THEORY & OBJECTIVE

REINFORCED CEMENT CONCRETE

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INTRODUCTION

THEORY

1.1 PLAIN CONCRETE

It is a mixture of sand, gravel, cement, and water which results in a solid mass. Concrete is strong in compression but weak in tension. Its tensile strength is approx. One tenth of compressive strength. Plain concrete is mostly used in mass concrete work. (As in dams).

1.2 REINFORCED CONCRETE

It is a concrete with reinforcement embedded in it. The embedded reinforcement makes it capable of resisting tension also.

Steel bars embedded in the tension zone of concrete, relieves concrete of any tension and takes all tension without separating from concrete.

The bond between steel and surrounding concrete ensures strain compatibility i.e., the strain at any point in the steel is equal to that in the adjoining concrete.

Reinforcing steel imparts ductility to concrete which is otherwise brittle material.

Here ductility means large deflection owing to yielding of steel, thereby giving ample warning of impending collapse.

Tensile stress in concrete arises on account of direct tension, flexural tension, diagonal tension (due to shear), temperature and shrinkage effect and restraint to deformation.

Under these conditions, reinforcements must be provided across potential tensile crack.

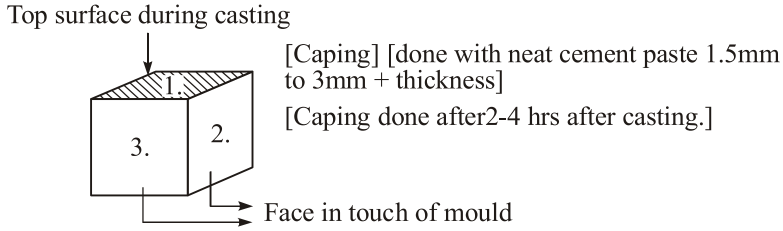
1.3 GRADE OF CONCRETE

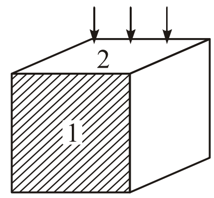
Compressive strength of concrete is the most important property of concrete. Because other properties like tensile strength, shear strength, bond strength, density, impermeability, durability etc. can be inferred from the compressive strength using established correlations.

Compressive strength can be measured by standard test on concrete cube, (or cylinder) specimen.

Strength of concrete in uniaxial compression is determined by loading standard test cube (150 mm size) to failure in compression testing machine.

The test specimen is generally tested 28 days after casting (and continuous curing)





Cube is always tested on sides i.e., face in touch with mould.

Strength of cube is expressed to the nearest of 0.5 N/mm^2

As per IS 456 : 2000, three specimen of a sample is taken.

Additional samples may be required for various purposes such as to determine the strength of concrete at 7 days or at the time of striking of the foam work, or to determine the duration of curing, or to check the testing error. Additional specimen may also be required for testing samples cured by accelerated methods

To report, strength of cube, we take average of three specimen of a sample.

Individual variation should not be more than ±15% of average if variation is more, test results of the sample are invalid.

1.4 Acceptance Criteria

Compressive Strength : The concrete shall be deemed to comply with the strength requirements when both the following condition are met:

(a) The mean strength determined from any group of four non–overlapping consecutive test results compiles with the appropriate limits in col. 2 of table shown below

(b) Any individual test result complies with the appropriate limits in col 3 of table shown below

Characteristic compressive strength compliance requirement (Clauses 16.1 and 16.3)

Specified grade (1)	Mean of the group of 4 non-overlaping consecutive test results in N/mm^2 (2)	Individual test result in N/mm^2 (3)
M 15	≥ f_{ck} + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2, whichever is greater	f_{ck} – 3N/mm^2
M20 or above	≥ f_{ck} + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm^2) or f_{ck} + 4N/mm^2, whichever is greater	f_{ck} – 4N/mm^2

Flexural Strength : When both the following conditions are met, the concrete complies with the specified flexural strength.

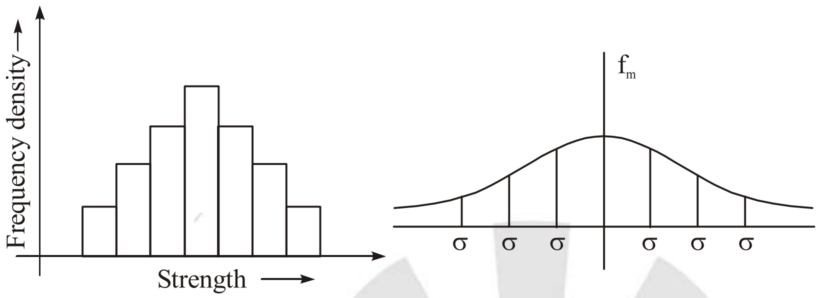
(a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm^2.

(b) The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm^2.

Variation in strength : No material is truly homogeneous, so the strength of similar concrete varies in different testing.

$$\text{Frequency density} = \frac{\text{No. of samples in an interval}}{\text{Total no. of samples}}$$

If the number of sample are increased indefinitely, the histogram becomes probability distribution curve. For most of the engineering material, probability is symmetrical about mean and such a curve is called ***Normal Probability distribution curve***.



$$\text{Mean strength } (f_m) = \frac{\Sigma f}{m} \begin{array}{l} \leftarrow \text{Strength of sample} \\ \leftarrow \text{No. of sample} \end{array}$$

$$\sigma = \sqrt{\frac{\Sigma\left(f - f_m\right)^2}{m}}$$

$f - f_m$ = deviation from mean,

σ = standard deviation.

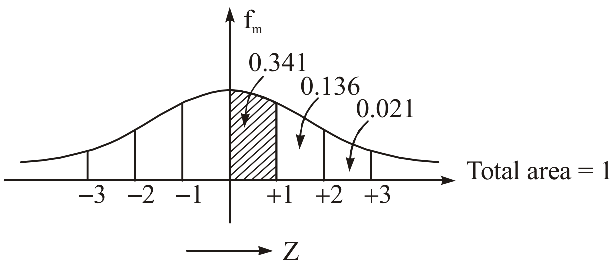
Spread of σ is the measure of quality control.

(Large σ) ⇒ (more strength variation) ⇒ poor quality control.

(Small σ) ⇒ (less strength variation) ⇒ high quality control.

Taking mean as origin. Let $Z = \frac{f - f_m}{\sigma}$. then probability density (or frequency density)

$$\boxed{y = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}}$$



Probability of strength failing below $(f_m - \sigma)$

$= 1 - (0.5 + 0.341) = 0.159 = 15.9\%$

2

REINFORCED CONCRETE DESIGN METHODS

THEORY

2.1 WORKING STRESS METHOD

This was the traditional method of design

Both concrete and steel are assumed to behave in linearly elastic manner.

Stresses with in the materials are not allowed to exceed the permissible stresses.

Working stress method of design used to be the basis of design for all RCC structures in the past. But these days it finds application in calculating serviceability requirement like deflection and crack width under service load condition.

It is also used in the design of few structures like liquid retaining structures and highway bridges and chimney.

Drawbacks : It may not be possible to keep the stress with in permissible stress. This is because of

(a) term effect of shrinkage and creep

(b) Effect of stress concentration and other secondary effect.

All such effects result in significant local increase in stresses into inelastic range and redistribution of the calculated stress.

In working stress method actual margin of safety is not equal to the factor of safety used in WSM because the stress strain curve is not linear upto collapse.

Actual margin of safety here is given in term of factor like $\frac{\text{collpase load}}{\text{working load}}$ the

F.O.S on the other hand is $\frac{\text{characteristic stress}}{\text{permissible stress}}$

WSM fails to discriminate between different types of loads that act simultaneously, but have different degrees of uncertainty.

This may some times lead to significantly conservative design particularly when two different loads have counteracting effect, example, if dead load and wind load produce counteracting stress but if they are simply added, the design load would be much larger.

2.2 PERMISSIBLE STRESSES IN STEEL & CONCRETE

In working stress method, the stresses in materials are not exceeded beyond their permissible values. The permissible stress in a material is given by

$$\text{Permissible stress} = \frac{\text{Limiting strength}}{\text{Factor of safety}}$$

In case of steel reinforcement, the limiting strength is either the yield stress or 0.2% proof stress, as the case may be. For concrete, the limiting strength is the crushing strength in compression.

The factor of safety in the case of tensile steel reinforcement is approximately = 1.82. Hence, the permissible tensile stress in steel is $\sigma_{st} = 0.55\ f_y$.

For concrete, the factor of safety is higher than steel. This is so because concrete suffers from higher degree of variability regarding its strength and properties than steel which is produced under well controlled conditions.

The factor of safety for flexural compressive in concrete is = 3. Thus, the permissible compressive stress in concrete in flexural compression is $\sigma_{cbc} = 0.333\ f_{ck}$.

2.2.1 *Stresses in Concrete*

The permissible stress of concrete in direct tension is denoted by σ_{td}. The values of σ_{td} for member in direct tension for different grades of concrete are given in the table below.

It may be worth nothing that the factor of safety of concrete in direct tension is from 8.5 to 9.5.

The permissible stresses of concrete in bending compression σ_{cbc}, in direct compression σ_{cc} and the permissible stress in bond for plain bars in tension τ_{bd} are given in table 21 of IS 456 for different grades of concrete which is presented in table below.

For plain bars in compression, the values of bond stress are obtained by increasing the respective value in tension by 25 percent, as given in the table below and

For deformed bars in tension the values of bond stress given in table are to be increased by 60 % .

Grade of concrete	Direct tension σ_{td} (N/mm^2)	Bending compression σ_{cbc} (N/mm^2)	Direct compression σ_{cc} (N/mm^2)	Permissible bond stress in τ_{bd} for plain bars in tension (N/mm^2)
M 20	2.8	7.0	5.0	0.8
M 25	3.2	8.5	6.0	0.9
M 30	3.6	10.0	8.0	1.0
M 35	4.0	11.5	9.0	1.1
M 40	4.4	13.0	10.0	1.2

2.2.2 *Stresses in Steel*

Permissible stresses in steel reinforcement for different grades of steel, diameters of bars and the types of stress in steel reinforcement are given in table IS 456.

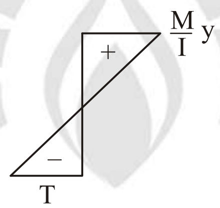
Selective values of permissible stresses of steel of grade Fe 250 (mild steel) and Fe 415. (high yield strength deformed bars) in tension (σ_{st} or σ_{ss}) and compression in column (σ_{sc}) are furnished in Table as a ready reference.

Permissible stress in steel reinforcement.

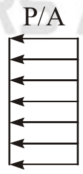
Type of stress in steel reinforcement	Mild steel bars, Fe 250, (N/mm^2)	High yield strength deformed bars, Fe 415 (N/mm^2)
Tension σ_{st} or σ_{ss}		
(a) up to including 20mm diameter	140	230
(b) over 20 mm diameter	130	230
Compression in column bars σ_{sc}	130	190

Note:

It can be observed that for a given grade of concrete $\sigma_{cc} < \sigma_{cbc}$ i.e. a greater F.O.S. is adopted for direct stress than for a bending stress. This is because when a cross-section is subjected to bending stress, the stress induced on it is variable being maximum at extreme fibre and zero at. N.A.



When the maximum stress exceeds the permissible value, the extreme fibre will not fail actually, but will transfer the additional force to the inner fibre which has a lower stress. However, When the section is subjected to a direct stress, all points of the section have uniform stress having no scope for such a transfer of the force.



It is for this reason larger F.O.S is adopted for direct stress than Bending stress.

Note:

In case of steel reinforcement of small diameter. The stress will be uniform for Direct stress as well or for bending stress. Therefore in steel bars, the permissible stresses in bending and direct stresses are same for lower dia bars up to 20 mm diameter. For more than 20 mm, permissible tensile stress is usually reduced.

The value of σ_{st} is given at the centroid of tension reinforcement subjected to the condition that when more than one layer of tensile reinforcement is provided, stress at the centroid of outer most layer shall not exceed by more than 10% of that given in the above table.

BOND AND ANCHORAGE

THEORY

3.1 TYPES OF BOND STRESS

The bond stress 4in reinforced concrete members arises due to two distinct situations.

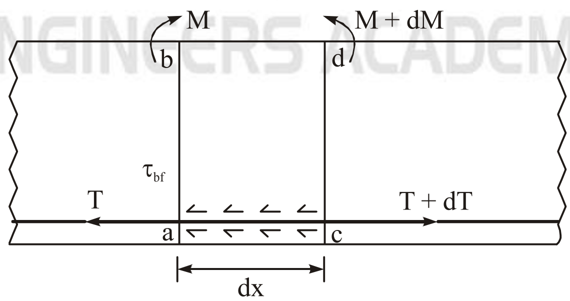
- The change in the bar force along its length due to variation in bending moment in this length. This type of bond stress is called flexural bond stress.
- From the anchorage of bar in case of tension or compression. This type of bond force is known as Anchorage bond stress. Anchorage bond is also called development bond.

3.2 FLEXURAL BOND STRESS

'Flexural bond' is that which arises in flexural members on account of shear or a variation in bending moment, which in turn causes a variation in axial tension along the length of a reinforcing bar. Flexural bond is critical at points where the shear (V = dM/dx) is significant.

Consider the segment between two sections ab and cd, spaced dx apart of a R.C. beam, as shown in Fig.

Let M be the bending moment at section ab and M + dM be the bending moment at section cd. Let T and



T + dT be the tensile forces developed in steel reinforcement at ab and cd respectively.

Now, $M = T.jd$

and $(M + dM) = (T + dT).jd$

Hence, $dM = dT.jd$

or, $$dT = \frac{dM}{jd} = \text{change in bar force}$$

If τ_{bf}, is the bond stress acting along the surface of bar, then for equilibrium.

Bond force acting along periphery of bar = Change in bar force dT. or

or $$\tau_{bf}\left[dx\,\Sigma O\right] = dT$$

where, ΣO = Sum of perimeters of all steel bars resisting tension,

or, $$\tau_{bf}\left(dx\,\Sigma O\right) = \frac{dM}{jd}$$

or, $$\tau_{bf} = \frac{dM}{dx}\cdot\frac{1}{jd\Sigma O}$$

But, $$\frac{dM}{dx} = \text{Shear force} = V$$

Hence, $$\tau_{bf} = \frac{V}{jd\Sigma O}$$

From above equation it, is clear that the flexural bond stress is directly proportional to the shear force and inversely proportional to the sum of perimeters of the bars at the section.

It may be noted that the actual bond stress will be influenced by flexural cracking, local slip, splitting and other secondary effects - which are not accounted for in above eq. In particular, flexural cracking has a major influence in governing the magnitude and distribution of local bond stresses.

Note:

The magnitude of the bond stress at a point is called local bond stress which varies with the bending moment.

Flexural bond stress is high at locations of high shear, and that this bond stress can be effectively reduced by providing an increased number of bars of smaller diameter bars (to give the same equivalent A_{st}).

3.3 | ANCHORAGE BOND STRESS AND DEVELOPMENT LENGTH

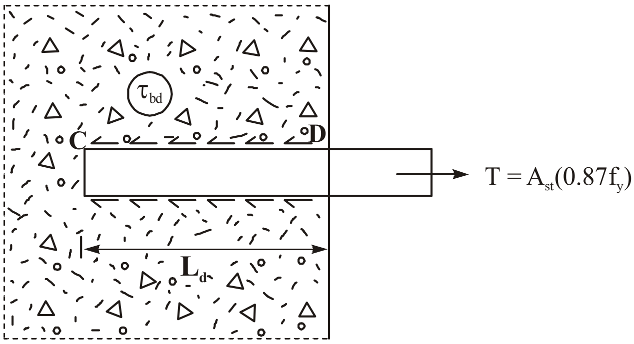
Anchorage bond stress arises when a bar is carrying certain force. In anchorage bond, it is necessary to transfer this force in the bar to the surrounding concrete over a certain length. The length of bar 'L_d' is required to transfer the force in the bar.

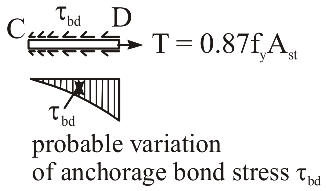
This condition arises near the extreme end (or cutoff point) of a bar subjected to tension (or Compression).

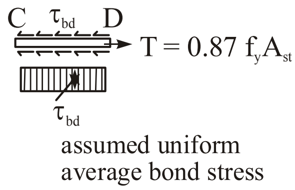
The development length is an embedded length of the bar required to develop the design strength of reinforcement at the critical section.

Following fig. shows a steel bar embedded in concrete and subjected to a tensile force T. Due to this force, there will be a tendency of the bar to slip out and this tendency is resisted by the bond stress developed over the perimeter of the bar, along its length of embedment.

This required length 'L_d' is called anchorage length in case of axial tension (or compression) and development length in case of flexural tension.







If ϕ is the nominal diameter of a bar, then

Tension, $$T = (0.87f_y)A_{st}$$

$$T = (0.87f_y)\left(\frac{\pi}{4}\phi^2\right)$$

This force must be transferred from steel to concrete through bond acting over the perimeter of the bar along its length of embedment L_d.

If τ_{bd} is the average bond stress, then

$$\text{Force} = \tau_{bd} \times (\pi\phi) \cdot L_d$$

For equilibrium $$0.87f_y\left(\frac{\pi}{4}\phi^2\right) = \tau_{bd} \cdot (\pi\phi)L_d$$

$$\boxed{L_d = \frac{0.87f_y}{4\tau_{bd}}\phi}$$

The concept underlying 'development length' is that a certain minimum length of the bar is required on either side of a point of maximum steel stress, to prevent the bar from pulling out under tension (or pushing in, under compression).

The value of design bond stress for plain bars in tension prescribed by IS code are reproduced in table below

Permissible Bond Stress in Tension

Grade of concrete	M20	M25	M30	M35	M40 and above
Design bond stress τ_{bd}, (N/mm^2)	1.2	1.4	1.5	1.7	1.9

In the above above discussion ϕ is defined as the nominal diameter of the bar. For the plain bars, nominal diameter and actual diameter are the same.

However, for deformed bars, the cross-section is not perfectly circular.

The actual area of the cross-section of a deformed bar is equated with an area of a circle and corresponding diameter of the circle is known as the normal diameter.

Thus, although the shapes of cross-sections of plain and deformed bars are not equal but for a particular diameter, their cross-sectional areas and mass per metre length are the same.

4

LIMIT STATE OF COLLAPSE IN SHEAR

THEORY

4.1 SHEAR

4.1.1 *Punching Shear*

The shear associated with the possibility of punching a thin member by a concentrated load is called punching shear.

A slab carrying a concentrated wall load, a beamless floor slab supported directly by columns (called flat slab) or a footing slab carrying a concentrated column load are subjected to punching shear.

For the member subjected to both the above types of shear, the flexural shear is referred to as one-way shear, where as punching shear is called two way shear. A footing slab carrying concentrated column load is subjected to both these shears.

4.1.2 *Torsion Shear*

When a member is subjected to torsion, it is subjected to torsional shear.

The beams are usually subjected to flexural shear, and sometimes to torsion shear also.

The slab are the plate elements and usually subjected to flexural shear. However, sometimes they are subjected to all the types of shears as in case of restrained two-way slabs and the flat slabs.

Usually the shear failures of shallow RCC beams may not lead to immediate failure, however it considerably reduces its flexural strength and thus there is a state of impending shear failure. Hence the shear design is considered as limit state of collapse.

If the shear failures take place before flexural failures, they are brittle and occur without warning. If the the flexural failure takes place prior to shear failure, the ductile failure of the beam is ensured.

4.1.3 *Flexural Shear*

The shear associated with change of bending moment along the span is known as flexural shear, or simply shear.

Flexural shear force present in beam is given by $\frac{dM}{dx} = V$

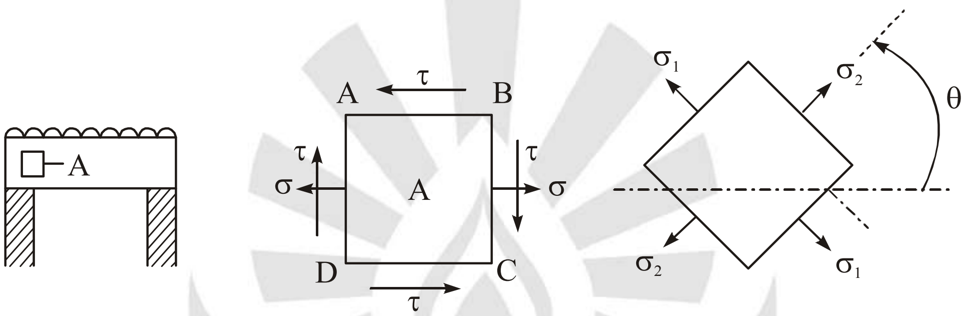
The horizontal and vertical shear stresses are to be accounted for in the designs of beams. Exact analysis of shear in a reinforced concrete beam is quite complex, several experimental studies have been conducted to understand the various modes of failure. Which could occur due to possible combination of shear and bending momentum acting at a given section.

Note:

Concrete is very strong in compression and also quite strong in shear, however, the combination of vertical and horizontal shear stress along with tension due to bending produces diagonal tension which is quite serious and will be now examined. The complementary diagonal compression should also be taken into account.

4.2 | Diagonal Tension and Diagonal Compression

Consider a small element along the length of the beam. Subjected to pure shear.



(a) Small element along the length of beam (b) Principal stresses

The principal stress on this element are given by

$$\sigma_1 \text{ or } \sigma_2 = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$$

the inclination of principal planes is given by

$$\tan 2\theta = \frac{2\tau}{\sigma}.$$

The major principal stress is tensile and is equal to

$$\sigma_1 = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$$

The minor principal stress is compressive and equal to

$$\sigma_2 = \frac{\sigma}{2} - \sqrt{\left(\frac{\sigma}{2}\right)^2 + (\tau)^2}$$

Two important cases are discussed below.

OBJECTIVE SHEET

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

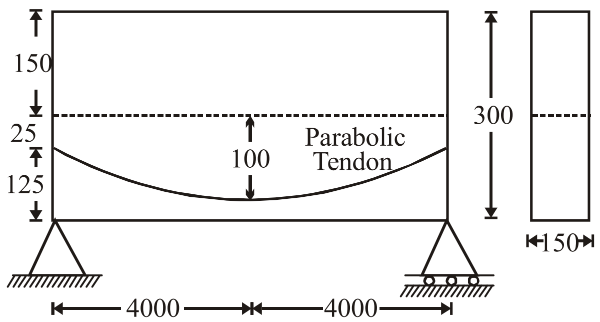
2. Shear span is defined as the zone where

(a) bending moment is zero
(b) shear force is zero
(c) shear force is constant
(d) bending moment is constant

3. Which one of the following statements is correct?

(a) Web shear cracks start due to high diagonal tension in case of beams with their webs and high prestressing force.
(b) Shear design for a prestressed concrete beam is based on elastic theory.
(c) In the zone where bending moment is dominant and shear is insignificant, cracks occur at 20° to 30°
(d) After diagonal cracking, the mechanism of shear transfer in a prestressed concrete member is very much different from that in reinforced concrete members.

4. In the PSC beam shown, f_{ck} = 45 MPa and it supports a UDL of 15 kN/m including self weight. It is prestressed by a parabolic cable carrying an effective prestress of 200 kN. The shear resistance of uncracked section at the support will be



(a) 93.8 kN (b) 94.5 kN
(c) 94.2 kN (d) 95.4 kN

5. The safe shear resistance of an anchor connector is given by (K is a coefficient and other symbols have the usual meanings)

(a) $V = Kf_{sy}A_t$ (b) $v = Kf_{sy}^2A_t$
(c) $V = Kf_{sy}^{1/2}A_t$ (d) $V = Kf_{sy}^{1/2}A_t^{1/2}$

6. The propagation of a shear crack in prestressed concrete member depends on

(a) tensile reinforcement
(b) compression reinforcement
(c) shear reinforcement
(d) shape of the cross-section of the beam

7. 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) $\frac{V_u}{bd}$

8. A simply supported beam of a beam and slab system, rests on a support of width 450mm. The clear span of the beam is 10.0m. The thickness of the slab is 120mm. The depth of the beam below the slab is 480mm and the width of the beam is 250mm. The beam is reinforced with one row of 32 mm diameter steel rods. The total load including the super imposed dead load, live load and its own weight is 25.0kN/m at service stage. Compute the maximum nominal design shear stress in the concrete.

9. The width and effective depth of a reinforced concrete beam is 250mm and 440mm respectively. The beam is provided with 4 number of 20mm tor bars in the tension zone. The beam is subjected to a shear force of 150kN (Factored). Check the requirement of shear reinforcement and provide if required. Grade of concrete is M 20 and that of steel is Fe 415. The shear strength of concrete for different percentages of tensile steel are as below/ 8mm diameter vertical stirrups are available.

[$V_{us} = 0.87\ f_y A_{sv}\ d/S_y$ and $(A_{SV}/S_V) \geq 0.4b/f_y$ with the terms having usual meaning]

% of steel	Shear strength of concrete (τ_c) in N/mm^2 k
1.0	0.62
1.25	0.67
1.50	0.72

10. ***Assertion (A):*** Shear capacity of a concrete beam increases with the increase in tension reinforcement.

Reason (R): Increase in tension reinforcement increases aggregate interlocking force.

11. The maximum permissible shear stress $\tau_{c\ xax}$ given in BIS : 456-1978 is based on

(a) diagonal tension failure
(b) diagonal compression failure
(c) flexural tension failure
(d) flexural compression failure

12. In case of deep beam or in thin webbed RCC members, the first crack form is

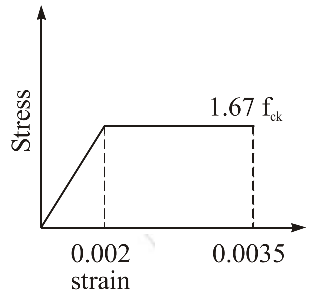
(a) flexural crack
(b) diagonal crack due to compression
(c) diagonal crack due to tension
(d) shear crack

13. The chances of diagonal tension cracks in R.C.C. member reduce when

(a) axial compression and shear force act simultaneously
(b) axial tension and shear force act simultaneously
(c) only shear force act
(d) flexural and shear force act

Linked answer questions 14 & 15:

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 M20.

14. The depth of the neutral axis from the compression fibre is

(a) 76 mm (b) 81 mm
(c) 87 mm (d) 100 mm

15. The depth of the neutral axis obtained as per IS: 456-2000 differs from the depth of neutral axis obtained in Q.08 by

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

16. The codal provisions recommend minimum shear reinforcement in the form of stirrups in the beams

1. to cater for any torsion in the beam section
2. to improve ductility of the cross-section
3. to improve dowel action of longitudinal tension bars

Select the correct answer using the codes given below:

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

17. A reinforced concrete beam of 10 m effective span and 1 in effective depth is supported on 500 mm × 500 mm columns. If the tot al 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