CIVIL ENGINEERING

Summary of IS 456 : 2000

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Summary of IS 456 : 2000

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LIST OF IMPORTANT CODES

IS Code No.	Title
456 : 2000	Code of practice for plain and reinforced concrete
800 : 2007	Code of practice for general construction in steel
875 : 1987	Code of practice for design loads (other than earthquake) for building and structures
875 (Part-1) : 1987	Dead load
875 (Part-2) : 1987	Imposed load
875 (Part-3) : 1987	Wind load
875 (Part-4) : 1987	Snow loads
875 (Part-5) : 1987	Special loads and load combinations
1343 : 1980	Code of practice for prestressed concrete
1893 : 2002	Criteria for earthquake resistance design of structures
3370 : 1965	Code of practice for concrete structures for the storage of liquids
10262 : 2009	Guideline for concrete mix proportioning
13920 : 1993	Code of practice for ductile detailing of reinforced Concrete structure subjected to seismic forces
SP 6 (1) : 1964	Handbook for structural engineers (Structural Steel Section)
SP 16 : 1980	Design aid for reinforced concrete to IS 456 : 1978
SP 23 : 1982	Handbook on concrete mixes
SP 24 : 1983	Explanatory handbook on IS 456 : 1978
SP 34 : 1987	Handbook on concrete reinforcement and detailing

Example:

Q.1 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	List-II
A. IS-875	1. Earthquake resistant design
B. IS-1343	2. Loads
C. IS-1893	3. Liquid storage structure
D. IS-3370	4. Prestressed concrete

Codes:

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

[IES-2009]

Ans. (d)

SALIENT FEATURES

- Targeted readers are B.Tech students and students preparing for IES, GATE and PSUs.
- No doubt, each word of IS codes are very important but for students, all are not of same importance. So, effort has been made to consolidated the important clauses (for students only) with explanations and pictorial representation.
- Objective questions that have been asked previously in IES and GATE, placed just after the relevant clause.
- On extreme left, clause numbers are given which is same as clause number of original code.
- Figure number and Table number has been kept same as original code.

INTRODUCTION

This code is used for design and analysis of plain and reinforced concrete structures. It comprises five sections and eight annexures. Out of which 3 sections and 3 annexures only are important for competitive examinations.

Example:

Q.1 Do we use PCC in structural elements?

Ans. We seldom use PCC in structural element. Here we should not confuse PCC means no reinforcement. A minimum amount of reinforcement is definitely provided in concrete to prevent cracks due to shrinkage but that reinforcement is not taken into account while calculating strength of that member, that is why it is called PCC.

[Interview]

Q.2 Is there any difference between steel and reinforcement?

Ans. Yes, steel is a metal which is widely used as reinforcement. It is used because coefficient of thermal expansion of steel and concrete is approximately same otherwise we can go for other reinforcing material aluminium, brass, bamboo etc. Currently rigorous research is being conducted to replace steel by some other material like bamboo, because it is environmental friendly and economical.

[Interview]

SECTION 1 : GENERAL

Description of symbols are given which is used in case of any confusion between two symbols.

SECTION 2 : MATERIAL, WORKMANSHIP, INSPECTION & TESTING

5.0 MATERIALS

5.1 Cement

Types of recommended cement:

(i) 33 grade ordinary portland cement (OPC)
(ii) 43 grade ordinary portland cement (OPC)
(iii) 53 grade ordinary portland cement (OPC)
(iv) Rapid hardening portland cement

(v) Portland slag cement
(vi) Portland pozzolana cement (fly ash based) (PPC)
(vii) Portland pozzolana cement (calcined clay based) (PPC)
(viii) Hydrophobic cement
(ix) Low heat portland cement
(x) Sulphate resisting portland cement

Example:

Q.1 What is the meaning of 33, 43 and 53 grade of ordinary portland cement?

Ans. Digits 33, 43 and 53 represents 28 days compressive strength (N/mm^2) of standard cube of face area 50 cm^2 made up of cement mortar 1 : 3.

[Interview]

Q.2 **Assertion (A):** Low heat cement is used in the construction of large dams.
Reason (R): Very high compressive strength is achieved by low heat cement in 28 days.
Codes:
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[IES-2010]

Ans. (c)
The feature of low heat cement is a slow rate of gain of strength and slow rate of release of heat. But the ultimate strength of low heat cement is the same as that of ordinary portland cement.

Q.3 The proper size of mould for testing compressive strength of cement is
(a) 7.05 cm cube (b) 10.05 cm cube
(c) 15 cm cube (d) 12.05 cm cube

[IES-2003]

Ans. (a)

5.3 Aggregates

Coarse aggregates of light weight with comparable strength is preferable as it reduces dead load of structure. Aggregates should not be more porous (should not absorb more than 10% of their own mass of water) and free from excessive sulphate in the form of SO_3. Size of coarse aggregate is governed by following:

(i) Size of structural member – aggregates should go to each corner of member and cover reinforcement completely.
(ii) Distance between two main bars – aggregates should be small enough so that it can pass through the distance between two main bars. Due to this reason, it is kept 5 mm less than distance between two main bars.
(iii) Minimum cover – If aggregate size is more than the minimum cover provided for member, then there is possibility of exposure of reinforcement to environment so it is kept 5 mm less to minimum nominal cover.

In general, 20 mm nominal size coarse aggregate is used for most of the work but in the case of massive concreting, like dam construction, 40 mm and even higher nominal size can be used. For extremely thin slabs, like shelf, 10 mm nominal size aggregate is used for better finish.

Example:

Q.1 Which one of the following aggregates gives maximum strength in concrete?
(a) Rounded aggregate (b) Elongated aggregate
(c) Flaky aggregate (d) Cubical aggregate
[IES-2001]

Ans. (d)

The rounded aggregate has minimum voids and minimum ratio of surface area to volume, thus requiring minimum cement paste to make good concrete. However due to absence of interlocking, these aggregates are not suitable for high strength concrete and pavements.

5.4 Water

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalies, salts, sugar, organic materials etc. Potable water is preferable. The pH value of water shall be not less than 6. Sea water is not recommended because of presence of harmful salts in sea water. Water found satisfactory for mixing is also suitable for curing of concrete.

5.5 Admixture

Admixture should not impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement. Chloride content of admixtures shall be independently tested as it is harmful to concrete.

Broadly, admixtures are divided into two parts:

(i) Mineral admixture
- Fly ash
- Silica fume
- Rice husk ash

(ii) Chemical admixture
- Accelerating admixture – Calcium chloride, Fluosilicate, Tri ethanolamine
- Retarding admixture – Sodium tartrate, Tartaric acid
- Water reducing or plasticiser – Calcium lignosulphonate
- Air entraining admixture – Aluminium powder, Neutralised vinsol resin

Example:

Q.1 Consider the following statements:
Entrainment of air in concrete is done so as to
1. increase the workability.
2. increase the strength.
3. increase the resistance to freezing and thawing.
Which of these statements is/are correct?
(a) 1, 2 and 3 (b) 1 only
(c) 1 and 3 only (d) 3 only
[IES-2010]

Ans. (c)

Air-entrainment improves durability, workability and plasticity but it have an adverse effect on the strength of concrete. The decrease in strength is usually proportional to the amount of entrained air. For each per cent increase in air content, the compressive strength reduces approximately by 1.4 MPa.

Q.2 Consider the following statements:
Admixtures are added to concrete to
1. increase its strength. 2. reduce heat of hydration.
3. delay the setting of cement. 4. reduce water-cement ratio.

Which of these statements is/are correct?

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

[IES-2010]

Ans. (d)

Admixtures are essentially classified as water-reducers (plasticizers), set-retarders and accelerators. The purpose of water-reducers is to achieve a higher strength by decreasing the water/cement ratio. Set-retarders are admixtures which delay the setting of concrete. Accelerators accelerate the hardening or the development of early strength of concrete. However, reducing the heat of hydration is not the main purpose of admixtures.

Q.3 Consider the following statements:

The use of superplasticizers as admixture

1. increases compressive strength of concrete
2. permits lower water-cement ratio, thereby strength is increased
3. reduces the setting time of concrete
4. permits lower cement content, thereby strength is increased?

Which of these statements is/are correct?

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

[IES-2007]

Ans. (d)

Superplasticizers permit the reduction of water to the extent upto 30% without affecting workability for the same amount of cement.

Q.4 Match **List-I** (Admixture) with **List-II** (Action in concrete) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Calcium lignosulphonate	**1.** Anti-bleeder
B. Aluminium powders	**2.** Retarder
C. Tartaric Acid	**3.** Air entrainer
D. Aluminium sulphate	**4.** Water reducer

Codes:

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

[IES-2003]

Ans. (b)

1. Retarders delay setting time of cement either by forming a thin coating on the cement particles and thus slowing down their dissolution in and reaction with water, or by increasing the intra-molecular distance of reacting silicates and aluminates from water molecules by forming certain transient compounds in the system. These belong to following two groups:

(i) Soluble carbohydrate derivatives like sugar, starch, dextrin etc.

(ii) Inorganic retarders based on hydroxides of zinc and lead, alkali-bi-carbonates, calcium borate, calcium sulphate (gypsum), skimmed milk powder (casein) etc.

Other admixtures used as retarders are Ligno sulphonic acids and their salts, hydroxylated carboxylic acids and their salts, calcium acetate.

2. Air entrainers-natural wood resins containing abietic and pimeric acid salts, various sulphonated compounds, some animal and vegetable fats and oils such as fallow, olive oil and their fatty acids such as stearic and oleic acid.
   Various wetting agents like alkali salts or sulphated and sulphonated compounds. Sodium salts of petroleum sulphonic acids, hydrogen peroxide, and aluminium powder etc. are also used.
3. Water reducers-anionic surfactants such as lignosulphonates and their modifications and derivatives, salts of sulphonates hydrocarbons. Among these calcium, sodium and ammonium lignosulphonates are most used.

Q.5 Match **List-I** (Admixtures) with **List-II** (Chemicals) and select the correct answer using the codes given below the lists:

	List-I		**List-II**
A.	Water-reducing admixture	**1.**	Sulphonated melanin formaldehyde
B.	Air-entraining agent	**2.**	Calcium chloride
C.	Superplasticiser	**3.**	Lignosulphonate
D.	Accelerator	**4.**	Neutralised vinsol resin

Codes:

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

[IES-1998]

Ans. (c)

5.6 Reinforcement

5.6.3 Modulus of Elasticity of steel shall be taken as 2×10^5 MPa.

Three grades of steel is covered in this code

(i) Fe 250

(ii) Fe 415

(iii) Fe 500

Recent development: Fe 550 and TMT (Thermo Mechanically Treated) bars is also available in market.

6.0 CONCRETE

6.1.1 The characteristic strength is defined as the strength of material below which not more than 5 percent of the test results are expected to fall. It is denoted by f_{ck}.

6.2.1 There is normally a gain of strength beyond 28 days also but the design should be based on 28 days characteristic strength of concrete.

Table 2 : Grades of Concrete

Group	Grade designation	Specified characteristic compressive strength of 150 mm cube at 28 days in N/mm^2
Ordinary Concrete	M 10 M 15 M 20	10 15 20
Standard Concrete	M 25 M 30 M 35 M 40 M 45 M 50 M 55	25 30 35 40 45 50 55
High strength Concrete	M 60 M 65 M 70 M 75 M 80	60 65 70 75 80
Note: For design of high strength concrete mix (M 60 or above), specialized literatures is used.		

Example:

Q.1 What is the meaning of grade designation in Table 2 as M 20?

Ans. In M 20, M refers to concrete mix and 20 is the compressive strength of 150 mm cube at 28 days in N/mm^2.

[Interview]

Q.2 What is the approximate ratio of the strength of cement concrete at 7 days to that at 28 days curing?

(a) 0.40 (b) 0.65
(c) 0.90 (d) 1.15

[IES-2006]

Ans. (b)

6.2.2 Tensile strength of concrete is calculated using compressive strength by following formula.

Flexural strength,

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

Example:

Q.1 At what stress does the first flexural crack appear in RCC beams made of M 25 grade concrete ?

(a) 3.0 MPa (b) 3.5 MPa
(c) 4.0 MPa (d) 4.5 MPa

[IES-2009]

Ans. (b)

Q.2 What is the value of flexural strength of M25 concrete?

(a) 4.0 MPa (b) 3.5 MPa
(c) 3.0 MPa (d) 1.75 MPa

[IES-2005]

Ans. (b)

6.2.3.1 The modulus of elasticity of concrete can be assumed as follows:

$$E_c = 5000\sqrt{f_{ck}}\ \text{N/mm}^2$$

E_c is short term static modulus of elasticity. Actual measured values may differ by ±20 percent from the values obtained from the above expression.

Example:

Q.1 As per IS 456-2000, which one of the following correctly expresses the modulus of elasticity of concrete? (read with the relevant units)

(a) $E_c = 0.7\sqrt{f_{ck}}$
(b) $E_c = 500\sqrt{f_{ck}}$
(c) $E_c = 5000\sqrt{f_{ck}}$
(d) $E_c = 5700\sqrt{f_{ck}}$

[IES-2006]

Ans. (c)

6.2.4 The total shrinkage of concrete is significantly influenced by the total amount of water present while mixing and to a lesser extent, by the cement content. The approximate value to total shrinkage strain for design may be taken as 0.0003.

6.2.5.1 Creep coefficient, which is used for the calculation of total creep depends upon age of concrete at the time of loading applied on it.

$$\text{Creep coefficient} = \phi = \frac{\text{Ultimate creep strain}}{\text{Elastic strain at the age of loading}}$$

Age at loading	Creep coefficient (ϕ)
7 days	2.2
28 days	1.6
1 year	1.1

Effective modulus of elasticity using creep coefficient is $E_{ce} = \dfrac{E_c}{1+\phi}$.

Example:

Q.1 Which one of the following predicts the effective modulus of elasticity of concrete?

(a) $\dfrac{E_c}{1+\theta}$
(b) $\dfrac{E_c}{1+2\theta}$
(c) $\dfrac{E_c}{1+3\theta}$
(d) $\dfrac{E_c}{1+5\theta}$

where E_c is short-term elastic modulus and θ is the ultimate creep coefficient

[IES-2007]

Ans. (a)

Q.2 Long term elastic modulus in terms of creep coefficient (θ) and 28-day characteristic strength (f_{ck}) is given by

(a) $\dfrac{5000\sqrt{f_{ck}}}{1+\theta}$ MPa
(b) $\dfrac{50000\sqrt{f_{ck}}}{1+\theta}$ MPa
(c) $\dfrac{5000 f_{ck}}{1+\sqrt{\theta}}$ MPa
(d) $\dfrac{5000\sqrt{f_{ck}}}{\sqrt{1+\theta}}$ MPa

[IES-2004]

Ans. (a)

7.0 WORKABILITY OF CONCRETE

Workability of concrete is defined as ease to work with concrete. There are five degree of workability as follows:

Degree of workability	Placing condition
Very low	In highway construction, a layer of lean concrete with very low workability is used and it is compacted using roller
Low	Mass concreting (like, dam construction), light reinforced section of slab, beam, column
Medium	Heavily reinforced section of slab, column, beams and when pumping of concrete is required
High	In-situ piling
Very high	In-situ piling using tremie pipe

There are four tests for measurement of workability of concrete:

(i) Compacting factor test – preferable for very low workability. Higher compacting factor means high workability.

(ii) Slump test – preferable for low, medium and high. Its value varies from 25 (low) to 150 (high)

(iii) Vee-bee test – Higher value of time means low workability.

(iv) Flow test

Example:

Q.1 The workability of concrete can be increased by which of the following?

1. Increasing the quantity of coarse aggregate without altering the total aggregate quantity.
2. Decreasing the quantity of coarse aggregate and at the same time correspondingly increasing the quantity of fine aggregate.
3. Using round aggregate.

Select the correct answer using the codes given below:

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

[IES-2008]

Ans. (c)

Q.2 Which factors influence the workability of concrete without sacrificing strength?

1. Fine aggregate
2. Quantity of mixing water
3. Maximum size of coarse aggregate
4. Shape of coarse aggregate

Select the correct answer using the codes given below:

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

[IES-2008]

Ans. (d)

Q.3 Consider the following pairs:

1. Hand compaction of heavily reinforced sections
 : Low workability (0-25 mm slump)

2. Concreting of shallow sections with vibrations
: High workability (125-150 mm slump)
3. Concreting of lightly reinforced sections like pavements
: Low workability (5-50 mm slump)
4. Concreting of lightly reinforced section by hand or heavily reinforced sections with vibration
: Medium workability (25-75 mm slump)

Which of the pairs given above are correctly matched?

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

[IES-2004]

Ans. (c)

For hand compaction of heavily reinforced concrete high workability (100-150 mm) is required. For concreting of shallow sections with vibrations low workability (12-25 mm) is required.

Q.4 The values of slump commonly adopted for the various concrete mixes are given below:

1. Concrete for road works : 20 to 28 mm
2. Ordinary RCC work : 50 to 100 mm
3. Columns retaining walls : 12 to 25 mm
4. Mass concrete : 75 to 175 mm

Which of the pairs given above are correctly matched?

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

[IES-2004]

Ans. (b)

Concrete for road work	20-30 mm
Ordinary RCC work	50-100 mm
Columns, retaining walls	75-150 mm
Vibrated concrete	12-25 mm
Mass concrete	25-50 mm

Q.5 Slump and compaction factors are two different measures of workability of concrete. For a slump of 0 to 20 mm, what is the equivalent range of compaction factor?

(a) 0.50 – 0.70 (b) 0.70 – 0.80
(c) 0.80 – 0.85 (d) 0.85 – 0.92

[IES-2004]

Ans. (b)

As the range of slump increases, the range of compacting factor also increases.

Slump in mm		Compacting factor
0 – 25	:	0.78 – 0.80
25 – 75	:	0.85 – 0.87
50 – 100	:	0.92 – 0.935
100 – 150	:	0.95 – 0.96

Q.6 Consider the following statements:
For increasing the workability of concrete, it is necessary to
1. increase the quantity of cement
2. decrease the quantity of sand
3. alter the proportion of fine and coarse aggregates
4. decrease the quantity of water
5. use angular aggregate

Which of these statements are correct?
(a) 1, 2, 3, 4 and 5 (b) 2, 4 and 5
(c) 2 and 3 (d) 1 and 5

[IES-2004]

Ans. (c)
The factors affecting workability are:
1. The higher the water content per cubic metre of concrete, the higher will be the fluidity of concrete.
2. Higher the aggregate/cement ratio, the leaner the concrete and lesser the workability. Lower aggregate/cement ratio gives cohesive and fatty mix with better workability.
3. The bigger the size of aggregate, higher will be the workability.
4. Angular, elongated or flaky aggregate makes the concrete very harsh compared to rounded or cubical aggregates.
5. Smooth textured aggregates contribute to higher workability.
6. Well graded aggregates with less void content, gives higher workability.
7. Admixture may increase workability.

Q.7 Match **List-I** (Workability test) with **List-II** (Measurements) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Slump test	**1.** 300-500 mm
B. Compacting factor	**2.** 75-125 mm
C. Vee-bee test	**3.** 0.80 to 0.98
D. Flow test	**4.** 0 to 10 sec

Codes:

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

[IES-2001]

Ans. (d)

Q.8 Maximum possible value of compaction factor for fresh (green) concrete is
(a) 0.5 (b) 1.0
(c) 1.5 (d) 2.0

[GATE-2013]

Ans. (b)

8.0 DURABILITY OF CONCRETE

Durability of concrete is mainly influenced by following:
(i) the surrounding climate condition
(ii) the cover to embedded steel
(iii) the type and quality of constituent materials
(iv) the cement content and water/cement ratio of the concrete
(v) workmanship, to obtain full compaction and efficient curing
(vi) the shape and size of the member

Example:

Q.1 Which one of the following is correct regarding the most effective requirements of durability in concrete?
(a) Providing reinforcement near the exposed concrete surface
(b) Applying a protective coating to the exposed concrete surface
(c) Restricting the minimum cement content and the maximum water cement ratio and the type of cement
(d) Compacting the concrete to a greater degree

[IES-2009]

Ans. (c)

8.2.2 Exposure conditions:

There are five environmental exposure condition:

Table 3 : Environmental Exposure Conditions

S.No.	Environment	Exposure condition
(i)	Mild	Concrete surface protected against weather. Structure of coastal areas doesn't come in this category.
(ii)	Moderate	Concrete surface sheltered from severe rain, saturated salt air in coastal areas, concrete continuously under normal water and in contact with non-aggressive soil.
(iii)	Severe	Concrete surface exposed to severe rain, alternate wetting and drying, completely immersed in sea water, exposed to coastal environment.
(iv)	Very severe	Concrete surface exposed to sea water spray, corrosive fumes, severe freezing condition and in contact with aggressive soil/ ground water.
(v)	Extreme	Surface of member in tidal zone or in direct contact with liquid/ solid aggressive chemicals.

8.2.5 There are three constituents that adversely affects the concrete.

(i) Chlorides – It increases rate of corrosion to steel. Due to this reason, chloride content of admixture is tested separately.

(ii) Sulphates – Excessive amount of water soluble sulphate (expressed as SO_3) can cause expansion and disruption of concrete.

(iii) Alkali-aggregate reaction – Some aggregates containing particular type of silica may be susceptible to attack by alkalis (Na_2O and K_2O) originating from cement, producing an expansive reaction which can cause cracking and disruption of concrete.

8.2.8 Concrete in sea water or exposed directly along the sea coast shall be at least M20 grade in the case of plain cement concrete and M30 in case of reinforced cement concrete.

Example:

Q.1 What should be the minimum grade of reinforced concrete in and around sea coast construction?
(a) M 35
(b) M 30
(c) M 25
(d) M 20

[IES-2005]

Ans. (b)

Exposure	Minimum grade of plain concrete	Minimum grade of reinforced concrete
(i) Mild	–	M20
(ii) Moderate	M15	M25
(iii) Severe	M20	M30
(iv) Very severe	M20	M35
(v) Extreme	M25	M40

9.0 CONCRETE MIX PROPORTIONING

Concrete mix design is the calculation of proportion of constituent elements (Like, cement, coarse aggregate, fine aggregate, water and sometime admixture also) to achieve desired degree of workability of fresh concrete and desired strength, durability, surface finish of hardened concrete.

9.1.1 There are two type of concrete mix:
(i) Design mix concrete
(ii) Nominal mix concrete

Design mix is always preferable to nominal mix for characteristic strength 20 N/mm^2 and above. Nominal mix is used for M20 and lesser strength concrete only.

Grade of concrete	Nominal Mix proportion (Cement : Sand : Coarse aggregate)
M20	1 : 1.5 : 3
M15	1 : 2 : 4
M10	1 : 3 : 6

Design mix proportions must be by weight while nominal mix proportions could be by volume also but by weight is preferable.

10.0 PRODUCTION OF CONCRETE

Production of concrete for construction is done in batching plant.

Q.1 Batching refers to
(a) controlling the total quantity at each batch
(b) weighing accurately, the quantity of each material for a job before mixing
(c) controlling the quantity of each material into each batch
(d) adjusting the water to be added in each batch according to the moisture content of the materials being mixed in the batch

[IES-1998]

Ans. (c)

The measurement of material for making concrete is called batching. It is essential to ensure uniformity of proportions and aggregate grading in successive batches.

11.0 FORMWORK

11.3.1 Vertical form work of beam, column, walls is removed after 16-24 hrs of concreting (not horizontal).

12.0 ASSEMBLY OF REINFORCEMENT

12.3.2 Actual concrete cover at site should not deviate from the required nominal cover by 0 to +10 mm. (no negative variation is allowed)

13.0 TRANSPORTING, PLACING, COMPACTION AND CURING

13.1 Transporting and Handling

After mixing, concrete shall be transported to the form work as rapidly as possible by methods which will prevent the segregation. Common way of transportation are given below:

(i) Head load
(ii) Dumper
(iii) Transit mixer (If site is far away from batching plant)
(iv) Concrete pump

13.2 Placing the maximum permissible free fall of concrete may be taken as 1.5 m. If free fall is 2 m or 3 m, then there may be possibility of segregation.

Example:

Q.1 Consider the following statements:

Curing of concrete is necessary because

1. concrete needs more water for chemical reaction
2. it is necessary to protect the water initially mixed in concrete from being lost during evaporation
3. penetration of surrounding water increases the strength of concrete

Which of these statements is/are correct ?

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

[IES-2008]

Ans. (c)

Q.2 What is the correct sequence of operations involved in concrete production?

(a) Batching—mixing—handling— transportation
(b) Mixing—batching—handling—transportation
(c) Transportation—handling—mixing—batching
(d) Handling—transportation—mixing—batching

[IES-2006]

Ans. (a)

13.3 Compaction

Concrete should be thoroughly compacted and fully worked around the reinforcement, and into corners of the formwork. Common way of compaction are given below:

(i) Manually, by using steel rod

(ii) Needle vibrator (Most commonly used)
(iii) Surface vibrator (Used to compact slab concreting)
(iv) Form work vibrator

Now a days, self compacting concrete is being used which does not require any compaction.

13.5 Curing

Curing is the process of preventing the loss of moisture from the concrete whilst maintaining a satisfactory temperate regime. The prevention of moisture loss from the concrete is particularly important if the water cement ratio is low. Broadly, curing is divided into two types:

(i) **Moist curing** - Exposed surface of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas for at least 7 days from the date of placing of concrete. Steam curing can also be done for high strength concrete. Railways sleepers are steam cured.

(ii) **Membrane curing** - Curing compound may be used in line of moist curing. It is applied to all exposed surfaces of the concrete as soon as possible after the concrete has set. It prevents evaporation of concrete water content.

14.0 CONCRETING UNDER SPECIAL CONDITION

14.2.4 Concrete cast under water should not fall freely through the water otherwise, it may be segregated.

There are few techniques for underwater concreting:

(i) Tremie pipe method
(ii) Direct placement with pumps
(iii) Drop bottom bucket
(iv) Grouting

15.0 SAMPLING AND STRENGTH OF DESIGNED CONCRETE MIX

15.1.1 Cubes casted using fresh concrete at the time of construction is tested for compressive strength after 28 days but in the case of speedy work progress it may be tested for 7 days strength also.

15.2.1 A random sampling procedure shall be adopted for testing. The minimum frequency of sampling of concrete of each grade shall be accordance with the following:

15.2.2 Frequency

Quantity of concrete in the work (m^3)	Number of test samples
1 – 5	1
6 – 15	2
16 – 30	3
31 – 50	4
51 and above	4 + one additional sample for each additional 50 m^3 and part thereof
Note: At least one sample shall be taken from each shift	

15.4 The test results of the sample shall be the average of the strength of three specimens. The individual variation should not be more than ±15 percent of the average.

Example:

Q.1 Is there any difference between test samples and test specimens?

Ans. Yes, a test sample comprise three test specimens and test specimen means one concrete cube of standard dimension 150 mm.

[Interview]

16.0 ACCEPTANCE CRITERIA

The concrete shall be acceptable when both the following condition are met:

(a) The mean strength determined from group of four consecutive test results satisfy the appropriate limits in column (2) of **Table 11**.

(b) Any individual test result should satisfy the appropriate limits in column (3) of **Table 11.**

Table 11 : Characteristic Compressive Strength Compliance Requirement (After Amendment 4)

Specified Grade (1)	Mean of the Group of 4 Non-overlapping consecutive test result in N/mm^2 (2)	Individual test results in N/mm^2 (3)
M 15 or above	$\geq f_{ck}$ + 0.825 × standard deviation or f_{ck} + 3 whichever is greater	$\geq f_{ck} - 3$

ILLUSTRATIVE EXAMPLE: Assume 100 m^3 of M 25 concrete has been placed at the site in 30 days as below.

Days (1)	Quantity (2)	Number of samples (3)	Number of specimens (4)	Sample number (5)	Compressive strength of each sample in N/mm^2 (6)
1st Day	28 m^3	3	3 + 3 + 3	1 2 3	29.5 30.0 28.5
7th Day	45 m^3	4	3 + 3 + 3 +3	4 5 6 7	32.0 31.5 28.0 29.0
18th Day	20 m^3	3	3 + 3 + 3	8 9 10	28.5 30.0 32.5
30th Day	7 m^3	2	3 + 3	11 12	31.0 30.5

In above table, column (1) represents the day of concreting at site and column (2) represents volume of concreting on that day. Column (3) is number of samples taken on the day of concreting at site as per clause 15.2.2. Since each sample is having 3 specimens so column (4) represents number of specimen taken during concreting. Each sample has been given a number that is represented in column (5). Column (6) is the compressive strength of the sample (average of 3 specimen of each sample).

Acceptance Criteria:

Mean of any four non-overlapping consecutive test results = So, take either 3, 4, 5, 6 or 5, 6, 7, 8 or so on (not, 1, 2, 5, 6 or 3, 4, 9, 10)

Average of sample numbers 5, 6, 7, 8 = 29.25 N/mm^2

Check as per Table 11

$29.25 \geq f_{ck} + 0.825 \times$ standard deviation
25 + 0.825 × 4 (as per Table No. 8 of IS 456 : 2000)
28.3 N/mm^2
or
$f_{ck} + 3$
25 + 3
28 N/mm^2
whichever is greater

All value of compressive strength of sample given in column 6 is greater than $f_{ck} - 3 = 22$ N/mm^2. So, concrete is acceptable.

Example:

Q.1 What is the minimum value of individual test results (in N/mm^2) for compressive strength compliance requirement for concrete M20 as per codal provision?
(a) $f_{ck} - 1$ (b) $f_{ck} - 3$
(c) $f_{ck} - 4$ (d) $f_{ck} - 5$

[IES-2009]

Ans. (b)

Q.2 In a random sampling procedure for cube strength of concrete, one sample consists of X number of specimens. These specimens are tested at 28 days and average strength of these X specimens is considered as test result of the sample, provided the individual variation in the strength of specimens is not more than ± Y per cent of the average strength. The values of X and Y as per **IS : 456-2000** are
(a) 4 and 10 respectively (b) 3 and 10 respectively
(c) 4 and 15 respectively (d) 3 and 15 respectively

[GATE-2005]

Ans. (d)

17.0 INSPECTION AND TESTING OF STRUCTURES

In case of any doubt regarding the grade of concrete used in construction, testing is conducted again.

(i) Destructive test
  (a) Core test
  (b) Load test
(ii) Non-destructive test
  (a) Rebound hammer test
  (b) Ultrasonic pulse velocity test

Example:

Q.1 Consider the following statements:
Ultrasonic pulse velocity test to measure the strength of concrete is
1. used to measure the strength of wet concrete.
2. used to obtain estimate of concrete strength of finished concrete elements.
3. a destructive test.
4. a non-destructive test.

Which of these statements is/are correct?

(a) 2 only (b) 1 and 3

(c) 2 and 4 (d) 3 and 4

[IES-2010]

Ans. (c)

The non-destructive test may be performed directly on the in-situ concrete without the removal of a sample. These tests do not impair the intended performance of the element or member being tested. They also include methods which cause localized surface zone damage and may be called partially destructive.

The ultrasonic pulse velocity method is a non-destructive test for hardened concrete which basically involves the measurement of velocity of electronic pulses passing through concrete from a transmitting transducer to a receiving transducer. This method is based on the principle that the velocity of pulse passing through concrete is primarily dependent upon the density and the elastic properties of the materials and is independent of geometry of the component. The density and elastic properties are in turn related to the quality and strength of the material.

Q.2 Which of the following tests compares the dynamic modulus of elasticity of samples of concrete?

(a) Compression test (b) Ultrasonic pulse velocity test

(c) Split test (d) Tension test [IES-2009]

Ans. (b)

The value of modulus of elasticity found out by actual loading of concrete i.e. the static modulus of elasticity does not truly represent the elastic behaviour of concrete due to the phenomenon of creep. The value of modulus of elasticity found out by the velocity of sound or frequency of sound is referred as dynamic modulus of elasticity. The value of dynamic modulus of elasticity computed from ultrasonic pulse velocity method is somewhat higher than those determined by static method because dynamic modulus is unaffected by creep.

Q.3 Which of the following statements refer to correct purposes as regards testing of concrete by ultrasonic pulse velocity method?

1. To assess the quality of concrete in-situ.
2. To determine the dynamic modulus of elasticity of concrete.
3. To locate the presence of cracks in it.

(a) 1 and 2 only (b) 1 and 3 only

(c) 2 and 3 only (d) 1, 2 and 3 [IES-2011]

Ans. (d)

Ultra sonic pulse velocity test is an in-situ test of hardened concrete when it is already acting as a structural member.

This test is based on the principle that the velocity of sound in a solid material is a function of the square root of the ratio of its modulus of elasticity E to its density, ρ.

Higher the velocity of pulses greater is the strength of concrete.

Q.4 **Assertion (A):** Rebound hammer (Schmidt hammer) test gives only approximate estimation of strength of the concrete specimen.

Reason (R): The test represents the hardness of the surface and provides no idea of the concrete inside.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true [IES-2006]

Ans. (c)

The rebound hammer test measures the elastic rebound of concrete. The rebound number is correlated with compressive strength of concrete. The variation of strength of a properly calibrated hammer may lie between ±15% and ±20%.

SECTION 3 : GENERAL DESIGN CONSIDERATION

18.0 BASES FOR DESIGN

18.1 The aim of design is to fulfil following five requirements:

(i) Safety
(ii) Serviceability
(iii) Durability
(iv) Economy
(v) Aesthetic

19.0 LOADS AND FORCES

Types of load which are taken into account while designing any structure are as follows:

(i) Dead load
(ii) Imposed load
(iii) Wind load, snow load
(iv) Earthquake load
(v) Effect due to shrinkage, creep and temperature
(vi) Foundation movement
(vii) Soil and fluid pressure
(viii) Vibration, impact, fatigue
(ix) Erection load

19.2.1 The unit weight of plain concrete and reinforced concrete may be taken as 24 kN/m^3 and 25 kN/m^3 respectively for calculation of dead load.

19.9 Design load is the load to be taken for design of any structural member. In case of working stress method it is characteristic load while appropriate partial safety factor is multiplied for limit state design method.

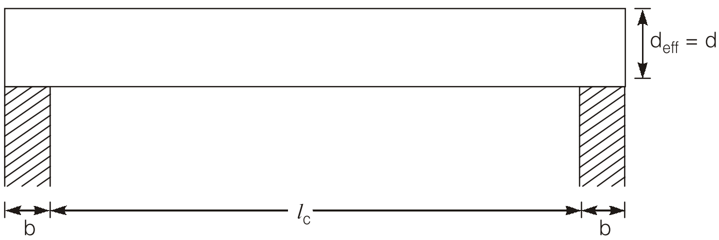
21.0 FIRE RESISTANCE

A structure is made fire resistance by using suitable construction material and providing appropriate cover to steel. Measurement of fire resistance capacity of any structure is in terms of hours for which structure can behave satisfactorily. Minimum width of beam that should be used for fire resistance building is 200 mm.

22.0 ANALYSIS

22.2 Effective Span

(a) **Simply supported beam and slab –** The effective span of a member that is not built integrally with its supports shall be taken as clear span plus the effective depth of slab or beam or centre to centre of supports, whichever is less.

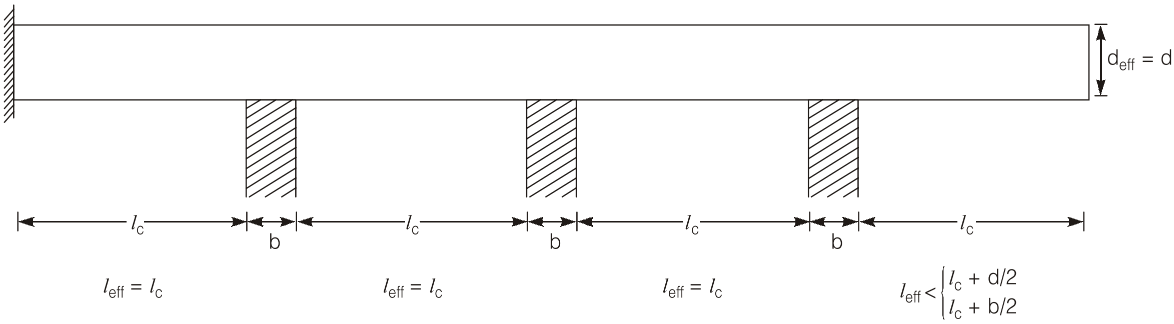


$l_{eff} = l_c + d$ or $l_c + b$ whichever is less

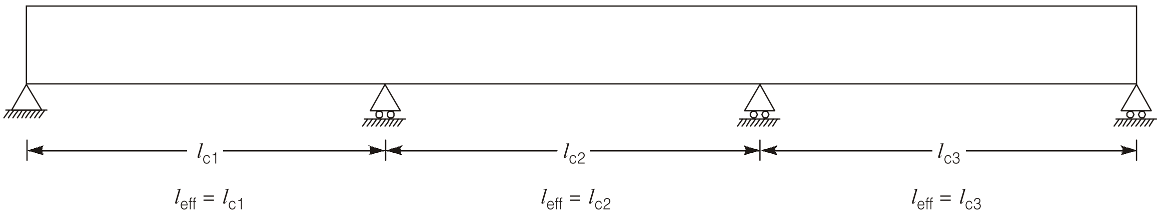
(b) Continuous beam or slab

- If the width of support is less than 1/12th of clear span then effective span is same as mentioned in (a).
- If the width of support is more than 1/12th of clear span or 600 mm whichever is less, then effective span is as follows:

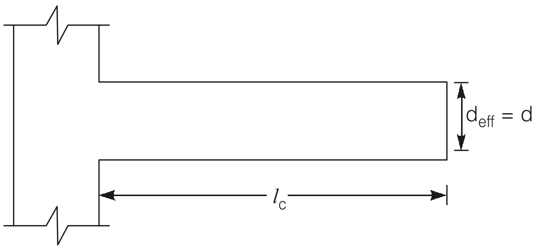
$$b > \frac{l_c}{12} \text{ or } 600 \text{ mm}$$



- In the case of spans with roller or rocket bearings, the effective span shall always be the distance between the centers of bearing.



(c) Cantilever

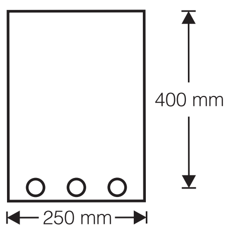


$$l_{eff} = l_c + \frac{d}{2}$$

(d) **Frames** – In the analysis of continuous frame, centre to centre distance is used.

Example:

Q.1 A simply supported RC beam having clear span 5 m and support width 300 mm has the cross-section as shown in figure below.



What is the effective span of the beam as per IS:456 ?

(a) 5300 mm (b) 5400 mm
(c) 5200 mm (d) 5150 mm [IES-2009]

Ans. (a)

22.3.1 Gross section – The cross-section of the member ignoring reinforcement.

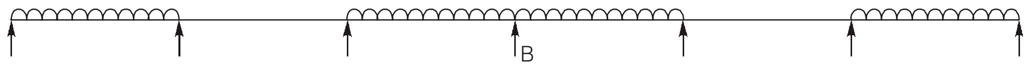
Transformed section – The concrete cross-section plus the area of reinforcement transformed using modular ratio.

Cracked section – The area of concrete in compression plus the area of reinforcement transformed on the basis of modular ratio.

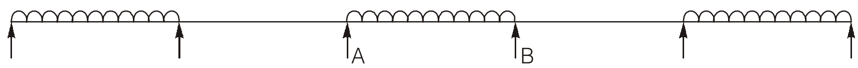
22.4.1 Arrangement of Imposed Load

Consideration may be limited to combinations of:

1. Design dead load on all spans with full design imposed load on two adjacent spans plus alternate spans for maximum hogging bending moment at the support B as shown below.



2. Design dead load on all spans with full design imposed load on alternate spans for maximum sagging bending moment in between support A and B as shown below.



Example:

Q.1 In the case of a continuous RC beam, in order to obtain the maximum positive span moment, where should the live load be placed ?

(a) On all the spans
(b) On alternate spans starting from the left
(c) On spans adjacent to the spans under consideration
(d) On the span plus alternate spans

[IES-2007]

Ans. (d)

Q.2 For maximum sagging bending moment at support in a continuous RC beam, live load should be placed on

(a) spans adjacent to the support plus alternate spans
(b) all the spans except the spans adjacent to the support
(c) spans next to the adjacent spans of the support plus alternate spans
(d) spans adjacent to supports only

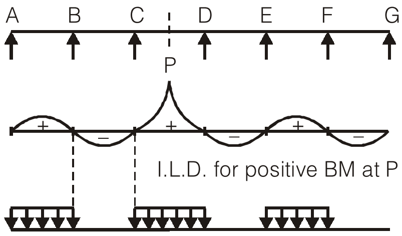
[IES-1995]

Ans. (c)

The maximum moment or shear force at a section depends on the position of the live load.

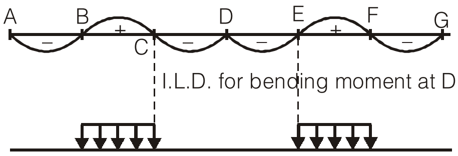
(i) For maximum positive span moment at mid point, load that span and all other alternate spans.
(ii) For maximum positive support moment, unload the spans on either side of the support and load the next spans.
(iii) For maximum negative span moment at mid point, load the adjacent spans on either side of the span and all other alternate spans.
(iv) For maximum negative moment at support, load the two spans adjacent to the support and all other alternate spans.

For case (i)



Position of load for maximum positive BM at P

For case (ii)



Position of load for positive bending moment at D.

Q.3 For maximum sagging bending moment in a given span of a multiple span beam,
(a) that very span as well as alternate spans are loaded
(b) adjacent spans are loaded
(c) spans adjoining this span are loaded
(d) adjacent spans are unloaded and next spans are loaded

[IES-2000]

Ans. (a)

22.5 Moment and shear coefficient for continuous beams

Unless more exact estimates are made, for beams of uniform cross-section which support substantially uniformly distributed loads over three or more span which do not differ by more than 15 percent of the longest, the bending moment shear forces used in design may be obtained using the coefficients given in Table 12 and Table 13 respectively.

Table 12 : Bending Moment Coefficients

Type of load	Span moments		Support moments	
	Near middle of end span	At middle of interior span	At support next to the end support	At other interior supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

Note: For obtaining the bending moment, the coefficient shall be multiplied by the total design and effective span.

Table 13 : Shear Force Coefficients

Type of load	At end support	At support next to the end support		At all other interior supports
		Outer side	Inner side	
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	0.4	0.6	0.55	0.5
Imposed load (not fixed)	0.45	0.6	0.6	0.6

Note: For obtaining the shear force, the coefficient shall be multiplied by the total design load.

Example:

Q.1 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists :

List-I

A. At end support, for imposed load (not fixed)
B. At inside support, next inner to end support, for imposed load (fixed)
C. At end support, for dead load and (fixed) imposed load
D. At all other interior supports (other than at 'B'), for imposed load (fixed)

List-II

1. 0.5
2. 0.55
3. 0.60
4. 0.45
5. 0.4

Codes:

	A	B	C	D
(a)	5	3	2	4
(b)	4	2	5	1
(c)	1	2	3	4
(d)	5	3	2	1

[IES-2009]

Ans. (b)

22.6.1 Critical Section for Moment

For monolithic construction the moments computed at the face of the support shall be used in the design of the members at those section.

22.6.2 Critical Section for Shear

The shears computed at the face of the support shall be used in the design of the member at that section except as in **22.6.2.1**.

22.6.2.1 When the reaction in the direction of the applied shear introduces compression into the end region of the member, sections located at a distance less than d from the face of the support may be designed for the same shear as that computed at distance d.

Note: The above clauses are applicable for beams generally carrying uniformly distributed load or where the principal load is located farther than 2d from the face of the support.

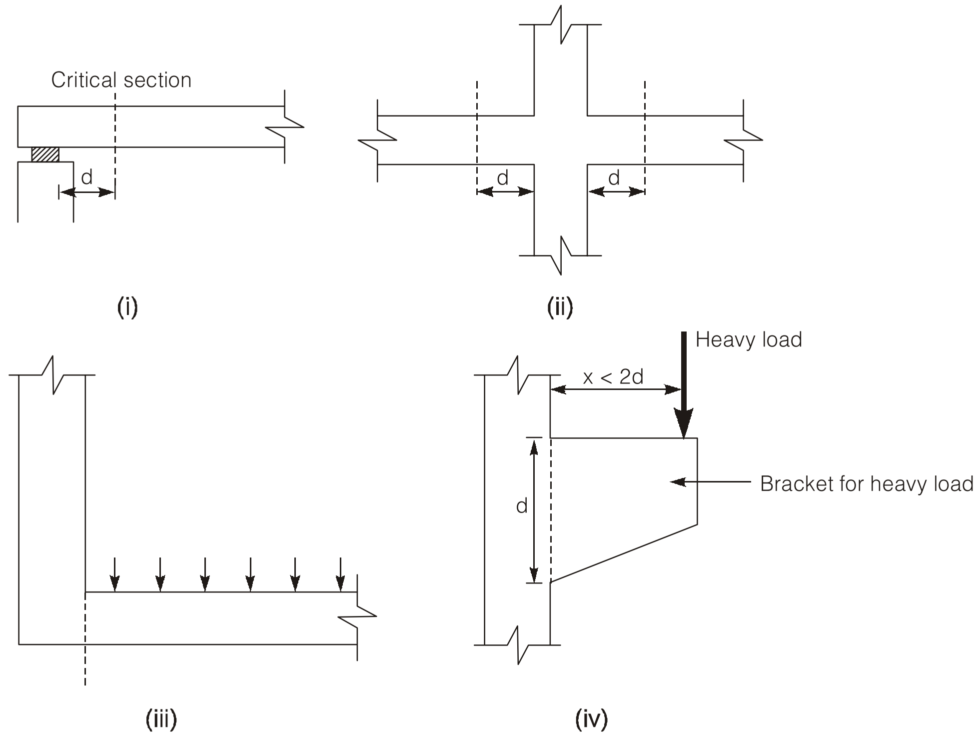


Fig.2 : Typical support conditions for locating factored shear force

Example:

Q.1 A beam is designed for uniformly distributed loads causing compression in the supporting columns. Where is the critical section for shear? (d is effective depth of beam and L_d is development length)

(a) A distance $L_d/3$ from the face of the support

(b) A distance d from the face of the support

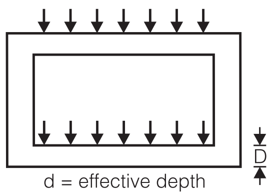
(c) At the centre of the support

(d) At the mid span of the beam

[IES-2006]

Ans. (b)

Q.2 A box girder section is subjected to loads as shown in the figure below. The critical section for shear in the bottom slab will occur at



(a) D from the face of the wall

(b) 'd' from the face of the wall

(c) 'd/2' from the face of the wall

(d) the face of the wall

[IES-1997]

Ans. (d)

For top slab the critical section will be at a distance 'd' from the face of the wall. For bottom slab it will be at the face of the wall.

Q.3 A reinforced concrete beam of 10 m effective span and 1 m effective depth is supported on 500 mm × 500 mm columns. If the total uniformly distributed load on the beam is 10 MN/m, the design shear force for the beam is

(a) 50 MN (b) 47.5 MN
(c) 37.5 MN (d) 43 MN **[IES-2003]**

Ans. (c)

The shear force should be calculated at critical section i.e. 1 m away from the face of the column.

Effective span of beam is to be taken as the clear span plus effective depth of beam or centre to centre spacing of supports whichever is less. The location for shear calculation will be

$$x = 0.25 + 1 = 1.25 \text{ m}$$

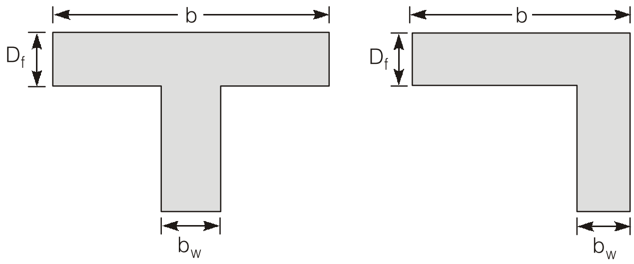
$$\therefore \quad \text{Design shear force} = \frac{10 \times 10}{2} - 10 \times 1.25 = 37.5 \text{ MN}$$

23.0 BEAMS

Effective depth of a beam is the distance between the centroid of area of tension reinforcement and the maximum compression fibre. In the case of two or three layers of tension reinforcement, centroid of all tension reinforcement is considered.

23.1 A slab which is assumed to act as a compression flange of a T-beam or L-beam must be cast monolithically with the web or bonded firmly together.

23.1.2 Effective width of flange may be taken as the following but in no case greater than the width of the web plus half the sum of the clear distance to the adjacent beams on either side.



(a) For T-beam, $b_f = \frac{l_0}{6} + b_w + 6D_f$

(b) For L-beam, $b_f = \frac{l_0}{12} + b_w + 3D_f$

(c) For isolated beams, the effective flange width shall be obtained as below but in no case greater than the actual width

T-beam, $$b_f = \frac{l_0}{\frac{l_0}{b} + 4} + b_w$$

L-beam, $$b_f = \frac{0.5\, l_0}{\frac{l_0}{b} + 4} + b_w$$

b_f = effective width of flange

l_0 = distance between points of zero moments in the beam

Note: For continuous beam and frames 'l_0' may be assumed as 0.7 times the effective span.

Example:

Q.1 A T-beam roof section has the following particulars:

Thickness of slab	:	100 mm
Width of rib	:	300 mm
Depth of beam	:	500 mm
Centre to centre distance of beams	:	3.0 m
Effective span of beams	:	6.0 m
Distance between points of contraflexure	:	3.6 m

What is the effective flange width of the T-beam?

(a) 3000 mm (b) 1900 mm
(c) 1600 mm (d) 1500 mm

[IES-1996]

Ans. (d)

Q.2 The effective width 'b_f' of flange of a continuous T-beam in a floor system is given by

$$b_f = \frac{L_o}{6} + b_w + 6D_f$$

where L_0 represents the
(a) distance between points of contraflexure in a span
(b) effective span of beams
(c) clear span of beams
(d) spacing between beams [IES-2006]

Ans. (a)

23.2 The final deflection due to all loads including effects of temperatures, creep and shrinkage and measured from the as cast level of the supports of floors, should not normally exceed effective span/250.

And the deflection due to effects of temperature, creep and shrinkage after erection of partitions and the application of finishes should not normally exceed span/350 or 20 mm whichever is less.

Example:

Q.1 The final deflection due to all including effects of temperature, creep and shrinkage measured from as – cast level of the supports of floors, roofs and all other horizontal members of reinforced concrete should not normally exceed
(a) Span/350
(b) Span/250
(c) (Span/350) or 20 mm whichever is less
(d) (5/348) of span [IES-1996]

Ans. (b)

Q.2 Limit state of serviceability for deflection including the effects due to creep, shrinkage and temperature occurring after erection of partitions and application of finishes as applicable to floors and roofs is restricted to

(a) $\frac{\text{Span}}{150}$ (b) $\frac{\text{Span}}{200}$

(c) $\frac{\text{Span}}{250}$ (d) $\frac{\text{Span}}{350}$

[IES-1995]

Ans. (d)

23.2.1 The vertical deflection of beams is ensured within limit by providing following recommended values of effective span to effective depth ratio.

Basic values of span to effective depth ratios for span upto 10 m:

Cantilever	7
Simply supported	20
Continuous	26

Example:

Q.1 How is the deflection in RC beams controlled as per IS:456 ?
(a) By using large aspect ratio
(b) By using small modular ratio
(c) By controlling span/depth ratio
(d) By moderating water-cement ratio

[IES-2009]

Ans. (c)

Q.2 Usually stiffness of a simply supported beam is satisfied if the ratio of its span to depth does not exceed which one of the following?
(a) 7 (b) 10
(c) 20 (d) 26

[IES-2008]

Ans. (c)

Q.3 As per IS:456-1978 the vertical deflection limit for beams may generally be assumed to be satisfied provided that the ratio of span to effective depth of a continuous beam of span up to 10 m is not be greater than
(a) 35 (b) 26
(c) 20 (d) 18

[IES-1999]

Ans. (b)

23.3 Slenderness limits for beams to ensure lateral stability

A simply supported or continuous beam shall be so proportioned that the clear distance between the lateral restraints does not exceed 60 b or 250 b^2/d whichever is less, where d is the effective depth of the beam and b the breadth of the compression face midway between the lateral restraints.

For a cantilever, the clear distance from the free end of the cantilever to the lateral restraint shall not exceed 25 b or 100 b^2/d whichever is less.

Example:

Q.1 Match **List-I** (Codal Parameter) with **List-II** (Structural Member) and select the correct answer using the codes given below the lists:

List-I	List-II
A. 0.04 bD	1. Column
B. 250 b^2/d	2. Cantilever
C. 100 b^2/d	3. Continuous beam
D. $(k_x l_x)/D_x$	4. Beam

Codes:

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

[IES-2005]

Ans. (c)

24.0 SOLID SLABS

24.1 For slabs spanning in two directions, the shorter of the two spans should be used for calculating the span to effective depth ratios.

For two way slabs of shorter span (up to 3.5 m) with mild steel reinforcement, the span to overall depth ratio given below may generally be assumed to satisfy vertical deflection limits for loading up to 3 kN/m^2.

Simply supported slab	35
Continuous slab	40

For high strength deformed bars of grade Fe415, the values given above should be multiplied by 0.8.

Example:

Q.1 In case of 2-way slab, the limiting deflection of the slab is
(a) primarily a function of the long span
(b) primarily a function of the short span
(c) independent of long or short spans
(d) dependent on both long and short spans

[IES-1995, 2003]

Ans. (b)

Q.2 For a continuous slab of 3 m × 3.5 m size, the minimum overall depth of slab to satisfy vertical deflection limits is
(a) 120 mm (b) 100 mm
(c) 75 mm (d) 50 mm

[IES-2011]

Ans. (c)

24.5 The loads on beams supporting solid slabs spanning in two directions at right angles and supporting uniformly distributed loads, may be assumed to be in accordance with Fig. 7 below.

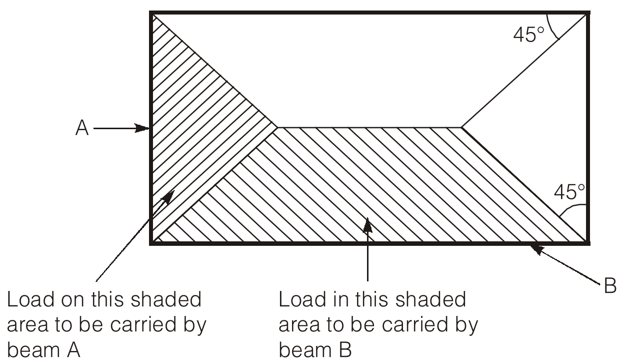
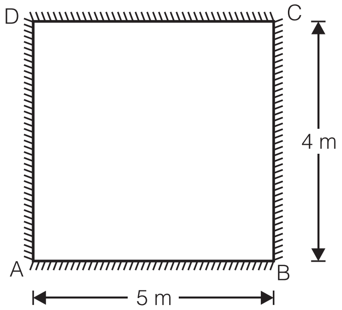


Fig. 7 : Load carried by supporting beams

Example:

Q.1 The RC slab, simply supported on all edges as in figure below, is subjected to a total UDL of 12 kN/m^2. The maximum shear force/unit length along the edge 'BC' is



(a) 16 kN
(b) 12 kN
(c) 8 kN
(d) 30 kN

[IES-2010]

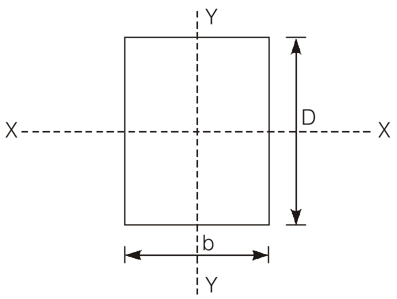
Ans. (a)

25.0 COMPRESSION MEMBERS

Column or strut is a compression member, the effective length of which exceeds three times the least lateral dimension. If it is less than or equal to three then consider it as a pedestal.

A compression member may be considered as short when both the slenderness ratios $\frac{l_{ex}}{D}$ and $\frac{l_{ey}}{b}$ are less than 12.

In general x-axis is taken as major axis and y-axis is taken as minor axis.



$I_{XX} > I_{YY}$

Example:

Q.1 According to IS 456, minimum slenderness ratio for a short concrete column is
(a) Less than 12
(b) Between 12 and 18
(c) Between 18 and 24
(d) More than 24

[IES-2011]

Ans. (a)

25.1.3 The unsupported length l of a compression member shall be taken as the clear distance between end restraints.

25.3 Slenderness Limits for Columns

The unsupported length between end restraints shall not exceed 60 times the least lateral dimension of a column.

If in any given plane, one end of a column is unrestrained, its unsupported length, l, shall not exceed 100 b^2/D.

25.4 **Minimum Eccentricity**

All column shall be designed for minimum eccentricity,

$$e_{min} = \frac{l_{unsupported}}{500} + \frac{\text{lateral dimension}}{30} \text{ or 20 mm, which ever is more}$$

Example:

Q.1 An axially loaded column is of 300 mm × 300 mm size. Effective length of column is 3 m. What is the minimum eccentricity of the axial load for the column?
(a) 0 (b) 10 mm
(c) 16 mm (d) 20 mm [IES-2006]

Ans. (d)

26.1 Reinforcing steel of same type and grade shall be used as main reinforcement in a structural member. However, simultaneous use of two different types of grades of steel for main secondary reinforcement respectively is permissible.

26.1.1 Bars may be arranged singly, or in pairs in contact, or in group of three or four bars bundled in contact. Bundled bars shall be enclosed within stirrups or ties. Bundled bars shall be tied together to ensure the bars remaining together. Bars larger than 32 mm diameter shall not be bundled, except in column.

26.2 **Development of Stress in Reinforcement**

The calculated tension or compression in any bar at any section shall be developed on each side of the section by providing development length or end anchorage or combination.

26.2.1 Development Length of bars

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}}$$

where, ϕ = nominal diameter of bar
σ_s = stress in bar at the section considered at design load
τ_{bd} = design bond stress

Design bond stress for deformed bar shall be 60 percent higher than design bond stress for plain bar. This is due to extra ribs provided on the surface of bar.

Plain bar Deformed bar

For bar in compression, the values of bond stress for bar in tension shall be increased by additional 25 percent.

Example:

Q.1 In limit state design, permissible bond stress in the case of deformed bars is more than that in plain bars by
(a) 60% (b) 50%
(c) 40% (d) 25% [IES-1995]

Ans. (a)

Q.2 In a reinforced concrete member, the best way to ensure adequate bond is
(a) to provide minimum number of large diameter bars
(b) to provide large number of smaller diameter bars
(c) to increase the cover for reinforcement
(d) to provide additional stirrups [IES-2004]

Ans. (b)

Q.3 **Assertion (A) :** The development length for HYSD Fe 415 bars is less than that for mild steel plain bars.

Reason (R) : The permissible bond stress for HYSD Fe 415 bars is more than that for mild steel plain bars.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[IES-1999]

Ans. (d)

Q.4 When HYSD bars are used in place of mild steel bars in a beam, the bond strength

(a) does not change
(b) increases
(c) decreases
(d) becomes zero

Ans. (b)

Q.5 Which one of the following is the correct expression to estimate the development length of deformed reinforcing bar as per IS code in limit state design ?

(a) $\dfrac{\phi\sigma_s}{4.5\tau_{bd}}$
(b) $\dfrac{\phi\sigma_s}{5\tau_{bd}}$
(c) $\dfrac{\phi\sigma_s}{6.4\tau_{bd}}$
(d) $\dfrac{\phi\sigma_s}{8\tau_{bd}}$

where ϕ is diameter of reinforcing bar, σ_s is the stress in the bar at a section and τ_{bd} is bond stress.

[IES-2007]

Ans. (c)

As per clause **26.2.1** of **IS:456-2000**, the development length L_d is given by

$$L_d = \frac{\phi\sigma_s}{4\tau_{bd}}$$

The value of τ_{bd} should be increased by 60% for deformed bars.

$$\therefore \qquad L_d = \frac{\phi\sigma_s}{4\left(\tau_{bd} + \frac{60}{100}\tau_{bd}\right)} = \frac{\phi\sigma_s}{6.4\,\tau_{bd}}$$

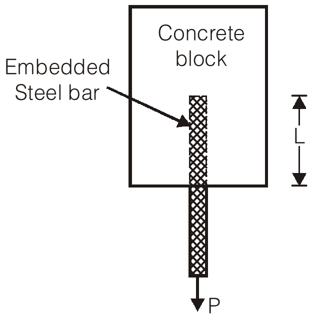
Q.6 What is the bond stress acting parallel to the reinforcement on the interface between bar and concrete?

(a) Shear stress
(b) Local stress
(c) Flexural stress
(d) Bearing stress

[IES-2008]

Ans. (a)

Q.7 Consider a bar of diameter 'D' embedded in a large concrete block as shown in the adjoining figure, with a pull out force P being applied. Let σ_b and σ_{st} be the bond strength (between the bar and concrete) and the tensile strength of the bar, respectively. If the block is held in position and it is assumed that the material of the block does not fail, which of the following options represents the maximum value of P?



(a) Maximum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

(b) Maximum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

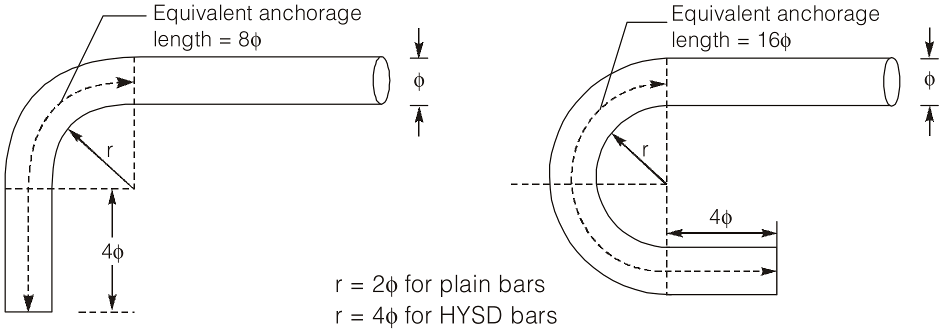
(c) Minimum of $\left(\frac{\pi}{4}D^2\sigma_{st}\right)$ and $(\pi DL\sigma_b)$

(d) Minimum of $\left(\frac{\pi}{4}D^2\sigma_b\right)$ and $(\pi DL\sigma_{st})$

[GATE-2011]

Ans. (c)

26.2.2 Anchoring is provided by bends and hooks at the end which is equivalent to resistance provided by straight bars.



(a) standard 90° bend (b) standard U-type hook

Anchorage lengths of standard bends and hooks

The anchorage value of bend shall be taken as four times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of bar. The anchorage value of a standard U-type hook shall be equal to 16 times the diameter of the bar.

Anchorage length of bend and hooks are not considered in the case of compression.

Example:

Q.1 What is the anchorage value of a standard hook of a reinforcement bar of diameter D?

(a) 4 D (b) 8 D

(c) 12 D (d) 16 D

[IES-2009]

Ans. (d)

26.2.3 Curtailment of Tension Reinforcement in Flexural Members

26.2.3.1 For curtailment, reinforcement shall extend beyond the point at which it is not longer required to resist flexure for a distance equal to the effective depth of the member or 12 times the bar diameter, whichever is greater except at simple support or end of cantilever. In addition **26.3.3.2** to **26.2.3.5** shall also satisfied.

Note: A point at which reinforcement is no longer required to resist flexure is where the resistance moment of the section, considering only the continuing bars, is equal to the design moment.

26.2.3.2 Flexural reinforcement shall not be terminated in a tension zone unless any one of the following conditions is satisfied:

(a) The shear at the cut-off point does not exceed two-thirds that permitted, including the shear strength of web reinforcement provided.

(b) Stirrup area in excess of the required for shear and torsion is provided along each terminated bar over a distance from the cut-off point equal to three-fourths the effective depth of the member. The excess stirrup area shall be not less than $0.4\ bs/f_y$, where b is the breadth of beam, s is the spacing and f_y is the characteristic strength of reinforcement in N/mm^2. The resulting spacing shall not exceed $d/8\ \beta_b$ where β_b is the ratio of the area of bars cut-off to the total area of bars at the section, and d is the effective depth.

(c) For 36 mm and smaller bars, the continuing bars provide double the area required for flexure at the cut-off point and the shear does not exceed three-fourth that permitted.

26.2.3.3 Positive Moment Reinforcement

(a) At least one-third the positive moment reinforcement in simple members and one-fourth the positive moment reinforcement in continuous members shall extend along the same face of the member into the support, to a length equal to $L_d/3$.

(b) When a flexural member is part of the primary lateral load resisting system, the positive reinforcement required to be extended into the support as described in (a) shall be anchored to develop its design stress in tension at the face of the support.

(c) At simple supports and at points of inflection, positive moment tension reinforcement shall be limited to a diameter such that L_d computed for f_d by **26.2.1** does not exceed

$$\frac{M_1}{V} + L_0$$

where,

M = moment of resistance of the section assuming all reinforcement at the section to be stressed to f_d

f_d = $0.87\ f_y$ in the case of limit state design and the permissible stress σ_{st} in the case of working stress design

V = shear force at the section due to design loads

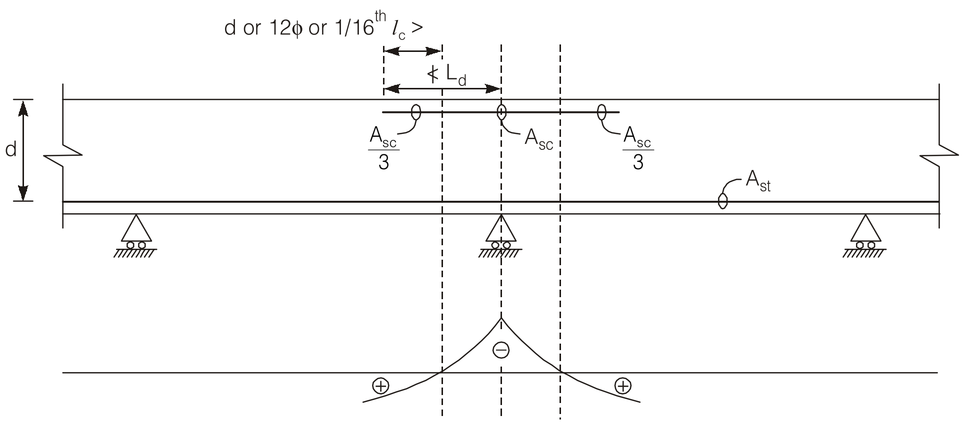
L_0 = sum of the anchorage beyond the center of the support and the equivalent anchorage value of any hook or mechanical anchorage at simple support; and a point of inflection, L_0 is limited to the effective depth of the members or 12ϕ, whichever is greater, and

ϕ = diameter of bar

The value of M_1/V in the above expression may be increased by 30 percent when the ends of the reinforcement are confined by a compressive reaction.

26.2.3.4 Negative Moment Reinforcement

At least one-third of the total reinforcement provided for negative moment at the support shall extend beyond the point of inflection for a distance not less than the effective depth of the member of 12ϕ or one-sixteenth of the clear span whichever is greater.



Bending moment diagram

26.2.3.5 Curtailment of Bundled Bars

Bars in a bundle shall terminate at different points spaced apart by not less than 40 times the bar diameter except for bundles stopping at a support.

Example:

Q.1 Consider the following statements dealing with flexural reinforcement to be terminated in the tension zone:

1. The shear at the cut-off point not to exceed two-third of the otherwise permitted value.
2. Shear reinforcement is provided along each terminated bar overlapping three-fourth of the appropriate distance from the cut-off point.
3. For 36 mm and smaller bars, the continuing bars shall provide double the area required for flexure at the cutoff and shear does not exceed three-fourth of the permitted value.

Which of these statements is/are correct ?

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

[IES-2009]

Ans. (a)

Q.2 The distance between theoretical cut-off point and actual cut-off point in respect of the curtailment of reinforcement of reinforced concrete beams should not be less than

(a) Development length
(b) 12 × diameter of bar or effective depth whichever is greater
(c) 24 × diameter of bar or effective depth whichever is greater
(d) 30 × diameter of bar or effective depth whichever is greater

[IES-2006]

Ans. (b)

Q.3 Consider the following statements:

1. Reinforcement that is no longer required for flexure beyond a certain section, shall however be extended by d or 12 ϕ, whichever is greater, before being curtailed.
2. At least half the bars should be bent up at the cut-off point.
3. The shear capacity at cut-off point should at least be 1.5 times the shear force at that section.

Which of these statements are correct?

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

[IES-2004]

Ans. (b)

Q.4 Match **List-I** (Reinforcement type) with **List-II** (Anchorage requirement) and select the correct answer using the codes given below the lists:

List-I

A. Footing slab, tensile reinforcement
B. Cantilever beam, tensile reinforcement
C. Simply supported beam, tensile reinforcement
D. Beam, shear stirrup

List-II

1. $\frac{L_d}{3}$ into the support
2. 6ϕ for 135° bend
3. L_d into the support
4. L_d from the column face

Codes:

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

[IES-2009]

Ans. (c)

For shear stirrup in beam, anchorage length is

(i) 8ϕ for 90° bend
(ii) 6ϕ for 135° bend
(iii) 4ϕ for 180° bend

26.2.5 It is recommended that splices in flexural members should not be done at sections where the bending moment is more than 50 percent of the moment of resistance and not more than half the bars shall be splice at a section.

26.2.5.1 Lap splices

(a) Lap splices shall not be used for bars larger than 32 mm; for larger diameters, bars may be welded or mechanically spliced.

(b) Lap length including anchorage value of hooks for bars in flexure tension shall be L_d or 30ϕ whichever is greater and for direct tension shall bc $2L_d$ or 30ϕ whichever is greater. The straight length of the lap shall not be less than 15ϕ or 200 mm.

(c) The lap length in compression shall be equal to the development length in compression, calculated as described in 26.2.1, but not less than 24ϕ.

(d) When bars of two different diameters are to be spliced, the lap length shall be calculated on the basis of diameter of the smaller bar.

Example:

Q.1 Lap length of reinforcement in compression shall not be less than

(a) 30 ϕ (b) 24 ϕ

(c) 20 ϕ (d) 15 ϕ

where ϕ = diameter of bar.

[IES-2011]

Ans. (b)

26.3.3 Maximum distance between bars in tension:

(a) **Beams :** The horizontal distance between parallel reinforcement bars near the tension face of the beam shall not be greater than the following.

f_y (N/mm^2)	Clear distance between bars (mm)
250	300
415	180
500	150

(b) **Slabs :** The horizontal distance between parallel main bars shall not be more than three times the effective depth of solid slab or 300 mm whichever is smaller.

The horizontal distance between parallel reinforcement bars provided against shrinkage and temperature shall not be more than five times these effective depth of a solid slab or 300 mm whichever is smaller.

26.4 Minimum values of nominal cover for different structural member depends upon exposure condition because cover is directly related to durability of the structure.

Exposure	Nominal cover (mm)
Mild	20
Moderate	30
Severe	45
Very severe	50
Extreme	75

26.4.2.2 For footings, minimum cover shall be 50 mm.

Example:

Q.1 The cover of longitudinal reinforcing bar in a beam subjected to sea spray should not be less than which one of the following ?

(a) 30 mm (b) 70 mm

(c) 75 mm (d) 80 mm

[IES-2007]

Ans. (b)

Above exposure condition comes under very sever range (see 8.22), so minimum is 50 mm. But no answer is 50 mm so appropriate answer is 70 mm.

Q.2 Match **List-I** with **List-II** regarding the minimum concrete cover to reinforcing steel and select the correct answer using the codes given below the lists:

List-I

A. For longitudinal reinforcement in columns of size 200 mm and less, with 12 mm diameter bars as longitudinal steel.

B. For longitudinal reinforcement in beams.

C. For longitudinal bars in slabs.
D. For longitudinal bars in columns of size more than 200 mm.

List-II

1. 40 mm or diameter of bar whichever is more
2. 15 mm or diameter of bar whichever is more
3. 25 mm or diameter of bar whichever is more
4. 25 mm

Codes:

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

[IES-1996]

Ans. (a)

26.5 Requirements of Reinforcement for Structural Members

26.5.1.1 Tension reinforcement

Minimum tension reinforcement in beams

$$A_s \geq \frac{0.85\,bd}{f_y}$$

Maximum tension reinforcement in beams

$$A_{st} \leq 0.04\,bD$$

26.5.1.2 Compression Reinforcement

There is no limit of minimum compression reinforcement in beam but maximum amount is limited to 0.04 bD.

26.5.1.3 Side Face Reinforcement

Where the depth of the web in a beam exceeds 750 mm, side face reinforcement shall be provided along the two faces. The total area of such reinforcement shall be not less than 0.1 percent of the web area and shall be distributed equally on two faces at a spacing not exceeding 300 mm or web thickness whichever is less.

Example:

Q.1 What shall be the maximum area of reinforcement (i) in compression and (ii) in tension to be provided in an RC beam, respectively, as per IS:456?

(a) 0·08% and 2% (b) 2% and 4%
(c) 4% and 2% (d) 4% and 4%

[IES-2009]

Ans. (d)

Q.2 Minimum tension steel in RC beam needs to be provided to

(a) prevent sudden failure (b) arrest crack width
(c) control excessive deflection (d) prevent surface hair cracks

[IES-2004]

Ans. (a)

Q.3 Given that d = effective depth, b = width and D = overall depth, the maximum area of compression reinforcement in a beam is
(a) 0.04bd (b) 0.04bD
(c) 0.12bd (d) 0.12bD [IES-1997]

Ans. (b)

Q.4 Side face reinforcement is provided in a beam when the depth of web exceeds
(a) 300 mm (b) 450 mm
(c) 500 mm (d) 750 mm [IES-1997]

Ans. (d)

Q.5 In an RCC beam of breadth 'b' and overall depth D exceeding 750 mm, side face reinforcement required and the allowable area of maximum tension reinforcement shall be respectively
(a) 0.2% and 0.02bD (b) 0.3% and 0.03bD
(c) 0.1% and 0.04bD (d) 0.4% and 0.01bD [IES-1999]

Ans. (c)

26.5.1.5 Transverse Reinforcement Spacing

The maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 *d* for vertical stirrups and *d* for inclined stirrups at 45°, where *d* is the effective depth of the section under consideration. In no case the spacing exceed 300 mm.

Example:

Q.1 What is the adoptable maximum spacing between vertical stirrups in an RCC beam of rectangular cross-section having an effective depth of 300 mm?
(a) 300 mm (b) 275 mm
(c) 250 mm (d) 225 mm
[IES-2009]

Ans. (d)

26.5.1.6 Minimum Shear Reinforcement

Minimum shear reinforcement in the form of stirrups shall be provided such that

$$\frac{A_{sv}}{bS_v} \geq \frac{0.4}{0.87\, f_y}$$

where, A_{sv} = total cross-sectional area of stirrup legs effective in shear.
S_v = stirrup spacing along the length of the member.
f_y = should not be more than 415 N/mm^2.

Example:

Q.1 Minimum shear reinforcement in beams is provided in the form of stirrups
(a) to resist extra shear force due to live load
(b) to resist the effect of shrinkage of concrete
(c) to resist principal tension
(d) to resist shear cracks at the bottom of beam
[IES-2004]

Ans. (c)
The section at which the inclined crack in beam without shear reinforcement is formed first, is taken as the shear strength of concrete as the difference between the loads corresponding to the first crack and the ultimate failure is very less. Formation of such crack occur when the principal tensile stress reaches the tensile strength of concrete. At the mid-span of a simply supported beam subjected to uniformly distributed load, where shear is small and bending stress is large, the direction of principal tensile

stress is flat and is nearly equal to the flexural tensile stress. This will cause flexural cracks nearly vertical to the axis of the beam.

These are initiated even when $0.5\,\tau_c < \tau_v < \tau_c$. Thus minimum reinforcement is needed to prevent flexural crack due to principal tension.

26.5.2.1 Slabs

26.5.2.1 Minimum Reinforcement

A minimum reinforcement must be provided in slabs to take care of shrinkage and temperature effect. The mild steel reinforcement in either direction of slabs shall not be less than 0.15 percent of the total cross-sectional area. However, this value can be reduced to 0.12 percent when high strength deformed bars is used.

26.5.2.2 Maximum Diameter

The diameter of reinforcing bars shall not exceed one-eight of the total thickness of the slab.

Example:

Q.1 What is the value of minimum reinforcement (in case of Fe 415) in a slab?

(a) 0.1% (b) 0.12%
(c) 0.15% (d) 0.2%

[IES-2004]

Ans. (b)

Q.2 Temperature and shrinkage steel is provided in reinforced concrete slabs because

(a) it occupies larger area
(b) its thickness is less
(c) it is a main structural element
(d) it is a flexural member

[IES-2004]

Ans. (a)

Temperature and shrinkage reinforcement is invariably provided at right angles to the main longitudinal reinforcement in a slab because the surface area of slab is large.

Q.3 A reinforced concrete slab is 75 mm thick. The maximum size of reinforcement bar that can be used is

(a) 6 mm diameter (b) 8 mm diameter
(c) 10 mm diameter (d) 12 mm diameter

[IES-2011]

Ans. (b)

26.5.3 Columns

26.5.3.1 Longitudinal Reinforcement:

(a) The cross-sectional area of longitudinal reinforcement, shall be not less than 0.8 percent nor more than 6 percent of the gross cross-sectional area of column.

Note: The use of 6 percent reinforcement may involve practical difficulties in placing and compacting of concrete; hence lower percentage is recommended. Where bars from the columns below have to be lapped with those in the column under consideration, the percentage of steel shall usually not exceed 4 percent.

(b) In any column that has a larger cross-sectional area than that required to support the load the minimum percentage of steel shall be based upon the area of concrete required to resist the direct stress and not upon the actual area.

(c) The minimum number of longitudinal bars provided in a column shall be four in rectangular columns and six in circular columns.

(d) The bars shall not be less than 12 mm in diameter.

(e) A reinforced concrete column having helical reinforcement shall have at least six bars of longitudinal reinforcement within the helical reinforcement.

(f) In a helically reinforced column, the longitudinal bars shall be in contact with the helical reinforcement and equidistant around its inner circumference.

(g) Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300 mm.

(h) In case of pedestals in which the longitudinal reinforcement is not taken into account in strength calculations, nominal longitudinal reinforcement not less than 0.15 percent of the cross-sectional are shall be provided.

Note: Pedestal is a compression member, the effective length of which does not exceed three times the least lateral dimension.

Example:

Q.1 The limits of percentage 'p' of the longitudinal reinforcement in a column is
(a) 0.15% to 2% (b) 0.8% to 4%
(c) 0.8% to 6% (d) 0.8% to 8% **[IES-1996]**

Ans. (c)

Q.2 What is the minimum nominal percentage longitudinal reinforcement to be provided in a concrete pedestal as per relevant IS code?
(a) 0.4 (b) 0.2
(c) 0.15 (d) 0.1
[IES-2007]

Ans. (c)

Q.3 What is the minimum number of longitudinal bars provided in a reinforced concrete column of circular cross-section?
(a) 4 (b) 5
(c) 6 (d) 8
[IES-2005]

Ans. (c)

26.5.3.2 Transverse Reinforcement

(a) General: A reinforced concrete compression member shall have transverse or helical reinforcement so disposed that every longitudinal bar nearest to the compression face has effective lateral support against buckling. The effective lateral support is given by transverse reinforcement either in the form of circular rings capable of taking up circumferential tension or by polygonal links (lateral ties) with internal angles not exceeding 135°. The ends of the transverse reinforcement shall be properly anchored.

(c) Pitch and diameter of lateral ties

1. **Pitch:** The pitch of transverse reinforcement shall be not more than the least of the following distances:
   (i) The least lateral dimension of the compression members;
   (ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and
   (iii) 300 mm
2. **Diameter:** The diameter of the polygonal links or lateral ties shall be not less than one-fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm.

(d) Helical reinforcement

1. **Pitch:** Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar. Where an increased load on the column on the strength of the helical reinforcement is allowed for, the pitch of helical turns shall be not more than 75 mm, nor more than one-sixth of the core diameter of the column, nor less than 25 mm, nor less than three times the diameter of the steel bar forming the helix. In other cases, the requirements of **26.5.3.2** shall be complied with.

2. The diameter of the helical reinforcement shall be in accordance with **26.5.3.2** (c) (2).

Example:

Q.1 Lateral ties in RC columns are provided to resist
(a) bending moment
(b) shear
(c) buckling of longitudinal steel bars
(d) both bending moment and shear **[IES-2000]**

Ans. (c)

Q.2 A square column section of size 350 mm × 350 mm is reinforced with four bars of 25 mm diameter and four bars of 16 mm diameter. Then the transverse steel should be
(a) 5 mm dia @240 mm c/c (b) 6 mm dia @250 mm c/c
(c) 8 mm dia @250 mm c/c (d) 8 mm dia @350 mm c/c **[IES-2005]**

Ans. (c)

The diameter of transverse reinforcement shall not be less than one fourth of the diameter of the largest longitudinal bar and in no case less than 6 mm. So the diameter of the bar $\frac{25}{4}$ = 6.25 mm. Choose 8 mm diameter bar.

The pitch of the transverse reinforcement shall not be more than the least of the following:
(i) The least lateral dimension of the compression members i.e. 350 mm.
(ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied i.e. 16 × 16 = 256 mm
(iii) 300 mm

So pitch will be 250 mm c/c.

Q.3 Which one of the following statements is correct?
(a) Maximum longitudinal reinforcement in an axially loaded short column is 6% of gross sectional area
(b) Columns with circular section are provided with transverse reinforcement of helical type only
(c) Spacing of lateral ties cannot be more than 16 times the diameter of the tie bar
(d) Longitudinal reinforcement bar need not be in contact with lateral ties
[IES-1995]

Ans. (a)

27.0 EXPANSION JOINTS

The structures adjacent to the joint should preferably be supported on separate columns or walls but not necessarily on separate foundation. Expansion joint should be completely clear, reinforcement should not extend across expansion joint.

Normally, structures exceeding 45 m in length are designed with one or more expansion joints.

SECTION 4 : SPECIAL DESIGN REQUIREMENT FOR STRUCTURAL MEMBERS & SYSTEM

29.0 DEEP BEAMS

A beam shall be termed as deep beam when the ratio of effective span to overall depth, l / D is less than

(i) 2.0 for a simply supported beam; and

(ii) 2.5 for a continuous beam.

31.0 FLAT SLAB

The term flat slab means a reinforced concrete slab supported directly by column. There is no role of beam in this case. Some times drops are provided at interface of column and slab.

31.2.1 The minimum thickness of flat slab shall be 125 mm.

31.6.1 The critical section for shear shall be at a distance $d/2$ from the periphery of the column/capital/drop panel, perpendicular to the plane of the slab where d is the effective depth of the section. The shape of critical section for shear is geometrically similar to the support immediately below the slab as shown in the figure below.

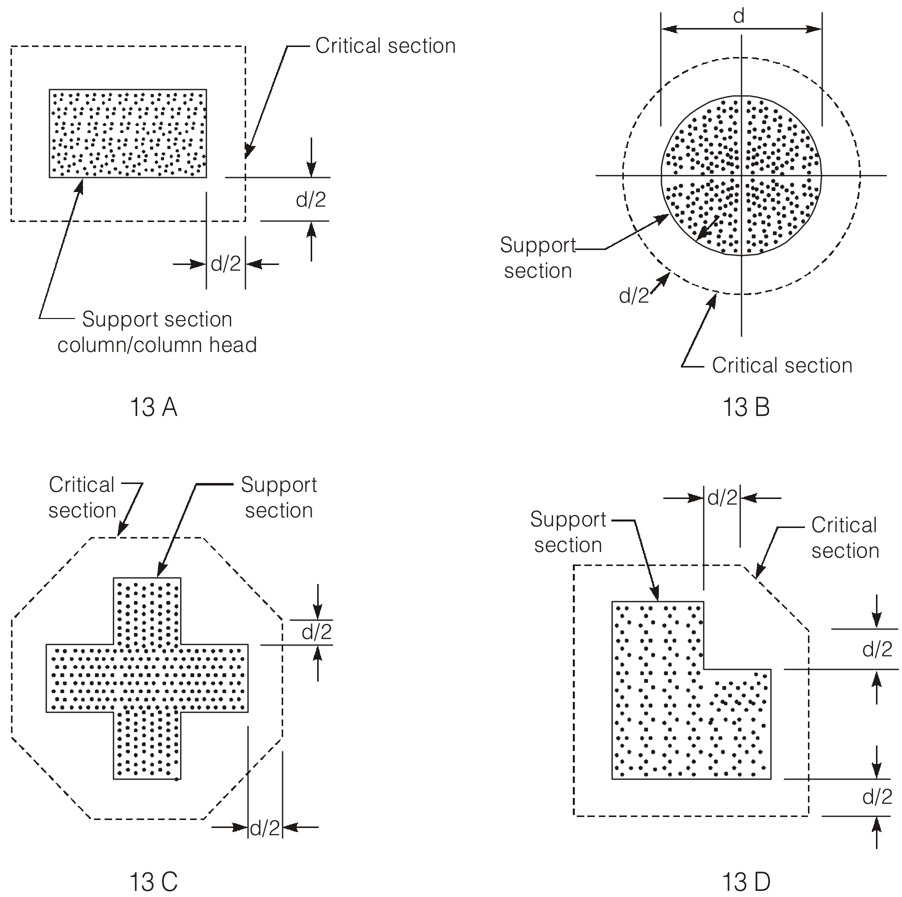


Fig. 13 : Critical sections in plan for shear in flat slab

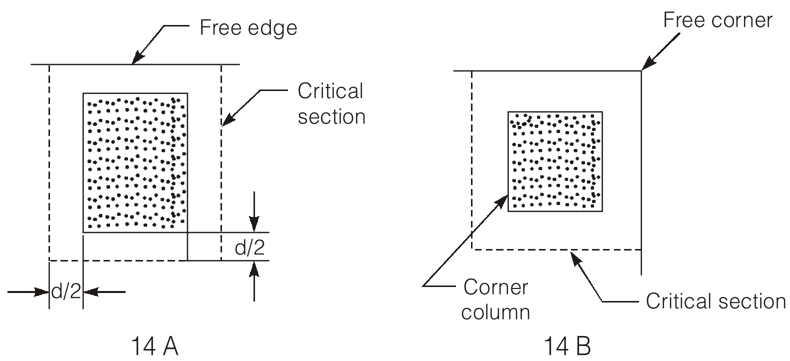


Fig. 14 : Effect of free edges on critical section for shear

Example:

Q.1 For shorter storey height, cheaper form work and better lighting facilities, what is the recommended slab floor?

(a) T beam and slab
(b) Two way slab
(c) Flat slab
(d) Framed structure

[IES-2008]

Ans. (c)

A flat slab is a typical type of construction in which a reinforced slab is built monolithically with the supporting columns and is reinforced in two or more directions without any provision of beams. Because of exclusion of beam-system in this type of construction, a plain ceiling is obtained, thus giving attractive appearance from architectural point of view. The plain ceiling diffuses the light better and is considered less vulnerable in the case of fire than the usual beam slab construction. The flat slab is easier to construct and requires cheaper formwork.

Q.2 Drop panel is a structural component in

(a) Grid floor
(b) Flat plate
(c) Flat slab
(d) Slab-beam system of floor

[IES-2005]

Ans. (c)

Q.3 Drops are provided in flats slabs to resist

(a) bending moment
(b) thrust
(c) shear
(d) torsion

[IES-1997]

Ans. (c)

The slabs supported directly on columns without beams are know as flat slabs. In such slabs, large bending moments and shear forces are induced in the vicinity of columns. Therefore the columns are flared at the top called column heads or column capitals and slab are thickened around the column capitals called drops for reducing the stresses due to moments and shears. The drops primarily resist shear.

32.0 WALLS

The minimum thickness of walls shall be 100 mm.

32.2.2 The design of a wall shall take account of the actual eccentricity of the vertical force subject to a minimum value of $0.05t$. Where, t is thickness of wall.

32.2.3 The ratio of effective height to the thickness shall not exceed 30.

32.5 **Minimum Requirements for Reinforcement in Walls**

The reinforcement for walls shall be provided as below:

(a) the minimum ratio of vertical reinforcement to gross concrete area shall be:
   1. 0.0012 for deformed bars not larger than 16 mm in diameter and with a characteristic strength of 415 N/mm^2 or greater.
   2. 0.0015 for other types of bars.
   3. 0.0012 for welded wire fabric not larger than 16 mm in diameter.

(b) Vertical reinforcement shall be spaced not farther apart than three times the wall thickness nor 450 mm.

(c) The minimum ratio of horizontal reinforcement to gross concrete area shall be:
   1. 0.0020 for deformed bars not larger than 16 mm in diameter and with a characteristic strength of 415 N/mm^2 or greater.
   2. 0.0055 for other types of bars.
   3. 0.0020 for welded wire fabric not larger than 16 mm in diameter.

(d) Horizontal reinforcement shall be spaced not farther apart than three times the wall thickness nor 450 mm.

32.5.1 For wall having thickness more than 200 mm, the vertical and horizontal reinforcement shall be provided in two grids, one near each face of the wall.

Example:

Q.1 Consider the following statements for minimum reinforcement to be provided in a wall as a ratio of vertical reinforcement to gross concrete area:
1. 0.0012 for deformed bars.
2. 0.0015 for all other types of bars.
3. 0.0012 for welded wire fabric with wires not larger than 16 mm in diameter.

Which of these statements is/are correct ?

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

[IES-2009]

Ans. (a)

34.0 FOOTINGS

34.1.2 In reinforced and plain concrete footings the thickness at the edge shall not be less than 150 mm for footings on soils.

34.2.3.2 The greatest bending moment to be used in the design of an isolated concrete footing which supports a column, pedestal or wall, shall be calculated at section located as follows:

(a) At the face of the column, pedestal or wall for footings supporting monolithic constructed column or walls.

(b) Half way between the centre-line and the edge of the wall, for footing under masonry walls.

(c) Halfway between the face of the Column or pedestal and the edge of the gusseted base, for footings under gusseted bases.

34.2.4 **Critical section for shear:** There are two type of shear failure in footings, namely, one way shear and two way shear (punching shear).

(a) In case of one way shear, critical section is at a distance *d* from face of column or wall. Where, *d* is effective depth of footing.

(b) In case of two way shear, critical section is at a distance *d*/2 from the face of column. Where, *d* is effective depth of footing.

Example:

Q.1 In the case of isolated square concrete footing, match the locations at which the stress resultants are to be checked, where d is effective depth of footing and select the correct answer using the codes given below the lists:

	Stress Resultant		Location
A.	Bending moment	1.	At face of column
B.	One way shear	2.	At d/2 from face of column
C.	Punching shear	3.	At d from face of column

Codes:

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

[IES-2006]

Ans. (d)

Q.2 While designing combined footing, the resultant of the column loads passes through the centre of gravity of the footing slab such that the net soil pressure obtained is
(a) parabolic
(b) trapezoidal
(c) uniform
(d) non-uniform

[IES-2008]

Ans. (c)

Q.3 How is the depth of footing for an isolated column governed?
1. By maximum bending moment
2. By shear force
3. By punching shear

Select the correct answer using the codes given below:
(a) 2 and 3 only
(b) 1 and 2 only
(c) 1 and 3 only
(d) 1, 2 and 3

[IES-2008]

Ans. (d)

34.4 Transfer of Load at the Base of Column

The compressive stress in concrete at the base of a column or pedestal shall be considered as being transferred by bearing to the top of the supporting pedestal or footing. The bearing pressure on the loaded area shall not exceed the permissible bearing stress in direct compression multiplied by a value equal to $\sqrt{A_1/A_2}$ but not greater than 2;

where A_1 = supporting area for bearing of footing, which in sloped or stepped footing may be taken as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base, the area actually loaded and having side slope of one vertical to two horizontal, and

A_2 = Loaded area at the column base.

For working stress method of design the permissible bearing stress on full area of concrete shall be taken as 0.25 f_{ck}; for limit state method of design the permissible bearing stress shall be 0.45 f_{ck}.

SECTION 5 : STRUCTURAL DESIGN (LIMIT STATE METHOD)

35.0 SAFETY AND SERVICEABILITY REQUIREMENT

35.1 The acceptable limit for the safety and serviceability requirements before failure occurs is called 'Limit state'.

35.3.2 There is limiting value of crack width from serviceability and durability point of view. Limit of crack width directly depends upon exposure condition as follows:

Maximum allowable crack	Exposure condition
0.3 mm	mild
0.2 mm	moderate
0.1 mm	severe, and more aggressive environment

Example:

Q.1 Consider the following statements with regard to crack formation and its control:
1. The surface width of the crack should not, in general, exceed 0.30 mm for structures not subjected to aggressive environment.
2. When depth of web in a beam exceeds 750 mm, side face reinforcement @0.1 per cent of web area should be provided on each face.
3. The nominal spacing of main bars in a slab should not exceed three times the effective depth of a solid slab or 300 mm, whichever is smaller.

Which of these statements is/are correct?

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

[IES-2005]

Ans. (c)

36.0 CHARACTERISTIC AND DESIGN VALUES AND PARTIAL SAFETY FACTORS

36.1 Characteristic strength means that value of the strength of the material below which not more than 95 percent of the test results are expected to fall.

Example:

Q.1 Characteristic strength of M20 concrete is 20 MPa. What is the number of cubes having 28 days' compressive strength greater than 20 MPa out of 100 cubes made with this concrete?

(a) All (b) 95
(c) 80 (d) 50

[IES-2006]

Ans. (b)

36.2 Characteristic load means that value of load which has a 95 percent probability of not being exceeded during the life of the structure.

36.3 Design values

Materials:

Design strength of material; $f_d = \dfrac{f}{\gamma_m}$

Loads:

Design load; $F_d = F\,\gamma_f$

where, f, F = Characteristic strength of material and characteristic load respectively.

γ_m, γ_f = Partial safety factor for material and load respectively.

γ_m = 1.5 for concrete and 1.15 for steel.

γ_f = depends upon combination of load that in being used for analysis.

36.4 Partial Safety Factors

36.4.1 Partial Safety Factors γ_f for Loads

The values of γ_f given in Table 18 shall normally be used.

36.4.2 Partial Safety Factors γ_m for Material Strength

36.4.2.1 When assessing the strength of a structure or structural member for the limit state of collapse, the values of partial safety factor, γ_m should be taken as 1.5 for concrete and 1.15 for steel.

Table 18 : Values of Partial Safety Factor γ_f for Loads

Load combination	Limit state of collapse			Limit states of serviceability		
	DL	IL	WL	DL	IL	WL
(1)	(2)	(3)	(4)	(5)	(6)	(7)
DL + IL	1.5	1.5	–	1.0	1.0	–
DL + WL	1.5	–	1.5	1.0	–	1.0
DL + IL + WL	1.2	1.2	1.2	1.0	0.8	0.8

Note: While considering earthquake effects, substitute EL for WL.

Example:

Q.1 When assessing the strength of a structure as per the limit state of collapse, the value of partial safety factor for steel is taken as

(a) 2.0 (b) 1.5

(c) 1.15 (d) 1.00

[IES-1998]

Ans. (c)

Q.2 A reinforced concrete beam is subjected to the following bending moments:

Dead load – 20 kN-m

Live load – 30 kN-m

Seismic load – 10 kN-m

The design bending moment for limit state of collapse is

(a) 60 kN-m (b) 75 kN-m

(c) 72 kN-m (d) 80 kN-m

[IES-2004]

Ans. (b)

The various load combinations are as follows:

(i) For Dead Load and Live Load the ultimate bending moment is given by,

$$M_u = 1.5\,(DL + LL)$$
$$= 1.5 \times (20 + 30)$$
$$= 75 \text{ kN-m}$$

(ii) For Dead Load and Earthquake (Seismic) Load the ultimate bending moment is given by,

$$M_u = 1.5\,(DL + EL)$$
$$= 1.5 \times (20 + 10)$$
$$= 45 \text{ kN-m}$$

(iii) For Dead Load, Live Load and Earthquake (Seismic) Load the ultimate bending moment is give by,

$$M_u = 1.2\,(DL + LL + EL)$$
$$= 1.2 \times (20 + 30 + 10)$$
$$= 72 \text{ kN-m}$$

So, design BM is maximum of all three combinations i.e. 75 kN-m.

Q.3 The factored loads at the limit state of collapse for DL + LL, DL + WL and DL + LL + WL combinations, according to IS : 456 - 1978 are respectively.
(a) 1.5 DL + 1.5 LL, 1.2 DL + 1.2 WL, 1.5 DL + 1.5 LL + 1.5 WL
(b) (0.9 or 1.5) DL + 1.5 LL, 1.5 DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL
(c) 1.2 DL + 1.2 LL, 1.5 DL + 1.5 WL, 1.5 DL + 1.5 LL + 1.5 WL
(d) 1.5 DL + 1.5 LL, (0.9 or 1.5)DL + 1.5 WL, 1.2 DL + 1.2 LL + 1.2 WL

[GATE-1993]

Ans. (d)

Q.4 For avoiding the limit state of collapse, the safety of RC structures is checked for appropriate combinations of Dead Load (DL), Imposed Load or Live Load (IL), Wind Load (WL) and Earthquake Load (EL). Which of the following load combinations is NOT considered?
(a) 0.9 DL + 1.5 WL
(b) 1.5 DL + 1.5 WL
(c) 1.5 DL + 1.5 WL + 1.5 EL
(d) 1.2 DL + 1.2 IL + 1.2 WL

[GATE-2004]

Ans. (c)

Q.5 Un-factored maximum bending moments at a section of a reinforced concrete beam resulting from a frame analysis are 50, 80, 120 and 180 kN-m under dead, live, wind and earthquake loads respectively. The design moment (kNm) as per **IS : 456-2000** for the limit state of collapse (flexure) is
(a) 195
(b) 250
(c) 345
(d) 372

[GATE-2008]

Ans. (d)

37.0 ANALYSIS

37.1.1 In no case, more than 30 percent moment redistribution is allowed.

Example:

Q.1 The maximum per cent of moment redistribution allowed in RCC beams is
(a) 10%
(b) 20%
(c) 30%
(d) 40%

[IES-2010]

Ans. (c)

37.1.2 Yield line theory or any other acceptable method may be used for analysis of slabs spanning in two directions at right angle.

38.0 LIMIT STATE OF COLLAPSE : FLEXURE

38.1 Assumptions

Design for the limit sate of collapse in flexure shall be based on the assumptions given below:

(a) Plane sections normal to the axis remain plane after bending.

(b) The maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending.

(c) The relationship between the compressive stress distribution in concrete and the strain in concrete may be assumed to be rectangle, trapezoid, parabola or any other shape which results in prediction of strength in substantial agreement with the results of test. An acceptable stress-strain curve is given in Fig. 21. For design purpose, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength. The partial safety factor γ_m = 1.5 shall be applied in addition to this.

Note: For the stress-strain curve in Fig. 21 the design stress block parameters are as follows Fig. 22.

Area of stress block = 0.36 f_{ck} x_u
Depth of centre of compressive force = 0.42 x_u
from the extreme fibre in compression

where,

f_{ck} = characteristic compressive strength of concrete, and
x_u = depth of neutral axis.

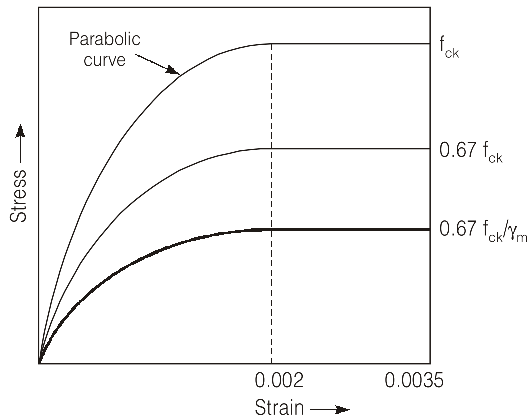


Fig. 21 : Stress-strain curve for concrete

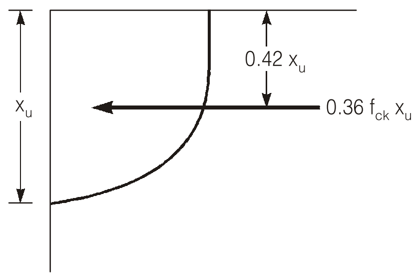


Fig. 22 : Stress block parameters

(d) The tensile strength of the concrete is ignored.

(e) The stresses in the reinforcement are derived from representative stress-strain curve for the type of steel used. Typical curves are given in Fig. 23. For design purposes the partial safety factor γ_m, equal to 1.15 shall be applied.

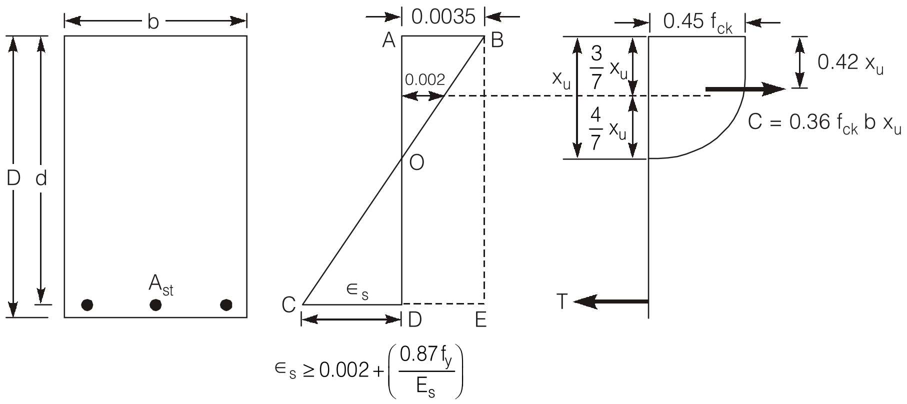
(f) The maximum strain in the tension reinforcement in the section at failure shall not be less than:

$$\frac{f_y}{1.15\,E_s} + 0.002$$

where, f_y = characteristic strength of steel, and
E_s = modulus of elasticity of steel

Thus stress in concrete at collapse = $\frac{0.67}{1.5} f_{ck} = 0.447 f_{ck}$

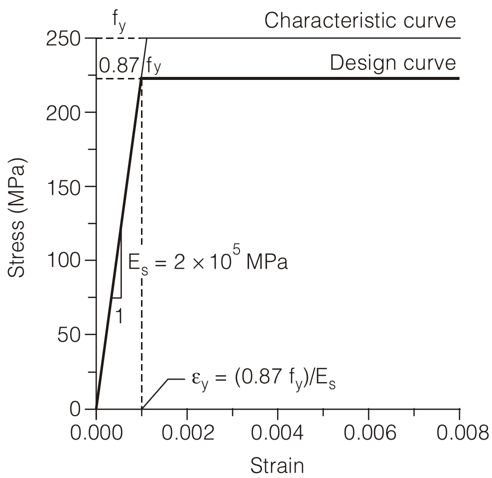
Assumption (b) and (f) govern the maximum depth of neutral axis in flexural members. The strain distribution across the member corresponding to those limiting condition is shown in figure below. The maximum depth of neutral axis $X_{u,max}$ is obtained directly from the strain diagram by considering similar triangle, ΔABO, and ΔBCE



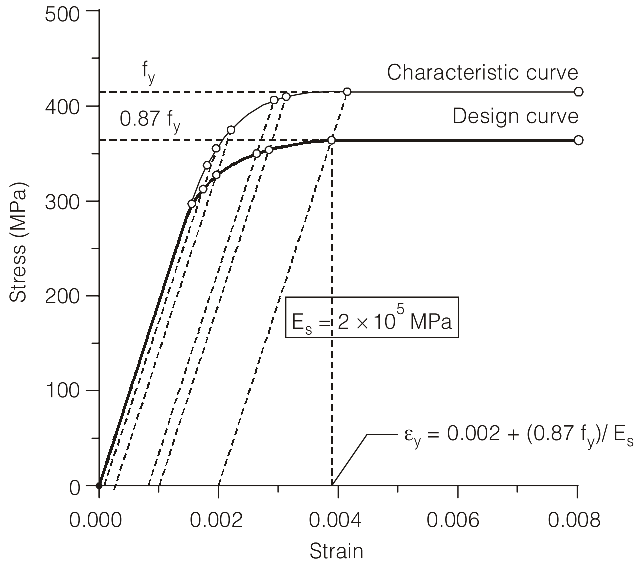
Rectangular section Strain diagram Stress diagram

$$\frac{x_{u,max}}{d} = \frac{0.0035}{0.002 + 0.0035 + \frac{0.87 f_y}{E_s}}$$

f_y	$x_{u,max}/d$
250	0.53
415	0.48
500	0.46



23 A Characteristic and design stress-strain curves for Fe250 grade mild steel



23 B Characteristic and design stress-strain curves for Fe415 grade cold-worked steel

Fig. 23 Representative stress strain curve for reinforcement

Example:

Q.1 If f_{cu} and f_y are cube compressive strength of concrete and yield stress of steel respectively and E_s is the modulus of elasticity of steel for all grades of concrete, the ultimate flexural strain in concrete can be taken as

(a) 0.002 (b) $\frac{f_{cu}}{1000}$

(c) 0.0035 (d) $\frac{f_y}{1.15E_s} + 0.002$

[IES-1995]

Ans. (d)

Q.2 The maximum strain in concrete at the outermost compression fiber in the limit state design of flexural member is (as per IS:456)

(a) 0.0020 (b) 0.0035

(c) 0.0065 (d) 0.0050

[IES-1996]

Ans. (b)

Q.3 As per IS:456, the ratio of stress in concrete to its characteristic strength at collapse in flexure for design purposes is taken as

(a) 0.67 (b) 0.576

(c) 0.447 (d) 0.138

[IES-1999]

Ans. (c)

Q.4 The minimum strain at failure in the tensile reinforcement (F_y = 400 MPa) of RCC beam as per limit state method is

(a) 0.0020 (b) 0.0028

(c) 0.0037 (d) 0.0045

[IES-2011]

Ans. (c)

Q.5 According to Whitney's theory, the maximum depth of concrete stress block in a balanced RCC beam section of depth 'd' is
(a) 0.3d
(b) 0.43d
(c) 0.5d
(d) 0.53d [IES-2000]

Ans. (d)

Whitney's theory is ultimate load theory. It is based on the assumption that ultimate strain in concrete is 0.3% and the compressive stress at the extreme edge of the section corresponds to this strain. Whitney replaced the actual parabolic stress diagram by a rectangular stress diagram such that the centre of gravity of both diagrams lies at the same point and their areas are also equal. He found that the average stress of the rectangular stress diagram is $K\sigma'_{cu}$. Where $K\sigma'_{cu}$ is the ultimate compressive strength of concrete cylinders at 28-day and K = 0.85.
The depth of rectangular stress block = 0.537d.

Q.6 In limit state design of concrete for flexure, the area of stress block is taken as
(a) $0.530\ f_{ck} \cdot X_u$
(b) $0.446\ f_{ck} \cdot X_u$
(c) $0.420\ f_{ck} \cdot X_u$
(d) $0.360\ f_{ck} \cdot X_u$ [IES-2011]

Ans. (d)

Q.7 As per IS:456, for a singly reinforced rectangular section,
(a) $\frac{X_{u,max}}{d}$ for Fe 415 steel is 0.48
(b) the depth of the centroid of compression is 0.43 $x_{u,max}$
(c) the depth of the rectangular position of the stress block is 0.38 $x_{u,max}$
(d) the maximum value of lever arm is $d - x_{u,max}$ [IES-2000]

Ans. (a)

Q.8 Stress-strain curve of concrete is
(a) A perfect straight line upto failure
(b) Straight line upto 0.002% strain value and then parabolic upto failure.
(c) Nearly parabolic upto 0.002% strain value and then a straight line upto failure
(d) Hyperbolic upto 0.002% strain value and then a straight line upto failure
[IES-2003, 2011]

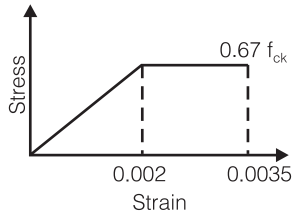
Ans. (c)

Q.9 The maximum strain in the tension reinforcement in the section at failure when designed for the limit state of collapse should be
(a) $> \left(\frac{f_y}{1.15E_s} + 0.002\right)$
(b) $< \left(\frac{f_y}{1.15E_s} + 0.002\right)$
(c) exactly equal to $\left(\frac{f_y}{1.15E_s} + 0.002\right)$
(d) < 0.002
where, f_y = Characteristic strength of steel, and E_s = Modulus of elasticity of steel
[IES-2006]

Ans. (a)

Linked Answer Questions (10 and 11):

Assume straight line instead of parabola for stress-strain curve of concrete as given below and partial factor of safety as 1.0.



A rectangular under-reinforced concrete section of 300 mm width and 500 mm effective depth is reinforced with 3 bars of grade Fe-415, each of 16 mm diameter. Concrete mix is M-20.

Q.10 The depth of the neutral axis from the compression fibre is

(a) 76 mm (b) 81 mm
(c) 87 mm (d) 100 mm **[GATE-2005]**

Ans. (a)

Q.11 The depth of the neutral axis obtained as per **IS:456-2000** differs from the depth of neutral axis obtained in above question by

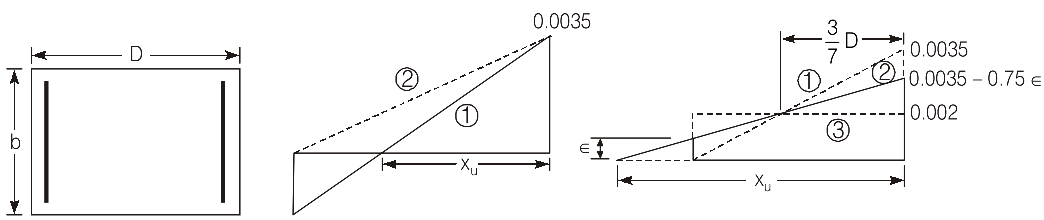
(a) 15 mm (b) 20 mm
(c) 25 mm (d) 32 mm

[2005 : 2 Marks]

Ans. (c)

39.0 LIMIT STATE OF COLLAPSE : COMPRESSION

39.1 **Assumptions :** (a), (c), (d) and (e) of 38.1 for flexural members are also applicable to members subjected to combined axial load and bending. The assumption (b) that the maximum strain in concrete at the outermost compression fibre is 0.0035 is also applicable when the neutral axis lies within the section and in limiting case when the neutral axis lies along the edge of the section; in the later case the strain varies from 0.0035 at the highly compressed edge to zero at the opposite edge as shown by line ② in the Fig. (b). For purely axial compression, the strain is assumed to be uniformly equal to 0.002 across the section as shown by the line ③ in Fig. (c). The strain distribution lines for these two cases intersect each other at a depth of 3D/7 from the highly compressed edge. This point is assumed to act as a fulcrum from the strain distribution line when the neutral axis lies outside the section as shown in the Fig. (c). This leads to the assumption that the strain at the highly compressed edge is 0.0035 minus 0.75 times the strain at the least compressed edge.



(a) Column section (b) Strain diagram-neutral axis within the section (c) Strain diagram-neutral axis outside bending

Example:

Q.1 Read the following two statements:

I. Maximum strain in concrete at the outermost compression fibre is taken to be 0.0035 in bending

II. The maximum compressive strain in concrete in axial compression is taken as 0.002

Keeping the provisions of IS 456 2000 on limit state design in mind, which of the following is true:

(a) Statement I is True but II is False
(b) Statement I is False but II is True
(c) Both statement I and II are True
(d) Both statement I and II are False [GATE-2002]

Ans. (c)

39.3 When the minimum eccentricity calculated as per clause 25.4 does not exceed 5 percent the lateral dimension, the member may be designed by the following equation

$$P_u = 0.4\, f_{ck}\, A_c + 0.67\, f_y\, A_{sc}$$

where,
P_u = axial load on the member
f_{ck} = characteristic compressive strength of concrete
A_c = area of concrete (excluding area of steel, means, $A_c = A_{gross} - A_{steel}$)
f_y = characteristic strength of the compression reinforcement
A_{sc} = area of longitudinal reinforcement for column

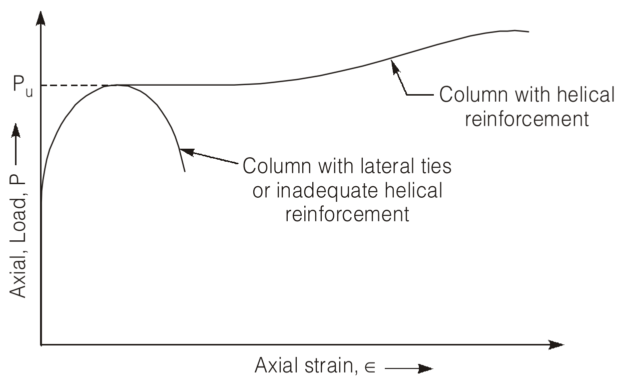
Example:

Q.1 A rectangular column section of 250 mm × 400 mm is reinforced with five steel bars of grade Fe-500, each of 20 mm diameter. Concrete mix is M 30. Axial load on the column section with minimum eccentricity as per **IS:456-2000** using limit state method can be applied upto

(a) 1707.37 (b) 1805.30
(c) 1806.40 (d) 1903.7 [GATE-2005]

Ans. (a)

39.4 The strength of compression members with helical reinforcement satisfying the requirement of code shall be taken as 1.05 times the strength of similar member with lateral ties. Failure of column with helical ties is more ductile compare to column with lateral ties as shown in figure below.



Behaviour of columns with and Without helical reinforcement

39.4.1 The ratio of the volume of helical reinforcement to the volume of the core shall not be less than $0.36\left(\frac{A_g}{A_c}-1\right)\frac{f_{ck}}{f_y}$

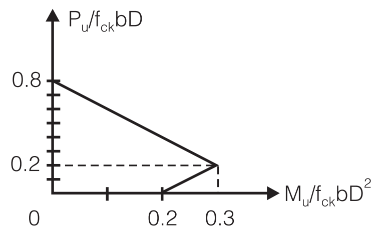
where,

A_g = gross area of the section,
A_c = area of the core of the helically reinforced column measured to the outside diameter of the helix,
f_{ck} = characteristic compressive strength of the concrete, and
f_y = characteristic strength of the helical reinforcement but not exceeding 415 N/mm^2.

39.5 A member subjected to axial force and uniaxial bending shall be designed using interaction diagrams available in **SP : 16**.

Example:

Q.1 A RC column of square cross-section (400 × 400 mm^2) has its column load-moment interaction diagram as shown in figure below.



What is the maximum uniaxial eccentricity at which a factored load P_u = 640 kN can be applied safely? (Take f_{ck} = 20 MPa)

(a) 300 mm (b) 400 mm
(c) 600 mm (d) 800 mm

[IES-2009]

Ans. (c)

$$\frac{P_u}{f_{ck}bD} = \frac{640\times10^3}{20\times400\times400} = 0.2$$

For $$\frac{P_u}{f_{ck}bD} = 0.2,$$

we have $\frac{M_u}{f_{ck}bD^2}$ = 0.3 from the interaction diagram.

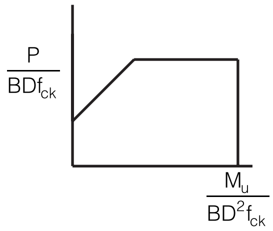
$\therefore$ $M_u = 0.3\times20\times400\times400^2\times10^{-3}$

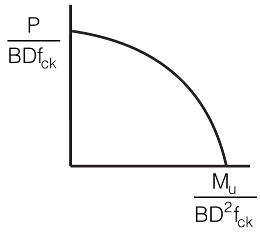
$\Rightarrow$ M_u = 384000 kN-mm

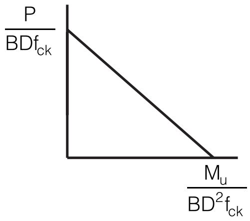
But maximum uniaxial eccentricity is given by

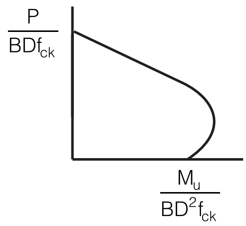
$$e = \frac{M_u}{P_u} = \frac{384000}{640} = 600 \text{ mm}$$

Q.2 A rectangular reinforced column (B × D) has been subjected to uniaxial bending moment M and axial load P. Characteristic strength of concrete = f_{ck}. Which one among the following column design curves shows the relation between M and P qualitatively?

(a) 

(b) 

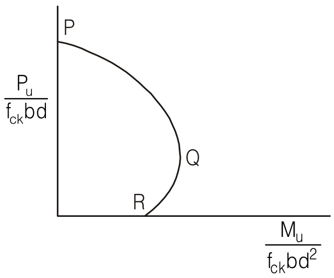
(c) 

(d) 

[IES-2006]

Ans. (d)

Q.3 (i) Interaction diagram of a rectangular reinforced concrete beam column is shown in the figure. With reference to this figure, which of the following statements in (a) and in (b) below are correct?



(a) Point Q represents balanced failure
(b) Point R represents balanced failure
(c) Point P represents balanced failure
(d) Point Q represents balanced failure under maximum eccentric compression

(ii) (a) PQ corresponds to the primary tension failure range
(b) QR corresponds to the primary tension failure range
(c) QR corresponds to the primary compression failure range
(d) PQ corresponds to the range of increase in axial force capacity with increase in bending moment capacity

[GATE-1993]

Ans. (i) (a), (ii) (b)

39.6 The resistance of member subjected to axial force and biaxial bending shall be obtained by the satisfying following equation

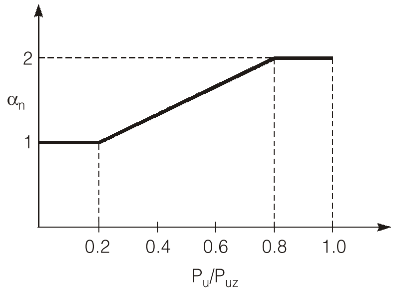
$$\left[\frac{M_{ux}}{M_{ux1}}\right]^{\alpha_n} + \left[\frac{M_{uy}}{M_{uy1}}\right]^{\alpha_n} \leq 1.0$$

where, M_{ux}, M_{uy} = Moments about x and y axis due for an axial load of P_u, bending about x and y axis respectively and

M_{ux1}, M_{uy1} = Maximum uniaxial moment capacity for an axial load of P_u, bending about x and y axis respectively and

α_n = is related to P_u/P_{uz} as shown in the figure below

P_{uz} = $0.45\, f_{ck}\, A_c + 0.75\, f_y\, A_{sc}$



39.7 **Slender compression member (Long column)**

An additional moment is considered while designing long column which is calculated as follows:

$$M_{ax} = \frac{P_u D}{2000}\left\{\frac{l_{ex}}{D}\right\}^2$$

$$M_{ay} = \frac{P_u b}{2000}\left\{\frac{l_{ey}}{b}\right\}^2$$

Design of long column is done as per procedure of clause 39.5 and 39.6.

Example:

Q.1 Which of the following are the additional moments considered for design of slender compression member in lieu of deflection in x and y directions?

(a) $\frac{P_u l_{ex}^2}{2000D}$ and $\frac{P_u l_{ey}^2}{2000D}$ (b) $\frac{P_u l_{ex}}{2000D}$ and $\frac{P_u l_{ey}}{2000D}$

(c) $\frac{P_u l_{ex}^2}{2000D}$ and $\frac{P_u l_{ey}^2}{2000b}$ (d) $\frac{P_u l_{ex}^2}{200D}$ and $\frac{P_u l_{ey}^2}{200D}$

[IES-2005]

where P_u is axial load; l_{ex} and l_{ey} are effective lengths in respective directions; D is depth of section perpendicular to major axis; b is width of the member).

Ans. (c)

40.0 LIMIT STATE OF COLLAPSE : SHEAR

40.1 The nominal shear stress in beams of uniform depth shall be obtained by the following equation:

$$\tau_v = \frac{V_u}{bd}$$

In the case of beams of varying depth the equation shall be modified as:

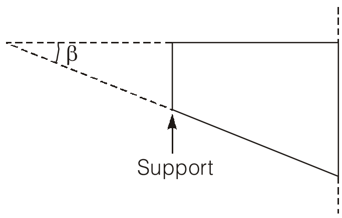


Fig. (i)

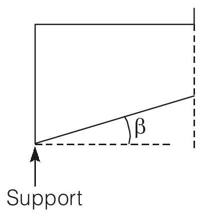


Fig. (ii)

$$\tau_v = \frac{V_u \pm \frac{M_u}{d}\tan\beta}{bd} \qquad \begin{bmatrix} -\text{ve for Fig. (i) and} \\ +\text{ve for Fig. (ii)} \end{bmatrix}$$

where, V_u, M_u = shear force and bending moment at the section due to design load

β = angle between the top and bottom edge of the beam as shown in the figure above.

Example:

Q.1 While checking shear resistance of reinforced concrete beams for limit state of collapse as per IS:456, which one of the following nominal shear stress recommendations is to be adhered to? (V_u is shear force at vertical cross-section, 'b' and 'd' are overall breadth and effective depth of beam respectively)

(a) $\frac{0.5V_u}{bd}$ (b) $\frac{2V_u}{5bd}$

(c) $\frac{V_u}{0.5bd}$ (d) $\frac{V_u}{bd}$

[IES-2000]

Ans. (d)

40.2 Design Shear Strength of Concrete

40.2.1 The design shear strength of concrete in beams without shear reinforcement is given in Table 19.

40.2.1.1 For solid slabs, the design shear strength for concrete shall be $\tau_c k$, where k has the values given below:

Overall depth of slab (mm)	300 or more	275	250	225	200	175	150 or less
(k)	1.00	1.05	1.10	1.15	1.20	1.25	1.30

Note: This provision shall not apply to flat slabs for which **31.6** shall apply.

40.2.2 Shear Strength of Members under Axial Compression

For members subjected to axial compression P_u, the design shear strength of concrete, given in table 19, shall be multiplied by the following factor:

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \text{ but not exceeding 1.5}$$

where, P_u = axial compressive force in Newtons,

A_g = gross area of the concrete section in mm^2, and

f_{ck} = characteristic compressive strength of concrete.

Example:

Q.1 **Assertion (A) :** The design shear strength of axially loaded beams is increased by a factor, as per IS codes, $1+\left(\frac{3P_u}{A_g f_{ck}}\right)$ or 1.5 whichever is less.

(where P_u is axial load, A_g gross area of column and f_{ck} characteristic concrete strength)

Reason (R) : The presence of axial compressive force is to hasten the formation of both flexural and inclined cracks.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[IES-2005]

Ans. (c)

40.2.3 **With Shear Reinforcement:** Under no circumstances, even with shear reinforcement, shall the nominal shear stress in beams τ_v exceed τ_{cmax} given in Table 20.

40.3 **Minimum Shear Reinforcement:** When τ_v is less than τ_c given in Table 19, minimum shear reinforcement shall be provided in accordance with **26.5.1.6**.

Q.1 If the nominal shear stress (τ_v) at a section does not exceed the permissible shear stress (τ_c)
(a) minimum shear reinforcement is still provided
(b) shear reinforcement is provided to resist the nominal shear stress
(c) no shear reinforcement is provided
(d) shear reinforcement is provided for the difference of the two

[IES-1995]

Ans. (a)

Q.2 **Assertion (A) :** Minimum shear reinforcement in all shallow beams is provided when shear stress exceeds $0.5\tau_c$ (Where τ_c is design shear stress).
Reason (R) : Minimum shear reinforcement prevents formation of inclined cracks and avoids abrupt failures and introduces ductility in shear.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[IES-2005]

Ans. (a)

Q.3 Minimum shear reinforcement is provided to
(a) resist shear force at the support
(b) resist shear on account of accidental torsion
(c) arrest the longitudinal cracks on side faces due to shrinkage and temperature variation
(d) resist shear in concrete developing on account of non-homogeneity of concrete

[IES-2004]

Ans. (c)

40.4 **Design of Shear Reinforcement:** When τ_v exceeds τ_c given in Table 19, shear reinforcement shall provided in any of the following forms:
(a) Vertical stirrups,
(b) Bent-up bars along with stirrups, and
(c) Inclined stirrups

Table 19 : Design Shear Strength of Concrete, τ_c, N/mm²

$100\frac{A_s}{bd}$	Concrete grade M15	M20	M25	M30	M35	M40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
≤ 0.15	0.28	0.28	0.29	0.29	0.29	0.30
0.25	0.35	0.36	0.36	0.37	0.37	0.38
0.50	0.46	0.48	0.49	0.50	0.50	0.51
0.75	0.54	0.56	0.57	0.59	0.59	0.60
1.00	0.60	0.62	0.64	0.66	0.67	0.68
1.25	0.64	0.67	0.70	0.71	0.73	0.74
1.50	0.68	0.72	0.74	0.76	0.78	0.79
1.75	0.71	0.75	0.78	0.80	0.82	0.84
2.00	0.71	0.79	0.82	0.84	0.86	0.88
2.25	0.71	0.81	0.85	0.88	0.90	0.92
2.50	0.71	0.82	0.88	0.91	0.93	0.95
2.75	0.71	0.82	0.90	0.94	0.96	0.98
3.00 above	0.71	0.82	0.92	0.96	0.99	1.01

Note: The term A_s is the area of longitudinal tension reinforcement.

Table 20 : Maximum Shear Stress, τ_c, N/mm²

Concrete grade	M15	M20	M25	M30	M35	M40 and above
$\tau_{c\,max}$, N/mm²	2.5	2.8	3.1	3.5	3.7	4.0

Where bent-up bars are provided, their contribution towards shear resistance shall not be more than half that of the total shear reinforcement.
Shear reinforcement shall be provided to carry a shear equal to $V_u - \tau_c\, bd$. The strength of shear reinforcement V_{us} shall be calculated as below:

(i) For vertical stirrups:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{S_v}$$

(ii) For inclined stirrups of a series of bars bent-up at different cross-sections:

$$V_{us} = \frac{0.87 f_y A_{sv} d}{S_v}(\sin\alpha + \cos\alpha)$$

(iii) For single bar or single group of parallel bars, all bent-up at the same cross-section:

$$V_{us} = 0.87 f_y A_{sv} \sin\alpha$$

where, A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance s_v

S_v = spacing of the stirrups or bent-up bars along the length of the member

τ_v = nominal shear stress
τ_c = design shear strength of the concrete
b = breadth of the member which for flanged beams, shall be taken as the breadth of the web b_w
f_y = characteristic strength of the stirrups or bet-up reinforcement which shall not be taken greater than 415 N/mm^2
α = angle between the inclined stirrup or bent-up bar and the axis of the member
d = effective depth

Example:

Q.1 Diagonal tension reinforcement is provided in a beam as
(a) longitudinal bars
(b) bent up bars
(c) helical reinforcement
(d) 90° bend at the bends of main bars

[IES-2004]

Ans. (b)

Q.2 Shear strength of concrete in a reinforced concrete beam is a function of which of the following:
1. Compressive strength of concrete
2. Percentage of shear reinforcement
3. Percentage of longitudinal reinforcement in tension in the section
4. Percentage total longitudinal reinforcement in the section

Select the correct answer using the codes given below:
(a) 1, 2 and 4 (b) 1, 2 and 3
(c) Only 1 and 3 (d) Only 1 and 4

[IES-2006]

Ans. (c)

Q.3 The maximum permissible shear stress $\tau_{c,\,max}$ given in **IS : 456** is based on
(a) diagonal tension failure (b) diagonal compression failure
(c) flexural tension failure (d) flexural compression failure

[IES-2001]

Ans. (b)
If the area of shear reinforcement is large, failure may occur due to shear compression failure of concrete prior to the yielding of the steel. Therefore the upper limit of the area of shear reinforcement corresponds to the yielding of shear reinforcement and shear compression failure of bars simultaneously.

Q.4 How can shear strength be ensured in a beam?
(a) By providing binding wire on main bars
(b) By providing HYSD bars instead of mild steel bars
(c) By providing rounded aggregate
(d) By providing stirrups

[IES-2008]

Ans. (d)

41.0 LIMIT STATE OF COLLAPSE : TORSION

41.2 Critical Section

Sections located less than a distance d, from the face of the support may be designed for the same torsion as computed at a distance *d*, where *d* is the effective depth.

41.3 Shear and Torsion

41.3.1 Equivalent shear, V_e, shall be calculated from the formula:

$$V_e = V_u + 1.6\frac{T_u}{b}$$

where,
V_e = equivalent shear,
V_u = shear,
T_u = torsional moment, and
b = width of beam

The equivalent nominal shear stress, τ_{ve} in this case shall be calculated as given in **40.1**, except for substituting V_u by V_e. The values of τ_{ve} shall not exceed the values of $\tau_{c\,max}$ given in Table 20.

41.3.2 If the equivalent nominal shear stress, τ_{ve} does not exceed τ_c given in Table 19, minimum shear reinforcement shall be provided as per **26.5.1.6**.

41.3.3 If τ_{ve} exceed τ_c given in Table 19, both longitudinal and transverse reinforcement shall be provided in accordance with **41.4**.

41.4 Reinforcement in Members Subjected to Torsion

41.4.1 Reinforcement for torsion, when required, shall consist of longitudinal and transverse reinforcement.

41.4.2 Longitudinal reinforcement: The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{el}, given by

$$M_{el} = M_u + M_t$$

where,
M_u = bending moment at the cross-section, and

$$M_t = T_u\left(\frac{1+D/b}{1.7}\right)$$

T_u is torsional moment, D is the overall depth of the beam and b is the width of the beam.

Example:

Q.1 An RC structural member rectangular in cross section of width b and depth D is subjected to a combined action of bending moment M and torsional moment T. The longitudinal reinforcement shall be designed for a moment M_e given by

(a) $M_e = M + \frac{T(1+D/b)}{1.7}$

(b) $M_e = M + \frac{T(1-D/b)}{1.7}$

(c) $M_e = \frac{T(1+D/b)}{1.7}$

(d) $M_e = \frac{T(1-b/D)}{1.7}$

[IES-2006]

Ans. (a)

Common Data for Questions (2 and 3):

At the limit state of collapse, an RC beam is subjected to flexural moment 200 kN-m, shear force 20 kN and torque 9 kN-m. The beam is 300 mm wide and has a gross depth of 425 mm, with an effective cover of 25 mm. The equivalent nominal shear stress (τ_{ve}) as calculated by using the design code turns out to be lesser than the design shear strength (τ_c) of the concrete.

Q.2 The equivalent shear force (V_c) is

(a) 20 kN (b) 54 kN
(c) 56 kN (d) 68 kN

[GATE-2004]

Ans. (d)

Q.3 The equivalent flexural moment (M_{eq}) for designing the longitudinal tension steel is

(a) 187 kN-m (b) 200 kN-m
(c) 209 kN-m (d) 213 kN-m

[GATE-2004]

Ans. (d)

41.4.2.1 If the numerical value of M_t as defined in **41.4.2** exceeds the numerical value of the moment M_u, longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also withstand an equivalent M_{e2} given by $M_{e2} = M_t - M_u$, the moment M_{e2} being taken as acting in the opposite sense to the moment. M_u.

41.4.3 Transverse reinforcement: Two legged closed hoops enclosing the corner longitudinal bars shall have an area of cross-section A_{sv}, given by

$$A_{sv} = \frac{T_u s_v}{b_1 d_1 (0.87 f_y)} + \frac{V_u s_v}{2.5 d_1 (0.87 f_y)}$$

but the total transverse reinforcement shall not be less than

$$\frac{(\tau_{ve} - \tau_c) b \cdot s_v}{0.87 f_y}$$

where,
T_u = torsional moment,
V_u = shear force,
S_v = spacing of the stirrup reinforcement,
b_1 = centre-to-centre distance between corner bars in the direction of the width,
d_1 = centre-to-centre distance between corner bars,
b = breadth of the member,
f_y = characteristic strength of the stirrup reinforcement,
τ_{ve} = equivalent shear stress as specified in **41.3.1**, and
τ_c = shear strength of the concrete as per Table 19.

Example:

Common Data for Questions (1 and 2):

A reinforced concrete beam of rectangular cross section of breadth 230 mm and effective depth 400 mm is subjected to a maximum factored shear force of 120 kN. The grades of concrete, main steel and stirrup steel are M 20, Fe 415 and Fe 250 respectively. For the area of main steel provided, the design shear strength t_c as per **IS:456-2000** is 0.48 N/mm^2. The beam is designed for collapse limit state.

Q.1 The spacing (mm) of 2-legged 8 mm stirrups to be provided is
(a) 40 (b) 115
(c) 250 (d) 400

[GATE-2008]

Ans. (b)

Q.2 In addition, the beam is subjected to a torque whose factored value is 10.90 kN-m. The stirrups have to be provided to carry a shear (kN) equal to
(a) 50.42 (b) 130.56
(c) 151.67 (d) 200.23

[GATE-2008]

Ans. (c)

ANNEX B : STRUCTURAL DESIGN (WORKING STRESS METHOD)

B-1.3 Assumption for Design of Members

Since working stress method is based on elastic theory so the following assumptions shall be made:

(a) At any cross-section, plane sections before bending remain plain after bending.

(b) All tensile stresses are taken up by reinforcement and none by concrete, except as otherwise specifically permitted.

The tensile stress shall be calculated as $\dfrac{F}{A_c + mA_{st}}$.

where, F_t = total tension on the member minus pretension in steel, if any, before concreting;

A_c = cross-sectional area of concrete excluding any finishing material and reinforcing steel;

m = modular ratio; and

A_{st} = cross-sectional area of reinforcing steel in tension.

B-2.1.2 The stress-strain relationship of steel and concrete, under working loads, is a straight line.

The modular ratio m has the value $\dfrac{280}{3\sigma_{cbc}}$, where σ_{cbc} is permissible compressive stress due to bending in concrete in N/mm^2 as specified in Table 21.

Note: The expression given for m partially takes into account long term effects such as creep. Therefore this m is not the same as the modular ratio derived based on the value E_c given in **6.2.3.1**.

Example:

Q.1 What is the modular ratio to be used in the analysis of RC beams using working stress method if the grade of concrete is M20?
(a) 18.6 (b) 13.3
(c) 9.9 (d) 6.5

[IES-2009]

Ans. (b)

Q.2 The working stress method of design specifies the value of modular ratio, $m = 280/(3\sigma_{cbc})$, where σ_{cbc} is the allowable stress in bending compression in concrete. To what extent does the above value of 'm' make any allowance for the creep of concrete?

(a) No compensation (b) Full compensation
(c) Partial compensation (d) The two are unrelated

[GATE-2003]

Ans. (c)

B-2.0 PERMISSIBLE STRESSES

B-2.1 Permissible stresses for the various grades of concrete shall be taken as those given in Table 21 and 23.

Table 21 : Permissible Stresses in Concrete

Grade of concrete	Permissible stress in compression (N/mm^2)	
	Bending σ_{cbc}	Direct σ_{cc}
(1)	(2)	(3)
M 10	3.0	2.5
M 15	5.0	4.0
M 20	7.0	5.0
M 25	8.5	6.0
M 30	10.0	8.0
M 35	11.5	9.0
M 40	13.0	10.0
M 45	14.5	11.0
M 50	16.0	12.0

B-2.1.1 Direct Tension

For members in direct tension, when full tension is taken by the reinforcement alone, the tensile stress shall be not greater than the value given below:

Grade of concrete	M10	M15	M20	M25	M30	M35	M40	M45	M50
Tensile stress (N/mm^2)	1.2	2.0	2.8	3.2	3.6	4.0	4.4	4.8	5.2

B-2.2 Permissible Stresses in Steel Reinforcement

Permissible stresses in steel reinforcement shall not exceed the values specified in Table 22.

B-2.2.1 In flexural members the value of σ_{st} given in Table 22 is applicable at the centroid of the tensile reinforcement subjected to the condition that when more than one layer of tensile reinforcement is provided, the stress at the centroid of the outermost layer shall not exceed by more than 10 percent the value given in Table 22.

B-2.3 Increases in Permissible Stresses

Where stresses due to wind (or earthquake) temperature and shrinkage effects are combined with those due to dead, live and impact load, the stresses specified in Tables 21, 22 and 23 may be exceeded upto a limit of $33\frac{1}{3}$ percent. Wind and seismic forces need not be considered as acting simultaneously.

B-3 PERMISSIBLE LOADS IN COMPRESSION MEMBERS

B-3.1 Pedestals and Short Columns with Lateral Ties

The axial load P permissible on a pedestal or short column reinforced with longitudinal bars and lateral ties shall not exceed that given by the following equation:

$$P = \sigma_{cc} A_c + \sigma_{sc} A_{sc}$$

where, σ_{cc} = permissible stress in concrete in direct compression,
A_c = cross-sectional area of concrete excluding any finishing material and reinforcing steel,
σ_{sc} = permissible compressive stress for column bars, and
A_{sc} = cross-sectional area of the longitudinal steel.

Note: The minimum eccentricity mentioned in 25.4 may be deemed to be incorporated in the above equation.

B-3.2 Short Columns with Helical Reinforcement

The permissible load for columns with helical reinforcement satisfying the codal requirement shall be 1.05 times the permissible load for similar member with lateral ties or rings.

B-3.3 Long Columns

The maximum permissible stress in a reinforced concrete column having a ratio of effective column length to least lateral dimension above 12 shall not exceed that which results from the multiplication of the appropriate maximum permissible stress as specified under **B-2.1** and **B-2.2** by the coefficient C_r, given by the following formula:

$$C_r = 1.25 - \frac{l_{eff}}{48b}$$

where, C_r = reduction coefficient;
l_{eff} = effective length of column; and
b = least lateral dimension of column; for column with helical reinforcement, b is the diameter of the core.

For more exact calculations, the maximum permissible stresses in a reinforced concrete column having a ratio of effective column length to least lateral radius of gyration above 40,

$$C_r = 1.25 - \frac{l_{eff}}{160\, i_{min}}$$

where, i_{min} is the least radius of gyration.

Example:

Q.1 The reduction coefficient of a reinforced concrete column with an effective length of 4.8 m and size 250 mm × 300 mm is

(a) 0.80 (b) 0.85
(c) 0.90 (d) 0.95

[IES-1997]

Ans. (b)

B-3.4 Composite Columns

Metal core and reinforcement: The cross-sectional area of the metal core shall not exceed 20 percent of the gross area of the column.

Example:

Q.1 Cross sectional area of metal core in composite column should not be more than
(a) 4% (b) 8%
(c) 16% (d) 20%

[IES-2001]

Ans. (d)

The cross sectional area of the metal core in a composite column shall not exceed 20% of the gross area of the column. A clearance of 75 mm shall be maintained between the spiral and metal core at all points, except that when the core consists of steel H-column, the minimum clearance should be reduced to 50 mm.

Table 22 : Permissible Stresses in Steel Reinforcement

S.No.	Type of stress in steel reinforcement	Permissible stress in N/mm^2 Mild steel bar (Fe 250)	High yield strength deformed bars (Fe 415)
(1)	(2)	(3)	(4)
(i)	Tension (σ_{st} or σ_{sv})		
	(a) Up to and including 20 mm	140	230
	(b) Over 20 mm	130	230
(ii)	Compression in column bars (σ_{sc})	130	190
(ii)	Compression in bars in a beam or slab when the compressive resistance of the concrete is taken into account	The calculated compressive stress in the surrounding concrete multiplied by 1.5 times the modulator ratio or σ_{sc} whichever is lower.	
(iv)	Compression in bars in a beam or slab where the compressive resistance of the concrete is not taken into account:		
	(a) Up to and including 20 mm	140	190
	(b) Over 20 mm	130	190

Note: For high yield strength deformed bars of Grade Fe 500 the permissible stress in direct tension and flexural tension shall be 0.55 f_y. The permissible stresses for shear and compression reinforcement shall be as for Grade Fe415.

B-4.0 MEMBERS SUBJECTED TO COMBINED AXIAL LOAD AND BENDING

B-4.1 Design Based on Uncracked Section

A member subject to axial load bending (due to eccentricity of load, monolithic construction, lateral forces, etc.) shall be considered safe provided the following conditions are satisfied:

(a) $$\frac{\sigma_{cc,cal}}{\sigma_{cc}} + \frac{\sigma_{cbc,cal}}{\sigma_{cbc}} \leq 1$$

where, $\sigma_{cc,\,cal}$ = calculated direct compressive stress in concrete,
σ_{cc} = permissible axial compressive stress in concrete,
$\sigma_{cbc,\,cal}$ = calculated bending compressive stress in concrete, and
σ_{cbc} = permissible bending compressive stress in concrete.

(b) The resultant tension in concrete is not greater than 35 percent and 25 percent of the resultant compression for biaxial and uniaxial bending respectively, or does not exceed three-fourth, the 7 day modulus of rupture of concrete.

Notes:

1. $\sigma_{cc,cal} = \frac{P}{A_c + 1.5\, mA_{sc}}$ for columns with ties where P, A_c and A_{sc} defined in B-3.1 and m is the modular ratio.

2. $\sigma_{cbc,cal} = \frac{M}{Z}$ where M equals the moment and Z equals modulus of section. In the case of sections subject to moments in two directions, the stress shall be calculated separately and added algebraically.

B-4.2 Design Based on Cracked Section

If the requirements specified in **B-4.1** are not satisfied, the stresses in concrete and steel shall be calculated by the theory of cracked section in which the tensile resistance of concrete is ignored. If the calculated stresses are within the permissible stress specified in table 21, 22 and 23 the section may be assumed to be safe.

Note: The direct load should be equal to the algebraic sum of the forces on concrete and steel.

(a) The direct load should be equal to the algebraic sum of the forces on concrete and steel.

(b) The moment of the external loads about any reference line should be equal to the algebraic sum of the moment of the forces in concrete (ignoring the tensile force in concrete) and steel about the same line, and

(c) The moment of the external loads about any other reference lines should be equal to the algebraic sum of the moment of the forces in concrete (ignoring the tensile force in concrete) and steel and about the same line.

B-5.0 SHEAR (SAME AS LIMIT STATE METHOD)

B-5.1 Nominal Shear Stress

The nominal shear stress τ_v in beams or slabs of uniform depth shall be calculated by the following equation:

$$\tau_v = \frac{V}{bd}$$

where, V = shear force due to design loads,

b = breadth of the member, which for flanged sections shall be taken as the breadth of the web, and

d = effective depth,

B-5.1.1 Beams of Varying depth: In the case of beams of varying depth, the equation shall be modified as:

$$\tau_v = \frac{V \pm \frac{M\tan\beta}{d}}{d}$$

where, τ_v, V, b and d are the same as in **B-5.1**.

M = bending moment at the section, and

β = angle between the top and the bottom edges of the beam.

The negative sign in the formula applies when the bending moment M increases numerically in the same direction as the effective depth d increases, and the positive sign when the moment decreases numerically in this direction.

B-5.2 Design Shear Strength of Concrete

B-5.2.1 The permissible shear stress in concrete in beam without shear reinforcement is given in Table 23.

Table 23 : Permissible Shear Stress in Concrete

$100\frac{A_s}{bd}$	Permissible Shear Stress in Concrete, τ_c, N/mm^2 Grade of concrete					
	M15	M20	M25	M30	M35	M40 and above
(1)	(2)	(3)	(4)	(5)	(6)	(7)
≤ 0.15	0.18	0.18	0.19	0.20	0.20	0.20
0.25	0.22	0.22	1.23	0.23	0.23	0.23
0.50	0.29	0.30	0.31	0.31	0.31	0.32
0.75	0.34	0.35	0.36	0.37	0.37	0.38
1.00	0.37	0.39	0.40	0.41	0.42	0.42
1.25	0.40	0.42	0.44	0.45	0.45	0.46
1.50	0.42	0.45	0.46	0.48	0.49	0.49
1.75	0.44	0.47	0.49	0.50	0.52	0.52
2.00	0.44	0.49	0.51	0.53	0.54	0.55
2.25	0.44	0.51	0.53	0.55	0.56	0.57
2.50	0.44	0.51	0.55	0.57	0.58	0.60
2.75	0.44	0.51	0.56	0.58	0.60	0.62
3.00 and above	0.44	0.51	0.57	0.60	0.62	0.63

Note: A_s is the area of longitudinal reinforcement.

B-5.2.1.1 For solid slabs the permissible shear stress in concrete shall be $k\tau_c$ where k has the value given below:

Overall depth of slab (mm)	300 or more	275	250	225	200	175	150 or less
k	1.00	1.05	1.10	1.15	1.20	1.25	1.30

Note: The does not apply to flat slabs.

B-5.2.2 Shear Strength of Members Under Axial Compression

For member subjected to axial compression P, the permissible shear stress in concrete τ_c given in Table 23, shall be multiplied by the following factor:

$$\delta = 1 + \frac{5P}{A_g f_{ck}}, \text{but not exceeding } 1.5$$

where, P = axial compressive force in N,
A_g = gross area of the concrete section in mm^2, and
f_{ck} = characteristic compressive strength of concrete.

B-5.2.3 With Shear Reinforcement

When shear reinforcement is provided the nominal shear stress τ_v in beams shall not exceed τ_{cmax} given in Table 24.

B-5.2.3.1 For slabs, τ_v shall not exceed half the value of τ_{cmax} given in Table 24.

B-5.3 Minimum Shear Reinforcement

When τ_v is less than τ_c given in Table 23, minimum shear reinforcement shall be provided in accordance with **26.5.1.6**.

B-5.4 Design of Shear Reinforcement

When τ_v exceeds τ_c given in table 23, shear reinforcement shall be provided in any of the following forms:

(a) Vertical stirrups,
(b) Bent-up bars along with stirrups, and
(c) Inclined stirrups.

Where bent-up are provided, their contribution towards shear resistance shall not be more than half that of the total shear reinforcement.

Shear reinforcement shall be provided to carry a shear equal to $V - \tau_c \cdot bd$. The strength of shear reinforcement V_s shall be calculated as below:

(a) For vertical stirrups

$$V = \frac{\sigma_{sv} A_{sv} d}{S_v}$$

(b) For inclined stirrups or a series of bars bent-up at different cross-sections:

$$V = \frac{\sigma_{sv} A_{sv} d}{S_v}(\sin\alpha + \cos\alpha)$$

(c) For single bar or single group of parallel bars, all bent-up at the same cross-section:

$$V_s = \sigma_{sv} A_{sv} \sin\alpha$$

where, A_{sv} = total cross-sectional area of stirrup legs or bent-up bars within a distance,

S_v = spacing of the stirrups or bent-up bars along the length of the member,

τ_c = design shear strength of the concrete,

σ_{sv} = permissible tensile stress in shear reinforcement which shall not be taken greater than 230 N/mm^2,

α = angle between the inclined stirrup or bent-up bar and the axis of the member, not less than 45°, and

d = effective depth.

Note: Where more than one type of shear reinforcement is used to reinforcement the same portion of the beam, the total shear resistance shall be computed as the sum of the resistance for the various types separately. The area of the stirrups shall not be less than the minimum specified in **26.5.1.6**.

Table 24 : Maximum Shear Stress, $\tau_{c\,max}$, N/mm²

Concrete grade	M15	M20	M25	M30	M35	M40 and above
$\tau_{c\,max}$, N/mm²	1.6	1.8	1.9	2.2	2.3	2.5

B-6.0 TORSION

B-6.2 Critical Section

Sections located less than a distance d, from the face of the support may be designed for the same torsion as computed at a distance d, where d is the effective depth.

B-6.3 Shear and Torsion

B-6.3.1 Equivalent shear, V_e shall be calculated from the formula:

$$V_e = V + 1.6\frac{T}{b}$$

where, V_e = equivalent shear,
V = shear,
T = torsional moment, and
b = breadth of beam.

The equivalent nominal shear stress, τ_{ve}, in this case shall be calculated as given in **B-5.1**, except for substituting V by V_e. The values of τ_{ve} shall not exceed the values of τ_{cmax} given in Table 24.

B-6.3.2 If equivalent nominal shear stress τ_{ve} does not exceed τ_c, given in Table 23, minimum shear reinforcement shall be provided as specified in **26.5.1.6**.

B-6.3.3 If τ_{ve} exceeds τ_c given in Table 23, both longitudinal and transverse reinforcement shall be provided in accordance with **B-6.4**.

B-6.4 Reinforcement in Members Subjected to Torsion

B-6.4.1 Longitudinal Reinforcement: The longitudinal reinforcement shall be designed to resist an equivalent bending moment, M_{el}, given by

$$M_{el} = M + M_t$$

where, M = bending moment at the cross-section, and

$$M_t = T\frac{(1 - D/b)}{1.7},$$ where T is the torsional moment, D is the overall depth of the beam and b is the breadth of the beam.

B-6.4.2.1 If the numerical value of M_t as defined in **B-6.4.2** exceeds the numerical value of the moment M, longitudinal reinforcement shall be provided on the flexural compression face, such that the beam can also withstand an equivalent moment M_{e2} given by $M_{e2} = M_t - M$, the moment M_{e2} being taken as acting in the opposite sense to the moment M.

B-6.4.3 Transverse Reinforcement: Two legged closed hoops enclosing the corner longitudinal bars shall have an area of cross-section A_{sv}, given by

$$A_{sv} = \frac{T \cdot s_v}{b_1 d_1 \sigma_{sv}} + \frac{V \cdot s_v}{2.5 d_1 \sigma_{sv}}$$

but the total transverse reinforcement shall not be less than

$$\frac{(\tau_{ve} - \tau_c)\, b \cdot s_v}{\sigma_{sv}}$$

where, T = torsional moment
V = shear force
s_v = spacing of the stirrup reinforcement
b_1 = centre-to-centre distance between corner bars in the direction of the width
d_1 = centre-to-centre distance between corner bars in the direction of the depth
b = breadth of the member
σ_{sv} = permissible tensile stress in shear reinforcement
τ_{ve} = equivalent shear stress as specified in **B-6.3.1**
τ_c = shear strength of the concrete as specified in Table 23

ANNEXURE D : SLABS SPANNING IN TWO DIRECTIONS

D-1 RESTRAINED SLABS

D-1.0 When the corners of a slab are prevented from lifting, the slab may be designed as specified in **D-1.1** to **D-1.11**.

D-1.1 The maximum bending moments per unit width in a slab are given by the following equations:

$$M_x = \alpha_x w l_x^2$$

$$M_y = \alpha_y w l_x^2$$

where, α_x and α_y are coefficient given in Table 26
w = total design load per unit area
M_x and M_y = moments on strips of unit width spanning l_x and l_y respectively, and
l_x and l_y = lengths of the shorter span and longer span respectively

D-1.2 Slabs are considered as divided in each direction into middle strips and edge strips as shown in Fig. 25, the middle strip being three-quarters of the width and each edge strip one-eight of the width.

D-1.3 The maximum moments calculated as in **D-1.1** apply only to the middle strips and no redistribution shall be made.

D-1.4 Tension reinforcement provided at mid-span in the middle strip shall extend in the lower part of the slab upto 0.25 l from center of support of a continuous edge, or 0.15 l of a discontinuous edge.

D-1.5 Over the continuous edges of a middle strip, the tension reinforcement shall extend in the upper part of the slab a distance of 0.15 l from the support, and atleast 50 percent shall extend a distance of 0.3 l.

D-1.6 At a discontinuous edge, negative moments may arise. They depend on the degree of fixity at the edge of the slab but, in general, tension reinforcement equal to 50 percent of that provided at mid-span extending 0.1 l into the span will be sufficient.

D-1.7 Reinforcement in edge strip, parallel to that edge, shall comply with the minimum given in Section 3 and the requirements for torsion given in **D-1.8** to **D-1.10**.

D-1.8 Torsion reinforcement shall be provided at any corner where the slab is simply supported on both edges meeting at that corner. It shall consists of top and bottom reinforcement, each with layers of bars placed parallel to the sides of the slab and extending from the edges a minimum distance of one-fifth of the shorter span. The area of reinforcement in each of these four layers shall be three-quarters of the each required for the maximum mid-span moment in the slab.

Example:

Q.1 In the design of two-way slab restrained at all edges, torsional reinforcement required is

(a) 0.75 times the area of steel provided at midspan in the same direction
(b) 0.375 times the area of steel provided at midspan in the same direction
(c) 0.375 times the area of steel provided in the shorter span
(d) nil

[IES-1997]

Ans. (a)

For restrained slab, the area of reinforcement in each of the four corner layers shall be three-quarters of the area required for the maximum mid span moment in the slab simply supported on both edges meeting at that corner. If the corner contained by edges over only one of which the slab is continuous, torsion reinforcement equal to 0.375 times the area of reinforcement provided the mid-span in the same direction shall be provided. If both edges are continuous, no torsion reinforcement shall be provided.

D-1.9 Torsion reinforcement equal to half that described in **D-1.8** shall be provided at a corner contained by edges over only one of which the slab is continuous.

D-1.10 Torsion reinforcements need not be provided at any corner contained by edges over both of which the slab is continuous.

D-1.11 Torsion l_y / l_x is greater than 2, the slabs shall be designed as spanning one way.

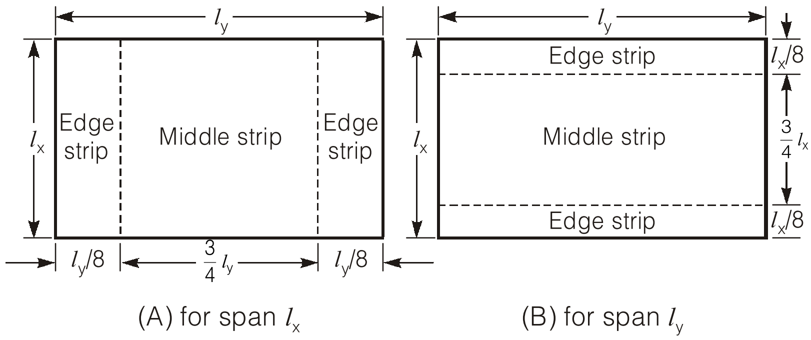


Fig. 25 : Division of slab into middle and edge strips

Table 26 : Bending moment coefficients for rectangular panels supported on four sides with provision for torsion at corners (Clauses D-1.1 and 24.4.1)

(1)	Type of panel and moments considered (2)	Short span coefficients α_x (Values of l_y/l_x) 1.0 (3)	1.1 (4)	1.2 (5)	1.3 (6)	1.4 (7)	1.5 (8)	1.75 (9)	2.0 (10)	Long span coefficients α_y for all values of l_y/l_x (11)
1.	Interior panels:									
	Negative moment at continuous edge	0.032	0.037	0.043	0.047	0.051	0.053	0.060	0.065	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.036	0.041	0.041	0.045	0.049	0.024
2.	One short edge continuous:									
	Negative moment at continuous edge	0.037	0.043	0.048	0.051	0.055	0.057	0.064	0.068	0.037
	Positive moment at mid-span	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052	0.028
3.	One long edge discontinuous:									
	Negative moment at continuous edge	0.037	0.044	0.052	0.057	0.063	0.067	0.077	0.085	0.037
	Positive moment at mid-span	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065	0.028
4.	Two adjacent edges discontinuous:									
	Negative moment at continuous edge	0.047	0.053	0.060	0.065	0.071	0.075	0.084	0.091	0.047
	Positive moment at mid-span	0.035	0.040	0.045	0.049	0.053	0.056	0.063	0.069	0.035
5.	Two short edges discontinuous:									
	Negative moment at continuous edge	0.045	0.049	0.052	0.056	0.059	0.060	0.065	0.069	–
	Positive moment at mid-span	0.035	0.037	0.040	0.043	0.044	0.045	0.049	0.052	0.035
6.	Two long edges discontinuous:									
	Negative moment at continuous edge	–	–	–	–	–	–	–	–	0.045
	Positive moment at mid-span	0.035	0.043	0.051	0.057	0.063	0.068	0.080	0.088	0.035
7.	Three edges discontinuous: (One long edge continuous)									
	Negative moment at continuous edge	0.057	0.064	0.071	0.076	0.080	0.084	0.091	0.097	–
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.064	0.069	0.073	0.043
8.	Three edges discontinuous: (One short edge continuous)									
	Negative moment at continuous edge	–	–	–	–	–	–	–	–	0.057
	Positive moment at mid-span	0.043	0.051	0.059	0.065	0.071	0.076	0.087	0.096	0.043
9.	Four edges discontinuous:									
	Positive moment at mid-span	0.056	0.064	0.072	0.079	0.085	0.089	0.100	0.107	0.056

D-2 Simply Supported Slabs

D-2.1 When simply supported slabs do not have adequate provision to resist torsion at corners and to prevent the corners from lifting, the maximum moment per unit width are given by the following equation:

$$M_x = \alpha_x w l_x^2$$

$$M_y = \alpha_y w l_x^2$$

where, M_x, M_y, w, l_x, l_y are same as those in **D-1.1**, and α_x and α_y are moment coefficients given Table 27.

D-2.1.1 At least 50 percent of the tension reinforcement provided at mid-span should extend to the supports. The remaining 50 percent should extend to within 0.1 l_x or 0.1 l_y of the support, as appropriate.

Table 27 : Bending moment coefficients for slabs spanning in two directions at right angles, simply supported on four sides

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.051	0.046	0.037	0.029	0.020	0.014

Example:

Q.1 When is an RCC roof slab designed as a two way slab?
(a) If the slab is continuous over two opposite edges only
(b) If the slab is unsupported at one edge only
(c) If the ratio of spans in two directions is > 2
(d) If the ratio of spans in two directions is < 2

[IES-2008]

Ans. (b)

Q.2 As per codal provisions in two way slabs, the minimum mild steel reinforcement to be provided in the edge strip is
(a) On the basis of minimum bending moment
(b) Half of the area of steel provided in middle strip in the shorter span
(c) Half of the area of steel provided in middle strip in the longer span
(d) 0.15% of the cross-sectional area of concrete

[IES-2006]

Ans. (d)

ANNEXURE E : EFFECTIVE LENGTH OF COLUMNS

In the absence of more exact analysis, the effective length of columns in framed structures may be obtained from the ratio of effective length to unsupported length l_{eff} / l given in Fig. 26 when relative displacement of the ends of the column is prevented.

Note: In Fig. 26, β_1 and β_2 are equal to $\dfrac{\Sigma K_c}{\Sigma K_c + \Sigma K_b}$ where the summation is to be done for the members framing into a joint at top and bottom respectively; and K_c and K_b being the flexural stiffness for column and beam respectively.

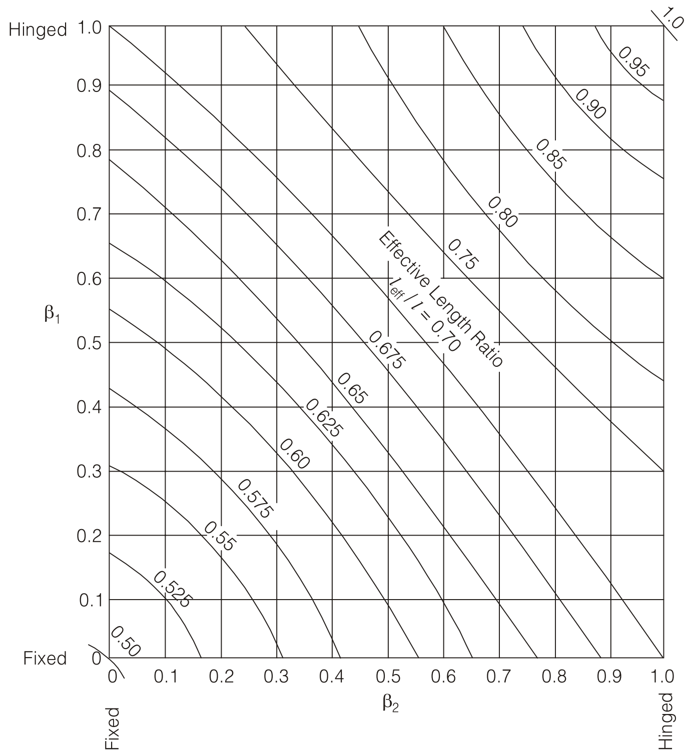
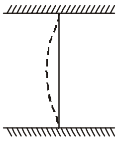
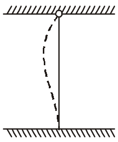
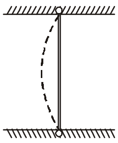
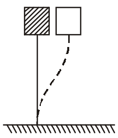
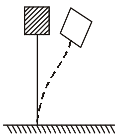
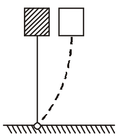
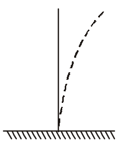


Fig. 26 : Effective length ratios for a column in a frame with no sway

Table 28 : Effective Length of Compression Members

Degree of end restraint of compression members (1)	Symbol (2)	Theoretical value of Effective length (3)	Recommended value of Effective length (4)
Effectively held in position and restrained against rotation in both ends		0.50 l	0.65 l
Effectively held in position at both ends, restrained against rotation at one end		0.70 l	0.80 l
Effectively held in position at both ends, but not restrained against rotation		1.00 l	1.00 l
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 l	1.20 l
Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		–	1.50 l
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.00 l	2.00 l
Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.00 l	2.00 l

Note: l is the unsupported length of compression member.

Example:

Q.1 The effective length of a R.C. column continuing through two storeys, properly restrained at both ends in position and direction is

(a) 0.50 L
(b) 0.75 L
(c) L
(d) 2 L

[IES-2011]

Ans. (a)

Q.2 The effective length of a column in a reinforced concrete building frame, as per IS:456-2000, is independent of the

(a) frame type i.e., braced (no sway) or unbraced (with sway)
(b) span of the beam
(c) height of the column
(d) loads acting on the frame

[GATE-2003]

Ans. (d)

ANNEXURE G : MOMENTS OF RESISTANCE FOR RECTANGULAR AND T-SECTIONS

G-1 RECTANGULAR SECTIONS

G-1.1 Sections Without Compression Reinforcement

The moment of resistance of rectangular sections without compression reinforcement should be obtained as follows:

(a) Determine the depth of neutral axis from the following equation:

$$\frac{x_u}{d} = \frac{0.87\, f_y\, A_{st}}{0.36\, f_{ck}\, b.d}$$

(b) If the value of x_u/d is less than the limiting value (0.53, 0.48 and 0.46), calculate the moment of resistance by the following expression:

$$M_u = 0.87\, f_y\, A_{st}\, d\left(1-\frac{A_{st}\, f_y}{bd\, f_{ck}}\right)$$

(c) If the value of x_u/d is equal to the limiting value, the moment of resistance of the section is given by the following expression:

$$M_{u,\,lim} = 0.36\,\frac{x_{u,max}}{d}\left(1-0.42\,\frac{x_{u,max}}{d}\right)bd^2\, f_{ck}$$

(d) If x_u/d is greater than the limiting value, the section should be redesigned.

In the above equations,

x_u = depth of neutral axis
d = effective depth
f_y = characteristic strength of reinforcement
A_{st} = area of tension reinforcement
f_{ck} = characteristic compressive strength of concrete
b = width of the compression face
$M_{u,\,lim}$ = limiting moment of resistance of a section without compression reinforcement
$x_{u,\,max}$ = limiting value of x_u from 39.1

G-1.2 Section with Compression Reinforcement

Where the ultimate moment of resistance of section exceeds the limiting value, $M_{u, lim}$ compression reinforcement may be obtained from the following equation:

$$M_u - M_{u, lim} = f_{sc} A_{sc} (d - d')$$

where, $x_{u, max}$ = the limiting value of x_u from 38.1
A_{sc} = area of compression reinforcement, and
d' = depth of compression reinforcement from compression face.

The total area of tension reinforcement shall be obtained from the following equation:

$$A_{st} = A_{st1} + A_{st2}$$

where, A_{st} = area of the total tensile reinforcement,
A_{st1} = area of the tensile reinforcement for a singly reinforced section for $M_{u, lim}$
$A_{st2} = A_{sc}\ f_{sc}/0.87\ f_y$

Example:

Q.1 What is the assumption in the steel beam theory of doubly reinforced beams?
(a) Only steel bars will resist tension
(b) Only concrete will resist tension
(c) Stress in tension steel equals the stress in compression steel
(d) Both concrete and steel will resist compression

[IES-2008]

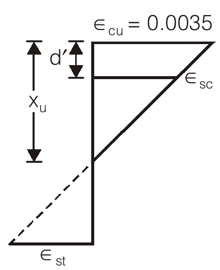
Ans. (c)

In the steel beam theory the concrete is completely neglected and the moment of resistance is taken equal to the moment of steel. Couple, taking the permissible value of stresses in compressive steel equal to permissible value in tensile steel. Thus, in the steel beam theory, the concrete serves only as a web and the compressive and tensile steels as the flanges of an imaginary steel joint having an equal area of both the flanges.

Q.2 A doubly reinforced concrete beam has effective cover d′ to the centre of compression reinforcement. ‘x_u’ is the depth of neutral axis, and ‘d’ is the effective depth to the centre of tension reinforcement. What is the maximum strain in concrete at the level of compression reinforcement?
(a) $0.0035 (1 - d'/d)$ (b) $0.0035 (1 - d'/x_u)$
(c) $0.002 (1 - d'/x_u)$ (d) $0.002 (1 - d'/d)$

[IES-2005]

Ans. (b)



$$\frac{\epsilon_{sc}}{x_u - d'} = \frac{\epsilon}{x_u}$$

$$\therefore \quad \epsilon_{sc} = 0.0035\left(1 - \frac{d'}{x_u}\right)$$

Linked Answer Questions (3 and 4):

A doubly reinforced rectangular concrete beam has a width of 300 mm and an effective depth of 500 mm. The beam is reinforced with 2200 mm^2 of steel in tension and 628 mm^2 of steel in compression. The effective cover for compression steel is 50 mm. Assume that both tension and compression steel yield. The grades of concrete and steel used are M20 and Fe250, respectively. The stress block parameters (rounded off to first two decimal places) for concrete shall be as per **IS 456 : 2000**.

Q.3 The depth of neutral axis is

(a) 205.30 mm (b) 184.56 mm

(c) 160.91 mm (d) 145.30 mm

[GATE-2010]

Ans. (c)

Q.4 The moment of resistance of the section is

(a) 206.00 kN-m (b) 209.20 kN-m

(c) 237.80 kN-m (d) 251.90 kN-m

[GATE-2010]

Ans. (b)

G-2 FLANGED SECTION

G-2.1 For $x_u < D_f$, the moment of resistance may be calculated from the equation given in **G-1.1.** Because it behaves as a rectangular section.

G-2.2 The limiting value of the moment of resistance of the section may be obtained by the following equation when the ratio D_f / d does not exceed 0.2:

$$M_u = 0.36 \frac{x_{u,max}}{d}\left(1 - 0.42\frac{x_{u,max}}{d}\right) f_{ck}\, b_w\, d^2 + 0.45\, f_{ck}\,(b_f - b_w)\, D_f\left(d - \frac{D_f}{2}\right)$$

where,

M_u, $x_{u,max}$, d and fck are same as **G-1.1**.

b_f = breadth of the compression face/flange

b_w = breadth of the web

D_f = thickness of the flange

G-2.2.1 When the ratio D_t / d exceeds 0.2, the moment of resistance of the section may be calculated by the following equation:

$$M_u = 0.36 \frac{x_{u,max}}{d}\left(1 - 0.42\frac{x_{u,max}}{d}\right) f_{ck}\, b_w\, d^2 + 0.45\, f_{ck}\,(b_f - b_w)\, y_f\left(d - \frac{y_f}{2}\right)$$

where, $y_f = (0.15\, x_u + 0.65\, D_f)$, but not greater than D_f, and the other symbols are same as in **G-1.1** and **G-2.2**.

G-2.3 For $x_{u,\,max} > x_u > D_f$, the moment of resistance may be calculated by the equations given in **G-2.2** when D_f / x_u does not exceed 0.43 and **G-2.2.1** when D_f / x_u exceeds 0.43; in both cases substituting $x_{u,\,max}$ by x_u.

Example:

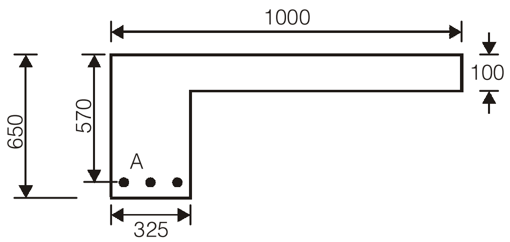
Q.1 A T-beam behaves as a rectangular beam of width equal to its flange if its neutral axis
(a) coincides with centroid of reinforcement
(b) coincides with centroid of T-section
(c) remains within the flange
(d) remains in the web

[IES-2006]

Ans. (c)

Linked Answer for Questions (2 and 3):

The cross-section at mid-span of a beam at the edge of a slab is shown in the sketch. A portion of the slab is considered as the effective flange width for the beam. The grades of concrete and reinforcing steel are M25 and Fe415 respectively. The total area of reinforcing bars (A_3) is 4000 mm^2. At the ultimate limit sate, x_u denotes the depth of the neutral axis from the top fibre. Treat the section as under-reinforced and flanged (x_u > 100 mm).



Q.2 The value of x_u (in mm) computed as per the Limit State Method of IS 456 : 2000 is
(a) 200.0 (b) 223.3
(c) 236.3 (d) 273.6

[GATE-2012]

Ans. (c)

Q.3 The ultimate moment capacity (in kNm) of the sections as per the Limit State Method of IS 456 : 2000 is
(a) 475.2 (b) 717.0
(c) 756.4 (d) 762.5

[GATE-2012]

Ans. (b)

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