IAT - 1, SOLUTION

DESIGN OF RCC STRUCTURES [10CV52]

Department of Civil Engg. - 5th sem

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Q.1 (a) **Working stress Method (WSM)**

The conceptual basis of WSM is simple. The method basically assumes that the structural material behaves in a linear elastic manner, and the adequate safety can be ensured by suitably restricting the stresses in the material induced by the expected "working load" (Service load) on structure. As specified permissible (allowable) stresses are kept well below the material strength (i.e in the initial phase of stress strain curve), the assumption of linear elastic behaviour is considered justifiable. The ratio of strength of material to the permissible stress is often referred to as the factor of safety. —— (2½)

The stresses under the applied loads are analysed by applying the methods of 'Strength of material', Such as Simple bending theory. In order to apply Such methods to a composite material like reinforced concrete, Strain compatibility (due to bond) is assumed, where-by the strain in reinforcing steel is assumed to be equal to the adjoining concrete to which it is bonded. Further more, as the stresses in concrete and steel are assumed to be linearly related to there respective strains, it follows that the stress in steel in linearly related to adjoing concrete by a constant factor (Modular ratio),

The Stresses under working load within the permissible Stresses are not found realistic by the assumptions made. This may be because of the following reasons.

1. Perm effect of creep and shrinkage
2. The effect of stress concentration
3. And other secondary effects.

All such effects result in significant local increase in re-distribution of calculated stresses.

WSM does not provide realistic measure of actual factor of safety.

The design usually results in large sections of structural members, compare to ULM & LSM, thereby resulting in better serviceability performance (Less deflection, less crack width,) under the usual working load.

- **Ultimate Load Method:**

This method sometimes also called as load factor method or ultimate strength method. in this method the stress condition at the state of impending collapse of the structure is analysed and nonlinear stress strain are made used. The safety measure in the design is introduced by an appropriate choice

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In this method, the stress condition @ state of impending failure of section @ the ultimate strength is analysed, and non-linear stress-strain curves of concrete and steel are made use of.

The safety measures in design is introduced by an appropriate choice of load factor, defined as ratio of ultimate load to working load.

This method generally results in more slender section, and more economical design of beams and column compared to WSM, particularly when high strength reinforcing steel and concrete are used.

The use of non-linear stress-strain behaviour for the design of section becomes truly meaningful only if appropriate non-linear analysis is performed on the structure for determining the load effects as well. Unfortunately, such a structural analysis is generally not performed on reinforcing concrete structure. (except in yeild line theory for slab).

*** "LIMIT STATE METHOD [LSM]" (2½)

An ideal method is the one which takes into account not only the ultimate strength of the structure but also the serviceability and durability requirements. The newly emerging limit state method of design is oriented towards the simultaneous satisfaction of all requirements.

A structure is designed for safety against collapse (for ultimate strength to resist ultimate load) and checked for its serviceability @ working load. The LSM includes consideration of a structure @ both the working and ultimate load level with a view to satisfy the requirements of safety and serviceability.

"The acceptable limit of safety and serviceability requirements, before failure occurs is called Limit State"

A limit state is a state of impending failure, beyond which a structure ceases to perform its intended function satisfactorily, in terms of either safety or serviceability. i.e either by collapses or become unserviceable.

For Ensuring above objectives, the design should be based on characteristic values of material strength and applied loads, which takes into account the variations in material strengths and in the loads to be supported. The characteristic values should be based on statistical data if available where such data are not available, they should be based on experience. The design values are derived from the characteristic value through the use of partial safety factor, one for material strength and one for load.

Types of limit states.

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

Two catagories of limit states are considered in design.

1. Limit state of collapse.
2. Limit state of serviceability.

1. Limit state of collapse: which deals with strength, over turning, sliding, buckling, fatigue fracture etc.

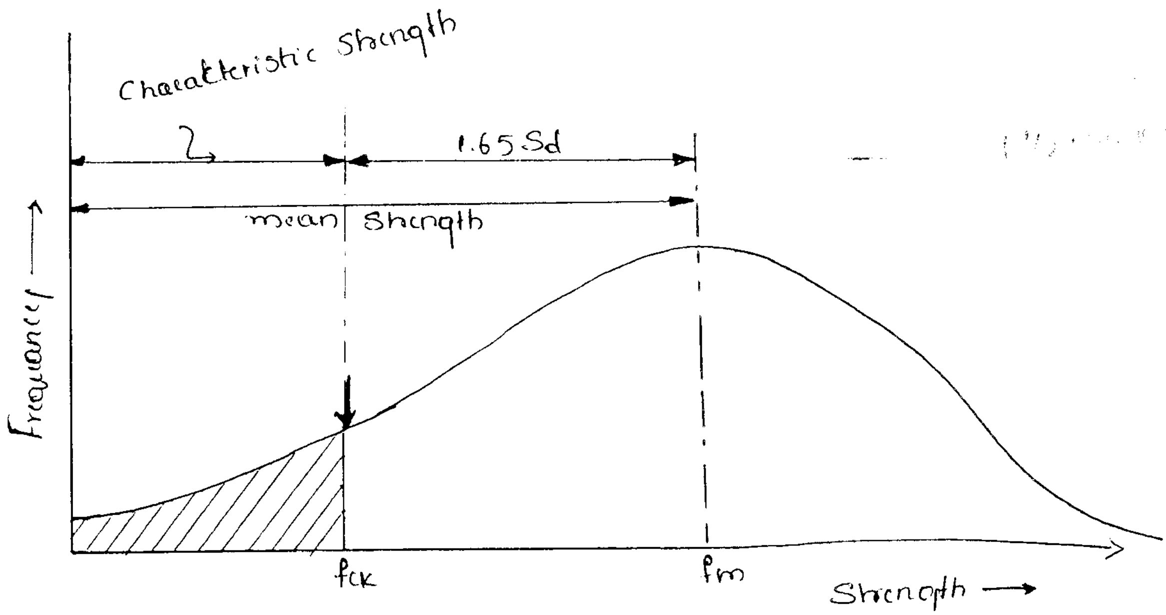
The limit state of collapse of structure could be assesed ~~with~~ from rupture of one or more critical section and from buckling due to elastic or plastic instability or overturning. The resistance to bending, shear, torsion and axial loads @ every section shall not be less than the appropriate value @ that section produced by the probable most unfavorable combination of loads on structure using appropriate partial safety factor.

2. Limit State of Serviceability:

It is behaviour of structure @ working load. Normally, design is based on the consideration of limit state of collapse on ultimate load and on serviceability limit state of deflection and cracking under service loads. Durability is taken care by prescribing appropriate grade of concrete, nominal cover for various exposure condition, cement content etc,

Q.1 (b) Characteristic Strength of materials

Value of strength of material below which not more than a minimum acceptable percentage of test results are expected to fall. Most of design codes adopted the minimum acceptable percentage as 5% for reinforced concrete structures. This implies that there is only 5% probability or chance of the actual strength being less than the characteristic strength or in other words, the characteristic strength has 95% reliability.



Characteristic Strength = [Mean Strength] - K x [Standard deviation]

$$f_K = f_m - K S_d$$

f_K - Characteristic Strength of Material

f_m = mean Strength   K = constant = 1.65

S_d = Standard deviation for a set of test results

The value of standard deviation (Sd)

$$S_d = \sqrt{\frac{\Sigma \delta^2}{n-1}}$$

δ = Deviation of the individual test strength from the average strength of n samples.

n = no. of test results.

(1 mark)

Design strength of Material:

The design strength of material (f_d) is given by.

$$f_d = \frac{f_k}{\gamma_m}$$

f_k = Characteristic strength of material (f_{ck} – Concrete, f_y - Steel)

γ_m = Partial safety factor of material.

(1 mark)

Characteristic load & Design load.

A Characteristic load is defined as the value of load which has a 95% probability of not being exceeded during the life of structure.

Thus the characteristic value of a particular load can be calculated theoritically. However research for determining actual loading on structures has not yielded adequate data to enable us to compute theoritical values of variations for arriving @ the actual loading on a structure. Code states that since the data are not available to express loads in statistical terms, the loads given in respective code books are assumed as the characteristic loads.

$$F_k = F_m + K S_d$$

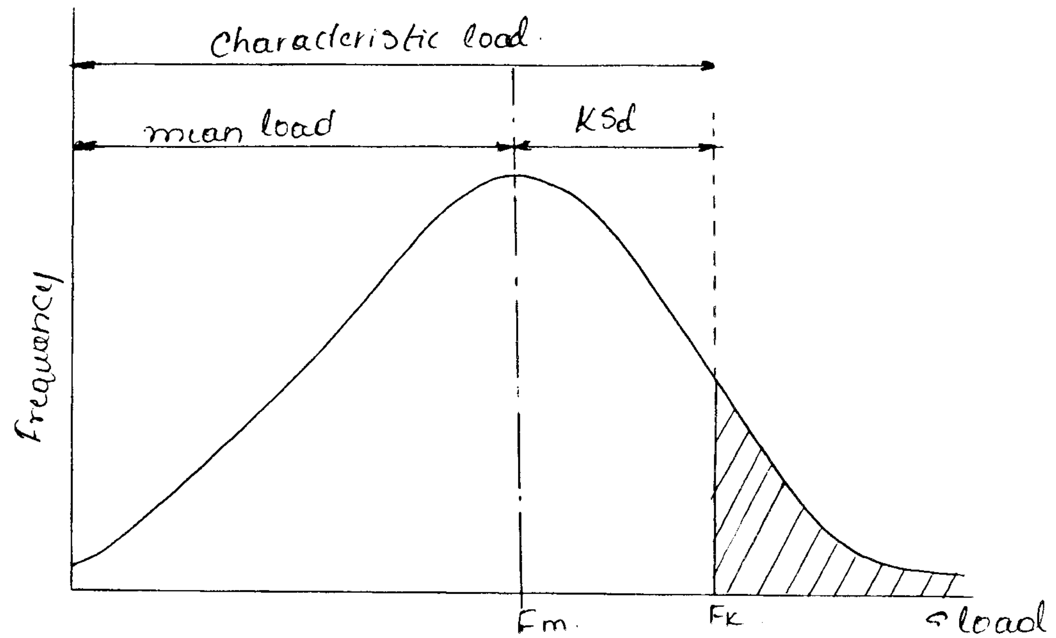
F_k = Characteristic load.

F_m = Mean load.

K = Constant = 2.645 ≈ 2.65

S_d = Standard deviation for load.

(½ mark)



Design loads: The design load (F_d) is given by. (1 mark)

$F_d = F_K \cdot \lambda_f$ (also known as Factored load)

F_K = Characteristic load.

λ_f = Partial Safety factor.

Q.2 (b) (i) Partial safety factor (λ_m) for material: (2½ marks)

when assessing the strength of a structure for limit state of collapse. the value of partial safety factor λ_m should be taken as 1.5 for concrete and 1.15 for steel. A higher value of partial safety factor for concrete has been adopted because there are greater chances of variation of strength of concrete due to improper compaction, inadequate curing, improper batching and mixing and variations in properties of ingredients. The chance of variations in strength of reinforcement are known to be small and hence a lower value has been adopted.

The design stress $f_{ds} = \frac{f_y}{\lambda_m} = \frac{f_y}{1.15} = 0.87 f_y$

LIMIT STATE OF COLLAPSE IN FLEXURE - I

SINGLY REINFORCED RECTANGULAR SECTION.

(1) COPY

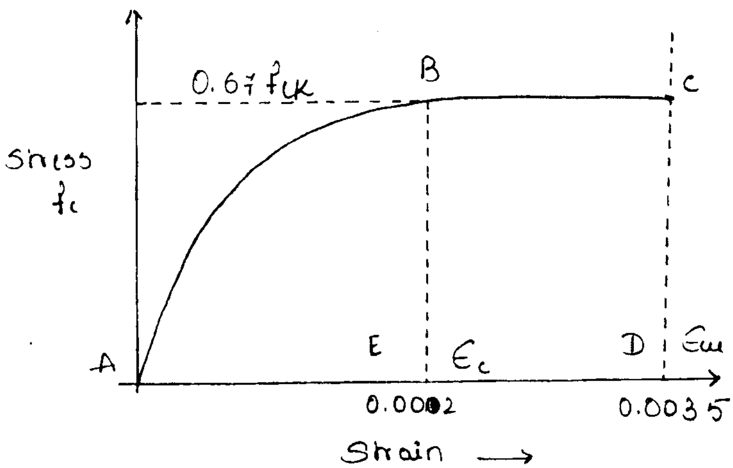
Stress Block parameter:

The stress strain behaviour of concrete under compression are generally obtained from cylinder (or) cube of concrete subjected to compression test (or) loading.

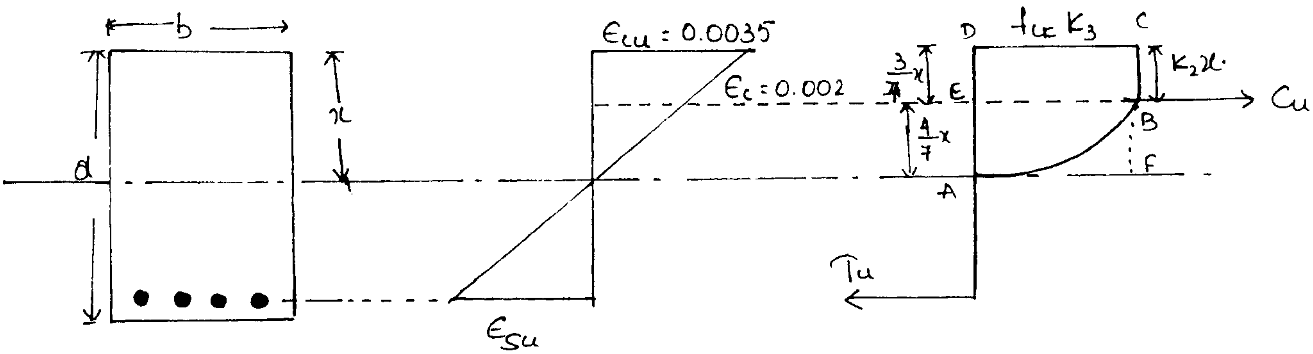
where as the stress and strains are uniform for a cube (or for a cylinder), they vary across the depth of Bending members.

The IS code recommends the compressive strength of concrete in structure = $0.67 f_{ck}$.

The stress strain diagram is as shown in fig.



Stress Strain curve of concrete.



Strain and Stress Variation across section.

→ 2

$\therefore$ Substituting eq (1)

$$K_1 = \frac{\text{Area of } ABCD}{\text{Area of } AFCD} = \frac{\text{Area of } \cancel{AFCD}\ (17/21)}{\text{Area of } \cancel{AFCD}}$$

$$\boxed{K_1 = \frac{17}{21}}$$

Resultant compressive force is located @ depth of $K_2 x$

$$K_2 x = K_2 AD = \frac{(\text{area of } ABE)\bar{x}_1 + (\text{area of } BCDE)\bar{x}_2}{\text{area } ABCD}$$

$$= \frac{(8/21)\left(ED + \frac{3}{8}AE\right) + \left(\frac{9}{21}\right)\left(\frac{1}{2}DE\right)}{17/21}$$

$$K_2 AD = \frac{(8/21)\left(3/7 + (3/8 \times 4/7)\right)AD + 9/21\left(1/2 \times 3/7\right)AD}{17/21}$$

$$= \frac{99}{238} = 0.416 \simeq 0.42$$

$$\boxed{K_2 = 0.42} \qquad \therefore \boxed{K_2 x = 0.42x}$$

To find compressive force

$$C_u = b \times \text{area of } ABCD$$

$$= b \times K_1 x \times Dc$$

$$= b \times K_1 x \times K_3 f_{ck}$$

$$= b \times 0.81\, x \times 0.67 f_{ck}$$

$$\boxed{C_u = 0.542 f_{ck}\, x\, b}$$

& for design $\frac{C_u}{\cancel{D}\,\delta} = \frac{0.542}{1.5} f_{ck}\, x\, b$

$$\boxed{C_u = 0.36 f_{ck}\, x\, b}$$

Q.1.(c) Given data. (2 marks)

$l = 7.0m$

$b_f = 3m\,c/c$

$D_f = 220mm$

$LL = 5 kN/m^2$

$f_{ck} = 20$

$f_y = 415$

$D = 700mm$

Assuming $b_w = 300mm$

$b_f = \frac{l_0}{6} + 6D_f + b_w = \frac{7000}{6} + 6\times220 + 300 = 2786\ mm.$ — 1 marks

$b_f = b_w + \frac{1}{2}3000 = 1500 + 300 = 1800mm$ — (1 mark)

$x_{umax} = 0.48 \times 650$

$x_{umax} = 312mm$ (1 mark)

$W = W_L + W_D$ (2 marks)

$= 5 + (0.3\times0.7\times25)$

$W = 10.25\ kN/m^2$, $W_u = 15.37.$

$M_u = \frac{W_u l^2}{8} = 94.171\ kN-m.$ (1 mark)

$M_u = C_{uw}(\text{lar dist}) + C_{uf}(\text{lar dis})$ (1 marks)

$= 0.36\times f_{ck} b_w x_u(d - 0.42x_u) + 0.45 f_{ck}(b_f - b_w)D_f(d - D_f/2)$

$94.17\times10^6 = 0.36\times20\times300\times x_u(650 - 0.42\times x_u) + 0.45(20)(1800-300)(220)(650-110)$

$= 1404\times10^3 x_u - 907.2x_u^2 + 1603.8\times10^6 - 94.17\times10^6.$

$+ 1509.63\times10^6.$ (2 marks)

$x_u = 750mm > x_{umax} = 312mm \rightarrow$ Over Reinforced. — (1 mark)

$x_u = x_{umax} = 312mm$

(3 marks)

$C_{uw} + C_{uf} = T_u.$

$0.36\times f_{ck} b_w x_u + 0.45 f_{ck}(b_f - b_w)D_f = 0.87 f_y A_{st}.$

$0.36\times20\times300\times312 + 0.45\times20(1500)220 = 0.87\times415\times A_{st}$

$A_{st} = 1904.55\ mm^2$

Assuming 20mm ϕ #. $n = \frac{A_{st}}{\frac{\pi d^2}{4}} = \frac{1904.55\times4}{\pi\times20^2} = 6\ no$

In a singly reinforced section, it has a limiting value of moment of resistance, corresponding to limiting value of steel reinforcement. However, if applied moment M_{ua} is larger than M_{ulimit}, two alternative will be available.

(i) Increase the depth of section.

(ii) To provide compression reinforcement.

A Doubly reinforced section of a beam, provided for following reason.

1. Head room requirements, appearance.
2. Restriction in depth @ the location of beam @ plinth level, along with the provision of ventilator b/w the ground level & the bottom of plinth beam.
3. where it is required to increase the stiffness of beam.
4. It is found that the compression steel increases the rotation capacity and ductility. Structure with high ductility respond better to seismic forces.

STRESS BLOCK AND LOCATION OF N.A

A_{sc} = Reinforcement in compression side.

C_u = Compressive force in concrete = $0.36 f_{ck} x_u b$.

C_{sc} = Compressive force in compression steel = $f_{sc} A_{sc}$

f_{sc} = Design stress in compression reinforcement read off from stress & strain curve

$$e_{sc} = \text{Strain in Compression reinforcement} = \frac{0.0035\,(x_u - d')}{x_u} =$$

fig(b) shows strain diagram.

fig (c) shows stress diagram across the section.

The stress block ABCDEA has parabolic part same as stress-strain curve from fig ① i.e AB part., & then CB linear part is from CB part of graph. = stress of 0.67fck constant.

The total compressive force = Cu which is below the top fiber & can be expressed in stress block parameters K_1 K_2 K_3.

were K_1 = Shape factor = $\frac{\text{Area of Stress block}}{\text{Area of Rectangle}} = \frac{ABCD}{AFCD}$

$$K_1 = \frac{\text{area of } ABCD}{\text{area is } (x \times CD)}$$

Now Ultimate strain in concrete = 0.0035 = e_{cu} = AD

Strain after yeilding in concrete = 0.002 = e_c = AE @ stress of 0.67 fck.

The Ratio of $\frac{e_c}{e_{cu}} = \frac{AE}{AD} = \frac{0.002}{0.0035} = \frac{4}{7}$ ∴ $\boxed{AE = \frac{4}{7} AD}$

lly $\frac{ED}{AD} = \frac{0.0035 - 0.002}{0.0035} = \frac{3}{7}$ ∴ $\boxed{ED = \frac{3}{7} AD}$

Now area ABCD = Area ABE + Area BCDE

$$= \left(\frac{2}{3} AE \times BE\right) + (ED \times CD)$$

$$= \left(\frac{2}{3} \times \frac{4}{7} \times AD \times CD\right) + \left(\frac{3}{7} AD \times CD\right)$$

$$= \frac{8}{21} (AD \times CD) + \frac{9}{21} (AD \times CD)$$

$$\text{Area } ABCD = \frac{17}{21} (AD \times CD) = \text{Area of } AFCD \left(\frac{17}{21}\right)$$