UPPSC-AE 2023

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Civil Engineering

Design of Concrete and Masonry Structures

Well Illustrated **Theory** *with*

Solved Examples and **Practice Questions**

MADE EASY Publications

Design of Concrete and Masonry Structures

Contents

UNIT	TOPIC	PAGE NO.
1.	Basic Design Concepts	1
2.	Limit State Method	27
3.	Working Stress Method	64
4.	Design for Shear in Reinforced Concrete	82
5.	Design for Bond in Reinforced Concrete	103
6.	Design for Torsion in Reinforced Concrete	114
7.	Design of Beam	124
8.	Design of Slab	138
9.	Column	153
10.	Footing	174
11.	Design of Retaining Wall	188
12.	Design of Water Tank	198
13.	Design of Staircase	208
14.	Prestressed Concrete	217
15.	Earthquake Resistant Design of Structure	258
16.	Design of Brick Masonry	288
	Annexure	297

CHAPTER 1

Basic Design Concepts

1.1 Introduction

Concrete is such a wonderful construction material that an *Italian architect* once said:

"*Concrete has liberated us from the rectangle*".

It is because of the flexibility and mouldability property of concrete (when wet) that we are now having structure of any shape and size. It has replaced the conventional building materials like stone, timber and steel. Any reinforced concrete structure (be it simple or complex), is an assembly of basic structural elements like beams, columns, footings, slabs and walls. Thus, design of reinforced concrete structures lies in the design of these basic structural elements i.e. the design of beams, columns, slabs, walls, footings etc. Numerous theories were proposed in the last century for the design of concrete structures. In this chapter, we will look into the various theories for design of concrete structure.

1.2 Necessity of Designing Reinforced Concrete Structures

The principal aim of structural design is that the structures should perform its intended function *safely* at ultimate loads within their life time and also *serviceable* at service or working loads.

The term '**safety'** includes the following parameters:

1. Reserve strength of the material of the structure.
2. Limited or permissible deformation(s) in the structure.
3. Durability of the structure in the long run.

Thus, **safety** implies that the possibility of the failure of the structure (partial or complete failure) is very low even at **ultimate loads** considering appropriate factor of safety.

Serviceability implies that the structure should perform its intended function very well at **working loads.** It includes deflection, vibration, crack widths, durability, permeability, acoustics, thermal insulation etc.

Thus, the basic objectives to fulfil serviceability criteria can be summarized as:

1. Properly designed structures should perform its intended function at service loads quite satisfactorily.
2. Structure should bear all the loads and should deform within the permissible limits.
3. The structures should be durable enough against the adverse environmental conditions.
4. The designed structure must adequately resist the probable hazardous effects of structural misuse and fire.

NOTE

- Increasing the **factor of safety** in the design of structures increases the safety and serviceability of the structure but at the same time it increases the cost of structure also. Here comes the role of **economy** in the design of structures. While considering the overall economy of a structure, the increased cost associated with the increased factor of safety must be properly weighed against the possibility of structural failure.

1.2.1 Objectives of Structural Design

The rational design of a structure must satisfy the following requirements:

1. **Stability:** The structure must be stable enough to resist the failure of structure in terms of overturning, sliding, buckling of the structure or parts thereof under the severe action of loads viz. both permanent (dead load) and temporary (superimposed live load etc.).
2. **Strength:** The structure must be able to carry safely the stresses induced by the severe most possible combination of loads acting on the structure.
3. **Serviceability:** The structure must perform its intended function i.e. it must be serviceable. This implies that the deflections, vibrations, crack-widths, permeability to water etc. are within the permissible limits.
4. **Aesthetics:** The structure must be in harmony with the surroundings and should look pleasing. It is purely an architectural consideration.
5. **Economy:** At last, economy plays the most important role in structural design. The cost of the structure and its associated facilities must not be so gargantuan that it may dictate the overall functional requirement of the structure.

1.3 Concrete

It is a mixture of binding material (cement), fine aggregate (sand), coarse aggregate, water and admixture in proper proportion to achieve concrete of desired properties at fresh state and hardened state.

1.3.1 Plain Concrete

- Concrete can be defined as a mass which is made from any cementing material and consists of sand, gravel and water. Mixing of such naturally occurring materials along with a cementing material result in a partial solid mass that can be molded in any shape and form, when wet, and which becomes hard on drying. Concrete is being used as a building material probably from the last 150 years.

  Concrete is a highly successful building material and has gained wide popularity because of the following reasons:

  1. Concrete is highly durable even under hostile environmental conditions.
  2. It can be easily casted into any shape and size.
  3. It is relatively cheaper and widely available.
- The most important property of concrete is its compression resisting ability i.e. compressive strength, which supersedes any other building material. At present we have concrete grades ranging from 5 MPa to 100 MPa.
- The major drawback of concrete is that it cannot resist significant tension. The tensile strength of concrete is about 10% of its compressive strength. Thus, the use of plain concrete as a building material is limited to places where tensile stresses/strains never develop. For example pedestals, mass concreting in dams etc.

1.3.2 Reinforced Concrete

- Concrete has gained so much importance and popularity because of the development of **reinforced concrete**. Introducing the reinforcing bars in concrete makes the concrete an excellent composite building material which can resist significant amount of tensile stresses/strains also. Construction of load bearing building elements like beams, slabs etc. is made possible due to the reinforced concrete only. Steel bars embedded in the tension zone of concrete make it able to take tension.

- In reinforced concrete, strain compatibility is assumed to exist i.e. there exists a perfect bond between the concrete and steel bars so that strain in concrete is equal to the strain in steel at the interface of concrete and steel.
- Moreover, since the failure of concrete is brittle in nature which takes place without giving any warning, introduction of steel in concrete makes it a ductile material which gives sufficient warning before collapse.
- Now tensile stresses occur either directly (e.g. direct tension, flexural tension) or indirectly (e.g. shear which causes tension along the diagonal planes). Temperature and shrinkage effects may also induce tensile stresses. At all such locations, steel is invariably provided which is in fact inevitable, that passes across the tensile cracks. Insufficient steel causes propagation of cracks which can lead to complete failure.
- Embedding reinforcing bars in compression zone of concrete increases the compressive strength of member (e.g. In columns, doubly reinforced beams etc.).

1.3.3 Prestressed Concrete

- Development of prestressed concrete took place along with the reinforced concrete. It is a high strength concrete with high tensile wires embedded in concrete and tensioned before the application of actual working load. While doing so, the concrete can be compressed to such an extent that when the structure is actually loaded, there is almost no tension developed in the beam section. Prestressed concrete is frequently used where, even a hair line crack is not admissible like, high pressure vessels, pipes, water tanks etc. and at locations which are subjected to fatigue loading like long span bridges or rail sleepers etc.

1.4 Concrete Mix Design

`• Design of concrete mix for a particular grade of concrete involves proper selection of relative proportions of cement, sand and coarse aggregates. While designing a concrete mix, it is always tried to obtain a minimum strength which is equal to characteristic strength of concrete but concrete must also have the desired workability (when fresh/green), impermeability and durability (in hardened state). **Table below** depicts the various grades of concrete based on concrete mix design. Concrete mix design is classified as nominal mix design and the design mix.

Various grades of concrete as per IS 456: 2000

Concrete Grade	Type of Concrete
M10	Ordinary grade concrete
M15	
M20	
M25 - M55	Standard grade concrete
M60 - M100	High Strength concrete

NOTE: Provision of **IS 456: 2000** do not apply to grades of concrete M60 and above.

1.4.1 Nominal Mix Design

Concrete mix design is a process that needs experience. Earlier, concrete mixes were specified in terms of fixed ratios like 1:2:4, 1:1.5:3 and so on for cement, sand and coarse aggregates respectively (by mass or by volume). This is a very rough method of concrete mix design which often gives wrong translations of concrete grades like M15, M20, M25, M30 etc.

IS 456: 2000 provides a more precise nominal mix proportions for M5, M7.5, M10, M15 and M20 grades of concrete in terms of total mass of aggregates, proportions of fine to coarse aggregates and volume of water to be used per 50 kg (i.e. 1 bag) of cement (which is in volume equal to **34.5 liters**). Nominal mix concrete can only be used in ordinary concrete constructions involving concrete grade not higher than M20. For higher grades of concrete, design mix concrete is adopted.

Traditional nominal mix of 1 : 2 : 4 (cement : sand : coarse aggregate, by weight) with 33 grade of OPC conforms approximately to M15 concrete grade. This nominal mix with higher grades of cement (43, 53 grades) yields higher grades of concrete (M 20 and above).

1.4.2 Design Mix Concrete

Design mix concrete is based on the principles of "mix design" and is always preferred over nominal mix of concrete. It yields concrete of desired quality and is more economical than the nominal mix. The IS recommendations of the mix design are given in **IS 10262: 1982** and **SP 23: 1982**.

1.5 Steps Involved in Mix Design of Concrete as per IS Recommendation

Step 1. Determine the mean target strength (f_{cm}) from the desired characteristic strength (f_{ck}) as:

$$f_{cm} = f_{ck} + 1.65\sigma$$

where, σ is the standard deviation that depends on quality control as listed in Table 8 of IS 456: 2000.

Step 2. Determine the water-cement ratio based on 28 days strength of cement and the mean target strength of concrete. This ratio must not exceed the limits specified in Table 5 of IS 456: 2000.

Step 3. Determine the water content based on requirements of workability. Select the type of proportion of fine and coarse aggregate (by mass) based on aggregate grading and type. Water requirement is usually in the range of 170-200 litres per cubic metre of concrete (without admixtures) and ratio of fine and coarse aggregates is generally taken as 1:1.5, 1:2, or 1:2.5.

Step 4. Determine the cement content (in kg/m^3) as:

$$\text{Cement Content} = \frac{\text{Water content}}{\text{Water-cement ratio}}$$

Cement content should not be less than that specified in Tables 4 and 5 of IS 456: 2000 for durability considerations.

Example - 1.1 Consider the following particulars in respect of a concrete mix design:

	Weight	Specific Gravity
Cement	400 kg/m^3	3.2
Fine aggregates	—	2.5
Coarse aggregates	1040 kg/m^3	2.6
Water	200 kg/m^3	1.0

What shall be the weight of the Fine aggregates?

(a) 520 kg/m^3 (b) 570 kg/m^3

(c) 690 kg/m^3 (d) 1000 kg/m^3

Solution: (c)

For 1 m^3 of concrete,

$$1 = \frac{W_c}{\rho_c} + \frac{W_{ca}}{\rho_{ca}} + \frac{W_w}{\rho_w} + \frac{W_{fa}}{\rho_{fa}}$$

$$\Rightarrow \quad 1 = \frac{400}{3.2\times1000} + \frac{1040}{2.6\times1000} + \frac{200}{1\times1000} + \frac{W_{fa}}{2.5\times1000}$$

$$W_{fa} = (1 - 0.125 - 0.4 - 0.2) \times 2.5 \times 1000$$

$$= 687.5 \text{ kg/m}^3 \simeq 690 \text{ kg/m}^3$$

1.6 Hardened Concrete

After final setting time (10 hr) from mixing concrete is assumed to be hard, from final setting time concrete starts gaining strength up to very long time (1 to 5 years).

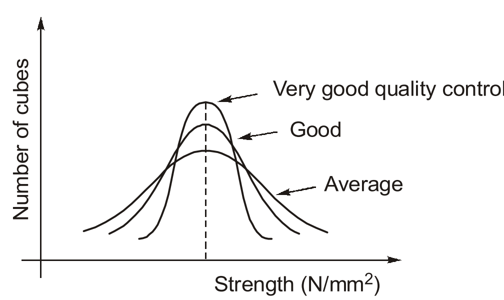


Fig. *Influence of quality control on the frequency distribution of concrete strength*

1.6.1. Compressive Strength

(a) **Compressive strength of cube:** It is the compressive strength of cube of size 150 mm, subjected to uniaxial compression after 28 days from day of casting.

(b) **Characteristics compressive strength of cube:** It is the strength below which not more than 5% of the test results are expected to fail.

Example - 1.2 If the characteristics strength of concrete f_{ck} is defined as the strength below which not more than 50% of the test result are expected to fail, the expression for f_{ck} in terms of mean strength f_t and the standard deviation 's' would be

(a) $f_t - 0.1645s$ (b) $f_t - 1.645s$

(c) f_t (d) $f_t + 1.645s$

Solution: (c)

We know that, $f_t = f_{ck} + ks$

for 50% of definition, $k = 0$

$\therefore$ $f_t = f_{ck}$

Example - 1.3 Uniaxial compressive test, results of 100 cubes are listed below in increasing order. What is characteristics strength of concrete 26, 26.5, 27, 27, 28.5, 29, 29.5, 30, ..., 44.5?

Solution:

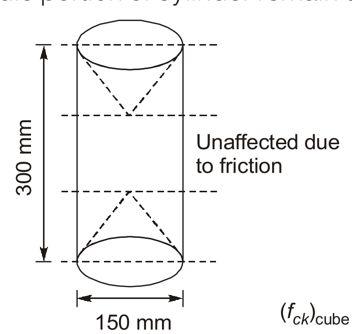
As per definition, characteristics strength should be 29 N/mm^2 since f_{ck} is designated in multiple of 5. So, f_{ck} should be either 25 or 30, in this case 7 samples (7%) are below 30 N/mm^2 so, 30 cannot be characteristics strength now, 25 is the characteristics strength of this concrete because zero sample (0% < 5%) is below 25 N/mm^2

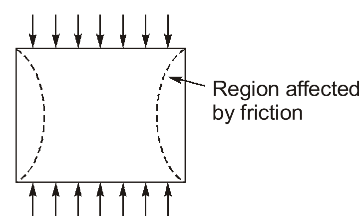
$$\therefore \quad f_{ck} = 25 \text{ N/mm}^2$$

(c) **Characteristics strength of concrete:** It is obtained by dividing characteristics compressive strength of cube by a factor 1.5 to account for variation in loading condition (other than uniaxial compression) and variation in shape of concrete (other than cube of 150 mm).

(d) **Characteristics strength of cylinder:** Uniaxial compressive strength of concrete can be determined by using different types of shapes of specimen (cube, cylinder, prism).

- Cylinder gives more appropriate result for uniaxial compressive strength because effect of friction between machine plate and ends of specimen is least.
- Middle portion of cylinder remain unaffected of friction.

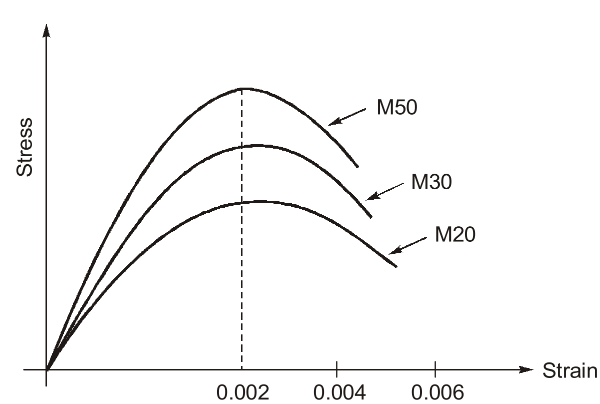




$(f_{ck})_{cube} = 1.25\ (f_{ck})_{cylinder}$

(e) **Stress-strain diagram of concrete under uniaxial compression:**

- Stress-strain diagram is non-linear.
- Maximum stress is corresponding to 0.002 strain (approximately).
- Ultimate strain lies between 0.004 to 0.006.
- Brittleness increases with increase in grade of concrete.
- Modulus of elasticity increases with increase in grade of concrete.
- Falling portion of stress-strain curve is obtained by controlled strain machine.



1.6.2 Grade of Concrete

Grade of concrete are based on characteristics strength. As per IS code (Amendment No. 4) the various grades of concrete are

M10, M15, M20 } Ordinary grade

M25-M60] - Standard grade

M65-M100] - High strength concrete

where, M represents mix and number represents grade which is characteristics strength of 150 mm cube at 28 days.

Ex:

M20 → Mix ↙ ↘ Characteristics strength (N/mm^2)

NOTE

- IS 456 : 2000 is not applicable to grade above M-60 (Amendment No. 4, May 2013)
- IS 456 : 2000 recommends the minimum grade as M-20 for reinforced concrete.
- Minimum grade of RCC and PCC used, depends on the exposure condition.

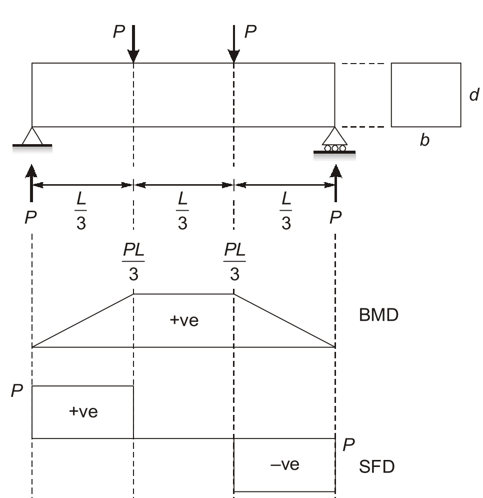
Exposure Condition	Minimum Grade (RCC)	Minimum Grade (PCC)
Mild	M20	–
Moderate	M25	M15
Severe	M30	M20
Very Severe	M35	M20
Extreme	M40	M25

1.6.3 Tensile Strength of Concrete

It is approximately 7 to 15% of compressive strength and stress-strain diagram is almost linear. Since, tensile strength of concrete is ignored in design so, it has vary less importance however it may be used to calculate cracking width and cracking moment.

(i) Direct tension test: Practically it is difficult to perform direct tension test due to stress concentration and non-homogeneity of material.

(ii) Flexure test:



Flexural formula, $$\frac{M}{I} = \frac{f}{y} = \frac{E}{R}$$

$$\frac{\left(\frac{PL}{3}\right)}{\left(\frac{bd^3}{12}\right)} = \frac{f_{cr}}{\left(\frac{d}{2}\right)}$$

$$f_{cr} = ?$$

- Third point loading is applied for pure bending condition.
- Value of *P* is increased from 0 to value corresponding to which first crack develops.
- Corresponding to cracking load, bending moment is calculated in central portion and tensile strength is calculated as shown above.
- IS : 456 provides a standard formula for flexure tensile strength/modulus of rupture as shown above:
- IS : 456 provides a standard formula for flexure tensile strength/modulus of rupture as shown below:

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

$$\downarrow \qquad \downarrow$$

$$\text{N/mm}^2 \qquad \text{N/mm}^2$$

(iii) Cylinder split test/splitting tensile strength of concrete: Owing to limitations of direct tensile strengthtest of concrete, cylinder splitting test is performed which gives more uniform results. In this test, a standard plain concrete cylinder (as used in compression test) is loaded on its sides along a diameter. Failure occurs by splitting of the cylinder along the plane of loading. This type of loading produces a uniform tensile stress across the plane of loading.

The splitting tensile strength (f_{ct}) is obtained as:

$$f_{ct} = \frac{2P}{\pi dL}$$

Where, *P* is the maximum load applied at failure, *d* is the diameter of the cylinder specimen, *L* is the length of the cylinder specimen.

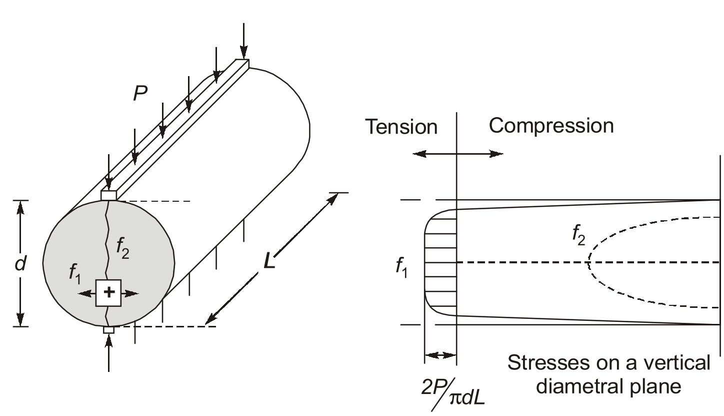


Fig. *Cylinder splitting test for tensile strength*

1.13.4 Codes for aggregates, admixtures and water to be used in RCC

IS 383: 1970	:	Specification for coarse and fine aggregates from natural sources for concrete
IS 2386 (Parts 1 to 8)	:	Methods of tests for aggregate for concrete
IS 1344: 1981	:	Specification for calcined clay pozzolana
IS 3812: 1981	:	Specification for flyash for use as pozzolana and admixture
IS 9103: 1999	:	Specification for admixtures for concrete
IS 3025 (Parts 17 to 32)	:	Methods of sampling and test (physical and chemical) for water and waste water.

Student's Assignment

Q.1 The characteristic strength of concrete is
(a) higher than the average cube strength
(b) lower than the average cube strength
(c) the same as the average cube strength
(d) higher than 90% of the average cube strength

Q.2 As compared to working stress method of design, limit state method takes concrete to
(a) a higher stress level
(b) a lower stress level
(c) the same stress level
(d) sometimes higher but generally lower stress level

Q.3 The stresses in concrete in a reinforced concrete element under sustained load due to creep
(a) increase with time
(b) decrease with time
(c) remain unchanged
(d) fluctuate

Q.4 Long term elastic modulus in terms of creep coefficient (θ) and 28-day characteristic strength (f_{ck}) is given by
(a) $\dfrac{5000\sqrt{f_{ck}}}{1+\theta}$ MPa (b) $\dfrac{50000\sqrt{f_{ck}}}{1+\theta}$ MPa
(c) $\dfrac{5000 f_{ck}}{1+\sqrt{\theta}}$ MPa (d) $\dfrac{5000\sqrt{f_{ck}}}{\sqrt{1+\theta}}$ MPa

Q.5 In limit state design of reinforced concrete, deflection is computed by using
(a) initial tangent modulus
(b) secant modulus
(c) tangent modulus
(d) short-and long-term values of Young's modulus

Q.6 In the limit state method of design, the failure criterion for reinforced concrete beams and columns is
(a) maximum principal stress theory
(b) maximum principal strain theory
(c) maximum shear stress theory
(d) maximum strain energy theory

Q.7 As per **IS 456-2000**, which one of the following correctly expresses the modulus of elasticity of concrete? (read with the relevant units)
(a) $E_c = 0.7\sqrt{f_{ck}}$ (b) $E_c = 500\sqrt{f_{ck}}$
(c) $E_c = 5000\sqrt{f_{ck}}$ (d) $E_c = 5700\sqrt{f_{ck}}$

Q.8 What is the value of flexural strength of M 25 concrete?
(a) 4.0 MPa (b) 3.5 MPa
(c) 3.0 MPa (d) 1.75 MPa

Q.9 Characteristic strength of M20 concrete is 20 MPa. What is the number of cubes having 28 days' compressive strength greater than 20 MPa out of 100 cubes made with this concrete?
(a) All (b) 95
(c) 80 (d) 50

Q.10 Working stress method of design for reinforced concrete is
(a) not a limit state design
(b) a serviceability limit state design
(c) a limit state for crack width
(d) a collapse limit state

Q.11 Modulus of elasticity of concrete is increased with
(a) Higher W/C ratio
(b) Shorter curing period
(c) Lesser vibration
(d) Increase in age

Q.12 As compared to the working stress method of design, the limit state method of design premises that the concrete can admit
(a) A lower stress level
(b) A higher stress level
(c) Occasionally higher, but usually lower, stress level
(d) Only the same stress level

Q.13 A certain RC structure has to be constructed along a sea coast. The minimum grade of concrete to be used as per IS 456 : 2000 is
(a) More than M 20
(b) More than M 20 and less than M 30
(c) Not less than M 30
(d) Less than M 45 and more than M 30

Q.14 What is the pH value of potable water, as specified by IS 456 : 2000?
(a) Equal to 7 (b) Between 6 and 9
(c) Less than 6 (d) Not less than 6

Q.15 Let the characteristic strength be defined as that value, below which not more than 50% of the results are expected to fall. Assuming a standard deviation of 4 MPa, the target mean strength (in MPa) to be considered in the mix design of a M25 concrete would be
(a) 18.42 (b) 21.00
(c) 25.00 (d) 31.58

Q.16 The deformation in concrete due to sustained loading is
(a) creep (b) hydration
(c) segregation (d) shrinkage

Q.17 The characteristic strength of concrete is defined as that compressive strength below which not more than
(a) 10% of results fail
(b) 5% of results fail
(c) 2% of results fail
(d) None of the above

Q.18 The cylinder strength of the concrete is less than the cube strength because of
(a) the difference in the shape of the cross-section of the specimens
(b) the difference in the slenderness ratio of the specimens
(c) the friction between the concrete specimens and the steel plate of the testing machine
(d) the cubes are tested without capping but the cylinders are tested with capping

Q.19 The modulus of rupture of concrete gives
(a) the direct tensile strength of the concrete
(b) the direct compressive strength of the concrete
(c) the tensile strength of the concrete under bending
(d) the characteristic strength of the concrete

Q.20 In a random sampling procedure for cube strength of concrete, one sample consists of X number of specimens. These specimens are tested at 28 days and average strength of these X specimens is considered as test result of the sample, provided the individual variation in the strength of specimens is not more than ± Y per cent of the average strength. The values of X and Y as per IS 456 : 2000 are
(a) 4 and 10 respectively
(b) 3 and 10 respectively
(c) 4 and 15 respectively
(d) 3 and 15 respectively

ANSWER KEY // STUDENT'S ASSIGNMENT

1. (b)	**2.** (a)	**3.** (b)	**4.** (a)	**5.** (d)
6. (b)	**7.** (c)	**8.** (b)	**9.** (b)	**10.** (a)
11. (d)	**12.** (b)	**13.** (c)	**14.** (d)	**15.** (c)
16. (a)	**17.** (b)	**18.** (c)	**19.** (c)	**20.** (d)

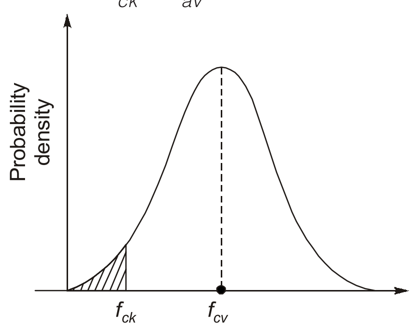
HINTS & SOLUTIONS / STUDENT'S ASSIGNMENT

1. (b)

Characteristics strength = f_{ck}

$f_{av} = f_{ck} + 1.65s$

$\therefore \quad f_{ck} < f_{av}$



2. (a)

Limit state method takes concrete to higher stress level as compared to working stress method by taking into account non linear stress strain diagram.

3. (b)

The stresses in concrete under sustained load due to creep decrease with time because of

4. (a)

Long term modulus of elasticity

$$= \frac{E_c}{1+\theta} = \frac{5000\sqrt{f_{ck}}}{(1+\theta)} \text{ MPa}$$

5. (d)

The short term deflections may be calculated using methods for elastic deflections using the short term modulus of elasticity of concrete E_c and effective moment of inertia.

For long term deflections, the long term modulus

$E_{ce} = \frac{E_c}{1+\theta}$ is used where θ is creep coefficient

8. (b)

As per **IS 456 : 2000** (clause 6.2.2)

Flexure strength of concrete

$$f_{cr} = 0.7\sqrt{f_{ck}} \text{ N/mm}^2$$
$$= 3.5 \text{ N/mm}^2$$

9. (b)

The characteristic strength is that below which not more than 5% of the test results are expected to fall. Thus 95% of cubes will have strength more than characteristic strength.

10. (a)

WSM assumes that working stress does not exceed maximum permissible stress at any stage and concrete remains linear elastic up to collapse.

11. (d)

Modulus of elasticity of concrete is dependent on its compressive strength. Higher W/C ratio, shorter curing period or lesser vibration will produce concrete of lesser compressive strength. With increase in age compressive strength increases and therefore modulus of elasticity of concrete increases.

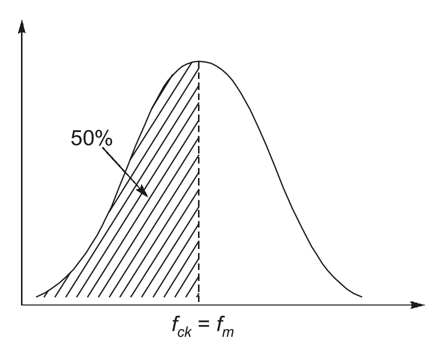
13. (c)

For sea water grade of concrete lower than M30 shall not be used in reinforced concrete (As per IS 456:2000).

14. (d)

As per clause 5.4.2 of IS456:2000, pH value of potable water shall not be less than 6.

15. (c)



If f_{ck} is the value below which not more than 50% of test results are expected then,

$$f_m = f_{ck}$$

[Mean strength = Characteristics strength]