(A) 5.25 kg/cm^3 (B) 5.85 kg/cm^3
(C) 5.65 kg/cm^3 (D) 5.55 kg/cm^3

35. The specific gravity of paving bitumen as per IS:73–1992 lies between
(A) 1.06 and 1.02 (B) 1.02 and 0.97
(C) 1.10 and 1.06 (D) 0.97 and 0.92

36. During a CBR test, the load sustained by a remolded soil specimen at 5.0 mm penetration is 82 kg. The CBR value of the soil will be _____.

37. In a Marshall sample, the bulk specific gravity of mix and aggregates are 2.32 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 2.44. The void filled with bitumen (VFB) in the Marshall sample is (in %) _____.

38. Plate bearing test with 75 cm diameter plate yielded a pressure of 800 kN/cm^2 at 2.5 mm deflection what is the elastic modulus of sub grade?
(A) 75 kN/cm^2 (B) 180 kN/cm^2
(C) 110 kN/cm^2 (D) 140 kN/cm^2

Previous Years' Questions

1. The consistency and flow resistance of bitumen can be determined from the following: **[GATE, 2007]**
(A) Ductility test. (B) Penetration test.
(C) Softening point test. (D) Viscosity test.

2. Match the following tests on aggregate and its properties: **[GATE, 2007]**

	Test		Property
P.	Crushing test	1.	Hardness
Q.	Los Angles abrasion test	2.	Weathering
R.	Soundness test	3.	Shape
S.	Angularity test	4.	Strength

Codes:

	P	Q	R	S		P	Q	R	S
(A)	2	1	4	3	(B)	4	2	3	1
(C)	3	2	1	4	(D)	4	1	2	3

3. A combined value of flakiness and elongation index is to be determined for a sample of aggregates.
The sequence in which the two tests are conducted is **[GATE, 2008]**
(A) elongation index test followed by flakiness index test on the whole sample.
(B) flakiness index test followed by elongation index test on the whole sample.
(C) flakiness index test followed by elongation index test on the non-flaky aggregates.
(D) elongation index test followed by flakiness index test on non elongated aggregates.

4. The specific gravity of paving bitumen as per IS:73–1992 lies between **[GATE, 2008]**
(A) 1.1 and 1.06 (B) 1.06 and 1.02
(C) 1.02 and 0.97 (D) 0.97 and 0.92

5. During a CBR test, the load sustained by a remoulded soil specimen at 5 mm penetration is 50 kg. The CBR value of the soil will be **[GATE, 2009]**
(A) 10.0% (B) 5.0%
(C) 3.6% (D) 2.4%

6. Aggregate impact value indicates which one of the following property of aggregates? **[GATE, 2010]**
(A) Durability (B) Toughness
(C) Hardness (D) Strength

7. In Marshall testing of bituminous mixes, as the bitumen content increases the flow value **[GATE, 2011]**
(A) remains constant.
(B) decreases first and then increases.
(C) increases monotonically.
(D) increases first and then decreases.

8. Road roughness is measured using **[GATE, 2012]**
(A) benkelman beam.
(B) bump indicator.
(C) dynamic cone penetrometer.
(D) falling weight deflectometer.

9. A subgrade soil sample was tested using standard CBR apparatus and the observations are given as follows: **[GATE, 2012]**

Load, Kg	Penetration, (mm)
60.5	2.5
80.5	5.0

Assuming that the load penetration curve is convex throughout, the CBR value (%) of the sample is
(A) 6.5 (B) 5.5
(C) 4.4 (D) 3.9

10. Two bitumen samples X and Y have softening points 45°C and 60°C respectively. Consider the following:
I. Viscosity of X will be greater than that of Y at the same temperature.
II. Penetration value of X is lesser than that of Y under standard conditions. **[GATE, 2012]**
(A) Both I and II are true.
(B) I is false and II is true.
(C) Both are false.
(D) I is true and II is false.

11. The percentage voids in mineral aggregate (VMA) and percentage air voids (V_a) in a compacted cylindrical bituminous mix specimen are 15 and 4.5 respectively. The percentage voids filled with bitumen (VFB) for this specimen is **[GATE, 2013]**
(A) 24 (B) 30
(C) 54 (D) 70

12. 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 _____. **[GATE, 2014]**

13. The penetration value of a bitumen sample tested at 25°C is 80. When this sample is heated to 60°C and tested again, the needle of the penetration test apparatus penetrates the bitumen sample by '*d*' mm. The value of '*d*' CANNOT be less than _____ mm. **[GATE, 2015]**

14. In Marshall method of mix design, the coarse aggregate, fine aggregate, fines and bitumen having respective values of specific gravity 2.6, 2.7, 2.65 and 1.01 are mixed in the relative proportions (% by weight) of 55.0, 35.8, 3.7 and 5.5 respectively. The theoretical specific gravity of the mix and the effective specific gravity of the aggregates in the mix respectively are **[GATE, 2015]**

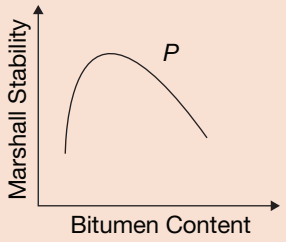
(A) 2.42 and 2.63
(B) 2.42 and 2.78
(C) 2.42 and 2.93
(D) 2.64 and 2.78

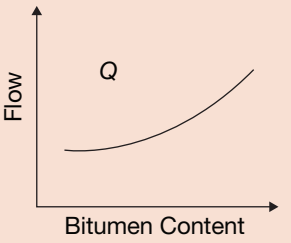
15. Match the information related to tests on aggregates given in List I with that in List II. **[GATE, 2015]**

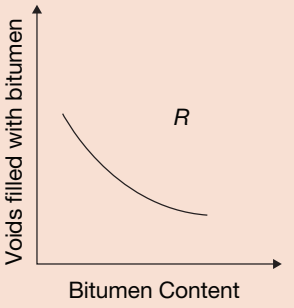
	List I		List II
P.	Resistance to impact	1.	Hardness
Q.	Resistance to water	2.	Strength
R.	Resistance to weathering action	3.	Toughness
S.	Resistance to crushing	4.	Soundness

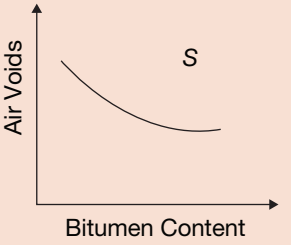
(A) P-1, Q-3, R-4, S-2
(B) P-3, Q-1, R-4, S-2
(C) P-4, Q-1, R-3, S-2
(D) P-3, Q-4, R-2, S-1

16. During a forensic investigation of pavement failure, an engineer reconstructed the graphs P, Q, R and S, using partial and damaged old reports. **[GATE, 2016]**









Theoretically plausible correct graphs according to the 'Marshall mixture design output' are
(A) P, Q, R
(B) P, Q, S
(C) Q, R, S
(D) R, S, P

Answer Keys

Exercises

1. D **2.** B **3.** C **4.** A **5.** B **6.** D **7.** C **8.** A **9.** A

10. $\begin{pmatrix} V_v = 3.74\% \\ V_b = 8048\% \\ \text{VMA} = 12.22\% \end{pmatrix}$ **11.** 2.85–2.95 **12.** C **13.** A **14.** C **15.** D **16.** A **17.** B

18. 2.50–2.52 **19.** A **20.** B **21.** B **22.** D **23.** D **24.** A **25.** D **26.** A
27. D **28.** D **29.** B **30.** B **31.** D **32.** D **33.** C **34.** A **35.** B
36. 3.99–4.01 **37.** 68 to 70 **38.** D

Previous Years' Questions

1. D **2.** D **3.** C **4.** C **5.** D **6.** B **7.** C **8.** B **9.** C **10.** C
11. D **12.** 68.8 **13.** B **14.** A **15.** B **16.** B