Handbook
of
Material Testing

March 2006

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING
PUNE 411001

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Material Testing

PREFACE

While designing a structure, engineer assumes certain value of strength for each of material being used therein. When the structure is being constructed, it is the bounden duty of the field engineers to get the same validated by regular testing of material. The quality of materials used in any infrastructure does play a vital role with regard to its ultimate strength and durability in the long run. Hence, the materials need to be tested according to certain standard procedures developed by ASTM, BIS, RDSO to give a clear picture of material strength.

The "Handbook of Material Testing" is an attempt by IRICEN to bring together the standard test procedures for materials frequently used in the civil engineering infrastructure of Indian Railways. It is hoped that this will be a helpful guide to the field engineers. A list of suppliers of various testing equipments has also been provided alongwith their addresses to enable the engineers in setting up of a field laboratory, in case the need be.

Any suggestions to ameliorate the content of this handbook would be welcome.

Shiv Kumar
Director
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ACKNOWLEDGEMENT

Strength and durability of any infrastructure is a reflection of the quality of materials used. Quality control of materials can only be ensured through certain standard test procedures designed by ASTM, BIS, RDSO and others.

The "Handbook of Material Testing" is an attempt towards this aim, of creating a collection of standard test procedures for materials, commonly used in civil engineering infrastructure on the Indian Railways. This will serve as a guide to the field engineers. The readers are advised in their interest to refer to the latest standards to avoid any omission, due to changes/amendments in the standards. The handbook also includes a list of suppliers of material testing equipments, alongwith their addresses to facilitate the setting up of a field laboratory.

The support rendered by the faculty and staff of IRICEN in this endeavour, needs mention. Shri Praveen Kumar, Professor/ Computers and Shri J.M. Patekari, Chief Technical Assistant, have been of technical assistance and Shri Vijayakumaran. V, my Personal Assistant, has been extremely useful in the task of word processing.

I am thankful to Shri Shiv Kumar, Director/IRICEN for his guidance and encouragement.

R.K. Verma
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1. TESTS ON CEMENT

1.1 FINENESS

AIM

To determine the fineness of cement by dry sieving as per IS: 4031 (Part 1) - 1996.

PRINCIPLE

The fineness of cement is measured by sieving it through a standard sieve. The proportion of cement, the grain sizes of which, is larger than the specified mesh size is thus determined.

APPARATUS

FIG. 1 : IS SIEVE

i) 90μm IS Sieve

ii) Balance capable of weighing 10g to the nearest 10mg

iii) A nylon or pure bristle brush, preferably with 25 to 40mm bristle, for cleaning the sieve

PROCEDURE

i) Weigh approximately 10g of cement to the nearest 0.01g and place it on the sieve.

ii) Agitate the sieve by swirling, planetary and linear movements, until no more fine material passes through it.

iii) Weigh the residue and express its mass as a percentage R_1, of the quantity first placed on the sieve to the nearest 0.1 percent.

iv) Gently brush all the fine material off the base of the sieve.

v) Repeat the whole procedure using a fresh 10g sample to obtain R_2. Then calculate R as the mean of R_1 and R_2 as a percentage, expressed to the nearest 0.1 percent. When the results differ by more than 1 percent absolute, carry out a third sieving and calculate the mean of the three values.

REPORTING OF RESULTS

Report the value of R, to the nearest 0.1 percent, as the residue on the 90μm sieve.

1.2 CONSISTENCY

AIM

To determine the quantity of water required to produce a cement paste of standard consistency as per IS: 4031 (Part 4) - 1988.

PRINCIPLE

The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger to penetrate to a point 5 to 7mm from the bottom of the Vicat mould.

APPARATUS

FIG. 2 : VICAT APPARATUS

i) Vicat apparatus conforming to IS: 5513 - 1976

ii) Balance, whose permissible variation at a load of 1000g should be ±1.0g

iii) Gauging trowel conforming to IS: 10086 - 1982

PROCEDURE

i) Weigh approximately 400g of cement and mix it with a weighed quantity of water. The time of gauging should be between 3 to 5 minutes.

ii) Fill the Vicat mould with paste and level it with a trowel.

iii) Lower the plunger gently till it touches the cement surface.

iv) Release the plunger allowing it to sink into the paste.

v) Note the reading on the gauge.

vi) Repeat the above procedure taking fresh samples of cement and different quantities of water until the reading on the gauge is 5 to 7mm.

REPORTING OF RESULTS

Express the amount of water as a percentage of the weight of dry cement to the first place of decimal.

1.3 INITIAL AND FINAL SETTING TIME

AIM

To determine the initial and the final setting time of cement as per IS: 4031 (Part 5) - 1988.

APPARATUS

i) Vicat apparatus conforming to IS: 5513 - 1976

ii) Balance, whose permissible variation at a load of 1000g should be ±1.0g

iii) Gauging trowel conforming to IS: 10086 - 1982

PROCEDURE

i) Prepare a cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency (see Para 1.2).

ii) Start a stop-watch, the moment water is added to the cement.

iii) Fill the Vicat mould completely with the cement paste gauged as above, the mould resting on a non-porous plate and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared in the mould is the test block.

A) INITIAL SETTING TIME

Place the test block under the rod bearing the needle. Lower the needle gently in order to make contact with the surface of the cement paste and release quickly, allowing it to penetrate the test block. Repeat the procedure till the needle fails to pierce the test block to a point 5.0 ± 0.5mm measured from the bottom of the mould.

The time period elapsing between the time, water is added to the cement and the time, the needle fails to pierce the test block by 5.0 ± 0.5mm measured from the bottom of the mould, is the initial setting time.

B) FINAL SETTING TIME

Replace the above needle by the one with an annular attachment.

The cement should be considered as finally set when, upon applying the needle gently to the surface of the test block, the needle makes an impression therein, while the attachment fails to do so. The period elapsing between the time, water is added to the cement and the time, the needle makes an impression on the surface of the test block, while the attachment fails to do so, is the final setting time.

REPORTING OF RESULTS

The results of the initial and the final setting time should be reported to the nearest five minutes.

1.4 SOUNDNESS

AIM

To determine the soundness of cement by Le-Chatelier method as per IS: 4031 (Part 3) - 1988.

APPARATUS

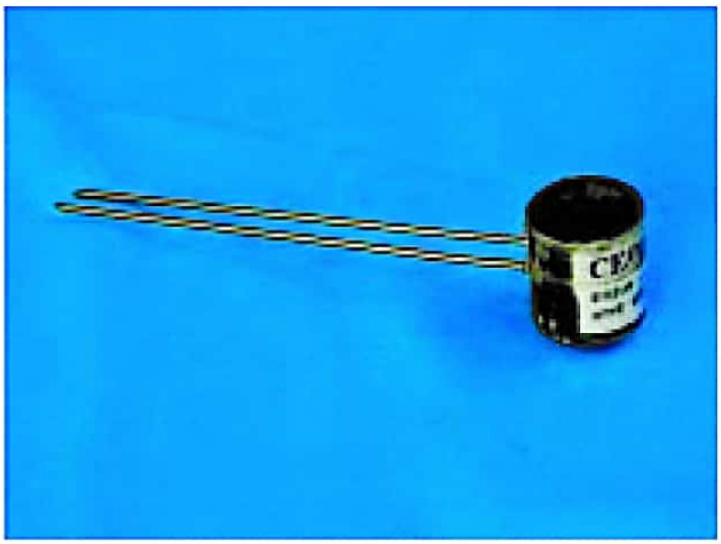


FIG. 3 : LE-CHATELIER'S TEST APPARATUS

i) The apparatus for conducting the Le-Chatelier test should conform to IS: 5514 - 1969

ii) Balance, whose pemissible variation at a load of 1000g should be ±1.0g

iii) Water bath

PROCEDURE

i) Place the mould on a glass sheet and fill it with the cement paste formed by gauging cement with 0.78 times the water required to give a paste of standard consistency (see Para 1.2).

ii) Cover the mould with another piece of glass sheet, place a small weight on this covering glass sheet and immediately submerge the whole assembly in water at a temperature of 27 ± 2°C and keep it there for 24hrs.

iii) Measure the distance separating the indicator points to the nearest 0.5mm (say d_1).

iv) Submerge the mould again in water at the temperature prescribed above. Bring the water to boiling point in 25 to 30 minutes and keep it boiling for 3hrs.

v) Remove the mould from the water, allow it to cool and measure the distance between the indicator points (say d_2).

vi) $(d_2 - d_1)$ represents the expansion of cement.

REPORTING OF RESULTS

Calculate the mean of the two values to the nearest 0.5mm to represent the expansion of cement.

2. TESTS ON AGGREGATES

2.1 SIEVE ANALYSIS

AIM

To determine the particle size distribution of fine and coarse aggregates by sieving as per IS: 2386 (Part I) - 1963.

PRINCIPLE

By passing the sample downward through a series of standard sieves, each of decreasing size openings, the aggregates are separated into several groups, each of which contains aggregates in a particular size range.

APPARATUS

FIG. 4 : A SET OF IS SIEVES

i) A set of IS Sieves of sizes - 80mm, 63mm, 50mm, 40mm, 31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75mm, 3.35mm, 2.36mm, 1.18mm, 600μm, 300μm, 150μm and 75μm

ii) Balance or scale with an accuracy to measure 0.1 percent of the weight of the test sample

SAMPLE

The weight of sample available should not be less than the weight given below:-

Maximum size present in substantial proportions (mm)	Minimum weight of sample despatched for testing (kg)
63	100
50	100
40	50
25	50
20	25
16	25
12.5	12
10.0	6
6.3	3

The sample for sieving should be prepared from the larger sample either by quartering or by means of a sample divider.

PROCEDURE

i) The test sample is dried to a constant weight at a temperature of 110 $\pm$ 5°C and weighed.

ii) The sample is sieved by using a set of IS Sieves.

iii) On completion of sieving, the material on each sieve is weighed.

iv) Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.

v) Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

REPORTING OF RESULTS

The results should be calculated and reported as:

i) the cumulative percentage by weight of the total sample

ii) the percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1 percent.

The results of the sieve analysis may be recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate. A sample chart is provided on page 12.

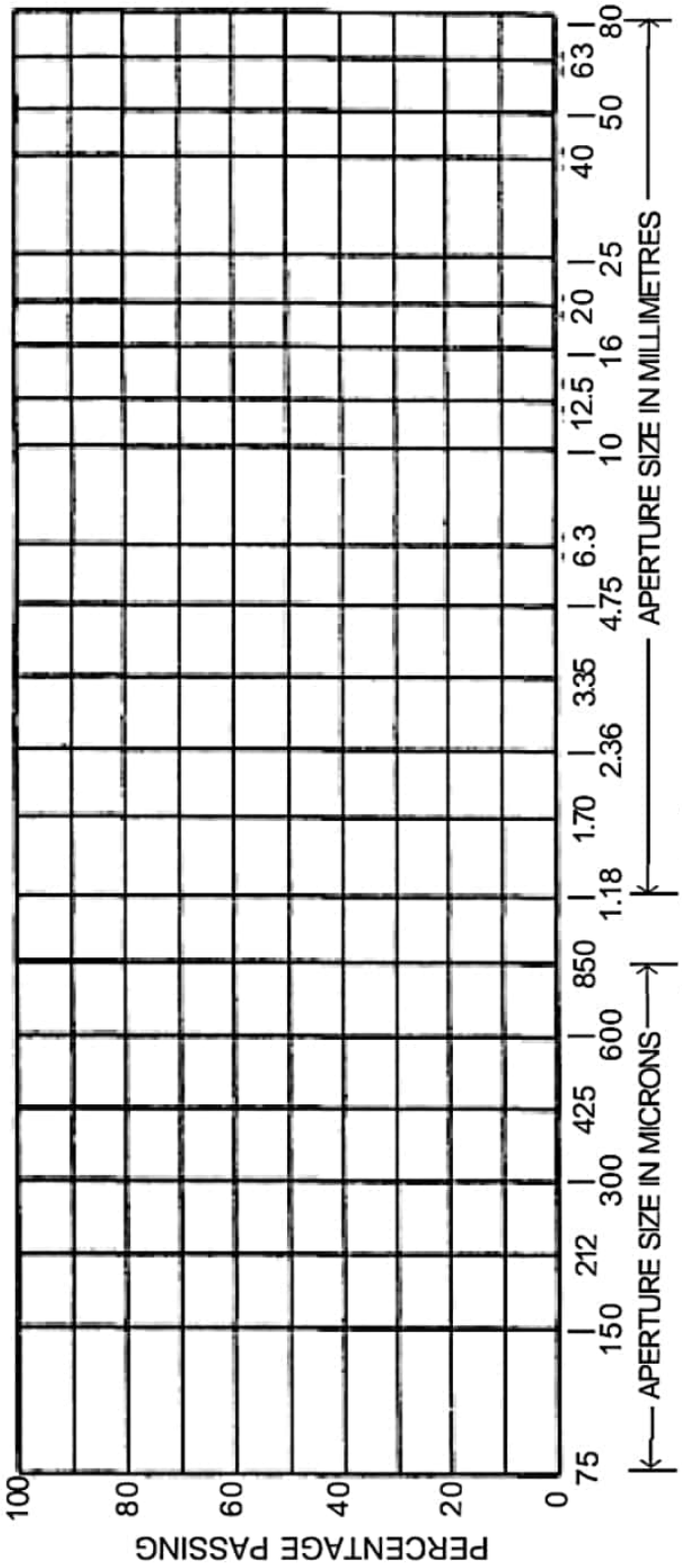


CHART FOR RECORDING SIEVE ANALYSIS RESULTS

Note - The vertical scale of this chart is an arithmetic scale and the horizontal scale is logarithmic.

2.2 WATER ABSORPTION

AIM

To determine the water absorption of coarse aggregates as per IS: 2386 (Part III) - 1963.

APPARATUS

i) Wire basket - perforated, electroplated or plastic coated with wire hangers for suspending it from the balance

ii) Water-tight container for suspending the basket

iii) Dry soft absorbent cloth - 75cm x 45cm (2 nos.)

iv) Shallow tray of minimum 650 sq.cm area

v) Air-tight container of a capacity similar to the basket

vi) Oven

SAMPLE

A sample not less than 2000g should be used.

PROCEDURE

i) The sample should be thoroughly washed to remove finer particles and dust, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22 and 32°C.

ii) After immersion, the entrapped air should be removed by lifting the basket and allowing it to drop 25 times in 25 seconds. The basket and sample should remain immersed for a period of 24 ± ½ hrs. afterwards.

iii) The basket and aggregates should then be removed from the water, allowed to drain for a few minutes, after which the

aggregates should be gently emptied from the basket on to one of the dry clothes and gently surface-dried with the cloth, transferring it to a second dry cloth when the first would remove no further moisture. The aggregates should be spread on the second cloth and exposed to the atmosphere away from direct sunlight till it appears to be completely surface-dry. The aggregates should be weighed (Weight 'A').

iv) The aggregates should then be placed in an oven at a temperature of 100 to 110°C for 24hrs. It should then be removed from the oven, cooled and weighed (Weight 'B').

REPORTING OF RESULTS

$$\text{Water absorption} = \frac{A - B}{B} \times 100\%$$

Two such tests should be done and the individual and mean results should be reported.

A sample proforma for the record of the test results is given in Annexure-I.

2.3 AGGREGATE ABRASION VALUE

AIM

To determine the abrasion value of coarse aggregates as per IS: 2386 (Part IV) - 1963.

APPARATUS

FIG. 5 : LOS ANGLES MACHINE

i) Los Angles abrasion testing machine

ii) IS Sieve of size - 1.7mm

iii) Abrasive charge - 12 nos. cast iron or steel spheres approximately 48mm dia. and each weighing between 390 and 445g ensuring that the total weight of charge is 5000 $\pm$ 25g

iv) Oven

PREPARATION OF SAMPLE

The test sample should consist of clean aggregates which has been dried in an oven at 105 to 110°C to a substantially constant weight and should conform to one of the gradings shown in the table below:

Grading of test samples

Sieve size (Square hole)		Weight in g of test sample for grade						
		A	B	C	D	E	F	G
Passing through (mm)	Retained on (mm)							
80	63	-	-	-	-	2500*	-	-
63	50	-	-	-	-	2500*	-	-
50	40	-	-	-	-	5000*	5000*	-
40	25	1250	-	-	-	-	5000*	5000*
25	20	1250	-	-	-	-	-	5000*
20	12.5	1250	2500	-	-	-	-	-
12.5	10	1250	2500	-	-	-	-	-
10	6.3	-	-	2500	-	-	-	-
6.3	4.75	-	-	2500	-	-	-	-
4.75	2.36	-	-	-	5000	-	-	-

* Tolerance of ±2 percent permitted.

PROCEDURE

The test sample and the abrasive charge should be placed in the Los Angles abrasion testing machine and the machine rotated at a speed of 20 to 33 revolutions/minute for 1000 revolutions. At the completion of the test, the material should be discharged and sieved through 1.70mm IS Sieve.

REPORTING OF RESULTS

i) The material coarser than 1.70mm IS Sieve should be washed, dried in an oven at a temperature of 100 to 110°C to a constant weight and weighed (Weight 'B').

ii) The proportion of loss between weight 'A' and weight 'B' of the test sample should be expressed as a percentage of the original weight of the test sample. This value should be reported as,

$$\text{Aggregate abrasion value} = \frac{A - B}{A} \times 100\%$$

A sample proforma for the record of the test results is given in Annexure-II.

2.4 AGGREGATE IMPACT VALUE

AIM

To determine the aggregate impact value of coarse aggregates as per IS: 2386 (Part IV) - 1963.

APPARATUS

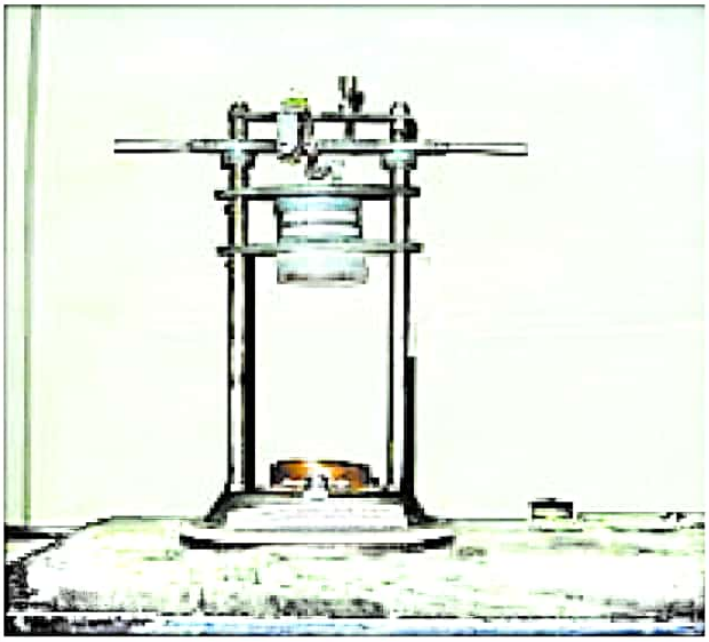


FIG. 6 : AGGREGATE IMPACT TEST MACHINE

i) Impact testing machine conforming to IS: 2386 (Part IV) - 1963

ii) IS Sieves of sizes - 12.5mm, 10mm and 2.36mm

iii) A cylindrical metal measure of 75mm dia. and 50mm depth

iv) A tamping rod of 10mm circular cross section and 230mm length, rounded at one end

v) Oven

PREPARATION OF SAMPLE

i) The test sample should conform to the following grading:

- Passing through 12.5mm IS Sieve 100%
- Retention on 10mm IS Sieve 100%

ii) The sample should be oven-dried for 4hrs. at a temperature of 100 to 110°C and cooled.

iii) The measure should be about one-third full with the prepared aggregates and tamped with 25 strokes of the tamping rod. A further similar quantity of aggregates should be added and a further tamping of 25 strokes given. The measure should finally be filled to overflow, tamped 25 times and the surplus aggregates struck off, using a tamping rod as a straight edge. The net weight of the aggregates in the measure should be determined to the nearest gram (Weight 'A').

PROCEDURE

i) The cup of the impact testing machine should be fixed firmly in position on the base of the machine and the whole of the test sample placed in it and compacted by 25 strokes of the tamping rod.

ii) The hammer should be raised to 380mm above the upper surface of the aggregates in the cup and allowed to fall freely onto the aggregates. The test sample should be subjected to a total of 15 such blows, each being delivered at an interval of not less than one second.

REPORTING OF RESULTS

i) The sample should be removed and sieved through a 2.36mm IS Sieve. The fraction passing through should be weighed (Weight 'B'). The fraction retained on the sieve should also be weighed (Weight 'C') and if the total weight

(B+C) is less than the initial weight (A) by more than one gram, the result should be discarded and a fresh test done.

ii) The ratio of the weight of the fines formed to the total sample weight should be expressed as a percentage.

$$\text{Aggregate impact value} = \frac{B}{A} \times 100\%$$

iii) Two such tests should be carried out and the mean of the results should be reported.

A sample proforma for the record of the test results is given in Annexure-III.

2.5 AGGREGATE CRUSHING VALUE

AIM

To determine the aggregate crushing value of coarse aggregates as per IS: 2386 (Part IV) - 1963.

APPARATUS

FIG. 7 : CYLINDRICAL MEASURE AND PLUNGER

i) Cylindrical measure and plunger

ii) Compression testing machine

iii) IS Sieves of sizes - 12.5mm, 10mm and 2.36mm

PROCEDURE

i) The aggregates passing through 12.5mm and retained on 10mm IS Sieve are oven-dried at a temperature of 100 to 110°C for 3 to 4hrs.

ii) The cylinder of the apparatus is filled in 3 layers, each layer tamped with 25 strokes of a tamping rod.

iii) The weight of aggregates is measured (Weight 'A').

iv) The surface of the aggregates is then levelled and the plunger inserted. The apparatus is then placed in the compression testing machine and loaded at a uniform rate so as to achieve 40t load in 10 minutes. After this, the load is released.

v) The sample is then sieved through a 2.36mm IS Sieve and the fraction passing through the sieve is weighed (Weight 'B').

vi) Two tests should be conducted.

REPORTING OF RESULTS

$$\text{Aggregate crushing value} = \frac{B}{A} \times 100\%$$

The result should be recorded to the first decimal place and the mean of the two results reported.

3. TESTS ON FRESH CONCRETE

3.1 WORKABILITY

3.1.1 SLUMP

AIM

To determine the workability of fresh concrete by slump test as per IS: 1199 - 1959.

APPARATUS

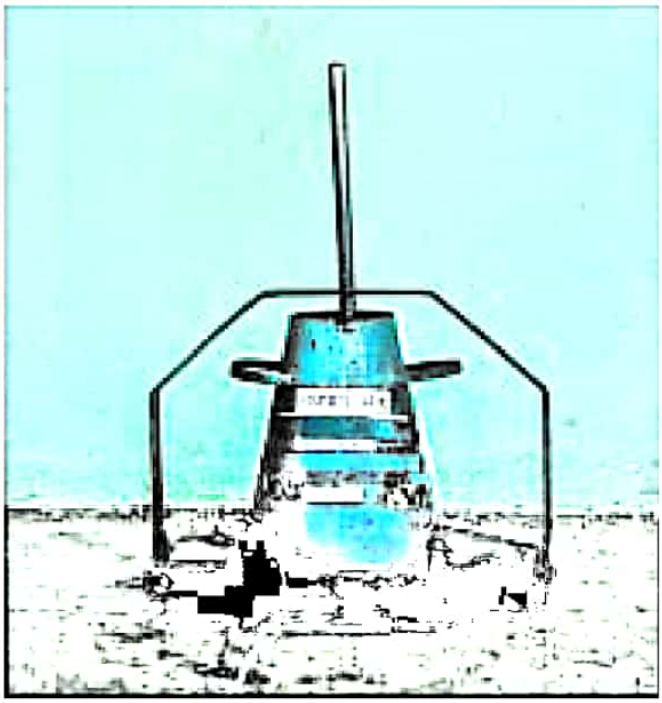


FIG. 8 : SLUMP CONE

i) Slump cone

ii) Tamping rod

PROCEDURE

i) The internal surface of the mould is thoroughly cleaned and applied with a light coat of oil.

ii) The mould is placed on a smooth, horizontal, rigid and non-absorbent surface.

iii) The mould is then filled in four layers with freshly mixed concrete, each approximately to one-fourth of the height of the mould.

iv) Each layer is tamped 25 times by the rounded end of the tamping rod (strokes are distributed evenly over the cross-section).

v) After the top layer is rodded, the concrete is struck off the level with a trowel.

vi) The mould is removed from the concrete immediately by raising it slowly in the vertical direction.

vii) The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured.

viii) This difference in height in mm is the slump of the concrete.

REPORTING OF RESULTS

The slump measured should be recorded in mm of subsidence of the specimen during the test. Any slump specimen, which collapses or shears off laterally gives incorrect result and if this occurs, the test should be repeated with another sample. If, in the repeat test also, the specimen shears, the slump should be measured and the fact that the specimen sheared, should be recorded.

3.1.2 COMPACTING FACTOR

AIM

To determine the workability of fresh concrete by compacting factor test as per IS: 1199 - 1959.

APPARATUS

FIG. 9 : COMPACTING FACTOR APPARATUS

i) Compacting factor apparatus

PROCEDURE

i) The sample of concrete is placed in the upper hopper upto the brim.

ii) The trap-door is opened so that the concrete falls into the lower hopper.

iii) The trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.

iv) The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades.

v) The concrete in the cylinder is weighed. This is known as weight of partially compacted concrete.

vi) The cylinder is filled with a fresh sample of concrete and vibrated to obtain full compaction. The concrete in the cylinder is weighed again. This weight is known as the weight of fully compacted concrete.

REPORTING OF RESULTS

$$\text{Compacting factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

It should normally be stated to the nearest second decimal place.

3.1.3 VEE-BEE

AIM

To determine the workability of fresh concrete by using a Vee-Bee consistometer as per IS: 1199 - 1959.

APPARATUS

FIG. 10 : VEE-BEE CONSISTOMETER

i) Vee-Bee consistometer

PROCEDURE

i) A conventional slump test is performed, placing the slump cone inside the cylindrical part of the consistometer.

ii) The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot.

iii) The electrical vibrator is switched on and a stop-watch is started, simultaneously.

iv) Vibration is continued till the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.

v) When the concrete fully assumes a cylindrical shape, the stop-watch is switched off immediately. The time is noted.

REPORTING OF RESULTS

The consistency of the concrete should be expressed in VB-degrees, which is equal to the time in seconds, recorded in Para v), above.

4. TESTS ON HARDENED CONCRETE

4.1 NON-DESTRUCTIVE TESTS

4.1.1 REBOUND HAMMER

AIM

To assess the likely compresive strength of concrete by using rebound hammer as per IS: 13311 (Part 2) - 1992.

PRINCIPLE

The rebound of an elastic mass depends on the hardness of the surface against which its mass strikes. When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such a rebound depends upon the surface hardness of the concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound value is read from a graduated scale and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer.

APPARATUS

FIG. 11 : REBOUND HAMMER

i) Rebound hammer

PROCEDURE

i) Before commencement of a test, the rebound hammer should be tested against the test anvil, to get reliable results, for which the manufacturer of the rebound hammer indicates the range of readings on the anvil suitable for different types of rebound hammer.

ii) Apply light pressure on the plunger - it will release it from the locked position and allow it to extend to the ready position for the test.

iii) Press the plunger against the surface of the concrete, keeping the instrument perpendicular to the test surface. Apply a gradual increase in pressure until the hammer impacts. (Do not touch the button while depressing the plunger. Press the button after impact, in case it is not convenient to note the rebound reading in that position.)

iv) Take the average of about 15 readings.

INTERPRETATION OF RESULTS

The rebound reading on the indicator scale has been calibrated by the manufacturer of the rebound hammer for horizontal impact, that is, on a vertical surface, to indicate the compressive strength. When used in any other position, appropriate correction as given by the manufacturer is to be taken into account.

4.1.2 ULTRASONIC PULSE VELOCITY

AIM

To assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) - 1992.

PRINCIPLE

The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.

APPARATUS

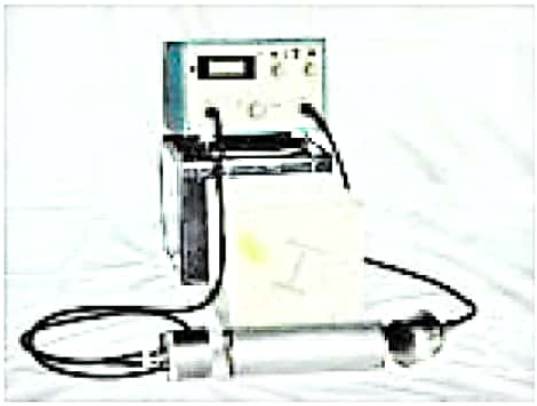


FIG. 12 : ULTRASONIC PULSE VELOCITY METER

i) Ultrasonic pulse velocity meter

PROCEDURE

i) *Preparing for use:* Before switching on the 'V' meter, the transducers should be connected to the sockets marked "TRAN" and " REC".

The 'V' meter may be operated with either:

a) the internal battery,

b) an external battery or

c) the A.C line.

ii) *Set reference:* A reference bar is provided to check the instrument zero. The pulse time for the bar is engraved on it. Apply a smear of grease to the transducer faces before placing it on the opposite ends of the bar. Adjust the 'SET REF' control until the reference bar transit time is obtained on the instrument read-out.

iii) *Range selection:* For maximum accuracy, it is recommended that the 0.1 microsecond range be selected for path length upto 400mm.

iv) *Pulse velocity:* Having determined the most suitable test points on the material to be tested, make careful measurement of the path length 'L'. Apply couplant to the surfaces of the transducers and press it hard onto the surface of the material. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements. Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance 'L'.

The mean value of the display readings should be taken when the units digit hunts between two values.

$$\text{Pulse velocity} = \frac{\text{Path length}}{\text{Travel time}}$$

v) *Separation of transducer leads:* It is advisable to prevent the two transducer leads from coming into close contact with each other when the transit time measurements are being taken. If this is not done, the receiver lead might pick-up unwanted signals from the transmitter lead and this would result in an incorrect display of the transit time.

INTERPRETATION OF RESULTS

The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc., indicative of the level of workmanship employed, can thus be assessed using the guidelines given below, which have been evolved for characterising the quality of concrete in structures in terms of the ultrasonic pulse velocity.

Pulse Velocity (km/second)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

4.2 COMPRESSION TEST

AIM

To determine the compressive strength of concrete specimens as per IS: 516 - 1959.

APPARATUS

FIG. 13 : COMPRESSION TESTING MACHINE

i) Compression testing machine conforming to IS: 516 - 1959

AGE AT TEST

Tests should be done at recognized ages of the test specimens, usually being 7 and 28 days. The ages should be calculated from the time of the addition of water to the drying of ingredients.

NUMBER OF SPECIMENS

At least three specimens, preferably from different batches, should be taken for testing at each selected age.

PROCEDURE

i) The specimens, prepared according to IS: 516 - 1959 and stored in water, should be tested immediately on removal from the water and while still in wet condition. Specimens when received dry should be kept in water for 24hrs. before they are taken for testing. The dimensions of the specimens, to the nearest 0.2mm and their weight should be noted before testing.

ii) The bearing surfaces of the compression testing machine should be wiped clean and any loose sand or other material removed from the surfaces of the specimen, which would be in contact with the compression platens.

iii) In the case a of cubical specimen, the specimen should be placed in the machine in such a manner that the load could be applied to the opposite sides of the cubes, not to the top and the bottom. The axis of the specimen should be carefully aligned with the centre of thrust of the spherically seated platen. No packing should be used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block is brought to rest on the specimen, the movable portion should be rotated gently by hand so that uniform seating is obtained.

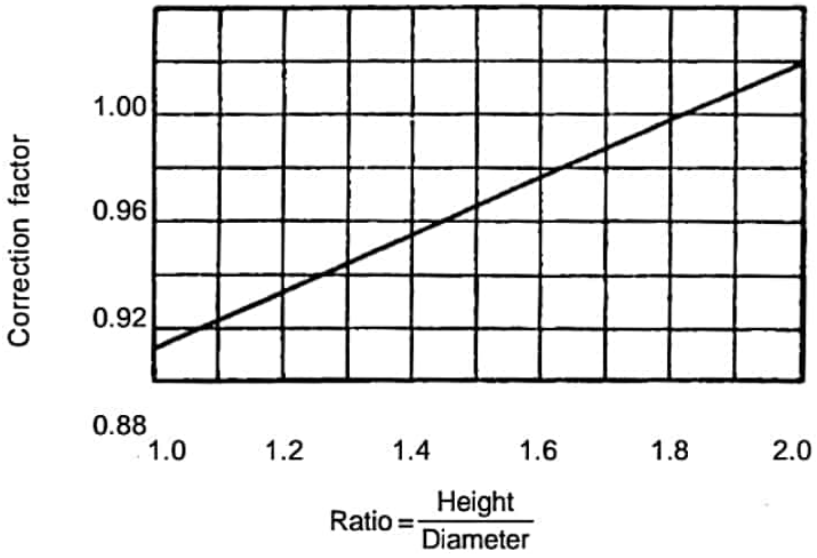
iv) The load should be applied without shock and increased continuosly at a rate of approximately 140kg/sq.cm/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen should then be recorded and the appearance of the concrete and any unusual features in the type of failure should be noted.

CALCULATION

The measured compressive strength of the specimen should be calculated by dividing the maximum load applied to the specimen during the test by the cross - sectional area,

calculated from the mean dimensions of the section and should be expressed to the nearest kg/sq.cm. An average of three values should be taken as the representative of the batch, provided the individual variation is not more than ±15% of the average. Otherwise repeat tests should be done.

A correction factor according to the height/diameter ratio of the specimen after capping should be obtained from the curve given below:-



Correction factor for height-diameter ratio of a core

The product of this correction factor and the measured compressive strength is known as the corrected compressive strength, this being the equivalent strength of a cylinder having a height/diameter ratio of two. The equivalent cube strength of the concrete should be determined by multiplying the corrected cylinder strength by 1.25.

REPORTING OF RESULTS

The following information should be included in the report on each test specimen:

i) identification mark

ii) date of test

iii) age of specimen

iv) curing conditions, including date of manufacture of specimen

v) weight of specimen

vi) dimensions of specimen

vii) cross-sectional area

viii) maximum load

ix) compressive strength

x) appearance of fractured faces of concrete and type of fracture, if unusual.

5. TESTS ON SOIL

5.1 WATER CONTENT

5.1.1 OVEN DRYING METHOD

AIM

To determine the water content in soil by oven drying method as per IS: 2720 (Part II) - 1973.

PRINCIPLE

The water content (w) of a soil sample is equal to the mass of water divided by the mass of solids.

APPARATUS

FIG. 14 : ELECTRIC OVEN

i) Thermostatically controlled oven maintained at a temperature of 110 ± 5°C

ii) Weighing balance, with an accuracy of 0.04% of the weight of the soil taken

iii) Air-tight container made of non-corrodible material with lid

iv) Tongs

SAMPLE

The soil specimen should be representative of the soil mass. The quantity of the specimen taken would depend upon the gradation and the maximum size of particles as under:

Size of particles more than 90 percent passing through IS Sieve	Minimum quantity of the soil specimen to be taken for test (g)
425μm	25
2.0mm	50
4.75mm	200
9.50mm	300
19mm	500
37.5mm	1000

PROCEDURE

i) Clean the container, dry it and weigh it with the lid (Weight 'W_1').

ii) Take the required quantity of the wet soil specimen in the container and weigh it with the lid (Weight 'W_2').

iii) Place the container, with its lid removed, in the oven till its weight becomes constant (Normally for 24hrs.).

iv) When the soil has dried, remove the container from the oven, using tongs.

v) Find the weight 'W_3' of the container with the lid and the dry soil sample.

REPORTING OF RESULTS

The water content $w = \frac{W_2 - W_3}{W_3 - W_1} \times 100\%$

An average of three determinations should be taken.

A sample proforma for the record of the test results is given in Annexure-IV.

5.1.2 CALCIUM CARBIDE METHOD

AIM

To determine the water content in soil by calcium carbide method as per IS: 2720 (Part II) - 1973.

PRINCIPLE

It is a method for rapid determination of water content from the gas pressure developed by the reaction of calcium carbide with the free water of the soil. From the calibrated scale of the pressure gauge the percentage of water on total mass of wet soil is obtained and the same is converted to water content on dry mass of soil.

APPARATUS

FIG. 15 : METALLIC PRESSURE VESSEL

i) Metallic pressure vessel, with a clamp for sealing the cup, alongwith a gauge calibrated in percentage water content

ii) Counterpoised balance, for weighing the sample

iii) Scoop, for measuring the absorbent (Calcium Carbide)

iv) Steel balls - 3 steel balls of about 12.5mm dia. and 1 steel ball of 25mm dia.

v) One bottle of the absorbent (Calcium Carbide)

PREPARATION OF SAMPLE

Sand - No special preparation. Coarse powders may be ground and pulverized.

Cohesive and plastic soil - Soil is tested with addition of steel ball in the pressure vessels.

The test requires about 6g of sample.

PROCEDURE

i) Set up the balance, place the sample in the pan till the mark on the balance arm matches with the index mark.

ii) Check that the cup and the body are clean.

iii) Hold the body horizontally and gently deposit the levelled, scoop-full of the absorbent (Calcium Carbide) inside the chamber.

iv) Transfer the weighed soil from the pan to the cup.

v) Hold cup and chamber horizontally, bringing them together without disturbing the sample and the absorbent.

vi) Clamp the cup tightly into place. If the sample is bulky, reverse the above placement, that is, put the sample in the chamber and the absorbent in the cup.

vii) In case of clayey soils, place all the 4 steel balls (3 smaller and 1 bigger) in the body alongwith the absorbent.

viii) Shake the unit up and down vigorously in this position for about 15 seconds.

ix) Hold the unit horizontally, rotating it for 10 seconds, so that the balls roll around the inner circumference of the body.

x) Rest for 20 seconds.

xi) Repeat the above cycle until the pressure gauge reading is constant and note the reading. Usually it takes 4 to 8 minutes to achieve constant reading. This is the water content (m) obtained on wet mass basis.

xii) Finally, release the pressure slowly by opening the clamp screw and taking the cup out, empty the contents and clean the instrument with a brush.

REPORTING OF RESULTS

The water content on dry mass basis,

$$w = \frac{m}{100 - m} \times 100\%$$

5.2 PARTICLE SIZE DISTRIBUTION

AIM

To determine the particle size distribution of soil as per IS: 2720 (Part 4) - 1985.

APPARATUS

i) A set of fine IS Sieves of sizes - 2mm, 600μm, 425μm, 212μm and 75μm

ii) A set of coarse IS Sieves of sizes - 20mm, 10mm and 4.75mm

iii) Weighing balance, with an accuracy of 0.1% of the weight of sample

iv) Oven

v) Mechanical shaker

vi) Mortar with rubber pestle

vii) Brushes

viii) Trays

PREPARATION OF SAMPLE

i) Soil sample, as received from the field, should be dried in air or in the sun. In wet weather, the drying apparatus may be used in which case the temperature of the sample should not exceed 60°C. The clod may be broken with wooden mallet to hasten drying. Tree roots and pieces of bark should be removed from the sample.

ii) The big clods may be broken with the help of wooden mallet. Care should be taken not to break the individual soil particles.

iii) A representative soil sample of required quantity as given below is taken and dried in the oven at 105 to 120°C.

Maximum size of material present in substantial quantities (mm)	Weight to be taken for test (kg)
75	60
40	25
25	13
19	6.5
12.5	3.5
10	1.5
6.5	0.75
4.75	0.4

PROCEDURE

i) The dried sample is taken in a tray, soaked in water and mixed with either 2g of sodium hexametaphosphate or 1g of sodium hydroxide and 1g of sodium carbonate per litre of water, which is added as a dispersive agent. The soaking of soil is continued for 10 to 12hrs.

ii) The sample is washed through 4.75mm IS Sieve with water till substantially clean water comes out. Retained sample on 4.75mm IS Sieve should be oven-dried for 24hrs. This dried sample is sieved through 20mm and 10mm IS Sieves.

iii) The portion passing through 4.75mm IS Sieve should be oven-dried for 24hrs. This oven-dried material is riffled and about 200g taken.

iv) This sample of about 200g is washed through 75μm IS Sieve with half litre distilled water, till substantially clear water comes out.

v) The material retained on 75µm IS Sieve is collected and dried in oven at a temperature of 105 to 120°C for 24hrs. The dried soil sample is sieved through 2mm, 600µm, 425µm and 212µm IS Sieves. Soil retained on each sieve is weighed.

vi) If the soil passing 75µm is 10% or more, hydrometer method is used to analyse soil particle size.

HYDROMETER ANALYSIS

i) Particles passed through 75µm IS Sieve alongwith water are collected and put into a 1000ml jar for hydrometer analysis. More water, if required, is added to make the soil water suspension just 1000ml. The suspension in the jar is vigorously shaken horizontally by keeping the jar in-between the palms of the two hands. The jar is put on the table.

ii) A graduated hydrometer is carefully inserted into the suspension with minimum disturbance.

iii) At different time intervals, the density of the suspension at the centre of gravity of the hydrometer is noted by seeing the depth of sinking of the stem. The temperature of the suspension is noted for each recording of the hydrometer reading.

iv) Hydrometer readings are taken at a time interval of 0.5 minute, 1.0 minute, 2.0 minutes, 4.0 minutes, 15.0 minutes, 45.0 minutes, 90.0 minutes, 3hrs., 6hrs., 24hrs. and 48hrs.

v) By using the nomogram given in IS: 2720 (Part 4) - 1985, the diameter of the particles for different hydrometer readings is found out.

REPORTING OF RESULTS

After completing mechanical analysis and hydrometer analysis, the results are plotted on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate (see page 12 for sample chart).

5.3 LIQUID LIMIT

AIM

To determine the liquid limit of soil as per IS: 2720 (Part 5) - 1985.

PRINCIPLE

The liquid limit of fine-grained soil is the water content at which soil behaves practically like a liquid, but has small shear strength. It's flow closes the groove in just 25 blows in Casagrande's liquid limit device.

APPARATUS

FIG. 16 : CASAGRANDE'S LIQUID LIMIT DEVICE

i) Casagrande's liquid limit device

ii) Grooving tools of both standard and ASTM types

iii) Oven

iv) Evaporating dish

v) Spatula

vi) IS Sieve of size 425µm

vii) Weighing balance, with 0.01g accuracy

viii) Wash bottle

ix) Air-tight and non-corrodible container for determination of moisture content

PREPARATION OF SAMPLE

i) Air-dry the soil sample and break the clods. Remove the organic matter like tree roots, pieces of bark, etc.

ii) About 100g of the specimen passing through 425µm IS Sieve is mixed thoroughly with distilled water in the evaporating dish and left for 24hrs. for soaking.

PROCEDURE

i) Place a portion of the paste in the cup of the liquid limit device.

ii) Level the mix so as to have a maximum depth of 1cm.

iii) Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.

iv) *For normal fine grained soil:* The Casagrande's tool is used to cut a groove 2mm wide at the bottom, 11mm wide at the top and 8mm deep.

v) *For sandy soil:* The ASTM tool is used to cut a groove 2mm wide at the bottom, 13.6mm wide at the top and 10mm deep.

vi) After the soil pat has been cut by a proper grooving tool, the handle is rotated at the rate of about 2 revolutions per second and the no. of blows counted, till the two parts of the soil sample come into contact for about 10mm length.

vii) Take about 10g of soil near the closed groove and determine its water content (see Para 5.1).

viii) The soil of the cup is transferred to the dish containing the soil paste and mixed thoroughly after adding a little more water. Repeat the test.

ix) By altering the water content of the soil and repeating the foregoing operations, obtain at least 5 readings in the range of 15 to 35 blows. Don't mix dry soil to change its consistency.

x) Liquid limit is determined by plotting a 'flow curve' on a semi-log graph, with no. of blows as abscissa (log scale) and the water content as ordinate and drawing the best straight line through the plotted points.

xi) Water content corresponding to 25 blows, is the value of the liquid limit.

REPORTING OF RESULTS

Report the water content corresponding to 25 blows, read from the 'flow curve' as the liquid limit.

A sample 'flow curve' is given in Annexure-V.

5.4 PLASTIC LIMIT

AIM

To determine the plastic limit of soil as per IS: 2720 (Part 5) - 1985.

PRINCIPLE

The plastic limit of fine-grained soil is the water content of the soil below which it ceases to be plastic. It begins to crumble when rolled into threads of 3mm dia.

APPARATUS

i) Porcelain evaporating dish about 120mm dia.

ii) Spatula

iii) Container to determine moisture content

iv) Balance, with an accuracy of 0.01g

v) Oven

vi) Ground glass plate - 20cm x 15cm

vii) Rod - 3mm dia. and about 10cm long

PREPARATION OF SAMPLE

Take out 30g of air-dried soil from a thoroughly mixed sample of the soil passing through 425µm IS Sieve. Mix the soil with distilled water in an evaporating dish and leave the soil mass for naturing. This period may be upto 24hrs.

PROCEDURE

i) Take about 8g of the soil and roll it with fingers on a glass plate. The rate of rolling should be between 80 to 90 strokes per minute to form a 3mm dia.

ii) If the dia. of the threads can be reduced to less than 3mm, without any cracks appearing, it means that the water content is more than its plastic limit. Knead the soil to reduce the water content and roll it into a thread again.

iii) Repeat the process of alternate rolling and kneading until the thread crumbles.

iv) Collect and keep the pieces of crumbled soil thread in the container used to determine the moisture content.

v) Repeat the process at least twice more with fresh samples of plastic soil each time.

REPORTING OF RESULTS

The plastic limit should be determined for at least three portions of the soil passing through 425μm IS Sieve. The average water content to the nearest whole number should be reported.

5.5 FREE SWELL INDEX

AIM

To determine the free swell index of soil as per IS: 2720 (Part XL) - 1977.

PRINCIPLE

Free swell or differential free swell, also termed as free swell index, is the increase in volume of soil without any external constraint when subjected to submergence in water.

APPARATUS

i) IS Sieve of size 425µm

ii) Oven

iii) Balance, with an accuracy of 0.01g

iv) Graduated glass cylinder- 2 nos., each of 100ml capacity

PROCEDURE

i) Take two specimens of 10g each of pulverised soil passing through 425µm IS Sieve and oven-dry.

ii) Pour each soil specimen into a graduated glass cylinder of 100ml capacity.

iii) Pour distilled water in one and kerosene oil in the other cylinder upto 100ml mark.

iv) Remove entrapped air by gently shaking or stirring with a glass rod.

v) Allow the suspension to attain the state of equilibrium (for not less than 24hrs.).

vi) Final volume of soil in each of the cylinder should be read out.

REPORTING OF RESULTS

$$\text{Free swell index} = \frac{V_d - V_k}{V_k} \times 100\%$$

where, V_d = volume of soil specimen read from the graduated cylinder containing distilled water.

V_k = volume of soil specimen read from the graduated cylinder containing kerosene.

5.6 SPECIFIC GRAVITY

AIM

To determine the specific gravity of fine-grained soil by density bottle method as per IS: 2720 (Part III/Sec 1) - 1980.

PRINCIPLE

Specific gravity is the ratio of the weight in air of a given volume of a material at a standard temperature to the weight in air of an equal volume of distilled water at the same stated temperature.

APPARATUS

i) Two density bottles of approximately 50ml capacity alongwith stoppers

ii) Constant temperature water bath ($27.0 \pm 0.2^{\circ}C$)

iii) Vacuum desiccator

iv) Oven, capable of maintaining a temperature of 105 to $110^{\circ}C$

v) Weighing balance, with an accuracy of 0.001g

vi) Spatula

PREPARATION OF SAMPLE

The soil sample (50g) should if necessary be ground to pass through a 2mm IS Sieve. A 5 to 10g sub-sample should be obtained by riffling and oven-dried at a temperature of 105 to $110^{\circ}C$.

PROCEDURE

i) The density bottle alongwith the stopper, should be dried at a temperature of 105 to $110^{\circ}C$, cooled in the desiccator and weighed to the nearest 0.001g (W_1).

ii) The sub-sample, which had been oven-dried should be transferred to the density bottle directly from the desiccator in which it was cooled. The bottles and contents together with the stopper should be weighed to the nearest 0.001g (W_2).

iii) Cover the soil with air-free distilled water from the glass wash bottle and leave for a period of 2 to 3hrs. for soaking. Add water to fill the bottle to about half.

iv) Entrapped air can be removed by heating the density bottle on a water bath or a sand bath.

v) Keep the bottle without the stopper in a vacuum desiccator for about 1 to 2hrs. until there is no further loss of air.

vi) Gently stir the soil in the density bottle with a clean glass rod, carefully wash off the adhering particles from the rod with some drops of distilled water and see that no more soil particles are lost.

vii) Repeat the process till no more air bubbles are observed in the soil-water mixture.

viii) Observe the constant temperature in the bottle and record.

ix) Insert the stopper in the density bottle, wipe and weigh (W_3).

x) Now empty the bottle, clean thoroughly and fill the density bottle with distilled water at the same temperature. Insert the stopper in the bottle, wipe dry from the outside and weigh (W_4).

xi) Take at least two such observations for the same soil.

REPORTING OF RESULTS

The specific gravity G of the soil = $$\frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

The specific gravity should be calculated at a temperature of 27°C and reported to the nearest 0.01. If the room temperature is different from 27°C, the following correction should be done:-

$$G' = kG$$

where,

G' = Corrected specific gravity at 27°C

$$k = \frac{\text{Relative density of water at room temperature}}{\text{Relative density of water at 27°C}}$$

A sample proforma for the record of the test results is given in Annexure-VI. Relative density of water at various temperatures, given in Annexure-VII, can be used in the above calculation.

5.7 MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT

AIM

To determine the maximum dry density and the optimum moisture content of soil using heavy compaction as per IS: 2720 (Part 8) - 1983.

APPARATUS

FIG. 17 : CYLINDRICAL METAL MOULD

i) Cylindrical metal mould - it should be either of 100mm dia. and 1000cc volume or 150mm dia. and 2250cc volume and should conform to IS: 10074 - 1982

ii) Balances - one of 10kg capacity, sensitive to 1g and the other of 200g capacity, sensitive to 0.01g

iii) Oven - thermostatically controlled with an interior of non-corroding material to maintain temperature between 105 and 110°C

iv) Steel straightedge - 30cm long

v) IS Sieves of sizes - 4.75mm, 19mm and 37.5mm

PREPARATION OF SAMPLE

A representative portion of air-dried soil material, large enough to provide about 6kg of material passing through a 19mm IS Sieve (for soils not susceptible to crushing during compaction) or about 15kg of material passing through a 19mm IS Sieve (for soils susceptible to crushing during compaction), should be taken. This portion should be sieved through a 19mm IS Sieve and the coarse fraction rejected after its proportion of the total sample has been recorded.

Aggregations of particles should be broken down so that if the sample was sieved through a 4.75mm IS Sieve, only separated individual particles would be retained.

PROCEDURE

A) Soil not susceptible to crushing during compaction –

i) A 5kg sample of air-dried soil passing through the 19mm IS Sieve should be taken. The sample should be mixed thoroughly with a suitable amount of water depending on the soil type (for sandy and gravelly soil - 3 to 5% and for cohesive soil - 12 to 16% below the plastic limit). The soil sample should be stored in a sealed container for a minimum period of 16hrs.

ii) The mould of 1000cc capacity with base plate attached, should be weighed to the nearest 1g (W_1). The mould should be placed on a solid base, such as a concrete floor or plinth and the moist soil should be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9kg rammer dropped from a height of 450mm above the soil. The blows should be distributed uniformly over the surface of each layer. The amount of soil used

should be sufficient to fill the mould, leaving not more than about 6mm to be struck off when the extension is removed. The extension should be removed and the compacted soil should be levelled off carefully to the top of the mould by means of the straight edge. The mould and soil should then be weighed to the nearest gram (W_2).

iii) The compacted soil specimen should be removed from the mould and placed onto the mixing tray. The water content (w) of a representative sample of the specimen should be determined as in Para 5.1.

iv) The remaining soil specimen should be broken up, rubbed through 19mm IS Sieve and then mixed with the remaining original sample. Suitable increments of water should be added successively and mixed into the sample, and the above operations i.e. Para ii) to iv) should be repeated for each increment of water added. The total number of determinations made should be at least five and the moisture contents should be such that the optimum moisture content at which the maximum dry density occurs, lies within that range.

B) Soil susceptible to crushing during compaction –

Five or more 2.5kg samples of air-dried soil passing through the 19mm IS Sieve, should be taken. The samples should each be mixed thoroughly with different amounts of water and stored in a sealed container as mentioned in Para A) i), above. Follow the operations given in Para A) ii) to iv), above.

C) Compaction in large size mould –

For compacting soil containing coarse material upto 37.5mm size, the 2250cc mould should be used. A sample weighing about 30kg and passing through the 37.5mm IS Sieve is used for the test. Soil is compacted in five layers, each layer being given 55 blows of the 4.9kg rammer. The rest of the procedure is the same as in Para A) or B), above.

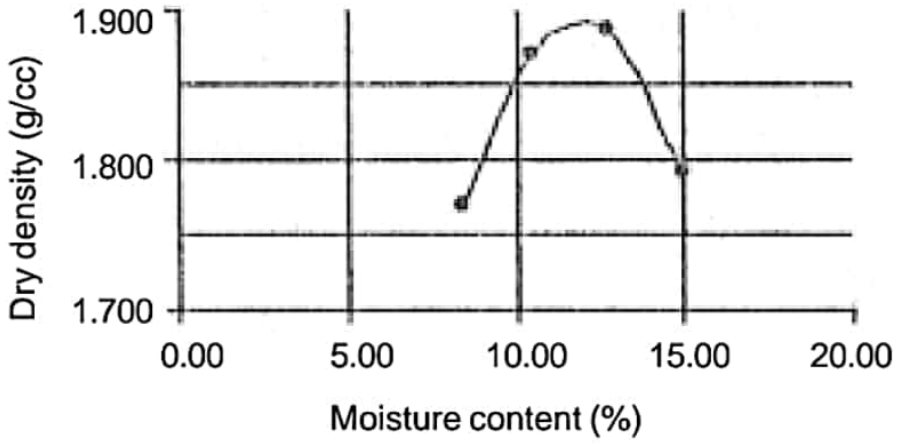
REPORTING OF RESULTS

Bulk density γ in g/cc of each compacted specimen should be calculated from the equation, $\gamma = \frac{W_2 - W_1}{V}$

where, V = volume in cc of the mould.

The dry density γ_d in g/cc $= \frac{100\gamma}{100 + w}$

The dry densities, γ_d obtained in a series of determinations should be plotted against the corresponding moisture contents, w. A smooth curve should be drawn through the resulting points and the position of the maximum on the curve should be determined. A sample graph is shown below:



The dry density in g/cc corresponding to the maximum point on the moisture content/dry density curve should be reported as the maximum dry density to the nearest 0.01.

The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve should be reported as the optimum moisture content and quoted to the nearest 0.2 for values below 5 percent, to the nearest 0.5 for values from 5 to 10 percent and to the nearest whole number for values exceeding 10 percent.

5.8 IN-SITU DRY DENSITY

5.8.1 CORE CUTTER METHOD

AIM

To determine the in-situ dry density of soil by core cutter method as per IS: 2720 (Part XXIX) - 1975.

APPARATUS

FIG. 18 : CYLINDRICAL CORE CUTTER

i) Cylindrical core cutter

ii) Steel dolley

iii) Steel rammer

iv) Balance, with an accuracy of 1g

v) Straightedge

vi) Square metal tray - 300mm x 300mm x 40mm

vii) Trowel

PROCEDURE

i) The internal volume (V) of the core cutter in cc should be calculated from its dimensions which should be measured to the nearest 0.25mm.

ii) The core cutter should be weighed to the nearest gram (W_1).

iii) A small area, approximately 30cm square of the soil layer to be tested should be exposed and levelled. The steel dolly should be placed on top of the cutter and the latter should be rammed down vertically into the soil layer until only about 15mm of the dolly protrudes above the surface, care being taken not to rock the cutter. The cutter should then be dug out of the surrounding soil, care being taken to allow some soil to project from the lower end of the cutter. The ends of the soil core should then be trimmed flat in level with the ends of the cutter by means of the straightedge.

iv) The cutter containing the soil core should be weighed to the nearest gram (W_2).

v) The soil core should be removed from the cutter and a representative sample should be placed in an air-tight container and its water content (w) determined as in Para 5.1.

REPORTING OF RESULTS

Bulk density of the soil $\gamma = \frac{W_2 - W_1}{V}$ g/cc

Dry density of the soil $\gamma_d = \frac{100\gamma}{100 + w}$ g/cc

Average of at least three determinations should be reported to the second place of decimal in g/cc.

A sample proforma for the record of the test results is given in Annexure-VIII.

5.8.2 SAND REPLACEMENT METHOD

AIM

To determine the in-situ dry density of soil by sand replacement method as per IS: 2720 (Part XXVIII) – 1974.

APPARATUS

FIG. 19 : SAND-POURING CYLINDER

i) Sand-pouring cylinder conforming to IS: 2720 (Part XXVIII) - 1974

ii) Cylindrical calibrating container conforming to IS: 2720 (Part XXVIII) - 1974

iii) Soil cutting and excavating tools such as a scraper tool, bent spoon

iv) Glass plate - 450mm square and 9mm thick or larger

v) Metal containers to collect excavated soil

vi) Metal tray - 300mm square and 40mm deep with a 100mm hole in the centre

vii) Balance, with an accuracy of 1g

PROCEDURE

A. Calibration of apparatus

a) The method given below should be followed for the determination of the weight of sand in the cone of the pouring cylinder:

i) The pouring cylinder should be filled so that the level of the sand in the cylinder is within about 10mm of the top. Its total initial weight (W_1) should be maintained constant throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil (or equal to that of the calibrating container) should be allowed to runout of the cylinder under gravity. The shutter of the pouring cylinder should then be closed and the cylinder placed on a plain surface, such as a glass plate.

ii) The shutter of the pouring cylinder should be opened and sand allowed to runout. When no further movement of sand takes place in the cylinder, the shutter should be closed and the cylinder removed carefully.

iii) The sand that had filled the cone of the pouring cylinder (that is, the sand that is left on the plain surface) should be collected and weighed to the nearest gram.

iv) These measurements should be repeated at least thrice and the mean weight (W_2) taken.

b) The method described below should be followed for the determination of the bulk density of the sand (γ_s):

i) The internal volume (V) in ml of the calibrating container should be determined from the weight of water contained in the container when filled to the brim. The volume may also be calculated from the measured internal dimensions of the container.

ii) The pouring cylinder should be placed concentrically on the top of the calibrating container after being filled to the constant weight (W_1) as in Para a) i), above. The shutter of the pouring cylinder should be closed during the operation. The shutter should be opened and sand allowed to runout. When no further movement of sand takes place in the cylinder, the shutter should be closed. The pouring cylinder should be removed and weighed to the nearest gram.

iii) These measurements should be repeated at least thrice and the mean weight (W_3) taken.

B. Measurement of soil density

The following method should be followed for the measurement of soil density:

i) A flat area, approximately 450sq.mm of the soil to be tested should be exposed and trimmed down to a level surface, preferably with the aid of the scraper tool.

ii) The metal tray with a central hole should be laid on the prepared surface of the soil with the hole over the portion of the soil to be tested. The hole in the soil should then be excavated using the hole in the tray as a pattern, to the depth of the layer to be tested upto a maximum of 150mm. The excavated soil should be carefully collected, leaving no loose material in the hole and weighed to the nearest gram (W_w). The metal tray should be removed before the pouring cylinder is placed in position over the excavated hole.

iii) The water content (w) of the excavated soil should be determined by the method specified in Para 5.1. Alternatively, the whole of the excavated soil should be dried and weighed (W_d).

iv) The pouring cylinder, filled to the constant weight (W_1) as in Para **A.**a) i) above, should be so placed that the base of the cylinder covers the hole concentrically. The shutter should then be opened and sand allowed to runout into the hole. The pouring cylinder and the surrounding area should not be vibrated during this period. When no further movement of sand takes place, the shutter should be closed. The cylinder should be removed and weighed to the nearest gram (W_4).

CALCULATIONS

i) The weight of sand (W_a) in gram, required to fill the calibrating container should be calculated from the formula:

$$W_a = W_1 - W_3 - W_2$$

ii) The bulk density of the sand (γ_s) in kg/m³ should be calculated from the formula:

$$\gamma_s = \frac{W_a}{V} \times 1000$$

iii) The weight of sand (W_b) in gram, required to fill the excavated hole should be calculated from the formula:

$$W_b = W_1 - W_4 - W_2$$

iv) The bulk density (γ_b), that is, the weight of the wet soil per cubic meter should be calculated from the formula:

$$\gamma_b = \frac{W_w}{W_b} \times \gamma_s \text{ kg/m}^3$$

v) The dry density (γ_d), that is, the weight of dry soil per cubic meter should be calculated from the formula:

$$\gamma_d = \frac{100\gamma_b}{100+w} \text{ kg/m}^3$$

$$\gamma_d = \frac{W_d}{W_b} \times \gamma_s \text{ kg/m}^3$$

REPORTING OF RESULTS

The following values should be reported:

i) dry density of soil in kg/m^3 to the nearest whole number; also to be calculated and reported in g/cc correct to the second place of decimal

ii) water content of the soil in percent reported to two significant figures.

A sample proforma for the record of the test results is given in Annexure-IX.

6. TESTS ON BLANKET MATERIAL

AIM

To determine the particle size distribution of blanket material as per IRS: GE - 3, July 2003.

PRINCIPLE

i) An oven-dried sample of known weight is washed in the prescribed manner and the decanted wash water containing suspended and dissolved matter is passed through 75µm IS Sieve. The percentage reduction in weight of the original material by washing is then reported as percentage fines in the blanket material.

ii) An oven-dried sample of known weight is separated through a set of IS Sieves of progressively smaller opening for obtaining the percentage of the material passing through each sieve and determining the particle size distribution.

APPARATUS

i) Balance, readable and accurate to 0.1g for fine particles and to 0.5g for coarse fraction or to 0.2% of the test load, whichever is greater

ii) IS Sieves of sizes - 40mm, 20mm, 10mm, 4.75mm, 2mm, 600µm, 425µm, 212µm, 75µm and bottom pan

iii) Thermostatically controlled oven of appropriate size to maintain the temperature inside between 105 and 110°C, having an interior of non-corroding material

iv) Mechanical sieve shaker

v) Tray - two or more of 30cm x 20cm x 10cm

vi) Wire brushes/sieve brushes

PREPARATION OF SAMPLE

i) The weight of field sample should normally be approximately four times the weight required for laboratory test, which is governed by the maximum size of particles present in the material in substantial quantity. Following quantities are required for grain size analysis:

Max. size of material present in substantial quantities (mm)	Minimum weight of field sample (kg)	Weight to be taken for test (kg)
40	75	25
25	50	13
19	25	6.5
12.5	15	3.5
10	10	1.5
6.5	6	0.75
4.75	5	0.4

ii) Blanket material sample received from the field should be dried in the air or in the sun. In wet weather, a drying apparatus may be used, in which the temperature of the sample should not exceed 60°C.

iii) Organic matter if present, like tree roots, pieces of barks, etc. should be removed from the sample. The sample should be sieved through 65mm IS Sieve and the material retained on 65 mm sieve should be rejected.

iv) The representative sample should be thoroughly mixed and spread on a flat surface. The spread sample should be

divided into four quadrants and the diagonally opposite quadrants should be mixed. This process should be repeated till the desired quantity of sample is obtained.

v) The big clods if present, may be broken with the help of a wooden mallet. Further pulverization if required, may be done in pestle and mortar. Care should be taken not to break the individual coarse size particles.

PROCEDURE

i) Dry the test sample to a constant weight in a thermostatically controlled oven at a temperature of 105 to 110°C and weigh it to the nearest 0.5g or 0.1% of the weight of the sample.

Note: If large quantity of particle size greater than 4.75mm is present, it may be separated to avoid overloading of individual sieves by sieving, using 4.75mm sieve. Material retained on the 4.75mm sieve is kept separately.

ii) After drying and weighing, place the test sample in the container and soak it in water. The soaking of soil should be continued for 10 to 12hrs. No dispersing agent or any other substance should be added to the water.

iii) Agitate the sample with sufficient vigour to result in complete separation of all particles finer than the 75µm IS Sieve, from the coarser particles and bring the fine material into suspension.

iv) The sample is washed through 4.75mm IS Sieve and 75µm IS Sieve with water till substantially clean water comes out. Material retained on sieves should be oven-dried at 105 to 110°C for 24hrs. The material retained on each sieve is weighed to the nearest 0.1g or 0.1% of the original weight of the sample, whichever is greater.

v) Nest the sieves 40mm, 20mm, 10mm and 4.75mm, 2mm, 600µm, 425µm, 212µm and 75µm sizes, in order of

decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by a mechanical apparatus for a sufficient period. The material retained on each sieve is weighed to the nearest 0.1g or 0.1% of the original weight of the sample, whichever is greater.

CALCULATION

i) Calculate the percentage passing, total percentage retained or percentage in various sizes to the nearest 0.1% on the basis of the total weight of the initial dry sample.

ii) Calculate the amount of material passing a 75μm sieve by working as follows-

$$A = \frac{B - C}{B} \times 100\%$$

where,

A = percentage of material finer than 75μm sieve after washing

B = original dry weight of sample, in gram

C = dry weight of sample after washing, in gram

REPORTING OF RESULTS

i) Report percentage to the nearest whole number and the percentage of material finer than 75μm sieve got by washing to the nearest 0.1%.

ii) A particle size distribution curve should be drawn on semi-log graph plotting size on the log scale against percentage finer than the corresponding size on the ordinary scale (see page 12).

7. TESTS ON BITUMEN

7.1 BITUMEN CONTENT

AIM

To determine the bitumen content as per ASTM 2172.

APPARATUS

FIG. 20 : CENTRIFUGE EXTRACTOR

i) Centrifuge extractor

ii) Miscellaneous - bowl, filter paper, balance and commercial benzene

SAMPLE

Take 500g sample.

PROCEDURE

i) If the mixture is not soft enough to separate with a trowel, place 1000g of it in a large pan and warm upto 100°C to separate the particles of the mixture uniformly.

ii) Place the sample (Weight 'A') in the centrifuge extractor. Cover the sample with benzene, put the filter paper on it with the cover plate tightly fitted on the bowl.

iii) Start the centrifuge extractor, revolving slowly and gradually increase the speed until the solvent ceases to flow from the outlet.

iv) Allow the centrifuge extractor to stop. Add 200ml benzene and repeat the procedure.

v) Repeat the procedure at least thrice, so that the extract is clear and not darker than the light straw colour and record the volume of total extract in the graduated vessel.

vi) Remove the filter paper from the bowl and dry in the oven at 110 ± 5°C. After 24hrs., take the weight of the extracted sample (Weight 'B').

REPORTING OF RESULTS

$$\text{Bitumen content} = \frac{A-B}{B} \times 100\%$$

Repeat the test thrice and average the results.

7.2 SPECIFIC GRAVITY

AIM

To determine the specific gravity of semi-solid bitumen road tars, creosote and anthracene oil as per IS: 1202 - 1978.

PRINCIPLE

It is the ratio of mass of a given volume of bitumen to the mass of an equal volume of water, both taken at a recorded/specified temperature.

APPARATUS

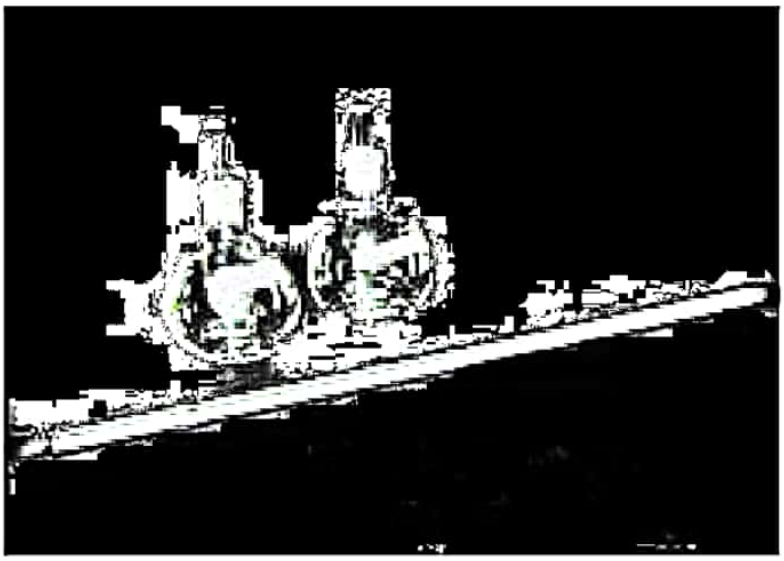


FIG. 21 : SPECIFIC GRAVITY BOTTLES

i) Specific gravity bottles of 50ml capacity

ii) Water bath

iii) Bath thermometer - Range 0 to 44°C, Graduation 0.2°C

SAMPLE

Take the sample (half the volume of the specific gravity bottles).

PROCEDURE

i) Clean, dry and weigh the specific gravity bottle alongwith the stopper (Weight 'A').

ii) Fill the specific gravity bottle with freshly boiled distilled water and insert the stopper firmly. Keep it in the water bath having a temperature of $27.0 \pm 1^{\circ}C$ for not less than half an hour and weigh it (Weight 'B').

iii) Weigh the specific gravity bottle about half-filled with the material (Weight 'C').

iv) Weigh the specific gravity bottle about half-filled with the material and the other half with distilled water (Weight 'D').

v) Weigh the specific gravity bottle completely filled with the material (Weight 'E').

REPORTING OF RESULTS

i) Specific gravity (Solids and semi-solids) $= \dfrac{C-A}{(B-A)-(D-C)}$

ii) Specific gravity (Liquids) $= \dfrac{E-A}{B-A}$

The average of the two results should be reported.

7.3 MARSHALL STABILITY

AIM

To determine the Marshall stability of bituminous mixture as per ASTM D 1559.

PRINCIPLE

Marshall stability is the resistance to plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60°C and is measured in kg.

APPARATUS

FIG. 22 : MARSHALL STABILITY APPARATUS

i) Marshall stability apparatus

ii) Balance and water bath

SAMPLE

From Marshall stability graph, select proportions of coarse aggregates, fine aggregates and filler in such a way, so as to fulfill the required specification. The total weight of the mix should be 1200g.

PROCEDURE

i) Heat the weighed aggregates and the bitumen separately upto 170°C and 163°C respectively.

ii) Mix them thoroughly, transfer the mixed material to the compaction mould arranged on the compaction pedestal.

iii) Give 75 blows on the top side of the specimen mix with a standard hammer (45cm, 4.86kg). Reverse the specimen and give 75 blows again. Take the mould with the specimen and cool it for a few minutes.

iv) Remove the specimen from the mould by gentle pushing. Mark the specimen and cure it at room temperature, overnight.

v) A series of specimens are prepared by a similar method with varying quantities of bitumen content, with an increment of 0.5% (3 specimens) or 1 bitumen content.

vi) Before testing of the mould, keep the mould in the water bath having a temperature of 60°C for half an hour.

vii) Check the stability of the mould on the Marshall stability apparatus.

REPORTING OF RESULTS

Plot % of bitumen content on the X-axis and stability in kg on the Y-axis to get maximum Marshall stability of the bitumen mix. A sample plot is given in Annexure-X.

7.4 PENETRATION

AIM

To determine the penetration of bitumen as per IS: 1203 - 1978.

PRINCIPLE

The penetration of a bituminous material is the distance in tenths of a mm, that a standard needle would penetrate vertically, into a sample of the material under standard conditions of temperature, load and time.

APPARATUS

FIG. 23 : PENETROMETER

i) Penetrometer

ii) Water bath

iii) Bath thermometer - Range 0 to 44°C, Graduation 0.2°C

SAMPLE

Bitumen should be just sufficient to fill the container to a depth of at least 15mm in excess of the expected penetration.

PROCEDURE

i) Soften the bitumen above the softening point (between 75 and 100°C). Stir it thoroughly to remove air bubbles and water.

ii) Pour it into a container to a depth of at least 15mm in excess of the expected penetration.

iii) Cool it at an atmospheric temperature of 15 to 30°C for $1\frac{1}{2}$hrs. Then place it in a transfer dish in the water bath at 25.0 $\pm$ 0.1°C for $1\frac{1}{2}$hrs.

iv) Keep the container on the stand of the penetration apparatus.

v) Adjust the needle to make contact with the surface of the sample.

vi) Adjust the dial reading to zero.

vii) With the help of the timer, release the needle for exactly 5 seconds.

viii) Record the dial reading.

ix) Repeat the above procedure thrice.

REPORTING OF RESULTS

The value of penetration reported should be the mean of not less than three determinations expressed in tenths of a mm.

7.5 FLASH POINT AND FIRE POINT

AIM

To determine the flash point and the fire point of asphaltic bitumen and fluxed native asphalt, cutback bitumen and blown type bitumen as per IS: 1209 - 1978.

PRINCIPLE

Flash Point - The flash point of a material is the lowest temperature at which the application of test flame causes the vapours from the material to momentarily catch fire in the form of a flash under specified conditions of the test.

Fire Point - The fire point is the lowest temperature at which the application of test flame causes the material to ignite and burn at least for 5 seconds under specified conditions of the test.

APPARATUS

FIG. 24 : PENSKY - MARTENS APPARATUS

i) Pensky-Martens apparatus

ii) Thermometer- Low Range : -7 to 110°C, Graduation 0.5°C

High Range : 90 to 370°C, Graduation 2°C

SAMPLE

The sample should be just sufficient to fill the cup upto the mark given on it.

PROCEDURE

A) FLASH POINT

i) Soften the bitumen between 75 and 100°C. Stir it thoroughly to remove air bubbles and water.

ii) Fill the cup with the material to be tested upto the filling mark. Place it on the bath. Fix the open clip. Insert the thermometer of high or low range as per requirement and also the stirrer, to stir it.

iii) Light the test flame, adjust it. Supply heat at such a rate that the temperature increase, recorded by the thermometer is neither less than 5°C nor more than 6°C per minute.

iv) Open flash point is taken as that temperature when a flash first appears at any point on the surface of the material in the cup. Take care that the bluish halo that sometimes surrounds the test flame is not confused with the true flash. Discontinue the stirring during the application of the test flame.

v) Flash point should be taken as the temperature read on the thermometer at the time the flash occurs.

B) FIRE POINT

i) After flash point, heating should be continued at such a rate that the increase in temperature recorded by the thermometer is neither less than 5°C nor more than 6°C per minute.

ii) The test flame should be lighted and adjusted so that it is of the size of a bead 4mm in dia.

REPORTING OF RESULTS

i) The flash point should be taken as the temperature read on the thermometer at the time of the flame application that causes a distinct flash in the interior of the cup.

ii) The fire point should be taken as the temperature read on the thermometer at which the application of test flame causes the material to ignite and burn for at least 5 seconds.

7.6 SOFTENING POINT

AIM

To determine the softening point of asphaltic bitumen and fluxed native asphalt, road tar, coal tar pitch and blown type bitumen as per IS: 1205 - 1978.

PRINCIPLE

It is the temperature at which the substance attains a particular degree of softening under specified condition of the test.

APPARATUS

FIG. 25 : RING AND BALL APPARATUS

i) Ring and ball apparatus

ii) Thermometer - Low Range : -2 to 80°C, Graduation 0.2°C

- High Range : 30 to 200°C, Graduation 0.5°C

PREPARATION OF SAMPLE

i) The sample should be just sufficient to fill the ring. The excess sample should be cut off by a knife.

ii) Heat the material between 75 and 100°C. Stir it to remove air bubbles and water, and filter it through IS Sieve 30, if necessary.

iii) Heat the rings and apply glycerine. Fill the material in it and cool it for 30 minutes.

iv) Remove excess material with the help of a warmed, sharp knife.

PROCEDURE

A) Materials of softening point below 80°C:

i) Assemble the apparatus with the rings, thermometer and ball guides in position.

ii) Fill the beaker with boiled distilled water at a temperature 5.0 ± 0.5°C per minute.

iii) With the help of a stirrer, stir the liquid and apply heat to the beaker at a temperature of 5.0 ± 0.5°C per minute.

iv) Apply heat until the material softens and allow the ball to pass through the ring.

v) Record the temperature at which the ball touches the bottom, which is nothing but the softening point of that material.

B) Materials of softening point above 80°C:

The procedure is the same as described above. The only difference is that instead of water, glycerine is used and the starting temperature of the test is 35°C.

REPORTING OF RESULTS

Record the temperature at which the ball touches the bottom.

7.7 DUCTILITY

AIM

To determine the ductility of distillation residue of cutback bitumen, blown type bitumen and other bituminous products as per IS: 1208 - 1978.

PRINCIPLE

The ductility of a bituminous material is measured by the distance in cm to which it will elongate before breaking when a standard briquette specimen of the material is pulled apart at a specified speed and a specified temperature.

APPARATUS

FIG. 26 : TESTING MACHINE

i) Standard mould

ii) Water bath

iii) Testing machine

iv) Thermometer - Range 0 to 44°C, Graduation 0.2°C

PROCEDURE

i) Completely melt the bituminous material to be tested by heating it to a temperature of 75 to 100°C above the approximate softening point until it becomes thoroughly fluid. Assemble the mould on a brass plate and in order to prevent the material under test from sticking, thoroughly coat the surface of the plate and the interior surfaces of the sides of the mould with a mixture of equal parts of glycerine and dextrin. While filling, pour the material in a thin stream back and forth from end to end of the mould until it is more than level full. Leave it to cool at room temperature for 30 to 40 minutes and then place it in a water bath maintained at the specified temperature for 30 minutes, after which cut off the excess bitumen by means of a hot, straight-edged putty knife or spatula, so that the mould is just level full.

ii) Place the brass plate and mould with briquette specimen in the water bath and keep it at the specified temperature for about 85 to 95 minutes. Remove the briquette from the plate, detach the side pieces and the briquette immediately.

iii) Attach the rings at each end of the two clips to the pins or hooks in the testing machine and pull the two clips apart horizontally at a uniform speed, as specified, until the briquette ruptures. Measure the distance in cm through which the clips have been pulled to produce rupture. While the test is being done, make sure that the water in the tank of the testing machine covers the specimen both above and below by at least 25mm and the temperature is maintained continuously within ± 0.5°C of the specified temperature.

REPORTING OF RESULTS

A normal test is one in which the material between the two clips pulls out to a point or to a thread and rupture occurs where the cross-sectional area is minimum. Report the average of three normal tests as the ductility of the sample, provided the three determinations be within ± 0.5 percent of their mean value.

If the values of the three determinations do not lie within ± 0.5 percent of their mean, but the two higher values are within ± 0.5 percent of their mean, then record the mean of the two higher values as the test result.

WATER ABSORPTION OF COARSE AGGREGATES

S.No.	Determination No.	I	II	III
1	Weight of saturated surface-dried sample in g (A)	2409	2380	2491
2	Weight of oven-dried sample in g (B)	2404	2375	2486
3	Water absorption $= \frac{A - B}{B} \times 100\%$	$\frac{5}{2404} \times 100 = 0.208\%$	$\frac{5}{2375} \times 100 = 0.210\%$	$\frac{5}{2486} \times 100 = 0.201\%$
	Average value		0.206%	

Note: *The figures given in the above table are for illustration purpose only.*

AGGREGATE ABRASION VALUE

S. No.	Sample passing through IS Sieve in mm	Sample retained on IS Sieve in mm	Weight of sample taken in g (A)	No. of charges	Weight of sample retained on 1.7mm IS Sieve after test in g (B)	Abrasion value $= \frac{A-B}{A} \times 100\%$
1	50	40	5000	12	8650	$\frac{(10000-8650)}{10000} \times 100 = 13.5\%$
	40	25	5000			
2	50	40	5000	12	8640	$\frac{(10000-8640)}{10000} \times 100 = 13.6\%$
	40	25	5000			
3	50	40	5000	12	8650	$\frac{(10000-8650)}{10000} \times 100 = 13.5\%$
	40	25	5000			
Average value						13.53%

Note: *The figures given in the above table are for illustration purpose only.*

ANNEXURE-III

AGGREGATE IMPACT VALUE

S.No.	Net weight of aggregates in the measure in g (A)	The fraction passing through 2.36mm IS Sieve in g (B)	The fraction retained on 2.36mm IS Sieve in g (C)	Aggregate impact value $= \frac{B}{A} \times 100\%$
1	366	50	316	13.66%
2	350	48	302	13.71%
Average value				13.68%

Note: *The figures given in the above table are for illustration purpose only.*

ANNEXURE-IV

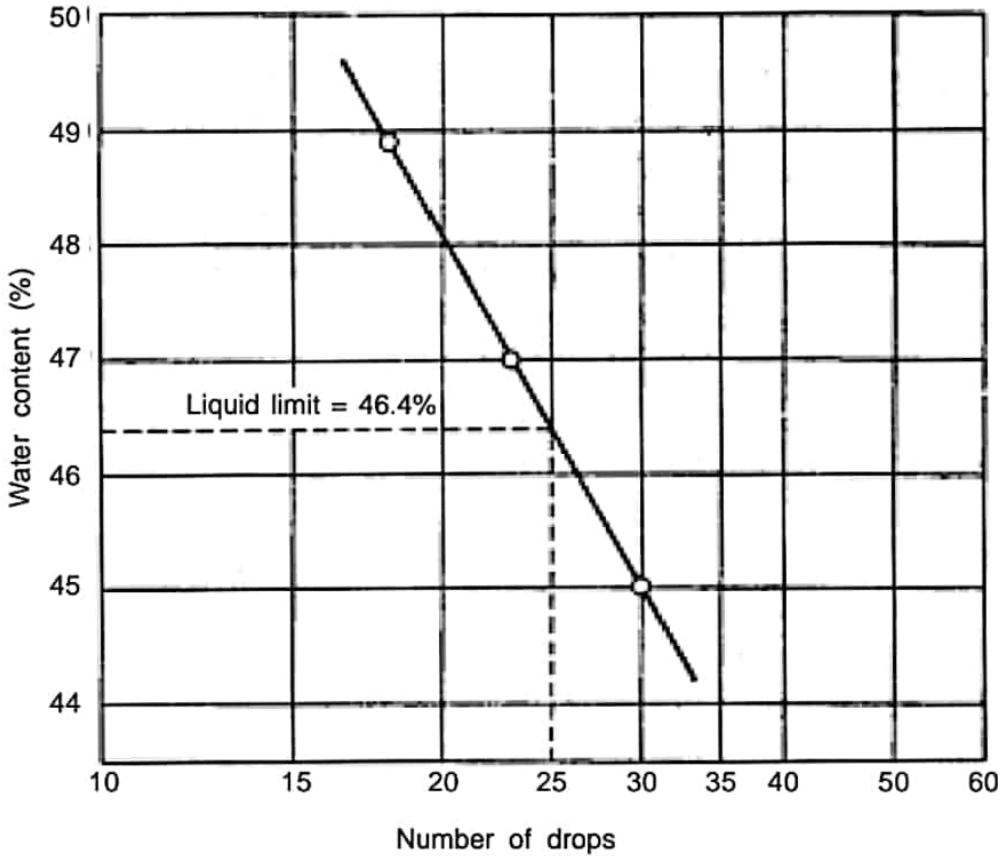
WATER CONTENT IN SOIL

S. No.	Description	Determination No.		
		I	II	III
1	Weight of empty container (W_1) in g	20.12	20.08	20.00
2	Weight of container + Wet soil (W_2) in g	44.12	44.11	46.10
3	Weight of container + Dry soil (W_3) in g	41.18	41.16	43.01
	CALCULATION:			
1	Weight of water = W_2-W_3	2.94	2.95	3.09
2	Weight of solid = W_3-W_1	21.06	21.08	23.01
3	Water content $w = \frac{W_2-W_3}{W_3-W_1} \times 100\%$	13.96	13.99	13.43
	Average value		13.79%	

Note: *The figures given in the above table are for illustration purpose only.*

ANNEXURE-V

FLOW CURVE



ANNEXURE-VI

SPECIFIC GRAVITY OF SOIL

S. No.	Description	Determination No.		
		I	II	III
1	Temperature in °C	31	31	31
2	Weight of bottle (W_1) in g	18.57	18.50	18.62
3	Weight of bottle + Dry soil (W_2) in g	28.57	28.50	28.62
4	Weight of bottle + Soil + Water (W_3) in g	90.88	90.20	91.02
5	Weight of bottle + Water (W_4) in g	84.74	84.00	84.83
	CALCULATION:			
1	Specific gravity $G = \frac{W_2-W_1}{(W_4-W_1) - (W_3-W_2)}$	2.59	2.63	2.62
2	Average G (at 31°C)		2.61	
3	Corrected G (at 27°C), $G' = G \times \frac{\text{Relative density of water at room temperature}}{\text{Relative density of water at } 27^\circ C}$ $= 2.61 \times \frac{0.995369}{0.996542} = 2.6069$, say 2.61			

Note: *The figures given in the above table are for illustration purpose only.*

ANNEXURE-VII

RELATIVE DENSITY OF WATER

S. No.	Temperature (°C)	Relative density	S. No.	Temperature (°C)	Relative density
1	4	1.000000	22	25	0.997074
2	5	0.999992	23	26	0.996813
3	6	0.999968	24	27	0.996542
4	7	0.999930	25	28	0.996262
5	8	0.999876	26	29	0.995974
6	9	0.999809	27	30	0.995676
7	10	0.999728	28	31	0.995369
8	11	0.999633	29	32	0.995054
9	12	0.999525	30	33	0.994731
10	13	0.999404	31	34	0.994399
11	14	0.999271	32	35	0.994059
12	15	0.999127	33	36	0.993712
13	16	0.998970	34	37	0.993357
14	17	0.998802	35	38	0.992994
15	18	0.998623	36	39	0.992623
16	19	0.998433	37	40	0.992246
17	20	0.998232	38	41	0.99186
18	21	0.998021	39	42	0.99147
19	22	0.997799	40	43	0.99107
20	23	0.997567	41	44	0.99066
21	24	0.997326	42	45	0.99024

ANNEXURE-VIII

IN-SITU DRY DENSITY OF SOIL BY CORE CUTTER METHOD

S. No.	Description	Determination No.		
		I	II	III
1	Internal dia. of core cutter in mm	100	100	100
2	Internal height of core cutter in mm	129.75	129.75	129.75
3	Volume of cutter (V) in cc	1019.05	1019.05	1019.05
4	Weight of core cutter (W_1) in g	1130	1130	1130
5	Weight of core cutter + Soil (W_2) in g	3120	3122	3119
6	Weight of soil ($W_2 - W_1$) in g	1990	1992	1989
7	Bulk density of soil $\gamma = \frac{W_2 - W_1}{V}$ g/cc	1.95	1.95	1.95
8	Moisture content (w) in %	17.75	17.76	17.73
9	Dry density of soil $\gamma_d = \frac{100\gamma}{100 + w}$ g/cc	1.66	1.66	1.66
	Average value	1.66g/cc		

Note: *The figures given in the above table are for illustration purpose only.*

ANNEXURE-IX

IN-SITU DRY DENSITY OF SOIL BY SAND REPLACEMENT METHOD

Calibration of apparatus

S. No.	Description	Determination
1	Mean weight of sand in cone (of pouring cylinder) (W_2) in g	450
2	Volume of calibrating container (V) in ml	980
3	Weight of sand + Cylinder, before pouring (W_1) in g	11040
4	Mean weight of sand + Cylinder, after pouring (W_3) in g	9120
5	Weight of sand to fill calibrating container ($W_a = W_1 - W_3 - W_2$) in g	1470
6	Bulk density of sand $\gamma_s = \frac{W_a}{V} \times 1000 kg/m^3$ =	$1500 kg/m^3$

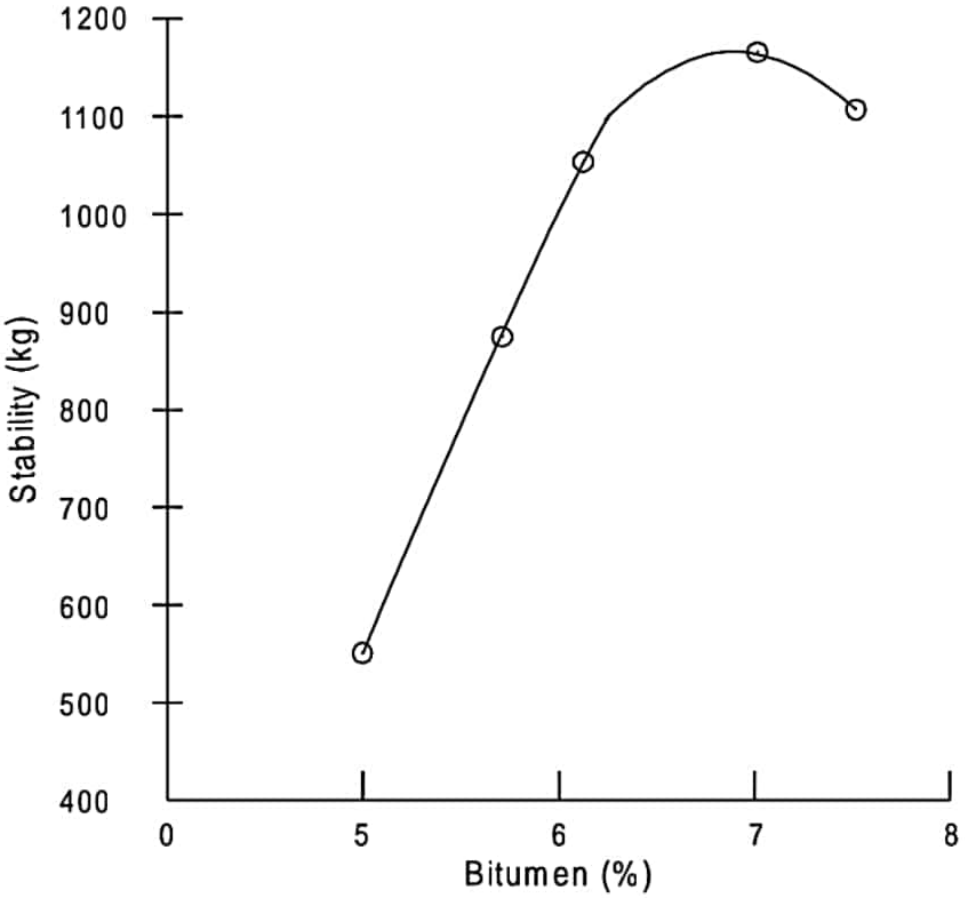
Measurement of soil density

S. No.	Observation and calculations	Determination No.		
		I	II	III
1	Weight of wet soil from the hole (W_w) in g	2310	2400	2280
2	Weight of sand + Cylinder, before pouring (W_1) in g	11040	11042	11037
3	Weight of sand + Cylinder, after pouring (W_4) in g	8840	8752	8882
4	Weight of sand in the hole ($W_b = W_1 - W_4 - W_2$) in g	1750	1840	1705
5	Bulk density $\gamma_b = \frac{W_w}{W_b} \times \gamma_s$ kg/m^3	1980	1956.5	2005.8
6	Water content (w) in %	18.48	18.81	19.26
7	Dry density $\gamma_d = \frac{100\gamma_b}{100 + w}$ kg/m^3	1671.17	1646.75	1681.87
	Dry density (Average value)	1667kg/m^3		

Note: *The figures given in the above tables are for illustration purpose only.*

ANNEXURE-X

MARSHALL STABILITY CURVE



LIST OF SUPPLIERS OF MATERIAL TESTING EQUIPMENTS ALONGWITH THEIR ADDRESSES

1. AIMIL Ltd.
   Malhotra House, Walchand Hirachand Marg,
   Opp. to G.P.O. Fort, Mumbai - 400 001.

2. Testwell Scientific Instrument Pvt. Ltd.
   5, Nand Dham, Ground Floor,
   Plot No. 270, Sion Cementary Road, Sion (W) - 400 022.

3. Utile Equipments
   13, Jal Tarang, Prabhat Road,
   Lane No.1, Pune - 411 004

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   Wakadewadi, Pune - 411 005.

8. DYEGLO
   820/7, Shee-Krishna Kunj,
   Bhandarkar Institute Road,
   Pune - 411 004.

Published by :

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING, PUNE

Typeset & printed by :

M. R. & Co.

1552 Chimanbag, Sadashiv Peth, Pune 411 030, Tel.: 020-56228163

Price Rs. 50