ELEMENTS OF ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 614

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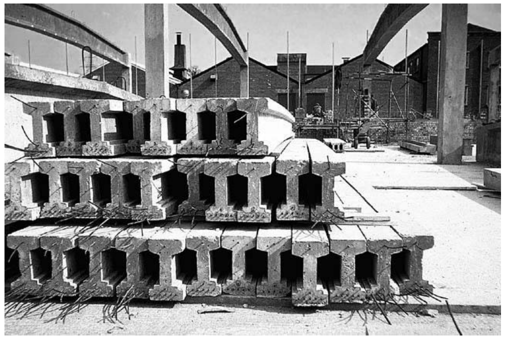
SPRING 2014

lecture
twenty one

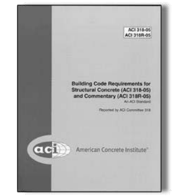


http:// nisee.berkeley.edu/godden

concrete construction:
materials & beams

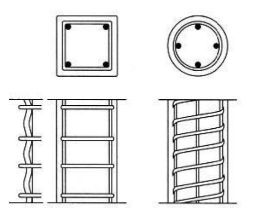
Concrete Beam Design

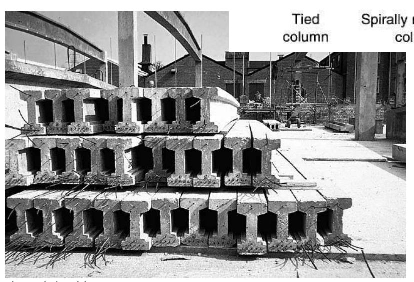
- composite of concrete and steel
- American Concrete Institute (ACI)
  – design for maximum stresses
  – limit state design
    - service loads x load factors
    - concrete holds no tension
    - failure criteria is yield of reinforcement
    - failure capacity x reduction factor
    - factored loads < reduced capacity
  – concrete strength = f'_c



Concrete Construction

- cast-in-place
- tilt-up
- prestressing
- post-tensioning





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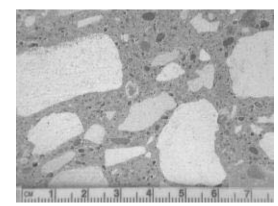
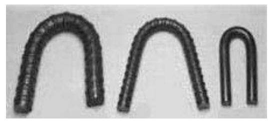
Concrete

- low strength to weight ratio
- relatively inexpensive
  – Portland cement
  – aggregate
  – water
- hydration
- fire resistant
- creep & shrink



Reinforcement

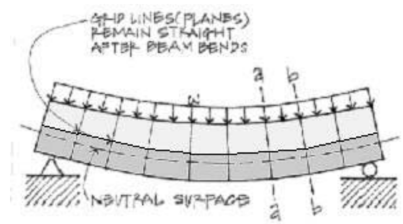
- *deformed steel bars (rebar)*
  - *Grade 40, F_y = 40 ksi*
  - *Grade 60, F_y = 60 ksi - most common*
  - *Grade 75, F_y = 75 ksi*
  - *US customary in # of 1/8” ϕ*

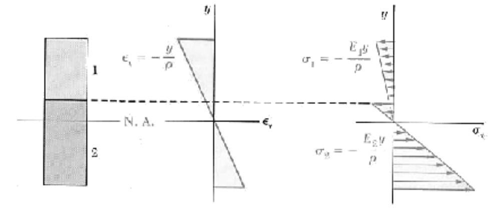


- *longitudinally placed*
  - *bottom*
  - *top for compression reinforcement*
  - *spliced, hooked, terminated...*

Behavior of Composite Members

- *plane sections remain plane*
- *stress distribution changes*

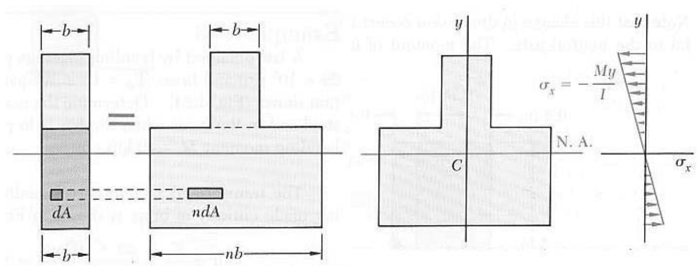




$$f_1 = E_1\varepsilon = -\frac{E_1 y}{\rho} \qquad f_2 = E_2\varepsilon = -\frac{E_2 y}{\rho}$$

Transformation of Material

- *n is the ratio of E’s* $n = \frac{E_2}{E_1}$
- *effectively widens a material to get same stress distribution*



Stresses in Composite Section

- *with a section transformed to one material, new I*
  - *stresses in that material are determined as usual*
  - *stresses in the other material need to be adjusted by n*

$$n = \frac{E_2}{E_1} = \frac{E_{steel}}{E_{concrete}}$$

$$f_c = -\frac{My}{I_{transformed}}$$

$$f_s = -\frac{Myn}{I_{transformed}}$$

Reinforced Concrete - stress/strain

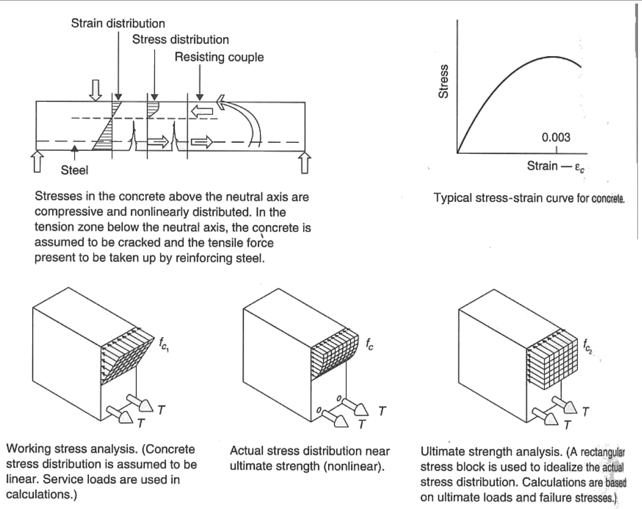
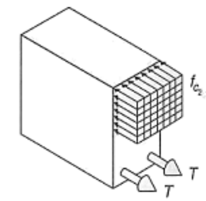


FIGURE 6–37 Reinforced concrete beams.

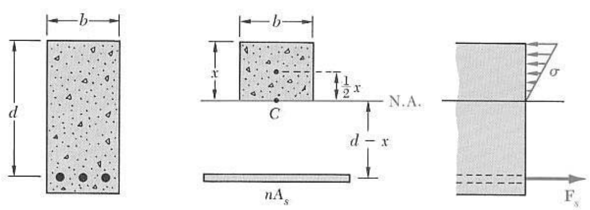
Reinforced Concrete Analysis

- for stress calculations
  - steel is transformed to concrete
  - concrete is in compression above n.a. and represented by an equivalent stress block
  - concrete takes no tension
  - steel takes tension
  - force ductile failure



Location of n.a.

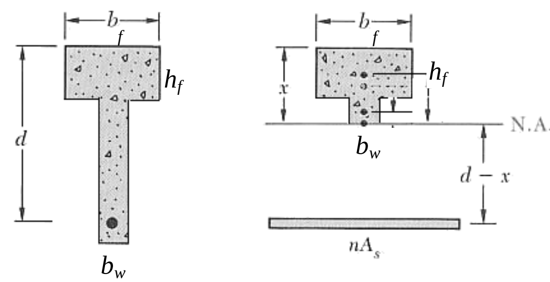
- ignore concrete below n.a.
- transform steel
- same area moments, solve for x



$$bx \cdot \frac{x}{2} - nA_s(d - x) = 0$$

T sections

- n.a. equation is different if n.a. below flange



$$b_f h_f\left(x - {h_f}/{2}\right) + (x - h_f)b_w\,\frac{(x - h_f)}{2} - nA_s(d - x) = 0$$

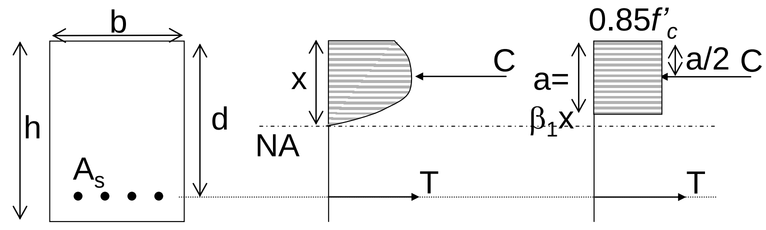
ACI Load Combinations*

- 1.4D
- 1.2D + 1.6L + 0.5(L_r or S or R)
- 1.2D + 1.6(L_r or S or R) + (1.0L or 0.5W)
- 1.2D + 1.0W + 1.0L + 0.5(L_r or S or R)
- 1.2D + 1.0E + 1.0L + 0.2S
- 0.9D + 1.0W
- 0.9D + 1.0E

*can also use old ACI factors

Reinforced Concrete Design

- stress distribution in bending



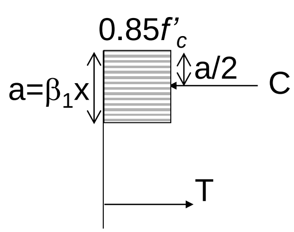
actual stress

Whitney stress block

Wang & Salmon, Chapter 3

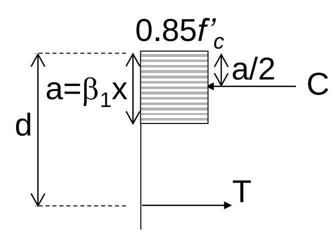
Force Equations

- $C = 0.85\, f'_c ba$
- $T = A_s f_y$
- where
  - f'_c = concrete compressive strength
  - a = height of stress block
  - β_1 = factor based on f'_c
  - x = location to the n.a.
  - b = width of stress block
  - f_y = steel yield strength
  - A_s = area of steel reinforcement



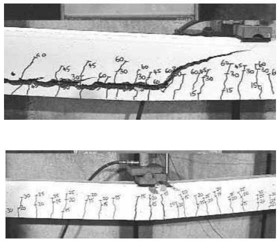
Equilibrium

- T = C
- $M_n = T(d-a/2)$
  - d = depth to the steel n.a.
- with A_s
  - $a = \dfrac{A_s f_y}{0.85\, f'_c b}$
  - $M_u \le \phi M_n$ $\phi = 0.9$ for flexure
  - $M_u = \phi\, T(d-a/2) = \phi\, A_s f_y (d-a/2)$



Over and Under-reinforcement

- over-reinforced
  - steel won't yield
- under-reinforced
  - steel will yield
- reinforcement ratio
  - $\rho = \frac{A_s}{bd}$
  - use as a design estimate to find A_s,b,d
  - max ρ is found with $\varepsilon_{steel} \geq 0.004$ (not ρ_{bal})



http://people.bath.ac.uk/abstji/concrete_video/virtual_lab.htm

A_s for a Given Section

- several methods
  - guess a and iterate
    1. guess a (less than n.a.)
    2. $A_s = \frac{0.85 f'_c ba}{f_y}$
    3. solve for a from $M_u = \phi A_s f_y (d-a/2)$
       $a = 2\left(d - \frac{M_u}{\phi A_s f_y}\right)$
    4. repeat from 2. until a from 3. matches a in 2.

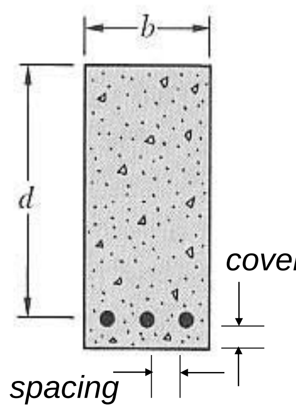
A_s for a Given Section (cont)

- chart method
  - Wang & Salmon Fig. 3.8.1 R_n vs. ρ

    1. calculate $R_n = \frac{M_n}{bd^2}$
    2. find curve for f'_c and f_y to get ρ
    3. calculate A_s and a
- simplify by setting h = 1.1d

Reinforcement

- min for crack control
- required $A_s = \frac{3\sqrt{f'_c}}{f_y}(bd)$
- not less than $A_s = \frac{200}{f_y}(bd)$
- $A_{s\text{-}max}$: $a = \beta_1(0.375d)$
- typical cover
  - 1.5 in, 3 in with soil
- bar spacing



Approximate Depths