UNIT-3
Hardened concrete

Module 1

Introduction

- The principle properties of hardened concrete which are of practical importance are those concerning its strength; stress strain characteristics ;shrinkage and creep deformations; response to temperature variation ;permeability and durability. Of these ,the strength of concrete assumes a greater significance because the strength is related to the structure of hardened cement paste and gives a an overall picture of the quality of concrete.
- The strength of concrete at a given age under giving curing conditions is assumed to depend mainly on water-cement ratio and degree of compaction
- Strength of concrete could be defined as the ultimate load that causes failure (or is its resistance to rupture) and its units are force units divided by area (N/mm2)

- The properties which determine the quality of the hardened concrete broadly fall into the
- following three groups:
- - Strength.
- - Dimensional stability.
- - Durability

Strength of Concrete

- 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.
- There are several factors affecting the strength of concrete as follows

1- **Concrete constituents and mix proportions:**
   a- **Cement** (type, amount, cement fineness, etc.)
   b- **Aggregates** (type, MSA, FM, surface area, unit weight, aggregate grading, inertness, aggregate/cement ratio, fine aggregates/coarse aggregates, etc.)
   c- **Mixing water** (type, amount, water/cement ratio, etc.)
   d- **Admixtures** (type, dosage, chemical effectiveness, etc.)
2- **Concrete production: (batching, mixing, transporting, casting, compaction).**
3- **Concrete curing: (curing method, temperature, degree of humidity, curing period).**
4- **Concrete age and testing conditions:** (shape and size of specimen, loading rate, loading direction, saturation of specimen, specimen contact surface with the machine, etc.).

Compressive Strength

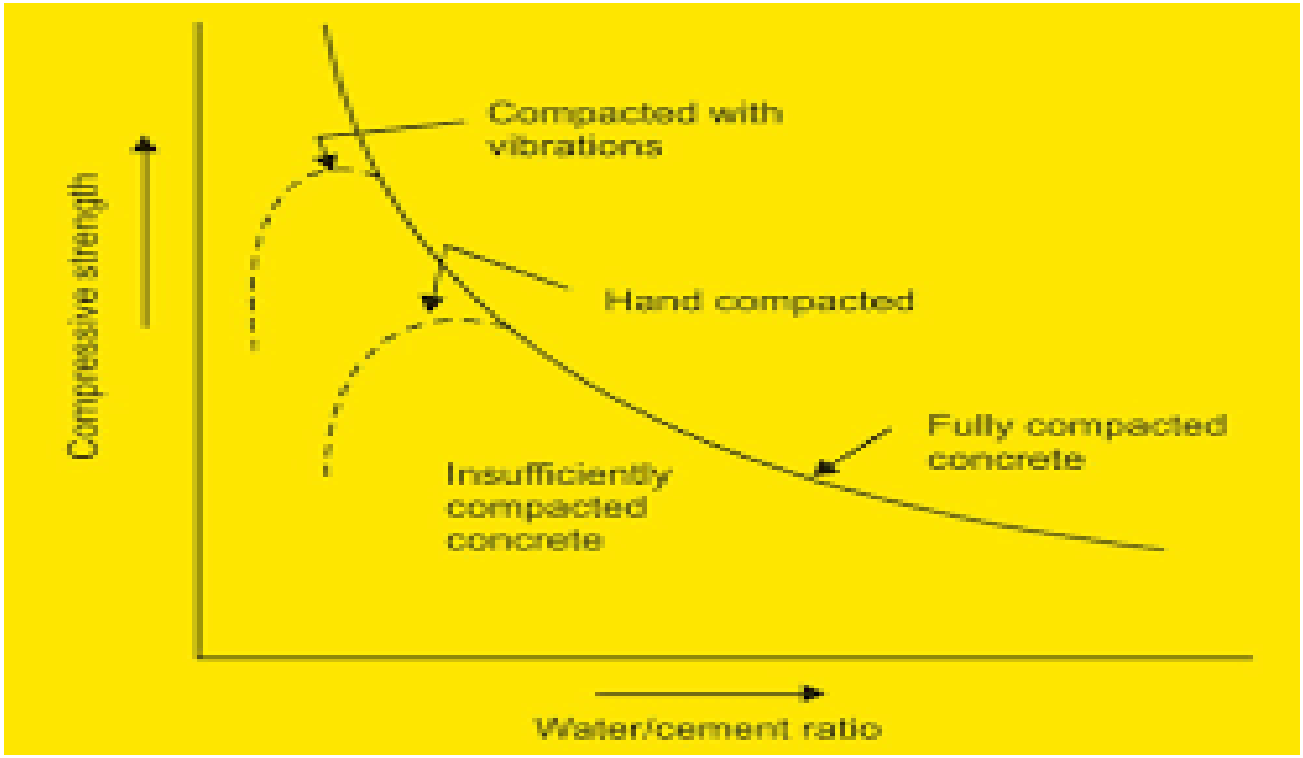
- The compressive strength of concrete is one of the most important and useful properties of concrete.
- In most structural applications concrete is employed primarily to resist compressive stresses. Therefore, the concrete making properties of various ingredients of mix are usually measured in terms 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.
- However, approximate or statistical relationships, in some cases, have been established and these give much useful information to engineers

- It should be emphasized 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.
- 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 phenomenon
- 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.

- Strength of hardened concrete depends on w/c ratio, ii) gel space ratio, iii) age,
- **i) w/c ratio:**
- Strength of paste increase with cement content and decreases with air and water content.
- In 1918 Abrams presented his classic law in the form:

$$S = A/B^{x}$$

- 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.
- Abrams' water/cement ratio law is held valid even today as a fundamental truth in concretebmakingbpractices though some modifications have been suggested to Abram's law.

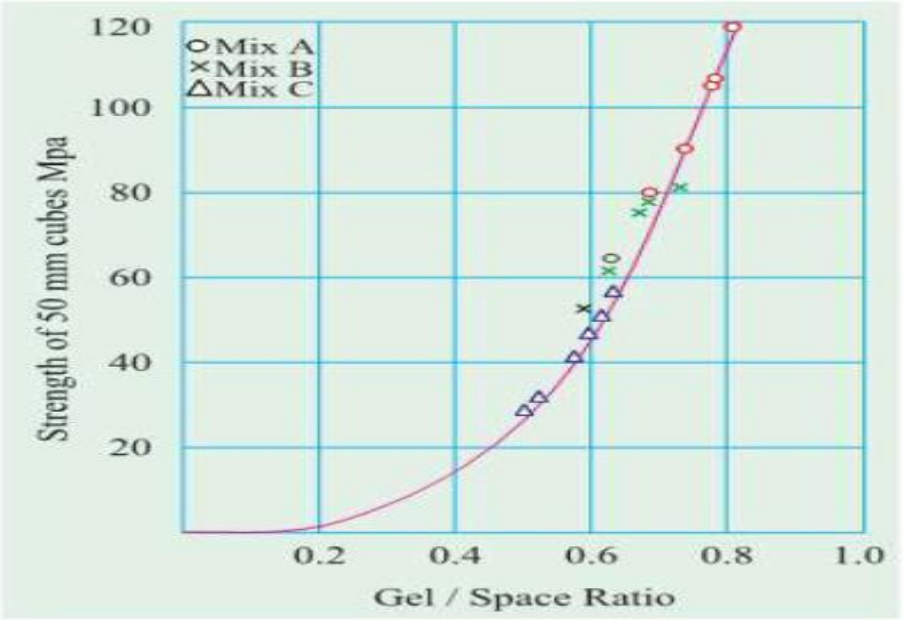


From the above graph, it can be seen that lower water/cement ratio could be used when theconcrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand-compacted.
In both cases when the water/cement ratio is below the practical limit the strength of the concrete falls rapidly due to introduction of air voids.

- **ii) Gel space ratio:**

- Many researchers commented on the validity of Abram's law as it does not include other factors which affect strength of concrete. 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.
- Strength also depends on the temperature at which the hydration takes place, the aircontent 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.
- 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.



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.

- 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 assumed that concrete attains full strength at 28days.
- Actually concrete develops strength beyond 28 days also. The increase in strength beyond28 days used to get immersed with the factor of safety.

  As per IS 456 of 2000, 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"

- To speed up the Research
-

mix concrete:

Type of cement = PPC / OPC

Eg 20 mm, 40 mm aggregates

Table 7.2. Grades of Concrete as per IS - 456 of 2000

Group	Grade Designation	Specified characterstic compressive strength of 150 mm cube at 28 days in N/mm²
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
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

M

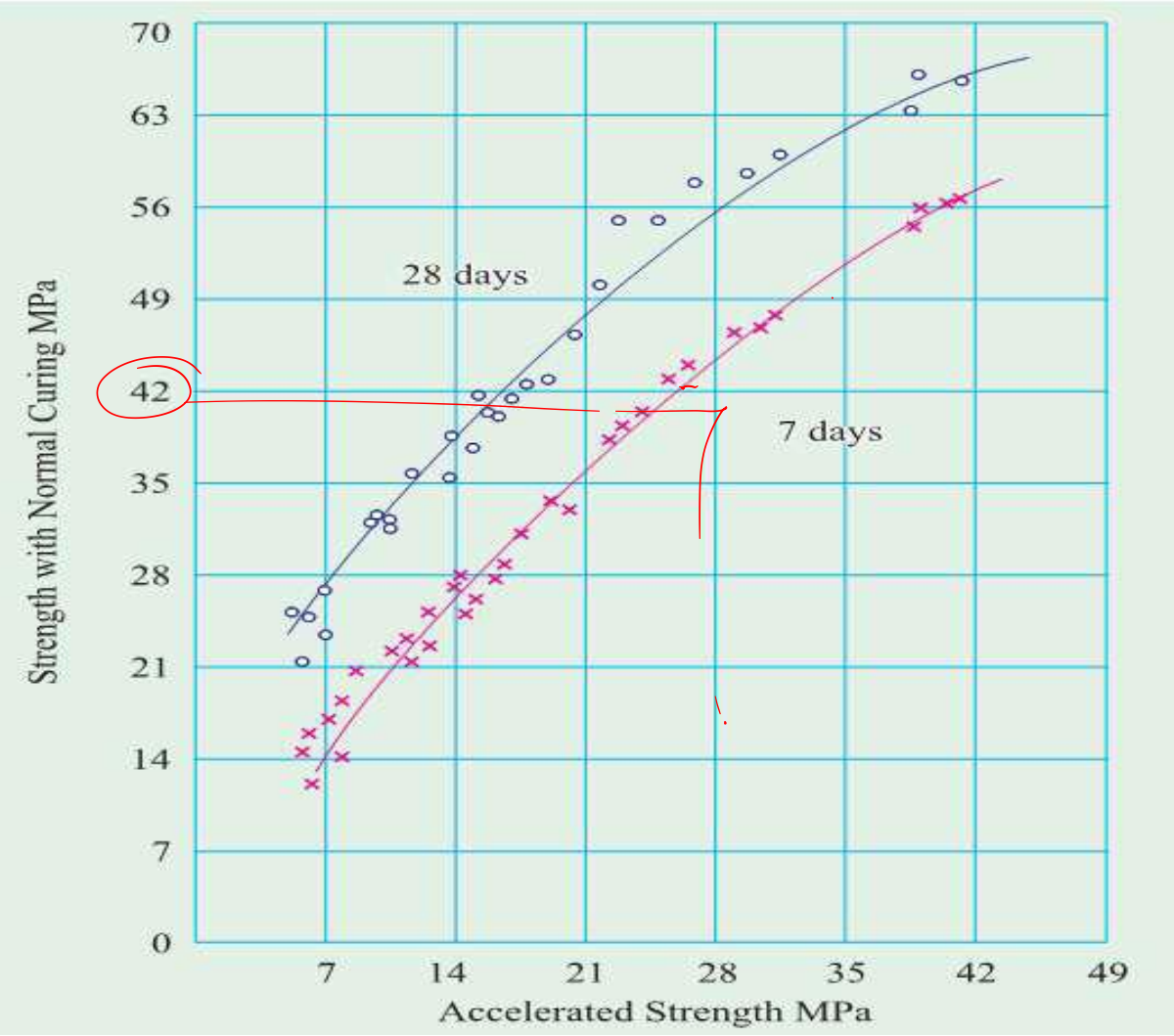
1:1:3
1:½:2

- Many a time it may be necessary to estimate the strength of concrete at an early age. One may not be able to wait for 28 days.
- Many research workers have attempted to estimate the strength of concrete at 1, 3 or 7 days and correlate it to 28 days strength.
- The relationship between the strength of concrete at a lower age and 28 days depends upon many factors such as compound
- composition of cement, fineness of grinding and temperature of curing etc.
- There are many methods for predicting the 28 days strength, within a short period of casting.
- Out of these, the method suggested by Prof. King is found to have good field correlations.

Accelerated Curing test:

- In the accelerated curing test, standard cubes are cast and are covered with top plate and the joints are sealed with special grease to prevent drying.
- Within 30 minutes of adding water, the cubes having sealed effectively, are placed in an air-tight oven which is then switched on.
- The oven temperature is brought to 93°C in about one hour time. It is kept at this temperature for 5hours. At the end of this period the cubes are removed from oven, stripped, cooled, and tested.The time allowed for this operation is 30 minutes.
- The strength of concrete is determined within 7 hours of casting and this accelerated strength shows good relationship with 7 and 28 days strengths of normally cured concrete

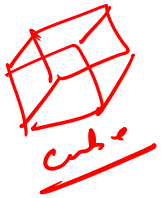
The figure below shows relationship between accelerated strength and normally cured concrete strength at 7 and 28 days.

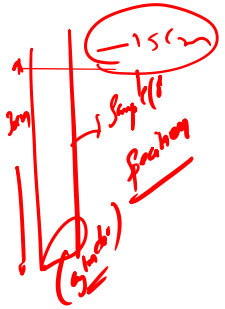


- One of the main factors that affect the rate of gain of strength is the fineness of cement.
- It has been estimated that particles of cement over 40 micron in size contribute to the compressive strength of concrete only over long periods, while those particles smaller than 25 to 30 micron contribute to the 28 days strength, those particles smaller than 20 to 25 micron contribute to the 7 days strength, and particles smaller than 5 to 7 micron contribute to the 1 or 2 days strength

Types of Concrete Strength

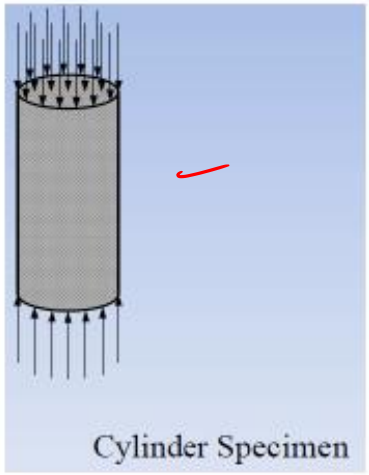
- Compressive strength
- Tensile strength
- Shear strength
- Bond strength
- Impact strength
- Fatigue strength

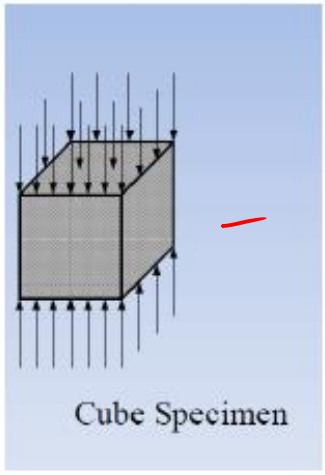




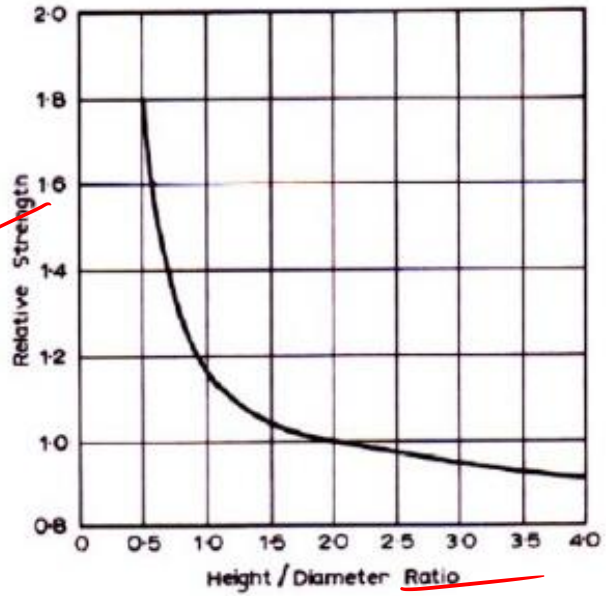
- The compressive strength of concrete is defined as the strength of 28 days old specimens tested under monotonic uniaxial compressive load.
- Testing of cylindrical samples with 15 cm diameter and 30 cm height is standard. Cube specimens of 15 cm × 15 cm × 15 cm are also being used.
- Normally, the compressive strength of concrete is determined by testing, and the tensile strength and modulus of elasticity are expressed in terms of the compressive strength.

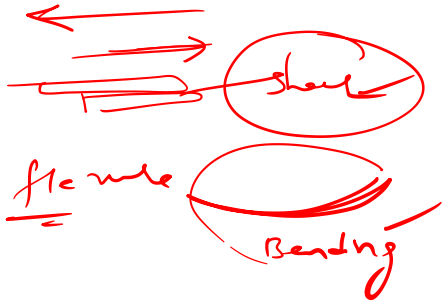
Compressive Strength





$$(f_c)_{cylinder} = (0.85 - 0.80)(f_c)_{cube}$$



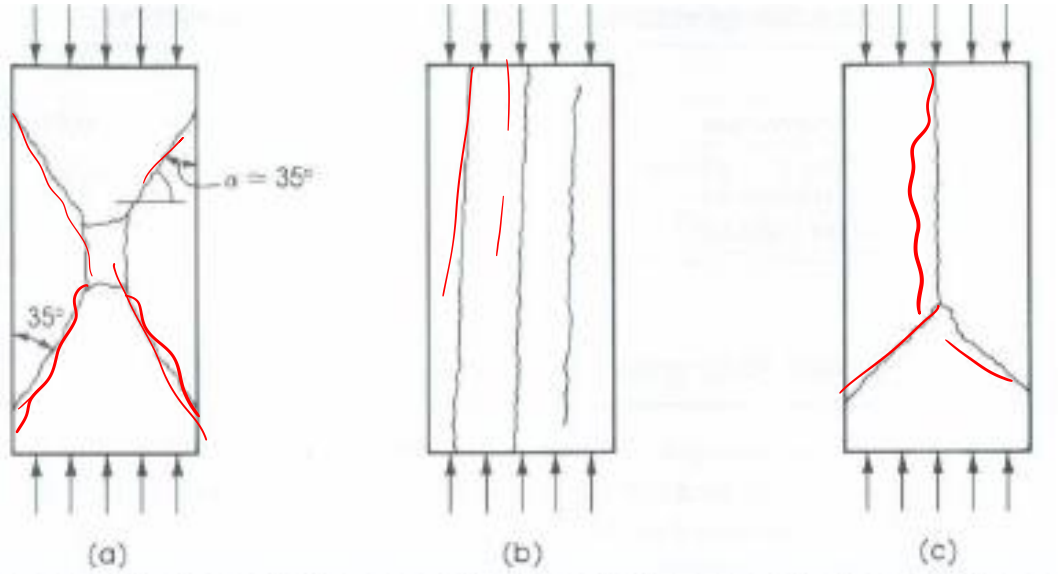


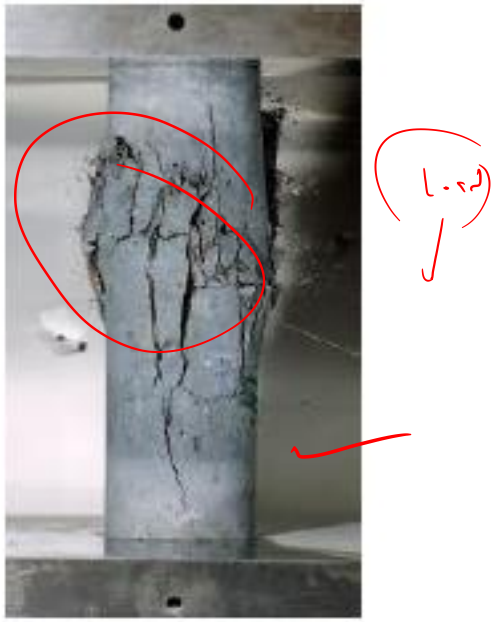
- There are three failure modes for cylinders.

  a)Under axial compression concrete fails in shear.

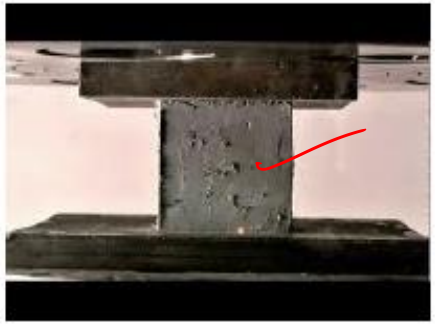
  b)The separation of the specimen into columnar pieces by what is known as splitting or columnar fracture.

  c)Combination of shear and splitting failure.



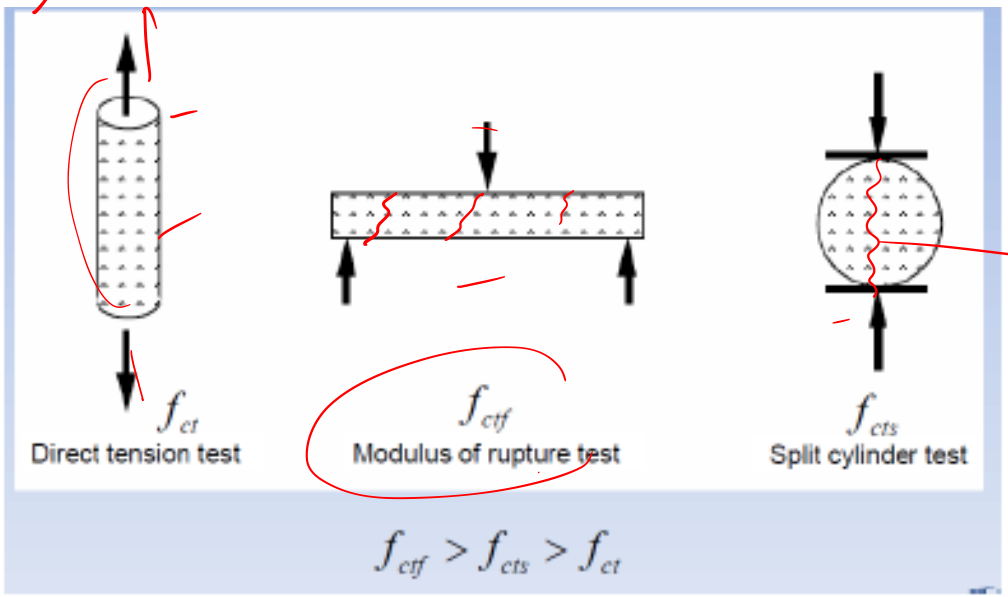


Compressive Strength



Tensile Strength of Concrete

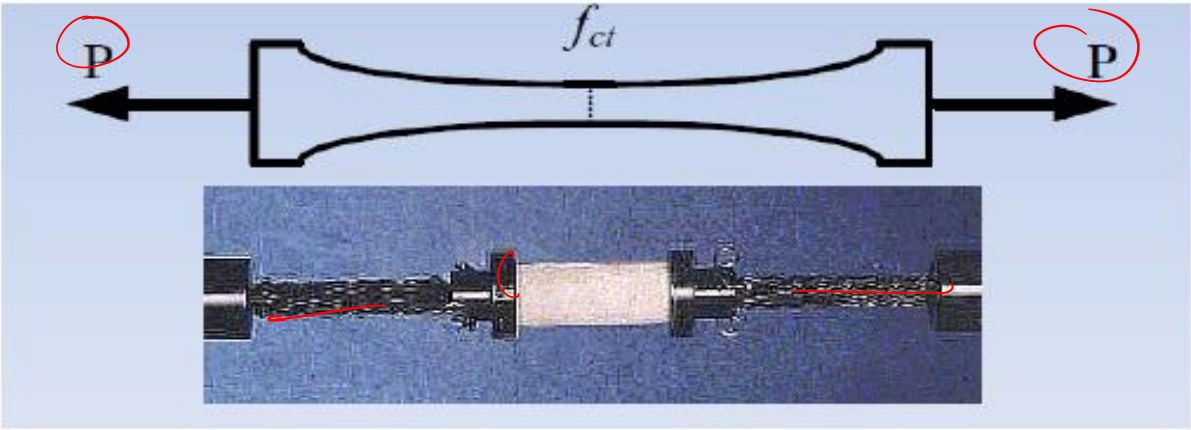
- The tensile strength of concrete is much lower than the compressive strength, largely because of the ease with which cracks can propagate under tensile loads
- The tensile strength of concrete is measured in three ways: direct tension, splitting tension, and flexural tension



- It is difficult to test concrete in direct (uniaxial) tension because of the problem of gripping the specimen satisfactorily and because there must be no eccentricity of the applied load. Therefore, direct tensile test is not standardized and rarely used
- Modulus of rupture test and splitting test are commonly used to determine the tensile strength of concrete
- Direct-Tension Test:

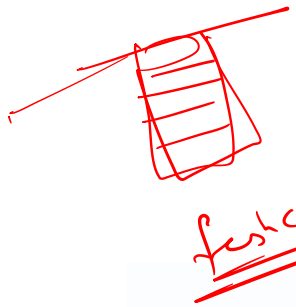
  The most direct way of measuring the tensile strength.

  Not a practical test .



Split-Cylinder Test:

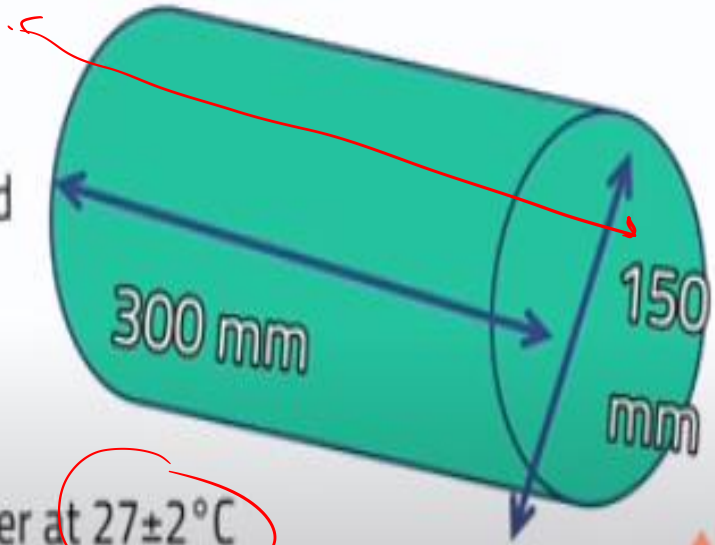
- Split Cylinder Test: In this test, a **concrete cylinder is placed horizontally between loading surfaces and loaded along its diameter**. This loading results in producing lateral tensile stress in the cylinder and its splits in tension along its diameter.
- Why we are going for split tensile test??
- In direct tensile test it is impossible to apply true axial load. there will be always some eccentricity present.
- Another problem is that stress induced due to grips there is tendency for specimen to break at its ends.



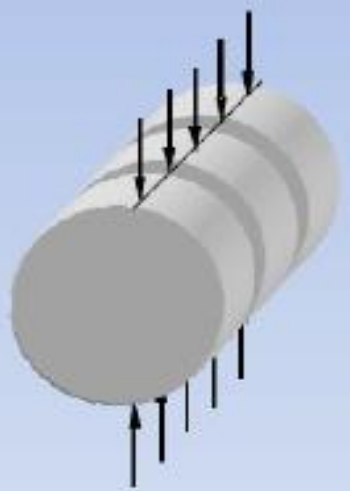
Machine we use is → UTM

Test cube → (Hardened concrete)

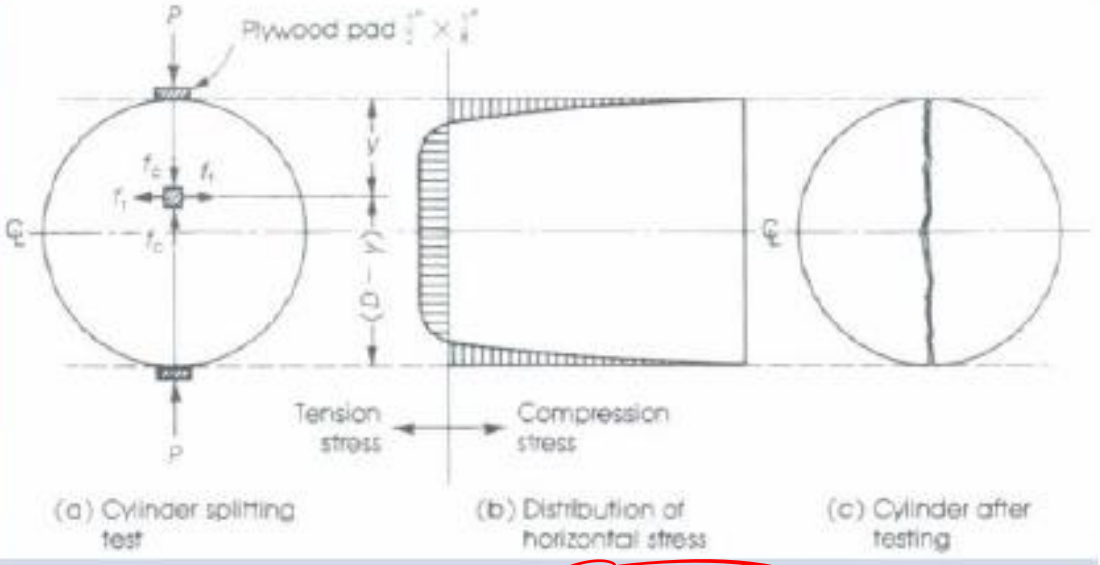
- The tensile Strength of Concrete is determined by applying a compressive force along the length of the concrete cylinder.
- By using Universal Testing Machine.
- specimen is prepared by a mould of specified dimensions by filling Concrete in about 5-6 layers and tamped 25 blows for each layer.



- After 24 hours the specimen is placed in water at 27±2°C
- Specimen can use for testing in 7, 14 and 28 days

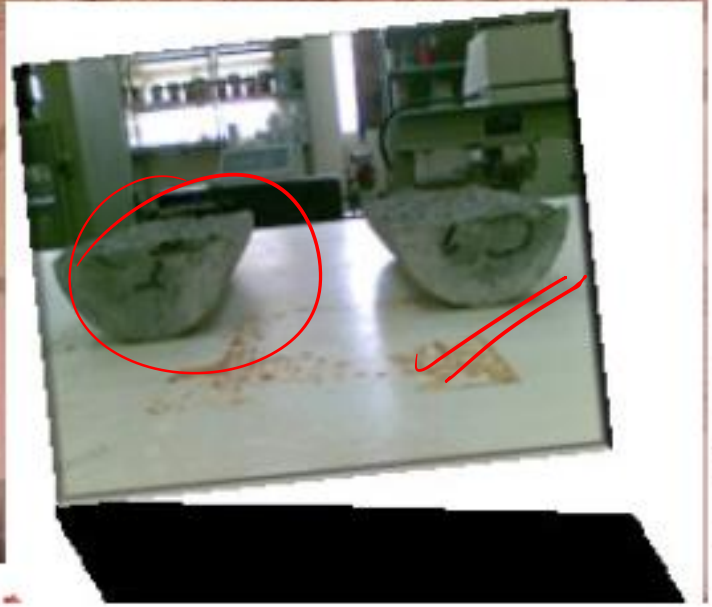


15cm × 30cm
cylinder specimen



$$f_{cts} = \frac{2P}{\pi LD}$$

SPLIT CYLINDER TEST



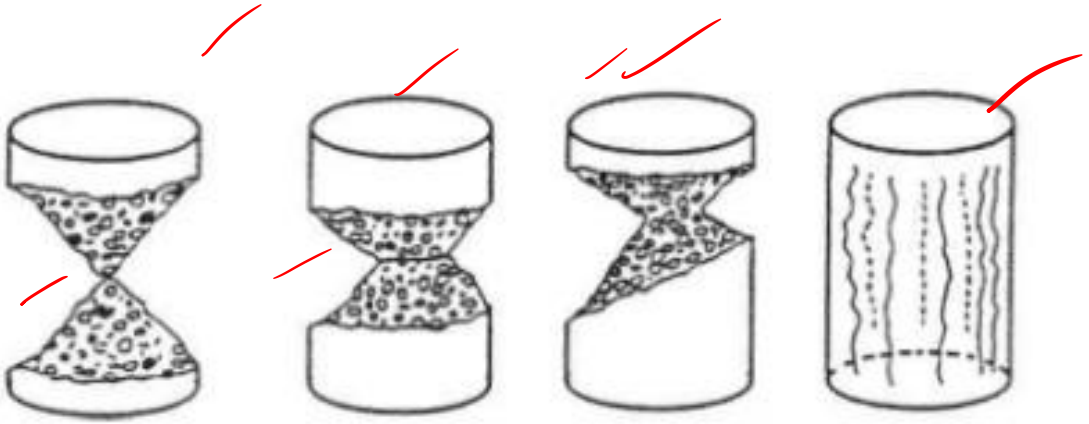


Figure 3 — Satisfactory failure of cylinder specimen

Some unsatisfactory failures of cylinder specimen

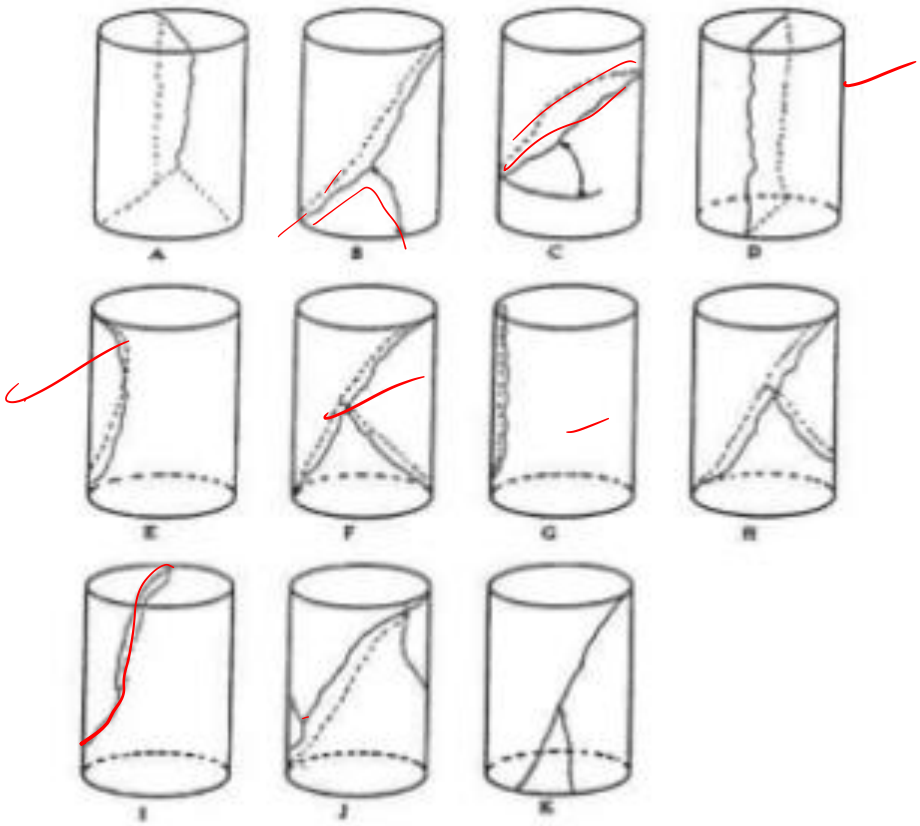


Figure 4 — Some unsatisfactory failures of cylinder specimens

Computations: Calculate the splitting tensile strength of the specimen as follows:

$$T = \frac{2P}{\pi L d}$$

Where:

T : splitting tensile strength, kPa

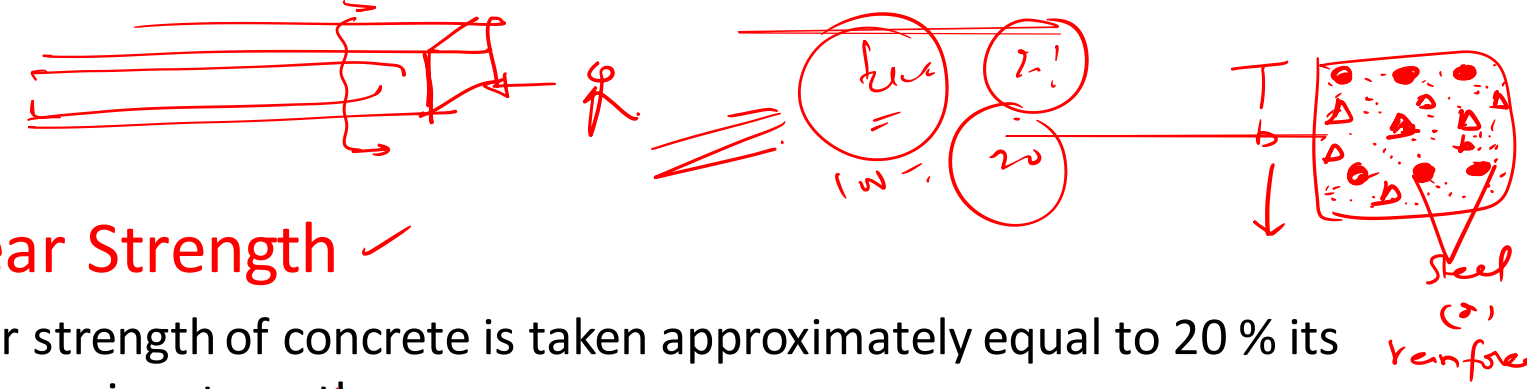
P : maximum applied load indicated by testing machine, kN

L : Length, m

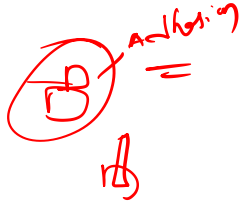
d : diameter, m

Result :

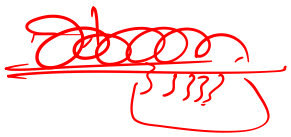
- It is found that the splitting test is closer to the true tensile strength of concrete it gives about 5 to 12% higher value than the direct tensile strength test.

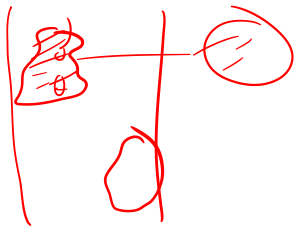


- ## Shear Strength
- Shear strength of concrete is taken approximately equal to 20 % its compressive strength.
- ## Bond Strength
- The strength of bond between steel reinforcement and concrete is called as bond strength of concrete
- Bond strength develops primarily due to friction and adhesion between steel reinforcement and concrete
- In general, bond strength is approximately proportional to the compressive strength of concrete up to about 20 MPa .

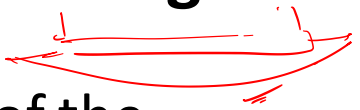


- ## Fatigue Strength
- The strength of concrete against cyclic or repeated loading is called as its fatigue strength

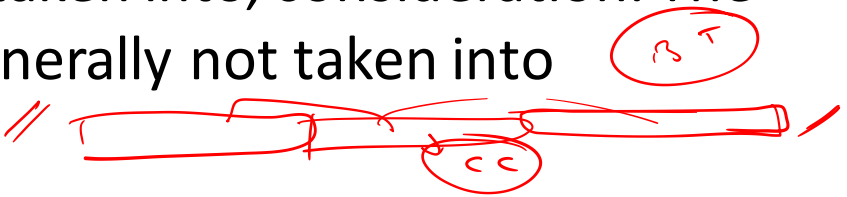




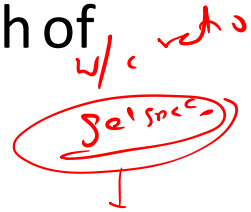
Relation between compressive and tensile strength:



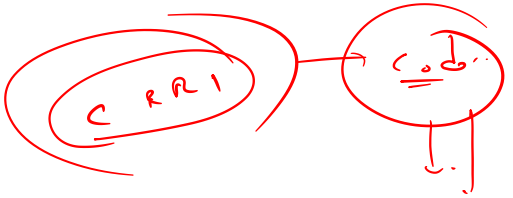
- In reinforced concrete construction, the strength of the concrete in compression is only taken into, consideration. The tensile strength of concrete is generally not taken into consideration.



- But in the design of concrete pavement, slabs are 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.

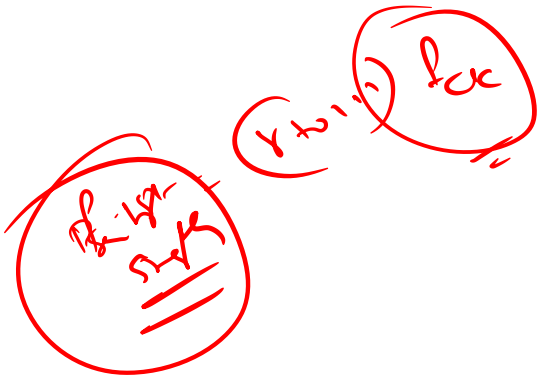


- The tensile strength of concrete, as compared to its compressive strength, is more sensitive to improper curing. This may be due to the inferior quality of gel formation as a result of improper curing and also due to the fact that improperly cured concrete may suffer from more shrinkage cracks.



- 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.
- *Where y is the compressive strength of concrete MPa and x is the flexural strength of concrete MPa*

- The flexural strength of concrete was found to be 8 to 11 per cent of the compressive stength of the concrete for higher ranges of concrete strength (greater than 25 MPa) and 9 to 12.8 per cent for lower ranges of concrete strength (less than 25 MPa).



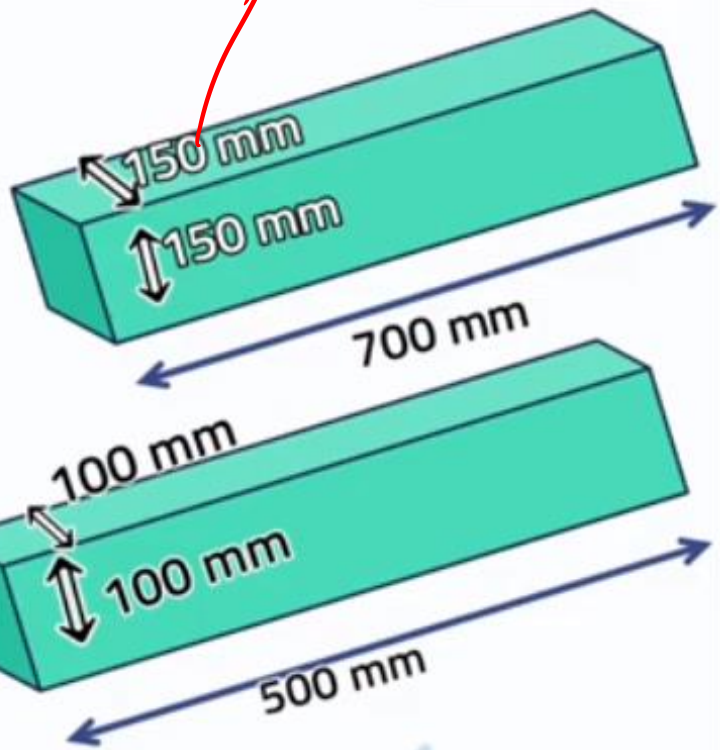
Flexural strength of concrete

- The flexural strength of concrete was found to be 8 to 11 per cent of the compressive strength of the concrete for higher ranges of concrete strength (greater than 25 MPa) and 9 to 12.8 per cent for lower ranges of concrete strength (less than 25 MPa).
- Flexural strength of concrete is usually found by testing plain concrete beams.
- Two methods of loading of the beam specimen for finding out flexural strength are practiced:
- **Center point loading and three point loading:**

Flexural Strength of Concrete

IQ #5

- It is an indirect process to determine the Tensile Strength of Concrete
- For Flexural Strength, the beam can be used to test by

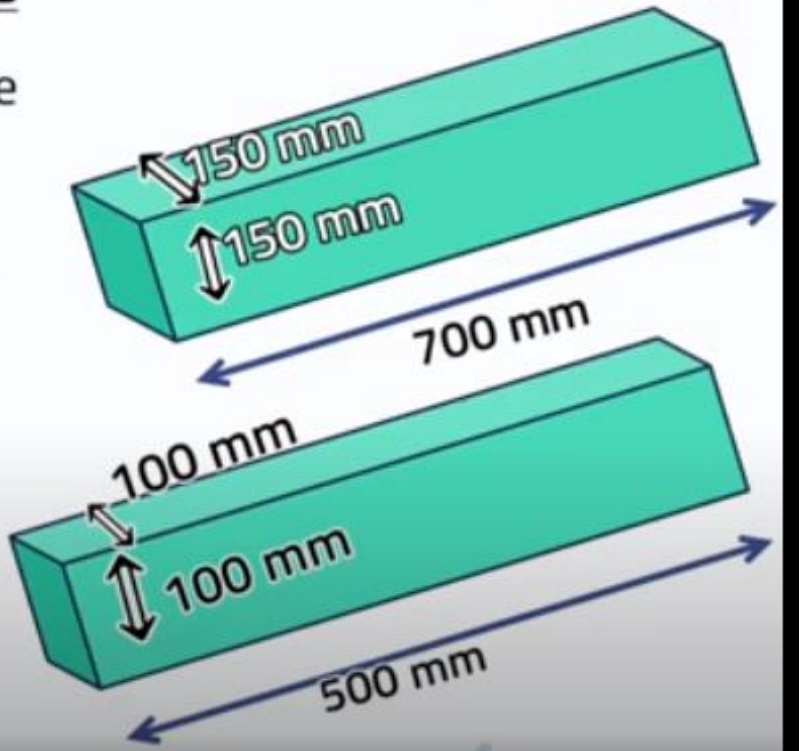


- UTM
- Concrete prepared & filled in mould, Tamped by 25 blows
- After 24 hours, kept in water at 27±2°C

Flexural Strength of Concrete

IQ # 5

- It is an indirect process to determine the Tensile Strength of Concrete
- For Flexural Strength, the beam can be used to test by
  - Central point Loading Test
  - Third point Loading Test
- UTM
- Concrete prepared & filled in mould, Tamped by 25 blows
- After 24 hours, kept in water at 27±2°C



Flexural Strength of Concrete

(Modulus of Rupture)

IQ #5

Distance between the supports-

for 150 mm specimen = 600 mm

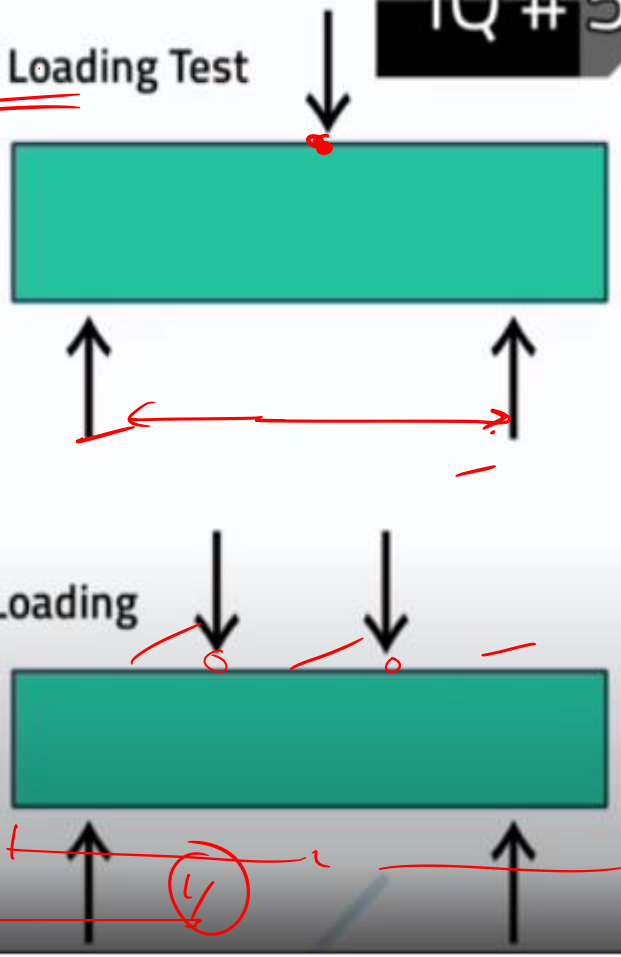
for 100 mm specimen = 400 mm

- In central point Loading test - Load applied at Center
- In third point Loading test - Loads apart at a distance of 200/133 mm

Load applied at a rate of -

400 kg/min. for 150 mm specimen

180 kg/min. for 100 mm specimen



IQ #5

M.R. = PL/bd^2

Where P = Load at failure

L = Length, b = Width, d = depth of specimen

If the fracture is in Tension surface is within the middle third of span length

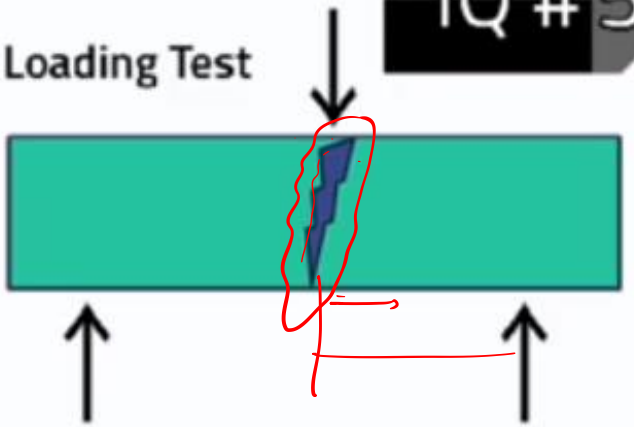
If the fracture is outside by not more than 5% of the span length

M.R. = 3Pa/bd^2

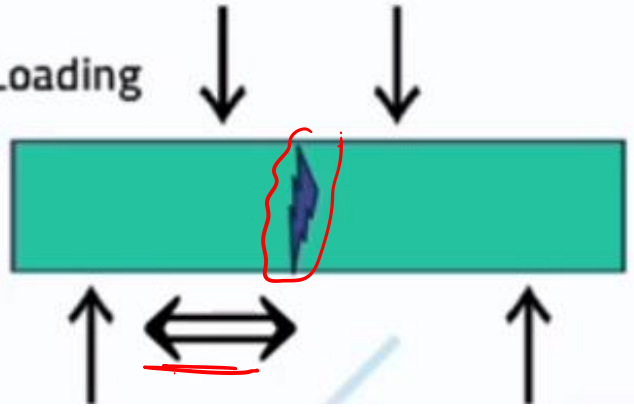
a = the average distance between the line of fracture and the nearest support.

If the fracture is outside by more than 5% of the span length, The test results are rejected.

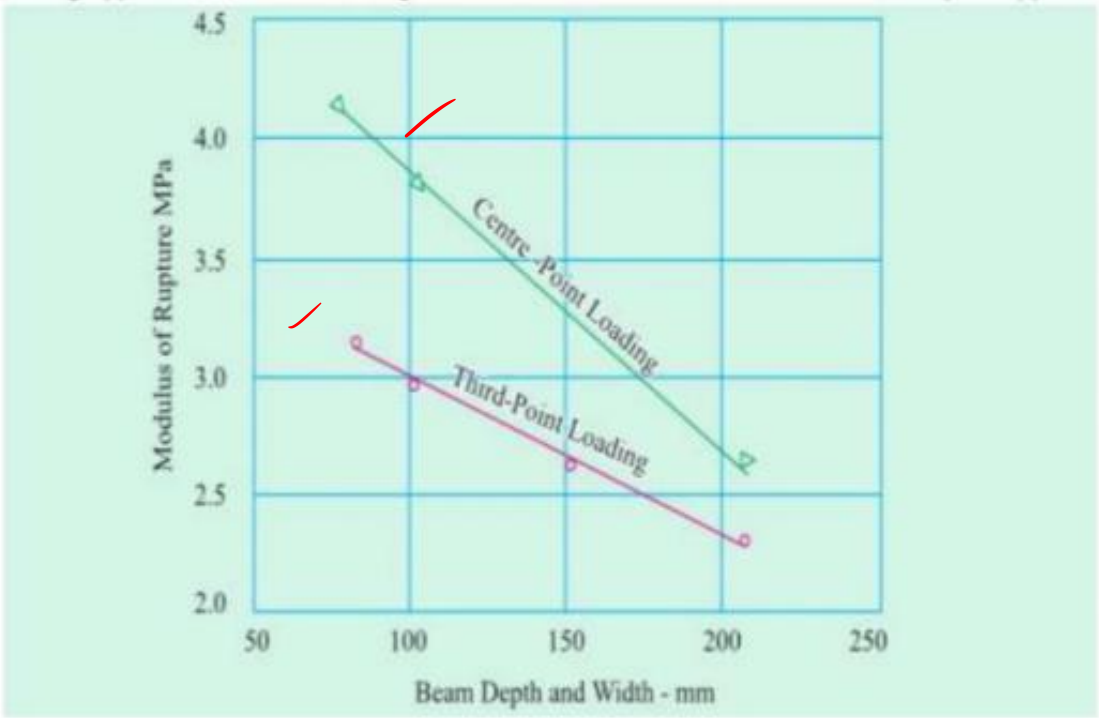
Central point Loading Test



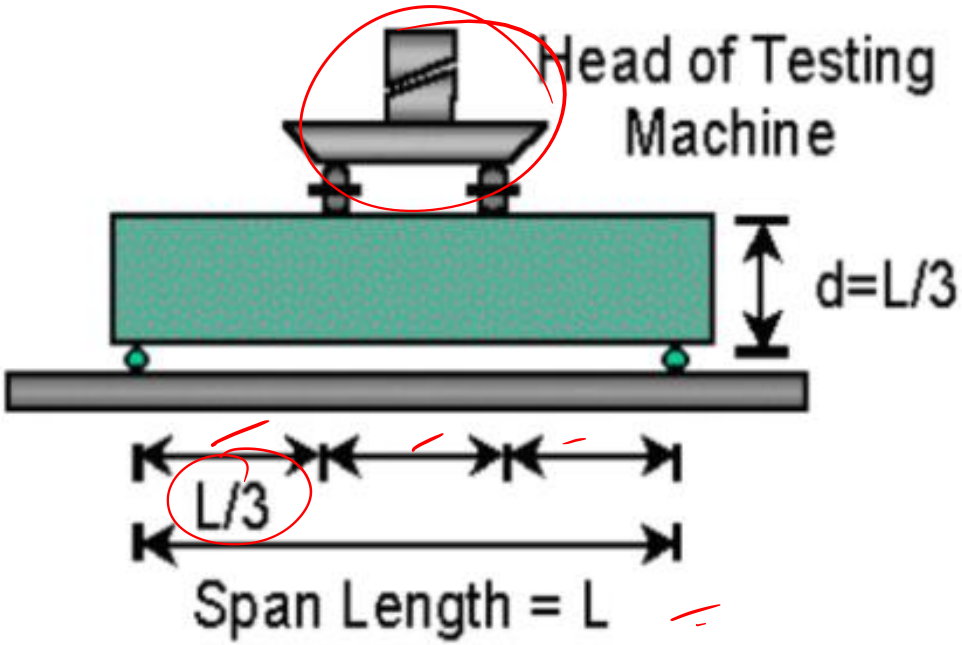
Third point Loading Test



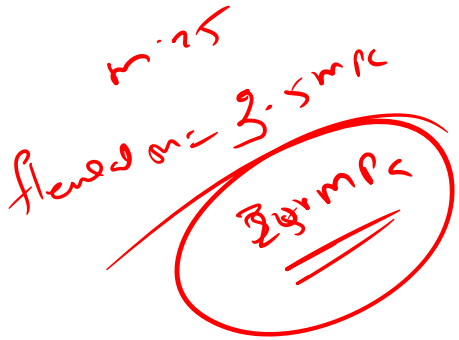
- Experience shows that the variability of results is less in third-point loading. The results of the flexural strength tested under central and third-points loading with constant span to depth ratios of 4 were analyzed statistically and the following general relationship was obtained at Central Road Research Laboratory.
- $x1 = x2 + 0.72$
- where, x1 = flaxural strength (MPa) of concrete under central point loading and
- x2 = flexural strength (MPa) of concrete under third point loading


4.5
4.0
3.5
3.0
2.5
2.0
Modulus of Rupture MPa
Centre-Point Loading
Third-Point Loading
50
100
150
200
250
Beam Depth and Width - mm

1 Third-point Loading



- In all the cases the central loading gave higher average value than the third-point loading irrespective of the size of the sample.
- The higher strength obtained in the case of central loading
- may be attributed to the fact that the beam is being subjected to the maximum stress at a predetermined location not necessarily the weakest.
- In the standard methods for finding the flexural strength of concrete, the span to depth ratio of the specimen is kept at 4.
- If the span to depth ratio is increased or decreased, the flexural strength was found to alter.
- A change in this ratio by 1 induced 3 per cent and 2.5 per cent change in strength when tested by third-point and central point loading respectively



- The rate of stress application was found to influence the flexural strength of concrete to a very significant extent.
- The strength increased upto about 25 per cent with increase in stressing rate compared to the standard rate of 0.7 MPa per minute. The increase was found more with the leaner mixes.
- There are number of empirical relationships connecting tensile strength and compressive strength of concrete.
- One of the common relationships is shown below.
- Tensile Strength = K (Compressive Strength)n where, value of K varies from 6.2 for gravels to 10.4 for crushed rock (average value is 8.3) and value of n may vary from 1/2 to 3/4.
- The Indian Standard IS = 456 of 2000 gives the following relationship between the compressive strength and flexural strength.
- **Flexural Strength = $0.7\sqrt{f_{ck}}$**
- where fck is the characteristic compressive strength of concrete in N/mm2.


Thank
you!!!