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Lab manual Civil engineering lab -1

(3rd Semester)

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Measuring Young’s modulus with a tensile tester

Abstract
We use a tensile testing machine to create stress-strain plots and determine Young’s modulus for some ductile and plastic materials. Supplementary videos are also provided.

Keywords: elasticity, materials science, physics education

Young’s modulus is a key concept in elasticity theory and mechanics of solids [1, 2]. Measurements of Young’s modulus in a classroom setting have been studied many times in the literature. These studies typically focus on simple orinexpensive ways of measuring Young’s modulus [3, 4]. Related studies describe alternative indirect ways of measuring the modulus [5, 6]. Nunn, for example, developed a technique for classroom use by which one can determine the Young’s modulus of a solid using the speed of sound in that material [7]. In this article, we will perform accurate measurements with a tensile testing machine to create stress-strain plots anddetermine Young’s modulus for several materials. We also discuss some possible limitations of our method of measurement.

Young’s modulus is defined to be the ratio:

$$E = \frac{\sigma}{\epsilon} = \frac{F/A}{dl/l}$$

where is the tensile strength (defined as force applied per unit area), is the tensile strain (defined as displacement per unit length), F is the applied lengthwise force, A is the cross sectional area of the sample, L is the total displacement, and l is the test length which was initially between the two grippers in the device. This ratio defines how a sample of material deforms in a response to a force which is applied lengthwise. The stress analysis device which we use to measure this modulus in our demonstration is the Tinius Olsen 25ST with a 25 KN load cell. We will mention here that the device and analysis software which we use are somewhat sophisticated and will likely only be available at a metrology laboratory at a university. High school students may be able to contact a technician at an Engineering department at a local university and ask if they can view a demonstration. The novelty of our result is to present complete stress–strain plots which are hard to obtain in a classroom environment with limited equipment.The technical method which we have used in carrying out our experiments can be compared with measurements which students can obtain using alternative means. We also provide several videos of the tests which may be useful to students.Note that we have chosen everyday materials for

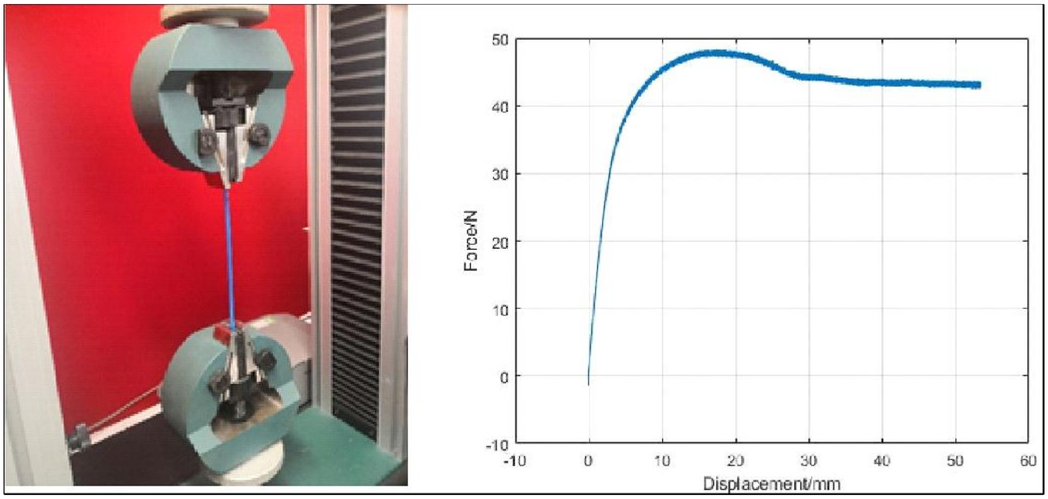

***Figure** 1. Stress testing with a plastic straw (left) and the associated force-displacement plot (right).*

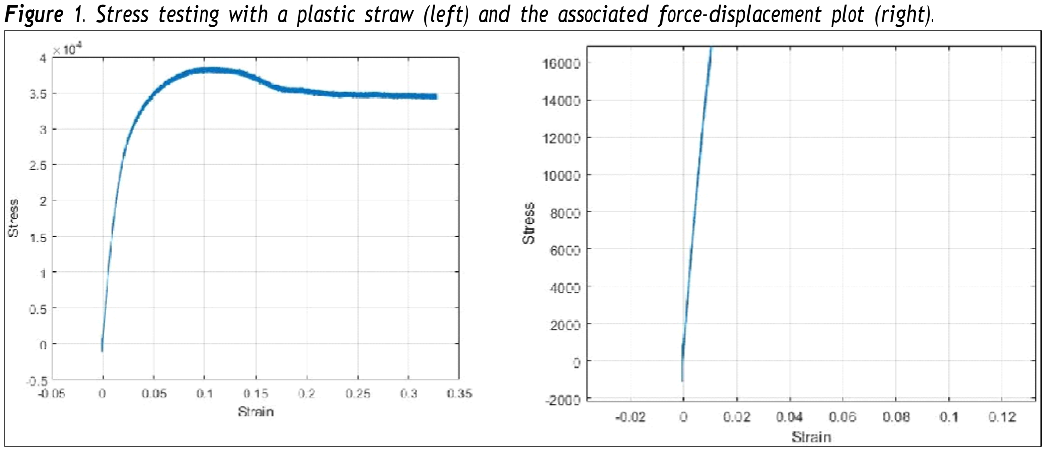

***Figure 2**. Stress–strain plot for a plastic straw (left) and the linear region (right).*

our tests to aid with comparisons in a classroom environment.

*A pedagogical point here is that different materials can have very different relationships between stress and strain. For example, students might intuitively think that a plastic straw would not have much resistance to stress because the straw is easy to cut or snap. However, in figure 1, we show a plastic straw (similar to a drinking straw) being used in our apparatus, along with the raw force-displacement plot. This plot can be converted to a stress-strain plot by dividing the force by the cross sectional area and the displacemen by the original test length. This is done in figure 2 (left-hand image) to produce a stress–strain plot for the plastic straw. We can see from the plot that the plastic straw has an initial elastic region where the relationship between the stress and the strain is close to linear. In the mathematical modelling of elasticity phenomena, this is known as linear elasticity. Since **E** is defined as the ratio of tensile strength to tensile strain, students should know that Young's modulus can be found by taking the gradient of the curve in figure 2. This only holds when the graph is linear because Young's modulus is*

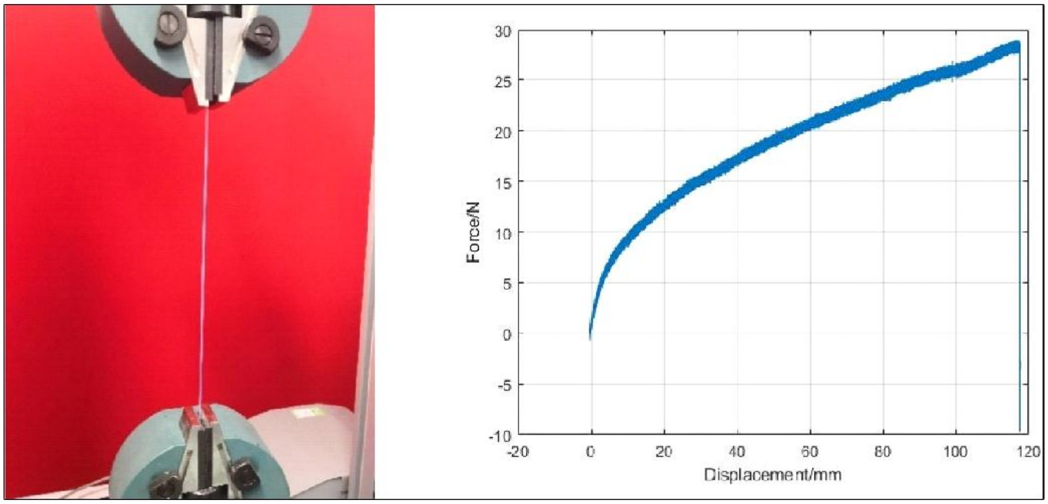

Figure 3. *Stress testing with flexible plastic cord (left) and the associated force-displacement plot (right).*

strictly speaking not valid outside of the linear elastic region. This turning point where the graph stops being linear is called the elastic limit and at this point, the material becomes stretched and deformed far enough that non-linear effects are introduced and the material cannot return to its original length [2]. This can be checked afterwards by seeing that the top of the straw has been stretched into a position from which it cannot recover.

In figure 2 (right-hand image), we zoom in on the region of the stress-strain plot which is approximately a straight line. Young's modulus can now be found from the gradient of this line. In this case, E = 1.75 × 105 Pa, or 1.75 GPa. The type of irreversible deformation which occurs beyond the elastic limit due to dislocations of the material on the atomic scale is typically known as plastic deformation in the literature. This is to be contrasted with an elastic deformation, which is reversible and does not cause a permanent change to the structure of the material. In figure 3, we figure 3, we repeat the experiment with flexible plastic wire cord. Students might guess that since the material is flexible, it will have a lot of resistance to tensile strain and that it will stretch out by a large displacement before suddenly breaking. This approximate behaviour is indeed observed in figure 3. The applied force is lower than the force for figure 1,

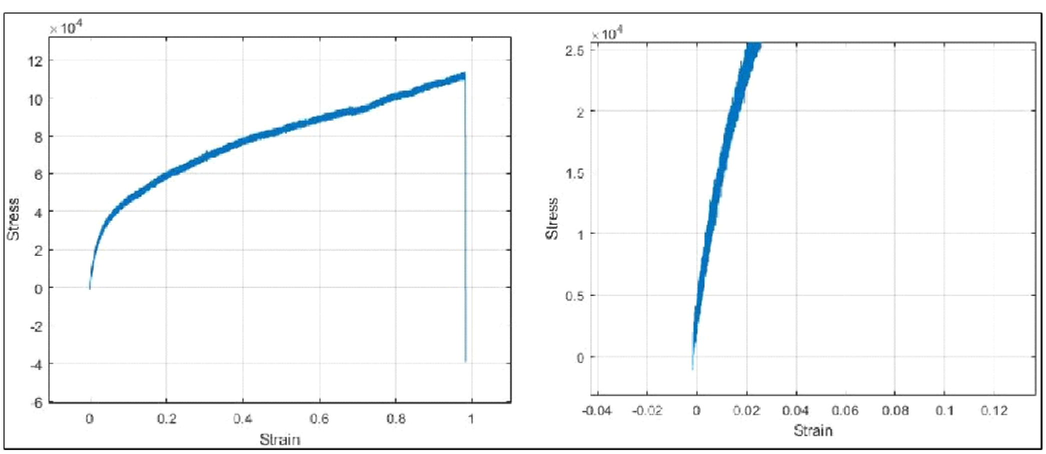

Figure 4. Stress–strain plot for a plastic cord (left) and the linear region (right).

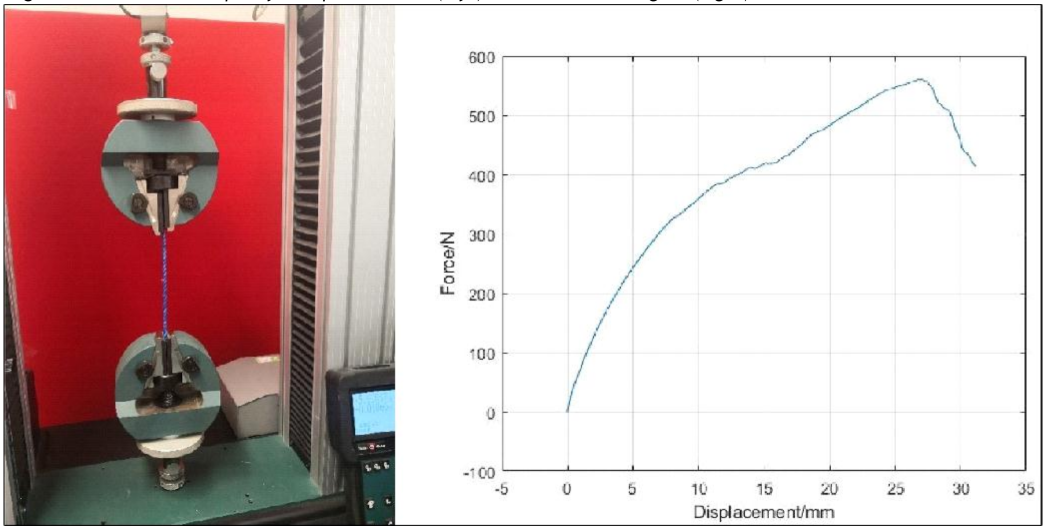

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Figure 5. Stress testing with nylon rope with a force-displacement diagram.

between that of a brittle and a ductile material. The rope is clearly not ductile, since as stated earlier, ductile materials like steel typically yield under an applied force, before hardening and then finally breaking (see figure 1 for an example). We have also included videos in the supplementary material so that students can see the tests being performed on the apparatus. In video 1, we use the rope sample and demonstrate how the rope sample is pulled until it is tense. As the name of the device suggests, it is necessary to have this tension before we can perform any measurements. In video 2 (sped up 4×), we show the stress test being performed on the plastic cord. Note how after some time the cord starts to turn white (corresponding to hardening and passing beyond the elastic region) before the cord finally breaks. In video 3 (also sped up 4×), we show the stress test for the plastic straw. It can be clearly seen the straw is stretched by a substantial amount.

FINENESS OF CEMENT

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence faster the development of strength. The fineness of grinding has increased over the years. But now it has got nearly stabilized. Different cements are ground to different fineness. The particle size fraction below 3 microns has been found to have the predominant effect on the strength at one day while 3-25 micron fraction has a major influence on the 28 days strength. Increase in fineness of cement is also found to increase the drying shrinkage of concrete.

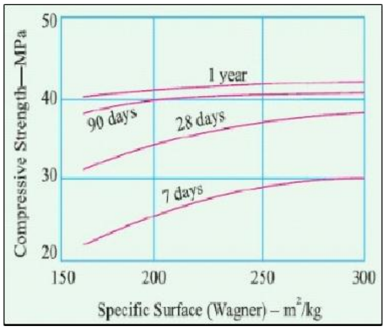


Fig. 1: Specific Surface versus Compressive Strength of Cement

Fineness of cement is tested in two ways :

- *By sieving.*
- *By determination of specific surface (total surface area of all the particles in one gram of cement) by air-permeability apparatus. Expressed as cm²/gm or m2/kg. Generally Blaine Air permeability apparatus is used.*

- ## *Apparatus Required*

Fig. 2: Cement

The samples of the cement shall be taken according to the requirements of IS 3535:1986 and the relevant standard specification for the type of cement being tested. The representative sample of the cement selected as above shall be thoroughly mixed before testing.

Fig. 3: Balance

Balance be capable of weighing up to 10 g to the nearest 10 mg.


Fig. 4: Sieve

It comprises a firm, durable, non-corrodible, cylindrical frame of 150 mm to 200 mm nominal diameter and 40 mm to 100 mm depth, fitted with 90 micron mesh sieve cloth of woven stainless steel, or other abrasion-resisting and non- corrodible metal wire.
The sieve cloth shall comply with the requirements of IS 460 (Part 1):1985 and IS 460 (Part 3):1985 and shall be free of visible irregularities in mesh size when inspected optically by the methods of IS 460 (Part 3):1985. A tray fitting beneath the sieve frame and a lid fitting above it shall be provided to avoid loss of material during sieving.

Fig. 5: Nylon Bristol Brush


For cleaning of sieve.

- ## *Reference*

IS 4031(Part 1):1996 Methods of Physical Tests for Hydraulic Cement: Determination of Fineness by Dry Sieving (second revision). Reaffirmed- May 2016

- ## *Procedure*

  - *Agitate the sample of cement to be tested by shaking for 2 min in a stoppered jar to disperse agglomerates. Wait 2 min. Stir the resulting powder gently using a clean dry rod in order to distribute the fines throughout the cement.*
  - *Fit the tray under the sieve, weigh approximately 10 g of cement to the nearest 0.01 g and place it on the sieve, being careful to avoid loss. Disperse any agglomerates. Fit the lid over the sieve. Agitate the sieve by swirling, planetary and linear movement until no more fine material passes through it. Remove and weigh the residue. Express its mass as a percentage, R_1, of the quantity first placed in the sieve to the nearest 0.1 percent. Gently brush all the fine material off the base of the sieve into the tray.*
  - *Repeat the whole procedure using a fresh 10 g sample to obtain R_2. Then calculate the residue of the cement 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.*
  - *Check the sieve after every 100 sieving as per para 4.4.2 of IS: 4031 (Part 1)*

5. Observation

- *The fineness of a given sample of cement is_______________________%*
- *Report the value of R, to the nearest 0.1 percent, as the residue on the 90 micron sieve for the cement tested.*

The standard deviation of the repeatability is about 0.2 percent and of the reproducibility is about 0.3 percent.

INITIAL AND FINAL SETTING TIME OF CEMENT

- ## Objective

For convenience, initial setting time is regarded as the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure. The temperature of moulding room, dry materials and water shall be maintained at 27 ±2°C. The relative humidity of the laboratory shall be 65 ±5 percent.

- ## Apparatus Required

Fig. 1: Balance

On balance in use, the permissible variation at a load of 1000 g shall be ± 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall be not greater than twice the permissible variation.

Fig. 2: Vicat's Apparatus

Vicat apparatus should confirm to IS : 5513-1976. It consists of an arrangement to hold the plunger of 10 mm diameter and two other needles which are made to freely fall into a mould filled with the cement paste and the amount of penetration of the needles of plunder can be noted using the vertical graduations from 0 mm to 50 mm.

Fig. 3: Stop Watch

Fig. 4: Gauging Trowel

Gauging trowel conforming to IS : 10086-1982

- ***Reference***

IS 4031(Part 5):1988 Methods of Physical test for Hydraulic Cement:Determination of Initial and Final Setting Times. Reaffirmed- May 2014

- ***Procedure***

Preparation of Test Block

- *Prepare a neat cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency. Potable or distilled water shall be used in preparing the paste. The paste shall be gauged in the manner and under the conditions prescribed in IS:4031 (Part 4)-1988.*
- *Start a stop-watch at the instant when water is added to the cement. Fill the Vicat mould with a cement paste gauged as above, the mould resting on a nonporous plate. Fill the mould completely 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.*
- *Immediately after moulding, place the test block in the moist closet or moist room and allow it to remain there except when determinations of time of setting are being made.*

Determination of Initial Setting Time

- *Place the test block confined in the mould and resting on the non-porous plate, under the rod bearing the needle (C); lower the needle gently until it comes in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block. In the beginning, the needle will \ completely* *pierce the test block.*

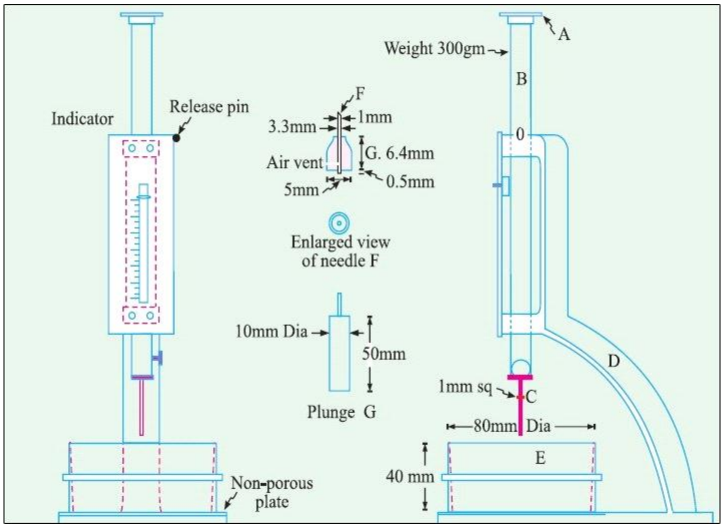


Fig. 5: Needles used in Vicat's Apparatus

- *Repeat this procedure until the needle, when brought in contact with the test block and released as described above, fails to pierce the block beyond 5.0 ±0.5 mm measured from the bottom of the mould. The period elapsing between the time when water is added to the cement and the time at which the needle fails to pierce the test block to a point 5.0 ±0.5 mm measured from the bottom of the mould shall be the initial setting time.*

Determination of Final Setting Time

- *Replace the needle (**C**) of the Vicat apparatus by the needle with an annular attachment (**F**).*
- *The cement shall be considered as finally set when, upon applying the needle gently to the surface of the test block, the needle makes an impression thereon, while the attachment fails to do so.*
- *The period elapsing between the time when water is added to the cement and the time at which the needle makes an impression on the surface of test block while the attachment fails to do so shall be the final setting time.*
- *In the event of a scum forming on the surface of the test block, use the underside of the block for the determination.*

• *Observation And Recording*

Weight of given sample of cement is____________________gms
Volume of water addend (0.85 times the water required to give a paste of standard consistency) for preparation of test block_________________ml
The normal consistency of a given sample of cement is__________________________%

S. No.	***Setting Time (second)***	***Penetration(mm)***
1		
2		
3		

***Table 1** : Initial and Final Setting Time of Cement*

• *Conclusion / Result*

- *The initial setting time of the cement sample is found to be ….. (shall be reported to the nearest five minutes.)*
- *The final setting time of the cement sample is found to be ….. (shall be reported to the nearest five minutes.)*

- ***Objective***

SOUNDNESS TEST OF CEMENT

It is very important that the cement after setting shall not undergo any appreciable change of volume. Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This will cause serious difficulties for the durability of structures when such cement is used. The unsoundness in cement is due to the presence of excess of free lime than that could be combined with acidic oxide at the kiln. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement. Soundness of cement may be determined by two methods, namely Le-Chatelier method and autoclave method.

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is speeded up and can be detected. Soundness means the ability to resist volume expansion.

- ***Apparatus Required***

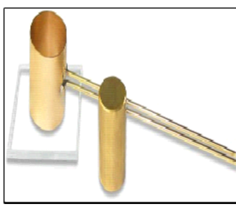


Fig. 1: Le-Chateliers Apparatus

Le- Chatelier apparatus conforming to IS : 5514-1969

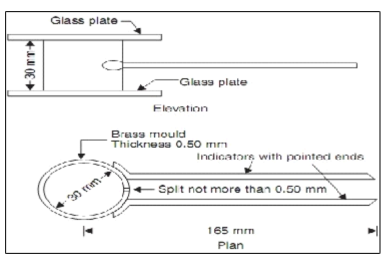


Fig. 2: Schematic of Le-Chateliers Apparatus

Consist of a small split cylinder of spring brass to other non-corrodible metal of 0.5mm thickness forming a mould of 30mm internal diameter and 30mm high. On either side of the split, two indicators are brazed suitably with pointed ends made of 2mm diameter brass wire in such a way that the distance of these ends to the centre of the cylinder is 165mm. The split cylinder will be

kept between two glass plates. The temperature of the moulding room,
dry materials and water shall be maintained at 27±2°C The relative humidity of the laboratory shall be 65 ±5 percent. The moist closet or moist room shall be maintained at 27 ±2°C and at a relative humidity of not less than 90 percent.

Fig. 3: Water bath

Water bath capable of containing immersed Le-Chatelier moulds with specimens and of raising their temperature from 27±2°C to boiling in 27±3 minutes.

Fig. 4: Vernier Calliper

Vernier Calliper should be able to measure upto 30 mm with least count of 0.1 mm

Fig. 5: Balance

On balance in use, the permissible variation at a load of 1000 g shall be ±1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall be not greater than twice the permissible variation.

Weights

The permissible variations on weights in use in weighing the cement shall be as prescribed in Table 1.

Table 1 : Permissible Variations on Weights

Weight (g)	Permissible Variation on Weights in use Plus or Minus (g)
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15
50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

- ## *Reference*

IS 4031(Part 3):1988 Methods of Physical Test for Hydraulic Cement: Determination of Soundness. Reaffirmed-May 2014

- ## *Procedure*

  - *Place the lightly oiled mould on a lightly oiled glass sheet and fill it with cement paste formed by gauging cement with 0.78 times the water required to give a paste of standard consistency. [refer IS : 4031 (Part 4)-1988].*
  - *Cover the mould with another piece of lightly oiled glass sheet, place a small weight on this covering glass sheet and immediately submerge the whole assembly in water at a temperature of 27 ±2°C and keep there for 24 hours.*
  - *Measure the distance separating the indicator points to the nearest 0.5 mm. Submerge the mould again in water at the temperature prescribed above.*
  - *Bring the water to boiling, with the mould kept submerged, in 25 to 30 minutes, and keep it boiling for three hours. Remove the mould from the water, allow it to cool and measure the distance between the indicator points.*
  - *The difference between these two measurements indicates the expansion of the cement. This must not exceed 10 mm for ordinary, rapid hardening and low heat Portland cements. If in case the expansion is more than 10 mm as tested above, the cement is said to be unsound.*

- ## *Observation And Recording*

Soundness/expansion of cement = L1-L2

L1=Measurement taken after 24 hours of immersion in water at a temp. of 27 ±2^{0C}

L2=Measurement taken after 3 hours of immersion in water at boiling temperature.

Calculate the mean of two values to the nearest 0.5 mm.

- ## *Discussions*

- *In the event of cement failing to comply with the specified requirements, a further test should be made from another portion of the same sample in manner described above, but after aeration (done by*

spreading out to a depth of 75 mm and store it for 7 days in an atmosphere maintained at 27±2°C and relative humidity of 50 to 80 percent).

- *Volume expansion in cement mortar or in cement concrete is caused by the presence of unburnt lime (CaO), dead burnt MgO and also $CaSO_4$.*
- *By Le-chatelier method we can only find out presence of unburnt lime (CaO).*
- *Presence of unburnt lime may develop cracks in the cement because of increase in volume.*
- *Free lime (CaO) and Magnesia (MgO) are known to react with water very slowly and increase in volume considerably, which result in cracking, distortion and disintegration.*

- ***Objective***

COMPRESSIVE STRENGTH OF CEMENT

The compressive strength of hardened cement is the most important of all the properties. Therefore, it is not surprising that the cement is always tested for its strength at the laboratory before the cement is used in important works. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement.

- ***Apparatus Required***

Fig. 1: Standard Sand

Standard Sand to be used in the test shall conform to IS : 650-1966

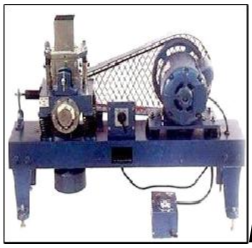


Fig. 2: Vibration Machine

Vibration Machine conforming to IS: 10080-1982

Fig. 3: Cube Mould

Cube Mould of 70.6 mm size conforming to IS : 10080-1982

Fig. 4: Compression Testing Machine

Compression Testing Machines conform to IS: 14858(2000) and calibrated with an accuracy of ±1% as per the requirement of 1828(Class1).

Fig. 5: Balance

On balance in use, the permissible variation at a load of 1000 g shall be ± 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall be not greater than twice the permissible variation.


Fig. 6: Graduated Glass Cylinders

Graduated glass cylinders of 150 to 200 ml capacity. The permissible variation on these cylinders shall be ±1 ml. The main graduation lines of the cylinders shall be in circles and shall be numbered. The least graduations shall extend at least one seventh of the way around, and, intermediate graduations shall extend at least one-fifth of the way around the cylinder. The graduation lines may be omitted for the lowest 5 ml.

- ***Reference***

IS 4031(Part 6):1988 Methods of Physical Tests for Hydraulic Cement- Determination of Compressive Strength of Hydraulic Cement other than Masonry Cement (First revision). Reaffirmed- May 2014

- ***Procedure***

  - *Preparation of test specimens - Clean appliances shall be used for mixing and the temperature of water and that of the test room at the time when the above operations are being performed shall be 27 ±2°C. Potable/distilled water shall be used in preparing the cubes.*
  - *The material for each cube shall be mixed separately and the quantity of cement, standard sand and water shall be as follows:*
    Cement 200 g and Standard Sand 600 g
    Water ((P/4)+3.0) percent of combined mass of cement and sand, where P is the percentage of water required to produce a paste of standard consistency determined as described in IS : 4031 (Part 4)-1988
  - *Place on a nonporous plate, a mixture of cement and standard sand. Mix it dry with a trowel for one minute and then with water until the mixture is of uniform colour. The quantity of water to be used shall be as specified in step 2. The time of mixing shall in any event be not less than 3 min and should the time taken to obtain a uniform colour exceed 4 min, the mixture shall be rejected and the operation repeated with a fresh quantity of cement, sand and water.*
  - *Moulding Specimens - In assembling the moulds ready for use, treat the interior faces of the mould with a thin coating of mould oil.*
  - *Place the assembled mould on the table of the vibration machine and hold it firmly in position by means of a suitable clamp. Attach a hopper of suitable size and shape securely at the top of the mould to facilitate filling and this hopper shall not be removed until the completion of the vibration period.*
  - *Immediately after mixing the mortar in accordance with step 1 & 2, place the mortar in the cube mould and prod with the rod. Place the mortar in the hopper of the cube mould and prod again as specified for the first layer and then compact the mortar by vibration.*
  - *The period of vibration shall be two minutes at the specified speed of 12000 ±400 vibration per minute.*
  - *At the end of vibration, remove the mould together with the base plate from the machine and finish the top surface of the cube in the mould by smoothing the surface with the blade of a trowel.*
  - *Curing Specimens - keep the filled moulds in moist closet or moist room for 24 ±1 hour after completion of vibration. At the end of that period, remove them from the moulds and immediately submerge in clean fresh water and keep there until taken out just prior to breaking.*
  - *The water in which the cubes are submerged shall be renewed every 7 days and shall be maintained at a temperature of 27 ±2°C. After they have been taken out and until they are broken, the cubes shall not be allowed to become dry.*
  - *Test three cubes for compressive strength for each period of curing mentioned under the relevant*

specifications (i.e. 3 days, 7 days, 28 days)

- The cubes shall be tested on their sides without any packing between the cube and the steel plattens of the testing machine. One of the plattens shall be carried on a base and shall be self- adjusting, and the load shall be steadily and uniformly applied, starting from zero at a rate of 35 $N/mm^{2}/min$.

- **Observation And Recording**

Sr. No.	Age of Cube	Cross Sectional Area(mm^2)	Load (N)	Compressive Strength (N/mm^2)	Avg. Compressive Strength (MPa)
1	3 days				
2					
3					
4	7 days				
5					
6					
7	28 days				
8					
9					

Table 1 : Recordings during Compressive Test on Cement

- **Calculation**

The measured compressive strength of the cubes shall be calculated by dividing the maximum load applied to the cubes during the test by the cross-sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest 0.5 N/mm^2. In determining the compressive strength, do not consider specimens that are manifestly faulty, or that give strengths differing by more than 10 percent from the average value of all the test specimens. After discarding specimens or strength values, if less than two strength values are left for determining the compressive strength at any given period, a retest shall be made.

- The average 3 Days Compressive Strength of given cement sample is found to be ....
- The average 7 Days Compressive Strength of given cement sample is found to be ....
- The average 28 Days Compressive Strength of given cement sample is found to be ....

FLY ASH BRICK

Description of item: Fly ash brick as per IS 12894-2002

Note: This item is already covered in Unified SOR 2010 item no. 055090. However it has been observed that fly ash bricks are not being used though it is beneficial in view of environmental protection as well as cost.

Available sizes- For Modular Size

Length 190±4mm

Width 90±2 mm

Height 90±2 mm and 40±2 mm

For Non-modular Size
Length 230±4mm

Width 110±2 mm

Height 70±2 mm and 30±2 mm

Composition of normal clay bricks and fly ash bricks

Fly Ash Bricks	***Normal Clay Bricks***
A) Fly ash- 60-65%	*Silica (sand) - 50% to 60%*
Sand/Stone dust- 20-25%	*Alumina (clay) - 20% to 30%*
Hydrated lime- 8-12% *Gypsum-5%*	*Lime – 2 to 5%* *Iron oxide - ≤ 7%*
B) Fly ash- 50% to 60%	*Magnesia - less than 1%*
Sand/stone dust - 32%-40%	
Cement - 8-10%	

Merits & Demerits of

fly ash bricks- Merit of

Fly Ash Brick:

- *Fly ash bricks are light weight, therefore, transportation is easy.*
- *Fly ash bricks are uniform in shape and size in comparison to burnt clay brick, therefore, require less mortar in brick work and finishing work resulting saving of cement mortar.*
- *As, fly ash brick are machine made, quality control is better in comparison to burnt clay bricks. 4- Fly ash bricks are environment friendly as:*
  - *It is a green building product and recommended in LEED & TERI-GRIHA systems.*
  - *It uses fly ash, which is a waste - product of thermal power plants having no value itself.*
  - *Saves agricultural land which is used for manufacturing clay bricks.*
  - *Less energy intensive compared to clay bricks and help in keeping clean environment.*

Demerit of Fly Ash Brick:

- *Mechanical bonding strength is weak. But this can be improved by adding marble/ stone dust and cementing materials.*
- *Limitation of size. Only modular size can be produced.*
- *Air exchange is poor incomparison to normal clay bricks. Hence proper ventilation of house is important.*

Comparison of Clay brick and Fly ash Brick:

Clay Brick	***Fly Ash Brick***
Not in uniform colour as the colour of brick depends upon type of soil and quality control during production.	*The colour of fly ash brick is same as the manufacturing is carried out using machinery in controlled condition.*
Clay brick are uneven in shape as the mostly clay bricks are made manually.	*Uniform in shape and smooth in finish as the manufacturing is carried out using machinery*
As the surface finish is not even, plastering is necessary.	*As the surface is even and joints are thinner, no plastering required in normal cases.*
Clay brick are Heavier.	*Fly ash brick are lighter as the main composition is fly ash.*
Clay bricks are more porous	*Fly ash bricks are less porous*
The cost of clay brick is higher than fly ash brick.	*The cost of fly ash brick is approximate 30%lower than clay brick.*
Continuing use of clay bricks in construction industry will lead to extensive loss of fertile top soil. This could be a devastating environmental hazard.	*This is made by using by-product of Thermal Power Plant. Which save environment from being polluted.*

Manufacturing Process of Fly Ash Brick:

- *Fly Ash Bricks are made bricks manufactured by hydraulic or vibratory press.*
- *Raw material required are fly ash shall conform to Grade 1 or Grade 2 of IS*

3812 (60-65%), Bottom ash used as replacement of shall not have more than 12 percent loss on ignition when tested according IS 1727, lime shall conform to class C hydrated lime of IS 712(8-12%), gypsum (5%), locally available sand/stone dust (18-27%) and water.

- *Ordinary Portland Cement can also be used in place of hydrated lime and gypsum.*
- *Raw materials in the required proportion are mixed in the pan mixer to have a semi dry uniform mix.*
- *Semi dry mix is placed in the moulds of hydraulic/ vibro press.*

- *Moulded bricks are air dried for one/two days in a shed depending upon the weather conditions and then water curred for 14-21 days.*
- *The bricks thus produced are sound, compact and uniform in shape.*

Use of Fly Ash Brick: *Fly Ash Bricks can be used as replacement of common burnt clay building bricks.*

Some examples of Fly Ash Bricks used by other organizations are as under:

- *NTPC townships at Simhadri in Andhra Pradesh, Sipat in Chhattisgarh, Faridabad in Haryana and Talchar – Kaniha in Orissa .*
- *NTPC's power plant construction works at Rihand, Unchahar & Dadri (Uttar Pradesh), Talchar – Kaniha (Orissa) and Ramagundam (Andhra Pradesh).*
- *NTPC's NETR office building at Greater Noida & residential quarters at Township at Noida . 4- Cafeteria and Management School building in IIT Delhi.*

5- Office building construction by Greater Noida Development Authority .

Technical Specification: *Technical Specification of Fly Ash Brick as per IS: 12894-2002 is as under:*

- ***Compressive Strength***

  The minimum average wet compressive strength of pulverized fuel ash-lime bricks shall not be less than the one specified for each class as mentioned in table 1 in IS: 12894, when tested as described in IS 3495 (Part 1). The wet compressive strength of any individual brick shall not fall below the minimum average wet compressive strength specified for the corresponding class of bricks by more than 20 percent.

- ***Drying Shrinkage***

  The average drying shrinkage of the bricks when tested by the method described in IS 4139, being the average of three units, shall not exceed 0.15 percent.

- ***Efflorescence Test***

  The bricks when tested in accordance with the procedure laid down in IS 3495

(Part 3), shall have the rating of efflorescence not more than 'moderate' up to Class 12.5 and 'slight' for higher classes.

- ***Water Absorption***
  The bricks, when tested in accordance with the procedure laid down in IS 3495 (Part 2), after immersion in cold water for 24 hour, shall have average water absorption not more than 20 percent by mass up to class 12.5 and 15 percent by mass for higher classes.

Market Price: *As per the analysis of SOR item no. 055093 of USSOR 2010, the rate of Fly ash brick is Rs. 1881/- per 1000. However, the markets prices obtain from supplier through IndiaMART.com is Rs. 3900/- per 1000 brick + freight + taxes from Gurgaon. The supplier has also informed that in case of bulk supply the plant can be installed at site to minimize the freight charges.*

Market rate of 1st class burnt clay brick (ordinary brick) is Rs. 6500/- per 1000 brick + freight in Lucknow (U.P.)

Suppliers:

Manufacturer & Supplier of Fly Ash Bricks

- ***Hindustan Tiles***
  Mr. Narendra Saxena (Director)
  No. 601/602, Suneja Tower - 2,., District Center, Janak Puri New Delhi - 110058, Delhi, India
  ***Contact No.:** 08447496498*

- ***G. L. T. Enterprises***
  Mr. Lokesh Gupta (CEO)
  D - 639, Saraswati Vihar, Pitampura Delhi - 110 034, India
  ***Contact No.:** 09953362622*

- ***Eco Vision Industries.***
  Mr. Jitendra Pareek (Managing Director)
  D-15 & 16, Site B, UPSIDC, Surajpur Industrial Area Greater Noida - 203207, Uttar Pradesh, India
  ***Contact No.:**08447570282*

- ***S.R Windows & Glass Solutions***
  Mr. Manoj Sharma (Proprietor)

Shop No. 4, Kadamba Shopping Complex,
Gamma - 1 Greater Noida - 201308, Uttar
Pradesh, India
Contact No.: 08587900505

- ***V K Enterprises***
  Mr. Inderjeet
  Singh (Manager)
  Plot No. 2957,
  Sector-57
  Gurgaon - 122003, Haryana, India
  ***Contact No.:** 09643007698*

- ***Aparna Enterprises Limited***
  Mr. Naveen/ Mrs.Varsha
  No. 8-2-293/82/A, Plot No. - 1214, Road No. - 60,
  JubileeHills Hyderabad - 500 033, Andhra Pradesh,
  India
  Contact No.: 08377809349

- ***Affa Tile Company***
  Mr. Anaz
  No. 1116/8, Poonamalee High Road, Opposite Hotel Shan
  Royal Chennai - 600107, Tamil Nadu, India
  Contact No.: 08377802185

- ***A.B.N. Enterprise***
  Mr. Tapan Dutta (Owner)
  Nabin Sen Palli, Post
  Nabapalli Barasat Kolkata
  - 700126, West Bengal,
  *India **Contact No.:***
  08588832343

- ***Aster Enterprise***
  Mr. Joseph John (CEO)
  32/3055-A1, Near Marthoma Centre, St. Rita's Road, Vyttila, Landmark -
  Near Gold Souk Kochi - 682019, Kerala, India
  Contact No.: 08588800787

- ***Dev Infratech***
  Mr. Kiran Patel
  Survey No. 862, Beside Patel Tractor Showroom, Opposite GSFC Main Gate,

Chhani Vadodara - 391740, Gujarat, India
Contact No.: 09582599487

- ***Marshall Corporation Limited***
  Mr. Anshul Chauhan (Director -Operation) No. 2,
  Chowringhee Approach
  Kolkata - 700072, West Bengal, India
  ***Contact No.:** 09953362698*

- ***Techno Design***
  Mr. R. Manivasagam (Proprietor)
  No. - 1/3, Chandrasekar Street, S. M. Narayanan Nagar, Anna Nagar West Chennai - 600101, Tamil Nadu, India
  ***Contact No.:**08588832165*

- ***Metco Blocks Mfg. Co.***
  Mr. Imtiyaz Patel / Mr Sattar Patel (Partners)
  Shop No. 2, Patel Compound, Behind Bharat Petrol Pump, Panvel-Mumbra Road, Taloja- Kharghar
  Navi Mumbai - 410208, Maharashtra, India
  ***Contact No.:**08377808662*

- ***Bhoomi Trading Corporation***
  Mr. Sandeep Budhavale (Proprietor)
  F - 51, Lake City Mall, Next To Big Bazaar, 1st Floor, Kapurbaudi, Thane Mumbai - 400604, Maharashtra, India
  ***Contact No.:** 08376806063*

- ***Mohta Cement Pvt. Ltd.***
  Mr. Saurabh Mohta / Mr. Gaurav Mohta (Managing Director) Plot No 61-62,
  Pithampur Sector 3
  Dhar - 454001, Madhya Pradesh, India
  Contact No.: 09953354394

- ***Pooja Enterprise***
  Mr. Anil Shinde / Ms. Lata Shinde (Proprietor)
  Gate No. 281/2, Plot No. D-1, Kahane Malla, Chikhali Pune - 412114,
  Maharashtra, India
  ***Contact No.:** 08376807223*

- ***Allied Concrete Works***
  Mr. Jayendra H. Gupta (Director)
  S. H. Gupta Compound, Near Dattani Park, Western Express Highway, Opposite Sai Dham Mandir, Kandivali
  Mumbai - 400101, Maharashtra, India
  Contact No.: 08587096799

- ***Shreeji Flyash Bricks***
  Mr. Chandrakant Patel / Mr.Dilip patal (Proprietor) No. 58, Navdurga Industrial Park, Village Sakarda Vadodara - 390001, Gujarat, India
  ***Contact No.:** 08586979384*

- ***SRG Infratech***
  Mr. Kailash Morwal (Proprietor)
  No. 70, Near Naraina Vihar, Village Asarpura, Teh. Sanganer Jaipur - 302011, Rajasthan, India
  ***Contact No.:** 09873117160*

- ***Sheetal Pipes***
  Mr. Anuj Agrawal (Proprietor)
  No. 180, Small Factory Area, Bhandara Road Nagpur - 440008, Maharashtra, India
  ***Contact No.:** 08377809299*

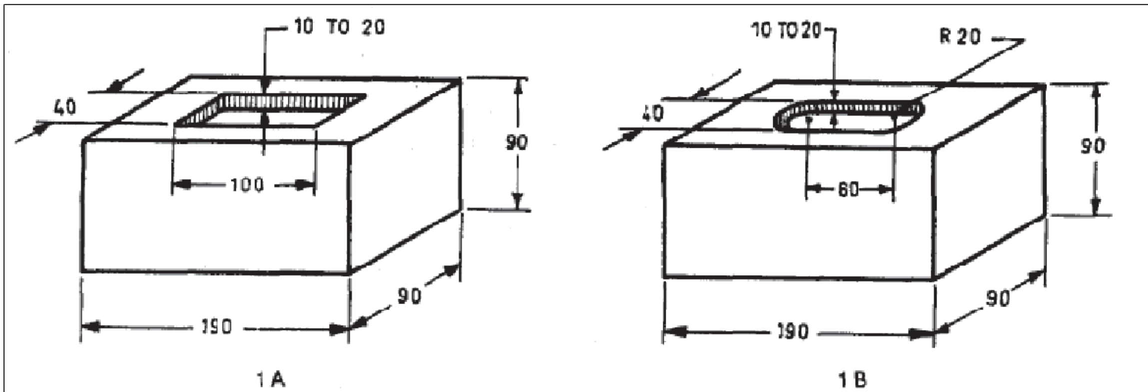
- ***Shri Sai Pavers***
  Mr. Sameer Singhal / Mr. Anil Single (Partner) Kohara-Machiwara Road, Village Kumkalan Ludhiana - 141001, Punjab, India
  ***Contact No.:** 08588859155*

- ***Sonali International***
  Mr. K. Chakraborty
  *246, Shyambabu's Ghat, P. O. Chinsurah Hooghly - 712101, West Bengal, India **Contact No.:** 09953363063*

- ***Teraco Tiles***
  Mr. Sreeram Kumar BE (Proprietor)
  No. 2/4, Hanumaiah Reddy Road,Halasuru Bengaluru - 560008, Karnataka, India
  Contact No.: 09643007025

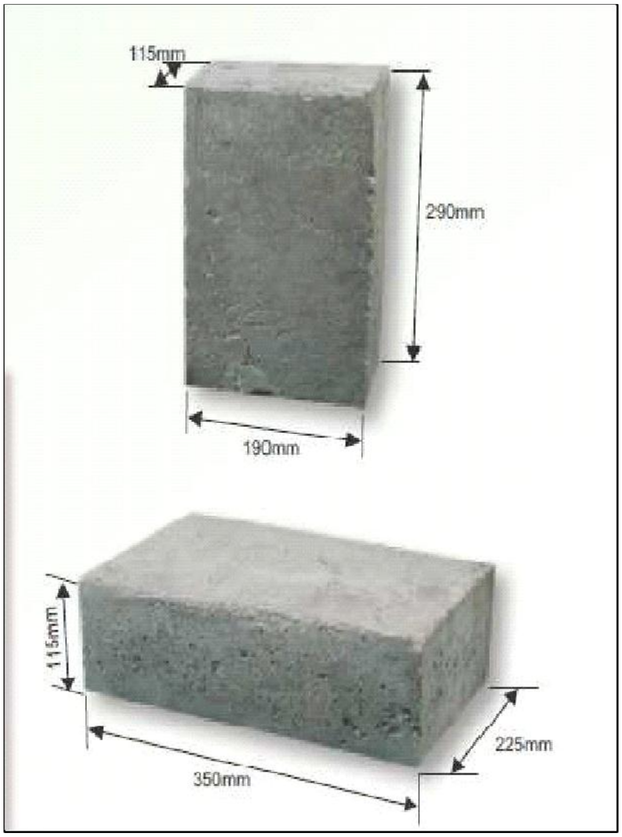
- ***Balaji Cement Product***
  Mr. Karan Kamani (Director)
  Kohthariya Ring Road Chowkdi,Ranuja Temple Main Road, Near Brahmani Hall Rajkot - 360002, Gujarat, India
  Contact No.: 08376809237

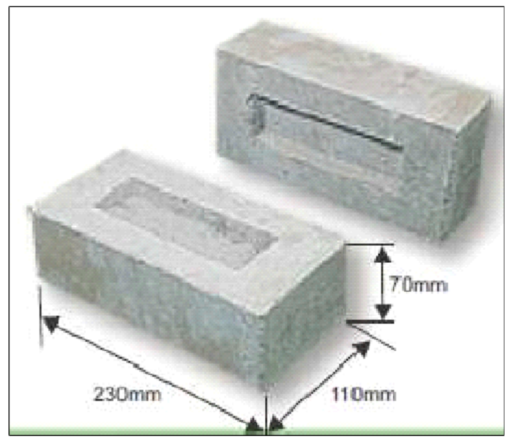
- *The details of above suppliers have been collected from internet.*



All dimensions in millimetres.

FIG. 1 SHAPE AND SIZE OF FROGS IN BRICKS





IMAGES OF FLYASH BRICKS (WITH & WITHOUT FROG)

Sizes and Grading of Aggregates for Road Maintenance and Construction

W. A. Sutton, Field Engineer
Materials and Tests
Indiana State Highway Commission

The use of tested, sized, and graded aggregates will assure quality materials for maintenance and construction of your roads. It is not the only item one must consider, but in consideration with the other factors that provide for a good road, well-prepared, sized, and graded aggregates must be especially emphasized. In order to assist you in making a good selection, we are presenting two publications prepared by Jean Hittle, Purdue University, research engineer for the Highway Extension and Research Project for Indiana Counties. He has requested and obtained advice, including ours, in their preparation. One is "Mineral Aggregate Materials for County Road Construction," designated as Herpic Report 1-61. Along with this information one should use the second report, titled "Sizes and Grading of Aggregate for Road Construction," Herpic Report 2-61. Each of these publications contains a chart and these are reproduced here for your information and convenience. Figure 1 shows principal construction uses of aggregate road materials by sizes. Figure 2 is a tabulation of gradings for coarse and fine aggregate sizes.

These charts were prepared from the 1960 Standard Specifications of the State Highway Department of Indiana in order to provide a quick reference. A choice of numbered sizes is offered on the "use" chart by the marking "X" under the type of construction. Also an attempt was made to emphasize the more commonly used sizes with a bold-faced "X" when the multiple choice as offered covers several sizes. There are many gradation specifications one could successfully use. The reason for recommending the State Highway Department sizes to you is that they represent a contribution from both user and producer interests based upon many years of experience. They represent, accordingly, the all-Hoosier choice. You should be able to obtain State Highway Department sizes from any well-established producer. The

PRINCIPAL CONSTRUCTION USES OF AGGREGATE ROAD MATERIALS BY SIZES

1960 INDIANA STATE HIGHWAY DEPARTMENT STANDARD SPECIFICATIONS

CONSTRUCTION USE	1960 Indiana State Highway Department Standard Specifications	BASE COURSE CONSTRUCTION: Cement Concrete Base	Waterbound Macadam Base	Hot Asphaltic Concrete Base	Bituminous Coated Aggregate Base	Bituminous Coated Aggregate Base (Dense – Graded)	Bituminous Coated Blended Aggregate Base	Road – Mix Bituminous Base	Penetration Macadam Base	Compacted Aggregate Base	Plant – Mix Aggregate Base	Compacted Aggregate Base, Widening, and Shoulders	Compacted Aggregate Shoulders	SURFACE COURSE CONSTRUCTION: Reinforced Cement Concrete Pavement	Hot Asphaltic Concrete Surface	Bituminous Coated Blended Aggregate Surface	Bituminous Coated Aggregate Surface	Bituminous Retread Surface	Road – Mix Bituminous Surface	Road Oil Surface	Bituminous Surface Treatment	Seal Coats
Specification Section		C1	C2	C4	C5	C6	C7	C8	C9	C10	C12	F40	F41	D1	D3	D4	D5	D7	D8	D9	D10	D12
Aggregate Size No.																						
Open Graded	1		X						X													
Open Graded	1F		X						X													
Open Graded	1W		X																			
Open Graded	2	X			X									X			X	X				
Open Graded	4			X	X		X	X							X	X	X	X				X
Open Graded	5	X					X							X		X						X
Open Graded	7							X								X			X	X		
Open Graded	8							X	X						X	X	X		X		X	X
Open Graded	9							X	X						X	X	X	X	X		X	X
Open Graded – Screenings	10		X																			
Open Graded – Screenings	10FF		X							X												
Open Graded – Screenings	10W		X																			
Open Graded	11														X	X	X	X			X	X
Open Graded	12																			X	X	X
Open Graded	12C																			X	X	X
Dense Graded	53		X							X	X	X										
Dense Graded	53B					X		X									X		X			
Dense Graded	63		X																			
Dense Graded	73												X									
Sand	14	X												X								
Sand	15																					
Sand	16														X							
Sand	17			X			X								X	X						

X Major usage under Standard Specifications for construction item indicated
X Minor usage under Standard Specifications for construction item indicated

IMPORTANT NOTE: Consult the 1960 ISHD Standard Specifications for applicable details of materials and construction.

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Fig. 1.

Sizes and Grading of Aggregates for Road Maintenance and Construction

W. A. Sutton, Field Engineer Materials and Tests
Indiana State Highway Commission

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Fig. 1

PRINCIPAL CONSTRUCTION USES OF AGGREGATE ROAD MATERIALS BY SIZES

1MO INDIAN STATE HGHWAY DEPARTMENT STANDARD SPECIFICATIONS

Fig. 2.

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GRADING OF COARSE AGGREGATE SIZES

1960 INDIANA STATE HIGHWAY DEPARTMENT STANDARD SPECIFICATIONS – SECTION K3

Aggregate Size No.	TOTAL PER CENTS PASSING SIEVES HAVING SQUARE OPENINGS															Aggregate Size No.
	4"	3-1/2"	3"	2-1/2"	2"	1-1/2"	1"	3/4"	1/2"	3/8"	No. 4	No. 8	No. 30	No. 100	No. 200	
1		100	–	45-85	0-25	0-10	0-5	0-2								1
1F			100	60-90	0-45	0-15	0-5	0-2								1F
1W	100	90-100	–	25-60	–	0-15	–	0-5								1W
2				100	95-100	–	0-20	0-5	0-2							2
4						100	70-90	40-70	10-30	–	0-5	0-2				4
5						100	85-98	60-85	30-60	–	0-10	0-5				5
7							100	65-95	25-80	–	0-15	0-10	0-5			7
8							100	85-100	20-60	–	0-5	0-2				8
9								100	65-90	–	0-10	–	0-2			9
10								100	65-90	–	20-60	10-30	0-10			10
10FF								100	85-100	–	40-80	15-50	0-30			10FF
10W									100	90-100	–	–	–	10-30		10W
11									100	75-95	5-20	0-5				11
12									100	–	50-80	0-35	0-4			12
12C									100	–	25-55	0-20	0-4			12C
53						100	80-100	70-90	55-80	–	35-60	25-50	15-30	–	5-10	53
53B						100	80-100	70-90	55-80	–	35-60	25-50	15-30	–	0-5	53B
63						100	95-100	75-90	50-80	–	25-55	–	10-25			63
73							100	90-100	60-90	–	35-60	–	15-30	–	5-10	73

GRADING OF FINE AGGREGATE SIZES

1960 INDIANA STATE HIGHWAY DEPARTMENT STANDARD SPECIFICATIONS – SECTION J6

Aggregate Size No.	SCREEN SIZES (SQUARE OPENINGS) AND TOTAL PER CENT PASSING										Aggregate Size No.
	1/2"	3/8"	No. 4 .187"	No. 6 .132"	No. 8 .0937"	No. 30 .0232"	No. 50 .0117"	No. 80 .0070"	No. 100 .0059"	No. 200 .0029"	
14-No. 1	–	100	95-100	–	80-95	20-50	5-20	–	0-5	–	14-No. 1
14-No. 2	–	100	95-100	–	80-95	25-55	10-30	–	2-10	–	14-No. 2
15	–	–	–	100	90-100	50-75	15-40	–	0-10	–	15
16	–	–	–	–	–	100	–	95-100	–	65-100	16

Asphalt Sand		FRACTIONAL PER CENT BETWEEN SQUARE-OPENING SIEVES									Asphalt Sand
	Passing No. 4	4–8	8–16	8–40	16–50	40–80	50–100	80–200	100–200	Passing No. 200	
17	100	0-10	15-35	–	25-65	–	5-35	–	1-10	0-5	17
18	100	0-5	–	12-40	–	25-60	–	25-45	–	0-5	18

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Fig. 2.

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aggregate will be controlled for uniformity of sizing. If you offer the producer enough quantity of a special size, he will attempt to accom- modate you. But if you use State Highway size numbers he will be better able to service your needs inasmuch as he stocks these sizes. Also, as you know, getting something made special often results in delay and increased costs.

Control of these sizes and gradations is by means of test sieves. For our State Highway material, an inspector with a set of scales and sieves samples the aggregate and separates it into various sizes using the sized sieves. He then weighs the various fractions and calculates whether the required percentage amounts passing the test sieves used are within the required limits of Figure 2. Producers in many instances are gradation-minded enough that they test their product with test sieves without relying on the State Highway inspectors. If you will state, "I want State Highway Department No. 9," the producer will understand your needs better. If No. 9 is marked "X " on the intended "use" chart for the purpose, its use will go a long way towards the work being successful in having the right sizing for the job.

Producers use plant screens with square openings properly selected to make the required gradation size. From coarse to fine for the various size numbers, the producer may use 4-inch, 3^-inch, 2^2-inch, 2-inch, lj^-inch, l-inch, %-inch, J^-inch, inch and No. 4 square-opening sieves. There is an arbitrary line drawn between coarse aggregate and fine aggregate at the No. 4 sieve, or approximately A -inch square opening. Coarse aggregate has most of the product rationed on a No. 4 sieve and fine aggreate, like sand, passes a No. 4 sieve. This arbitrary line explains our having coarse-aggregate and fine-aggreate tables for gradation. There is also a top size and a bottom size as applied to screens used by the producer, but for uniformity we have placed controls on certain in-between sizes. He may have to use certain intermediate sizes to meet our requirements. W ith fine aggregate we use sieve sizes such as No. 6, No. 8, No. 16, No. 30, No. 50, and No. 200 to control the intermediate gradation, even though the No. 8 is about the finest sieve the producer can use in a production operation.

It has been our experience in the past that we get about as good aggregates as the quality of our inspection, but with improved equip- ment there is greater willingness on the part of producers to make properly-graded material. Very few, indeed, adopt the attitude any more that stone is stone and gravel is gravel. You may not have the time or money to perform gradation tests on your material, although

you should. If you will call for a numbered size, any attempts to supply completely off-size material will be visually apparent. However, do not commit the error of assuming that visual inspection is a sub- stitute for a sieve analysis. If this were possible, no one would need to run sieve analyses to insure obtaining required sizing. Between certain materials, especially gravel with rounded pieces and crushed stone in which the pieces may be more elongated, it appears visually that the stone has coarser sizing. When the sieve test is applied one learns the need for more than visual inspection. The gradation tables permit the purchaser to declare the overall sizing wanted, and furnish a standard for production and a basis for inspection to get it. They accordingly simplify buying and supplying and remove guess work as to what is wanted. Specifying the size of the aggregate for the job then becomes a very important decision for the purchaser.

Coarse aggregates are classified as open-graded and dense-graded. One of the difficulties with use is a tendency of aggregate sizes to segregate in handling. This tendency is pronounced with dense-graded aggregates. A well-tested, acceptable aggregate when stockpiled in cone- like stockpiles may easily be separated into coarse and fine. When dump, dropped or otherwise rolled in handling, the large material moves to the outside, leaving the fine in the center. The longer the gradation from coarse to fine, especially in dense-graded material, the greater the tendency to segregate. It is necessary in use, where combina- tions of coarse and fine aggregate are wanted in the finished work, to combine them separate^. For example, in portland cement concrete one or more sizes of coarse aggregate are separately batched with the fine aggregate to get uniformity in the final mixture. The proportions of coarse and fine aggregate must be carefully controlled to get the maximum advantage with the minimum portland cement.

It is usually a good idea to use as large a top size aggregate as the use will permit. For example, *the State Highway Department may select No. 2 (2-inch top size), No. 5 (l-inch top size), and No. 14 sand for portland cement concrete pavement. Two-inch is the maximum size that can be conveniently worked for paving. For structures where much steel reinforcing is used o. 5, or 1-inch top size, is preferred for placing around the reinforcing. There is much mass concrete in dams where even larger sizes, up to 5-inch and 6-inch, are used to provide savings in sand and cement. W e are advocating selection of the largest aggregate size that can be conveniently handled. In bitu- minous work the top size usually should not be larger than one-half the thickness of the finished course. No explanation is needed for the*

fact that one cannot successfully put a two-inch piece in a one-inch course. For a l-inch course, J^-inch top size would be safest, with 24-inch as the maximum.

The subject of aggregate sizes applies not only for new construction but also for maintenance. Deep chuck holes may be advantageously filled with lj^-inch or larger top size aggregate, like No. 63, No. 53, No. 4, or No. 2. Many thin patches will not accommodate over a size No. 11, which is a j4-inch top size aggregate. For thicker repairs, however, larger aggregate is better due to the added strength. Aggre- gates for bituminous concrete are also batched, coarse and fine separately, in order to prevent segregation and to obtain a more positive and uniform gradation control. It would be a good idea to separate the coarse and fine in aggregate sizes like No. 53, No. 63, and No. 73 and recombine if it were not for economical considerations. When made as one size, the handling to prevent segregation becomes a serious problem. Addi- tion of a controlled amount of water will aid materially in preventing this condition.

Final use in the road dictates combining coarse and fine material for most types of construction. Even waterbound and penetration macadams that start with very coarse, open-graded sizes for initial application use finer sizes for filling or choking the voids or cavities that are left after compacting the coarse sizes. It has been recognized for many years that both Portland cement concrete and bituminous concrete are successful only if properly proportioned with uniformly- graded coarse and fine aggregate. More recently it has been demon- strated that similar gradation control for size and uniformity pays off in base construction where limited amounts of soil binder, bituminous material, portland cement, calcium chloride, sodium chloride, lime and fly ash, or whatever one prefers to assist the inherent binding qualities of the aggregate, are used.

This discussion has been limited, and we do not feel that we have explained all the possible advantages that come with sizing and grading aggregates. Much time and discussion could be devoted to the No. 200 sieve material alone and its importance to bituminous concrete, sheet asphalt, portland cement concrete, and the dense-graded, traffic-bound gradations. This material is almost flour-like in size and may be bene- ficial or harmful depending on quality and amounts used.

To sum up our discussion, it has been our hope to explain the need for graded and sized aggregates that are only obtained from a producer who is equipped with proper sizing equipment. W e have

attempted to explain the meaning of gradation sizes and the use of sieve sizes for controlling top size and gradation limits. The importance of ordering and using the correct size of aggregates to fit the job, and of insuring by testing that the size requirements are met, has been empha- sized. W e have hoped to make you gradation and size minded, and are sure you will enjoy the benefits of better work if you select, order, and get your aggregates by the correct State Highway Department size number.

SPECIFIC GRAVITY OF COARSE AGGREGATE

GLOSSARY

Absorption: *The increase in weight due to water contained in the pores of the material.*

Bulk Specific Gravity (also known as Bulk Dry Specific Gravity): *The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at the stated temperature.*

Bulk SSD Specific Gravity: *The ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours, to the weight in air of an equal volume of gas-free distilled water at the stated temperature.*

Apparent Specific Gravity: *The ratio of the weight in air of a unit volume of the impermeable portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at the stated temperature.*

SSD *- Saturated, Surface Dry. The condition in which the aggregate has been soaked in water and has absorbed water into its pore spaces. The excess, free surface moisture has been removed so that the particles are still saturated, but the surface of the particle is essentially dry.*

SCOPE

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Water, at a temperature of 73.4°F (23°C) has a specific gravity of 1. Specific Gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used during production to separate the deleterious particles from the good using a heavy media liquid.

Specific gravity is critical information for the Hot Mix Asphalt Design Engineer. The value is used in calculating air voids, voids in mineral aggregate (VMA), and voids filled by asphalt (VFA). All are critical to a well performing and durable asphalt mix. Water absorption can also be an indicator of asphalt absorption. A highly absorptive aggregate may lead to a low durability asphalt mix.

In Portland Cement Concrete the specific gravity of the aggregate is used in calculating the percentage of voids and the solid volume of aggregates in computations of yield. The absorption is important in determining the net water-cement ratio in the concrete mix.

Knowing the specific gravity of aggregates is also critical to the construction of water filtration systems, slope stabilization projects, railway bedding and many other applications.

This test method determines the specific gravity of coarse aggregates that have been soaked for a period of 15 hours (Figure 1). There are four determinations that may be made from this procedure. They are as follows:

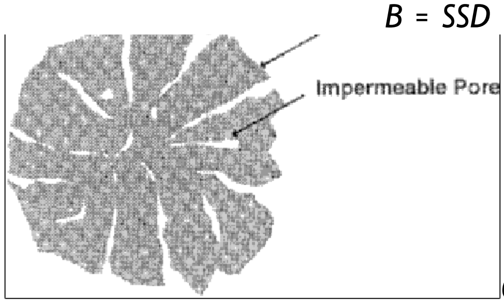
Figure 1
Coarse Aggregate Gravity Apparatus

- <u>*Bulk Specific Gravity (Gsb) (also known as Bulk Dry Specific Gravity)*</u>

  The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature (Figure 2). This unit volume of aggregates is composed of the solid particle, permeable voids, and impermeable voids.

  $Gsb = A / (B-C)$

  Where: A = Oven dry weight.
  B = SSD weight.



C = Weight in water.

Figure 2
Diagram of Bulk Specific Gravity

- <u>*Bulk SSD Specific Gravity (Gsb SSD)*</u>

  The ratio of the weight in air of a unit volume of aggregate, INCLUDING the weight of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours, to the weight in air of an equal volume of gas-free distilled water at a stated temperature (Figure 3).

Gsb SSD = B / (B - C)

Where: *B = SSD weight.*
C = Weight in water.

Figure 3
Diagram of Bulk SSD Specific Gravity

- <u>*Apparent Specific Gravity (Gsa)*</u>

  This ratio of the weight in air of a unit volume of the IMPERMEABLE portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at a stated temperature (Figure 4).

  Gsa = A / (A - C)

  Where: *A = Oven dry weight.*
  C = Weight in water

Figure 4
Diagram of Apparent Specific Gravity

- <u>*Absorption (% Abs.)*</u>

  The increase in weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles (Figure 5).

  % Abs. = [(B - A) / A] x 10

  Where: *A = Oven dry weight.*
  B = SSD weight.

Figure 5
Increase in Mass due to Absorption of Water

SUMMARY OF TEST

Apparatus

Balance, conforming with class G5 (AASHTO M231)

Sample container, wire basket of No. 6 (3.35 mm) or less mesh wire cloth, with a capacity of 1 to 1 3/4 gal. (4 to 7 L) to contain aggregate with a nominal maximum size of 1 1/2 in. (37.5 mm) or smaller; larger basket for larger aggregates.

Water tank, watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water at a constant level.

Suspended apparatus, wire used to suspend apparatus with the smallest practical diameter. A hi- test fishing leader or other thin wire with utility hook can be used with a small hook attached to the handle of the basket or sample container.

Sieves, No. 4 (4.75 mm) or other size as needed, conforming to AASHTO M 92.

Procedure

- *Thoroughly mix the sample and reduce the sample to the required size (Figure 6) in accordance with AASHTO T248 (Reducing Field Samples of Aggregate to Test Size). Use sample sizes as indicated in Table 1.*

Figure 6

Nominal Maximum Size	***Minimum Sample Weight***
1/2 in. (12.5 mm)	*4.4 lbm (2 kg)*
3/4 in. (19 mm)	*6.6 lbm (3 kg)*
1 in. (25 mm)	*8.8 lbm (4 kg)*
1 1/2 in. (37.5 mm)	*11 lbm (5 kg)*
2 in. (50 mm)	*18 lbm (8 kg)*
2 1/2 in. (63 mm)	*26 lbm (12 kg)*
3 in. (75 mm)	*40 lbm (18 kg)*

Reducing Sample to

Test Size TABLE 1

- *Dry sieve the sample through a No. 4 (4.75 mm) sieve and discard any material that passes the sieve (if a substantial amount of material passes the No. 4 (4.75 mm) sieve, you may need to use a No. 8 (1.18 mm) sieve instead of the No. 4 (4.75 mm), or you may need to perform a specific gravity on the minus No. 4 (4.75 mm) material). Wash the aggregate retained on the No. 4 (4.75 mm) sieve.*

- *Dry test sample to constant weight in an oven regulated at 230 ±9°F (110 ±5°C). Cool sample at room temperature for 1 to 3 hr. After the cooling period, immerse the aggregate in water at room temperature for a period of 15 hr.*

- *Place entire sample in a container and weigh in water maintained at 73.4 ±3°F (23 ±1.7°C). Shake container to release any entrapped air and weigh on minimum diameter wire suspended below scale apparatus. Ensure that the water overflow outlet is working properly to compensate for the water displaced by the sample (Figure 7). Record to the nearest 1.0 g or 0.1% of total weight, whichever is greater, as the weight in Water (C).*

Figure 7

Water Overflow Outlet

- *Remove the sample from the container and drain any excess water from the aggregate. Using an absorbent cloth (an absorbent towel usually works best), roll the aggregate until the surface water has been removed (Figure 8). Rolling up the aggregate into the towel and then shaking and rolling the aggregate from side to side is also an effective procedure in reducing the sample to an SSD (saturated, surface-dry) condition.*

Figure 8

Removing Excess Water

An SSD condition is one in which the aggregate has no FREE water on the surface of the aggregate. If the test sample dries past the SSD condition, immerse the sample in water for 30 minutes and resume the process of surface-drying.

- *Weigh SSD sample to nearest 1.0 g or 0.1% of the total weight,* whichever is greater and record this as SSD weight.

- Dry the sample in a pan to a constant weight in an oven set at 230 ± 9°F (110 ±5°C). Cool in air at room temperature for 1 to 3 hr, or until the aggregate can be comfortably handled. Record weight to nearest 1.0 g or 0.1%, whichever is greater, as oven dry weight.

Calculations

Determine calculations based on appropriate formula.

A = Oven
dry weight
B = SSD
weight.
C = Weight in water

Bulk Specific Gravity (Gsb) Gsb = A /

(B-C) Bulk SSD Specific Gravity (Gsb SSD) Gsb SSD =

B / (B-C) Apparent Specific Gravity (Gsa) Gsa = A /

(A-C)

Absorption (% Abs) % Abs. = [(B-A) / A] x 100

<u>Example</u>

Trial	A	B	C	B-C	A-C	B-A
1	2030.9	2044.9	1304.3	740.6	726.6	14.0
2	1820.0	1832.5	1168.1	664.4	651.9	12.5
3	2035.2	2049.4	1303.9	745.5	731.3	14.2

Trial	Bulk SSD B/B-C	Bulk A/B-C	Apparent A/A-C	Abs. (B-A/A)100
1	2.761	2.742	2.795	0.691
2	2.758	2.739	2.792	0.698
3	2.749	2.730	2.783	0.698
Ave.	2.756	2.737	2.790	0.693

A = Weight of Oven Dry
Specimen in Air B = Weight of

SSD Specimen in Air
C = Weight of SSD Specimen in Water

These calculations demonstrate the relationship between Gsb, Gsb SSD, and Gsa. The Gsb (bulk specific gravity) will always be the lowest value since the volume calculated includes voids permeable to water. The Gsb SSD (bulk specific gravity at SSD) will always be the intermediate value, and the Gsa (apparent specific gravity) will always be the highest, since the volume calculated includes only the "solid" aggregate particle (does not include those voids permeable to water). When conducting this test, check to make sure the values calculated make sense in relation to one another.

Gradation of Aggregates and its Effects on Properties of Concrete

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Abstract *- Aggregate are the important constituent in concrete. They give body to concrete, reduce shrinkage and affect economy. Earlier, aggregate were considered chemically inert but now it has been recognized that some of the aggregate are chemically active and also certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that they occupy 70-80% of volume of concrete, their impact on various characteristics of concrete is undoubtedly considerable along with its gradation. The depth of range of studies that are required to be made in respect of aggregate to understand their widely varying effect and influence on properties of concrete such as compressive strength, durability, workability, shrinkage, density etc. cannot be underrated. The emphasis is given on the gradation and type of aggregate which influence the properties effectively. The grading curves are studied in detail to know the behaviour of coarse as well fine aggregate as properties of concrete.*

Keywords: *Grading, Well Graded, Uniform Graded, Gap Graded*

- ***INTRODUCTION***

Concrete, in the broadest sense, is any product or mass made by use of a cementing medium. This medium is a product of reaction between hydraulic cement and water. This medium cover a wide range of products: several types of cement containing pozzolona, fly ash, blast furnace slag, a „regulated set" additive, sulphur, admixtures, fibers, and so on. The cementing medium, i.e. the products of hydration of cement, is the essential building material, with the aggregates fulfilling the role of a cheap, or cheaper, dilutant. Also the coarse aggregate is the mini-masonry which is joined together by mortar, i.e. a mixture of hydrated cement and the fine aggregate. Or as the approximation, concrete consists of two phases: hydrated cement paste and aggregate, as a result, the properties of the two phases and also the presence of interfaces between them govern the properties of concrete.

Aggregate gradation determines the void content within the structure of aggregate and consequently the amount of cement paste that is required to fill the void space and ensure a workable concrete. It is desirable to optimize the aggregate gradation in concrete using Portland cement, as it is the most expensive and high carbon footprint ingredient, to minimize the void content in the aggregate and therefore the volume of cement paste required to achieve a workable, economical and an environmentally sound concrete for a given application. The optimization of aggregate gradation also improves the rheological, mechanical and durability properties of concrete.

Proper aggregate gradation not only ensure a workable concrete mixture that can be compacted easily, but also reduces problems associated with plastic concrete such as potential for segregation, bleeding and loss of entrained air and plastic shrinkage cracking. Furthermore, most concrete that is used in construction of transportation infrastructure is

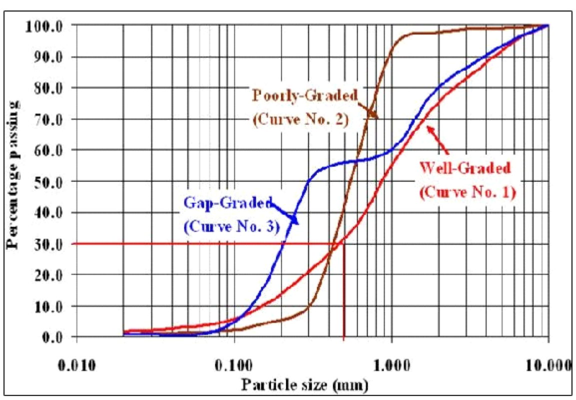
often vibrated to achieve good compaction in concrete. Segregation in plastic state under vibration particularly is the most vulnerable problem in concrete containing aggregate with poor gradation. Cement paste filling the void space between the aggregate has a tendency to shrink when there is a progressive loss of moisture from concrete, either due to evaporation from surface of concrete or through internal consumption of moisture due to hydration reactions of cement. Aggregates in concrete, being much stiffer than the hardened cement paste, act to resist the shrinkage behaviour of concrete. Aggregate gradation, which determines the relative proportions of aggregate and cement paste in a concrete, therefore dictates the shrinkage behaviour of concrete and hence long-term durability of concrete.

- **Gradation Of Aggregates**

The **particle** size **distribution** of an aggregate as determined by sieve analysis is termed as **grading** of **the aggregates**. If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids whereas aggregate comprising particles of various sizes will give a mass with lesser voids .The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles. The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement waste, therefore, it is essential that coarse and fine aggregates be well graded to produce quality concrete.

- **The Grading Curve**

The grading of aggregates is represented in the form of a curve or an **S CURVE**. The curve showing the cumulative percentages of the material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa is termed as **Grading Curve**. The grading curve for a particular sample indicates whether the grading of a given sample conforms to that specified, or it is too coarse or too fine, or deficient in a particular size.



- **Types Of Grade Of Aggregates**

• UNIFORM GRADED AGGREGATE

It refers to a gradation that contains most of the particles in a very narrow size range. In essence, all the particles are the

same size. The curve is steep and only occupies the narrow size range specified.

- Narrow range of sizes
- Grain-to-grain contact

- High void content
- High permeability
- Low stability
- Difficult to compact

- *OPEN GRADED AGGREGATE*

It refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near vertical in the mid-size range, and flat and near-zero in the small-size range.

- *GAP GRADED AGGREGATE*

It refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is flat in the mid-size range. Some PCC mix designs use gap graded aggregate to provide a more economical mix since less sand can be used for a given workability.

- Missing middle sizes
- No grain-to-grain contact
- Moderate void content
- Moderate permeability
- Low stability
- Easy to compact

- *DENSE GRADED AGGREGATE*

A dense gradation refers to a sample that is approximately of equal amounts of various sizes of aggregate. By having a dense gradation, most of the air voids between the materials are filled with particles. A dense gradation will result in an even curve on the gradation graph.

- Wide range of sizes
- Grain-to-grain contact
- Low void content
- Low permeability
- High stability
- Difficult to compact

- ***MATERIALS USED***

CEMENT – Ordinary Portland cement, 53 grade was used.

Physical property	IS: 8112-1989 specifications
Fineness (retained on 90- m sieve)	10mm
Normal Consistency	-
Vicat initial setting time (minutes)	30 min
Vicat final setting time (minutes)	600 max
Compressive strength 3-days (MPa)	22.0 min
Compressive strength 7-days (MPa)	33.0 min
Compressive strength 28days(MPa)	43.0 min
Specific Gravity	-

AGGREGATE - The maximum nominal size of aggregate is taken as 40 mm. Rounded aggregates are desirable and the sample should be of uniform quality. Fine aggregate can be

natural or manufactured. The moisture content or absorption characteristics must be closely monitored. The *percentage of each size of aggregate taken is mentioned in the given table as per the grade of aggregate desired.*

Well Graded aggregate

IS Sieve Designation	Percentage of particular size present (%)	Weight of aggregate of size used (in kg)
40 mm	5	1.175
20 mm	45	10.575
4.75 mm	20	4.7
600 microns	15	3.525
150 microns	15	3.525

Uniform Graded aggregate

IS Sieve Designation	Percentage of particular size present(%)	Weight of aggregate of size used (in kg)
40 mm	14	2.165
20 mm	81	12.530
10 mm	5	0.773

Gap Graded aggregate

IS Sieve Designation	Percentage of particular size present (%)	Weight of aggregate of size used (in kg)
40 mm	5	1.175
20 mm	13	3.055
10 mm	12	2.82
4.75 mm	-	-
2.36 mm	35	8.225
1.18 mm	18	4.23
600 microns	5	1.175
300 microns	4	0.94

- ***TESTING OF TRIAL MIXES***

In all, 3 batches of concrete were made each of grade M20 with a constant W/C and cement content, by varying the proportions of the fine as well as coarse aggregate as per IS recommendations required (proportions are mentioned in the above tables). They are designated as follows:

SN	Batch Designation		Grade of Concrete	Adopted Mix Proportions
	Title	Description		
1	M1	Well Graded Aggregate	M20	1 : 1.5 : 3
2	M2	Uniform Graded Aggregate	M20	1 : 1.5 : 3
3	M3	Gap Graded Aggregate	M20	1 : 1.5 : 3

Note: Adopted a common W/C = 0.5 and cement for each batch is taken 5kg.

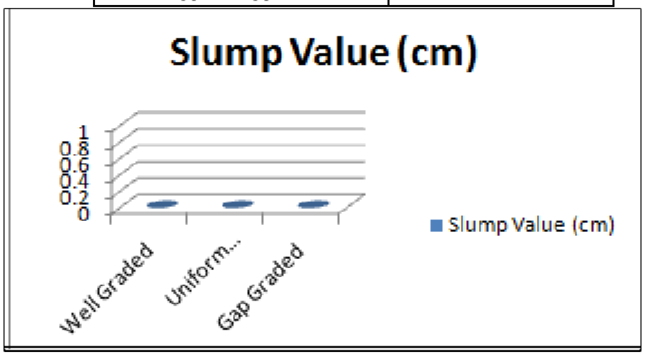
To check the stability of the Batches, the following tests were conducted on the concrete:

- *Slump Test*
- *Compaction Factor Test*
- *Compressive Strength Test*

- ***OBSERVATIONS AND INTERPRETATION OF RESULTS***

- *Slump Test*

Grade of Concrete (M-20)	Value of Slump (in mm)
WELL GRADED	00
UNIFORM GRADED	00
GAP GRADED	00



- *Compaction Factor Test*

Weight of empty cylinder = Wa = 8.601kg

Grade of Aggregate used	Weight of partially compacted Wb (kg)	Weight of fully compacted Wc (kg)	Wb-Wa (kg)	Wc-Wa (kg)	Compaction Factor
Well Graded	17.77	19.36	9.169	10.759	0.852
Uniform Graded	18.08	19.80	9.479	11.199	0.847
Gap Graded	17.627	18.947	9.026	10.346	0.873

- *Compressive Strength Test*

Sample No.	Load Of Failure (in KN)	Compressive Strength after 7 days curing (in N/mm^2)	Percentage of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	305	13.56	67.8	

Sample 02	300	13.33	66.66	13.163

WELL GRADED

Sample 03	290	12.6	63.2	

UNIFORM GRADED

Sampl e No.	Load Of Failur e (in KN)	Compressiv e Strength after 7 days curing (in N/mm^2)	Percentag e of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	280	12.5	62.2	
Sample 02	315	14	70	13.57
Sample 03	320	14.22	71.1	

GAP GRADED

Sampl e No.	Load Of Failur e (in KN)	Compressiv e Strength after 7 days curing (in N/mm^2)	Percentag e of strength after 28 days curing (%)	Average Value fc (in N/mm^2)
Sample 01	315	14	70	
Sample 02	320	14.22	71.1	14
Sample 03	310	13.78	68.9	

SUMMARY AND CONCLUSIONS

- The study gives a picture of the effects of aggregate type, size, and content on the compressive strength, workability, durability and other properties of fresh as well as hardened concrete.
- The fine aggregate gradation has more detrimental effect on concrete properties than coarse aggregate gradations.
- The study helps to understand that the gradation has no effect on the slump value of freshly prepared concrete.
- The Compaction factor test is more sensitive towards the gradation of aggregates and result shows that Gap Graded with compaction factor 0.872 has better workability among different grades.
- Though, well graded concrete has been preferred over gap graded but the results obtained by performing tests show that the compressive strength of latter is more than the former.
- The presence of more bigger sized aggregates causes a more homogeneity in concrete preventing the uniform distribution of the load when stressed.

FLAKINESS AND ELONGATION INDEX OF AGGREGATE

- ***Objective***

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 % by weight of the total aggregate.

- ***Apparatus Required***

Fig. 1: Balance

Balance should be able to weigh upto 1 g.

Fig. 2: Sieves

Sieves required are 63, 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3 mm (Based on requirement and Gradation of Aggregate).

Fig. 3: Thickness Gauge- For Flakiness Index

Thickness Gauge have width equal to 0.6 times the mean dimension of the aggregate.

Fig. 4: Length Gauge- For Elongation Index

Length Gauge have length equal to 1.8 times the mean dimension of the aggregate.

- ***Reference***

IS 2386(Part 1):1963 Methods of Test for Aggregates of Concrete- Particle Size and Shape. Reaffirmed- Dec 2016

- ***Procedure***

  - *A quantity of aggregate shall be taken sufficient to provide the minimum number of 200 pieces of any fraction to be tested.*
  - *The sample shall be sieved with the sieves specified in Table 1:*

Size of Aggregate thickness (mm)		Thickness Gauge * (mm)	Length Gauge ** (mm)
Passing through IS Sieve	Retained on IS Sieve		
63	50	33.90	-
50	40	27.00	81.0
40	25	19.50	58.5
31.5	25	16.95	-
25	20	13.50	40.5
20	16	10.80	32.4
16	12.5	8.55	25.6
12.5	10	6.75	20.2
10.0	6.3	4.89	14.7

***** This dimension is equal to 0.6 times the mean Sieve size*
*** This dimension is equal to 1.8 times the mean Sieve size*

Table 1 : Dimensions (Length and Thickness) of Gauges

  - *Separation of Flaky material- Each fraction shall be gauged in turn for thickness on a metal gauge of the pattern shown in Fig. 3, or in bulk on sieves having elongated slots. The width of the slot used in the gauge or sieve shall be of the dimensions specified in co1. 3 of Table 1 for the appropriate size of material.*
  - *The total amount passing the gauge shall be weighed to an accuracy of at least 0.1 percent of the weight of the test sample.*

- *The Flakiness Index is the total weight of the material passing the various thickness gauges or sieves, expressed as a percentage of the total weight of the sample gauged.*
- *Separation of Elongated Material- Each fraction shall be gauged individually for length on a metal length gauge of the pattern shown in Fig. 4. The gauge length used shall be that specified in co1. 4 of Table 1 for the appropriate size of material.*
- *The total amount retained by the length gauge shall be weighed to an accuracy of at least 0.1 percent of the weight of the test sample.*
- *The elongation index is the total weight of the material retained on the various length gauges, expressed as a percentage of the total weight of the sample gauged.*

- ## *Observation And Recording*

Passing through IS Sieves(mm)	*Retained on IS Sieves (mm)*	*Flakiness Gauge (mm)*	*Weight Passing on Flakiness Gauge (g)*	*Percentage Weight Passing (%)*
63	50	33.90		
50	40	27.00		
40	25	19.50		
31.5	25	16.95		
25	20	13.50		
20	16	10.80		
16	12.5	8.55		
12.5	10	6.75		
10	6.3	4.89		
		Total		

Table 2 *: Recordings for Flakiness Index*

Passing through IS Sieves(mm)	*Retained on IS Sieves (mm)*	*Elongation Gauge (mm)*	*Weight Retained on Elongation Gauge (g)*	*Percentage Weight Retained (%)*
63	50	--		
50	40	81.00		
40	25	58.5		
31	25	--		
25	20	40.50		
20	16	32.4		
16	12.5	25.6		
12.5	10	20.2		
10	6.3	14.7		
		Total		

- ## *Calculation*

Table 3 *: Recordings for Elongation Index*

- *The Flakiness Index on an aggregate is =*
  Total weight passing Flakiness Gauge x 100 / Total weight of test sample =
  (%)
- *The Elongation Index on an aggregate is =*
  Total weight retained on Elongation Gauge x 100 / Total weight of test sample =
  (%)

AGGREGATE CRUSHING VALUE

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. With aggregate of aggregate crushing value 30 or higher, the result may be anomalous, and in such cases the ten percent fines value should be determined instead.

- ***Apparatus Required***

Fig. 1: Balance

Balance should be accurate upto 1 gm.

Fig. 2: Sieve (12.5 mm, 10.0 mm and 2.36 mm)

Fig. 3: Mould, Measuring Cylinder with Plunger

15-cm diameter open-ended steel cylinder, with plunger and base-plate, of the general form and dimensions and a straight metal tamping rod. For measuring the sample, cylindrical metal measure of sufficient rigidity to retain its form under rough usage and of the following internal dimensions: Diameter 11.5 cm and Height 18.0 cm

- ***Reference***

IS 2386(Part 4):1963 Methods of Test for Aggregates for Concrete- Mechanical Properties. Reaffirmed- Dec 2016

- ***Procedure***

  - *The material for the standard test shall consist of aggregate passing a 12.5 mm IS Sieve and retained on a 10 mm IS Sieve, and shall be thoroughly separated on these sieves before testing.*
  - *The aggregate shall be tested in a surface-dry condition. If dried by heating, the period of drying shall not exceed four hours, the temperature shall be 100 to 110°C and the aggregate shall be cooled to room temperature before testing.*
  - *The appropriate quantity may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth, each layer being tamped 25 times with the rounded end of the tamping rod and finally leveled off, using the tamping rod as a straight-edge.*
  - *The weight of material comprising the test sample shall be determined (Weight A) and the same weight of sample shall be taken for the repeat test.*
  - *The cylinder of the test apparatus shall be put in position on the base plate and the test sample added in thirds, each third being subjected to 25 strokes from the tamping rod. The surface of the aggregate shall be carefully levelled and the plunger inserted so that it rests horizontally on this surface, care being taken to ensure that the plunger does not jam in the cylinder.*
  - *The apparatus, with the test sample and plunger in position, shall then be placed between the platens of the testing machine and loaded at as uniform a rate as possible so that the total load is reached in 10 minutes. The total load shall be 400 kN.*
- *The load shall be released and the whole of the material removed from the cylinder and sieved on a 2.36 mm IS Sieve for the standard test. The fraction passing the sieve shall be weighed (Weight B).*

- ***Calculation***

1. *The ratio of the weight of fines formed to the total sample weight in each test shall be expressed as a percentage, the result being recorded to the first decimal place:*

$$\text{Aggregate Crushing Value} = (B/A) \times 100$$

where A = weight of oven-dried sample
B = weight in 'g' of fraction passing through 2.36 mm IS sieve.

LOS ANGELES ABRASION VALUE OF AGGREGATE

- ***Objective***

Abrasion test is carried out to test the hardness property of aggregates. The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

- ***Apparatus Required***

Fig. 1: Balance

Balance should be accurate upto 1 g

Fig. 2: Sieves

Sieves required are 80, 63, 50, 40, 25, 20, 12.5, 10, 6.3, 4.75 (as per gradation of aggregate) and 1.7 mm

Fig. 3: Los Angeles Testing Machine

Inside Length = 50 cm and Inside Diameter = 70 cm

Fig. 4: Abrasive Charges

Diameter = 48 mm and Weight = 390 to 445 g

- **Reference**

IS 2386(Part 4):1963 Methods of Test for Aggregates for Concrete- Mechanical Properties. Reaffirmed- Dec 2016

- **Procedure**

  - ***Gradation Of Aggregate***

1. *Gradation of the aggregate should be carried out so as to assess the Grade of the Aggregate (A to G)*

Sieve Size		Weight in gm. of Test Sample for Grade						
Passing (mm)	Retained on (mm)	A	B	C	D	E	F	G
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			

Table 1: Gradation of Aggregate

  - ***Procedure For Los Angeles Abrasion Test***

- *The test sample shall consist of clean aggregate which has been dried in an oven at 105 to 110°C to substantially constant weight and shall conform to one of the gradings shown in Table 1. The grading or gradings used shall be those most nearly representing the aggregate furnished for the work.*
- *The test sample and the abrasive charge shall be placed in the Los Angeles abrasion testing machine and the machine rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine shall be rotated for 500 revolutions; for gradings E, F and G, it shall be rotated for 1000 revolutions as mentioned in Table 2.*

Grading	Number of spheres	Weight of charge (gm)
A	12	5000 ±25
B	11	4584 ±25
C	8	3330 ±20
D	6	2500 ±15
E	12	5000 ±25
F	12	5000 ±25

G	12	5000 ±25

Table 2: Number of Charges as per Grading of Aggregate

- *The machine shall be so driven and so counter-balanced as to maintain a substantially uniform peripheral speed. If an angle is used as the shelf, the machine shall be rotated in such a direction that the charge is caught on outside surface of the angle.*
- *At the completion of the test, the material shall be discharged from the machine and a preliminary separation of the sample made on a sieve coarser than the l.70 mm IS Sieve.*
- *The material coarser than the 1.70 mm IS Sieve shall be washed dried in an oven at 105 to 110°C to a substantially constant weight, and accurately weighed to the nearest gram (B).*

5. Calculation

1. *The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample. This value is reported as the percentage of wear.*

Aggregate Abrassion Value = ((A-B)/A) X 100

where,
A = weight in gm of oven-dried sample.
B = weight in gm of fraction retained on 1.70 mm IS Sieves after washing and oven-dried upto constant weight.

IMPACT VALUE OF AGGREGATE

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from its resistance to a slow compressive load.

- ### Apparatus Required

Fig. 1: Balance

Balance should be accurate upto 1 g

Fig. 2: Sieves

Seives required are 12.5, 10.0 and 2.36 mm

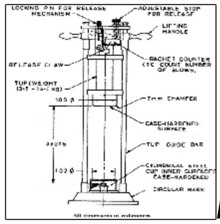


Fig. 3: Impact Testing machine

Weight of hammer is 13.5 to 14.0 kg and Height of Fall is 380±5 mm

- ***Reference***

IS 2386(Part 4):1963 Methods of Test for Aggregates for Concrete- Mechanical Properties. Reaffirmed- Dec 2016

- ***Procedure***

  - *The test sample shall consist of aggregate the whole of which passes a 12.5 mm IS Sieve and is retained on a 10 mm IS Sieve. The aggregate comprising the test sample shall be dried in an oven for a period of four hours at a temperature of 100 to 110°C and cooled.*
  - *The measure shall be filled about one-third full with the aggregate and tamped with 25 strokes of the rounded end of the tamping rod. Further similar quantity of aggregate shall be added and a further tamping of 25 strokes given. The measure shall finally be filled to overflowing, tamped 25 times and the surplus aggregate struck off, using the tamping rod as a straight edge. The net weight of aggregate in the measure shall be determined to the nearest gram (Weight A).*
  - *The impact machine shall rest without wedging or packing upon the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.*
  - *The cup shall be fixed firmly in position on the base of the machine and the whole of the test sample placed in it and compacted by a single tamping of 25 strokes of the tamping rod.*
  - *The hammer shall be raised until its lower face is 380 mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate. The test sample shall be subjected to a total of 15 such blows each being delivered at an interval of not less than one second.*
  - *The crushed aggregate shall then be removed from the cup and the whole of it sieved on the 2.36 mm IS Sieve until no further significant amount passes in one minute. The fraction passing the sieve shall be weighed to an accuracy of 0.1 g (Weight. B).*
  - *The fraction retained on the sieve shall also be weighed (Weight C) and, if the total weight (C+B) is less than the initial weight (Weight A) by more than one gram, the result shall be discarded and a fresh test made. Two tests shall be made.*

- ***Calculation***

1. *The ratio of the weight of fines formed to the total sample weight in each test shall he expressed as a percentage, the result being recorded to the first decimal place:*

Aggregate Impact Value = (B/A) X 100

where A = weight in g of saturated surface - dry sample,
B = weight in g of fraction passing through 2.36 mm IS Sieve

METHOD OF TEST FOR THE SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE

- ***SCOPE***

The procedure to be followed when testing aggregates to determine their resistance to disintegration by saturated solutions of sodium sulfate is described in this method. This method is a modification of AASHTO T 104.

- ***REFERENCES***

AASHTO M 92 - Wire-Cloth Sieves for Testing Purposes
AASHTO T 104 - Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate ASTM C 88 - Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

- ***APPARATUS***

  - *Sieves: Standard sieves conforming to AASHTO Designation: M 92 are required. The sieves sizes shall consist of the following: 2½in., 2 in., 1½in., 1 in., ¾in., ½ in., 3/8 in., ¼in., No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and No. 200.*

  - *Sieve shaker: A mechanical sieve shaker must conform to the requirements for thoroughness of sieving in accordance with California Test 202.*

  - *Sample containers: Wire screen baskets are required for immersing the aggregate samples in the solution. The wire screen and frames shall be made of corrosion- resistant metal such as brass, bronze, or stainless steel. The openings in the screen shall be smaller than the openings of the sieve that will be used to determine the percent loss at the end of the test. Sample baskets shall have a bail suitable for suspending them from brackets while in the solution and in the oven.*

  - *Balance: A 25 kg balance, or larger, is required. It shall be sensitive to 0.1 % of the sample mass.*

  - *Drying oven: A vented, forced-draft oven capable of maintaining a temperature of 230°F ±9°F is required. The interior of the oven shall be equipped with racks designed to suspend the sample baskets above the shelves allowing free circulation of air around and under the baskets.*

  - *Immersion tank: A suitable solution container is required for immersing samples. The container shall be of such height that the solution covers the samples in the sample containers to a depth of at least ½in., and of such capacity that it will hold a volume of solution equal to at least five times the total volume of the samples immersed at any one time. Protection against the accidental addition of extraneous*

    substances shall be provided. An enclosed cabinet housing the immersion tank or individual covers over the sample baskets are both satisfactory methods of protection.

- ***MATERIALS***

  - *Saturated sodium sulfate solution: The sodium sulfate solution shall be prepared by dissolving a C.P., U.S.P., or equal grade of the salt in water at a temperature of 77 to 86°F. Sufficient salt of either the anhydrous (Na_2SO_4) or the crystalline ($Na_2SO_4 \bullet 10H_2O$) form, shall be added to ensure not only* *saturation, but also the presence of excess crystals when the solution is ready for use in the tests. The mixture shall be thoroughly stirred during the addition of the salt and the solution shall be stirred at frequent intervals until used. The solution shall be cooled to a temperature of 70 ±2°F and maintained at the temperature for at least 48 h before use. The solution shall again be thoroughly stirred immediately before use and, when used, shall have a specific gravity of not less than 1.151 and not greater than 1.174.*

For the solution, 215 g of anhydrous salt or 700 g of the decahydrate per liter of water are sufficient for saturation at 72°F. However, since these salts are not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 225 g of the anhydrous salt or 750 g of the decahydrate salt for each liter of water is recommended.

- *Barium chloride, approximately 10% solution, is required.*

- ***CONTROL***

The temperature of the solution during testing shall be maintained at 70 ±2°F.

- ***PREPARATION OF SAMPLE***

  - *Fine aggregate*

    - *Split or quarter a representative portion of material of sufficient size to yield not less than 100 g of each of the following sizes after washing:*

Passing Sieve Size	*Retained Sieve Size*
No. 4	*No. 8*
No. 8	*No. 16*
No. 16	*No. 30*
No. 30	*No. 50*
No. 50	*No. 100*

    - *Wash the sample to remove all coatings. Washing may be done by any means, which will accomplish thorough cleaning without degrading the material. Inundating the sample in a pan of water and stirring by hand is an accepted method. Washing shall be continued until the water passing through or being poured off the sample is clear. All wash water shall be passed through a No. 100 sieve and all material retained on the sieve shall be returned to the sample.*

    - *Dry to constant mass at 230 ±9°F.*

    - *Divide the sample into representative portions for sieving.*

    - *Sieve the individual portions to refusal on the sieves listed above until the required 100 g fractions are obtained. Do not use the aggregate sticking in the meshes of the sieves.*

    - *Weigh out 100 g test portions from each aggregate size and* *place in separate sample containers.*

- *Coarse aggregate*

  - *Separate the aggregate on the sieve sizes listed in C-1 and determine the amount of each size fraction.*

  - *Split or quarter a test portion meeting the mass requirements shown below for each size fraction, which makes up 5 % or more of the submitted sample.*

WEIGHT OF TEST PORTIONS SCHEDULE A

Aggregate Size		
Passing Sieve Size	***Retained Sieve Size***	***Weight * (grams)***
2 ½in.	*2 in.*	*24,000*
2 in.	*1½in.*	*16,000*
1½in.	*1 in.*	*12,000*
1 in.	*¾in.*	*2,000*
¾in.	*½in.*	*1,500*
½in.	*3/8 in.*	*1,000*
3/8 in.	*No. 4*	*600*

SCHEDULE B

Aggregate Size		
Passing Sieve Size	***Retained Sieve Size***	***Weight * (grams)***
2 ½in.	*2 in.*	*3,000*
2 in.	*1½in.*	*2,000*
1½in.	*1 in.*	*1,500*
1 in.	*¾in.*	*1,000*
¾in.	*½in.*	*750*
½in.	*3/8 in.*	*500*
3/8 in.	*No. 4*	*300*

** The mass of the test portion may be reduced according to Schedule B when the soundness loss on the previous sample from the same source is less than 5 %. Any material tested according to mass Schedule B shall be retested using the mass specified in Schedule A when the determined loss is 5 % or more. All sources for which previous test data is not available shall be tested according to Schedule A.*

  - *Wash the individual test portions to remove all coatings.*

  - *Dry to constant weight at 230° ±9°F.*

  - *Resieve each test portion to refusal on the respective retaining sieve.*

  - *Weigh and record each test portion and place in separate sample containers.*

- ***TEST PROCEDURE***

- *Immerse the test samples in the sodium sulfate solution for 17 ± 1 h. Suspend the sample containers from racks over the tank in such a manner that the solution covers the samples to a minimum depth of ½in.*
- *Remove the samples from the solution and allow to drain for about 15 min.*
- *Dry to constant mass at 230° ±9°F and cool to room temperature.*
    - *Suspend the sample containers from the racks in the oven.*
    - *The oven shall not be used for any other purpose while it is being used to dry soundness test samples.*
- *Repeat the immersion, drying, and cooling for a total of five complete cycles.*
- *After completion of the fifth cycle, immerse the test samples in a continuous flow of fresh, water at 110° ±10°F until all of the sodium sulfate has been removed*
    - *The presence of sodium sulfate in the wash water can be detected by the reaction of the wash water with barium chloride ($BaCl_2$). Cloudiness indicates the presence of sodium sulfate.*
- *Dry to constant mass at 230° ±9°F and cool to room temperature.*
- *Sieve each test sample to refusal over a sieve having square openings one-half the size of the sieve on which the aggregate was originally retained. Weigh the particles retained on this sieve and record the mass.*

- ***CALCULATION OF SOUNDNESS LOSS***
    - *Individual Test Portions.*
        - *Compute the "Percentage Loss" for each test portion using the*

          equation: Percentage loss = [(Wo - Wf)/ Wo] x 100

          Where:

          Wo = Original mass of the test sample, to the nearest 1 g

          Wf = The mass of aggregate re-tained on the half size sieve after the sample has been tested to the nearest 1 g
        - *Size fractions which amount to less than 5 % of the total sample shall be considered to have the same loss as the average of the next smaller and next larger sizes. If one of these sizes is absent, use the loss of the portion, which is present.*
    - *Weighted Average Loss of Coarse Aggregate.*
        - *Determine the total sample percentage that each size fraction represents.*

- *Multiply the percent for each size by the percentage loss determined for that size.*

- *To determine the weighted average percentage loss of the sample, divide the sum of the products for the percent of each size and its respective percent loss by the sum of the percents for each size.*

- *Example*

Size Fractions in Sample	A Percent of Each Size in As Rec'd Grading	B Percen t Loss of Each	C Products of A & B
1 in. by ¾in.	4*	7.5	30.0
¾in. by ½in.	32	7.5	240.0
½in. by 3/8 in.	24	6.4	153.6
i i 3/8 in. by No. 4	35	8.0	280.0
Total	95		703.6

Weighted Average Percent Loss: 703.6/95 = 7.4

** Not tested size represents less than 5 % of total sample.*

- *Batch Soundness Loss of Coarse Aggregate.*

  - *The "batch soundness loss" is the combined loss of each primary size of coarse aggregate being used in the mix.*

  - *The "batch soundness loss" may be used only when the loss for one primary size exceeds the maximum allowable loss by not more than 2 %.*

  - *Calculate the batch soundness loss using the weighted average basis shown below regardless of the actual proportions to be used.*

2½in. Maximum	
2½in. x 1½in.	34%
1½in. x ¾in.	33%
1 in.x No. 4	33%

1½in. Maximum	
1½in. x ¾in.	67%
1 in.x No. 4	33%

- *Example:*

Primary Aggregate Size	Percent Loss	Weighted Percentage	
1½in. x ¾in.	11.8	67	= 7.9
1 in. x No. 4	6.1	33	= 2.0
Batch Soundness Loss			9.9

- *Weighted Average Loss of Fine Aggregate.*

    - *Use the following standard size distribution regardless of the actual sample grading:*

Size Fraction	*Total Sample (%)*
No. 4 x No. 8	*22*
No. 8 x No. 16	*19*
No. 16 x No. 30	*24*
No. 30 x No. 50	*20*
No. 50 x No. 100	*15*

    - *Multiply the loss determined for each size by the percent of the total sample shown in "a" above and divide the product by 100 to determine the loss of each fraction as a percentage of the total sample.*

    - *Example:*

Size Fraction	*Percent of Total Sample*	*Percent Loss of Each Size*	*Percent Loss on Total Sample Basis*
No. 4 x No. 8	*22*	*4.7*	*1.0*
No. 8 x No. 16	*19*	*4.2*	*0.8*
No. 16 x No. 30	*24*	*3.6*	*0.9*
No. 30 x No. 50	*20*	*4.0*	*0.8*
No. 50 x No. 100	*15*	*8.1*	*1.2*
Weighted Average Percent Loss			*4.7*

- ***PRECAUTIONS***

    - *Be sure that the aggregate is both clean and dry prior to subjecting it to the first cycle of the test because the solution must have free access to any cracks or crevices in the aggregate particles.*

    - *The aggregate must be completely dried during the drying phases of the test procedure.*

    - *Do not place aggregate in the solution until it has cooled to room temperature. Some aggregates may split and disintegrate when subjected to sudden temperature changes, and warm aggregate can cause objectionable increases in the temperature of the sodium sulfate solution.*

    - *Be sure to use sample baskets with openings smaller than the openings of the sieve that will be used at end of test for the determination of the percent loss.*

    - *Check both the specific gravity and the temperature of the solution daily, as test reproducibility will be seriously affected if the specific gravity and/or the temperature are allowed to vary from the specified requirements.*

- ***REPORTING THE RESULTS***

Report the weighted average percentage loss for the coarse and fine aggregate and the Batch Soundness Loss when necessary. When reporting the Batch Soundness Loss include the Test Number and Soundness Loss of each primary size of coarse aggregate used in the computation.

- ***SAFETY AND HEALTH***

It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Prior to handling, testing or disposing of any materials, testers must be knowledgeable about safe laboratory practices, hazards and exposure, chemical procurement and storage, and personal protective apparel and equipment.

COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of concrete is given in terms of the characteristic compressive strength of 150 mm size cubes tested at 28 days (f_{ck})- as per Indian Standards (ACI standards use cylinder of diameter 150 mm and height 300 mm). The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall.

Characteristic strength of concrete is the strength of concrete specimens casted and tested as per given code of practice and cured for a period of 28 days; 95% of tested cubes should not have a value less than this value.

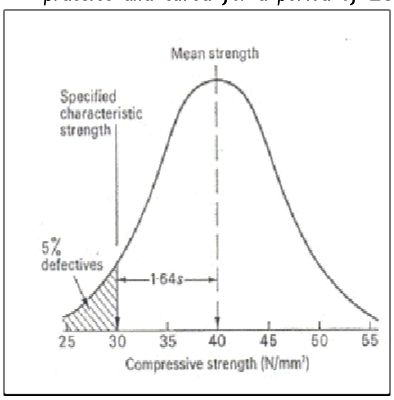


Fig. 1: Normal Distribution curve on test specimens for determining compressive strength

- ***Apparatus Required***

Fig. 2: Compression Testing Machine

The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the specified rate. The permissible error shall be not greater than ±2 percent of the maximum load.


Fig. 3: Moulds/ Cubes for Testing

The mould shall be of 150 mm size conforming to IS: 10086-1982.

- ## *Reference*

IS 516:1959 Methods of Tests for Strength of Concrete (Eighteenth revision). Reaffirmed- May 2013

- ## *Procedure*

  - *All materials shall be brought to room temperature, preferably 27 ±3 °C before commencing the test.*
  - *Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material. Care being taken to prevent intrusion of foreign materials.*
  - *The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.*
  - *The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.*
  - *The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.*
  - *Each batch of concrete shall be tested for consistency immediately after mixing, by one of the methods described in IS:1199-1959. Provided that care is taken to ensure that no water or other material is lost, the concrete used for the consistency tests may be remixed with the remainder of batch before making the test specimens. The period of re-mixing shall be as short as possible yet sufficient to produce a homogeneous mass.*
  - *Test specimens cubical in shape shall be 15 × 15 × 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter. They shall be 15 cm in diameter and 30 cm long. Smaller test specimens shall have a ratio of diameter of specimen to maximum size of aggregate of not less than 3 to 1, except that the diameter of the specimen shall be not less than 7·5 cm for mixtures containing aggregate more than 5 percent of which is retained on IS Sieve 480.*
  - *The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete shall be filled into the mould in layers approximately 5 cm deep. In placing each scoopful of concrete, the scoop shall he moved around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould. Each layer shall be compacted either by hand or by vibration.*
  - *The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ±2°C for 24 hours ±½ hour from the time of addition of water to the dry ingredients.*
  - *The ends of the specimen shall be capped before testing. The material used for the capping shall be such that its compressive strength is greater than that of the concrete in the core. Caps shall be made as thin as practicable and shall not flow or fracture before the concrete fails when the specimen is tested. The capped*

surfaces shall be at right angles to the axis of the specimen and shall not depart from a plane by more than 0·05 mm.

- *The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression platens.*
- *In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom.*
- *The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.*
- *The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.*
- *The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.*

• Observation And Recording

<

Sr. No.	Age of Cube	Cross Sectional Area(mm^2)	Load (N)	Compressive Strength (N/mm^2)	Avg. Compressive Strength (MPa)
1	3 days				
2					
3					
4	7 days				
5					
6					
7	28 days				
8					
9					

• Calculation

Table 1 *: Recordings during Compressive Test on Concrete*

The measured compressive strength of the cubes shall be calculated by dividing the maximum load applied to the cubes during the test by the cross-sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest 0.5 N/mm2. In determining the compressive strength, do not consider specimens that are manifestly faulty, or that give strengths differing by more than 10 percent from the average value of all the test specimens.

- *The average 3 Days Compressive Strength of given cement sample is found to be ……….*
- *The average 7 Days Compressive Strength of given cement sample is found to be ……….*
- *The average 28 Days Compressive Strength of given cement sample is found to be ……….*

• Graph

Draw graph between Characteristics Compressive Strength of Concrete versus Time (Days).

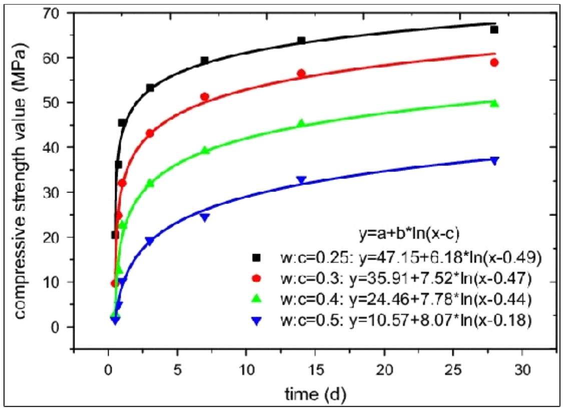


***Fig. 4** : Plot of Characteristics Compressive Strength of Concrete versus Time (Days).*

WORKABILITY OF CONCRETE BY SLUMP CONE TEST

- ## *Objective*

The word —workability or workable concrete signifies much wider and deeper meaning than the other terminology —consistency often used loosely for workability. Consistency is a general term to indicate the degree of fluidity or the degree of mobility. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are : (a) Water Content (b) Mix Proportions (c) Size of aggregates (d) Shape of aggregates (e) Surface Texture of aggregate (f) Grading of aggregate (g) Use of admixtures.

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor it is always representative of the placeability of the concrete.

It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slump. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence.

- ## *Apparatus Required*

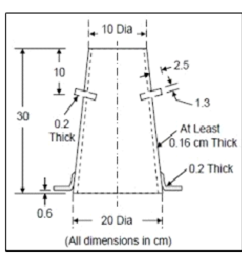


Fig. 1: Schematic Slump Cone Apparatus

The Slump Cone apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as : Bottom diameter : 20 cm, Top diameter : 10 cm, Height : 30 cm and the thickness of the metallic sheet for the mould should not be *thinner than 1.6 mm.*

Fig. 2: Slump Cone Apparatus

The Slump Cone apparatus along with Tamper (16 mm in diameter and 600 mm length. The tamping end of rod shall be rounded to a hemispherical tip), Ruler, etc.
Conforming to IS 7320:1974 Specifications for Concrete Slump Test Apparatus (Fourth revision). Reaffirmed- Dec 2013.

- ## *Reference*

IS 1199:1959 Methods of Sampling and Analysis of Concrete. Reaffirmed- Dec 2013.

- ## *Procedure*

  - *If this test is being carried out in the field, the sample mixed concrete shall be obtained. In the case of concrete containing aggregate of maximum size more than 38 mm, the concrete shall be wet-sieved through one and half inch screen to exclude aggregate particles bigger than 38 mm.*
  - *The internal surface of the mould shall be thoroughly cleaned and freed from superfluous moisture and any set concrete before commencing the test. The mould shall be placed on a smooth, horizontal, rigid and non-absorbent surface, such as a carefully levelled metal plate, the mould being firmly held in place while it is being filled.*
  - *The mould shall be filled in four layers, each approximately one-quarter of the height of the mould. Each layer shall be tamped with twenty-five strokes of the rounded end of the tamping rod. The strokes shall be distributed in a uniform manner over the cross-section of the mould and for the second and subsequent layers shall penetrate into the underlying layer.*
  - *The bottom layer shall be tamped throughout its depth. After the top layer has been rodded, the concrete shall be struck off level with a trowel or the tamping rod, so that the mould is exactly filled.*
  - *After the top layer has been rodded, strike off the surface of the concrete by means of screeding and rolling motion of the tamping rod.*
  - *Any mortar which may have leaked out between the mould and the base plate shall be cleaned away. The mould shall be removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside and the slump shall be measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested.*
  - *The above operations shall be carried out at a place free from vibration or shock, and within a period of two minutes after sampling.*

- ## *Observation And Recording*

The vertical difference between top of the mould and the displaced original center of the top surface of the specimen____________________mm

Workability	*Compaction Factor*	*Slump (mm)*
Very Low	*0.78*	*0 - 25*
Low	*0.85*	*25 - 50*

Medium	*0.92*	*50 - 100*
High	*0.95*	*100 - 175*

***Table 1** :Relation between Workability and Slump*

- *The pattern of slump is shown True Slump/Shear Slump/ Collapse Slump.*

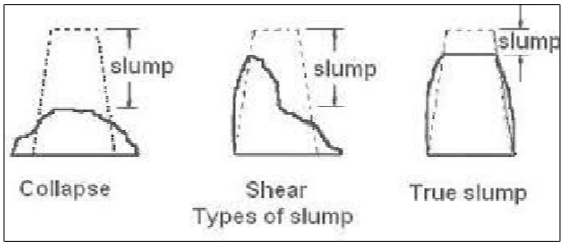


Fig. 3: Type of Slump

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

WORKABILITY OF CONCRETE BY COMPACTION FACTOR TEST

- ***Objective***

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability and normally used when concrete is to be compacted by vibration. The method applies to plain and air-entrained concrete, made with lightweight, normal weight or heavy aggregates having a nominal maximum size of 38 mm or less but not to aerated concrete or no-fines concrete.

- ***Apparatus Required***

Fig. 1: Balance

Balance should be able to weigh upto 1 g.

Fig. 2: Compaction Factor Apparatus with Allied Tools

Compacting Factor Apparatus, Trowel, Scoop about 150 mm long, Tamper (16 mm in diameter and 600 mm length), Ruler, etc.

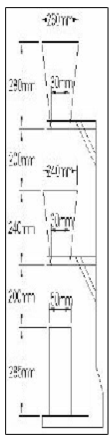


Fig. 3: Dimensions of Compaction Factor Apparatus

- ***Reference***

IS 1199:1959 Methods of Sampling and Analysis of Concrete (Eleventh revision). Reaffirmed- Dec 2013.

- ***Procedure***

  - *The sample of concrete to be tested shall be placed gently in the upper hopper, using the hand scoop. The hopper shall be filled level with its brim and the trap-door shall be opened so that the concrete falls into the lower hopper.*
  - *Certain mixes have a tendency to stick in one or both of the hoppers. If this occurs, the concrete may be helped through by pushing the rod gently into the concrete from the top. During this process, the cylinder shall be covered by the trowels.*
  - *Immediately after the concrete has come to rest, the cylinder shall be uncovered, the trap-door of the lower hopper opened, and the concrete allowed to fall into the cylinder. The excess of concrete remaining above the level of the top of the cylinder shall then be cut off by holding a trowel in each hand, with the plane of the blades horizontal, and moving them simultaneously one from each side across the top of the cylinder, at the same time keeping them pressed on the top edge of the cylinder.*

- *The outside of the cylinder shall then be wiped clean. The above operation shall be carried out at a place free from vibration or shock. The weight of the concrete in the cylinder shall then be determined to the nearest 10 g.*
- *The excess of concrete remaining above the level of the top of the cylinder shall then be cut off by holding a trowel in each hand, with the plane of the blades horizontal, and moving them simultaneously one from each side across the top of the cylinder, at the same time keeping them pressed on the top edge of the cylinder. The outside of the cylinder shall then be wiped clean. This entire process shall be carried out at a place free from vibration or shock.*
- *This weight shall be known as the weight of partially compacted concrete. The cylinder shall be refilled with concrete from the same sample in layers approximately 5 cm deep, the layers being heavily rammed or preferably vibrated so as to obtain full compaction.*
- *The top surface of the fully compacted concrete shall be carefully struck off level with the top of the cylinder. The outside of the cylinder shall then be wiped clean.*

• Observation And Recording

The compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It shall normally be stated to the nearest second decimal place.

Sr. No.	Description	Sample 1	Sample 2	Sample 3
1	Weight of Empty Cylinder (W_1)			
2	Weight of Empty Cylinder + Free Fall Concrete(W_2)			
3	Weight of Empty Cylinder + Hand Compacted Concrete (W_3)			
4	Weight of Partially Compacted Concrete($W_P = W_2 - W_1$)			
5	Weight of Fully Compacted Concrete($W_F = W_3 - W_1$)			
6	Compaction Factor = W_P / W_F			

• Result

***Table 1** : Compaction Factor Test*

- *Compaction Factor of Concrete is found out to be = ...*
- *The vertical difference between top of the mould and the displaced original center of the top surface of the specimen______________________mm*

Workability	Compaction Factor	Slump (mm)
Very Low	0.78	0 - 25
Low	0.85	25 - 50
Medium	0.92	50 - 100
High	0.95	100 - 175

Table 2 :Relation between Workability and Slump

REBOUND HAMMER TEST

- **Objective And Principle**

Objective:

The rebound hammer method could be used for:

- assessing the likely compressive strength of concrete with the help of suitable corelations between rebound index and compressive strength,
- assessing the uniformity of concrete,
- assessing the quality of the concrete in relation to standard requirements, and
- assessing the quality of one element of concrete in relation to another.

Principle:

When the plunger of rebound hammer is pressed against the surface of the concrete, the spring- controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

- **Apparatus Required**

Fig. 1: Rebound Hammer

It consists of a spring controlled mass that slides on a plunger within a tubular housing. The impact energy required for rebound hammers for different applications is given in Table 1.

S. No.	Application	Approx. Impact Energy required for Rebound hammer (Nm)
1	For Testing Normal Weight Concrete	2.25
2	For light-weight concrete or small and impact sensitive parts of concrete	0.75
3	For testing mass concrete for example, in roads, air field pavements and hydraulic structures	2.25

Table 1 : Impact Energy for Rebound hammer for different Applications.

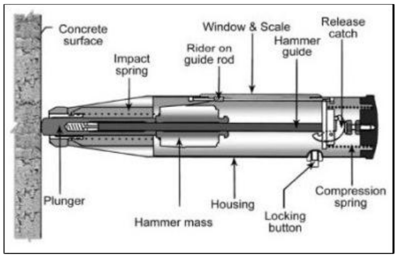


Fig. 2: Schematic of Rebound Hammer

- ## *Reference*

IS-13311 (Part 2):1992 (Reaffirmed- May 2013) "Non Destructive Testing of Concrete-Methods of Test (Rebound hammer)".

- ## *Procedure*

- *Checking of apparatus*

It is necessary that the rebound hammer is checked against the testing anvil before commencement of a test to ensure reliable results. The testing anvil should be of steel having Brinell hardness of about 5000 N/mm^2. The supplier/manufacturer of the rebound hammer should indicate the range of readings on the anvil suitable for different types of rebound hammers.

- *Procedure of obtaining Correlation between Compressive Strength of Concrete and Rebound Number*

The most satisfactory way of establishing a correlation between compressive strength of concrete and its rebound number is to measure both the properties simultaneously on concrete cubes. The concrete cube specimens are held in a compression testing machine under a fixed load, measurements of rebound number taken and then the compressive strength determined as per IS: 516- 1959. The fixed load required is of the order of 7 N/mm^2 when the impact energy of the hammer is about 2.2 Nm. The load should be increased for calibrating rebound hammers of greater impact energy and decreased for calibrating rebound hammers of lesser impact energy. The test specimens should be as large a mass as possible in order to minimise the size effect on the test result of a full scale structure. 150 mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.2 Nm), whereas for rebound hammers of higher impact energy, for example 30 Nm, the test cubes should not be smaller than 300 mm.

If the specimens are wet cured, they should be removed from wet storage and kept in the laboratory atmosphere for about 24 hours before testing. To obtain a correlation between rebound numbers and strength of wet cured and wet tested cubes, it is necessary to establish a correlation between the strength of wet tested cubes and the strength of dry tested cubes on which rebound readings are taken. A direct correlation between rebound numbers on wet cubes and the strength of wet cubes is not recommended. Only the vertical faces of the cube as cast should be tested. At least nine readings should be taken on each of the two vertical faces accessible in the compression testing machine when using the rebound hammers. The points of impact on the specimen must not be nearer an edge than 20 mm and should be not less than 20 mm from each other. The same points must not be impacted more than once.

- *Test Procedure*

    - *For testing, smooth, clean and dry surface is to be selected. If loosely adhering scale is present, this should be rubbed of with a grinding wheel or stone. Rough surfaces resulting from incomplete compaction, loss of grout, spalled or tooled surfaces do not give reliable results and should be avoided.*
    - *The point of impact should be at least 20 mm away from any edge or shape discontinuity.*
    - *For taking a measurement, the rebound hammer should be held at right angles to the surface of the concrete member. The test can thus be conducted horizontally on vertical surfaces or vertically*

upwards or downwards on horizontal surfaces. If the situation demands, the rebound hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.

- Rebound hammer test is conducted around all the points of observation on all accessible faces of the structural element. Concrete surfaces are thoroughly cleaned before taking any measurement. Around each point of observation, six readings of rebound indices are taken and average of these readings after deleting outliers as per IS:8900-1978 becomes the rebound index for the point of observation.

• Influence Of Test Conditions:

The rebound numbers are influenced by a number of factors like types of cement and aggregate, surface condition and moisture content, age of concrete and extent of carbonation of concrete.

- Influence of Type of Cement

Concretes made with high alumina cement can give strengths 100 percent higher than that with ordinary Portland cement. Concretes made with super sulphated cement can give 50 percent lower strength than that with ordinary Portland cement.

- Influence of Type of ggregate

Different types of aggregate used in concrete give different correlations between compressive strength and rebound numbers. Normal aggregates such as gravels and crushed rock aggregates give similar correlations, but concrete made with light weight aggregates require special calibration.

- Influence of Surface Condition and Moisture Content of Concrete

The rebound hammer method is suitable only for close texture concrete. Open texture concrete typical of masonry blocks, honeycombed concrete or no-fines concrete are unsuitable for this test. Al correlations

assume full compaction, as the strength of partially compacted concrete bears no unique relationship to the rebound numbers. Trowelled and floated surfaces are harder than moulded surfaces, and tend to over estimate the strength of concrete.

A wet surface will give rise to under estimation of the strength of concrete calibrated under dry conditions. In structural concrete, this can be about 20 percent lower than in an equivalent dry concrete.

- Influence of Curing and ge of Concrete

The relationship between hardness and strength varies as a function of time. Variations in initial rate of hardening, subsequent curing and conditions of exposure also influence the relationship. Separate calibration curves are required for different curing regimes but the effect of age can generally be ignored for concrete between 3 days and 3 months old.

- Influence of Carbonation of Concrete Surface

The influence of carbonation of concrete surface on the rebound number is very significant. Carbonated concrete gives an overestimate of strength which in extreme cases can be up to 50 percent. It is possible to establish correction factors by removing the carbonated layer and testing the concrete with the rebound hammer on the uncarbonated concrete.

• Interpretation Of Result

- The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete. The procedure of obtaining such correlation is given in 4.2.
- It is also pointed out that rebound indices are indicative of compressive strength of concrete to a limited depth from the surface. If the concrete in a particular member has internal microcracking, flaws or heterogeneity across the cross-section, rebound hammer indices will not indicate the same.
- As such, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in a structure is ±25 percent. If the relationship

between rebound index and compressive strength can be checked by tests on core samples obtained from the structure or standard specimens made with the same concrete materials and mix proportion, then the accuracy of results and confidence thereon are greatly increased.

ULTRASONIC PULSE VELOCITY METER

- ## Objective And Principle

Objective

The ultrasonic pulse velocity method could be used to establish:

- *the homogeneity of the concrete,*
- *the presence of cracks, voids and other imperfections,*
- *changes in the structure of the concrete which may occur with time,*
- *the quality of the concrete in relation to standard requirements,*
- *the quality of one element of concrete in relation to another, and*
- *the values of dynamic elastic modulus of the concrete.*

Principle

The ultrasonic pulse is generated by an electroacoustical transducer. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compressional), shear (transverse) and surface (rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete.

The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the puise velocity.

- ## Apparatus Required

- ## *Reference*

IS-516(Part 5/Sec 1):2018 "Part 5 Non-Destructive Testing of Concrete- Section 1 Ultrasonic Pulse Velocity Testing"

- ## *Procedure*

- *In this test method, the ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length **L** in the concrete, the pulse of vibrations is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transit time (T) of the pulse to be measured. The pulse velocity (**V**) is given by:*

$$V = L/T$$

- *Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross probing). However, in many situations two opposite faces of the structural member may not be accessible for measurements. In such cases, the receiving transducer is also placed on the same face of the concrete members (surface probing). Surface probing is not so efficient as cross probing, because the signal produced at the receiving transducer has an amplitude of only 2 to 3 percent of that produced by cross probing and the test results are greatly influenced by the surface layers of concrete which may have different properties from that of concrete inside the structural member. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5 to 20 percent depending largely on the quality of the concrete under test. For good quality concrete, a difference of about 0.5 km/ sec may generally be encountered.*
- *To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer, it is essential that there be adequate acoustical coupling between the concrete and the face of each transducer. Typical couplants are petroleum jelly, grease, liquid soap and kaolin glycerol paste. If there is very rough concrete surface, it is required to smoothen and level an area of the surface where the transducer is to be placed. If it is necessary to work on concrete surfaces formed by other means, -for example trowelling, it is desirable to measure pulse velocity over a longer path length than would normally be used. A minimum path length of 150 mm is recommended for the direct transmission method involving one unmoulded surface and a minimum of 400 mm for the surface probing method along an unmoulded surface.*
- *The natural frequency of transducers should preferably be within the range of 20 to 150 kHz. Generally, high frequency transducers are preferable for short path lengths and low frequency transducers for long path lengths. Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications.*
- *Since size of aggregates influences the pulse velocity measurement, it is recommended that the minimum path length should be 100 mm for concrete in which the nominal maximum size of aggregate is 20 mm or less and 150 mm for concrete in which the nominal maximum size of aggregate is between 20 to 40 mm.*

- *In view of the inherent variability in the test results, sufficient number of readings are taken by dividing the entire structure in suitable grid markings of 30 x 30 cm or even smaller. Each junction point of the grid becomes a point of observation.*
- *Transducers are held on corresponding points of observation on opposite faces of a structural element to measure the ultrasonic pulse velocity by direct transmission,*

  i.e., cross probing. If one of the faces is not- accessible, ultrasonic pulse velocity is measured on one face of the structural member by surface probing.
- *Surface, probing in general gives lower pulse velocity than in case of cross probing and depending on number of parameters, the difference could be of the order of about 1 km/sec.*

- ***Influence of Test Conditions***

- ***Influence of Surface Conditions and Moisture Content of Concrete***

Smoothness of contact surface under test affects the measurement of ultrasonic pulse velocity. For most concrete surfaces, the finish is usually sufficiently smooth to ensure good acoustical contact by the use of a coupling medium and by pressing the transducer against the concrete surface. When the concrete surface is rough and uneven, it is necessary to smoothen the surface to make the pulse velocity measurement possible.

In general, pulse velocity through concrete increases with increased moisture content of concrete. This influence is more for low strength concrete than high strength concrete. The pulse velocity of saturated concrete may be up to 2 percent higher than that of similar dry concrete. In general, drying of concrete may result in somewhat lower pulse velocity.

- ***Influence of Path Length, Shape and Size of the Concrete Member***

As concrete is inherently heterogeneous, it is essential that path lengths be sufficiently long so as to avoid any error introduced due to its heterogeneity. In field work, this does not pose any difficulty as the pulse velocity measurements are carried out on thick structural concrete members. However, in the laboratory where generally small specimens are used, the path length can affect the pulse velocity readings.

The shape and size of the concrete member do not influence the pulse velocity unless the least lateral dimension is less than a certain minimum value, for example the minimum lateral dimension of about 80 mm for 50 kHz natural frequency of the transducer. Table 1 gives the guidance on the choice of the transducer natural frequency for different path lengths and minimum transverse dimensions of the concrete members.

- ***Influence of Temperature of Concrete***

Variations of the concrete temperature between 5 and 30°C do not significantly affect the pulse velocity measurements in concrete. At temperatures between 30 to 60°C there can be reduction in pulse velocity up to 5 percent. Below freezing temperature, the free water freezes within concrete, resulting in an increase .in pulse velocity up to
7.5 percent.

- ***Influence of Stress***

When concrete is subjected to a stress which is abnormally high for the quality of the concrete, the pulse velocity may be reduced due to the development of micro-cracks. This influence is likely to be the greatest when the pulse path is normal to the predominant direction of the planes of such micro-cracks. This occurs when the pulse path is perpendicular to the direction of a uniaxial compressive stress in a member.

This influence is generally insignificant unless the stress is greater than about 60 percent of the ultimate strength of the concrete.

- ***Effect of Reinforcing Bars***

The pulse velocity measured in reinforced concrete in the vicinity of reinforcing bars is usually higher than in plain concrete of the same composition. This is because, the pulse velocity in steel is 1.2 to 1.9 times the velocity in plain concrete and, under certain conditions, the first pulse to arrive at the receiving transducer travels partly in concrete and partly in steel.

The apparent increase in pulse velocity depends upon the proximity of the measurements to the reinforcing bar, the diameter and number of the bars and their orientation with respect to the path of propagation.

• *Interpretation Of Result*

- *The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete.*

  For example, if the concrete is not compacted as thoroughly as possible, or if there is segregation of concrete during placing or there are internal cracks or flaws, the pulse velocity will be lower, although the same materials and mix proportions are used.
- *The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc, indicative of the level of workmanship employed; can thus be assessed using the guidelines given in Table 2, which have been evolved for characterising the quality of concrete in structures in terms of the ultrasonic pulse velocity.*

S. No.	Average velocity of Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1	Below 3.5	Doubtful"
2	3.50 to 4.50	Good
3	Above 4.50	Excellent

***Table 1** : For concrete (Less than or Equal to M 25).*

S. No.	Pulse velocity by Cross Probing (km/sec)	Concrete Quality Grading
1	Above 3.75	Doubtful"
2	3.75 to 4.50	Good
3	Above 4.50	Excellent

***Table 2** : For concrete (Greater than M 25).*

" In case of 'Doubtful quality', it shall be necessary to carry out additional tests.

- *Since actual values of the pulse velocity obtained, depend on a number of parameters, any criterion for assessing the quality of concrete on the basis of pulse velocity as given in Table 2 can be held as satisfactory only to a general extent. However, when the comparison is made amongst different parts of a structure, which have been built at the same time with supposedly similar materials, construction practices and supervision, the assessment of quality becomes more meaningful and reliable.*
- *The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate because the statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high. The reason is that a large number of parameters are involved, which influence the pulse velocity and compressive strength of concrete to different extents. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the*

  pulse velocity and the compressive strength of concrete specimens made with such materials and mix proportions, under environmental conditions similar to that in the structure. The estimated strength may vary from the actual strength by 20 percent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials.