CHAPTER 1

Reinforced Concrete

1.1 Introduction

Concrete is the most versatile material used for the construction of buildings and structures. The concrete is a cohesive mixture made of cement, coarse and fine aggregates, water and other admixtures used for special functions or replacement of cement. Cement acts as a binder which binds together the ingredients of concrete in the presence of water, allows the setting and hardening reactions to occur resulting in the formation of a hard mass. The function of water is to allow the chemical reaction to occur which takes longer time causing first setting and then hardening of the concrete. The aggregates act as inert filler in the concrete mass and impart strength to it. Other admixtures commonly include water proofing materials, air-entraining agents or inert fillers like fly ash, granulated blast furnace slag, silica fume, alccofine, etc.

Concrete is very strong in compression but it cannot resist tensile stresses hence use of plain or unreinforced concrete is limited to non-structural components. When concrete is to be used in structural components (like slabs, beams, columns, stairs, foundations, etc.) of a building, it must be reinforced with suitable reinforcing material which is strong to resist tensile stresses. Steel is a material which is very strong in tension (as well as in compression) and is therefore commonly used to reinforce concrete by placing it at those sections of members where tensile stresses develop. Again, the two materials develop adequate bond to act together for resisting the compressive and tensile stresses. The tensile stresses are resisted by steel and concrete resists the compression making the composite material strong in tension as well as compression.

Reinforced cement concrete is a composite material comprising of concrete with steel bars placed in the form of suitable cage at the sections of members subjected to tension. The composite mass is moulded in formwork (made of steel or timber) in suitable shapes to construct the structural components such as slabs, beams, columns, stairs, foundations, etc.

The design of reinforced concrete structures involves the determination of suitable sizes of the members (beams, columns, slabs, etc.) and the quantity (number and diameter) of reinforcement bars appropriate to bear the stresses developed. The design of reinforced concrete structures is carried out by following the provisions laid down in Indian standard code of practice IS: 456 -2000. The loads, allowable stresses in concrete and steel and the methods of design given in this standard are followed for the design of structural elements.

The concrete in its fresh or raw state should possess adequate workability but segregation and bleeding should not occur in it otherwise the mass produced may not be homogeneous resulting in poor quality. Upon hardening, concrete should possess adequate strength and durability without any significant shrinkage which otherwise may lead to development of cracks affecting the strength.

This chapter provides an insight in to different materials used in making concrete, design of concrete mix, tests on fresh and hardened concrete and the properties of hardened concrete. The characteristics and types of steel reinforcements used in reinforced concrete are given to provide information to the designer. Various structural components of buildings are described to make the designer aware of the type of the elements involved.

1.2 Constituent Materials

1.2.1 Cement

Cement is the most versatile construction material used in concrete construction and is the backbone of modern construction industry. Cement was first of all used by Joseph Aspdin, a brick layer of Leeds in England. The colour of hardened cement was similar to the rock in Portland and therefore the cement was named as Portland cement. Depending upon the work specific requirements, different types of cement are produced as described below:

1. *Ordinary Portland cement*: Ordinary Portland cement is the most common type of cement used in concrete construction. Three grades of ordinary Portland cement depending upon 28 days compressive strength (N/mm^2) of cement (cement: sand:: 1: 3 mortar) are used as given below:

   33 Grade ordinary Portland cement conforming to IS 269

   43 Grade ordinary Portland cement conforming to IS 8112

   53 Grade ordinary Portland cement conforming to IS 12269

2. *Rapid hardening cement*: This cement conforms to IS 8041 and contains larger quantity of tri-calcium silicate (C_3S) and is ground finely enabling it to react faster with water resulting in rapid hardening. The rate of strength development during the initial period is much faster compared to that of ordinary Portland cement. Due to early strength development, it is used for structures subjected to loading during service life particularly in repair works of roads and bridges. Its initial and final setting times are the same as those of ordinary Portland cement. The compressive strength of rapid hardening cement is 16 N/mm^2 after 1 day and 27.5 N/mm^2 after 3 days for cube specimens made of cement: sand (1: 3).

3. *Portland pozzolana cement*: Very fine pozzolanic materials such as fly ash, volcanic ash or surkhi are blended with ordinary Portland cement or clinker in certain proportions to give Portland pozzolana cement. This cement generates less heat of hydration and can be used in mass concreting where otherwise cracks may develop in concrete. It offers resistance to sulphate environments and marine waters. The rate of strength development is slow in this cement but the final strength may be higher than that of ordinary Portland cement. This cement conforms to IS 1489 and its compressive strength is 22 N/mm^2 after 7 days and 31 N/mm^2 after 28 days for cube specimens made of cement: sand (1: 3). Initial and final setting times of this cement are the same as those of ordinary Portland cement.

4. *Low heat cement*: This cement conforms to IS 12600 and it contains lesser quantity of tri-calcium silicate (C_3S) and tri-calcium aluminate (C_3Al) which helps in keeping the heat generated low. The strength is developed at a very slow rate in this cement. The initial setting time of this cement should be at least 60 minutes and final setting time should not be more than 600 minutes. This cement is normally used in mass concreting works such as dams and weirs.
5. *Portland slag cement*: This cement conforms to IS 455 and is manufactured by blending together the ordinary Portland cement with blast furnace slag. Due to the presence of slag, it can resist the sulphate attack and acidic environment. Upon mixing with water, it generates low heat of hydration. The compressive strength of this cement is 16 N/mm^2 after 3 days and 22 N/mm^2 after 7 days for cubes made of cement: sand (1: 3). This cement can be effectively used for construction under sea waters.
6. *High alumina cement*: This cement conforms to IS 6452 and is manufactured by burning a mixture of limestone and bauxite. Due to high content of alumina, it develops early strength quickly. It generates very large quantity of heat upon hydration and most of the heat is evolved during initial 8-10 hours. It is normally used for concrete construction in cold regions. It can resists the attack of chemicals particularly sulphates and chlorides present in the polluted and marine environments. Its initial setting time should be at least 30 minutes and final setting time should not be more than 600 minutes. Its compressive strength should be 30 N/mm^2 after 1 day and 35 N/mm^2 after 3 days for cube specimens made of cement: sand (1: 3).
7. *Super sulphated cement*: This cement conforms to IS 12330 and is resistant to sulphate attack and evolves lesser heat of hydration than ordinary Portland cement. This cement is used for concrete construction under the sea water or bridge structures and in chemical environment or concreting in sulphate bearing soils. The initial setting time of the cement should be at least 30 minutes and final setting time should not be more than 600 minutes. Its compressive strength should be 15 N/mm^2 after 3 days and 22 N/mm^2 after 7 days for cube specimens made of cement: sand (1: 3).
8. *Hydrophobic cement*: The hydrophobic compounds are blended with ordinary Portland cement while grinding the clinker. These compounds give water-retarding capacity to the cement due to the formation of a layer around the cement particles. While mixing, the layer of water retarding compound is broken. The strength of the cement is equal to that of ordinary Portland cement. This cement conforms to IS 8043 and it can be stored for a longer time.
9. *Quick setting cement*: In this cement, very small quanitiy of gypsum is added to accelerate its setting. It sets very quickly and its initial setting time is 5 minutes and final setting time is 30 minutes. It is used in under-water construction. It sets quickly due to the presence of alumina and it is ground very fine.
10. *White cement*: The white cement is manufactured by using pure lime and clay and is free of colouring compounds such as iron oxide, magnesia, etc. It is white in colour and possesses the same setting time and strength as those of ordinary Portland cement. It is costly due to use of selective materials. It is used for ornamental works and decorative purposes.

11. *Coloured cement*: A small quantity (usually 4-8%) of inert colouring pigment is blended with ordinary Portland cement to obtain the desired coloured cement. Commonly used colouring pigments are iron oxide, magnesia, chromium oxide, etc. Its properties are similar to those of ordinary Portland cement.
12. *Air entraining Portland cement*: In this cement, small amount of air entraining compounds such as oils, fats, resinous compounds and fatty acids are blended with ordinary Portland cement during the grinding operation. These compounds help in entraining very small air bubbles in concrete which improve its workability and thermal resistance. However, care should be taken to ensure that amount of entrapped air is less than 4% otherwise strength of concrete is reduced.
13. *High strength Portland cement*: For obtaining high strength concrete (such as prestressed concrete), the cement having higher strength is used. Its compressive strength is 23 N/mm^2 after 3 days and 33 N/mm^2 after 7 days for cube specimens made of cement: sand (1: 3). The initial setting time of cement is 30 minutes and final setting time is 600 minutes.

1.2.2 Aggregate

The aggregates used in concrete should be preferably natural aggregates and should be as per the requirements given in IS 383: 1970. The various sizes of coarse aggregates may be combined in suitable proportions to yield overall gradation conforming to Table 1.1 (Table 2 of IS: 383-1970) for a particular nominal maximum size of aggregate.

Table 1.1 Coarse aggregates.

IS sieve designation	Percentage passing for single-sized aggregate of nominal size (mm)						Percentage passing for graded aggregate of nominal size (mm)			
	63	**40**	**20**	**16**	**12.5**	**10**	**40**	**20**	**16**	**12.5**
80 mm	100						100			
63 mm	85-100	100								
40 mm	0-30	85-100	100				95-100	100		
20 mm	0-5	0-20	85-100	100			30-70	95-100	100	100
16 mm				85-100	100				90-100	
12.5 mm					85-100	100				90-100
10 mm	0-5	0-5	0-20	0-30	0-45	85-100	10-35	25-55	30-70	40-85
4.75 mm			0-5	0-5	0-10	0-20	0-5	0-10	0-10	0-10
2.36 mm						0-5				

The aggregates produced from blast furnace slag or crushed tiles or bricks and possessing adequate strength and durability can be used in plain concrete members. However the water absorption of these aggregates should be less than 10% and these should be free from any harmful ingredients particularly the sulphate (SO_3) content should be less than 0.5%. The light or heavy weight aggregates can be used after referring to literature studies and assessing their suitability in the construction project.

Size of Aggregate

The nominal maximum size of coarse aggregate should not be larger than one-fourth of the minimum thickness of the member so that concrete can be easily placed around all the reinforcements and fills the corners of the formwork without any difficulty. Usually, 20 mm nominal size aggregate is used but larger size coarse aggregate may be used when flow of concrete in the sections is not restricted. If the members consist of thin sections or have reinforcement closely spaced, the nominal size of coarse aggregate may be reduced to 10 mm.

In case of heavily reinforced concrete members such as ribs, the nominal maximum size of coarse aggregate should be 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to reinforcement whichever is lesser. The batching of coarse and fine aggregates is done separately and generally volume or weight batching may be used depending upon the nature of the work.

The fine aggregate should conform to grading zones as given in Table 1.2 (conforming to Table 4 of IS: 383-1970).

Table 1.2 Fine aggregates.

IS sieve designation	Percentage passing for			
	Grading zone I	**Grading zone II**	**Grading zone III**	**Grading zone IV**
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

1.2.3 Water

Water is used in the mixing of concrete and its curing afterwards and hence it should be clean and should not contain any harmful matter such as acids, alkalis, salts, sugar, oils, iron compounds and organic materials which are deleterious to concrete or reinforcement. The water fit for drinking is considered to be satisfactory for use in concrete and its pH value should not be less than 6.

Indian standard IS 3025 (Part 22) specifies that 100 milliliter of water should not require more than 5 ml of 0.02 normal Na OH for neutralizing when phenolphthalein is used as indicator. IS 3025 (Part 23) specifies that 100 ml sample of water should not require more than 25 ml of 0.02 normal H_2SO_4 for neutralizing using mixed indicator. The average 28 days compressive strength of at least three 150 mm concrete cubes prepared with water to be used in concrete should not be less than 90 percent of the average of strength of three similar concrete cubes prepared with distilled water using the procedure laid down IS: 516-1970. The use of sea (saline) water for curing of concrete should be avoided due to the presence of harmful salts. Generally, the water used in mixing of concrete should be used for curing purposes.

1.2.4 Admixtures

Admixtures are the materials (other than cement, fine aggregate, coarse aggregate and water) which are added to concrete to improve its properties in fresh as well as hardened state. Admixtures generally influence the properties of concrete such as consistency, setting time, workability, coherence, air content, etc. They help in controlling bleeding and segregation of concrete due to uniform dispersion of cement paste in between the aggregate. The admixtures are of two types:

1. *Chemical Admixtures*: Chemical admixtures mainly consist of the following (IS: 9103-1999):
   (a) water reducing admixtures such as poly carboxylic acid, sodium lignosulphonic acid, etc.
   (b) super plasticizers include following compounds: (i) sulphonated melamine formaldehyde condensate; (ii) sulphonated napthalene formaldehyde condensate; and (iii) polycarboxylate.
   (c) accelerators include nitrate, nitrite, thiocyanate and chloride salts;
   (d) retarders include carbohydrates, lignosulphonates, soluble borates and zinc;
   (e) air-entraining agents include synthetic surfactants like polyethylene oxides, vinsol resins or fatty acid salts which vary the surface tension of water.
2. Mineral Admixtures: Mineral admixtures consist of generally fine materials which are admixed in substantial quantities in concrete as partial replacement of cement. Mineral admixtures consist of the following materials:
   (a) Cementitious admixtures: Cementitious admixtures are those which contain sufficient quantity of oxide, silicate or aluminosilicate of calcium and hydrate like cement such as ground granulated blast furnace slag (IS 12089).
   (b) Pozzolanic and partially cementitious/pozzolanic materials such as class C fly ash, and
   (c) Pozzolanic admixtures such as class F fly ash, silica fume, rice husk ash and metakaolin.

   Admixtures are used to modify the following properties of fresh concrete:
   1. The admixtures are used to increase the workability of fresh concrete without increasing the water-cement ratio.
   2. They inhibit the segregation of aggregate.
   3. They control the bleeding of concrete.
   4. Admixtures control the initial setting time.
   5. The admixtures increase the pumpability of concrete.
   6. They reduce the shrinkage of concrete.

   The admixtures modify the following properties of hardened concrete:
   1. The admixtures decrease the rate of evolution of heat from concrete hardening.
   2. The rate of development of strength during early age is enhanced.
   3. The admixtures improve the durability of concrete.

4. The permeability of concrete is reduced due to use of admixtures.
5. The strength of concrete is improved due to use of admixtures.
6. Better bond between reinforcement and concrete can be ensured.
7. The abrasion and impact resistance of concrete is increased.
8. The expansion due to alkali-aggregate reaction in concrete can be controlled.
9. The corrosion of steel reinforcement in concrete is inhibited.
10. When used with old concrete, better bond can be ensured between existing and new concrete.

1.3 Concrete Mix

1.3.1 Grades of Concrete

The different grades of concrete are given in Table 1.3 having specified characteristic compressive of 150 mm cube at 28 days. The characteristic strength may be defined as the strength of material below which not more than 5 percent of the compressive strength test results on 150 mm cube at 28 days are expected to fall. In the symbol M20, M refers to mix and the number 20 indicates the specified compressive strength of 150 mm size cube at 28 days expressed in N/mm^2. For high strength concrete having compressive strength more than 55 N/mm^2, the literature and experimental results may be referred.

Table 1.3 Grades of concrete.

Group	Grade Designation	Specified characteristic compressive of 150 mm cube at 28 days in N/mm^2
Ordinary concrete	M10	10
	M15	15
	M20	20
Standard concrete	M25	25
	M30	30
	M35	35
	M40	40
	M45	45
	M50	50
	M55	55
High strength concrete	M60	60
	M65	65
	M70	70
	M75	75
	M80	80

1.3.2 Concrete Mix Design

The Indian standard gives the guidelines for the proportioning of concrete mixes for general requirements of concrete construction using concrete production materials and other supplementary additives and admixtures. The mix proportions are designed to achieve specified characteristic compressive strength at certain age, workability of fresh concrete and durability. The following characteristics are to be considered for the mix design:

(i) grade of concrete
(ii) type of cement
(iii) Nominal maximum size of aggregate
(iv) minimum cement content
(v) maximum water-cement ratio
(vi) workability of fresh concrete
(vii) exposure conditions
(viii) maximum temperature of concrete at pouring
(ix) method of transportation and placing
(x) early age strength requirements
(xi) type of aggregate
(xii) maximum cement content
(xiii) type of admixture used.

Using the data provided, material characteristics and procedure laid down in IS: 10262 - 2009; usually three trial mixes are designed and the test cubes are casted in the laboratory for each of the mixes. The compressive strength of concrete cubes is ascertained after testing at 28 days and the mix giving the maximum compressive strength is taken as the design mix of concrete to be used at the site for construction work.

1. Since the strength of the trial cubes may be less than the characteristic compressive strength of concrete; the concrete mix is proportioned for higher target mean compressive strength f_{1ck} using the standard deviation provided for different grades of concrete under different exposure conditions using the relationship:

   $$f_{1ck} = f_{ck} + 1.65\ s$$

   Where

   f_{1ck} = target mean compressive strength at 28 days in N/mm^2,

   f_{ck} = characteristic compressive strength at 28 days (N/mm^2) and

   s = standard deviation (N/mm^2).

   The standard deviation for each grade of concrete can be calculated based on the test results of samples, significant changes in concrete materials, mix proportions, handling equipment and technical control and subsequent changes in mix proportions. Alternatively, if sufficient test results for a particular grade of concrete are not available, the standard deviation may be assumed as per Table 1.4 (Table 1 in IS: 10262 – 2009).

Table 1.4 Assumed value of standard deviation.

S.No.	Grade of concrete	Assumed standard deviation	S.No.	Grade of concrete	Assumed standard deviation
1	M 10	3.5	6	M 35	5.0
2	M 15	3.5	7	M 40	5.0
3	M 20	4.0	8	M 45	5.0
4	M 25	4.0	9	M 50	5.0
5	M 30	5.0	10	M 55	5.0
Note: The above values correspond to the site control having proper storage of cement; weigh batching of all materials; controlled addition of water, regular checking of all materials, aggregate grading and moisture content; and periodical checking of workability and strength. Where there is deviation from the above, values given in the above table shall be increased by 1 N/mm^2.					

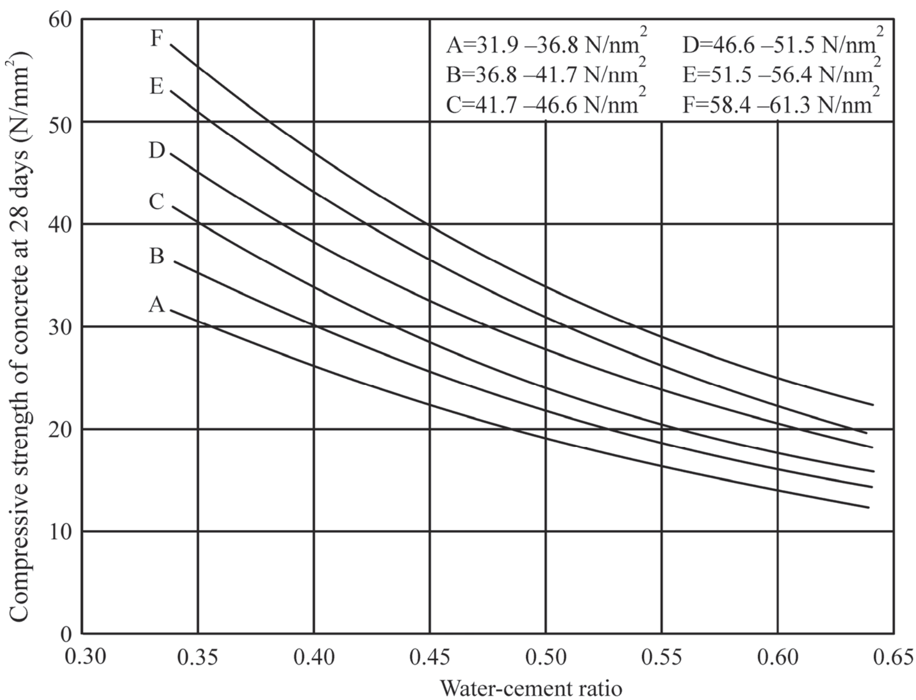

Fig. 1.1 Free water-cement ratio versus 28-days compressive strength of concrete.

2. The relationship between compressive strength and free water cement ratio should be established for the type of cement, cementitious materials and the aggregate used in concrete production. If such data is not available, preliminary free water-cement ratio (by mass) for target compressive strength at 28 days may be selected from the available relationships (Fig. 1.1) or else may be chosen from Table 1.5 (Table 5 of IS: 456) for the specified exposure conditions. The free water-cement ratio selected above may be checked against the limiting water-cement ratio for the requirements of durability and lesser of the two values should be considered in design.

3. Large number of factors including shape, size and texture of aggregate; type and content of cement and cementitious materials, chemical admixtures, water-cement ratio, workability and the environmental conditions affect the water content of the concrete mix. The requirement of water in concrete is reduced with increase in size of aggregate, use of rounded aggregate, decrease in water-cement ratio and slump and the use of water repelling admixtures. The water demand in concrete increases with increase in cement content, slump, water-cement ratio, aggregate angularity, decrease in proportion of coarse aggregate to fine aggregate and increase in temperature. The maximum quantity of water required per unit volume of concrete may be determined from Table 1.6 (Table 2 in IS: 10262) for angular aggregate and slump varying from 25 mm to 50 mm. The quantity of water so determined may be decreased by 10 kg for sub-angular aggregate, 20 kg for gravel with some crushed particles and 25 kg for rounded gravel to produce the same workability. For workability other than 25-50 mm range, the quantity of water may be determined either by trial or can be increased by about 3% for every additional 25 mm slump or alternatively by using chemical admixtures as per IS 9103. The water content is reduced by 5% to 10% and 20% or more (IS: 9103) on use of superplasticizer in concrete. If local aggregates are used in concrete, trial testing of the concrete specimens is required for determining the water content.

Table 1.5 Minimum cement content, maximum water-cement ratio and minimum grade of concrete for different exposures with normal weight aggregate of 20 mm nominal maximum size.

S. No.	Exposure	Plain concrete			Reinforced concrete		
		Minimum cement content kg/m^3	Maximum free water – cement ratio	Minimum grade of concrete	Minimum cement content kg/m^3	Maximum free water – cement ratio	Minimum grade of concrete
(i)	Mild	220	0.60	-	300	0.55	M 20
(ii)	Moderate	240	0.60	M 15	300	0.50	M 25
(iii)	Severe	250	0.50	M 20	320	0.45	M 30
(iv)	Very severe	260	0.45	M 20	340	0.45	M 35
(v)	Extreme	280	0.40	M 25	360	0.40	M 40

Note: 1. Cement content prescribed in this table is irrespective of the grades of cement and it is inclusive of additions. The additives such as fly ash or around granulated blast furnace slag may be taken into account in concrete composition with respect to cement content and water-cement ratio if suitability established and as long as maximum amounts taken into account do not exceed limit of pozzolona and slag specified in IS: 1489 (Part I) and IS: 455 respectively.
2. Minimum grade for plain concrete under mild exposure condition is not specified.

Table 1.6 Maximum water content/m^3 of concrete for nominal maximum size of aggregate.

S.No.	Nominal maximum size of aggregate (mm)	Maximum water content (kg)
(i)	10	208
(ii)	20	186
(iii)	40	165

Note: These quantities of mixing water are for use in computing cementitious material contents for trial batches.

4. The quantities of cement and supplementary cementitious materials required per unit volume of concrete can be calculated from the free water-cement ratio and the quantity of water per unit volume of concrete. These quantities of cementitious materials should be checked against the minimum content required from durability considerations and the greater of the two values is adopted in design. The minimum cement content may be adjusted, if required, for maximum size of aggregate other than 20 mm as per Table 1.7 (Table 6 of IS: 456). The maximum cement content shall be as per IS: 456.

Table 1.7 Adjustment to minimum cement contents for aggregates other than 20 mm nominal maximum size.

S. No.	Nominal maximum aggregate size (mm)	Adjustments to minimum cement contents (given in Table 5 of IS 456), kg/m^3
(i)	10	+ 40
(ii)	20	0
(iii)	40	- 30

5. The aggregates of same nominal maximum size, type and grading will produce concrete of requisite workability provided a given volume of coarse aggregate per unit volume of total aggregate is used. The approximate values of aggregate volume are given in Table 1.8 (Table 3 of IS: 10262) for a water cement ratio of 0.5 which are suitably adjusted for other water-cement ratios. The volume of coarse aggregate per unit volume of concrete possessing same workability is dependent on its nominal maximum size and grading zone of fine aggregate. When concrete is to be placed in heavily reinforced sections or by pumping, the coarse aggregate content determined above may be decreased up to 10% ensuring that slump, water-cement ratio and strength of concrete are as per IS: 456.

Table 1.8 Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate.

S.No.	Nominal maximum size of aggregate (mm)	Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate			
		Zone IV	Zone III	Zone II	Zone I
(i)	10	0.50	0.48	0.46	0.44
(ii)	20	0.66	0.64	0.62	0.60
(iii)	40	0.75	0.73	0.71	0.69
The volumes are based on aggregate in saturated surface dry condition.					

6. Coarse aggregate used shall conform to IS 383 and different sizes of coarse aggregates may be combined in suitable proportions to yield overall gradation conforming to Table 1.1 (Table 2 of IS: 383) for a particular nominal maximum size of aggregate.
7. Total quantity of coarse and fine aggregate can be estimated by determining the absolute volume of the cementitious material, water and chemical admixtures by dividing their mass by their respective specific gravity values, multiplying by 1/1000 and deducting the result of their summation from unit total volume of concrete. The values determined such may be

divided in to coarse aggregate and fine aggregate fractions by volume as per the coarse aggregate proportion determined above. The contents of coarse and aggregate are determined by multiplying with their respective specific gravity values and further multiplying with 1000. The fine aggregate should conform to grading zones as given in Table 1.2 (conforming to Table 4 of IS: 383).

8. Above determined mix proportions are checked by performing trial tests. The quantity of water and/or admixture is adjusted suitably if the measured workability of trial mix 1 is different from that taken in mix design. The mix proportions are recalculated after this adjustment keeping free water-cement ratio at already selected value which shall be designated as trial mix 2. Trial mixes 3 and 4 shall be prepared with the same water content as for trial mix 2 and varying the free water-cement ratio by ± 10% or suitably based upon experience. The concrete for field trials shall be prepared by actual method of production of concrete.
9. Prepare three 150 mm cubes and test them wet after 28 days of curing and check for the required compressive strength.
10. The mix design for obtaining the trial mixes can be performed as illustrated in the example below.

Example 1.1: Mix Design

1. *Design mix data:*

Grade of concrete	:	M 30
Type of cement	:	OPC 43 grade conforming to IS: 8112
Maximum nominal size of aggregate	:	20 mm
Minimum cement content	:	320 kg/m^3
Maximum water-cement ratio	:	0.45
Workability	:	100 mm (slump)
Exposure condition	:	severe (for reinforced concrete)
Method of placing of concrete	:	pumping
Degree of supervision	:	good
Type of aggregate	:	crushed angular
Maximum cement content	:	450 kg/m^3
Chemical admixture type	:	superplasticizer conforming to IS: 9103

2. *Material test data:*

Cement used	:	OPC 43 grade conforming to IS: 8112
Specific gravity of cement	:	3.15
Chemical admixture	:	superplasticizer conforming to IS: 9103
Specific gravity of coarse aggregate	:	2.68
Specific gravity of fine aggregate	:	2.64
Water absorption of coarse aggregate	:	0.5%

Water absorption of fine aggregate : 1.5%

Free surface moisture of coarse aggregate : nil

Free surface moisture of fine aggregate : nil

The particle size gradation of coarse aggregate is given in table 1.9.

Table 1.9 Particle size gradation of coarse aggregate.

IS sieve size	Cumulative percentage of aggregate passing		Percentage of different fractions			Remarks
	20 mm	10 mm	20 mm (60%)	10 mm (40%)	Combined (100%)	
20 mm	100	100.00	60	40	100	Conforming to Table 2 of IS: 383
10 mm	0	72.10	0	28.84	28.84	
4.75 mm		8.60		3.44	3.44	
2.36 mm		0		0	0	

Fine aggregate : conforming to grading zone I of table 4 of IS: 383.

3. *Target strength for mix proportion:*

$$f_{1ck} = f_{ck} + 1.65\ s$$

Where

f_{1ck} = target mean compressive strength at 28 days in N/mm^2,

f_{ck} = characteristic compressive strength at 28 days in N/mm^2, and

s = standard deviation, N/mm^2.

From Table 1 (IS: 10262 -2009),

Standard deviation, s = 5 N/mm^2.

Target mean strength = 30 + 1.65 × 5 = 38.25 N/mm^2.

4. *Selection of water-cement ratio:*

From Table 5 (IS: 456), maximum water-cement ratio = 0.45

However, adopt water-cement ratio = 0.40 < 0.45, hence O.K.

5. *Selection of water content:*

From Table 2 (IS: 10262) maximum water content = 186 litre (25 mm to 50 mm slump) for 20 mm aggregate.

Estimated water content for 100 slump = 186 + (6/100) × 186 = 197.2 litres

Since super plasticizer is used, therefore water content can be reduced by at least 20%.

However, based upon trials reduce the water content by 25%.

Hence, water content = 197.2 x 0.75 = 147.9 ≈ 148 litres.

6. *Selection of water content:*

Water-cement ratio = 0.40

Cement content = 148/0.4 = 370 kg/m^3 > 320 kg/m^3, the minimum content for severe conditions as per Table 5 of IS: 456; hence O.K.

7. *Proportioning of volume of coarse aggregate and fine aggregate:*

   From Table 3, volume of coarse aggregate for 20 mm size aggregate and fine aggregate conforming to Zone I for water-cement ratio of 0.50 is 0.60.

   Since the adopted water-cement ratio is 0.40, hence, the volume of coarse aggregate is to be increased by 0.02 (at the rate of 0.01 for every ± 0.05 decrease or increase in water-cement ratio). Hence, corrected proportion of coarse aggregate for water-cement ratio of 0.40 is 0.62.

   For pumpable concrete, this value should be decreased by 10%.

   Therefore, volume of coarse aggregate = 0.62 x 0.9 = 0.56.

   Volume of fine aggregate = 1 – 0.56 = 0.44.

8. *Mix design calculations:*

   The mix per unit volume of concrete shall be as under:

   (i) Volume of concrete = 1 m^3.

   (ii) Volume of cement = (Mass of cement/specific gravity of cement)/1000
   = (370/3.15)/1000 = 0.1175 m^3.

   (iii) Volume of water = (Mass of water/specific gravity of water)/1000
   = (148/1)/1000 = 0.148 m^3.

   (iv) Volume of chemical admixture (super plasticizer @ 2.0 % by mass of cementitious material)
   = (Mass of admixture/specific gravity of admixture)/1000
   = (7.4/1.145)/1000 = 0.0065 m^3.

   (v) Volume of all-in aggregate = (i) – [(ii) + (iii) + (iv)]
   = 1 – [0.1175 + 0.1480 + 0.0065] = 0.7280 m^3.

   (vi) Mass of coarse aggregate = (v) × volume of coarse aggregate × specific gravity of coarse aggregate × 1000
   = 0.7280 × 0.56 × 2.68 × 1000 = 1093 kg.

   (vii) Mass of fine aggregate = (v) × volume of fine aggregate × specific gravity of fine aggregate × 1000
   = 0.7280 × 0.44 × 2.64 × 1000
   = 846 kg.

9. *Mix proportions:*

   The mix proportions are as under:

   Cement = 370 kg/m^3.

   Water = 148 kg/m^3.

   Fine aggregate = 846 kg/m^3.

   Coarse aggregate = 1093 kg/m^3.

   Super plasticizer = 7.4 kg/m^3.

   Water-cement ratio = 0.40

The trial mix proportions of concrete are given in Table 1.10.

Table 1.10 Trial mix proportions of concrete.

Water-cement ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Super plasticizer (kg/m^3)	28-day compressive strength (N/mm^2)
0.38	141	365	856	1106	7.3	37.90
0.40	148	370	846	1093	7.4	39.20
0.42	155	375	836	1080	7.5	36.40

After field trials, concrete mix proportions given in table 1.11 may be adopted in construction.

Table 1.11 Final mix proportions of concrete.

Water-cement ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Super plasticizer (kg/m^3)
0.40	148	370	846	1093	7.4
-	0.40	1	2.42	2.95	0.02

The mix design must take in to account factors affecting workability and strength of concrete. Large number of factors such as quality and quantity of cement and other cementitious materials; type, shape, size and gradation of coarse aggregate; grading zone of fine aggregate; quality of water; addition of admixtures; water-cement ratio; methods of mixing, handling, transportation, placement and curing of concrete; exposure conditions, etc. affect the properties of fresh and hardened concrete. While designing a concrete mix, it is imperative to duly consider all the parameters by suitably applying corrections/adjustments to stipulated quantities of various materials as per IS: 10262, IS: 456, IS: 9103 and IS: 383. Further, since the actual material characteristics may vary from those considered in design mix, it is essential to test trial mixes by actually performing trials in laboratory before adoption of the final mix in the field.

1.4 Tests on Fresh Concrete

The following tests are performed on fresh concrete to adjudge its suitability:

1. **Consistency of freshly mixed concrete by slump test**

   Workability is the ease with which the given materials (cement, sand, coarse aggregate, water) can be mixed into concrete and subsequently handled, transported and placed with minimum loss of homogeneity. It depends upon many factors such as amount, fineness and chemical composition of cement; grading and shape of fine aggregate; grading, shape and surface texture of coarse aggregate; quantity of water; presence of admixtures and the water cement ratio.

   The slump test can be used in field or in the laboratory to determine the consistency of concrete (an element of workability) where the nominal maximum size of aggregate does not exceed 38 mm. This test gives an idea of water-cement ratio required for concrete and also about the variation in the uniformity of a mix of given nominal proportions. In this test, fresh concrete is filled in a mould of specified dimensions, and the slump of concrete on mould is measured (Fig. 1.2).

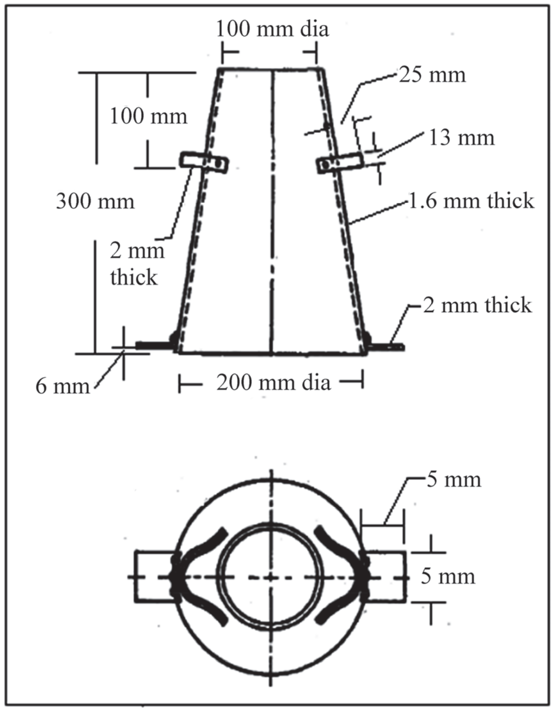

Fig.1.2 Slump test apparatus.

Segregation or bleeding should not occur in a workable concrete. Segregation occurs if coarse aggregate separates out from the finer material and a concentration of coarse particles is obtained at one place. This increases the voids in concrete leading to loss of strength and durability. Bleeding occurs when excess water comes up at the surface of concrete leading to small pores in the concrete mass. The following procedure can be used to determine the consistency of freshly mixed concrete by slump test:

1. Clean & remove the moisture from the internal surface of the mould thoroughly and place it on a smooth, horizontal, non-absorbent surface free from vibrations.
2. Prepare four mixes of concrete taking 10 kg of coarse aggregate, 5 kg of fine aggregate and 2.5 kg of cement with water-cement ratios 0.5, 0.6, 0.7 and 0.8. Mix the contents dry to give a uniform colour and then add water and mix thoroughly.
3. Pour the concrete in the slump cone in 4 layers each having a height nearly ¼th of the height of the mould tamping each layers 25 times with tamping rod, distributing the strokes uniformly over the cross section of the mould. The tamping rod should penetrate into the underlying layer for second and subsequent layers.

4. Strike-off the concrete level with a trowel or tamping rod and clean away the mortar which might have leaked between the mould and base plate.
5. Remove the mould immediately, raising it slowly and carefully in exactly vertical direction.
6. Measure the settlement (slump) of the concrete immediately after the subsidence stops, by determining the difference between the height of the mould and that of the highest point of the sample.

The slump values given in Table 1.12 may be considered for various construction works.

Table 1.12 Slump values for different concrete construction works.

Name of work	Slump (mm)
Mass concreting and road pavement work	25-50
Beams and slabs	75
Thin sections, columns and retaining walls	75-125

2. Workability of freshly mixed concrete by compaction factor test

Compaction factor is the ratio of the weight of partially compacted concrete to fully compacted concrete. Compaction factor test consist of applying a standard amount of work to a standard quantity of concrete and measuring the resulting compaction. It can be used for determining the workability of concrete where the nominal maximum size of the aggregate does not exceed 38mm. It utilizes the definition of workability according to which workability is the property of concrete which determines the quantity of work required to produce full compaction. As compared to slump test, this test gives more precise results and is particularly suited for concretes of low workability which are generally used when compaction is done by vibration. The following procedure can be used to determine the workability of freshly mixed concrete by using compaction factor test apparatus (Fig. 1.3):

Fig. 1.3 Compaction factor test apparatus.

1. Place the apparatus on level surface and thoroughly clean and oil the inner surfaces of hoppers and the cylinder. Clamp the hopper doors.
2. Record the weight W_1 of the empty cylinder accurately, fix it at the base of the apparatus and cover it with a plate to avoid falling of any concrete into it from the sides.
3. Prepare four concrete mixes in the ratio of 1: 2: 4 with water-cement ratios varying from 0.5 to 0.8. Mix the contents dry till a mixture of uniform colour is obtained, then add water and mix thoroughly.

4. Place the fresh concrete gently and carefully in the upper hopper taking care that no compaction occurs during this process. Fill the hopper level with top surface.
5. Release the trap door of upper hopper so that the concrete fall into the lower hopper. If any concrete is sticking to the side push it down gently with a rod.
6. As soon as the concrete comes to rest, uncover the cylinder and release the trap door of the lower hopper allowing the concrete to fall into the cylinder.
7. Cut-off the excess of concrete remaining above the level of the top of the cylinder by holding a trowel in each hand, with plane of the blades horizontal, and moving them simultaneously one from each side across the top of the cylinder, at the same time keeping them pressed on the top edge of the cylinder.
8. Wipe the outside of the cylinder clean and record its weight (W_2) along with partially compacted concrete.
9. Refill the cylinder with the same concrete in 50mm layers, preferably vibrating or heavily ramming each layer so as to obtain full compaction.
10. Strike off the concrete level with the top surface of the cylinder. Wipe the outside of the cylinder clean and record its weight (W_3) along with fully compacted concrete.

    Compaction factor = $(W_2-W_1)/(W_3-W_1)$

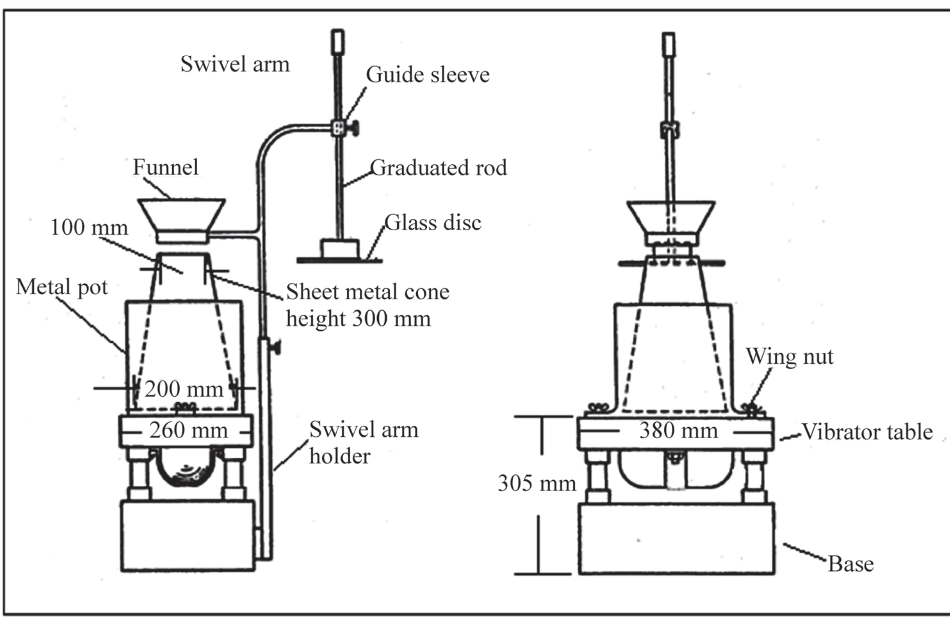

Fig. 1.4 Vee-Bee consistometer.

3. Workability of fresh concrete by Vee-Bee consistometer

This test describes the method of determination of consistency of concrete using a Vee-Bee consistometer (Fig. 1.4). In this test, the time required for the transforming by vibration a concrete specimen having the shape of a conical frustum into a cylinder is determined. The following procedure can be used to determine the workability of fresh concrete by Vee-Bee consistometer:

1. Clean the slump cone and the cylindrical container properly. Keep the sheet metal slump cone in the cylinder of the Vee-Bee consistometer. Place the concrete in the cone in four equal layers tamping each layer with twenty five strokes of the tamping rod, distributing the strokes uniformly over the cross section of the cone. The tamping rod should penetrate into the underlying layer for the second and subsequent layers.
2. Strike off the concrete level with the top of the cone using a trowel.
3. Move the glass disc attached to the swivel arm and place it just on the top of slump cone in the cylinder. Adjust the disc just to touch the top of concrete cone and record the initial reading on the graduated rod.
4. Remove the slump cone immediately from the concrete gradually and carefully raising it in exactly vertical direction. Lower the glass disc onto the top of the concrete and record the final reading on the graduated rod. The difference between the final and initial reading gives the slump.
5. Switch on the electrical vibrator, start the stop watch and allow the concrete to spread out in the pot. Continue the vibrations until the whole concrete surface uniformly adheres to the glass disc.
6. Record the time for this process to complete using a stop watch.

This test is very suitable for very stiff concrete mixes having very low workability or for dry mixes which may have tendency to stick to the hoppers of the compaction factor test leading to error in the results. However, it is difficult to establish the time at which the remoulding is complete especially in concrete mixes of higher workability. This test, therefore, cannot be suitably used for concretes of higher workability with a slump of 50mm or more. However, this involves the treatment of concrete which is closer to its placement in the field.

4. Workability of fresh concrete using flow table

This test consists of using the flow table to determine the fluidity of concrete, when the nominal size of aggregate does not exceed 38 mm. It gives an idea about the consistency of concrete and its tendency to segregate. In this test, the concrete is cast in the form of frustum of a cone on the top of flow table and given a number of jolts of magnitude of 12.5 mm and the spread of the concrete is measured. However, this test does not measure workability because the concretes having same fluidity may differ in their workability. The following procedure can be used to determine the workability of fresh concrete using flow table:

1. Wash and clean the table top and inside of the mould of all gritty material removing all excess water with a rubber squeezer or wet cloth.
2. Centre the mould on the table and hold it firmly in place.
3. Fill the mould in two equal layers tamping each layer with 25 strokes of tamping rod distributing the strokes uniformly over the cross sectional area of the mould. The rod should penetrate into the underlying layer for the second layer and the bottom layer should be tamped throughout its depth.

4. Strike off the surface of the concrete level with top of the mould using trowel. Remove the excess concrete which has overflowed the mould and clean the area of the table outside the mould.
5. Immediately remove the mould by gradually lifting up in exactly vertical direction.
6. Raise and drop the table by 12.5 mm, 15 times in about 15 seconds.
7. Measure the diameter of the spread concrete as the average of six symmetrically distributed caliper measurements read to the nearest 5 mm.
8. Record the flow of the concrete as the percentage increase in diameter of the spread concrete over the base diameter of the moulded concrete expressed as :

$$\text{Flow (percent)} = \frac{\text{spread diameter in mm} - 250}{250} \times 100$$

This test is limited to laboratory use only because of the unusual size of the apparatus. It gives more reproducible results than those of the slump test, but it has a limitation that the flow is unpredictable and scattered mass of concrete is obtained at the end of the test.

1.5 Tests on Hardened Concrete

The following tests are performed on hardened concrete to determine its suitability in construction works:

1. ***Compressive strength of concrete*****:** In concrete structures, the concrete resists primarily the compressive stresses and therefore the compressive strength of concrete is one of its most important properties. The strength of concrete in tension or in shear is also expressed, in terms of its compressive strength. Moreover, there exists a definite relationship between the compressive strength and other properties of concrete and hence the compressive strength can be used as a measure to express the overall performance of the concrete. The compressive strength of concrete is affected by the height to lateral dimension ratio of the specimen; larger the ratio, smaller is the strength. The least dimension of the specimen should be at least four times the maximum size of the aggregate; otherwise the compressive strength is affected. The following procedure can be used to determine the compressive strength of concrete:

1. Prepare a concrete mix of 1:2:4, by weight and taking water cement ratio as 0.6. Take 12 kg cement, 24 kg of fine aggregate and 48kg of coarse aggregate. Mix the ingredients in dry state in the mixer till a mixture of uniform color is obtained. Add water and mix again to obtain a homogeneous mass.
2. Fill the concrete in properly cleaned and oiled moulds in 50 mm layers (3 layers for cubes and 6 layers for cylinders) and ramming each layer with 35 blows uniformly distributed over the surface.
3. Level off the concrete flush with the top of moulds using a trowel.
4. After 4 hours cover the moulds with wet gunny bags and mark them.

5. *Curing of specimens*:
   (i) Remove the specimens from the moulds after 24 hours and cure them in water for 27 days.
   (ii) After 24 hours of casting, cap the cylindrical specimens by neat cement paste of 33% water content on the capping apparatus and then after another 24 hours immerse them in water for 26 days.
6. *Testing of specimens:*
   (i) Test the specimens as soon as possible after removing them from the curing tank. Keep the specimens wet by covering with wet gunny bags during the period between their removal from curing tank and testing.
   (ii) Measure the dimensions of the specimens (length of the cylinder including caps) to the nearest 0.2 mm by averaging the particular dimension at least at two perpendicular locations. Also record the weights of the specimens.
   (iii) Centre the specimens in the compression testing machine and apply the load continuously without any shock at a uniform rate of loading of 14 N/mm^2/minute or 300 kN/minute for cubes and 250 kN/minute for cylinders until the specimen fails. Note the maximum load taken by each specimen and also the nature of cracks and type of failure.

Compressive strength is an important characteristic of concrete which provides the most reliable measure of assessing the quality of concrete. The factors which affect strength of concrete are size and shape of specimen, aggregate content and grading in mix, aggregate moisture condition, delay in placement of concrete, temperature of curing and loading rate and method of testing etc. A 100 mm size cube gives 15% higher strength than 150 mm cubes. The strength of concrete determined by testing specimens with height/least lateral dimension ratio taken as 0.5, 1 and 4 is nearly 180, 130 and 90 percent respectively of the strength when this ratio is 2.

For the same water-cement ratio; concrete with more aggregate content gives higher strength. The rate of loading higher than 14 N/mm^2 per minute results in an apparent increase in strength whereas a slower rate may reduce the strength. The dry aggregates used in concrete absorb moisture from the water added to the mixes equal to or slightly less than their full absorption capacity. Similarly the concretes cured at higher temperatures exhibited higher strengths than those cured at low temperatures. The cubes are tested on sides (at right angles to direction of placement) whereas the cylinders are tested in the direction of placement and they require capping also. The cube strengths are higher than the cylinder strengths due to the development of tangential stresses as also due to side ratio. This test is quite simple and gives an indication of other properties of concrete such as elasticity, flexural and tensile strength, durability and impermeability.

2. *Flexural strength of concrete*: The flexural strength of concrete is the maximum tensile stress in concrete at rupture in the flexure test.

The flexural strength of concrete is given by:

$$\sigma_{cb} = \frac{My}{I} \qquad \text{.....(1.1)}$$

Where,

M = Bending moment at failure section in N-mm

y = distance of the extreme fiber from neutral axis in mm, and

I = moment of inertia (mm^4)

The flexure test gives the flexural strength of concrete in tension. In this test two equal concentrated loads are applied at 1/3 points of the concrete beam which produce constant bending moment and zero shear in the middle third of the span giving the flexural strength:

$$\sigma_{cb} = \frac{PL}{bd^2} \qquad \text{.....(1.2)}$$

if fracture occurs within middle third of the span.

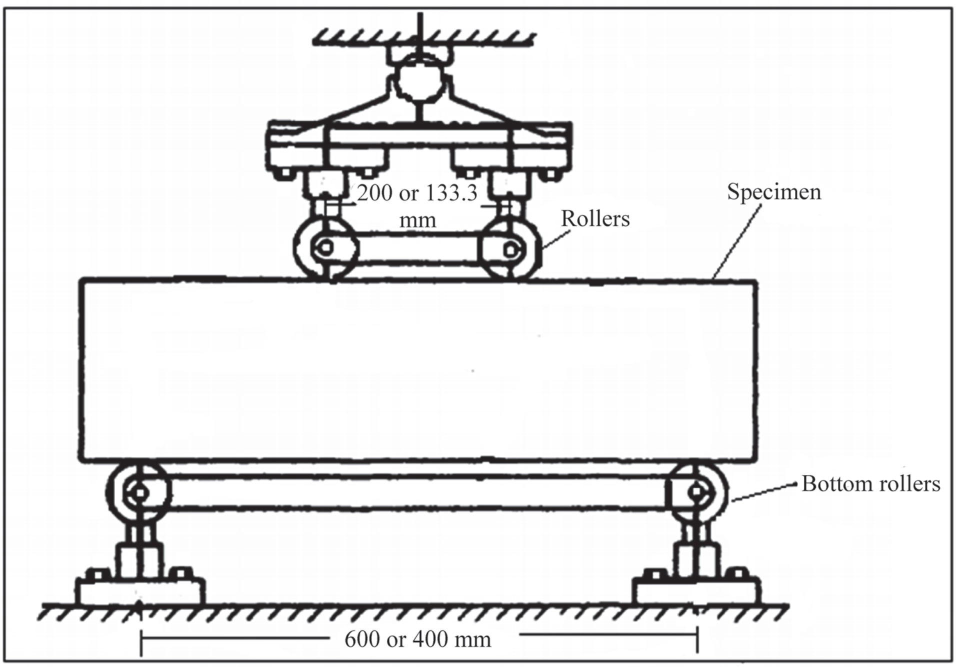

Fig. 1.5 Loading arrangement for flexure test.

Again, if fracture occurs outside the middle third, but within 5 percent of span length, the flexural strength is:

$$\sigma_{cb} = \frac{3Pa}{bd^2} \qquad \text{.....(1.3)}$$

Where,

P = maximum load applied to specimen in N.

b = measured width of specimen in mm.

L = effective span in mm.

d = measure depth of specimen in mm at point of failure.

a = distance between line of fracture and nearer support.

Generally, highway pavements made of concrete are subjected to flexure.

Equation (1) is used if 'a' is greater than 200 mm (133 mm) for 150 mm (100 mm) specimen.

Equation (2) is used if 'a' is less than 200 mm (133 mm) but greater than 170 mm (110 mm) for 150 mm (100 mm) specimen.

The loading arrangement for flexure test is shown in Fig. 1.5.

The following procedure can be used to determine the flexural strength of concrete:

1. Cast three prisms of size 150 mm × 150 mm × 700 mm (100 mm × 100 mm × 500 mm) in proportion of 1:2:4, when the size of aggregate is up to 30 mm (20 mm), taking water cement ratio as 0.6. Take 20 kg (6 kg) of cement, 40 kg (12 kg) of fine aggregate and 80 kg (25 kg) of coarse aggregate for the two types of moulds.
2. Fill the mould in three (two) layers, each layer being rammed with 100 strokes with steel ramming rod or by using vibrator.
3. Take the specimen out of the mould after 24 hours and immerse in water for 27 days. Take out the specimens 28 days after casting, note the dimensions carefully and immediately test when they are wet.
4. Clean the contact surfaces of the specimens and also surfaces of the steel rollers used for loading and supporting the samples. Place the specimen in the machine in such a way that the load is applied to the top surface as cast in the mould; keeping the distance between loading steel rollers as 200 mm (133 mm). The axis of the specimen should be carefully aligned with axis of loading device.
5. Apply the load gradually increasing at a rate of 4 kN/minute (1.8 kN/minute) for 150 mm (100 mm) specimen, without causing any shock. Increase the load until the specimen failure and note the load at failure, the fracture pattern of concrete and the type of failure.

The beams tested under dry conditions give lower values of flexural strengths than those tested under wet conditions. The flexural strength also depends upon the type of loading. The center loading with moment computed at the center gives the maximum flexural strength as compared to the center loading with moment computed at fracture point or the third point loading. The higher rates of loading also yield higher flexural strength. The angular aggregates give higher strength in flexure than the rounded ones. Again smaller the maximum size aggregate, the higher is the flexural strength.

3. ***Split tensile strength of concrete*:** Concrete mainly resists the compressive stresses but simultaneously it is supposed to resist small indirect tensile stresses which may occur due to the development of the cracks in concrete. The cracks may be caused in concrete due to shrinkage or temperature stresses or due to the differential settlement of the structural members. Therefore, the determination of the tensile strength of concrete is required to compute the load at which the concrete may crack.

The direct testing of concrete in tension is difficult due to the problems:

(a) Holding the specimen in the machine without causing stress concentration

(b) Application of non-eccentric uniaxial tensile load.

The apparatus for the splitting cylinder and cube in split tensile strength test of concrete is shown in Fig. 1.6.

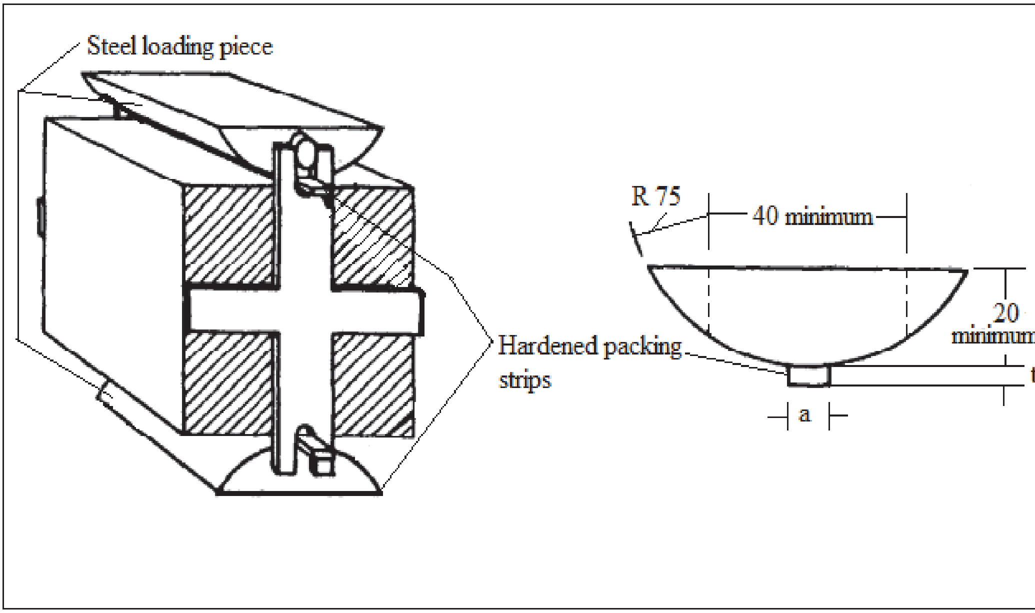

Fig. 1.6 Apparatus for splitting cylinder and cube.

The concrete is tested by the indirect test i.e. the split test. In this test, a concrete cylinder is subjected to compressive force along two opposite ends of a generator. A uniform tensile stress is introduced due to this over a depth of 0.87 D of the cylinder which splits the cylinder into two halves. The splitting tensile strength of concrete is given by:

$$\sigma_{st} = \frac{2P}{\pi dl} \quad \text{.....(1.4)}$$

Where,

P = maximum applied load in N

d = diameter of cylinder in mm

l = length of cylinder in mm

σ_{st} = split tensile strength of concrete in N/mm^2.

The diameter of the concrete specimen shall be at least four times the maximum size of the coarse aggregate and not less than 150 mm. The length of the specimen shall be at least equal to its diameter but not more than twice the diameter. For laboratory tests, the cylindrical specimen should be 150 mm in diameter and 300 mm long for concrete mix containing aggregate of maximum nominal size not greater than 38 mm. The following procedure can be used to determine the split tensile strength of concrete:

1. Clean the moulds carefully, wipe them clean and oil their inner surfaces.
2. Prepare a mix of concrete in the proportion of 1:2:4 taking water-cement ratio as 0.6. For this purpose, take 12 kg of cement, 24 kg of fine aggregate and 48 kg of coarse aggregate. Mix the materials in dry state to a uniform color, add water and then mix thoroughly in a concrete mixer.
3. Fill the mould with concrete in four equal layers of 75 mm each ramming each layer 35 times, the strokes being uniformly distributed over the cross-section. Level off the top surface of the mould with a trowel. Cast six cylinders.
4. Cover the moulds with wet gunny bags after 4 hours. After 24 hours, take the specimens out of the moulds and immerse them in fresh water. Three cylinders each are tested after age of 7 days and 28 days (age being counted from time of adding water to dry ingredients).
5. Test three cylinders each after 7 days and 28 days, immediately after taking out of water as:
   (a) Draw diametrical lines on the two ends of the cylindrical specimen ensuring that they are in the same axial plane.
   (b) Measure the diameter of the specimen lying in the plane of the pre-marked lines near its ends and the middle averaging the values to the nearest 0.2 mm. Also, determine the length of the specimens to the nearest 0.2 mm by averaging the two values measured in the plane containing the pre-marked lines
   (c) Wipe the bearing surfaces of the platens and the strips clean. Centre the plywood strip along the center of lower platen, place the specimen on it and align it in a way such that the lines marked on the specimen ends are vertical and centered over the strip. Place the second strip lengthwise on the cylinder centered on the lines marked at the ends of the cylinder.
6. Apply the load gradually at a rate so as to give a tensile stress of nearly 1.4 N/mm^2 per minute to 2.1 N/mm^2 per minute without any shock. Note the maximum load applied and the type of failure.

The split tensile strength is greater than direct tensile strength but lower than flexural strength of concrete. The tensile strength of concrete varies from 7.5 to 12 percent of its compressive strength and usually a value of 10 percent is adopted. The splitting tensile strength depends upon the grade and age of concrete. This test is simpler and gives more consistent results than the flexure test.

4. ***Modulus of elasticity of concrete*:** Concrete is not a truly an elastic material. The stress-strain curve for concrete being non-linear even at normal working stress level and the strain for first loading cycle is seldom entirely recoverable. However, if creep strains are neglected, the lower portion of instantaneous stress-strain curve is relatively straight after the specimen is subjected to initial loading cycle with a compressive load equal to one half of the compressive strength. The slope of this curve may be taken as the static modulus of elasticity. The modulus of elasticity is a measure of resistance offered by a material to deformation and may be expressed as the ratio of unit stress to unit strain. The modulus of elasticity of concrete is used in the design calculations of concrete structures. The following procedure may be used to determine the modulus of elasticity of concrete:

1. Prepare the concrete mix of proportion 1:2:4 and taking water-cement ratio 0.6. Take 11 kg cement, 22 kg of fine aggregate and 44 kg of coarse aggregate.
2. Prepare the concrete mix and cast three 150 mm cubes and three 150 mm x 300 mm cylinders. Cap the cylinders by neat cement paste of 33% water content on capping apparatus after 24 hours. The curing of the specimens is done as described earlier in determination of compressive strength.
3. After 28 days of curing test the three cubes in wet condition for compressive strength and record the average compressive strength.
4. Immediately on removing the cylinder or prism from water, while the specimen is still in water, while the specimen is still in wet condition, attach the extensometers at the ends or on opposite sides of the specimen and parallel to its axis in such a way that the gauge points are symmetrical about the centre of the specimen and in no case are nearer to either end of the specimen than a distance equal to the half the diameter or half the width of the specimen. Place the specimen immediately in the testing machine and centre it accurately. Apply the load continuously and without shock at a rate of 14 N/mm^2/minute until an average stress of (c + 0.5) N/mm^2 is reached, where c is one-third of the average compressive strength of the cubes calculated to the nearest 0.5 N/mm^2. Maintain the load at this stress for at least one minute and then reduce gradually to an average stress of 0.15 N/mm^2. When extensometer readings are recorded. Apply the load for the second time at the same rate until an average stress of (c + 0.15) N/mm^2 is reached. Maintain the load at this value while extensometer readings are recorded. Again, reduce the load gradually and note the readings at 0.15 N/mm^2. Apply the load a third time and note the extensometer readings at ten approximately equal increments of stress up to an average stress of (c + 0.15) N/mm^2. If the overall strains observed on the second and third readings differ by more than 5%, repeat the loading cycle until the difference in strain between consecutive readings at (c + 0.15) N/mm^2 does not exceed 5%.

The strains at various loads in the last two cycles are calculated separately for each extensometer and the results plotted graphically against the stress. Straight lines are drawn through the points for each extensometer, the slopes of these lines are determined and average value is found. If the difference between individual values is less than 15 percent of the average value, this average value expressed in N/mm^2 to the nearest 100 N/mm^2 is recorded as the modulus of elasticity of concrete. If the difference is greater than 15 percent, the specimen is re-centered in the testing machine and the test is repeated. If the difference after re-centering and testing is still greater than 15 percent of the average value, the results of the test are discarded.

The modulus of elasticity of concrete depends upon its constituent materials, moisture and temperature conditions. It increases with decrease in water cement ratio and increases in age of specimen. The modulus of elasticity of concrete ranges from 0.14×10^5 N/mm^2 for low quality concrete at early ages to 0.4×10^5 N/mm^2 for high quality concrete at higher ages.

1.6 Properties of Hardened Concrete

1.6.1 Compressive Strength

Compressive strength is the most important property of concrete and is an indicator of the quality of concrete in general. The compressive strength depends upon the age of concrete and increases with age as the hydration of cement in concrete progresses. The compressive strength of 150 mm concrete cubes at 28 days is considered as a standard for comparing the strength values at different age. The compressive strength of concrete below which not more than 5 percent of the strength test results are expected to fall is known as its characteristic strength.

The concrete is designated on the basis of its compressive strength as say M40, where M stands for 'mix' and 40 stands for the characteristic strength of 150 mm concrete cubes at 28 days. The different grades of concrete are given in Table 1.3.1 for ordinary, standard and high strength concrete. The compressive strength of concrete can be determined in the laboratory as described in section 1.5.

1.6.2 Tensile Strength

Concrete is basically strong in compression and weak in tension; due to this reason it is reinforced with steel, a material having large tensile strength comparatively. The tensile strength of concrete is small and normally varies from about 10-15% of its compressive strength. The split tensile strength of concrete is determined as per the procedure laid down in IS 5816. The flexural strength of concrete is about 1.5 times its tensile strength and can be determined as per the procedure given in IS 516. IS 456 gives the following relation between characteristic compressive strength and flexural strength, from which tensile strength can be estimated:

Flexural strength, $f_{cr} = 0.7\,(f_{ck})^{1/2}$ N/mm^2

Where, f_{ck} is the characteristic cube compressive strength of concrete in N/mm^2. The split tensile strength and flexural strength of concrete can be determined in the laboratory as described in section 1.5.

1.6.3 Modulus of Elasticity

The modulus of elasticity of concrete is mainly influenced by the elastic properties of the aggregate and to a lesser extent by the conditions of curing and age of the concrete, the mix proportions and the type of cement. The modulus of elasticity of concrete can be determined from its compressive strength as per IS 456:

$$E_c = (f_{ck})^{1/2}$$

Where, E_c is the short term static modulus of elasticity in N/mm^2.

The modulus of elasticity of concrete can be determined in the laboratory as described in section 1.5 and measured values may differ by ± 20 percent from the values given by the above expression. The Poisson's ratio of concrete varies from 0.15 to 0.20 and average value of 0.175 may be considered in the design under static loads and 0.24 may be taken under dynamic loads.

1.6.4 Shrinkage

The shrinkage of concrete is dependent upon its constituents, size of structural member and the environmental conditions. Under given conditions of temperature and humidity, the total shrinkage of concrete is mainly affected by the total amount of water present in concrete at the time of mixing and slightly by the cement content. IS 456 lays down that approximate value of total shrinkage strain may be considered as 0.0003 in the design.

1.6.5 Creep of Concrete

The creep of concrete is defined as the time-dependent continuous strain under sustained load. The creep depends upon grade of concrete, environmental conditions, stress in the concrete, age at loading and the duration of loading. The creep is considered to be proportional to stress for the stress values less than one-third of its characteristic compressive strength.

IS 456 specifies that the ultimate creep strain in ordinary concrete structures may be estimated from the values of creep coefficient given in Table 1.13. However, for long span structure, the actual creep strain should be determined. This estimated value of ultimate creep strain does not include the elastic strain.

Ultimate creep strain = creep coefficient × elastic strain at the age of loading.

Table 1.13 Creep coefficient of concrete.

Age of loading	Creep coefficient
7 days	2.2
28 days	1.6
1 year	1.1

1.6.6 Thermal Expansion

The variation in temperature affect causes the dimensional changes in concrete members which depend upon the coefficient of thermal expansion of concrete. The coefficient of thermal expansion depends on nature of cement, aggregate, cement content, relative humidity and size of concrete sections. IS 456 specifies the values of coefficient of thermal expansion for concrete with different aggregates as given in Table 1.14.

Table 1.14 Coefficient of thermal expansion for concrete.

Type of aggregate	Coefficient of thermal expansion for concrete/°C
Quartzite	$(1.2 \text{ to } 1.3) \times 10^{-5}$
Sandstone	$(0.9 \text{ to } 1.2) \times 10^{-5}$
Granite	$(0.7 \text{ to } 0.95) \times 10^{-5}$
Basalt	$(0.8 \text{ to } 0.95) \times 10^{-5}$
Limestone	$(0.6 \text{ to } 0.9) \times 10^{-5}$

1.6.7 Durability of Concrete

The durability of concrete means its satisfactory performance to environmental conditions such as weather, chemical attack, fire and corrosion of reinforcement. The concrete is said to be durable if it performs satisfactorily in the working environment under expected exposure conditions during service life. The quality of the materials used in concrete and the mix proportions should maintain its integrity and protect the reinforcement from corrosion.

The durability of concrete is assessed in terms of its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. The concrete will be impermeable depending upon the quality of its constituents and the workmanship in producing the concrete. A sufficiently low value of permeability can be obtained in normal-weight aggregate concrete by providing adequate cement content, low free water/cement ratio, complete compaction of concrete and adequate curing. The durability of concrete is influenced by the factors such as environment, cover to embedded steel, type and quality of constituent materials, cement content and water/cement ratio of the concrete, workmanship, compaction and efficient curing, and the shape and size of the member.

1.7 Reinforcement

The steel reinforcements used in reinforced concrete should be free from any loose mill scales, loose rust and paints, oil, mud or any other substances which may hamper proper bond between concrete and steel. The rusted of muddy reinforcement should be properly cleaned by sand blasting treatment. The characteristic strength of steel is taken as the minimum yield stress or 0.2 percent proof stress in accordance with the relevant Indian standard. The steel reinforcement used in reinforced concrete structures are generally any one of the following:

1. Mild steel and medium tensile steel bars conforming to IS 432 (Part I)
2. High strength deformed steel bars conforming to IS 1786
3. Hard-drawn steel wire fabric conforming to IS 1566
4. Structural steel conforming to Grade A of IS 2062.
   1. *Mild steel*: Mild steel is commonly known as Fe 250 steel, has yield strength 250 N/mm^2 and percentage elongation 23%. The modulus of elasticity of mild steel is 2×10^5 N/mm^2. Mild steel reinforcement is not commonly used now-a-days because of its less strength compared with that of high yield strength deformed (HYSD) steel bars.
   2. *High yield strength deformed (HYSD) steel bars*: High yield strength deformed (HYSD) steel bars are available in the following grades:
      (a) Fe 415 with characteristic strength 415 N/mm^2 and percentage elongation 14.5%.
      (b) Fe 500 with characteristic strength 500 N/mm^2 and percentage elongation 12%.
      (c) Fe 550 with characteristic strength 550 N/mm^2 and percentage elongation 8%.

High yield strength deformed (HYSD) steel bars are most commonly used in reinforced concrete structures designed by limit state method and constructed presently. High yield strength deformed (HYSD) steel bars are most commonly available in 8, 10, 12, 16, 20, 25, 28, 32 and 40 mm diameter. However, HYSD steel bars are also available in other diameters on special order.

1.8 Loads and Load Combinations

1.8.1 Loads

Various loads to be considered in the design of structure include dead, imposed, wind and earthquake loads and the loads caused by the effects due to shrinkage, creep, temperature, foundation movement, elastic axial shortening, soil and fluid pressure, vibration, fatigue, impact and erection of structure. If dead load counteracts the effects due to other loads and forces in a structural member or joint then case of stress reversal should be carefully considered (using appropriate partial safety factor) in the design for ensuring adequate safety of the structure. The different types of loads acting on a structure can be classified as under:

1. Dead loads are determined by using unit weights of materials as per IS: 875 (Part 1). The unit weights of plain concrete and reinforced concrete are taken as 24 kN/m^3 and 25 kN/m^3 respectively.
2. Imposed loads are considered as per IS 875 (Part 2).
3. Wind loads are considered as per IS 875 (Part 3).
4. Earthquake forces are calculated in accordance with IS 1893.
5. Snow loads are considered in accordance with IS 875 (Part 4).
6. Erection loads are considered in accordance with IS 875 (Part 2).
7. Loads due to shrinkage, creep and temperature effects are considered in accordance with IS 456 and IS 875 (Part 5). The effects due to temperature variations, shrinkage and creep can be ignored in design calculations in ordinary and low-rise buildings with lateral dimensions less than 45 m.
8. Loads due to foundation movement, elastic axial shortening and soil and fluid pressure are considered as per IS 1904 and IS 875 (Part 5).
9. Loads due to vibration, fatigue and impact are determined as per IS 875 (Part 5).

1.8.2 Design Load

The design load is defined as the load considered in the appropriate method of design and it is the characteristic load in working stress method and characteristic load with appropriate partial safety factors in limit state design.

1.8.3 Load Combinations

The loads listed above should be judiciously combined considering the probability of their simultaneous occurrence and the nature of the severity of stresses or deformations caused by different load combinations to ensure the safety of the structure. Various load combinations to be used in the design of structures are specified in IS 875 (Part 5) as listed in Table 1.15.

Out of these, the load combination producing the most unfavourable effect in the structure should be used in the design. Moreover, simultaneous occurrence of the maximum magnitudes of wind, earthquake, imposed and snow loads is not likely in a structure. The imposed load on a roof covered with snow is replaced with snow load in the load combinations. The design or factored loads are determined using the appropriate codal provisions in working stress method and partial safety factors in limit state design method for each of the above load combinations. While combining imposed load with earthquake load, the appropriate part of imposed load as specified in IS: 1893-1984 should be used for evaluating earthquake effect and for combined load effects in the load combination. The appropriate partial safety factors as specified in IS 456-2000 should be considered in limit state design method for each of the above load combinations.

Table 1.15 Load combinations specified in IS 875 (Part 5).

S. No.	Load combination	S. No.	Load combination	S. No.	Load combination
1.	DL	5.	DL+TL	9.	DL+WL+TL
2.	DL+IL	6.	DL+IL+WL	10.	DL+EL+TL
3.	DL+WL	7.	DL+IL+EL	11.	DL+IL+WL+TL
4.	DL+EL	8.	DL+IL+TL	12.	DL+IL+EL+ TL
DL = dead load, IL = imposed load, WL = wind load, EL = earthquake load, TL = temperature load.					

1.9 Structural Elements of RCC Building

The reinforced concrete building structure should be structurally strong and serve its purpose well. Further, the structure should be economical, serviceable and safe. The reinforced concrete buildings have usual life of 50 years, however, these may last longer if designed and constructed properly. The structural elements of a building mainly consist of slabs, beams, columns, staircases, walls and foundations.

1.9.1 Slabs

The slabs are two-dimensional flexural structural members of a building spanning horizontally and subjected to vertical loads mainly. The slabs are subjected to dead and live loads which are transmitted to the beams supporting them or directly to the columns. The slabs are either supported over the beams or may be supported over the column heads, which are known as flat slabs. Depending upon their relative spans in the two directions, the slabs can be categorized as one-way slabs (length/width ratio > 2) or two-way slabs (length/width ratio ≤ 2).

1.9.2 Beams

The beams are one-dimensional flexural structural members of buildings and transmit loads from slabs to the columns. The beams can be constructed independently or may be constructed monolithically with the slabs. The monolithic beams of interior panels are T-beams and those of the end panels are L-beams. Monolithic beams are more economical and structurally strong than independent beams.

1.9.3 Columns

The columns are vertical structural compression members of a building which transmit the loads of slabs or slabs and beams to the foundations. The columns are subjected to vertical loads or vertical loads and moments in one or both horizontal directions. The overall safety of a reinforced concrete building is mainly dependent upon the strength of the columns particularly when lateral loads such as earthquake loads act on it.

1.9.4 Staircases

The staircases are the structural members of a building which mainly consist of inclined/ horizontal beams and slabs spanning from lower floor level to the upper one. These are used for vertical transportation from one floor level to the other. The stairs are subjected to dead and live loads mainly. The loads of the flights of the stair are transmitted to the upper and lower floor beams depending upon their connections.

1.9.5 Walls

The walls may or may not form the structural members of a reinforced concrete building. The reinforced concrete walls or shear walls can resist lateral loads in addition to the vertical loads. However, walls made of other materials such as brick, stone or block masonry are not the structural members. The shear walls are designed to resist vertical as well as lateral loads.

1.9.6 Foundations

The foundations are the structural members which transfer the dead and superimposed loads of the super structure to the soil underneath. The foundations may be considered as inverted slabs transferring the soil load to the columns. The foundations are of two types namely shallow and deep foundations. The shallow foundations mainly consist of isolated or combined footings and rafts. The deep foundations consist of piles supporting the columns above.

Questions

1. Discuss the importance and use of concrete in construction works.
2. Explain various types of cement giving the specific use of each.
3. Discuss the specifications of aggregates used in production of concrete.
4. Discuss role of admixtures in concrete giving their importance in improving its properties.
5. Give the specification of water used in the production and curing of concrete.
6. Illustrate the mix design of concrete as per Indian standard provisions.
7. Explain how you will determine the workability of concrete in the laboratory.
8. Discuss the determination of compressive strength of concrete in the laboratory.
9. Illustrate the determination of split tensile strength of concrete with suitable diagrams.
10. How the flexural strength of concrete is determined? Explain in detail.
11. Illustrate the determination of modulus of elasticity of concrete in the laboratory.
12. Discuss various properties of hardened concrete giving the provision of Indian standards.
13. Explain various types of reinforcement used in concrete.
14. Illustrate different types of loads and load combinations used in the design of structures.
15. Illustrate the structural elements of a building explaining their role.