



DEPARTMENT OF CIVIL ENGINEERING  
FACULTY OF ENGINEERING & TECHNOLOGY

# TRANSPORTATION ENGINEERING – I (Highway Engineering)

## Topics to be covered:

- Compressive Strength of Concrete and Factors affecting it
- Characteristic Strength of Concrete
- Green Density and Dry Density Tests
- Problems Related to the Topics Discussed



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# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

- The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses.
- In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties.
- Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used as a qualitative measure for other properties of hardened concrete.
- No exact quantitative relationship between compressive strength and flexural strength, tensile strength, modulus of elasticity, wear resistance, fire resistance, or permeability have been established nor are they likely to be.
- However, approximate or statistical relationships, in some cases, have been established and these give much useful information to engineers.
- It should be emphasised that compressive strength gives only an approximate value of these properties and that other tests specifically designed to determine these properties should be useful if more precise results are required.
- For instance, the indicated compressive strength increases as the specimen size decreases, whereas the modulus of elasticity decreases. The modulus of elasticity in this case does not follow the compressive strength.
- The other case where the compressive strength does not indicate the useful property of concrete is when the concrete is subjected to freezing and thawing.
- Concrete containing about 6 per cent of entrained air which is relatively weaker in strength is found to be more durable than dense and strong concrete.
- The compressive strength of concrete is generally determined by testing cubes or cylinders made in laboratory or field or cores drilled from hardened concrete at site or from the non-destructive testing of the specimen or actual structures.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

Strength of concrete is its resistance to rupture. It may be measured in a number of ways, such as, strength in compression, in tension, in shear or in flexure.

All these indicate strength with reference to a particular method of testing. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure.

The mechanics of failure is a complex phenomena. It can be assumed that the concrete in resisting failure, generates both cohesion and internal friction.

The cohesion and internal friction developed by concrete in resisting failure is related to more or less a single parameter i.e., w/c ratio.

The modern version of original water/cement ratio rule can be given as follows:

**For a given cement and acceptable aggregates, the strength that may be developed by workable, properly placed mixture of cement, aggregate and water (under the same mixing, curing and testing conditions) is influenced by:**

- (a ) Ratio of cement to mixing water;**
- (b) Ratio of cement to aggregate;**
- (c ) Grading, surface texture, shape, strength and stiffness of aggregate particles;**
- (d) Maximum size of aggregate.**

In the above it can be further inferred that water/cement ratio primarily affects the strength, whereas other factors indirectly affect the strength of concrete by affecting the water/ cement ratio.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

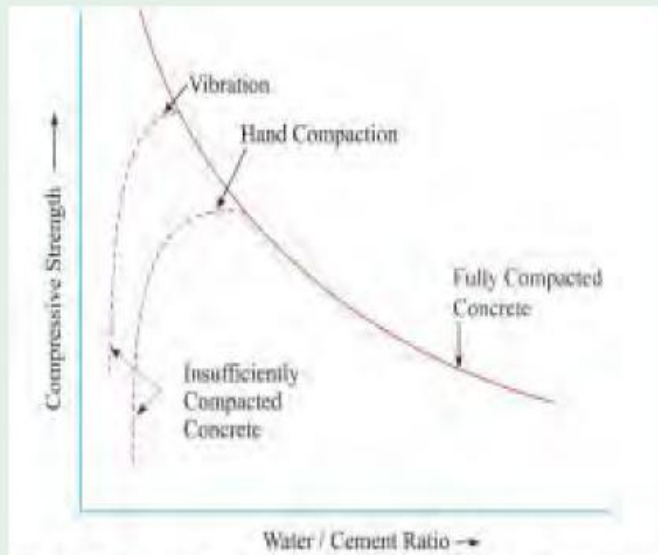
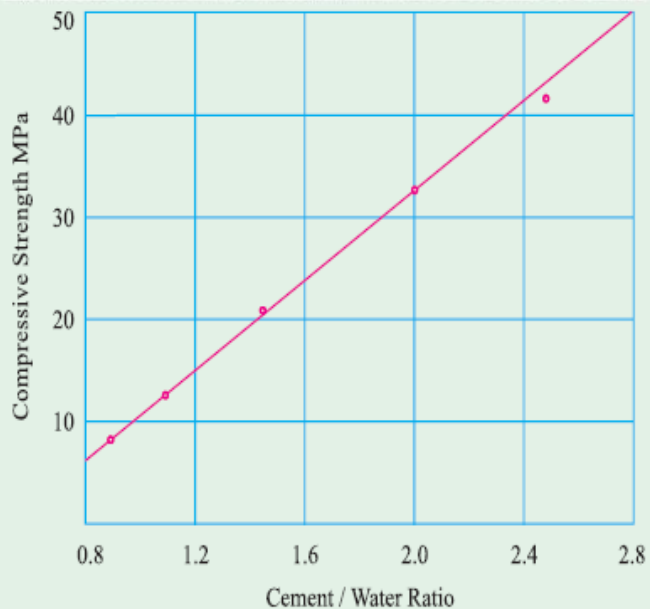


Fig. 7.1. The relation between strength and water/cement ratio of concrete.



Strength of concrete primarily depends upon the strength of cement paste. It has been shown in Chapter I that the strength of cement paste depends upon the dilution of paste or in other words, the strength of paste increases with cement content and decreases with air and water content. In 1918 Abrams presented his classic law in the form:  $S = \frac{A}{B^x}$

where  $x$  = water/cement ratio by volume and for 28 days results the constants  $A$  and  $B$  are 14,000 lbs/sq. in. and 7 respectively. Abrams water/cement ratio law states that the strength of concrete is only dependent upon water/cement ratio provided the mix is workable. In the past many theories have been propounded by many research workers. Some of them held valid for some time and then underwent some changes while others did not stand the test of time and hence slowly disappeared. But Abrams' water/cement ratio law stood the test of time and is held valid even today as a fundamental truth in concrete-making practices. No doubt some modifications have been suggested but the truth of the statement could not be challenged. Strictly speaking, it was Feret who formulated in as early as 1897, a general rule defining the strength of the concrete paste and concrete in terms of volume fractions of the constituents by the equation:  $S = K \left( \frac{c}{c+e+a} \right)^2$

where **S = Strength of concrete**

**c, e and a = volume of cement, water and air respectively and**

**K = a constant.**

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

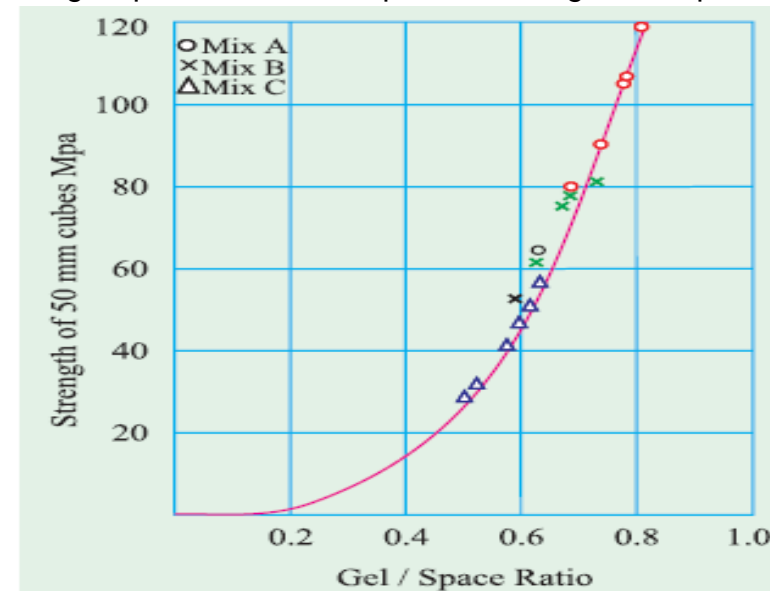
- In this expression the volume of air is also included because it is not only the water/ cement ratio but also the degree of compaction, which indirectly means the volume of air filled voids in the concrete is taken into account in estimating the strength of concrete.
- It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand-compacted. In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids.
- The graph showing the relationship between the strength and water/cement ratio is approximately hyperbolic in shape. Sometimes it is difficult to interpolate the intermediate value.
- From geometry it can be deduced that if the graphs is drawn between the strength and the cement/water ratio an approximately linear relations hip will be obtained.
- This linear relationship is more convenient to use than water/cement ratio curve for interpolation.

## GEL/SPACE RATIO :

- Many research workers commented on the validity of water/cement ratio law as propounded by Duff Abrams.
- They have forwarded a few of the limitations of the water/ cement ratio law and argued that Abrams water/cement ratio law can only be called a rule and not a law because Abrams' statement does not include many qualifications necessary for its validity to call it a law.
- Some of the limitations are that the strength at any water/cement ratio depends on the degree of hydration of cement and its chemical and physical properties, the temperature at which the hydration takes place, the air content in case of air entrained concrete, the change in the effective water/cement ratio and the formation of fissures and cracks due to bleeding or shrinkage.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

- Instead of relating the strength to water/cement ratio, the strength can be more correctly related to the solid products of hydration of cement to the space available for formation of this product.
- Powers and Brownyard have established the relationship between the strength and gel/space ratio.
- This ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of volumes of the hydrated cement and of the capillary pores.
- Power's experiment showed that the strength of concrete bears a specific relationship with the gel/space ratio.
- He found the relationship to be  $240 x^3$ , where  $x$  is the gel/space ratio and 240 represents the intrinsic strength of the gel in MPa for the type of cement and specimen used.
- The strength calculated by Power's expression holds good for an ideal case.
- It is pointed out that the relationship between the strength and water/cement ratio will hold good primarily for 28 days strength for fully compacted concrete, whereas, the relationship between the strength and gel/space ratio is independent of age. Gel/space ratio can be calculated at any age and for any fraction of hydration of cement.



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

## GAIN OF STRENGTH WITH AGE :

- The concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age.
- It is customary to assume the 28 days strength as the full strength of concrete.
- Actually concrete develops strength beyond 28 days also.
- Earlier codes have not been permitting to consider this increase of strength beyond 28 days for design purposes.
- The increase in strength beyond 28 days used to get immersed with the factor of safety. With better understanding of the material, progressive designers have been trying to reduce the factor of safety and make the structure more economical. In this direction, the increase in strength beyond 28 days is taken into consideration in design of structures.
- Some of the more progressive codes have been permitting this practice.

<i>Minimum age of member when full design load is applied, months</i>	<i>Age factor for low-strength concrete</i>	<i>Additional strength for high strength concrete MPa</i>
1	1.00	0
2	1.10	4.2
3	1.16	5.5
6	1.20	7.7
12	1.24	10.2



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

Earlier IS code 456 of 1978 considered age factor and allowed the increase in design stress in the lower columns in multistorey buildings. Earlier only one type of cement i.e., cement governed by IS- 269 of 1976 was used in which case there was appreciable increase in strength after 28 days. After gradation of OPC the present day cements particularly 53 grade cements, being ground finer, the increase in strength after 28 days is nominal. Most of the strength developments in respect of well cured concrete will have taken place by 28 days. Therefore, allowing age factor is not generally found necessary. Therefore, in IS 456 of 2000, the clause is revised. The clause states “There is normally a gain of strength beyond 28 days. The quantum of increase depends upon the grade and type of cement, curing and environmental conditions etc. The design should be based on 28 days characteristic strength of concrete unless there is an evidence to justify a higher strength for a particular structure due to age”.

<i>Group</i>	<i>Grade Designation</i>	<i>Specified characteristic compressive strength of 150 mm cube at 28 days in N/mm<sup>2</sup></i>
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
High Strength Concrete	M 55	55
	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

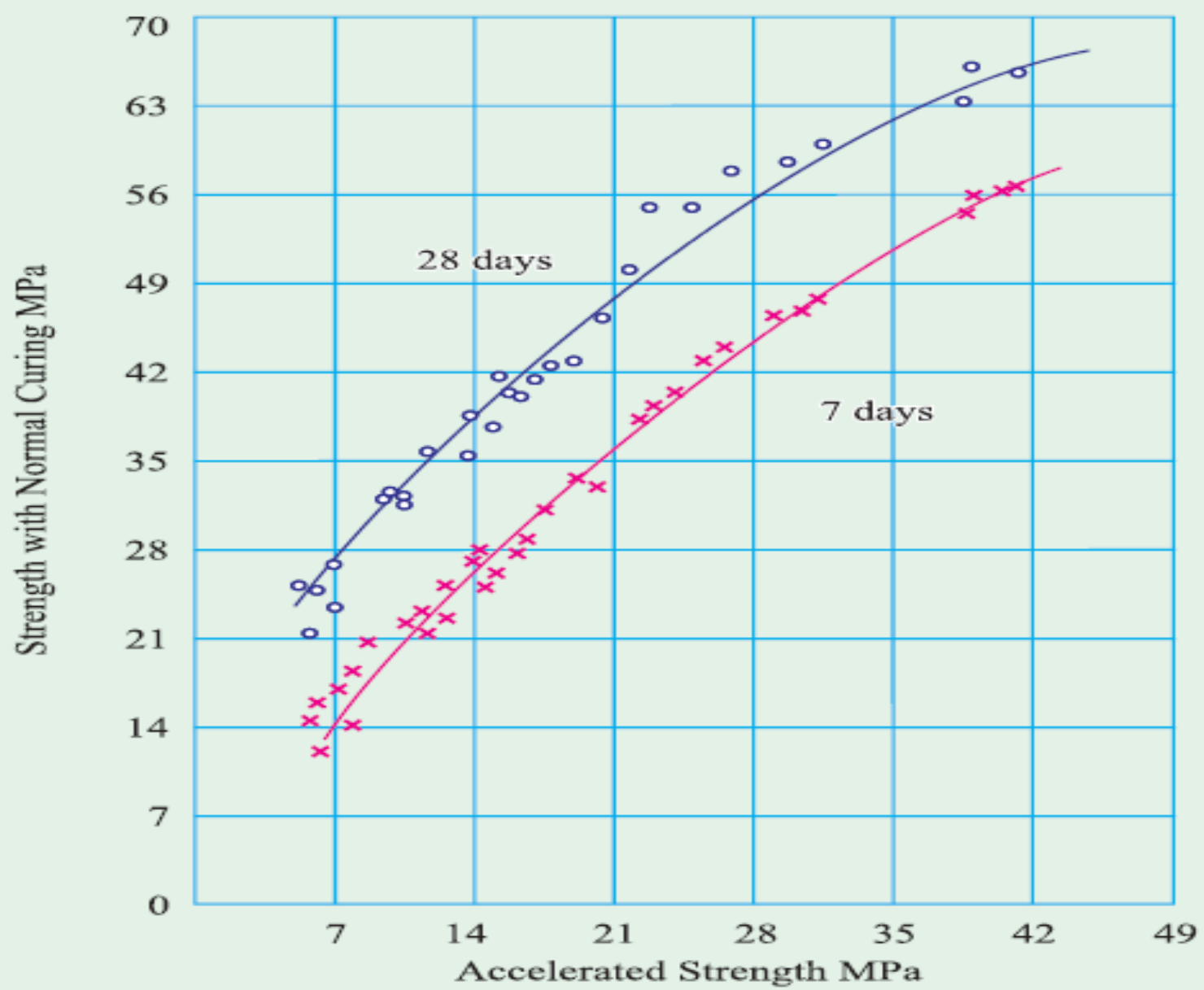
# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

Grade of concrete	Permissible stress in compression		Permissible stress in Bond (average) for Plain Bars in tension
	Bending	Direct	
M 10	3.0	2.5	—
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

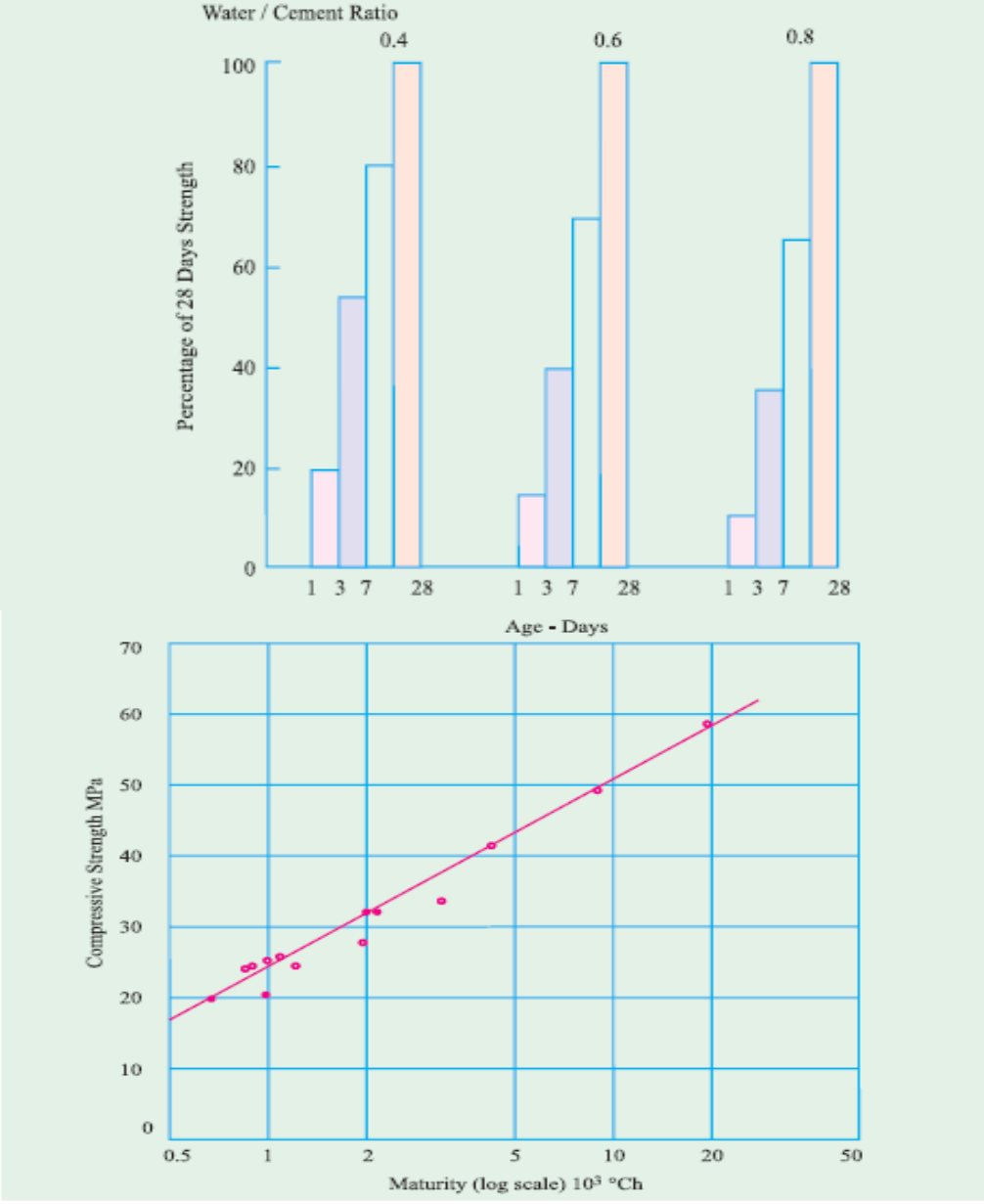
**Note:** The bond stress may be increased by 25 per cent for bars in compression.

$\frac{100 \times A_s}{bd}$	Permissible shear stress in concrete N/mm <sup>2</sup> Grades of concrete					
(1)	M 15 (2)	M 20 (3)	M 25 (4)	M 30 (5)	M 35 (6)	M 40 and above (7)
≤ 0.15	0.18	0.18	0.19	0.20	0.20	0.20
0.25	0.22	0.22	0.23	0.23	0.23	0.23
0.50	0.29	0.30	0.31	0.31	0.31	0.32
0.75	0.34	0.35	0.36	0.37	0.37	0.38
1.00	0.37	0.39	0.40	0.41	0.42	0.42
1.25	0.40	0.42	0.44	0.45	0.45	0.46
1.50	0.42	0.45	0.46	0.48	0.49	0.49
1.75	0.44	0.47	0.49	0.50	0.52	0.52
2.00	0.44	0.49	0.51	0.53	0.54	0.55
2.25	0.44	0.51	0.53	0.55	0.56	0.57
2.50	0.44	0.51	0.55	0.57	0.58	0.60
2.75	0.44	0.51	0.56	0.58	0.60	0.62
3.00	0.44	0.51	0.57	0.60	0.62	0.63
and Above						

COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :



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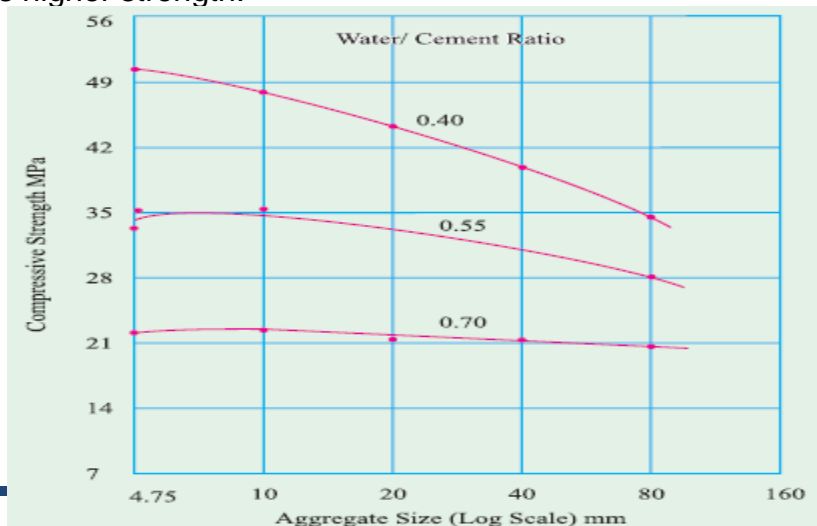
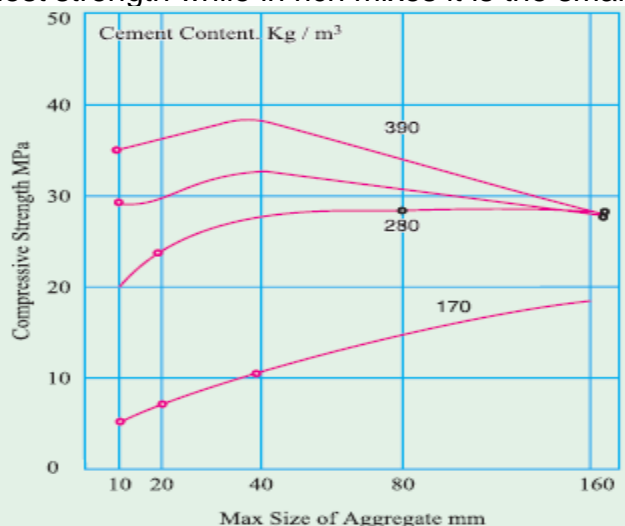
## EFFECT OF MAXIMUM SIZE OF AGGREGATE ON STRENGTH :

At one time it was thought that the use of larger size aggregate leads to higher strength. This was due to the fact that the larger the aggregate the lower is the total surface area and, therefore, the lower is the requirement of water for the given workability. For this reason, a lower water/cement ratio can be used which will result in higher strength.

However, later it was found that the use of larger size aggregate did not contribute to higher strength as expected from the theoretical considerations due to the following reasons. The larger maximum size aggregate gives lower surface area for developments of gel bonds which is responsible for the lower strength of the concrete. Secondly bigger aggregate size causes a more heterogeneity in the concrete which will prevent the uniform distribution of load when stressed.

When large size aggregate is used, due to internal bleeding, the transition zone will become much weaker due to the development of micro-cracks which result in lower compressive strength.

Generally, high strength concrete or rich concrete is adversely affected by the use of large size aggregate. But in lean mixes or weaker concrete the influence of size of the aggregate gets reduced. It is interesting to note that in lean mixes larger aggregate gives highest strength while in rich mixes it is the smaller aggregate which yields higher strength.



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

## RELATION BETWEEN COMPRESSIVE AND TENSILE STRENGTH :

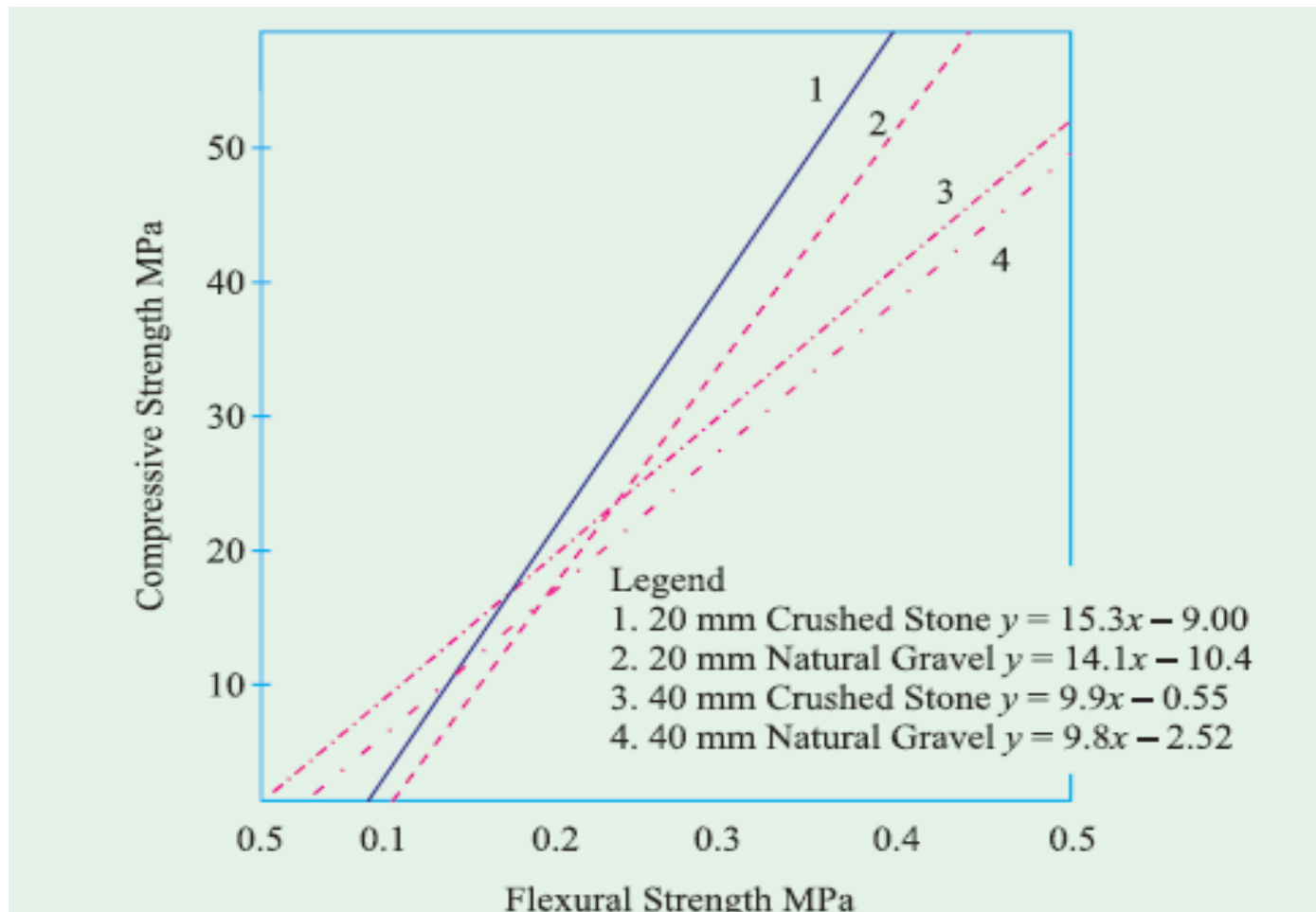
In reinforced concrete construction the strength of the concrete in compression is only taken into consideration. The tensile strength of concrete is generally not taken into consideration. But the design of concrete pavement slabs is often based on the flexural strength of concrete. Therefore, it is necessary to assess the flexural strength of concrete either from the compressive strength or independently. As measurements and control of compressive strength in field are easier and more convenient, it has been customary to find out the compressive strength for different conditions and to correlate this compressive strength to flexural strength. Having established a satisfactory relationship between flexural and compressive strength, pavement, can be designed for a specified flexural strength value, or this value could be used in any other situations when required.

It is seen that strength of concrete in compression and tension (both direct tension and flexural tension) are closely related, but the relationship is not of the type of direct proportionality. The ratio of the two strengths depends on general level of strength of concrete. In other words, for higher compressive strength concrete shows higher tensile strength, but the rate of increase of tensile strength is of decreasing order. The type of coarse aggregate influences this relationship. Crushed aggregate gives relatively higher flexural strength than compressive strength. This is attributed to the improved bond strength between cement paste and aggregate particles. The tensile strength of concrete, as compared to its compressive strength, is more sensitive to improper curing. This may be due to the inferior quality of gel formation as a result of improper curing and also due to the fact that improperly cured concrete may suffer from more shrinkage cracks. The use of pozzolanic material increases the tensile strength of concrete. From the extensive study, carried out at Central Road Research Laboratory (CRRI) the following statistical relationship between tensile strength and compressive strength were established.

- (i )  $y = 15.3x - 9.00$  for 20 mm maximum size aggregate.
- (ii )  $y = 14.1x - 10.4$  for 20 mm maximum size natural gravel.
- (iii)  $y = 9.9x - 0.55$  for 40 mm maximum size crushed aggregate.
- (iv )  $y = 9.8x - 2.52$  for 40 mm maximum size natural gravel.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

Where  $y$  is the compressive strength of concrete MPa and  $x$  is the flexural strength of concrete Mpa.



Subjecting all the data to statistical treatment the following general relationship has been established at CRRRI between flexural and compressive strength of concrete:

$$Y = 11X - 3.4$$

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

Compressive Strength MPa	Flexural Strength as Percentage of Compressive Strength per cent			
	Gravel Aggregate with Maximum size		Crushed Stone Aggregate with Maximum Size	
	20 mm	40 mm	20 mm	40 mm
49	8.7	-	7.7	-
42	9.0	10.8	7.9	10.2
35	9.3	10.9	8.2	10.3
28	9.9	11.1	8.6	10.2
21	10.8	11.3	9.3	10.3
14	12.5	12.0	10.8	10.5
Average	10.0	11.2	8.8	10.3

The flexural to compressive strength ratio was higher with aggregate of 40 mm maximum size than with those of 20 mm maximum size. In general the ratio was found to be slightly higher in the case of natural gravel as compared to crushed stone. Flexural strength of concrete is usually found by testing plain concrete beams.

Compressive Strength of Cylinders MPa	Strength Ratio		
	Modulus of repture* to compressive strength	Direct tensile strength to compressive strength	Direct tensile strength to modulus of rupture
7	0.23	0.11	0.48
14	0.19	0.10	0.53
21	0.16	0.09	0.57
28	0.15	0.09	0.59
35	0.14	0.08	0.59
42	0.13	0.08	0.60
49	0.12	0.07	0.61
56	0.12	0.07	0.62
63	0.11	0.07	0.63

The Indian Standard IS = 456 of 2000 gives the following relationship between the compressive strength and flexural strength

**FLEXURAL STRENGTH = 0.7 √F<sub>CK</sub>**

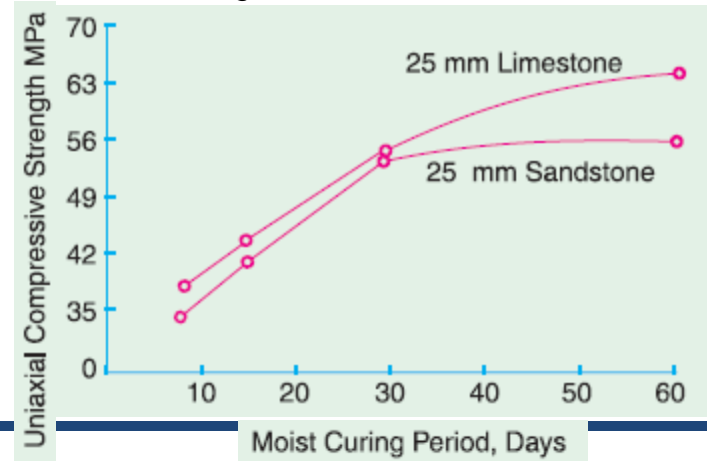
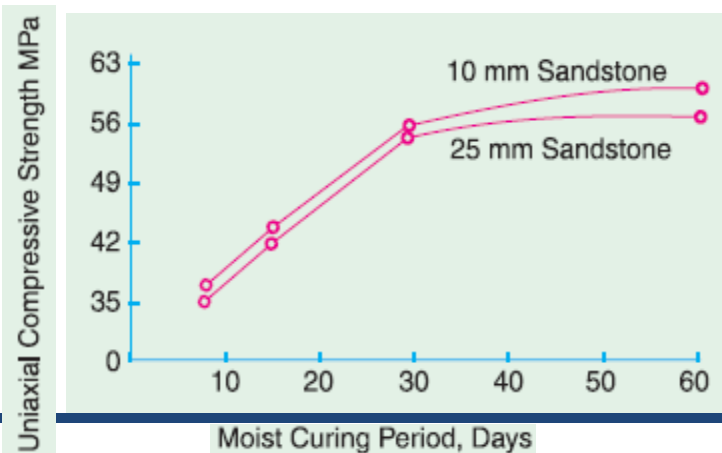
where fck is the characteristic compressive strength of concrete in N/mm2



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

## AGGREGATE-CEMENT BOND STRENGTHS :

- Concrete can be regarded as a chain in which aggregates are the links bonded together by cement paste.
- Just as the strength of a chain as a whole is depending upon the strength of welding of the individual links, the strength of concrete as a whole is depending upon the strength (bond strength) of the hydrated hardened cement paste (hcp).
- By and large the strength of hcp is depending upon w/c ratio which determines the quality, continuity, density, porosity of the products of hydration in particular the C-S-H gel.
- Stronger the gel bond stronger is the concrete. Aggregates generally being much stronger than the paste (gel bond), its strength is not of consequence in normal strength concrete.
- The strength of aggregate is of consideration in high strength concrete and light weight concrete.
- The explanation that the strength of Concrete is limited by strength of the paste, will hold good when we consider concrete as two phase material.
- If we take a closer look into the structure of the concrete, a third phase comes into consideration i.e., inter-face between the paste and aggregate known as Transition Zone.
- In the ultimate analysis it is the integrity of the transition zone that influences the strength of concrete.



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

There are special methods of making high strength concrete. They are given below.

- (a) Seeding
- (b) Re-vibration
- (c ) High speed slurry mixing;
- (d) Use of admixtures
- (e) Inhibition of cracks
- (f ) Sulphur impregnation;
- (g ) Use of cementitious aggregates.

**SEEDING:** This involves adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix. The mechanism by which this is supposed to aid strength development is difficult to explain. This method may not hold much promise.

**REVIBRATION:** Concrete undergoes plastic shrinkage. Mixing water creates continuous capillary channels, bleeding, and water accumulates at some selected places. All these reduce the strength of concrete. Controlled re-vibration removes all these defects and increases the strength of concrete.

**HIGH SPEED SLURRY MIXING:** This process involves the advance preparation of cement-water mixture which is then blended with aggregate to produce concrete. Higher compressive strength obtained is attributed to more efficient hydration of cement particles and water achieved in the vigorous blending of cement paste.

**USE OF ADMIXTURES:** Use of water reducing agents are known to produce increased compressive strengths.

**INHIBITION OF CRACKS:** Concrete fails by the formation and propagation of cracks. If the propagation of cracks is inhibited, the strength will be higher. Replacement of 2– 3% of fine aggregate by polythene or polystyrene “lenticules” 0.025 mm thick and 3 to 4 mm in diameter results in higher strength. They appear to act as crack arresters without necessitating extra water for workability. Concrete cubes made in this way have yielded strength upto 105 MPa.

**SULPHUR IMPREGNATION:** Satisfactory high strength concrete have been produced by impregnating low strength porous concrete by sulphur. The process consists of moist curing the fresh concrete specimens for 24 hours, drying them at 120°C for 24 hours, immersing the specimen in molten sulphur under vacuum for 2 hours and then releasing the vacuum and soaking them for an additional ½ hour for further infiltration of sulphur. The sulphur-infiltrated concrete has given strength upto 58 MPa.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**USE OF CEMENTITIOUS AGGREGATES:** It has been found that use of cementitious aggregates has yielded high strength. Cement fondu is kind of clinker. This glassy clinker when finely ground results in a kind of cement. When coarsely crushed, it makes a kind of aggregate known as ALAG. Using Alag as aggregate, strength upto 125 MPa has been obtained with water/cement ratio 0.32.

## TESTING OF HARDENED CONCRETE :

- Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works.
- Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programme for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete with regard to both strength and durability. The test methods should be simple, direct and convenient to apply.
- One of the purposes of testing hardened concrete is to confirm that the concrete used at site has developed the required strength. As the hardening of the concrete takes time, one will not come to know, the actual strength of concrete for some time.
- This is an inherent disadvantage in conventional test. But, if strength of concrete is to be known at an early period, accelerated strength test can be carried out to predict 28 days strength.
- But mostly when correct materials are used and careful steps are taken at every stage of the work, concretes normally give the required strength. The tests also have a deterring effect on those responsible for construction work.
- The results of the test on hardened concrete, even if they are known late, helps to reveal the quality of concrete and enable adjustments to be made in the production of further concretes.
- Tests are made by casting cubes or cylinder from the representative concrete or cores cut from the actual concrete. It is to be remembered that standard compression test specimens give a measure of the potential strength of the concrete, and not of the strength of the concrete in structure.
- Knowledge of the strength of concrete in structure can not be directly obtained from tests on separately made specimens.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

## COMPRESSION TEST :

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

The compression test is carried out on specimens cubical or cylindrical in shape. Prism is also sometimes used, but it is not common in our country.

Sometimes, the compression strength of concrete is determined using parts of a beam tested in flexure. The end parts of beam are left intact after failure in flexure and, because the beam is usually of square cross section, this part of the beam could be used to find out the compressive strength. The cube specimen is of the size 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 20 mm, 10 cm size cubes may also be used as an alternative. Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in diameter and 30 cm long. Smaller test specimens may be used but a ratio of the diameter of the specimen to maximum size of aggregate, not less than 3 to 1 is maintained.



Cube beam and cylinder moulding

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**MOULDS** : Metal moulds, preferably steel or cast iron, thick enough to prevent distortion are required. They are made in such a manner as to facilitate the removal of the moulded specimen without damage and are so machined that, when it is assembled ready for use, the dimensions and internal faces are required to be accurate within the following limits. The height of the mould and the distance between the opposite faces are of the specified size  $\pm 0.2$  mm. The angle between adjacent internal faces and between internal faces and top and bottom planes of the mould is required to be  $90^\circ \pm 0.5^\circ$ . The interior faces of the mould, are plane surfaces with a permissible variation of 0.03 mm. Each mould is provided with a metal base plate having a plane surface. The base plate is of such dimensions as to support the mould during the filling without leakage and it is preferably attached to the mould by springs or screws. The parts of the mould, when assembled, are positively and rigidly held together, and suitable methods of ensuring this, both during the filling and on subsequent handling of the filled mould, are required to be provided. A steel bar 16 mm in diameter, 0.6 m long and bullet pointed at the lower end serves as a tamping bar.

**COMPACTING** : The test cube specimens are 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 is filled into the mould in layers approximately 5 cm deep. In placing each scoopful of concrete, the scoop is required to be 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 is compacted either by hand or by vibration. After the top layer has been compacted the surface of the concrete is brought to the finished level with the top of the mould, using a trowel. The top is covered with a glass or metal plate to prevent evaporation.

**COMPACTING BY HAND** : When compacting by hand, the standard tamping bar is used and the strokes of the bar are distributed in a uniform manner over the cross-section of the mould. The number of strokes per layer required to produce the specified conditions vary according to the type of concrete. For cubical specimens, in no case should the concrete be subject to less than 35 strokes per layer for 15 cm or 25 strokes per layer for 10 cm cubes. For cylindrical specimens, the number of strokes are not less than thirty per layer. The strokes penetrate into the underlying layer and the bottom layer is rodded throughout its depth. Where voids are left by the tamping bar, the sides of the mould are tapped to close the voids.

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**COMPACTING BY VIBRATION** : When compacting by vibration, each layer is vibrated by means of an electric or pneumatic hammer or vibrator or by means of a suitable vibrating table until the specified condition is attained. The mode and quantum of vibration of the laboratory specimen shall be as nearly the same as those adopted in actual concreting operations. Care must be taken while compacting high slump concrete which are generally placed by pumping. If care is not taken severe segregation takes place in the mould, which results in low strength when cubes are crushed. The cube crushing strength does not represent the strength of the concrete.

**CAPPING SPECIMENS** : Capping is applicable to cylindrical specimen. The ends of all cylindrical test specimens that are not plane within 0.05 mm are capped. The capped surfaces are not departed from a plane by more than 0.05 mm and shall be nearly at right angles to the axis of the specimens. The planeness of the cap is required to be checked by means of a straight edge and feeler gauge, making a minimum of three measurements on different diameters. Caps are made as thin as practicable and care should be taken so that flaw or fracture does not take place, when the specimen is tested. Capping can be done on completion of casting or a few hours prior to testing of specimen.



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**CURING :** The test specimens are stored in place free from vibration, in moist air of at least 90% relative humidity and at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$  for 24 hours  $\pm$  1/2 hour from the time of addition of water to the dry ingredients. After this period, the specimens are marked and removed from the moulds and unless required for test within 24 hours, immediately submerged in clean fresh water or saturated lime solution and kept there until taken out just prior to test. The water or solution in which the specimens are submerged, are renewed every seven days and are maintained at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$ . The specimens are not to be allowed to become dry at any time until they have been tested.

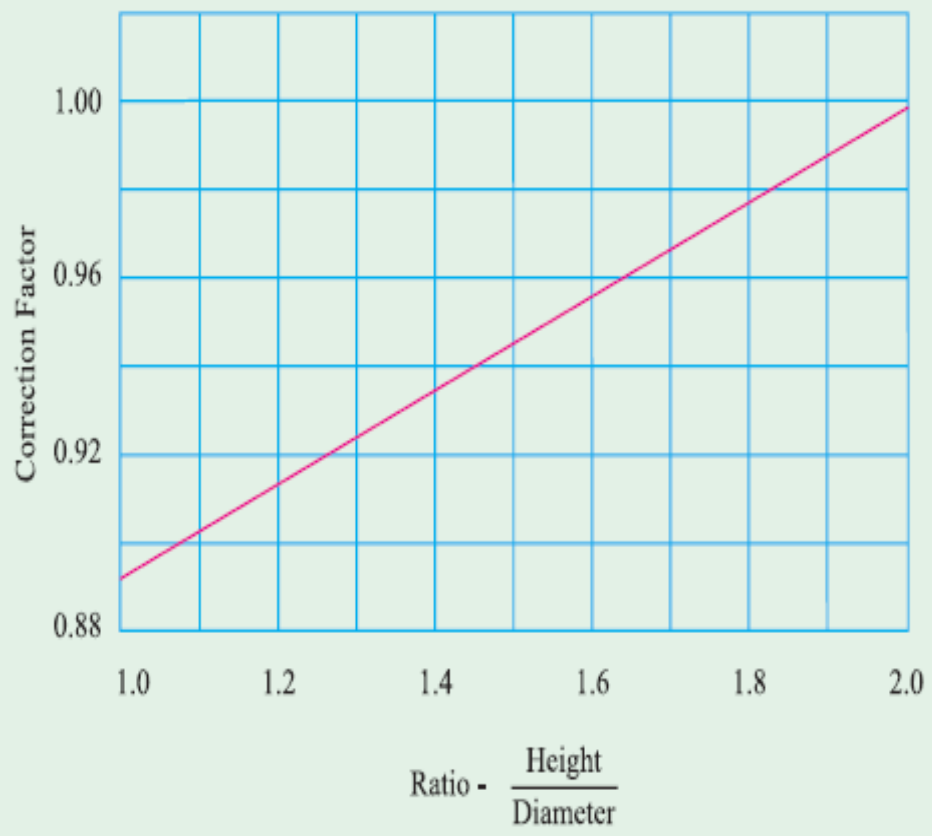
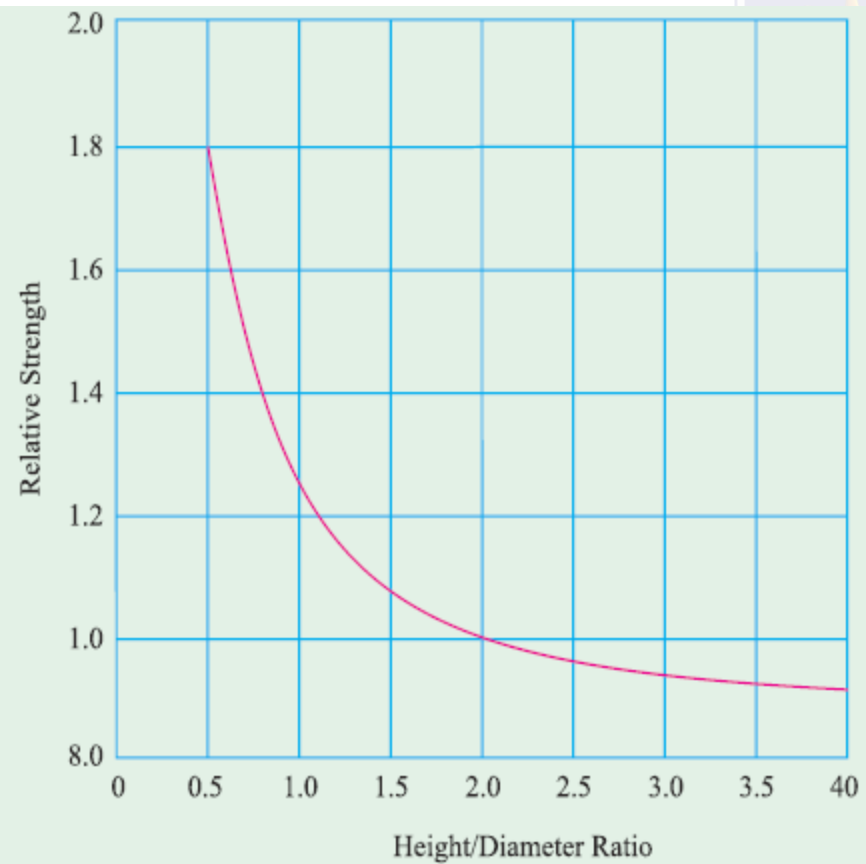
**MAKING AND CURING COMPRESSION TEST SPECIMEN IN THE FIELD :** The test specimens are stored on the site at a place free from vibration, under damp matting, sacks or other similar material for 24 hours  $\pm$  1/2 hour from the time of addition of water to the other ingredients. The temperature of the place of storage should be within the range of  $22^{\circ}$  to  $32^{\circ}\text{C}$ . After the period of 24 hours, they should be marked for later identification removed from the moulds and unless required for testing within 24 hours, stored in clean water at a temperature of  $24^{\circ}$  to  $30^{\circ}\text{C}$  until they are transported to the testing laboratory. They should be sent to the testing laboratory well packed in damp sand, damp sacks, or other suitable material so as to arrive there in a damp condition not less than 24 hours before the time of test. On arrival at the testing laboratory, the specimens are stored in water at a temperature of  $27^{\circ} \pm 2^{\circ}\text{C}$  until the time of test. Records of the daily maximum and minimum temperature should be kept both during the period the specimens remain on the site and in the laboratory particularly in cold weather regions.

**FAILURE OF COMPRESSION SPECIMEN :** Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson's ratio effect. The steel platens do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel platens of the testing machine. It has been found that the lateral strain in the steel platens is only 0.4 of the lateral strain in the concrete. Due to this the platen restrains the lateral expansion of the concrete in the parts of the specimen near its end.



# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

The degree of restraint exercised depends on the friction actually developed. When the friction is eliminated by applying grease, graphite or paraffin wax to the bearing surfaces the specimen exhibits a larger lateral expansion and eventually splits along its full length. With friction acting i.e., under normal conditions of test, the elements within the specimen is subjected to a shearing stress as well as compression. The magnitude of the shear stress decreases and the lateral expansion increases in distance from the platen. As a result of the restraint, in a specimen tested to destruction there is a relatively undamaged cone of height equal to  $\sqrt{3} / 2 d$  (where d is the lateral dimension of the specimen). But if the specimen is longer than about 1.7 d, a part it of will be free from the restraining effect of the platen. Specimens whose length is less than 1.5 d, show a considerably higher strength than those with a greater length.





# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

## COMPARISON BETWEEN CUBE AND CYLINDER STRENGTH :

It is difficult to say whether cube test gives more realistic strength properties of concrete or cylinder gives a better picture about the strength of concrete. However, it can be said that the cylinder is less affected by the end restrains caused by platens and hence it seems to give more uniform results than cube. Therefore, the use of cylinder is becoming more popular, particularly in the research laboratories. Cylinders are cast and tested in the same position, whereas cubes are cast in one direction and tested from the other direction. In actual structures in the field, the casting and loading is similar to that of the cylinder and not like the cube. As such, cylinder simulates the condition of the actual structural member in the field in respect of direction of load.

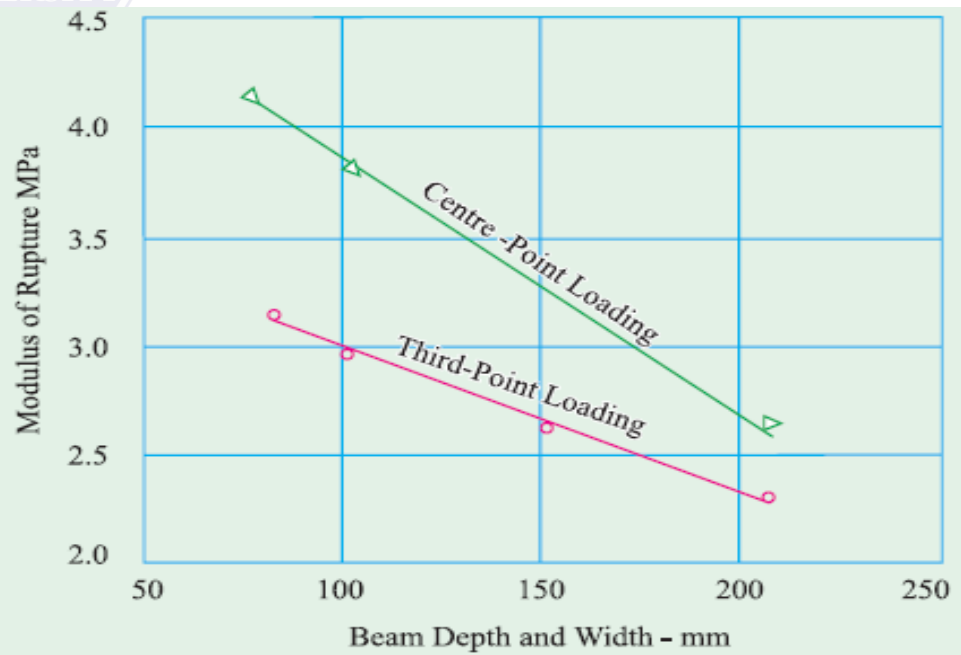
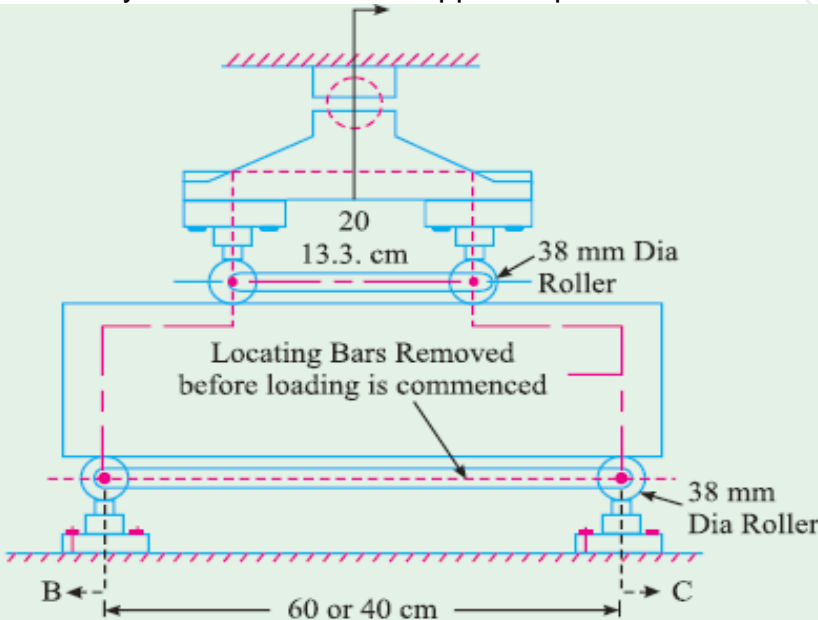
The points in favour of the cube specimen are that the shape of the cube resembles the shape of the structural members often met with on the ground. The cube does not require capping, whereas cylinder requires capping. The capping material used in case cylinder may influence to some extent the strength of the cylinder.

Table 10.1. Strength of Cubes and Cylinders

Compressive Strength		Ratio of strengths cylinder/ cube	Difference of strength (cube-cylinders)
Cube MPa	Cylinder MPa		MPa
9.0	7.0	0.77	2
16.0	12.0	0.77	4
20.0	16.0	0.76	4
25.0	20.0	0.81	5
28.0	25.0	0.87	3
30.0	27.0	0.91	3
30.0	28.0	3.91	2
36.0	32.0	3.89	4
37.0	35.0	0.94	2
43.0	37.0	0.87	6
45.0	42.0	0.92	3
49.0	45.0	0.91	4
54.0	51.0	0.96	3

# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**THE FLEXURAL STRENGTH OF CONCRETE :** Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons. Therefore, the knowledge of tensile strength of concrete is of importance. A concrete road slab is called upon to resist tensile stresses from two principal sources– wheel loads and volume change in the concrete. Wheel loads may cause high tensile stresses due to bending, when there is an inadequate sub-grade support. Volume changes, resulting from changes in temperature and moisture, may produce tensile stresses, due to warping and due to the movement of the slab along the sub-grade. Stresses due to volume changes alone may be high. The longitudinal tensile stress in the bottom of the pavement, caused by restraint and temperature warping, frequently amounts to as much as 2.5 MPa at certain periods of the year and the corresponding stress in the transverse direction is approximately 0.9 MPa. These stresses are additive to those produced by wheel loads on unsupported portions of the slab.

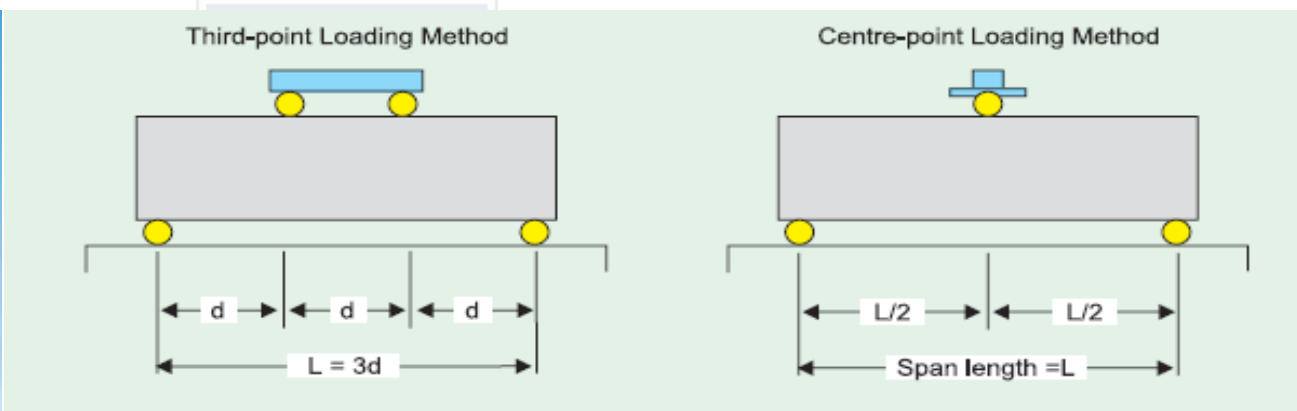


# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

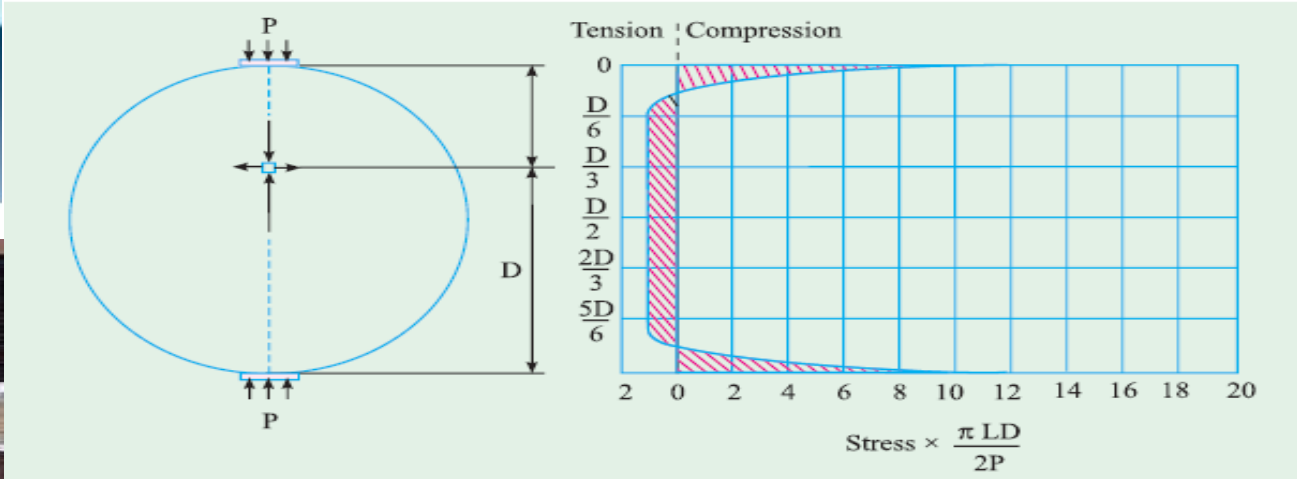
As mentioned earlier, it is difficult to measure the tensile strength of concrete directly. Of late some methods have been used with the help of epoxy bonded end pieces to facilitate direct pulling. Attempts have also been made to find out direct tensile strength of concrete by making briquette shape for direct pulling but this method was presenting some difficulty with grip and introduction of secondary stresses while being pulled. Whatever may be the methods adopted for finding out the ultimate direct tensile strength, it is almost impossible to apply truly axial load. There is always some eccentricity present. The stresses are changed due to eccentricity of loading. These may introduce major error on the stresses developed regardless of specimen size and shape.



Flexural testing of concrete beam mould



Principles of flexural testing

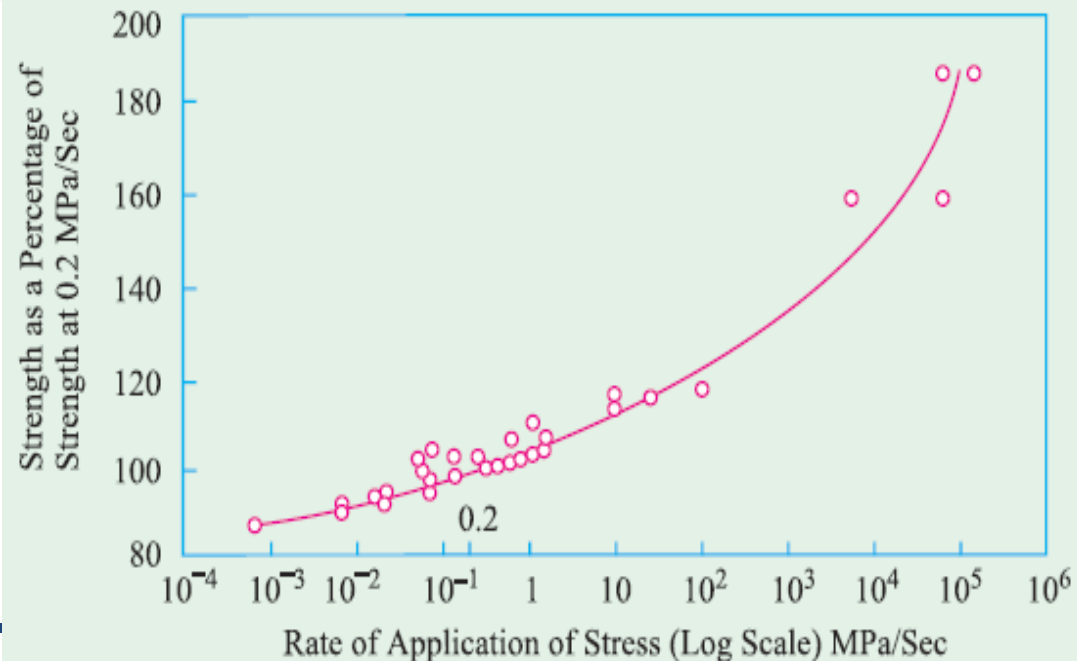


# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

**FACTORS INFLUENCING THE STRENGTH RESULTS :** It has already been pointed out that shape and size of specimen affects the strength results. If the strength of the 15 cm size cube is taken as standard, then the strength of 10 cm cube should be reduced by 10%. Strength of the cylinder of size 15 cm diameter and 30 cm long is taken as 0.8 of the strength of 15 cm cube. Where cubes larger than 15 cm are adopted, generally no modification to the strength is necessary unless otherwise specified. The planeness of the end condition of specimen and capping material used for the cylinder affects the strength. The employment of lubricating material at the bearing surface of the sample affect the strength of concrete.

The effect of height to diameter ratio has already been discussed. The rate of application of load has a considerable affect on the apparent strength of concrete; the lower the rate of application of load, the lower will be the recorded strength. The reason for this is probably the effect of creep. If the load is applied slowly, or in the application of load, if there is some time-lag, the specimen will undergo certain amount of creep which will increase the strain. The enhanced strain due to creep will be responsible for failure of the sample, at a lower value of stress applied.

The state of moisture content of the specimen influences the observed strength to a great extent. If two cubes made from identical concrete, one is wet and another is dry, if tested at the same age, the dry cube gives higher strength than the wet cube. It is quite probable that the dry cube may have undergone drying shrinkage which will have ultimately caused some amount of drying shrinkage cracks and bond failures. From this simple reason it must give an impression that dry cube must give a lower value, but on the contrary the result is the other way.

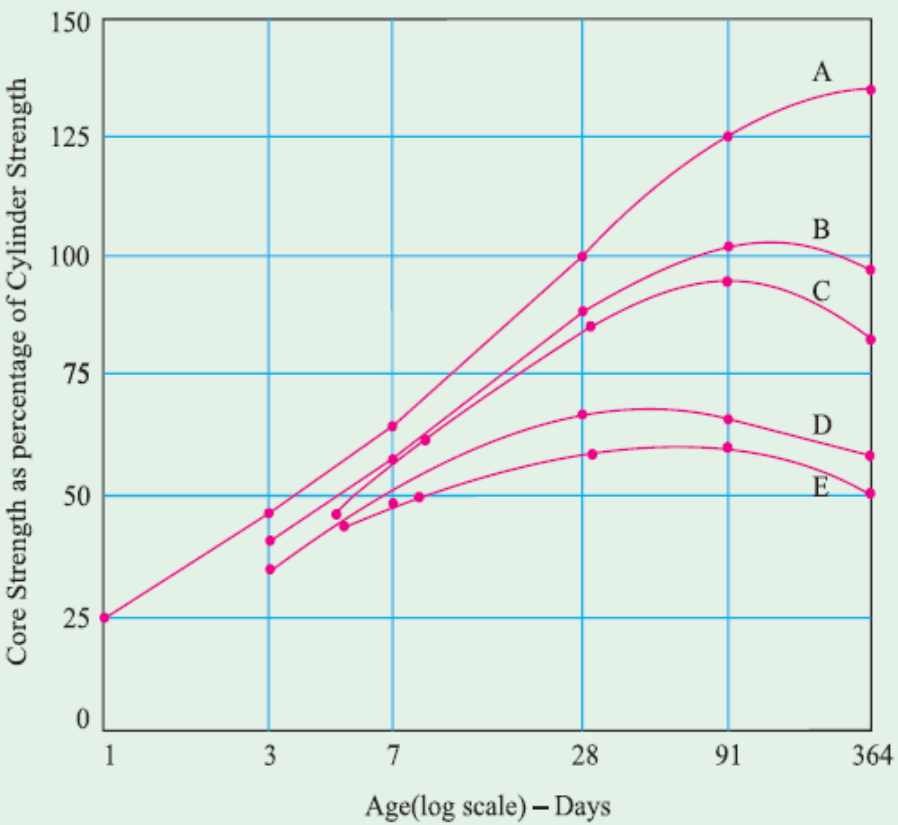


# COMPRESSIVE STRENGTH OF CONCRETE AND FACTORS AFFECTING IT :

The probable explanation is that due to wetting, some sort of dilation of cement gel will take place by the adsorbed water. The forces of cohesion of the solid particles are then decreased. Perhaps the decrease of strength on account of reduction of cohesion owing to the adsorbed water may be more than that of the loss of strength due to rupture of gel bonds on account of drying shrinkage. To have a standard condition for test specimens, it is usual to test a specimen immediately on removal from the curing water tank. This condition has the advantage of being better reproducible than a dry condition which includes greatly varying degrees of dryness. It was earlier pointed out that contrary to expectations, the wet concrete exhibits higher modulus of elasticity. Strength and modulus of elasticity do not go hand in hand in the case of wet concrete.

**Table 10.2. Development of strength of Cores with Age**

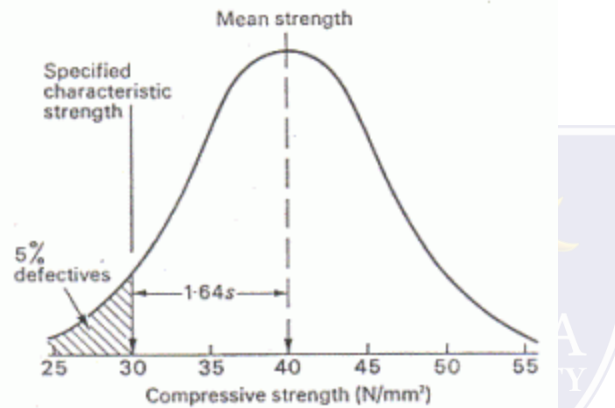
Age days	Strength MPa		Core strength as a proportion of strength of 28-day standard cylinder
	Standard cylinders	Cores	
7	66.0	57.9	0.72
28	80.4	58.5	0.73
56	86.0	61.2	0.76
180	97.9	70.6	0.88
365	101.3	75.4	0.94



# CHARACTERISTIC 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** whereas, as per **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.



The above sketch shows an idealized distribution of the values of compressive strength for a certain number of test specimens. The horizontal axis represents the values of compressive strength in MPa. The vertical axis represents the number of test samples for a particular compressive strength. This is also termed as frequency. The average of the values of compressive strength (mean strength) from the graph is 40 MPa. The characteristic strength ( $f_{ck}$ ) is the value in the x-axis below which 5% of the total area under the curve falls. From the graph we can clearly say that 30 MPa is the characteristic strength of the given concrete mix. The value of  $f_{ck}$  is lower than  $f_{cm}$  (40 MPa- mean strength) by  $1.64\sigma$ , where  $\sigma$  is the standard deviation of the normal distribution. So we can say the given concrete mix has a characteristic strength of 30 MPa or it is a M30 grade mix. **(M- MIX)**

Note - For a 95% confidence level  $k=1.64$ , hence  $k$  value varies on the confidence level of the experiment.

**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.**

# GREEN DENSITY AND DRY DENSITY TESTS :

The easiest way to measure the density of fresh Concrete is through Weighman of Concrete in case it is being loaded in Transit Mixer. In case of Concrete production from Batching plant, by the summation of weight of all the aggregate, the fresh Concrete Density can be measured. Otherwise you are to undergo the laboratory method **by Density Container**. This process is known as **Yield Test** of Concrete. But the Yield is reported in a factor , ratio between Density in laboratory bucket and Batched Density.

**CHECKING IN DENSITY CONTAINER** : It is the most technical way to determine the fresh density of Concrete as per standard. Reference for Determination of fresh density of concrete is **IS:1199**

## Procedure of testing follows:

The volume of Density container is as per **Table no-III of IS:1199-1959**

### 1. CALIBRATION OF DENSITY CONTAINER:-

the measure shall be calibrated by determining the weight of water at room temperature required to fill it so that no meniscus is present above the rim. Accurate filling of the measure may be secured by the use of a glass cover plate. The capacity of the measure in cubic meters shall then be obtained by dividing the weight of water ( in grams ) required to fill the measure by the unit weight of water, 1000 g/l.

**2. SAMPLING** - The sample of fresh mixed concrete shall be obtained in accordance with the method specified in **Clause 3 of IS:1199-1959** except when small batches are made under laboratory conditions.

**3. COMPACTING ( BY HAND):-** When compacting by hand the **standard tamping bar(IS:516, Clause 2.9.3)** shall be distributed in a uniform manner over the cross section of the measure. The number of strokes per layer required to produce the specified condition will vary according to the type of concrete, but in no case shall the concrete be subjected to less than 60 strokes per layer for the 0.01 cum measure or 120 strokes per layer for the 0.02 cum measure. After consolidation of the concrete, the top surface shall be struck-off and finished smoothly with a flat cover plate using great care to leave the measure just level full. All excess concrete shall then be cleaned from the exterior and the filled measure weighed.

# GREEN DENSITY AND DRY DENSITY TESTS :

## NOTES:-

1. Empty Weight Of Cylinder
2. Weight of Cylinder filled with Water
3. Weight of Cylinder filled with Compacted Concrete.

Bulk density of concrete is the mass of freshly mixed concrete required to fill the container of a unit volume. Bulk density of concrete reflects the ability of concrete to function for structural support, water and solute movement, and durability. This method helps to calculate the yield of concrete per cubic meter.

## Calculation

**1. Density of Concrete** ( $W_1$ ) is the weight per cubic meter of concrete shall be calculated by dividing the weight of fully compacted concrete in the cylindrical measure by the capacity of measure in kg/cu.m

$$W_1 = \frac{W}{0.01}$$

**2. Yield of Concrete** ( $V_2$ ) is the volume of concrete produced per cum

$$V_2 = \frac{W_c + W_f + W_{ca} + W_w}{W_1}$$

Where,

$W_c$  = Weight of cement in kg

$W_f$  = Weight of fine aggregate in kg

$W_{ca}$  = Weight of coarse aggregate in kg

$W_w$  = Weight of water in kg



# GREEN DENSITY AND DRY DENSITY TESTS :

In a laboratory, dry means oven dry. The other options include SSD, i.e. Saturated Surface Dry (which means as wet as it can be by soaking in cold water), boiled (which is one step further) and vacuum saturated. There is also the state where the concrete is in equilibrium with the RH in the air.

If the SSD density of concrete is 2400 kgm-3, and its moisture content is (say) 7% for fairly average commercial concrete, then the concrete is 93% of the whole. So, 93% of 2400 kgm-3 is around 2230 kgm-3 for the oven dry density.

The density (unit weight) of concrete is measured using a Type B pressure meter to verify agreement with the approved project mix design. The information obtained through this test can also be used to determine yield and relative yield, which helps you verify that you are getting the volume of concrete you ordered and paid for. You can also use this data to calculate the air content of the mix.

The unit weight is determined by the formula below. Subtract the weight of the measuring base from the combined weight of the measuring base and the concrete it contains. Next, divide this weight (in pounds) by the volume of the measuring base (cubic feet) to obtain the density expressed as kg/m<sup>3</sup>:  **$D = (M_c - M_m) / V_m$**

D	=	Density of the concrete, lb/ft <sup>3</sup>
M <sub>c</sub>	=	Weight of the measure holding the concrete
M <sub>m</sub>	=	Weight of the empty concrete measure (base of air meter)
V <sub>m</sub>	=	Volume of the measure (usually about 0.25 ft <sup>3</sup> for a pressure meter base)

when slump increases, the air content will generally increase. If significant, look for the unit weight to decrease measurably. If that is not reflected in the test results, keep an eye on the testing and examine the data, procedures, or reporting accuracy.

# GREEN DENSITY AND DRY DENSITY TESTS :

Concrete must have to ensure satisfactory compressive strength and durability. The mechanical properties of concrete are highly influenced by its density. A denser concrete generally provides higher strength and fewer amount of voids and porosity. Smaller the voids in concrete, it becomes less permeable to water and soluble elements. So water absorption will also be less and better durability is expected from this type of concrete. In this paper an experimental program conducting on compressive strength, density, absorption capacity and percent voids of hardened concrete is described. The variation of these properties with maturity of concrete was main focus of this experiment.

Concrete is a non-natural conglomerate stone made essentially of Portland cement, water, and aggregate. Cement enhances the binding property of concrete. A chemical reaction called hydration takes place between the water and cement, and concrete normally changes from a plastic to a solid state. The density and compressive strength of concrete cement paste are affected by several parameters like water cementitious materials ratio, supplementary cementitious materials, use of admixture, curing, cement type, etc. Curing is the procedure to endorse hydration of cement, and consists of a control of temperature and moisture movement from and into the concrete. Proper curing application has significant impact on density and compressive strength of concrete. The water-cement ratio (W/C) is defined as the proportion by mass of free water to cementitious material in a concrete mix. Structural lightweight concrete is defined as structural concrete made with low-density aggregate that has an air-dry density of not more than 1840 kg/m<sup>3</sup> and a 28-day compressive strength of around 17.25 MPa. Generally, lightweight aggregate concrete absorbs more impact energy than normal weight concrete. The density of normal weight concrete lies within the range of 2,200 to 2,600 Kg/m<sup>3</sup>. The primary purpose of lightweight concrete is to reduce the dead load of a concrete structure. Also, this type of concrete is used to improve buoyancy of the structures. But introducing lightweight aggregate in concrete construction often results poor strength and durability performance of concrete, if proper quality control protocol is not maintained. So, instead of using lightweight aggregate, air entraining admixture can be used to reduce density of concrete.

# GREEN DENSITY AND DRY DENSITY TESTS :

It is important to ensure structural safety through utilizing proper construction materials. Among these materials, concrete is a promising one. Concrete must have to guarantee adequate compressive strength, density, a minimum percent of void and minimum water absorption through the surface. Adequate strength and density is required to sustain a certain loading. Minimum void and absorption capacity reduce water permeability of concrete. From this experiment it is observed that, compressive strength and density increases with time and void and absorption capacity reduces with time. Mainly hydration process leads to strength gaining and attaining a certain level of durability. Concrete with SC yielded more compressive strength and density than concrete with BC. Also, it is observed that BC concrete is more permeable (having more amount of voids) than SC concrete.

It is necessary to ensure the hydration process through proper application of curing methods, adequate quality control measures and also maintenance of structure. Locally used brick aggregate concrete yields low strength and poor durability performance than stone aggregate. So, it is wiser to mix up BC with SC to achieve a better performance. Also, in cases of using BC, silica fume, fly ash or other supplementary cementitious material should be used with OPC in order to obtain satisfactory performances.

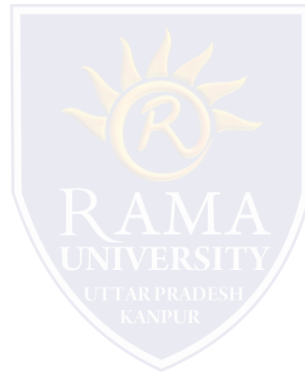
$$\text{Volume of hole} = \frac{\text{Mass of sand in hole}}{\text{Density of used sand}}$$

$$\text{Wet density} = \frac{\text{Mass of wet excavated soil}}{\text{Volume of hole}}$$

$$\text{Dry density} = \frac{\text{Wet density} \times 100 \%}{(\text{Moisture content of soil} + 100)}$$

$$\text{Degree of compaction} = \frac{\text{Dry density} \times 100 \%}{\text{Maximum dry density}}$$

# “Thank you”



**Have Any Query ?**

**Ask us @** [shashikant.fet@ramauniversity.ac.in](mailto:shashikant.fet@ramauniversity.ac.in) or [shashikantchitransh3@gmail.com](mailto:shashikantchitransh3@gmail.com)