CIVIL ENGINEERING

Reinforced Cement Concrete & Pre-stressed Concrete

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CHAPTER

1

Introduction

1.1 INTRODUCTION

Concrete is one of the most common building material used for constructing civil engineering structures and is essential in the infrastructure development of any nation. Concrete is used in the construction of various types of structures which include buildings, bridges, piers, chimneys, pavements, dams, hydraulic structures, conveying pipes, liquid retaining tanks/structures, assembly halls, auditorium, swimming pools, bunkers etc. and the list goes on.

1.2 TYPES OF CONCRETE

1.2.1 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 results in a partial solid mass (when wet) that can be molded in any shape and form and later 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 such places where tensile stresses/strains never develop. For example pedestals, mass concreting in dams etc.

1.2.2 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.).

1.2.3 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.

1.3 IMPORTANCE OF DESIGN CODES IN THE DESIGN OF STRUCTURES

Different countries have formulated their own codes for laying down the guidelines for the design and construction of structures. These codes came into picture after a collaborative effort of highly experienced structural engineers, construction engineers, academicians and other eminent fellows of respective areas. These codes are revised periodically based on current research and trends (e.g. IS 456: 1978 and IS 456: 2000). Codes serve the following objectives/purposes:

1. They ensure structural stability/safety by specifying certain minimum design requirements.
2. They make the task of a designer rather simple by making available results in the form of tables and charts.
3. They ensure a consistency in procedures adopted by the various designers in the country.
4. They protect the designer against structural failures that are caused by improper site construction practices, i.e., codes have legal sanctity and one can have a stand on the basis of these design codes.

1.3.1 Basic Indian Standard Codes for Structural Design

Some of the basic Indian Standard codes for reinforced concrete published by the BIS (Bureau of Indian Standards) are:

1. IS 456: 2000 Plain and reinforced concrete-Code of practice.
2. IS 875: 1987 (Part-I to V) Code of practice for design loads.
3. IS 1893: 2002 Criteria for earthquake resistant design of structures.
4. IS 13920: 1993 Ductile detailing of reinforced concrete structures subjected to seismic forces.

1.4 CHARACTERISTIC STRENGTH OF CONCRETE

Due to wide variation in the characteristics of concrete constituents (sand, coarse aggregates etc.), concrete is subjected to considerable variation in strength. Also, due to non-homogeneous nature of concrete, specimens taken from the same mix may give different compressive strengths in tests. This variation can be controlled by strict quality control and quality assurance.

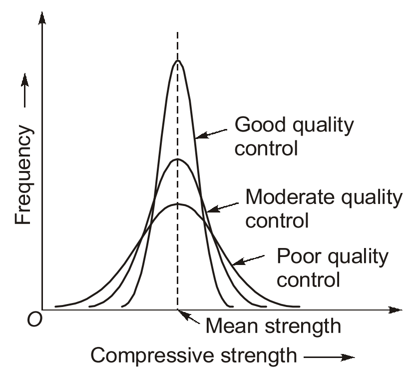

***Fig. :** Influence of quality control on the frequency distribution of concrete strength*

Statistically, the variation in concrete strength is studied in terms of **standard deviation** and/or **coefficient of variation**.

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Mean strength}}$$

Experimentally, it is found that probability distribution of concrete strength (for a particular concrete mix as found out by compressive strength tests in laboratory on a large number of specimens) follows **normal/Gaussian distribution**. The **coefficient of variation varies generally in the range of 0.01 to 0.02**. With higher degree of quality control, this variation can be reduced.

As pointed earlier, due to significant variation in the compressive strength of concrete (tested on concrete cube/cylinder specimens), it is quite essential to ensure that a certain minimum strength of concrete can always be obtained from a given mix. This is obtained by defining **Characteristic Strength** of concrete (which is applicable for other materials also).

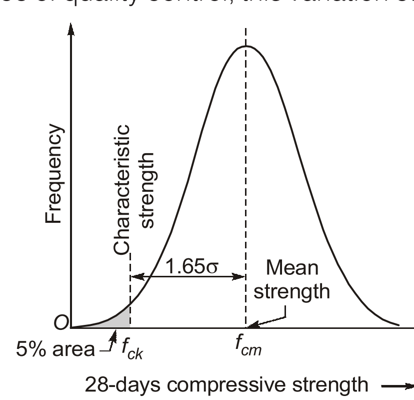

***Fig. :** Idealised normal distribution of concrete strength*

Characteristic Strength is defined as that strength of the material below which not more than 5% of the tests results are expected to fall.

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

where f_{cm} = Mean strength

f_{ck} = Characteristic strength

Thus, mean strength of concrete has to be significantly greater than the characteristic strength of concrete.

1.5 GRADE OF CONCRETE

The desired properties of concrete are its compressive strength, tensile strength, shear strength, bond strength, density, durability, impermeability etc. Among these properties, the most important property is the compressive strength of concrete. This is measured by standard tests on concrete cube/cylinder specimens. Many other properties of concrete can be inferred from its compressive strength.

The grade of concrete is expressed in terms of its characteristic compressive strength (of 150 mm cube at 28 days) expressed in N/mm^2 or MPa, as shown in table below.

***Table :** Grades of Concrete (Clause 6.1, 9.2.2, 15.1.1 and 36.1)*

Group (1)	Grade Designation (2)	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm^2 (3)
Ordinary Concrete	M10	10
	M15	15
	M20	20
Standard Concrete	M25	25
	M30	30
	M35	35
	M40	40
	M45	45
	M50	50
	M55	55
	M60	60
High Srength Concrete	M65	65
	M70	70
	M75	75
	M80	80
	M85	85
	M90	90
	M95	95
	M100	100

Notes :
1. In the designation of concrete mix *M* refers to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm^2.
2. For concrete of compressive strength greater than M60, design parameters given in the standard code may not be applicable and the values may be obtained from specialized literatures and experimental results.

1.6 DURABILITY OF CONCRETE

A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service life. The materials and mix proportions specified and used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.

One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship used in making the concrete. With normal-weight aggregates a suitably low permeability is achieved by having an adequate cement content, sufficiently low free water/cement ratio, by ensuring complete compaction of the concrete, and by adequate curing.

The factors influencing durability include :

(a) the environment;

(b) the cover to embedded steel;

(c) the type and quality of constituent materials;

(d) the cement content and water/cement ratio of the concrete;

(e) workmanship, to obtain full compaction and efficient curing; and

(f) the shape and size of the member.

The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship, design and detailing should be considered.

1.6.1 Methods to Increase the Durability of Concrete

By reducing the permeability of concrete in following ways:

1. Use of high strength concrete
2. By proper curing of concrete
3. By having a low water cement ratio
4. Using improved quality of admixtures
5. By having the maximum possible compaction of concrete
6. By the use of well graded, dense aggregates
7. By minimizing the possibility of cracks at the design phase itself

By providing protection to reinforcing steel in following ways:

1. By providing adequate clear cover to reinforcing steel as per relevant stipulations of IS codes.
2. Using coated steel or suitable corrosion resistant steel.
3. By preventing the corrosion of steel by the methods like sacrificial protection etc.
4. By the use of suitable corrosion resistant cement.
5. Avoid use of alkali reactive aggregates.
6. By preventing ponding on roof slabs and on other concrete surfaces by proper drainage of water.
7. By having a proper control on chloride and sulphate content in the concrete mix.

1.6.2 Environmental Exposure Conditions

The general environment to which the concrete will be exposed during its working life is classified into five levels of severity, that is, mild, moderate, severe, very severe and extreme as described in table.

The maximum strength of concrete is taken as 0.85 times the specified cylinder strength for the design of RCC members (for both in compression and flexure/bending). This comes out to be approximately equal to 0.67 times the characteristic cube strength. IS 456: 2000 also limits the failure strain to 0.002 in direct compression and 0.0035 in flexure.

REMEMBER When the predominant loading on the structure is of short term nature (like wind or earth quake loading on towers, chimneys etc.) and NOT the sustained loading then it is too conservative to limit the compressive strength of concrete to 0.85 times the cylinder strength or 0.67 times the characteristic cube strength. In such cases, a suitable higher value of compressive strength may be taken.

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OBJECTIVE BRAIN TEASERS

Q.1 Consider the following statements regarding core test of concrete:

1. The minimum numbers of core required for the testing is 3.
2. Core shall be prepared and tested as described in IS 516.
3. Concrete shall be considered acceptable if the average equivalent cube strength of core is equal to at least 70 percent of the cube strength of same grade of concrete for corresponding age.
4. No individual core should have a strength less than 75 percent of cube strength.

Which of the above statements are CORRECT?

(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 2 and 4 (d) 1, 3 and 4

Q.2 Minimum cement content for concrete of grade M-35 having nominal size of aggregate 20 mm is 340 kg/m^3 but at site only 10 mm nominal size of aggregate is present, then the modified minimum cement content will be

(a) 340 kg/m^3 (b) 370 kg/m^3
(c) 300 kg/m^3 (d) 380 kg/m^3

Q.3 Consider the following statements regarding testing of concrete:

1. The mean strength determined from any group of four consecutive test results should be more than or equal to $f_{ck} + 1.65\sigma$.
2. Minimum 30 samples are required to be tested for the establishment of value of standard deviation.
3. Individual test results should not fall below $f_{ck} - 3$.

Which of the above statements are CORRECT?

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

Q.4 According to IS-456:2000, the general environment to which concrete will be exposed during its working life is classified into a level of severity.

List-I (Exposure level)

A. Moderate
B. Severe
C. Very severe
D. Extreme

List-II (Level of severity)

1. Surface of member in tidal zone
2. Concrete surface exposed to sea water spray

3. Concrete completely immersed in sea water
4. Concrete member sheltered from saturated salt air in coastal area

	A	B	C	D
(a)	1	3	2	4
(b)	1	2	3	4
(c)	4	3	2	1
(d)	4	2	3	1

Q.5 Tensile strength of concrete is measured by

(a) direct tension test in the universal testing machine.
(b) applying compressive load along the diameter of the cylinder.
(c) applying third point load on a prism.
(d) applying tensile load along the diameter.

Q.6 In limit state method (LSM) of design, if the standard deviation is 4 for concrete of grade M25, then difference between mean load and characteristic load will be

(a) 3.5 (b) 4.2
(c) 5.4 (d) 6.6

Q.7 How many number of samples will be taken if 40 m^3 of concreting is to be done?

(a) 2 (b) 3
(c) 4 (d) 5

Q.8 The modulus of rupture of concrete gives

(a) the direct tensile strength of the concrete
(b) the direct compressive strength of concrete
(c) the tensile strength of the concrete under bending
(d) the characteristic strength of the concrete

Q.9 Larger the value of standard deviation

(a) Lower will be the variability
(b) Better will be level of control
(c) Poorer will be the level of control
(d) Not related to quality control

Q.10 Consider the following strengths of concrete:

1. Cube strength.
2. Cylinder strength.
3. Split-tensile strength.
4. Modulus of rupture.

The correct sequence in increasing order of these strengths is

(a) 3, 4, 2 and 1 (b) 3, 4, 1 and 2
(c) 4, 3, 2 and 1 (d) 4, 3, 1 and 2

ANSWERS KEY

1. (c)	**2.** (d)	**3.** (b)	**4.** (c)	**5.** (b)
6. (d)	**7.** (c)	**8.** (c)	**9.** (c)	**10.** (a)

HINTS & EXPLANATIONS

1. (c)

Refer Clause 17.4 of IS 456:2000 [Page no. 30]

2. (d)

As per Table No. 6 of IS 456:2000,

If nominal size of aggregate = 10 mm

then adjustment in minimum cement content = 40 kg/m^3

So modified minimum cement content = 340 + 40 = 380 kg/m^3

3. (b)

Refer Clause 16.2 and Table 11 of IS 456 : 2000.

6. (d)

$$f_m = f_{ck} + 1.65 \times (\sigma)$$

where, f_m = mean/avg. load

σ = standard deviation

$$\therefore \quad f_m - f_{ck} = 1.65 \times (\sigma) = 1.65 \times 4 = 6.6$$

7. (c)

Quantity of concrete	No. of sample(s)
1 to 5 m^3	1
6 to 15 m^3	2
16 to 30 m^3	3
31 to 50 m^3	4

8. (c)

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

= tensile strength of concrete under bending

10. (a)

Split tensile strength < Modulus of rupture < Cylinder strength < Cube strength

$$\frac{2P}{\pi DL} < 0.7\sqrt{f_{ck}} < \text{Cylinder strength} < f_{ck}$$

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