DESIGN OF BEAM

(AS PER ACI CODE)

CONTENT

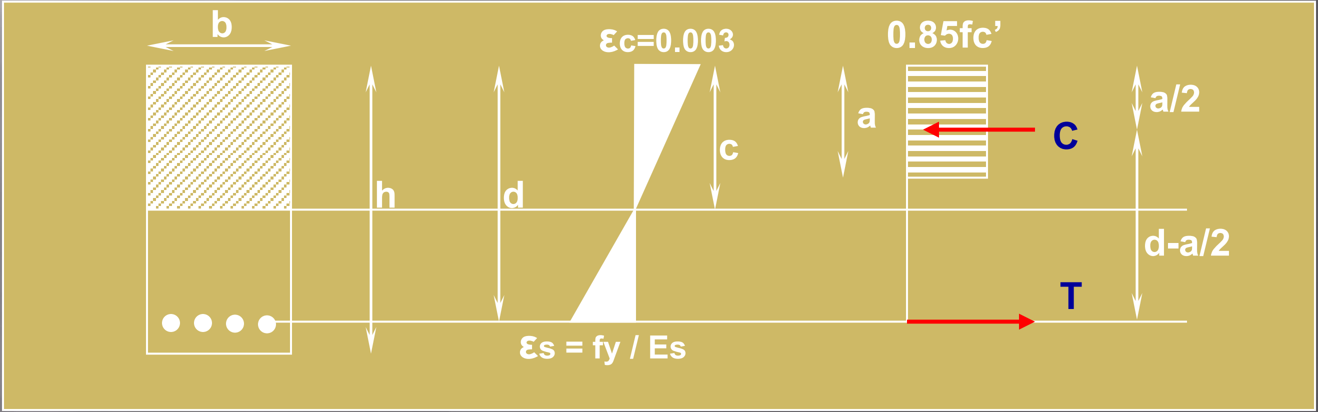
- **ASSUMPTIONS**
- **EVALUATION OF DESIGN PARAMETERS**

  MOMENT FACTORS Kn, ω
  STRENGTH REDUCTION FACTOR ϕ
  BALANCED REINFORCEMENT RATIO ρ_b
- **DESIGN PROCEDURE FOR SINGLY REINFORCED BEAM**

  CHECK FOR CRACK WIDTH
- **DESIGN PROCEDURE FOR DOUBLY REINFORCED BEAM**
- **FLANGED BEAMS**
  - **T – BEAMS**
  - **L - BEAMS**

ASSUMPTIONS

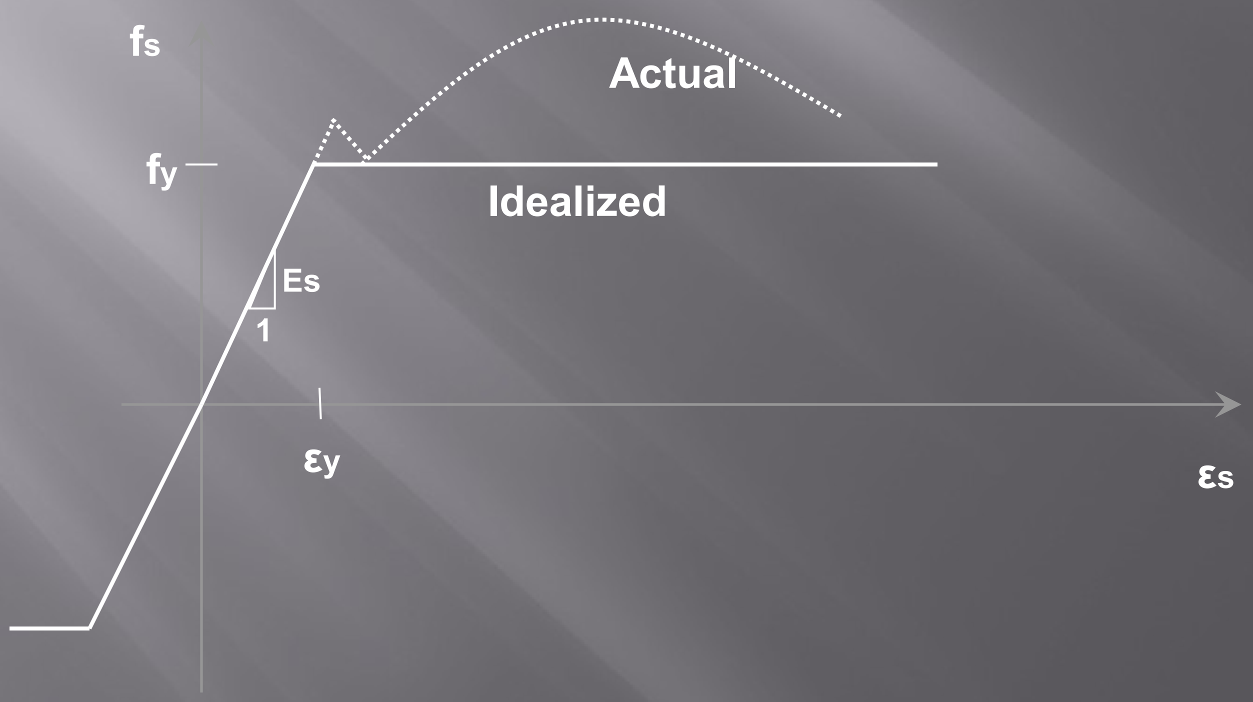
- Plane sections before bending remain plane and perpendicular to the N.A. after bending
- Strain distribution is linear both in concrete & steel and is directly proportional to the distance from N.A.
- Strain in the steel & surrounding concrete is the same prior to cracking of concrete or yielding of steel
- Concrete in the tension zone is neglected in the flexural analysis & design computation



TO SLIDE-5

- Concrete stress of 0.85fc’ is uniformly distributed over an equivalent compressive zone.

  fc’ = Specified compressive strength of concrete in psi.
- Maximum allowable strain of 0.003 is adopted as safe limiting value in concrete.
- The tensile strain for the balanced section is fy/Es
- Moment redistribution is limited to tensile strain of at least 0.0075



EVALUATION OF DESIGN PARAMETERS

- Total compressive force $C = 0.85 f_c' ba$ (Refer stress diagram)
- Total Tensile force $T = A_s f_y$

$C = T$

$0.85 f_c' ba = A_s f_y$

$a = A_s f_y / (0.85 f_c' b)$

$= \rho d f_y / (0.85 f_c')$ $\therefore \rho = A_s / bd$

- Moment of Resistance, $M_n = 0.85 f_c' ba (d - a/2)$ or

$M_n = A_s f_y (d - a/2)$

$= \rho bd f_y [d - (\rho d f_y b / 1.7 f_c')]$

$= \omega f_c' [1 - 0.59 \omega] bd^2$

$\therefore \omega = \rho f_y / f_c'$

$M_n = K_n bd^2$ $\therefore K_n = \omega f_c' [1 - 0.59 \omega]$

$M_u = \phi M_n$

$= \phi K_n bd^2$

TO SLIDE-7

ϕ = Strength Reduction Factor

Balaced Reinforcement Ratio (ρ_b)

From strain diagram, similar triangles

$c_b / d = 0.003 / (0.003 + fy / Es)$; $Es = 29 \times 10^6$ psi

$c_b / d = 87{,}000 / (87{,}000 + fy)$

Relationship b / n the depth `a' of the equivalent rectangular stress block & depth `c' of the N.A. is

$a = \beta_1 c$

$\beta_1 = 0.85$; $fc' \leq 4000$ psi

$\beta_1 = 0.85 - 0.05(fc' - 4000) / 1000$; $4000 < fc' \leq 8000$

$\beta_1 = 0.65$; $fc' > 8000$ psi

$\rho_b = A_{sb} / bd$

$= 0.85 fc' \, a_b / (fy. \, d)$

$= \beta_1 (0.85 \, fc' / fy) [87{,}000 / (87{,}000 + fy)]$

- In case of statically determinate structure ductile failure is essential for proper moment redistribution. Hence, for beams the ACI code limits the max. amount of steel to 75% of that required for balanced section. For practical purposes, however the reinforcement ratio (ρ = As / bd) should not normally exceed 50% to avoid congestion of reinforcement & proper placing of concrete.

$$\rho \leq 0.75 \rho_b$$

- Min. reinforcement is greater of the following:

$As_{min} = 3\sqrt{fc'} \times b_w d / fy$ or $200\, b_w d / fy$

$\rho_{min} = 3\sqrt{fc'} / fy$ or $200 / fy$

- For statically determinate member, when the flange is in tension, the b_w is replaced with $2b_w$ or bf whichever is smaller

- The above min steel requirement need not be applied, if at every section, Ast provided is at least 1/3 greater than the analysis

DESIGN PROCEDURE FOR SINGLY REINFORCED BEAM

- Determine the service loads
- Assume `h` as per the support conditions according to Table 9.5 (a) in the code
- Calculate d = h – Effective cover
- Assume the value of `b` by the rule of thumb.
- Estimate self weight
- Perform preliminary elastic analysis and derive B.M (M), Shear force (V) values
- Compute ρ_{min} and ρ_b
- Choose ρ between ρ_{min} and ρ_b
- Calculate ω, Kn
- From Kn & M calculate `d' required (Substitute b interms of d)
- Check the required `d' with assumed `d'
- Revise & repeat the steps, if necessary

- With the final values of ρ, b, d determine the Total As required
- Design the steel reinforcement arrangement with appropriate cover and spacing stipulated in code. Bar size and corresponding no. of bars based on the bar size #n.
- Check crack widths as per codal provisions

EXAMPLE ➢

DESIGN PROCEDURE FOR DOUBLY REINFORCED BEAM

- **Moment of resistance of the section**

$M_u = M_{u1} + M_{u2}$

M_{u1} = M.R. of Singly reinforced section

$= \phi A_{s1} fy (d - a/2)$; $A_{s1} = M_{u1} / [\phi fy (d - a/2)]$

$Mu2 = \phi A_{s2} fy (d - d')$; $A_{s2} = M_{u2} / [\phi fy (d - d')]$

$Mu = \phi A_{s1} fy (d - a/2) + \phi A_{s2} fy (d - d')$

If Compression steel yields,

$\varepsilon' \geq fy / Es$

I.e., $0.003 [1 - (0.85 fc' \beta_1 d') / ((\rho - \rho') fyd)] \geq fy / Es$

If compression steel does not yield,

$fs' = Es \times 0.003 [1 - (0.85 fc' \beta_1 d') / ((\rho - \rho') fyd)]$

Balanced section for doubly reinforced section is

$\rho_b = \rho_{b1} + \rho' (fs / fy)$

ρ_{b1} = Balanced reinforcement ratio for S.R. section

END

DESIGN STRENGTH

$$Mu = \phi\ Mn$$

- The design strength of a member refers to the nominal strength calculated in accordance with the requirements stipulated in the code multiplied by a Strength Reduction Factor ϕ, which is always less than 1.

Why ϕ ?

- To allow for the probability of understrength members due to variation in material strengths and dimensions
- To allow for inaccuracies in the design equations
- To reflect the degree of ductility and required reliability of the member under the load effects being considered.
- To reflect the importance of the member in the structure

RECOMMENDED VALUE

Beams in Flexure……………………..	0.90
Beams in Shear & Torsion …………	0.85

BACK

AS PER TABLE 9.5 (a)

Simply Supported	One End Continuous	Both End Continuous	Cantilever
L / 16	L / 18.5	L / 21	L/8

Values given shall be used directly for members with normal weight concrete (Wc = 145 lb/ft3) and Grade 60 reinforcement

- For structural light weight concrete having unit wt. In range 90-120 lb/ft3 the values shall be multiplied by

  (1.65 – 0.005Wc) but not less than 1.09

- For fy other than 60,000 psi the values shall be multiplied by (0.4 + fy/100,000)

- \`h\` should be rounded to the nearest whole number

BACK

CLEAR COVER

- Not less than 1.5 in. when there is no exposure to weather or contact with the ground
- For exposure to aggressive weather 2 in.
- Clear distance between parallel bars in a layer must not be less than the bar diameter or 1 in.

RULE OF THUMB

- d/b = 1.5 to 2.0 for beam spans of 15 to 25 ft.
- d/b = 3.0 to 4.0 for beam spans > 25 ft.
- \`b\` is taken as an even number
- Larger the d/b, the more efficient is the section due to less deflection

∢ BACK

BAR SIZE

- #n = n/8 in. diameter for n ≤8.

  Ex. #1 = 1/8 in.

  ....

  #8 = 8/8 i.e., l in.

Weight, Area and Perimeter of individual bars

Bar No	Wt.per Foot (lb)	Stamdard Nominal Dimensions			
		Diameter d_b		C/S Area, A_b (in^2)	Perimeter (in.)
		inch	mm		
3	0.376	0.375	9	0.11	1.178
4	0.668	0.500	13	0.20	1.571
5	1.043	0.625	16	0.31	1.963
6	1.502	0.750	19	0.44	2.356
7	2.044	0.875	22	0.60	2.749
8	2.670	1.000	25	0.79	3.142
9	3.400	1.128	28	1.00	3.544
10	4.303	1.270	31	1.27	3.990
11	5.313	1.410	33	1.56	4.430
14	7.650	1.693	43	2.25	5.319
18	13.600	2.257	56	4.00	7.091

∢ BACK

CRACK WIDTH

w = $0.000091 \cdot f_s \cdot \sqrt[3]{d_c \cdot A}$

Where,

w = Crack width

= 0.016 in. for an interior exposure condition

= 0.013 in. for an exterior exposure condition

fs = 0.6 fy, kips

dc = Distance from tension face to center of the row of bars closest to the outside surface

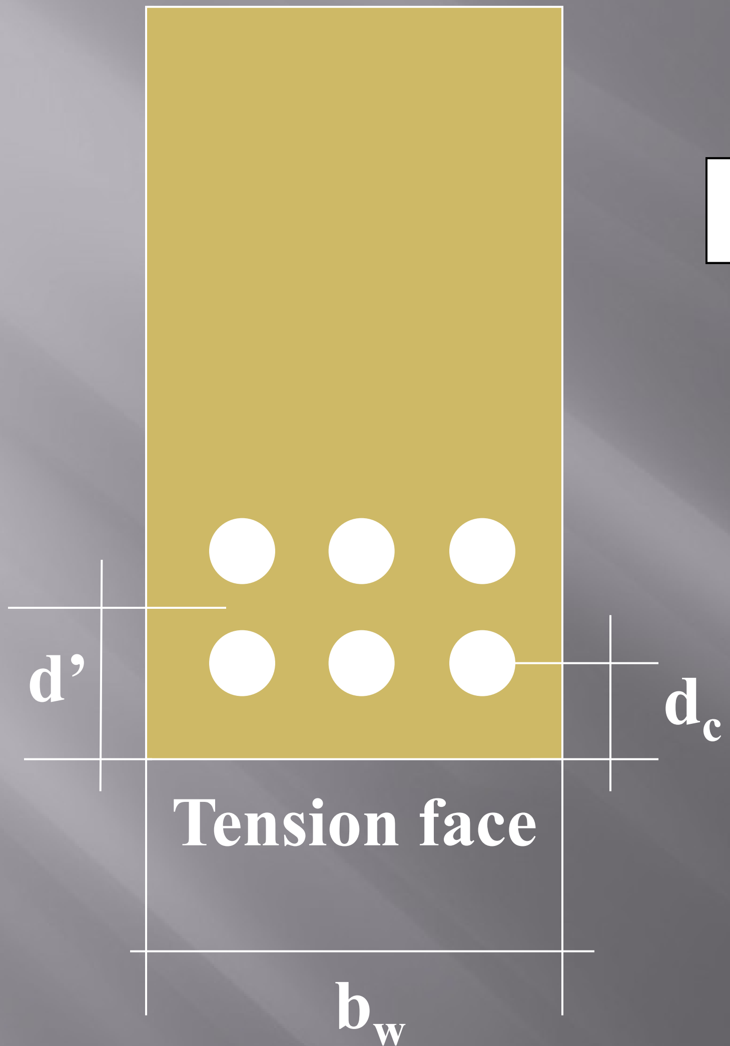
A = Effective tension area of concrete divided by the number of reinforcing bars

= A_{eff} / N

A_{eff} = Product of web width and a height of web equal to twice the distance from the centroid of the steel and tension surface

N = Total area of steel As / Area of larger bar

BACK

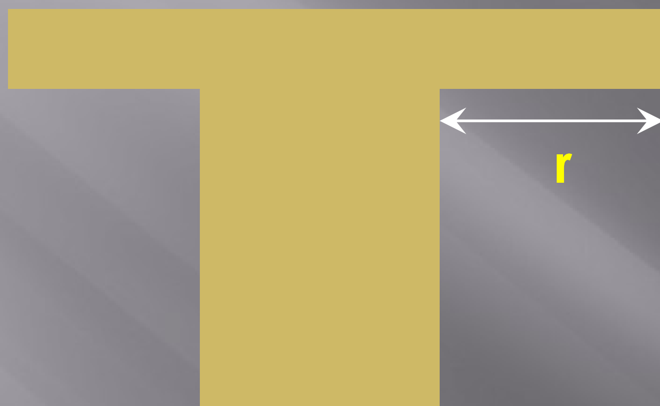


$$A_{eff} = b_w \times 2d'$$

< BACK

FLANGED BEAMS

- **EFFECTIVE OVERHANG, r**



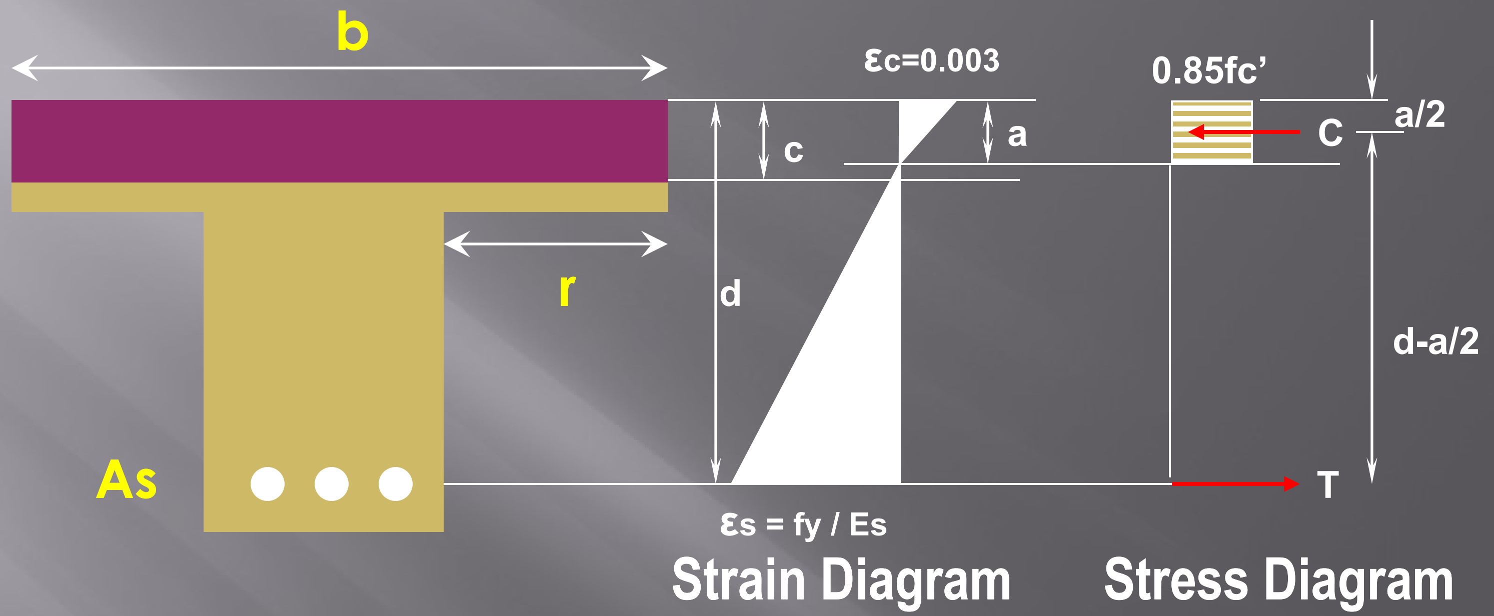
T – BEAM

1. $r \leq 8\,hf$
2. $r \leq \frac{1}{2}\,ln$
3. $r \leq \frac{1}{4}\,L$

L – BEAM

1. $r \leq 6\,hf$
2. $r \leq \frac{1}{2}\,ln$
3. $r \leq 1/12\,L$

Case-1: Depth of N.A `c‘ < hf



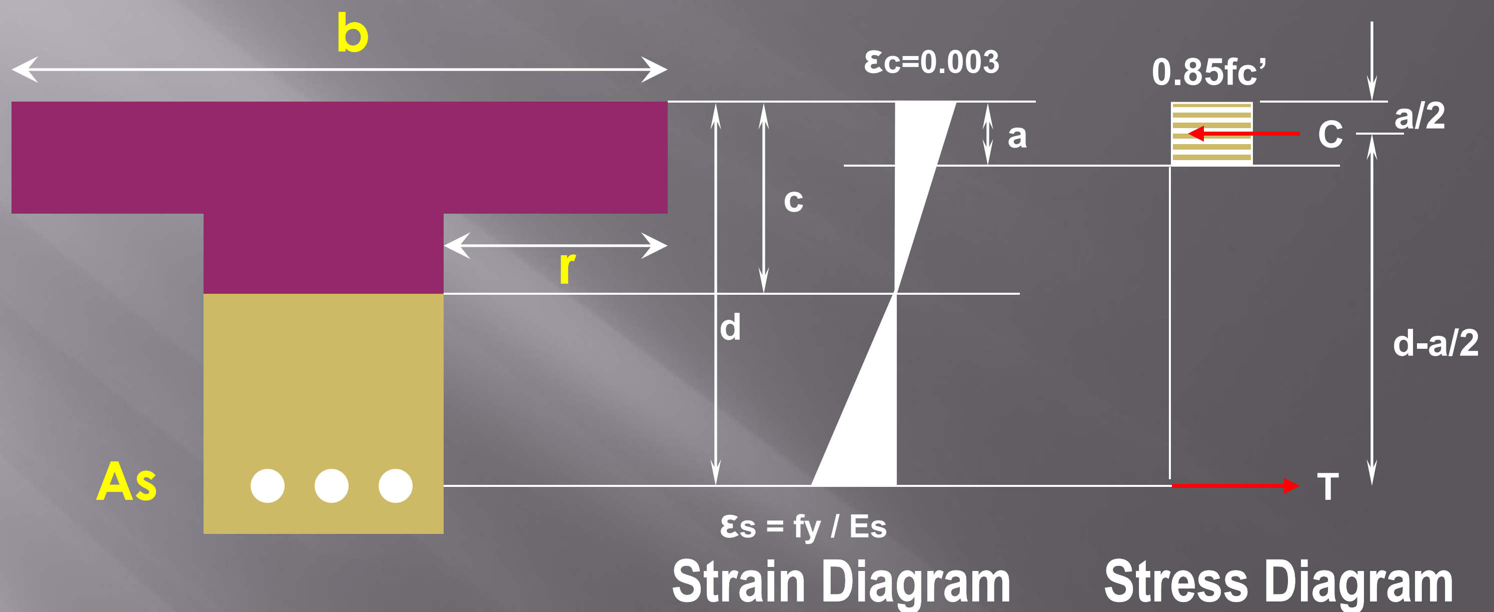
$$0.85 f_c' \, b \, a = A_s f_y$$

$$a = A_s f_y / [\, 0.85 f_c' \, b \,]$$

$$M_n = A_s f_y (d - a/2)$$

Case-2: Depth of N.A `c' > hf

i) a < hf



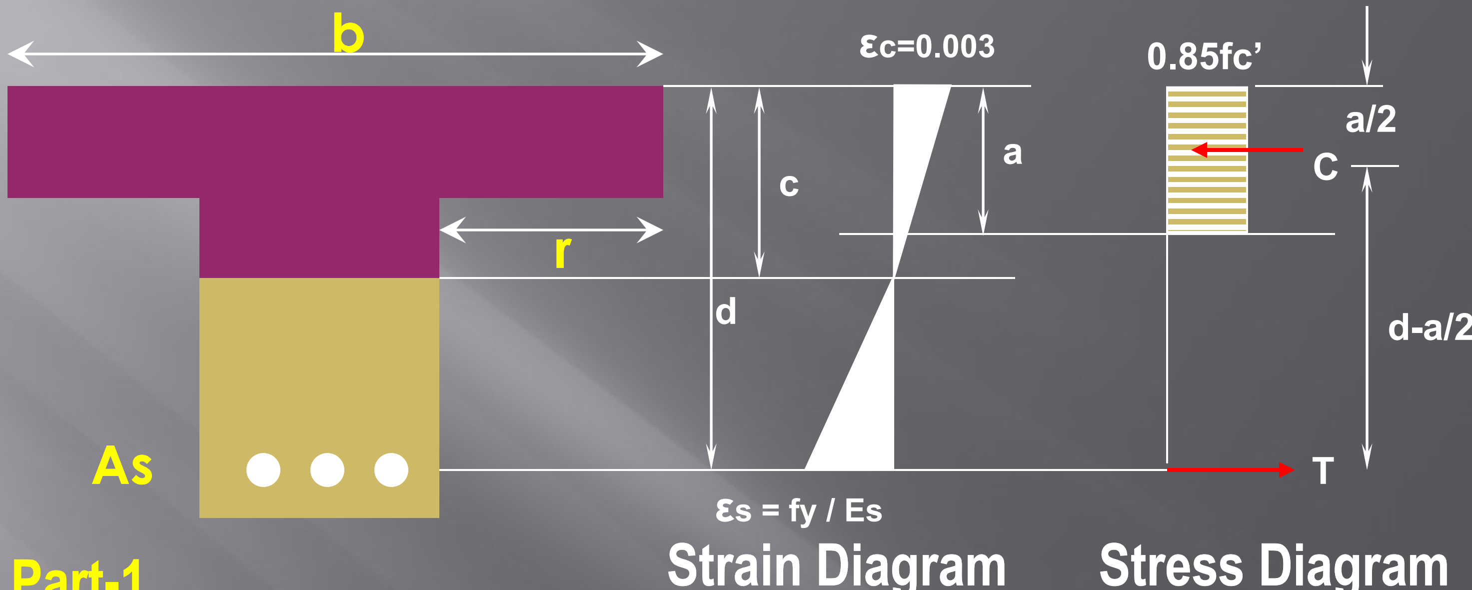
$0.85f_c' \, b \, a = A_s f_y$

$a = A_s f_y / [\, 0.85 f_c' \, b \,]$

$M_n = A_s f_y (d - a/2)$

Case-2: Depth of N.A `c' > hf

ii) a > hf



Part-1

$$0.85fc'\ bw\ a = As_1\ fy$$

Part-2

$$0.85fc'\ (b-bw)\ hf = As_2\ fy$$

$$0.85fc'\ bw\ a + 0.85fc'\ (b-bw)\ hf = As\ fy$$

$$a = [As\ fy - 0.85fc'\ (b-bw)\ hf] / [0.85fc'\ bw]$$

- Moment of resistance of the section

$$M_n = M_{n1} + M_{n2}$$

$$M_{n1} = A_{s1}\, fy\, (d - a / 2)$$

$$M_{n2} = A_{s2}\, fy\, (d - h_f / 2)$$

- **Moment Redistribution**

  For continuous beam members,

  Code permits Max of 20%

  when et $\geq$ 0.0075 at that section

- Balaced Reinforcement Ratio (ρ_b)

$\rho_b = (bw / b) [\rho_{\underline{b}} + \rho_f]$

$\rho_{\underline{b}} = A_{sb} / b_w d$

$= 0.85 fc' a_b / (fy. d)$

$= \beta_1 (0.85 fc' / fy) [87{,}000 / (87{,}000+fy)]$

$\rho_{\underline{f}} = 0.85 fc' (b-bw) hf / (fy\ bw\ d)$

$\rho \leq 0.75 \rho_b$

- Min. reinforcement is greater of the following:

$\rho_w = 3\sqrt{fc'} / fy$ or $200 / fy$; for +ve Reinf.

$\rho_{min} = 6\sqrt{fc'} / fy$ or $200 / fy$; for -ve Reinf.

THANK YOU