UNIT 4

CONCRETE TESTING WITH MIX DESIGN

Tests of cement, Fine aggregate, Coarse aggregate and Quality control at batching plant and Quality control at site - Water - Fresh concrete testing - Hardened concrete testing - Durability testing - Maturity of concrete - Modulus of rupture - Modulus of elasticity - Permeability - Test on permeability - RCPT - Half cell - Construction and measurement determination of pH of concrete - Phenolphthalein test - Non-destructive testing of concrete. Concept of proportioning concrete mixes - mix design - IS code method - ACI method - Testing, evaluation and control of concrete quality.

<u>TESTS OF CEMENT</u>

i. *Field Tests on Cement*

Field tests on cements are carried to know the quality of cement supplied at site. It gives some idea about cement quality based on color, touch and feel and other tests.

<u>The following are the field tests on cement</u>

(a) The color of the cement should be uniform. It should be grey color with a light greenish shade.

(b) The cement should be free from any hard lumps. Such lumps are formed by the absorption of moisture from the atmosphere. Any bag of cement containing such lumps should be rejected.

(c) The cement should feel smooth when touched or rubbed in between fingers. If it is felt rough, it indicates adulteration with sand.

(d) If hand is inserted in a bag of cement or heap of cement, it should feel cool and not warm.

(e) If a small quantity of cement is thrown in a bucket of water, the particles should float for some time before it sinks.

(f) A thick paste of cement with water is made on a piece of glass plate and it is kept under water for 24 hours. It should set and not crack.

(g) A block of cement 25 mm ×25 mm and 200 mm long is prepared and it is immersed for 7 days in water. It is then placed on supports 15cm apart and it is loaded with a weight of about 34 kg. The block should not show signs of failure.

(h) The briquettes of a lean mortar (1:6) are made. The size of briquette may be about 75 mm ×25 mm ×12 mm. They are immersed in water for a period of 3 days after drying. If the cement is of sound quality, the briquettes will not be broken easily.

ii. Laboratory Tests on Cement

1. Fineness test
    a. Sieve test
    b. Air permeability test
2. Standard consistency test
3. Setting time test
4. Soundness test

1. FINENESS TEST

a) **Sieve test** - The principle of this is to determine the proportion of cement whose grain size is larger than specified mesh size. The apparatus used are 90µm IS Sieve, Balance capable of weighing 10g to the nearest 10mg, a nylon or pure bristle brush preferably with 25 to 40mm, bristle for cleaning the sieve.

Procedure to determine fineness of cement

- ❖ Weigh approximately 10g of cement to the nearest 0.01g and place it on the sieve. Agitate the sieve by swirling, planetary and linear movements, until no more fine material passes through it.

- ❖ Weigh the residue and express its mass as a percentage R1,of the quantity first placed on the sieve to the nearest 0.1 percent.
- ❖ Gently brush all the fine material off the base of the sieve.
- ❖ Repeat the whole procedure using a fresh 10g sample to obtain R2. Then calculate R as the mean of R1 and R2 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.

b) Air permeability test - Blaine's air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The fineness is expressed as a total surface area in square centimeters per gram. The apparatus used are Blaine air permeability apparatus, balance and timer.

Procedure to determine fineness of cement

The procedure consists of 4 steps

- ✓ *Determination of the density of cement* - To determine the density or specific gravity of cement

- ✓ *Determination of the bed volume*
  - ❖ Apply a very thin film of light mineral oil to the cell interior. Place the perforated disc on the ledge in cell. Place two new filter paper discs on the perforated disc.
  - ❖ Fill the cell with mercury. Level the mercury to the top of the cell with a glass plate.
  - ❖ Remove the mercury from cell and it, $\mathbf{M_1}$.
  - ❖ Remove the top filter paper from the permeability cell and compress a trial quantity of 2.80 g of cement into the space above filter paper to the gauge line in the cell. Place the other filter paper above the cement bed.
  - ❖ Fill the remaining space in the cell above the filter paper with mercury. Level the mercury to the top of the cell with a glass plate and remove mercury from the cell and weigh it, $\mathbf{M_2}$.
  - ❖ Calculate the volume occupied by the cement bed in the cell from the following equation.

$$\mathbf{V = (M_1 - M_2)/D},$$

Where, D = Density of mercury (13.54 g/cm^3)

  - ❖ Average at least two volume determinations that agree to within ±0.005cm^3 and record this value.
- ✓ *Determination of apparatus constant*
  - ❖ Take an amount (W) of standard cement so as to give the cement bed of porosity e=0.500.

$$\mathbf{W = (1-e)\ \rho^*V} \text{ or } \mathbf{W = 0.500\rho V}$$

  - ❖ Place the perforated disc on the ledge at the bottom of the cell and place on it a new filter paper disc. Place the weighed quantity of standard cement, W, in the cell taking care to avoid loss.
  - ❖ Tap the cell to level the cement. Place a second new filter paper disc on the leveled cement.
  - ❖ Compress the cement with the plunger until the plunger collar is in contact with the top of the cell. Slowly withdraw the plunger a short distance, rotate 90^0, repress the cement bed, and then slowly withdraw.

- ❖ Attach the permeability cell to the manometer tube with an air tight connection and slowly evacuate the air in the manometer U-tube until the liquid reaches the top mark, then tightly close the valve.
- ❖ Start the timer when the bottom of the meniscus reaches next to the top mark and stop the timer when the bottom of the meniscus reaches the bottom mark. Record the time t and temperature of test.
- ❖ Repeat the whole procedure on two further samples of the same reference cement. Calculate the average time of the three determinations. Then calculate the apparatus constant using the formula given below.

$$K = 1.414 S_0 \rho_0 \frac{\sqrt{0.1}\eta_0}{\sqrt{t_0}}$$

Where,

K=Apparatus constant

S_0=Specific surface of reference cement

ρ_0=Density of reference cement

t_0=Mean of three measured times

η_0=Air viscosity at the mean of the three temperatures.

- ✓ *Determination of fineness*
  - ❖ Repeat the steps (1 to 6) as done in determination of apparatus constant, but this time using the cement whose fineness is to be calculated.
  - ❖ Calculate fineness of cement using following formula.

$$S = \frac{521.08 K \sqrt{t}}{\rho} cm^2/g$$

Where,

S = Specific surface area

K = Apparatus constant

ρ = Density of cement

t = Time

2. STANDARD CONSISTENCY TEST

The basic aim is to find out the water content required to produce a cement paste of standard consistency as specified by the IS: 4031 (Part 4) – 1988. The principle is that standard consistency of cement is that consistency at which the Vicat plunger penetrates to a point 5-7mm from the bottom of Vicat mould.

Apparatus – Vicat apparatus conforming to IS: 5513 – 1976, Balance, whose permissible variation at a load of 1000g should be +1.0g, Gauging trowel conforming to IS: 10086 – 1982.

<u>Procedure to determine consistency of cement</u>

- 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.
- Fill the Vicat mould with paste and level it with a trowel.
- Lower the plunger gently till it touches the cement surface.
- Release the plunger allowing it to sink into the paste.
- Note the reading on the gauge.
- Repeat the above procedure taking fresh samples of cement and different quantities of water until the reading on the gauge is 5 to 7mm.

<u>Reporting of Results</u> - Express the amount of water as a percentage of the weight of dry cement to the first place of decimal.

3. SETTING TIME TEST - *Initial and Final Setting Time*

To calculate the initial and final setting time as per IS: 4031 (Part 5) – 1988. To do so we need Vicat apparatus conforming to IS: 5513 – 1976, Balance, whose permissible variation at a load of 1000g should be +1.0g, Gauging trowel conforming to IS: 10086 – 1982.

Procedure to determine initial and final setting time of cement

- Prepare a cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency.

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

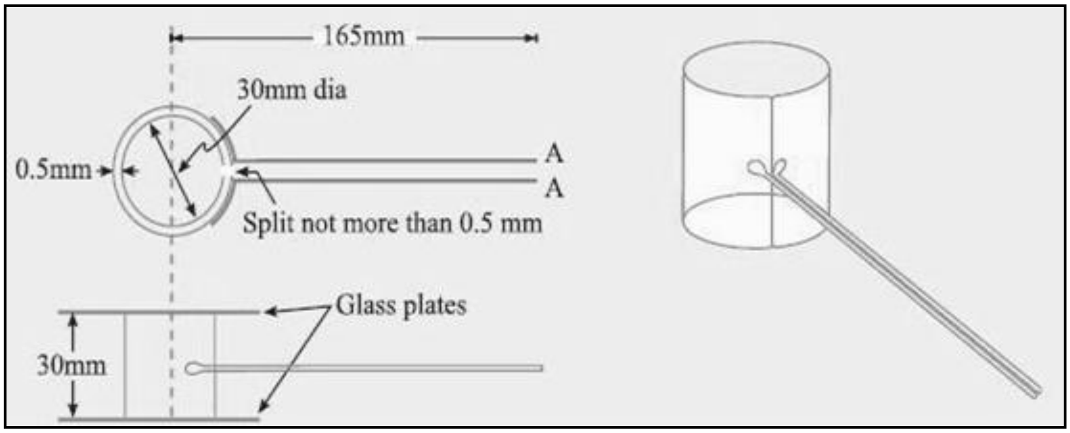
Initial Setting Time

- 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.

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.

4. ***SOUNDNESS TEST*** - Soundness of cement is determined by Le-Chatelier method as per IS: 4031 (Part 3) – 1988. The apparatus for conducting the Le-Chatelier test should conform to IS: 5514 – 1969, Balance, whose permissible variation at a load of 1000g should be +1.0g and Water bath.



Procedure to determine soundness of cement

- 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.
- 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^{o}C and keep it there for 24hrs.
- Measure the distance separating the indicator points to the nearest 0.5mm (say d_1).
- 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.
- Remove the mould from the water, allow it to cool and measure the distance between the indicator points (say d_2)
- (d_2–d_1) represents the expansion of cement.

TEST ON AGGREGATE

1. Test for determination of Flakiness Index and Elongation Index
2. Test for organic impurities in fine aggregate
3. Test for determination of clay, fine silt and fine dust
4. Test for determination of specific gravity
5. Test for Bulk density and Voids
6. Test for aggregate Crushing value
7. Test for aggregate Impact value
8. Test for aggregate Abrasion value

<u>Test for determination of Flakiness Index and Elongation Index</u>

The ***Flakiness index*** of aggregates is the percentage by weight of particles whose least dimension (thickness) is less than three- fifths (0.6times) of their mean dimension. This test is not applicable to sizes smaller than 6.3mm.

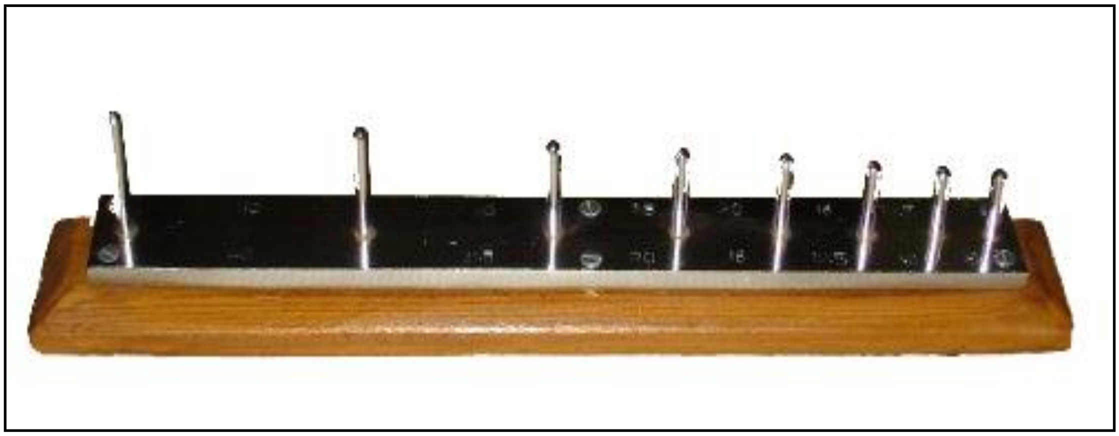
The ***Elongation index*** of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than nine-fifths (1.8times) their mean dimension. This test is not applicable for sizes smaller than 6.3mm.

The particle shape of aggregates is determined by the percentages of flaky and elongated particles contained in it. For base course and construction of bituminous and cement concrete types, the presence of flaky and elongated particles are considered undesirable as these cause inherent weakness with possibilities of breaking down under heavy loads. Thus, evaluation of shape of the particles, particularly with reference to flakiness and elongation is necessary.

The apparatus for the shape tests consists of the following:

i. A standard thickness gauge
ii. A standard length gauge
iii. IS sieves of sizes 63, 50 40, 31.5, 25, 20, 16, 12.5,10 and 6.3mm
iv. A balance of capacity 5kg, readable and accurate up to 1 gm

Thickness Gauge (Flakiness)



Length gauge (Elongation)

<u>*Procedure*</u>

- Sieve the sample through the IS sieves (as specified in the table).
- Take a minimum of 200 pieces of each fraction to be tested and weigh them.
- In order to separate the flaky materials, gauge each fraction for thickness on a thickness gauge. The width of the slot used should be of the dimensions specified in column (4) of the table for the appropriate size of the material.
- Weigh the flaky material passing the gauge to an accuracy of at least 0.1 per cent of the test
- In order to separate the elongated materials, gauge each fraction for length on a length gauge. The width of the slot used should be of the dimensions specified in column (6) of the table for the appropriate size of the material.
- Weigh the elongated material retained on the gauge to an accuracy of at least 0.1 per cent of the test sample.

Size of aggregates		Weight of fraction consisting of at least 200 pieces,g	Thickness gauge size, mm	Weight of aggregates in each fraction passing thickness gauge,mm	Length gauge size, mm	Weight of aggregates in each fraction retained on length gauge,mm
Passing through IS Sieve, mm	Retained on IS Sieve, mm					
1	**2**	**3**	**4**	**5**	**6**	**7**
63	50	W_1	23.90	X_1	-	-
50	40	W_2	27.00	X_2	81.00	Y_1
40	31.5	W_3	19.50	X_3	58.00	Y_2
31.5	25	W_4	16.95	X_4	-	-
25	20	W_5	13.50	X_5	40.5	Y_3
20	16	W_6	10.80	X_6	32.4	Y_4
16	12.5	W_7	8.55	X_7	25.5	Y_5
12.5	10	W_8	6.75	X_8	20.2	Y_6
10	6.3	W_9	4.89	X_9	14.7	Y_7
Total		W =		X =		Y =

Flakiness Index $= (X_1 + X_2 + \ldots..) / (W_1 + W_2 + \ldots.) \times 100$

Elongation Index $= (Y_1 + Y_2 + \ldots) / (W_1 + W_2 + \ldots.) \times 100$

Recommended value - The shape tests give only a rough idea of the relative shapes of aggregates. Flaky and elongated particles should be avoided in pavement construction, particularly in surface course. If such particles are present in appreciable proportions, the strength of pavement layer would be adversely affected due to possibility of breaking under loads. Workability is reduced for cement concrete. IRC recommendations for maximum limits of flakiness index are as given.

Test for Organic Impurities in Fine Aggregate **-** The aggregate must be checked for organic impurities such as decayed vegetations, humus, and coal dust, etc. Color test is a reliable indicator of the presence of harmful organic matter in aggregates except in areas where there are deposits of lignite.

Procedure

- Fill a 350 ml clear glass medicine bottle upto 75 ml mark with a 3% solution of caustic soda or sodium hydroxide. A 3% solution of caustic soda is made by dissolving 3 gm of sodium hydroxide (which can be purchased from any local laboratory chemicals shop) in 100 ml of clean water (preferably distilled water). The solution should be kept in glass bottle tightly closed with a rubber stopper. Handling sodium hydroxide with moist hands may result in serious burns. Care should be taken not to spill the solution for it is highly injurious to clothing, leather and other materials.
- The representative sands sample is next added gradually until the volume measured by the sandy layer is 125 ml. The volume is then made up to 200 ml by the addition of more of the solution. The bottle is then corked and shaken vigorously and allowed to stand for 24 hours.
- At the end o f this period, the color of the liquid will indicate whether the sand contains a dangerous amount of matter or not. A colorless liquid indicates clean sand free from organic matter. A straw-colored solution indicates some organic matter but not enough to be seriously objectionable. Darker color means that the sand contains injurious, amounts and should not be used unless it is washed and a retest then shows that it is satisfactory.

Test for determination of clay, fine silt and fine dust

This is a gravimetric method for determining the clay, fine silt and fine dust, which includes particles up to 20 micron as per IS 2386- II (1963). Differences in the nature and density of materials or in the temperature at the time of testing may vary the separation point.

The *apparatus* shall consist of the following:

- A watertight screw-topped glass jar of dimensions similar to a 1-kg fruit preserving jar.
- A device for rotating the jar about its long axis, with this axis horizontal, at a speed of 80±20 rev/min.
- A sedimentation pipette of the Andreason type of approximately 25 ml capacity and of the general form indicated in Figure. This consists mainly of a pipette fitted at the top

with a two-way tap and held rigidly in a clamp which can be raised or lowered as required, and which is fitted with a scale from which the changes in height of the pipette can be read.

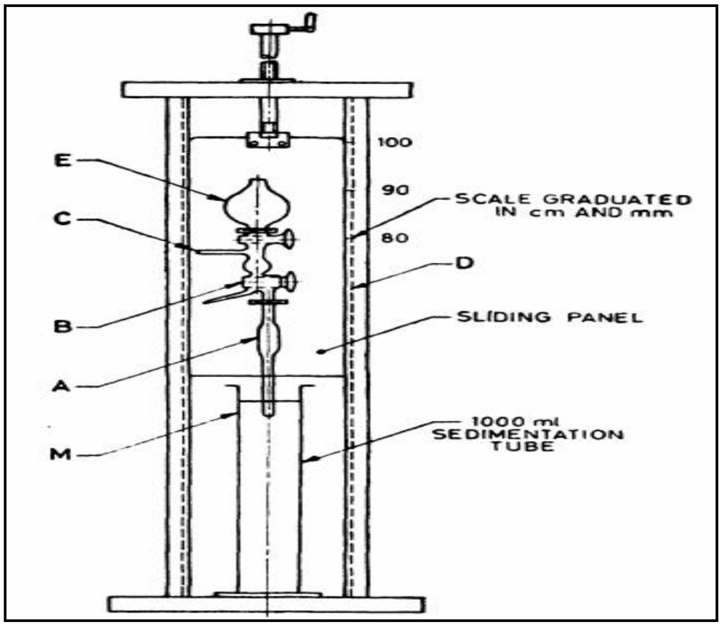
- The volume of the pipette A, including the connecting bore of the tap B, is determined by filling with distilled water; by reversing the tap, the water is run out into a bottle, weighed and the volume calculated.
- A 1000 ml measuring cylinder.
- A scale or balance of capacity not less than 10 kg, readable and accurate to 1 gm.
- A scale or balance of capacity not less than 250 g, readable and accurate to 0·001 gm.
- A well-ventilated oven, thermostatically controlled, to maintain a temperature of 100 to 110°c.

Chemicals - A solution containing 8 g of sodium oxalate per liter of distilled water shall be taken. For use, this stock solution is diluted with distilled water to one tenth (that is 100 ml diluted with distilled water to one liter).

Test Sample - The sample for test shall be prepared from the main sample taking particular care that the test sample contains a correct proportion of the finer material. The amount of sample taken for test shall be in accordance with table below.

Maximum Size Present in Substantial Proportions	Approximate Weight of Sample for Test
mm	kg
63 to 25	6
20 to 12·5	1
10 to 6·3	0·5
4·75 or smaller	0·3

All-in aggregates shall be separated into fine and coarse fractions by sieving on a 4·75-mm IS Sieve and the two samples so obtained shall be tested separately.



Method for Fine Aggregate - Approximately 300 g of the sample in the air-dry condition, passing the 4·75·mm IS Sieve, shall be weighed and placed in the screw-topped glass jar, together with 300 ml of the diluted sodium oxalate solution. The rubber washer and cap shall be fixed, care being taken to ensure water tightness. The jar shall then be rotated about its long axis, with this axis horizontal, at a speed of 80±20 rev/min for a period of 15 minutes. At the end of 15 minutes, the suspension shall be poured into the 1000 ml measuring cylinder and the residue washed by gentle swirling and decantation of successive 150 ml portions of sodium oxalate solution, the washings being added to the cylinder until the volume is made up to 1000 ml. The common procedure is given in *determination* paragraph.

Method for Coarse Aggregate - The weighed sample shall be placed in a suitable container, covered with a measured volume of sodium oxalate solution (0.8 g per liter), agitated vigorously to remove all adherent fine material and the liquid suspension transferred to the 1000 ml measuring cylinder. This process shall be repeated as necessary until all clayey material has been transferred to the cylinder. The volume shall be made up to 1000 ml with sodium oxalate solution. The common procedure is given in *determination* paragraph.

Determination - The suspension in the measuring cylinder shall be thoroughly mixed by inversion and the tube and contents immediately placed in position under the pipette. The pipette A shall then be gently lowered until the tip touches the surface of the liquid, and then lowered a further 10 cm into the liquid. Three minutes after placing the tube in position, the pipette A and the bore of tap B shall be filled by opening Band applying gentle suction at C. A small surplus may be drawn up into the bulb between tap B and tube C, but this shall be allowed to run away and any solid matter shall be washed out with distilled water from E. The pipette shall then be removed from the measuring cylinder and its contents run into a weighed container, any adherent solids being washed into the container by distilled water from E through the tap B. The contents of the container shall be dried at 100 to 110°C to constant weight, cooled and weighed.

Calculations - The proportion of fine silt and clay or fine dust shall then be calculated from the following formula:

$$\frac{100}{W_1}\left(\frac{1\,000\,W_2}{V} - 0{\cdot}8\right)$$

Where,

W_1 = weight in g of the original sample,

W_2 = weight in g of the dried residue,

V = volume in ml of the pipette, and

0·8 = weight in g of sodium oxalate in one litre of the diluted solution.

Reporting of Results - The clay, fine silt and fine dust content shall be reported to the nearest 0·1 percent.

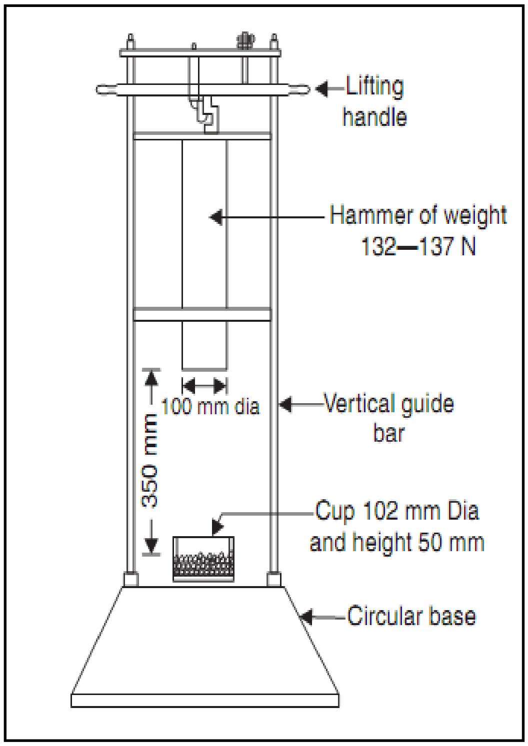
Test for aggregate Crushing value - This test helps to determine the aggregate crushing value of coarse aggregates as per IS: 2386 (Part IV) – 1963. The apparatus used is cylindrical measure and plunger, Compression testing machine, IS Sieves of sizes – 12.5mm, 10mm and 2.36mm

Procedure to determine Aggregate Crushing Value

- The aggregates passing through 12.5mm and retained on 10mm IS Sieve are oven-dried at a temperature of 100 to 110^{o}C for 3 to 4hrs.
- The cylinder of the apparatus is filled in 3 layers, each layer tamped with 25 strokes of a tamping rod.
- The weight of aggregates is measured (Weight 'A').
- The surface of the aggregates is then leveled 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.
- The sample is then sieved through a 2.36mm IS Sieve and the fraction passing through the sieve is weighed (Weight 'B').
- Two tests should be conducted.

Aggregate crushing value = (B/A) x 100%.

Test for Aggregate Impact value - This test is done to determine the aggregate impact value of coarse aggregates as per IS: 2386 (Part IV) – 1963. The apparatus used for determining aggregate impact value of coarse aggregates is Impact testing machine conforming to IS: 2386 (Part IV)- 1963,IS Sieves of sizes – 12.5mm, 10mm and 2.36mm, A cylindrical metal measure of 75mm dia. and 50mm depth, A tamping rod of 10mm circular cross section and 230mm length, rounded at one end and Oven.



Preparation of Sample

i. The test sample should conform to the following grading:
   a. Passing through 12.5mm IS Sieve – 100%
   b. Retention on 10mm IS Sieve – 100%

ii. The sample should be oven-dried for 4hrs. at a temperature of 100 to 110oC 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 to determine Aggregate Impact Value

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.

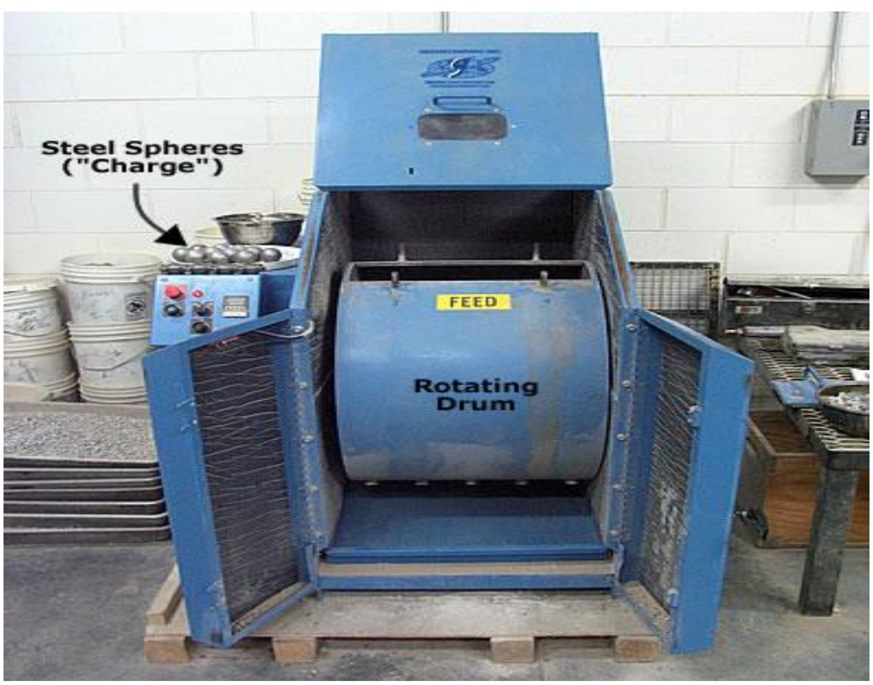
ii. The ratio of the weight of the fines formed to the total sample weight should be expressed as a percentage.

Aggregate impact value = (B/A) x 100%

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

Test for aggregate Abrasion value - This test helps to determine the abrasion value of coarse aggregates as per IS: 2386 (Part IV) – 1963.

The ***apparatus*** used in this test are Los Angles abrasion testing machine, IS Sieve of size – 1.7mm, Abrasive charge – 12 Nos. of cast iron or steel spheres approximately 48 mm diameter and each weighing between 390 and 445g ensuring that the total weight of charge is 5000 +25g and Oven.



Sample Preparation - The test sample should consist of clean aggregates which has been dried in an oven at 105 to 110^{o}C to a substantially constant weight and should conform to one of the grading 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	-	-	-

Procedure to determine Aggregate Abrasion Value

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 per 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

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

Aggregate abrasion value = (A-B)/B x 100%.

Test for Determination of Specific Gravity - The specific gravity of a substance is the ratio of the unit weight of the substance to the unit weight of water. A representative aggregate sample in SSD (*Saturated surface dry***)** condition is obtained by quartering and the following weights are used in the tests for the various sizes of aggregates.

Less than 4.75 mm	- 500 to 700 gm
4.75 mm to 10 mm	- 1000 to 1500 gm
10 mm to 20 mm	- 1500 to 2000 gm
20 mm to 40 mm	- more than 2000 gm

Procedure

- Take a suitable size jar, the top open side of which have flange, so that a glass plate may be put on it.
- The jar should be filled with clean water up to the flange and slide on it the glass plate. If there is any air bubble, which can be seen from top of glass plate, then the jar top should be filled with more water. There should not be any air bubble. Take the weight of jar fully filled with water and upon it glass plate (weight A).
- About half empty the jar fill it with known weight of SSD aggregate sample weight (B). As mentioned at b, fill the jar up to the top and putt glass plate on it. There should not be any air bubble. Take its weigh (weight C).

Specific gravity on SSD basis = B/ [B-(C-A)]

Test for Bulk density and Voids - Bulk density is the weight of a unit volume of aggregate, usually stated in kg per liter on room dry basis in estimating quantities of materials and in mix computation, when batching is done on a volumetric basis.

Concrete material proportion by weight can be converted to proportions by volume, by dividing with the bulk density of the materials available for use at site. The bulk density of cement may be taken 1.44 kg/lit.

For determination of bulk density the container size shall be as given below:

Size of particle	*Nominal capacity (litres)*	*Inside dia (mm)*	*Inside height (mm)*	*Thickness of metal (min) (mm)*
4.75 mm and under	3	150	170	3.15
Over 4.75 mm to 40 mm	15	250	300	4.00
Over 40 mm	30	350	310	5.00

Procedure

- About 100 kg of aggregate sample should be dried in the room.
- Take the weight in kg of empty container + glass plate (Weight A).
- The container is to be filled with loose sand or loose aggregate i.e. sand or aggregate should be dropped in the container from about 5 cm heights from top of container. Take the weight of container filled with sand or aggregate + glass plate (Weight B).
- Empty the container filled it with clean water up to the top ridge putt glass plate. There shall not be any air bubble. Take is weight (Weight C). All weight should be taken in kg.

  Loose bulk density in kg/lit on the basis

  Off room dry sand or aggregate = [B-A]/[C-A]

  And voids percentage = [(Specific gravity – bulk density)/ Specific gravity] x100

WATER **-** *Water* is the key ingredient, which when mixed with cement, forms a paste that binds the aggregate together. The water causes the hardening of concrete through a process called hydration. Hydration is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products. Details of the hydration process are explored in the next section. The water needs to be pure in order to prevent side reactions from occurring which may weaken the concrete or otherwise interfere with the hydration process. The role of water is important because the water to cement ratio is the most critical factor in the production of "perfect" concrete. Too much water reduces concrete strength, while too little will make the concrete unworkable. Concrete needs to be workable so that it may be consolidated and shaped into different forms (i.e. walls, domes, etc.). Because concrete must be both strong and workable, a careful balance of the cement to water ratio is required when making concrete.

Function of Water in Concrete

The water serves the following purpose:

1. To wet the surface of aggregates to develop adhesion because the cement pastes adheres quickly and satisfactory to the wet surface of the aggregates than to a dry surface.

2. To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and
3. Water is also needed for the hydration of the cementing materials to set and harden during the period of curing.

<u>Quality control at batching plant</u>

Quality Control of RMC can be divided into three convenient areas like forward control, immediate control and retrospective control.

Forward control basically deals with procedures of quality control to be followed before the production process.

This covers

- ❖ Materials storage,
- ❖ Monitoring of quality of materials,
- ❖ Modification of mix design,
- ❖ Plant maintenance,
- ❖ Calibration of equipment and
- ❖ Plant and transit mixer condition.

Immediate control is concerned with instant action to control the quality of concrete during production or that of deliveries closely following production.

This covers

- ❖ Weighing – correct reading of batch data and accurate weighing,
- ❖ Visual observation and testing of concrete during production and delivery (assessment of uniformity, cohesion, workability, adjustment of water content) and
- ❖ Making corresponding adjustments at the plant automatically or manually to batched quantities to allow for observed, measured or reported changes in materials or concrete qualities.

Retrospective control primarily deals with the quality control procedures after production.

This covers

- ❖ Sampling of concrete, testing and monitoring of results,
- ❖ Weighbridge checks of laden and unladen vehicle weights,
- ❖ Stock control of materials and

- Diagnosis and correction of identified faults.

Quality control at site

- Study duties responsibilities, Tender specification, standards, codes of practice and work instruction.
- Evolve effective acceptance/rejection procedures for construction materials in coordination with the project purchase department.
- Do proper sampling and testing of steel, cement, concrete, aggregates, water, etc., and verify test results in view of standards and work specifications prior to their use in construction. Also control quality of electrodes to their use in welding.
- Set procedures to control quality at the points of storage for raw materials, mixing and placing of concrete.
- Follow the prescribed curing and deshuttering schedules.
- Observe procedures to control quality of welded joints of structural steel members.
- Evolve a system to check quality of workmanship in all construction activities.
- Keep all revised Indian Standards and codes of practice available in QC laboratory and have them handy during discussion with client/consultant.
- Maintain sequence of construction required under any activity.
- Discuss QA/QC issues as a separate agenda during site review meetings with staff.
- Observe regular schedule for maintenance, repairs and calibration of plants and equipments.
- Keep spare parts/materials for laboratory equipments weigh batchers, batching plant, etc., always keep spare vibrators ready at site.
- Carry work instruction cards in pocket while supervising/inspecting works.
- Regularly maintain the formats prescribed under ISO 9002 Quality assurance system
- Practice sound housekeeping methods to achieve saving, safety and quality.

FRESH CONCRETE TESTING

- Slump test
- Compacting factor test
- Vee Bee test and
- Flow table test

- Kelly ball test

Slump Test

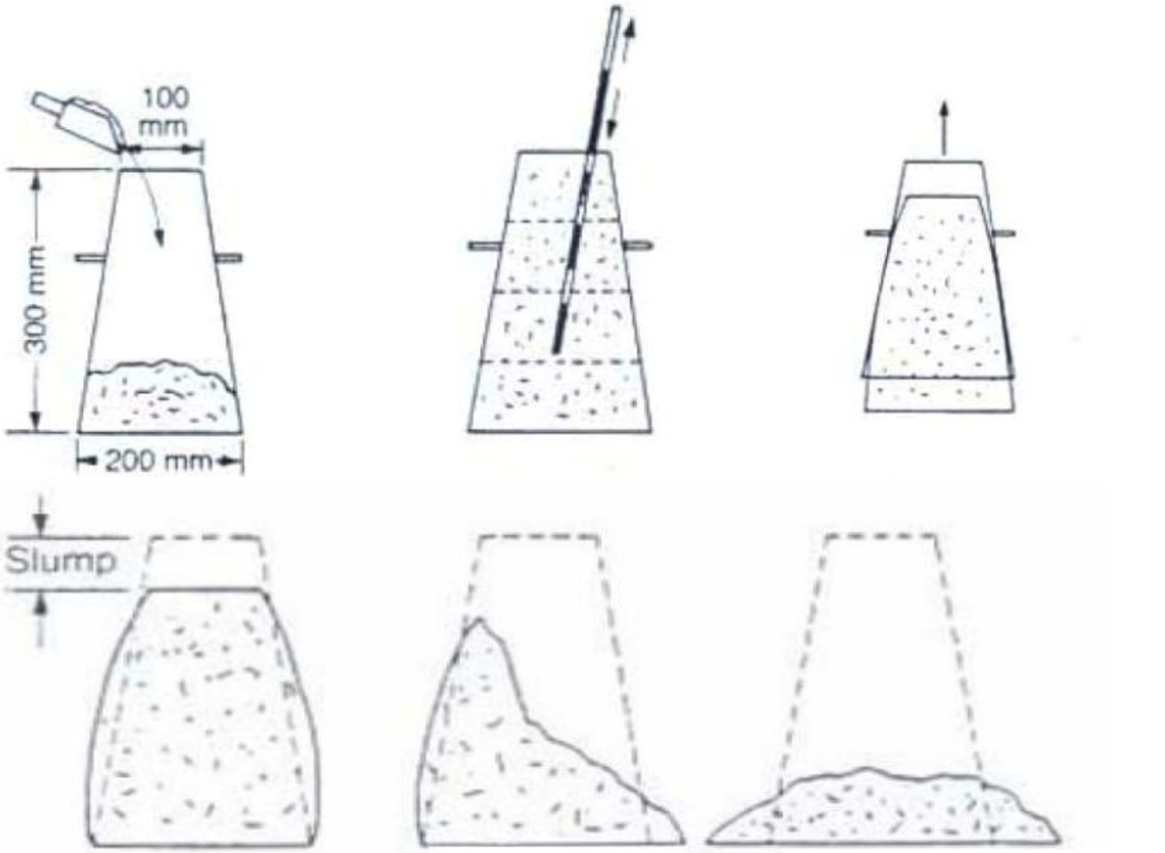
This test is performed to check the consistency of freshly made concrete. The slump test is done to make sure a concrete mix is workable. The measured slump must be within a set range, or tolerance, from the target slump.

Tools and apparatus used for slump test (equipment):

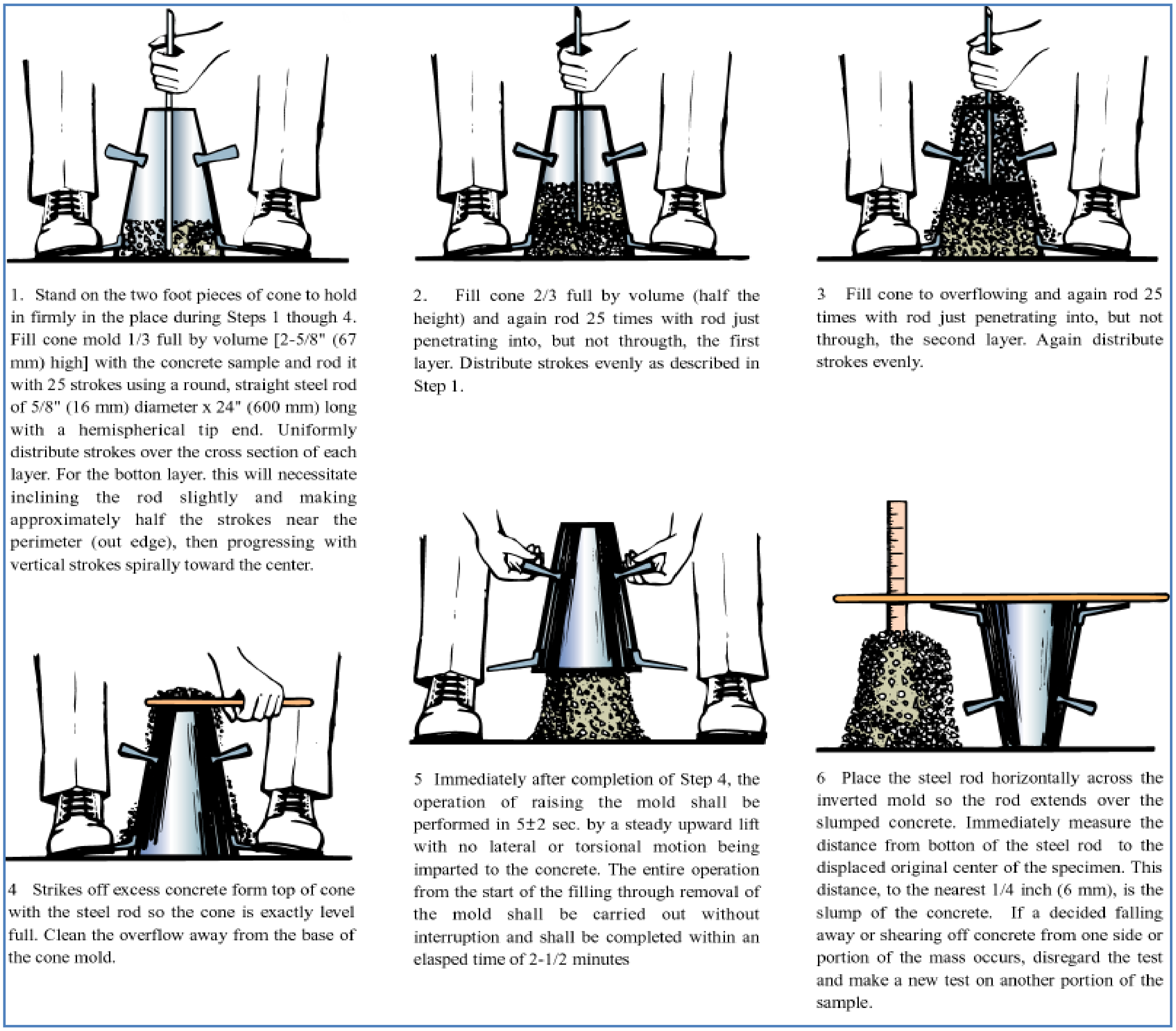
- Standard slump cone (100 mm top diameter x 200 mm bottom diameter x 300 mm high)
- **Small scoop** - Bullet-nosed rod (600 mm long x 16 mm diameter)
- **Rule** - Slump plate (500 mm x 500 mm)

Procedure of slump test for concrete

1. Clean the cone. Dampen with water and place on the slump plate. The slump plate should be clean, firm, level and non-absorbent. Collect a sample of concrete to perform the slum test.
2. Stand firmly on the foot pieces and fill 1/3 the volume of the cone with the sample. Compact the concrete by 'rodding' 25 times. Rodding means to push a steel rod in and out of the concrete to compact it into the cylinder, or slump cone. Always rod in a definite pattern, working from outside into the middle.
3. Now fill to 2/3 and again rod 25 times, just into the top of the first layer.
4. Fill to overflowing, rodding again this time just into the top of the second layer. Top up the cone till it overflows.
5. Level off the surface with the steel rod using a rolling action. Clean any concrete from around the base and top of the cone, push down on the handles and step off the foot pieces.
6. Carefully lift the cone straight up making sure not to move the sample.
7. Turn the cone upside down and place the rod across the up-turned cone.
8. Take several measurements and report the average distance to the top of the sample. If the sample fails by being outside the tolerance (ie the slump is too high or too low), another must be taken. If this also fails the remainder of the batch should be rejected.



True	**Shear**	**Collapse**
Valid slump measurement 0-175 mm	Mixes having tendency to segregate – repeat test	Slumps greater than 175 mm - self-leveling concrete



Slump Cone test and apparatus

<u>Compacting factor test</u>

Compacting factor of fresh concrete is done to determine the workability of fresh concrete by compacting factor test as per IS: 1199 – 1959. The apparatus used is Compacting factor apparatus.

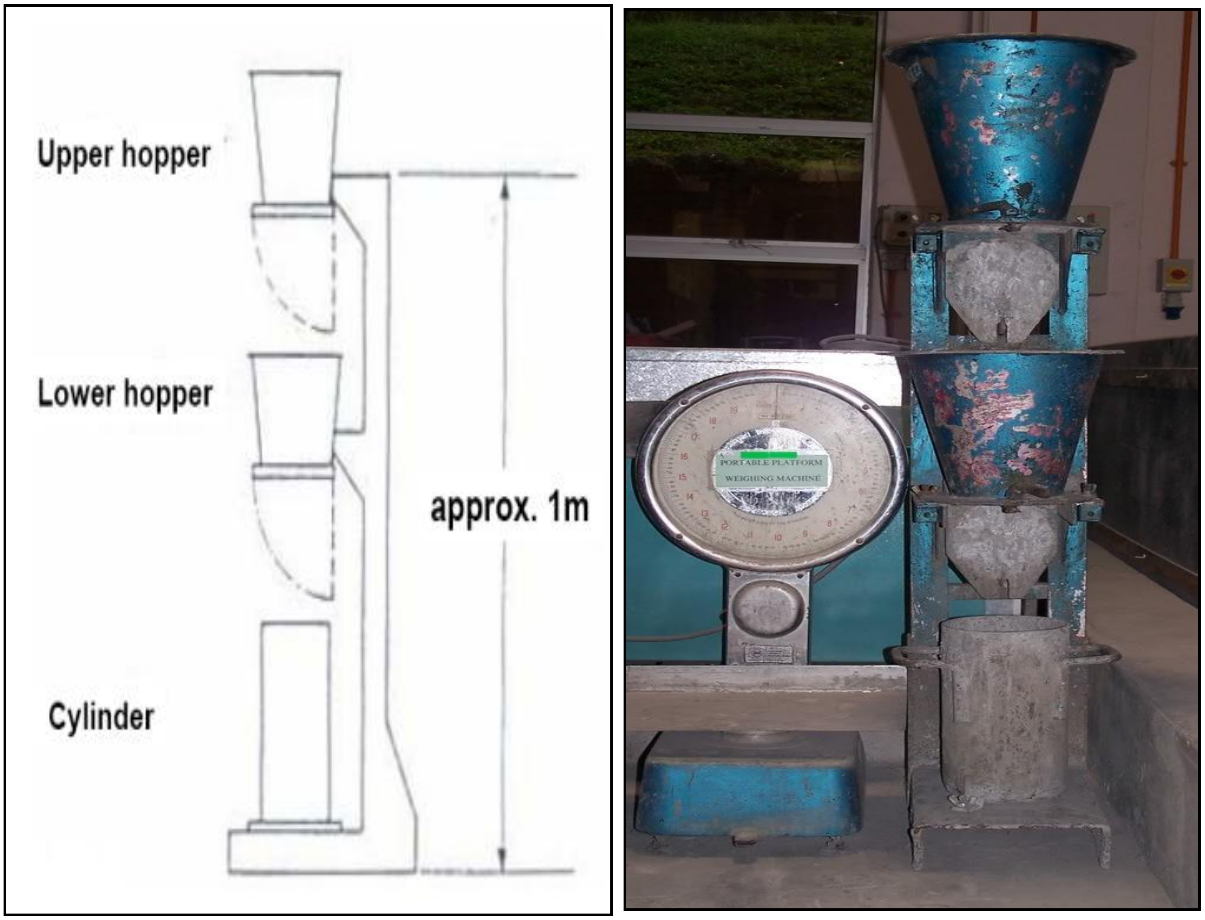
Procedure

- The sample of concrete is placed in the upper hopper up to the brim.

- The trap-door is opened so that the concrete falls into the lower hopper. The trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder.
- The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades
- The concrete in the cylinder is weighed. This is known as weight of partially compacted concrete.
- 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.

Compacting factor = (Weight of partially compacted concrete)/(Weight of fully compacted concrete) = (W1-W2 / W2-W)

***Note* -** The test is sufficiently sensitive to enable difference in work ability arising from the initial process in the hydration of cement to be measured. Each test, there for should be carried out at a constant time interval after the mixing is completed, if strictly comparable results are to be obtained. Convenient time for releasing the concrete from the upper hopper has been found to be two minutes after the completion of mixing.



Compaction factor apparatus

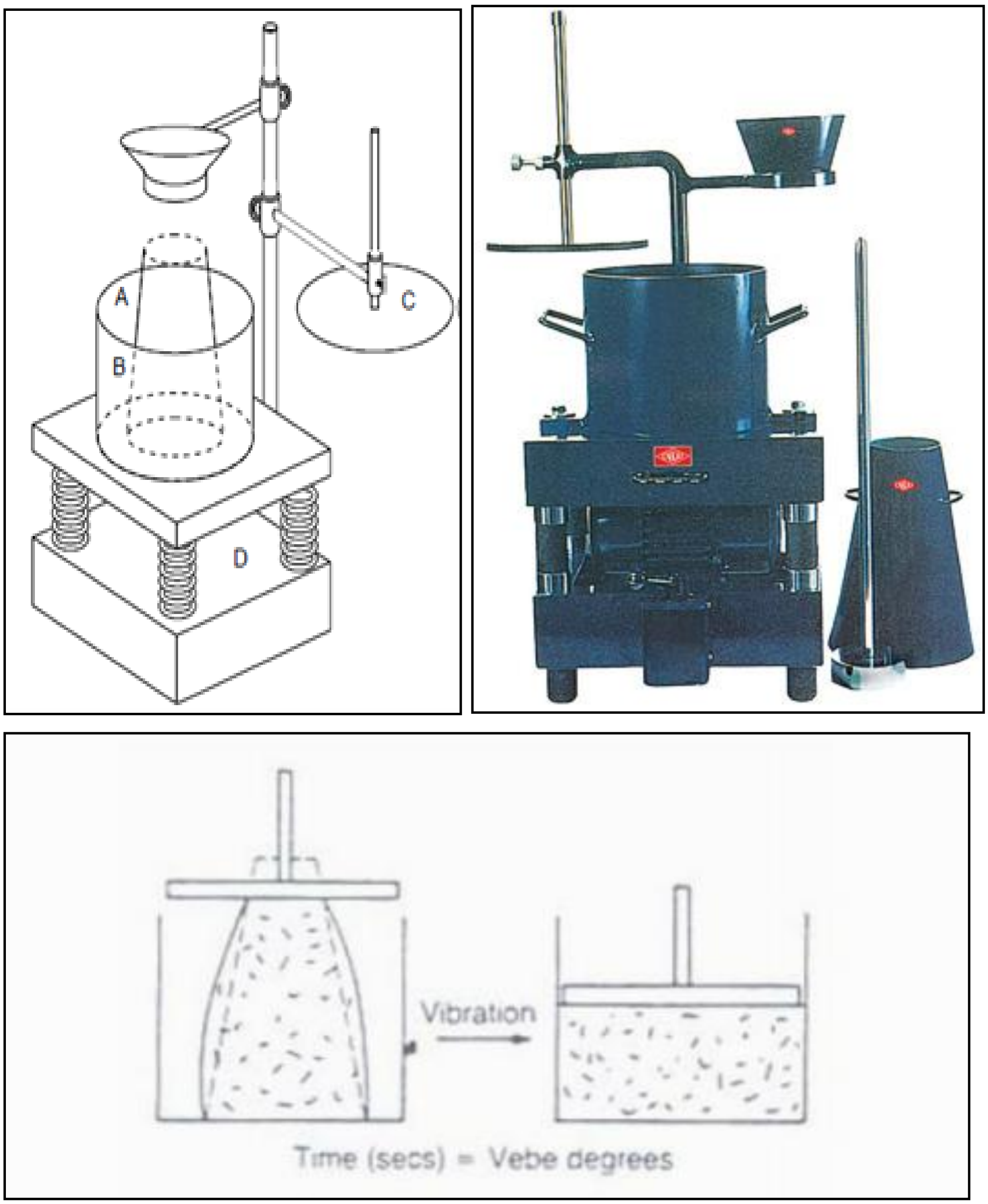
<u>Vee Bee test</u>

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

Procedure

- A conventional slump test is performed, placing the slump cone inside the cylindrical part of the consistometer.
- The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot.
- The electrical vibrator is switched on and a stop-watch is started, simultaneously. Vibration is continued till the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.

- When the concrete fully assumes a cylindrical shape, the stop-watch is switched off immediately. The time is noted.
- The consistency of the concrete should be expressed in VB-degrees, which is equal to the time in seconds recorded above.



Vee Bee test apparatus

Flow table test

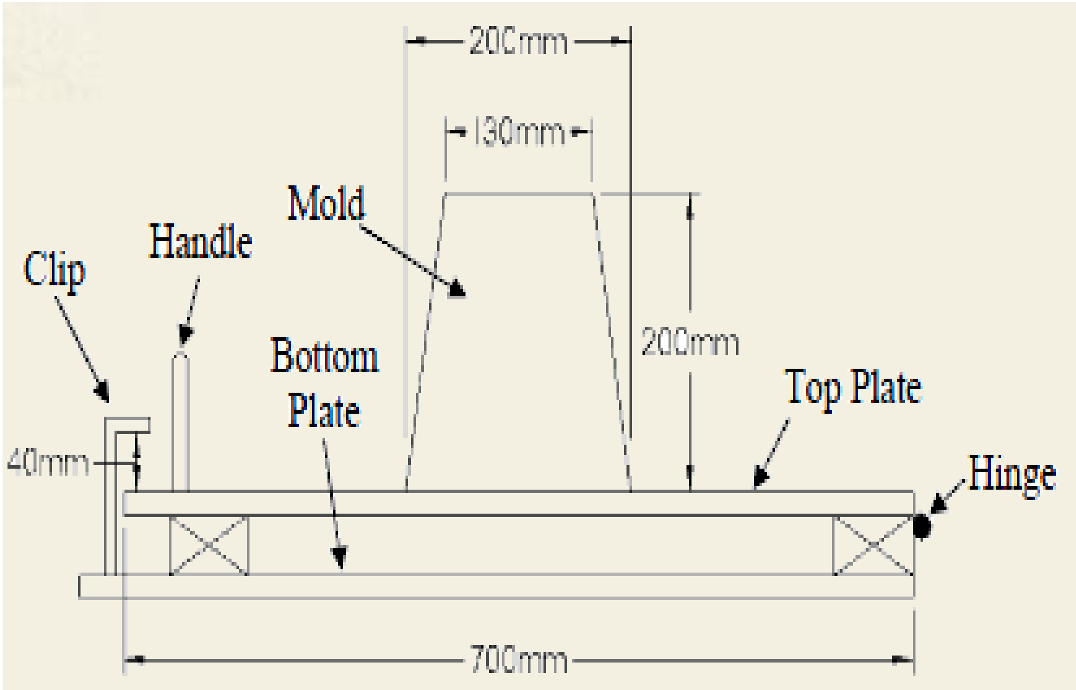
To determine the workability of fresh concrete by using a Flow table test as per IS: 5512 – 1983. The apparatus used is Flow table apparatus.

Procedure

- The 700 mm square flow table is hinged to a rigid base, proved with a stop that allows the far end to be raised by 40 mm.
- A cone, similar to that used for slump testing but truncated, is filled with concrete in two layers.
- Each layer is tamped 10 times with a special wooden bar and the concrete of the upper layer finished off level with the top of the cone. Any excess is cleaned off the outside of the cone.
- The cone is then raised allowing the concrete to flow out and spread out a little on the flow table.
- The table top is then raised until it meets the stop and allowed to drop freely 15 times.
- This causes the concrete to spread further, in a roughly circular shape.
- The flow diameter is the average of the maximum diameter of the pool of concrete and the diameter at right angles.

Flow = final diameter of the concrete
(mean of two measurements at right angles)

As well as getting an accurate measurement of the workability of the concrete, the flow test gives an indication of the cohesion. A mix that is prone to segregation will produce a non-circular pool of concrete. Cement paste may be seen separating from the aggregate. If the mix is prone to bleeding, a ring of clear water may form after a few minutes.

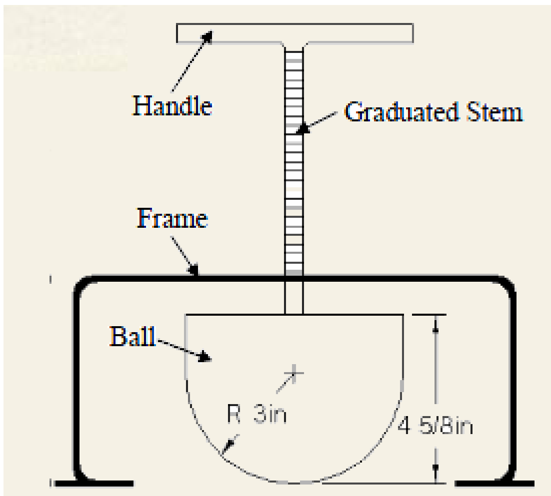


Flow table test apparatus

<u>Kelly ball test</u>

The simple and inexpensive test can be quickly performed on in-place concrete and the results can be correlated to slump. This method is used to determine the penetration of a hemispherical metal weight into freshly mixed concrete, which is related to the workability of the concrete.

The apparatus consists of a cylinder with one end having a hemispherical shape and the other end fit with a graduated handle. The weight assembly is lowered through a frame into the concrete and the penetration measured. The test apparatus consists of a 6 inch diameter, 30 pound ball attached to a stem, as shown in Figure. The stem, which is graduated in ¼ inch increments, slides through a frame that rests on the fresh concrete. To perform the test, the concrete to be tested is stuck off level. The ball is released and the depth of penetration is measured to the nearest ¼ inch. At least three measurements must be made for each sample.



The Kelly ball test provides an indication of yield stress, as the test essentially measures whether the stress applied by the weight of the ball is greater than the yield stress of the concrete. For a given concrete mixture, the results of the Kelly ball test can be correlated to slump.

Advantages

- The test is faster than the slump test and can be preformed on in-place concrete to obtain a direct result quickly
- It has been claimed that the Kelly ball test provides more accurate results than the slump test.

Disadvantages

- Like the slump test, the Kelly ball test is a static test.
- The test must be performed on a level concrete surface.
- The test is no longer widely used.
- Large aggregate can influence the results

HARDENED CONCRETE TESTING

1. **Compressive strength test on concrete**

Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not.

For cube test two types of specimens either cubes of 15 cm X 15 cm X 15 cm or 10cm X 10 cm x 10 cm depending upon the size of aggregate are used. For most of the works cubical moulds of size 15 cm x 15cm x 15 cm are commonly used. This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimen should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen.

These specimens are tested by compression testing machine after 7 days curing or 28 days curing. Load should be applied gradually at the rate of 140 kg/cm2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

The apparatus in this test is a Compression testing machine The proportion and material for making these test specimens are from the same concrete used in the field. The specimen used for testing is 6 cubes of 15 cm size Mix. M15 or above. The mixing can be done manually.

Hand mixing

- Mix the cement and fine aggregate on a water tight none-absorbent platform until the mixture is thoroughly blended and is of uniform color
- Add the coarse aggregate and mix with cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch
- Add water and mix it until the concrete appears to be homogeneous and of the desired consistency

Sampling

- Clean the mounds and apply oil
- Fill the concrete in the molds in layers approximately 5cm thick
- Compact each layer with not less than 35strokes per layer using a tamping rod (steel bar 16mm diameter and 60cm long, bullet pointed at lower end)
- Level the top surface and smoothen it with a trowel

Curing

The test specimens are stored in moist air for 24hours and after this period the specimens are marked and removed from the molds and kept submerged in clear fresh water until taken out prior to test. The water for curing should be tested every 7days and the temperature of water must be at 27±2^{o}C.

Procedure

i. Remove the specimen from water after specified curing time and wipe out excess water from the surface.
ii. Take the dimension of the specimen to the nearest 0.2m
iii. Clean the bearing surface of the testing machine

iv. Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast.

v. Align the specimen centrally on the base plate of the machine.

vi. Rotate the movable portion gently by hand so that it touches the top surface of the specimen.

vii. Apply the load gradually without shock and continuously at the rate of 140kg/cm^2/minute till the specimen fails

viii. Record the maximum load and note any unusual features in the type of failure.

Note

Minimum three specimens should be tested at each selected age. If strength of any specimen varies by more than 15 per cent of average strength, results of such specimen should be rejected. Average of there specimens gives the crushing strength of concrete. The strength requirements of concrete.

Calculations

Size of the cube =15cm x15cm x15cm

Area of the specimen (calculated from the mean size of the specimen)=225cm^2

Characteristic compressive strength(f_{ck})at 7 days =

Expected maximum load =f_{ck} * area * f.s

Range to be selected is …………………..

Similar calculation should be done for 28 day compressive strength

Maximum load applied =……….tones = …………N

Compressive strength = (Load in N/ Area in mm$^{2)}$=………..N/mm^2

=…………N/mm^2

Report

a) Identification mark

b) Date of test

c) Age of specimen

d) Curing conditions, including date of manufacture of specimen

f) Appearance of fractured faces of concrete and the type of fracture if they are unusual

Result

Average compressive strength of the concrete cube = …………N/ mm^2 (at 7 days)

Average compressive strength of the concrete cube =……… N/mm^2 (at 28 days)

Percentage strength of concrete at various ages

The strength of concrete increases with age. Table shows the strength of concrete at different ages in comparison with the strength at 28 days after casting.

Age	Strength per cent
1 day	16%
3 days	40%
7 days	65%
14 days	90%
28 days	99%

Compressive strength of different grades of concrete at 7 and 28 days

Grade of Concrete	Minimum compressive strength N/mm^2 at 7 days	Specified characteristic compressive strength (N/mm^2) at 28 days
M15	10	15
M20	13.5	20
M25	17	25
M30	20	30
M35	23.5	35
M40	27	40
M45	30	45

TENSILE STRENGTH TEST ON CONCRETE

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. The main aim is to determine the splitting tensile of concrete.

Equipment for Splitting Tensile Test of Concrete **-** Compression testing machine, two packing strips of plywood 30 cm long and 12mm wide.

Sampling of Concrete Cylinders - The cylinder mould shall is of metal 3mm thick. Each mould is capable of being opened longitudinally to facilitate the removal of the specimen and is provided with a means of keeping it closed while in use. The mean internal diameter of the mould is 15 cm ± 0.2 mm and the height is 30 +/- 0.1 cm. Each mould is provided with a metal base plate mould and base plate should be coated with a thin film of mould oil before use, in order to prevent adhesion of concrete.

Tamping Bar **-** The tamping bar is a steel bar of 16 mm diameter, 60 cm long and bullet pointed at the lower end.

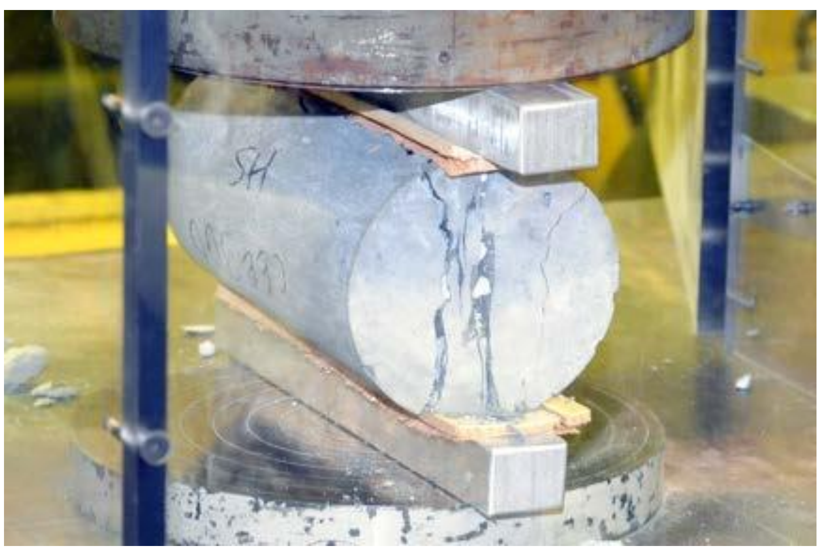
Compacting of Concrete - The test specimen should be made as soon as practicable after the concrete is filled into the mould in layers approximately 5 cm deep. Each layer is compacted either by hand or by vibration.

Compacting by Hand **-** When compacting by hand, the standard tamping bar is used and the stroke of the bar should be distributed in a uniform manner. The number of strokes for each layer should not less than 30. The stroke should penetrate in to the underlying layer and the bottom layer should be rodded throughout its depth. After top layer has been compacted .The surface of the concrete should be finished level with the top of the mould using a trowel and covered with a glass or metal plate to prevent evaporation.

Curing of Specimen **-** The test specimen should be stored in a place at a temperature of 27° ±2°C for 24±0.5 hrs from the time addition of water to the dry ingredients. After this period the specimen should be marked and removed from the moulds and immediately submerged in clean fresh water or saturated lime solution and kept there until taken out just prior to the test. The water or solution in which the specimen s are kept should be renewed every seven days and should be maintained at a temperature of 27° ± 2°c.Concrete cylinder 15 cm diameter &30cm long.

Note

Cast 6 cylinders (3 for split test &3 for compression test)



Procedure of Splitting Tensile Test

i. Take the wet specimen from water after 7 days of curing
ii. Wipe out water from the surface of specimen

iii. Draw diametrical lines on the two ends of the specimen to ensure that they are on the same axial place.
iv. Note the weight and dimension of the specimen.
v. Set the compression testing machine for the required range.
vi. Keep are plywood strip on the lower plate and place the specimen.
vii. Align the specimen so that the lines marked on the ends are vertical and centered over the bottom plate.
viii. Place the other plywood strip above the specimen.
ix. Bring down the upper plate to touch the plywood strip.
x. Apply the load continuously without shock at a rate of approximately 14-21kg/cm2/minute (Which corresponds to a total load of 9900kg/minute to 14850kg/minute)
xi. Note down the breaking load(P)

Calculations

Range Calculation

As per IS456, split tensile strength of concrete = 0.7 F_{ck}

The splitting tensile strength is calculated using the formula

Tsp = 2P/ pi DL

Where P = applied load

D = diameter of the specimen

L = length of the specimen

Therefore P = Tsp* pi DL/2

Expected load = P * f*s

Range to be selected is…………..

Split tensile strength

T = 2P/ pi DL

Report

(I) Date of test

(II) Identification mark and size of the specimen

(III) Age of test specimen and date of test

(IV) Curing history as detailed earlier

(V) Weight of specimen in kg

(VI) Type of fracture face, if they are unusual.

Result

Splitting tensile strength of given concrete =……………….N/mm²

FLEXURAL STRENGTH TEST

Objective

To determine the Flexural Strength of Concrete, which comes into play when a road slab with inadequate sub-grade support is subjected to wheel loads and / or there are volume changes due to temperature / shrinking.

Reference standards

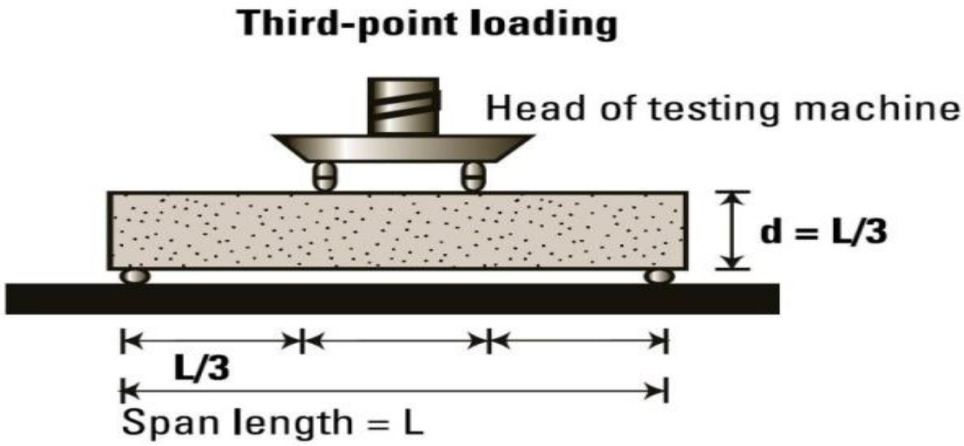
IS: 516-1959 – Methods of tests for strength of concrete

Equipment & apparatus

- Beam mould of size 15 x 15x 70 cm (when size of aggregate is less than 38 mm) or of size 10 x 10 x 50 cm (when size of aggregate is less than 19 mm)

- Tamping bar (40 cm long, weighing 2 kg and tamping section having size of 25 mm x 25 mm)
- Flexural test machine– The bed of the testing machine shall be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from centre to centre is 60 cm for 15.0 cm specimens or 40 cm for 10.0 cm specimens. The load shall be applied through two

similar rollers mounted at the third points of the supporting span that is, spaced at 20 or 13.3 cm centre to centre. The load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsion stresses or restraints.

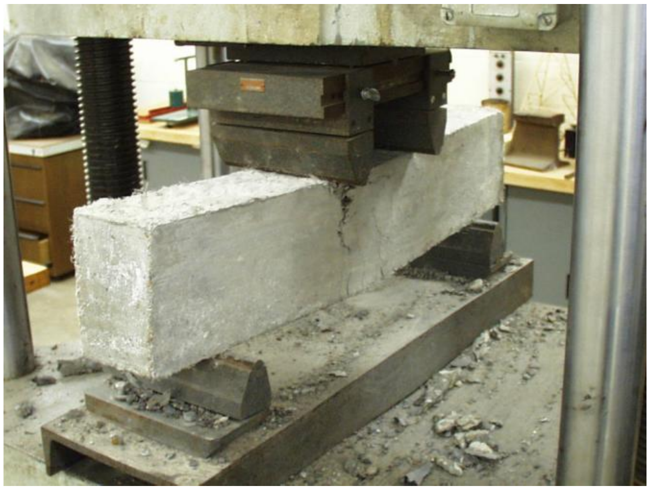


Procedure

i. Prepare the test specimen by filling the concrete into the mould in 3 layers of approximately equal thickness. Tamp each layer 35 times using the tamping bar as specified above. Tamping should be distributed uniformly over the entire crossection of the beam mould and throughout the depth of each layer.
ii. Clean the bearing surfaces of the supporting and loading rollers, and remove any loose sand or other material from the surfaces of the specimen where they are to make contact with the rollers.
iii. Circular rollers manufactured out of steel having cross section with diameter 38 mm will be used for providing support and loading points to the specimens. The length of the rollers shall be at least 10 mm more than the width of the test specimen. A total of four rollers shall be used, three out of which shall be capable of rotating along their own axes. The distance between the outer rollers (i.e. span) shall be 3d and the distance between the inner rollers shall be d. The inner rollers shall be equally spaced between the outer rollers, such that the entire system is systematic.

iv. The specimen stored in water shall be tested immediately on removal from water; whilst they are still wet. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the rollers. For molded specimens, the mould filling direction shall be normal to the direction of loading.

v. The load shall be applied at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.



Calculation

The Flexural Strength or modulus of rupture (f_b) is given by

$f_b = pl/bd^2$ (when a > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen)

or

$f_b = 3pa/bd^2$ (when a < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.)

Where,

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

p = max. Load (kg)

Reports

The Flexural strength of the concrete is reported to two significant figures.

Safety & precautions:

- Use hand gloves while, safety shoes at the time of test.
- After test switch off the machine.
- Keep all the exposed metal parts greased.
- Keep the guide rods firmly fixed to the base & top plate.
- Equipment should be cleaned thoroughly before testing & after testing.

MODULUS OF RUPTURE

Flexural strength, also known as **modulus of rupture**, bend strength, or fracture strength a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load.

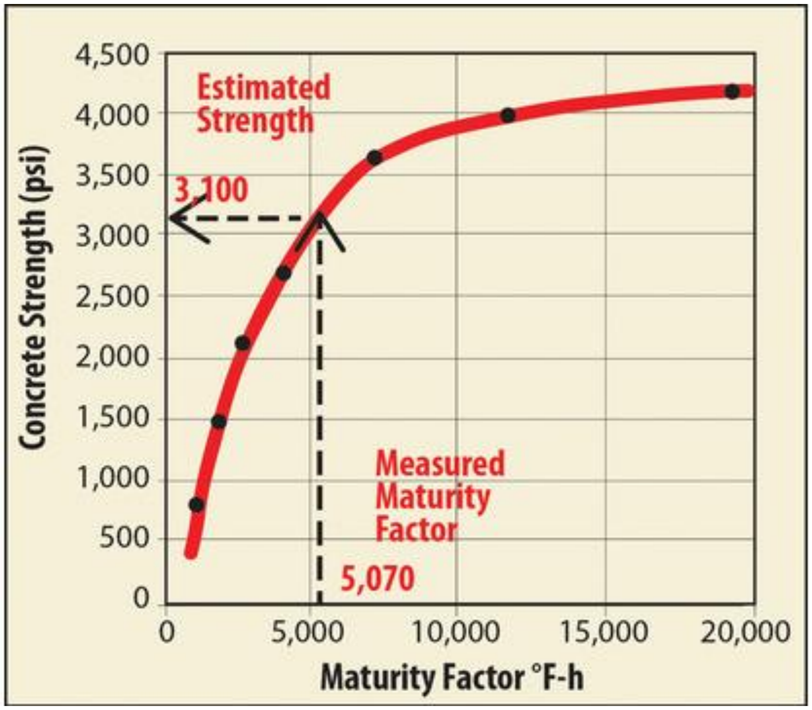
MATURITY OF CONCRETE

Concrete maturity indicates how far curing has progressed. Maturity is the relationship between concrete temperature, time, and strength gain. It is represented by an index value that can be measured in real time in the field.

The maturity method, often simply referred to as “maturity,” is a way of evaluating new concrete’s in-place strength by relating time and temperature measurements to actual strength values.

To expedite schedules, increase safety, and improve construction methods, construction teams want to know the strength of their concrete at the job site in real time. Since maturity is related to concrete strength, the maturity method is a way to accomplish this without solely relying on standard test specimens and laboratory testing.

Maturity is calculated by tracking changes in fresh concrete temperature over time. Since each concrete mix has its own strength-maturity relationship, we can use maturity to estimate the strength of that mix at any moment after placement. When we know the maturity of a certain concrete, we can use that concrete's specific strength-maturity relationship to make a reliable estimate of its strength.



Basic Steps

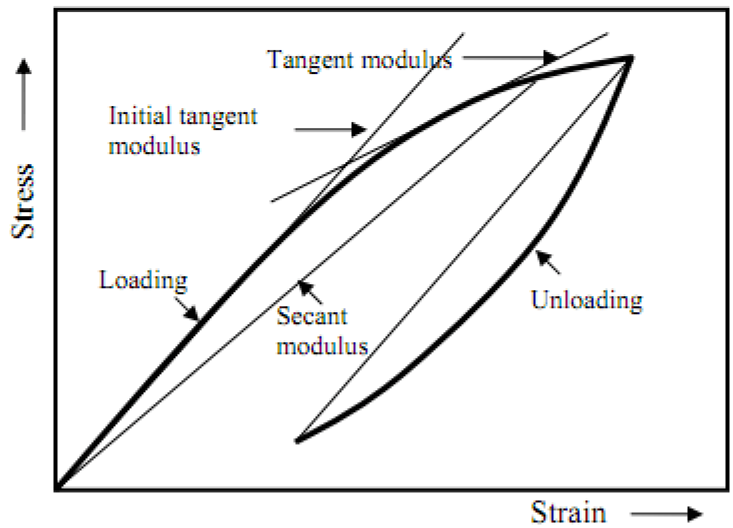
1. Track internal temperatures during curing
2. Use the tracked internal temperature history to calculate maturity
3. Use the strength-maturity relationship to estimate strength

MODULUS OF ELASTICITY

The modulus of elasticity or "Young's Modulus" is defined as the slope of the stress-strain curve within the proportional limit of a material. For a concrete material, the secant modulus is defined as the slope of the straight line drawn from the origin of axes to the stress-strain curve at some percentage of the ultimate strength. This is the value most commonly used in structural design.

Since no portion of the stress-strain curve is a straight line, the usual method of determining the Young's Modulus is to measure the tangent modulus, which is defined as the slope of the tangent to the stress-strain curve at some percentage of the ultimate strength of the concrete as determined by compression tests.

From the figure it's seen that the secant modulus is almost same to the tangent modulus obtained at some lower percentage of the ultimate strength.



Significance of elastic modulus of concrete:

The elastic modulus of concrete is a very important mechanical parameter reflecting the ability of the concrete to deform elastically. For example, in prestressed concrete structures, elastic shortening of prestressed concrete is one of the main factors contributing to prestress loss.

In addition, in order to make full use of the compressive strength potential, the structures using high-strength concrete tend to be slimmer and require a higher elastic modulus so as to maintain its stiffness. Therefore, knowledge of the modulus of high-strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability and achieving the most cost-effective designs.

PERMEABILITY

Permeability in concrete has direct relationship with the durability of the concrete. The lesser the permeability, the more durable the concrete will be. Permeability will make the concrete vulnerable to external media attack. These media include water, chemicals, sulfates, and etc. These external media, once capable of penetrating into concrete it will deteriorate the life span of that particular concrete structure. For example, water can cause corrosion to steel reinforcement bar in concrete. The permeability also reduces the resistance of concrete towards freeze-thaw action. Therefore, permeability is a very important characteristic of that need to be achieved in any application.

The permeability occurs in hardened concrete in two scenarios; firstly from the trapped air pockets from incomplete compaction, and secondly from the empty space due to loss of mixing water by evaporation. In both situations the air space is not good for concrete durability. It is therefore very important to make that any concrete placed in the formworks gets proper and adequate compaction. Some contractors might add water to the properly design concrete mix in order to make it more workable at site. This practice shall not be allowed at all for any reason. With so much development in concrete technology, now it is possible to do concreting without the need to compact it (or at least with minimum compaction). This type of concrete is known as self compacting concrete, which as it name sounds is capable of compacting on its own. It creates a very highly compacted and dense concrete; thus resulting in low permeability.

Since loss of mixing water is one of the reasons for higher permeability, simply adding water to concrete will create more air space after evaporation. Therefore, for any concrete to be watertight, the water-cement ratio shall be as low as possible. According to American Concrete Institute, for concrete exposed to fresh water the maximum water-cement shall not exceed 0.48, while this value shall be less than 0.44 if the concrete will be exposed to seawater.

Besides improper compaction and loss of mixing water, there are few other factors that affect the permeability in concrete. As the age of the concrete increases, the permeability will reduce. This is because concrete is material that will continue to hydrate over a long period of time as long as there is a presence of un-hydrated lime. So with the presence of water, the hydration products will fill the empty spaces in the matrix. Another factor that improves the permeability is the fineness of cement. Finer cement particles will hydrate much faster; thus creating the impermeable concrete faster.

Significance

- Permeability of concrete plays an *important role in durability* because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing. Higher the permeability lesser will be the durability

- Permeability of concrete is of interest also in relation to the water-tightness of liquid-retaining structures. Higher the permeability lesser will be the water-tightness

Test of permeability on concrete

1. *Sorptivity Test*

ASTM C1585 measures the sorptivity of a concrete specimen that has been conditioned at a constant relative humidity and then allowed to equilibrate to a presumed stable internal relative humidity. The specimens are 4-in. (100-mm) diameter, 2-in. (50-mm) long cylinders. Prior to testing, the specimens are stored in a chamber at a temperature of 122°F (50°C) and a relative humidity of 80% for 3 days. The target relative humidity of 80% was chosen since this is a common value observed for in-service bridge decks. The specimens are then sealed in individual containers and stored in the laboratory at 73°F (23°C) for 2 weeks to allow the internal relative humidity of the specimens to come to equilibrium. The sides of the specimens are then sealed with tape and the ends of the specimens opposite the absorbing surface are covered to impede evaporation from this surface during the test. The specimens are then weighed, and the absorbing surfaces are exposed to water, either by immersion into a reservoir or by ponding. At increasing time intervals, the specimens are removed from exposure to water, the surfaces blotted to remove excess surface water, and the specimens reweighed. Frequent measurements are made during the first 6 hours of testing, followed by daily measurements for at least 8 days. The change in mass over time is used to calculate the sorptivity. Typically, the rate over the first 6 hours is higher than the rate over the succeeding days. These are expressed as initial and secondary rates, respectively.

2. *Chloride Diffusion Coefficient*

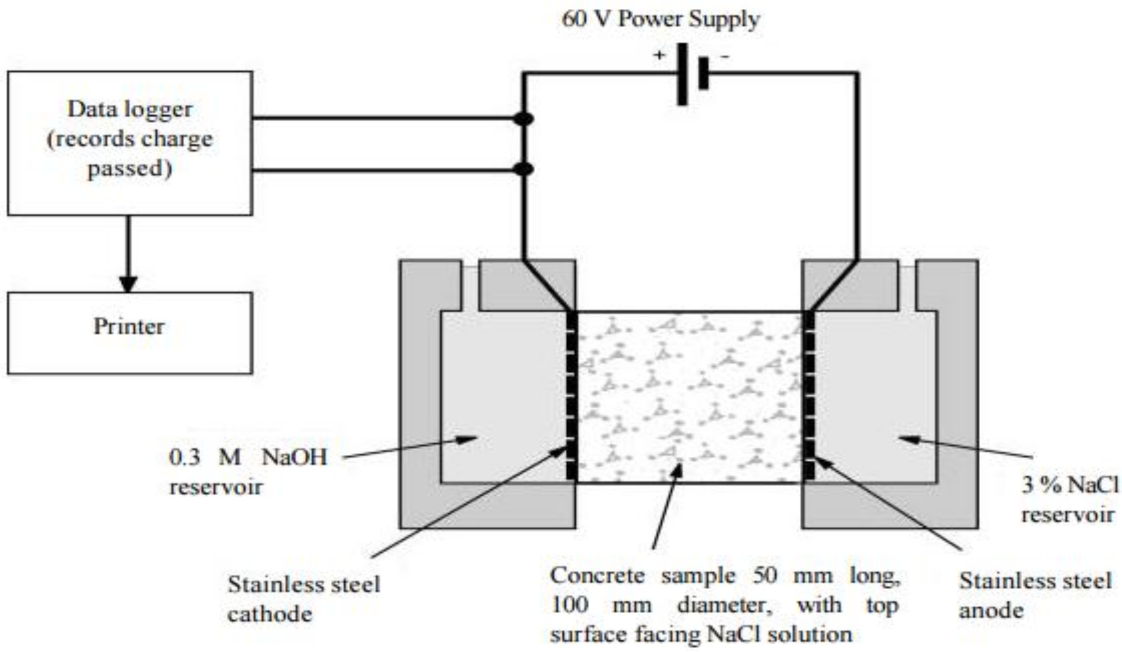
The chloride diffusion coefficient of concrete can be determined using ASTM C1556. Test specimens with a minimum dimension of 3 in. (75 mm) across the finished surface and a minimum length of 3 in. (75 mm) are used. Prior to final preparation for testing, specimens should be in a state of saturation to minimize the influence of transport mechanisms other than concentration driven diffusion. The specimens are then allowed to surface dry and the sides and one end of the specimens sealed. The specimens are then immersed in lime-saturated water for 6 days to complete re-saturation. The specimens are removed from the lime water, rinsed free of lime and immersed in salt solution. The standard solution is 15% by mass sodium chloride (NaCl), but other concentrations can be used. Specimens remain immersed in the salt solution for a minimum of 35 days, with longer periods necessary for high performance concretes with low permeability. Following exposure to the salt solution, the specimens are rinsed and allowed to dry for 1 day under laboratory conditions. If the sampling for chloride analysis is delayed more than 48 hours, the specimens should be sealed in a plastic bag and stored in the laboratory. If longer than 7 days, the bagged specimens should be frozen until sampling to prevent continued migration of chloride ions. Samples for chloride analysis are obtained by profile grinding in incremental depths of 0.04 to 0.08 in. (1 to 2 mm) parallel to the exposed surface. A sample of the concrete is also obtained prior to the salt exposure to provide its background chloride content. The samples are analyzed for total acid-soluble chloride content using either AASHTO T 260[(3)] or ASTM C1152.[(4)] The results of the chloride analysis tests are used to calculate the apparent chloride diffusion coefficient by fitting an equation to the data using non-linear regression analysis.

RCPT

Rapid Chloride Permeability (RCP) test is another method used to figure out concrete durability; however, is loaded with limitations. The RCP test is the standard test method for electrical indication of concrete's ability to resist chloride ion penetration.

The concrete cylindrical specimens - 50 mm thick are first prepared by coating the dry side surface with a special sealer and then vacuum conditioning it for 22 hrs as per the ASTM Codal procedure. The saturated specimens are then mounted in the Plexiglass cells, the sealant applied and the reservoirs filled with NaCl & NaOH solutions respectively. The cell terminals are then connected to the Power supply unit through cables provided – one for each channel and the test started.

The passing current magnitude depends on the ions passing through the pores of the concrete specimen (including chloride ions), which in turn depend on the permeability of concrete.



Advantages

- Is relatively quick—can be used for quality control
- Has simple and convenient setup and procedures
- Provides results that are easy to interpret
- Correlates well with 90-day chloride ponding test

Disadvantages

- May not represent the true permeability (or potential permeability) for concrete that contains supplementary cementitious materials or chemical admixtures
- May allow measurements before a steady state is achieved
- Can cause physical and chemical changes in the specimen, resulting in unrealistic values
- May not be suitable for concretes that contain conducting materials (such as steel or carbon fibers)
- Has low inherent repeatability and reproducibility

HALF CELL

- ***What is the Half Cell Potential Test?***

  In the presence of oxygen and humidity in the concrete, corrosion of the steel bars begins.

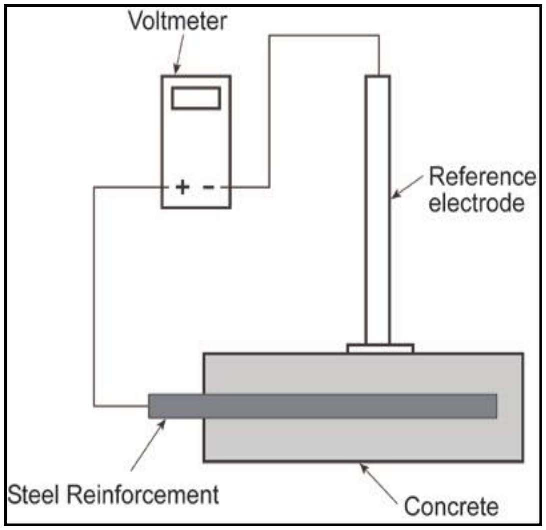
A symptom of the corrosion of steel in concrete is the development of macro cells, which is the co-existence of passive and corroding areas on the same reinforcement bar. The current flow in the steel is accompanied by an electrical field which is measured at the concrete surface, identifying the location of the most corroded areas at the most negative values.

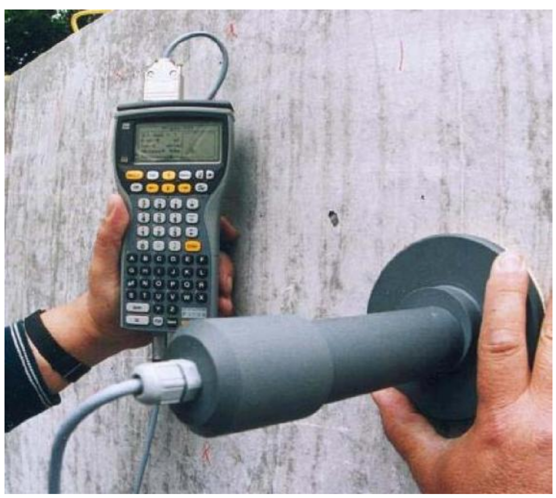
This is the basis of the half cell potential testing applied to the routine inspection of reinforced steel concrete structures. When surface measurements are taken, they are obviously measured away from the reinforcement due to the concrete cover. The potentials measured are therefore affected by the potential ohmic drop in the concrete. Several factors have a significant effect on the potentials measured

- Concrete Cover Depth
- Concrete Resistivity
- High Resistive Surface Layers
- Polarization Effects

- ***How do we do Half Cell Potential Testing?***

To measure half cell potentials, an electrical connection is made to the steel reinforcement in the concrete member to assess. This is connected to a high impedance digital multi meter, backed up with a data-logging device. The other connection to the milli-voltmeter is taken to a copper half cell, which has a porous connection at one end which can be touched to the concrete surface. This will then register the corrosion potential of the steel reinforcement nearest to the point of contact. We measure the results on a regular grid and by plotting results as a contour map areas of corroding steel may readily be seen. We never use this technique in isolation, but as part of a combined measurement of the chloride content of the concrete and its variation with depth and also the cover to the steel and the depth of carbonation.




PHENOLPHTHALEIN TEST

Carbonation of concrete is associated with the corrosion of steel reinforcement and with shrinkage. However, it also increases both the compressive and tensile strength of concrete, so not all of its effects on concrete are bad.

Carbonation is the result of the dissolution of CO_2 in the concrete pore fluid and this reacts with calcium from calcium hydroxide and calcium silicate hydrate to form calcite ($CaCO_3$). Aragonite may form in hot conditions.

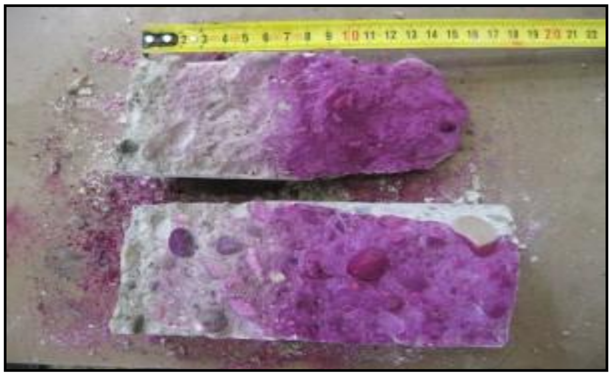
Within a few hours, or a day or two at most, the surface of fresh concrete will have reacted with CO_2 from the air. Gradually, the process penetrates deeper into the concrete at a rate proportional to the square root of time. After a year or so it may typically have reached a depth of perhaps 1 mm for dense concrete of low permeability made with a low water/cement ratio, or up to 5 mm or more for more porous and permeable concrete made using a high water/cement ratio.

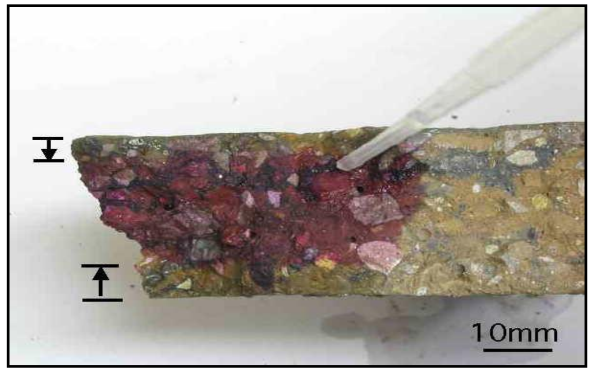
Testing for carbonation

The affected depth from the concrete surface can be readily shown by the use of phenolphthalein indicator solution. This is available from chemical suppliers. Phenolphthalein is a white or pale yellow crystalline material. For use as an indicator it is dissolved in a suitable solvent such as isopropyl alcohol (isopropanol) in a 1% solution.

The phenolphthalein indicator solution is applied to a fresh fracture surface of concrete. If the indicator turns purple, the pH is above 8.6. Where the solution remains colorless, the pH of the concrete is below 8.6, suggesting carbonation. A fully-carbonated paste has a pH of about 8.4. The phenolphthalein indicator solution is applied to a fresh fracture surface of concrete. If the indicator turns purple, the pH is above 8.6. Where the solution remains colorless, the pH of the concrete is below 8.6, suggesting carbonation. A fully-carbonated paste has a pH of about 8.4.

In practice, a pH of 8.6 may only give a faintly discernible slightly pink color. A strong, immediate, color change to purple suggests a pH that is rather higher, perhaps pH 9 or 10.





Normal concrete pore solution is saturated with calcium hydroxide and also contains sodium and potassium hydroxide; the pH is typically 13-14. Concrete with a pore solution of pH 10-12 is less alkaline than sound concrete but would still produce a strong color change with phenolphthalein indicator. It therefore follows that the indicator test is likely to underestimate the depth to which carbonation has occurred.

In confirmation of this, microscopy - either optical microscopy using thin-sections, or scanning electron microscopy using polished sections - shows carbonation effects at greater depths than indicated by phenolphthalein indicator. Nevertheless, this test is very useful as a means of making an initial assessment - it is quick, easy and widely used.

The indicator has not changed color near the top and bottom surfaces, suggesting that these near-surface regions are carbonated to a depth of at least 4 mm from the top surface and 6 mm from the lower surface. Where the indicator has turned purple - the center of the slab - the pH of the concrete pore fluid remains high (above 8.6, probably nearer 10). Whether the cement paste here is completely uncarbonated is unclear, despite the strong purple indicator color; a more complete assessment would require microscopic examination. Indicator was not applied to the concrete at the right of this image and so the concrete here retains its original color.

The carbonation depth is approximately proportional to the square root of time. For example, if the carbonation depth is 1mm in a one-year-old concrete, it will be about 3mm after 9 years, 5mm after 25 years and 10mm after 100 years.

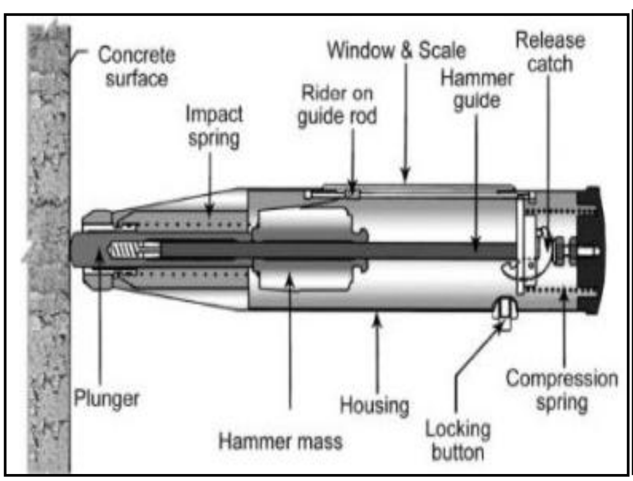
NON-DESTRUCTIVE TESTING OF CONCRETE

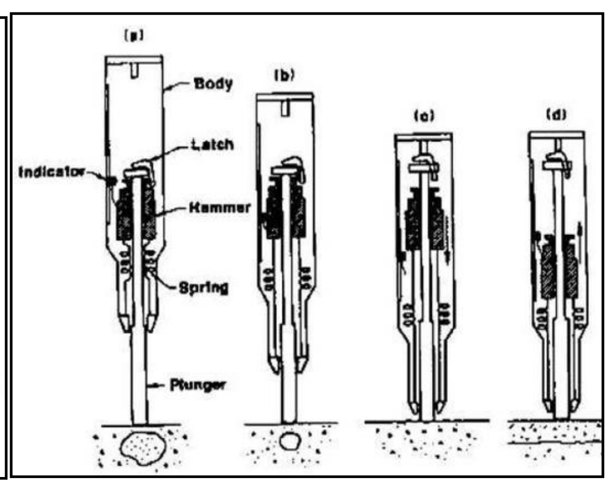
Non destructive test is a method of testing existing concrete structures to assess the strength and durability of concrete structure. In the non destructive method of testing, without loading the specimen to failure (i.e. without destructing the concrete) strength of concrete can be measured. Now days this method has become a part of quality control process. This method of testing also helps us to investigate crack depth, micro cracks and deterioration of concrete.

Non destructive testing of concrete is a very simple method of testing but it requires skilled and experienced persons having some special knowledge to interpret and analyze test results. Various non-destructive methods of testing concrete have been developed to analyze properties of hardened concrete, which are given below.

1. ***Surface Hardness Test* -** These are of indentation type, include the Williams testing pistol and impact hammers, and are used only for estimation of concrete strength.

2. ***Rebound Hammer Test*** - Rebound hammer test (Schmidt Hammer) is used to provide a convenient and rapid indication of the compressive strength of concrete. It consists of a spring controlled mass that slides on a plunger within a tubular housing. The operation of rebound hammer is shown in the figure below. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (rebound index). A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value.





The rebound hammer test method is used for the following purposes:

(a) To find out the likely compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength.

(b) To assess the uniformity of concrete.

(c) To assess the quality of concrete in relation to standard requirements.

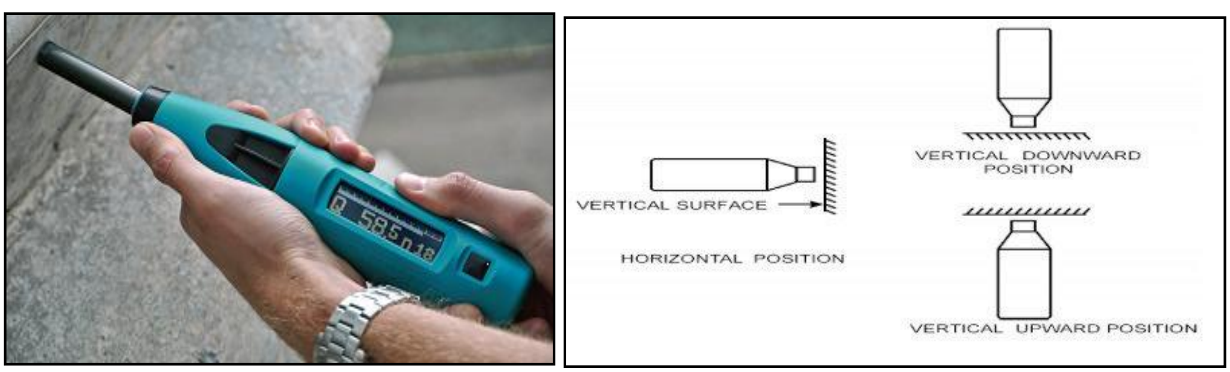
(d) To assess the quality of one element of concrete in relation to another.

Principle of Rebound Hammer Test

Rebound hammer test method is based on the principle that the rebound of an elastic mass depends on the hardness of the concrete surface against which the mass strikes. The operation of the rebound hammer is shown in figure above. When the plunger of rebound hammer is pressed against the concrete surface, the spring controlled mass in the hammer rebounds. The amount of rebound of the mass depends on the hardness of concrete surface. Thus, the hardness of concrete and rebound hammer reading can be correlated with compressive strength of concrete. The rebound value is read off along 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.

Procedure of Rebound Hammer Test

Procedure for rebound hammer test on concrete structure starts with calibration of the rebound hammer. For this, the rebound hammer is tested against the test anvil made of steel having Brinell hardness number of about 5000 N/mm^2. After the rebound hammer is tested for accuracy on the test anvil, the rebound hammer is held at right angles to the surface of the concrete structure for taking the readings. The test thus can be conducted horizontally on vertical surface and vertically upwards or downwards on horizontal surfaces as shown in figure below:



Rebound Hammer Positions for Testing Concrete Structure

If the rebound hammer is held at intermediate angle, the rebound number will be different for the same concrete.

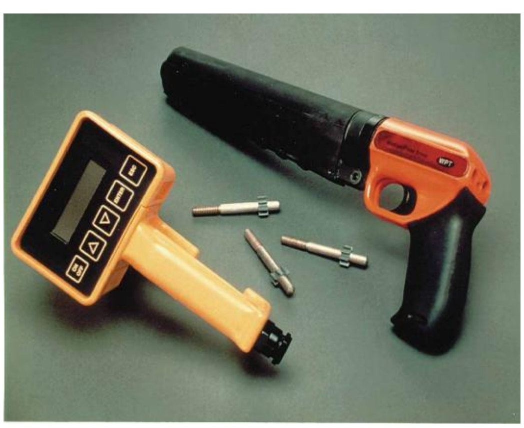
The following points should be observed during testing:

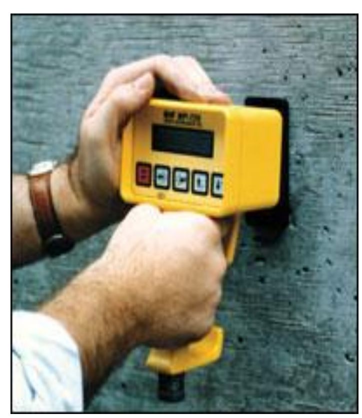
- The concrete surface should be smooth, clean and dry.
- Ant loose particles should be rubbed off from the concrete surface with a grinding wheel or stone, before hammer testing.
- Rebound hammer test should not be conducted on rough surfaces as a result of incomplete compaction, loss of grout, spalled or tooled concrete surface.
- The point of impact of rebound hammer on concrete surface should be at least 20mm away from edge or shape discontinuity.

Six readings of rebound number are taken at each point of testing and an average of value of the readings is taken as rebound index for the corresponding point of observation on concrete surface.

3. Penetration test

The Windsor probe is generally considered to be the best means of testing penetration. Equipment consists of a powder-actuated gun or driver, hardened alloy probes, loaded cartridges, a depth gauge for measuring penetration of probes and other related equipment. A probe, diameter 0.25 in. (6.5 mm) and length 3.125 in. (8.0 cm), is driven into the concrete by means of a precision powder charge. Depth of penetration provides an indication of the compressive strength of the concrete. Although calibration charts are provided by the manufacturer, the instrument should be calibrated for type of concrete and type and size of aggregate used.



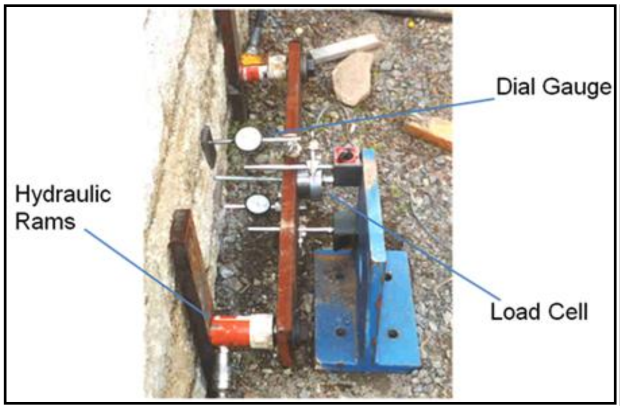


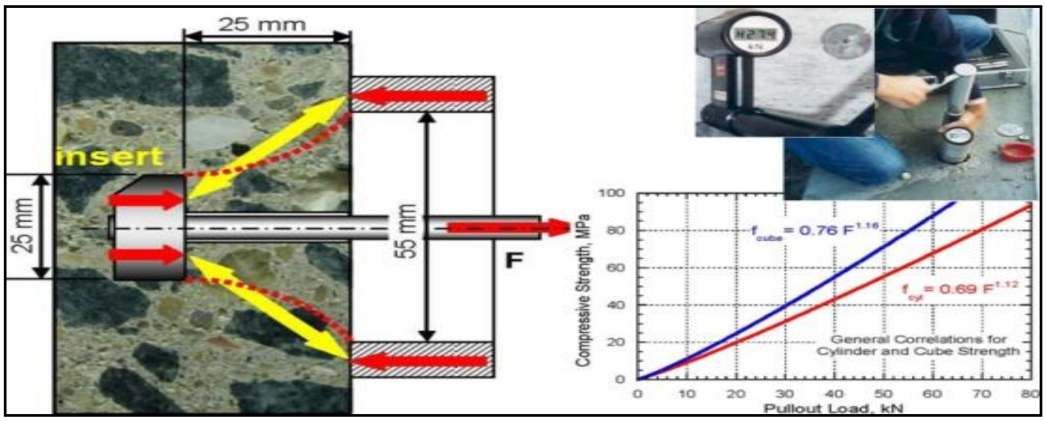
Limitations and Advantages

The probe test produces quite variable results and should not be expected to give accurate values of concrete strength. It has, however, the potential for providing a quick means of checking quality and maturity of in situ concrete. It also provides a means of assessing strength development with curing. The test is essentially non-destructive, since concrete and structural members can be tested in situ, with only minor patching of holes on exposed faces.

4. Pullout Techniques

A pull-out test measures, with a special ram, the force required to pull from the concrete a specially shaped steel rod whose enlarged end has been cast into the concrete to a depth of 3 in. (7.6 cm). The concrete is simultaneously in tension and in shear, but the force required to pull the concrete out can be related to its compressive strength. The pull-out technique can thus measure quantitatively the in-situ strength of concrete when proper correlations have been made. It has been found, over a wide range of strengths, that pull-out strengths have a coefficient of variation comparable to that of compressive strength.





<u>*Limitations and Advantages*</u>

Although pullout tests do not measure the interior strength of mass concrete, they do give information on the maturity and development of strength of a representative part of it. Such tests have the advantage of measuring quantitatively the strength of concrete in place. Their main disadvantage is that they have to be planned in advance and pull-out assemblies set into the formwork before the concrete is placed. The pull-out, of course, creates some minor damage. The test can be non-destructive, however, if a minimum pull-out force is applied that stops short of failure but makes certain that a minimum strength has been reached. This is information of distinct value in determining when forms can be removed safely.

5. *Dynamic or Vibration Tests*

At present the **ultrasonic pulse velocity method** is the only one of this type that shows potential for testing concrete strength in situ. It measures the time of travel of an ultrasonic pulse passing through the concrete. The fundamental design features of all commercially available units are very similar, consisting of a pulse generator and a pulse receiver. Pulses are generated by shock-exciting piezoelectric crystals, with similar crystals used in the receiver.

Piezoelectric crystals ***Ultrasonic pulse velocity tester***

The time taken for the pulse to pass through the concrete is measured by electronic measuring circuits. Pulse velocity tests can be carried out on both laboratory-sized specimens and completed concrete structures, but some factors affect measurement:

1. There must be smooth contact with the surface under test; a coupling medium such as a thin film of oil is mandatory.
2. It is desirable for path-lengths to be at least 12 in. (30 cm) in order to avoid any errors introduced by heterogeneity.
3. It must be recognized that there is an increase in pulse velocity at below-freezing temperature owing to freezing of water; from 5 to 30°C (41 – 86°F) pulse velocities are not temperature dependent.

4. The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity. It is therefore desirable and often mandatory to choose pulse paths that avoid the influence of reinforcing steel or to make corrections if steel is in the pulse path.

Applications and Limitations

The **pulse velocity method** is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction. Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective or deteriorated concrete is present. High pulse velocity readings are generally indicative of good quality concrete. A general relation between concrete quality and pulse velocity is given in Table.

General Conditions	Pulse Velocity ft/sec
Excellent	Above 15,000
Good	12,000-15,000
Questionable	10,000-12,000
Poor	7,000-10,000
Very Poor	below 7,000

Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within ±20 per cent, provided the types of aggregate and mix proportions are constant. The pulse velocity method has been used to study the effects on concrete of freeze-thaw action, sulphate attack, and acidic waters. Generally, the degree of damage is related to a reduction in pulse velocity. Cracks can also be detected. Great care should be exercised, however, in using pulse velocity measurements for these purposes since it is often difficult to interpret results. Sometimes the pulse does not travel through the damaged portion of the concrete.

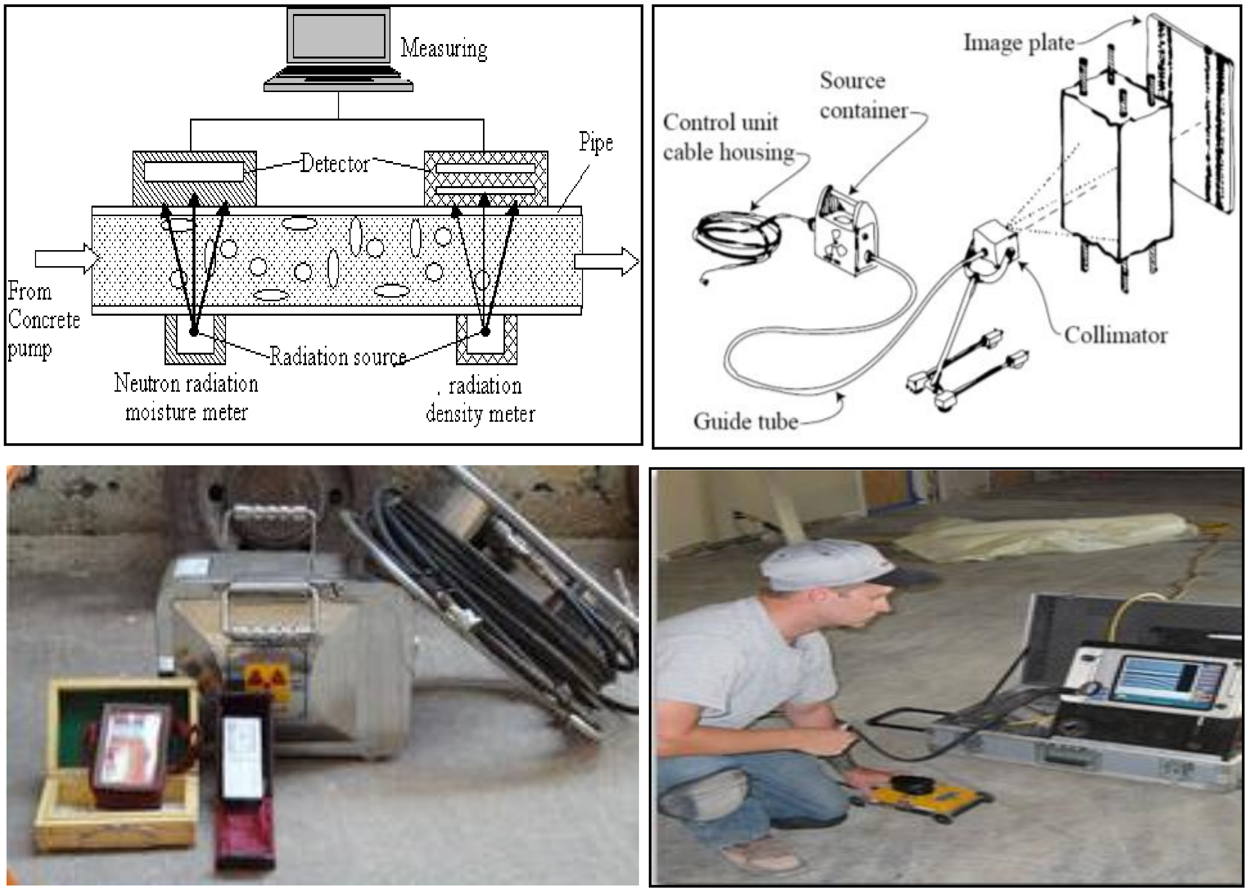
The pulse velocity method can also be used to estimate the rate of hardening and strength development of concrete in the early stages to determine when to remove formwork. Holes have to be cut in the formwork so that transducers can be in direct contact with the concrete surface. As concrete ages, the rate of increase of pulse velocity slows down much more rapidly than the rate of development of strength, so that beyond the strength of 2,000 to 3,000 psi (13.6 to 20.4 MPa) accuracy in determining strength is less than ±20%. Accuracy depends on careful calibration and use of the same concrete mix proportions and aggregate in the test samples used for calibration as in the structure.

In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

5. Radioactive Methods

Radioactive methods of testing concrete can be used to detect the location of reinforcement, measure density and perhaps establish whether honeycombing has occurred in structural concrete units.

Gamma radiography is increasingly accepted in England and Europe. The equipment is quite simple and running costs are small, although the initial price can be high. Concrete up to 18 in. (45 cm) thick can be examined without difficulty.



Radioactive Methods

<u>CONCEPT OF PROPORTIONING CONCRETE MIXES</u>

Introduction

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labor. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

Requirements of concrete mix design

- The requirements which form the basis of selection and proportioning of mix ingredients are The minimum compressive strength required from structural consideration
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

Types of Mixes

1. <u>Nominal Mixes</u>

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

2. <u>Standard mixes</u>

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

3. <u>Designed Mixes</u>

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

<u>Factors affecting the choice of mix proportions</u>

The various factors affecting the mix design are:

1. <u>Compressive strength</u>

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

2. <u>Workability</u>

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

3. <u>Durability</u>

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

4. <u>Maximum nominal size of aggregate</u>

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.

IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

5. <u>Grading and type of aggregate</u>

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.

The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

6. <u>Quality Control</u>

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

METHODS OF MIX DESIGN

Cement Concrete Mix Design means, determination of the proportion of the concrete ingredients i.e. Cement, Water, Fine aggregate, Coarse aggregate which would produce concrete possessing specified properties such as Workability, Strength and Durability with maximum overall economy. There are various methods followed for Mix Design. In this chapter, the discussion will be on two methods as follows;

- I.S. Method
- A.C.I. Method

INDIAN STANDARD METHOD OF MIX DESIGN OF CONCRETE

The Indian Standard (First Revision) was adopted by the Bureau of Indian Standards (BIS), after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1982. In this first revision, the following major modifications have been made:

- The title of the standard has been modified as 'Concrete mix proportioning - Guidelines' from the earlier title 'Recommended guidelines for concrete mix design'.
- The applicability of the standard has been specified for ordinary and standard concrete grades only.
- Various requirements have been modified in line with the requirements of IS 456: 2000 'Plain and reinforced concrete - Code of practice *(fourth revision).*

- The requirements for selection of water-cement ratio, water content and estimation of coarse aggregate content and fine aggregate content have been reviewed and accordingly modified. Similarly, other requirements such as trial mixes, illustrative examples, etc, have also been reviewed and modified.
- A new illustrative example of concrete mix proportioning using fly ash as one of the ingredients has been added.
- Considering that the air content in normal (non -air entrained) concrete is not of much significance in mix proportioning procedure and is also not a part of IS 456: 2000, the consideration of air content has been deleted.

The following points should be remembered before proportioning a concrete mix a per IS-10262-2009.

- This method of concrete mix proportioning is applicable only for ordinary and standard concrete grades.
- The air content in concrete is considered as nil.
- The proportioning is carried out to achieve specified characteristic compressive strength at specified age, workability of fresh concrete and durability requirements.

This method of concrete mix design consist of following 11 steps

1. Design specification
2. Testing of materials
3. Calculating target strength for mix proportioning
4. Selecting water/cement ratio
5. Calculating water content
6. Calculating cement content
7. Finding out volume proportions for Coarse aggregate & fine aggregate
8. Mix calculations
9. Trial mixing
10. Workability measurement (using slump cone method)
11. Repeating step 9 & 10 until all requirements is fulfilled.

STEP 1 - DESIGN SPECIFICATIONS

This is the step where we gather all the required information for designing a concrete mix from the client. The data required for mix proportioning is as follows.

- Grade designation (whether M10, M15, M20 etc)
- Type of cement to be used
- Maximum nominal size of aggregates
- Minimum & maximum cement content
- Maximum water-cement ratio
- Workability
- Exposure conditions (As per IS-456-Table-4)
- Maximum temperature of concrete at the time of placing
- Method of transporting & placing
- Early age strength requirement (if any)
- Type of aggregate (angular, sub angular, rounded etc)
- Type of admixture to be used (if any)

STEP 2 - TESTING OF MATERIALS

The table given below shows the list of most necessary tests to be done on cement, coarse aggregate, fine aggregate and admixture. After doing the test, store the test data for further calculation.

Concrete Ingredients	**Tests to be done**			
Cement	Specific gravity	—	—	—
Coarse aggregate	Specific gravity	Water absorption	Free surface moisture	Sieve analysis

Fine aggregate	Specific gravity	Water absorption	Free surface moisture	Sieve analysis
Admixture (if any)	Specific gravity	—	—	—

STEP 3 - TARGET STRENGTH CALCULATION

Calculate the target compressive strength of concrete using the formula given below.

$$f'_{ck} = f_{ck} + 1.65s$$

Where,

f'_{ck}= Target compressive strength at 28 days in N/mm^2.

f_{ck} = Characteristic compressive strength at 28 days in N/mm^2 (same as grade of concrete, see table

below)

s = Standard deviation

The value of standard deviation, given in the table below, can be taken for initial calculation.

Sl. No.	**Grade of Concrete**	**Characteristic compressive strength (N/mm^2)**	**Assumed standard deviation (N/mm^2)**
1	M10	10	3.5
2	M15	15	
3	M20	20	4.0
4	M25	25	
5	M30	30	6.0
6	M35	35	
7	M40	40	
8	M45	45	
9	M50	50	
10	M55	55	

STEP 4 - SELECTION OF WATER-CEMENT RATIO

For preliminary calculation, water cement ratio as given is IS-456-Table 5 (also given below) for different environmental exposure condition, may be used.

Note - Use **Table-1** for finding out water-cement ratio of **Plain Concrete** and use **Table-2** for finding out water-cement ratio of **Reinforced Concrete**.

Table -1

Sl.No.	Environmental Exposure Condition	Plain Concrete		
		Minimum Cement Content (kg/m3)	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1	Mild	220	0.60	—
2	Moderate	240	0.60	M15
3	Severe	250	0.50	M20
4	Very Severe	260	0.45	M20
5	Extreme	280	0.40	M25

Table -2

Sl.No.	Environmental Exposure Condition	Reinforced Concrete		
		Minimum Cement Content (kg/m3)	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1	Mild	300	0.55	M20
2	Moderate	300	0.50	M25
3	Severe	320	0.45	M30
4	Very Severe	340	0.45	M35
5	Extreme	360		

Refer the table given below (As per IS-456) to choose right type of environment depending upon different exposure conditions to concrete.

Sl. No.	Environment	Exposure condition
1	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal areas.
2	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet Concrete exposed to condensation and rain Concrete continuously under water Concrete in contact or buried under non aggressive soil/ground water Concrete surfaces sheltered from saturated salt air in coastal area
3	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation Concrete completely immersed in sea water Concrete exposed to coastal environment
4	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing condition whilst wet Concrete in contact with or buried under aggressive sub-soil/ground water
5	Extreme	Surface members in tidal zone Members in direct contact with liquid/solid aggressive chemicals

STEP 5 - SELECTION OF WATER CONTENT

Selection of water content depends upon a number of factors such as

- Aggregate size, shape & texture
- Workability
- Water cement ratio
- Type of cement and its amount
- Type of admixture and environmental conditions.

Factors that can reduce water demand are as follows

- Using increased aggregate size
- Reducing water cement ratio
- Reducing the slump requirement
- Using rounded aggregate
- Using water reducing admixture

Factors that can increase water demand are as follows

- Increased temp. at site
- Increased cement content
- Increased slump
- Increased water cement ratio
- Increased aggregate angularity
- Decrease in proportion of the coarse aggregate to fine aggregate

The quantity of maximum mixing water per unit volume of concrete may be selected from the table given below.

Maximum water content per cubic meter of concrete for nominal maximum size of aggregate		
Sl. No.	**Nominal maximum size of aggregate**	**Maximum water content**
1	10	208
2	20	186
3	40	165

The values given in the table shown above is applicable only for angular coarse aggregate and for a slump value in between 25 to 50mm.

Do the following adjustments if the material used differs from the specified condition.

Type of material/condition	Adjustment required
For sub angular aggregate	Reduce the selected value by 10kg
For gravel with crushed stone	Reduce the selected value by 20kg
For rounded gravel	Reduce the selected value by 25kg
For every addition of 25mm slump	Increase the selected value by 3%
If using plasticizer	Decrease the selected value by 5-10%
If using super plasticizer	Decrease the selected value by 20-30%

Note - Aggregates should be used in saturated surface dry condition. While computing the requirement of mixing water, allowance shall be made for the free surface moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregate are completely dry, the amount of mixing water should be increased by an amount equal to moisture likely to be absorbed by the aggregate

STEP 6 - CALCULATING CEMENTIOUS MATERIAL CONTENT

From the water cement ratio and the quantity of water per unit volume of cement, calculate the amount of cementious material. After calculating the quantity of cementious material, compare it with the values given in the table shown in Step-4. The greater of the two values is then adopted.

If any mineral admixture (such as fly ash) is to be used, then decide the percentage of mineral admixture to be used based on project requirement and quality of material.

STEP 7 - FINDING OUT VOLUME PROPORTIONS FOR COARSE AGGREGATE & FINE AGGREGATE

Volume of coarse aggregate corresponding to unit volume of total aggregate for different zones of fine aggregate is given in the following table.

Sl. No.	Nominal Maximum Size of Aggregate (mm)	Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate			
		Zone IV	Zone III	Zone II	Zone I
1	10	0.50	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

The values given in the table shown above is applicable only for a water-cement ratio of 0.5 and based on aggregates in saturated surface dry condition.

If water-cement ratio other than 0.5 is to be used then apply correction using the rule given below.

Rule- For every **increase or decrease** by **0.05** in **water-cement ratio**, the **above values** will be **decreased or increased** by **0.01,** respectively.

If the placement of concrete is done by a pump or where is required to be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined as above, up to 10 percent.

After calculating volume of coarse aggregate, subtract it from 1, to find out the volume of fine aggregate.

STEP 8 - MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be done as follows.

1	Volume of concrete	$1m^3$
2	Volume of cement	(Mass of cement/specific gravity of cement)*(1/1000)
3	Volume of water	(Mass of water/specific gravity of water)*(1/1000)
4	Volume of admixture	(Mass of admixture/specific gravity of admixture)*(1/1000)
5	Volume of total aggregate (C.A+F.A)	[a-(b+c+d)]
6	Mass of coarse aggregate	e*Volume of coarse aggregate*specific gravity of coarse aggregate*1000
7	Mass of fine aggregate	e*Volume of fine aggregate*specific gravity of fine aggregate*1000

STEP 9 - TRIAL MIXES

Conduct a trial mix as per the amount of material calculated above.

STEP 10 - MEASUREMENT OF WORKABILITY (BY SLUMP CONE METHOD)

The workability of the trial mix no.1 shall be measured. The mix shall be carefully observed for freedom from segregation and bleeding and its finishing properties.

STEP 11 - REPEATING TRIAL MIXES

If the measured workability of trial mix no.1 is different from stipulated value, the water and/or admixture content shall be adjusted suitably. With this adjustment, the mix proportion shall be recalculated keeping the free water-cement ratio at pre-selected value.

Trial-2 – increase water or admixture, keeping water-cement ratio constant

Trial-3 – Keep water content same as trial-2, but increase water-cement ratio by 10%.

Trial-4 – Keep water content same as trial-2, but decrease water-cement ratio by 10%

Trial mix no 2 to 4 normally provides sufficient information, including the relationship between compressive strength and water-cement ratio.

<u>ACI METHOD CONCRETE MIX DESIGN</u>

American Concrete Institute Method of Mix Design 11.3 - this method of **proportioning** was first published in 1944 by ACI committee 613. In 1954 the method was revised to include, among other modifications, the use of entrained air. In 1970, the method of ACI mix design became the responsibility of ACI committee 211. The latest is the ACI Committee 211.1 method.

It has the advantages of simplicity in that it:

1. Applies equally well
2. With more or less identical procedure to rounded or angular aggregate
3. To regular or light weight aggregates
4. To air entrained or non-air-entrained concretes.

The ACI Standard 211.1 is a "***Recommended Practice for Selecting Proportions for Concrete***".

The procedure is as follows:

Step 1 - Choice of slump

Step 2 - Choice of maximum size of aggregate

Step 3 - Estimation of mixing water and air content

Step 4 - Selection of water/cement ratio

Step 5 - Calculation of cement content

Step 6 - Estimation of coarse aggregate content

Step 7 - Estimation of Fine Aggregate Content

Step 8 - Adjustments for Aggregate Moisture

Step 9 - Trial Batch Adjustments

Step 1 - Choice of slump

If slump is not specified, a value appropriate for the work can be selected from the below Table which is reproduced from the text book below*, (note that the table numbers are given from the text book rather than the ACI standard).

Type of Construction	**Slump**	
	(mm)	**(inches)**
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

Step 2 - Choice of maximum size of aggregate

Large maximum sizes of aggregates produce fewer voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the ***maximum size of aggregate should be the largest available so long it is consistent with the dimensions of the structure.***

ACI 211.1 states that the maximum CA size should not exceed

- One-fifth of the narrowest dimension between sides of forms,
- One-third the depth of slabs,
- $3/4^{th}$ of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

Special Note: When high strength concrete is desired, best results may be obtained with reduced maximum sizes of aggregate since these produce higher strengths at a given w/c ratio.

Step 3 - Estimation of mixing water and air content

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump. In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum CA size, the shape and grading of CA and FA, as well as the amount of entrained air.

The approximate amount of water required for average aggregates is given in Table 1 below.

Table 1 - Approximate mixing water and air content requirements for different slumps and maximum aggregate sizes.

	Mixing Water Quantity in kg/m³ (lb/yd³) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm (0.375 in.)	12.5 mm (0.5 in.)	19 mm (0.75 in.)	25 mm (1 in.)	37.5 mm (1.5 in.)	50 mm (2 in.)	75 mm (3 in.)	100 mm (4 in.)
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4 - Selection of water/cement ratio

The required water/cement ratio is determined by strength, durability and finishing. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table 2 and/or Table 3

Table 2 - Water-Cement ratio and compressive strength relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table 3 - Water-Cement Ratio and Compressive Strength Relationship

Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

* Concrete should also be air-entrained.

Step 5 - Calculation of cement content

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

Step 6 - Estimation of coarse aggregate content

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	2.60	2.80	3.00
9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes

- These values can be increased by up to about 10 percent for pavement applications.
- Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29

The ACI method is based on large numbers of experiments which have shown that for properly graded materials, the finer the sand and the larger the size of the particles in the CA, the more volume of CA can be used to produce a concrete of satisfactory workability.

Step 7 - Estimation of Fine Aggregate Content

At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate. Then once the volumes are know the weights of each ingredient can be calculated from the specific gravities.

Step 8 - Adjustments for Aggregate Moisture

Aggregate weights Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

Amount of mixing water If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Step 9 - Trial Batch Adjustments

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishing, unit weight, air content and strength.

TESTING, EVALUATION AND CONTROL OF CONCRETE QUALITY

Satisfactory concrete construction and performance requires concrete with specific properties. To assure that these properties are obtained, quality control and acceptance testing are indispensable parts of the construction process. Test results provide important feedback used to base decisions regarding mix adjustments. However, past experience and sound judgment must be relied on in evaluating tests and assessing their significance in controlling the design, batching and placement processes that influence the ultimate performance of the concrete.

Specifiers are moving toward performance-based specifications (also called end-result or end-property specifications) that require the final performance of concrete be achieved independent of the process used to achieve the performance. Physical tests and concrete properties are used to measure acceptance. Such specifications may not have acceptance limits for process control tests such as slump or limits on the quantities of concrete ingredients as do prescriptive specifications. The end result of compressive strength, low permeability, documented durability, and a minimal number of cracks, for example, would be the primary measure of acceptance. Of course, even though process control tests may not be specified, the wise concrete producer would use them to guide the product to a successful end result.

Project specifications may affect

- Characteristics of the mixture, such as maximum size of aggregate, aggregate proportions, or minimum cement content;
- Characteristics of the cement, water, aggregates, and admixtures; and
- Characteristics of the freshly mixed and hardened concrete, such as temperature, slump, air content, and compressive or flexural strengths.

Cementitious materials are tested for their compliance with CSA (ASTM) standards to avoid any abnormal performance such as early stiffening, delayed setting, or low strengths in concrete. Standards for Cementitious materials are contained in CSA A-3000-98, Cementitious Materials Compendium.

Tests of **aggregates** have two major purposes:

- To determine the suitability of the material itself for use in concrete, including tests for abrasion, soundness against saturated freeze-thaw cycles, harmful materials by petro graphic examination, and potential alkali-aggregate reactivity; and
- To assure uniformity, such as tests for moisture control, relative density, and gradation of aggregates.
- To determine their potential alkali-aggregate

Tests of **concrete** are:

- To evaluate the performance of available materials,
- To establish mixture proportions, and
- To control concrete quality during construction

Slump, air content, and strength tests are usually required in project specifications for concrete quality control, whereas density is more useful in mixture proportioning. The slump, air-content, and temperature tests should be made when strength specimens are made.