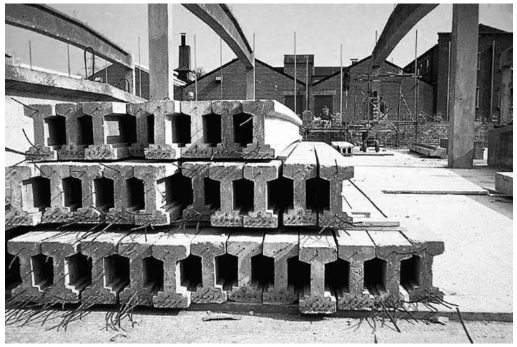
ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 331
DR. ANNE NICHOLS
SUMMER 2013

lecture
nineteen



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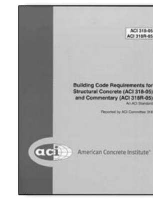
concrete construction: materials & beams

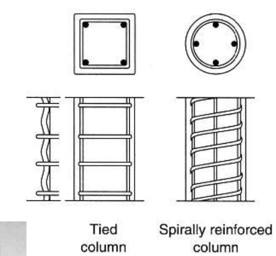
Concrete Beam Design

- *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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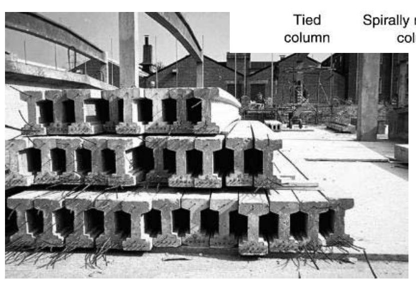

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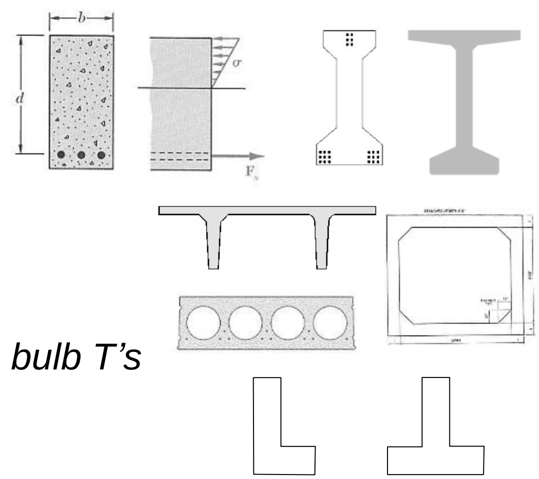
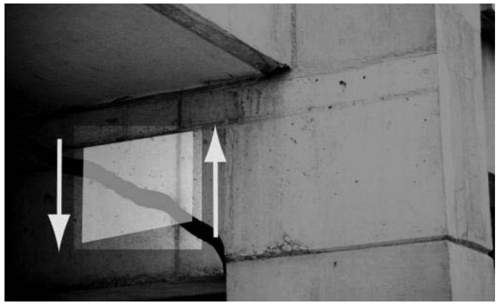
Concrete Beams

- *types*
  - *reinforced*
  - *precast*
  - *prestressed*
- *shapes*
  - *rectangular, I*
  - *T, double T's, bulb T's*
  - *box*
  - *spandrel*



Concrete Beams

- *shear*
  - *vertical*
  - *horizontal*
  - *combination:*
    - *tensile stresses at 45°*
- *bearing*
  - *crushing*



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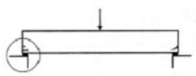
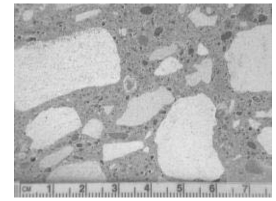
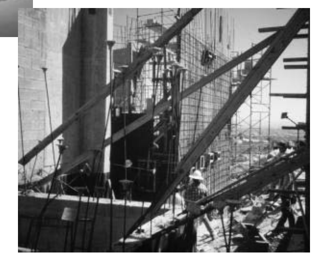


Concrete

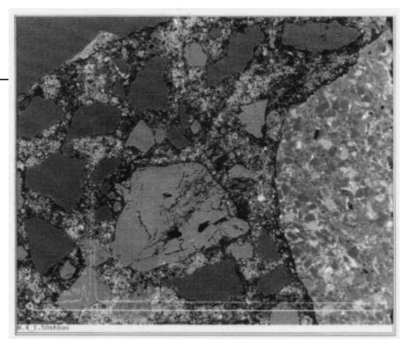
- *low strength to weight ratio*
- *relatively inexpensive*
  - *Portland cement*
    - *types I - V*
  - *aggregate*
    - *course & fine*
  - *water*
  - *admixtures*
    - *air entraining*
    - *superplasticizers*

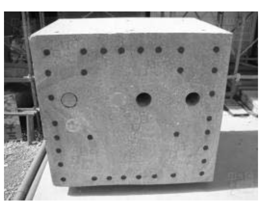




Concrete

- *hydration*
  - *chemical reaction*
  - *workability*
  - *water to cement ratio*
  - *mix design*
- *fire resistant*
- *cover for steel*
- *creep & shrinkage*





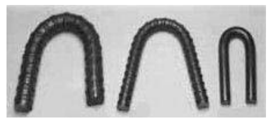
jci-web.jp

Concrete

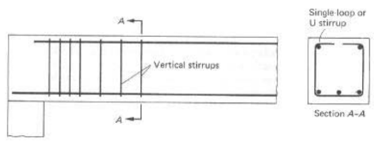
- *placement (not pouring!)*
- *vibrating*
- *screeding*
- *floating*
- *troweling*
- *curing*
- *finishing*

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 (nominal)

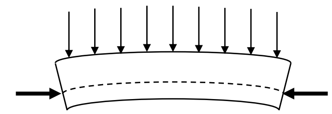


- longitudinally placed
  - bottom
  - top for compression reinforcement



Reinforcement

- prestressing strand
- post-tensioning
- stirrups
- detailing
  - development length
  - anchorage
  - splices



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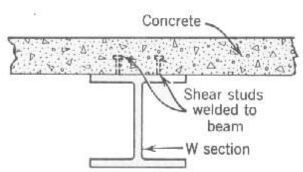
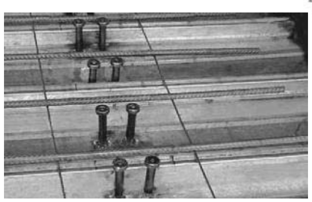
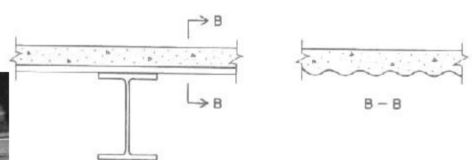
Composite Beams

- concrete
  - in compression
- steel
  - in tension
- shear studs



(c) Composite beam.

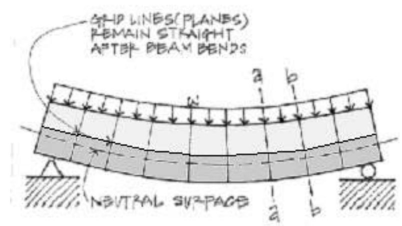


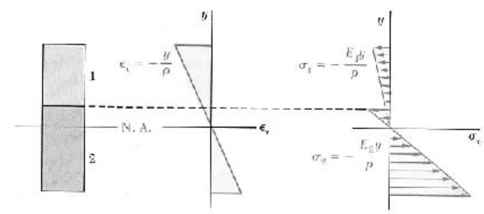


(b)

Behavior of Composite Members

- plane sections remain plane
- stress distribution changes

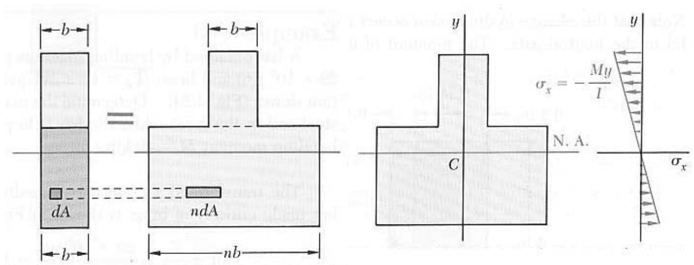




$$f_1 = E_1\varepsilon = -\frac{E_1 y}{\rho} \qquad f_2 = E_2\varepsilon = -\frac{E_2 y}{\rho}$$

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

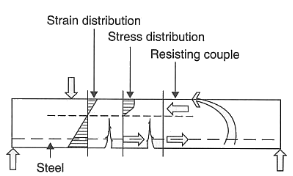
- with a section transformed to one material, new I
  - stresses in that material are determined as usual
  - stresses in the other material need to be adjusted by n

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

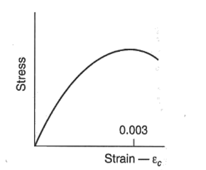
$$f_c = -\frac{My}{I_{transformed}}$$

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

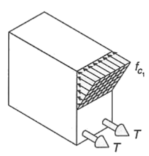
Reinforced Concrete - stress/strain



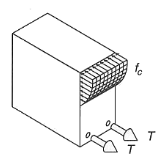
Stresses in the concrete above the neutral axis are compressive and nonlinearly distributed. In the tension zone below the neutral axis, the concrete is assumed to be cracked and the tensile force present to be taken up by reinforcing steel.



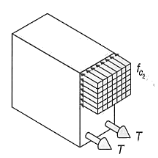
Typical stress-strain curve for concrete.



Working stress analysis. (Concrete stress distribution is assumed to be linear. Service loads are used in calculations.)



Actual stress distribution near ultimate strength (nonlinear).

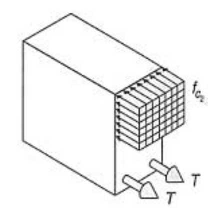


Ultimate strength analysis. (A rectangular stress block is used to idealize the actual stress distribution. Calculations are based on ultimate loads and failure stresses.)

FIGURE 6–37 Reinforced concrete beams.

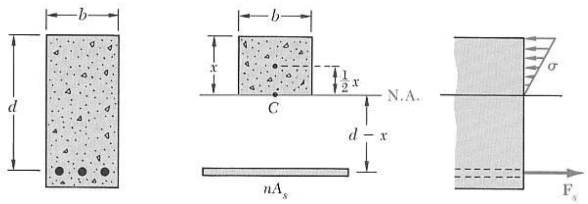
Reinforced Concrete Analysis

- 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.

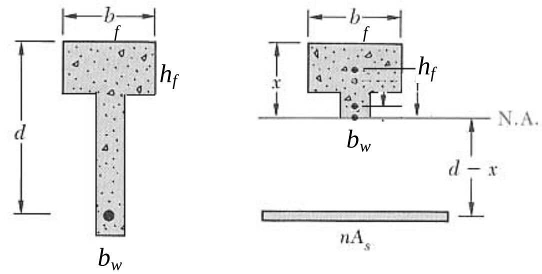
- ignore concrete below n.a.
- transform steel
- same area moments, solve for x



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

T sections

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



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

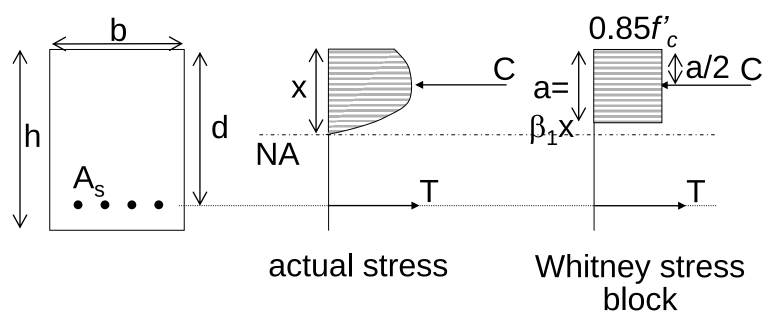
ACI Load Combinations*

- 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

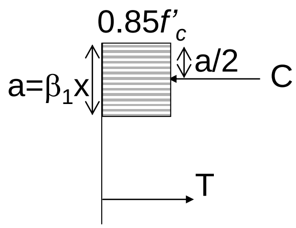
- stress distribution in bending



Wang & Salmon, Chapter 3

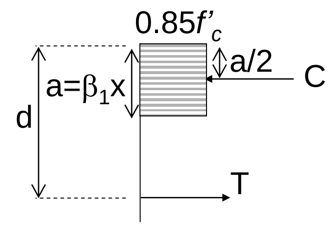
Force Equations

- $C = 0.85\, f'_c ba$
- $T = A_s f_y$
- *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*



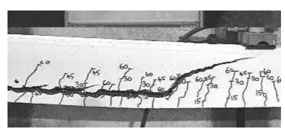
Equilibrium

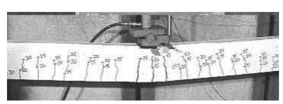
- $T = C$
- $M_n = T(d\text{-}a/2)$
  - *d = depth to the steel n.a.*
- *with* A_s
  - $a = \dfrac{A_s f_y}{0.85 f'_c b}$
  - $M_u \le \phi M_n \quad \phi = 0.9$ *for flexure*
  - $\phi M_n = \phi\, T(d\text{-}a/2) = \phi\, A_s f_y (d\text{-}a/2)$



Over and Under-reinforcement

- *over-reinforced*
  - *steel won't yield*
- *under-reinforced*
  - *steel will yield*
- *reinforcement ratio*
  - $\rho = \dfrac{A_s}{bd}$
  - *use as a design estimate to find* A_s*,b,d*
  - *max* ρ *is found with* $\varepsilon_{steel} \ge 0.004$ *(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. $A_s = \dfrac{0.85 f'_c ba}{f_y}$
    3. *solve for a from* $M_u = \phi\, A_s f_y (d\text{-}a/2)$
       $a = 2\left(d - \dfrac{M_u}{\phi A_s f_y}\right)$
    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* $R_n = \dfrac{M_n}{bd^2}$
    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

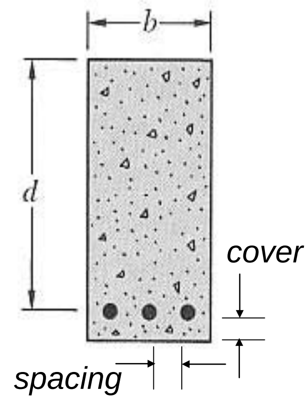
- *min for crack control*
- *required*

$$A_s = \frac{3\sqrt{f'_c}}{f_y}(bd)$$

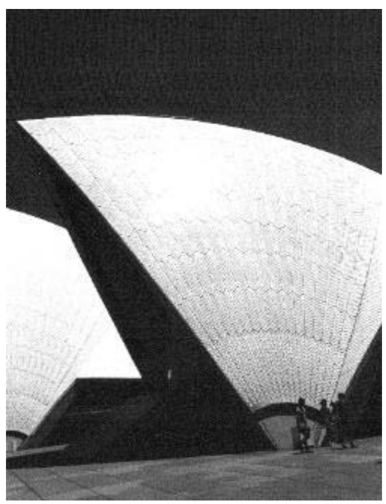
- *not less than*

$$A_s = \frac{200}{f_y}(bd)$$

- $A_{s\text{-}max}$: $a = \beta_1(0.375d)$
- *typical cover*
  - *1.5 in, 3 in with soil*
- *bar spacing*



Shells



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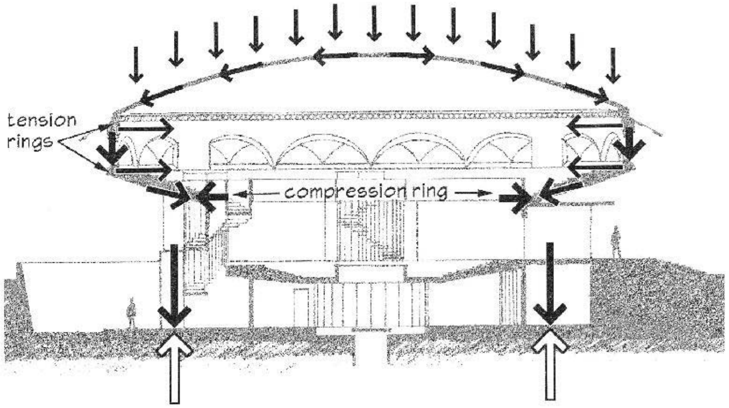
Annunciation Greek Orthodox Church

- *Wright, 1956*

http://www.bluffton.edu/~sullivanm/

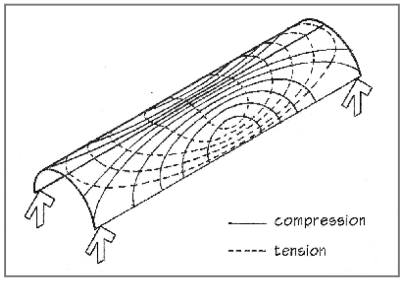
Annunciation Greek Orthodox Church

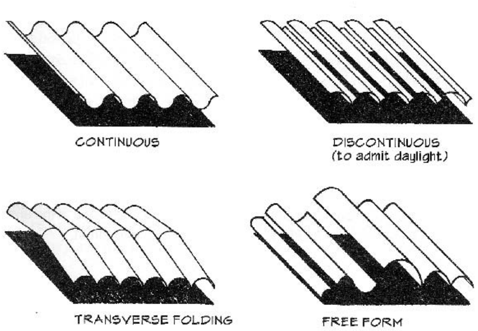
- Wright, 1956



Cylindrical Shells

- can resist tension
- shape adds "depth"



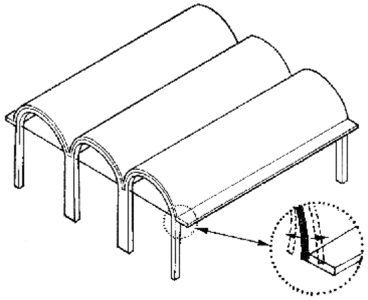


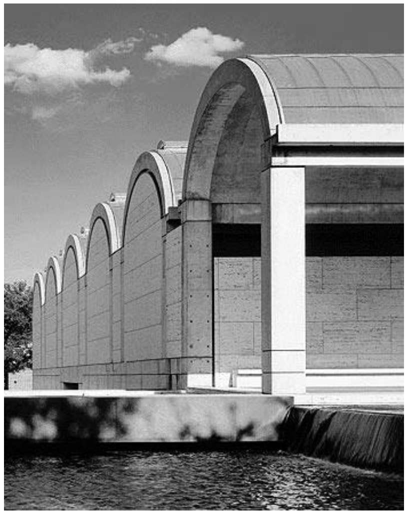
- not vaults
- barrel shells

Kimball Museum, Kahn 1972

Kimball Museum, Kahn 1972

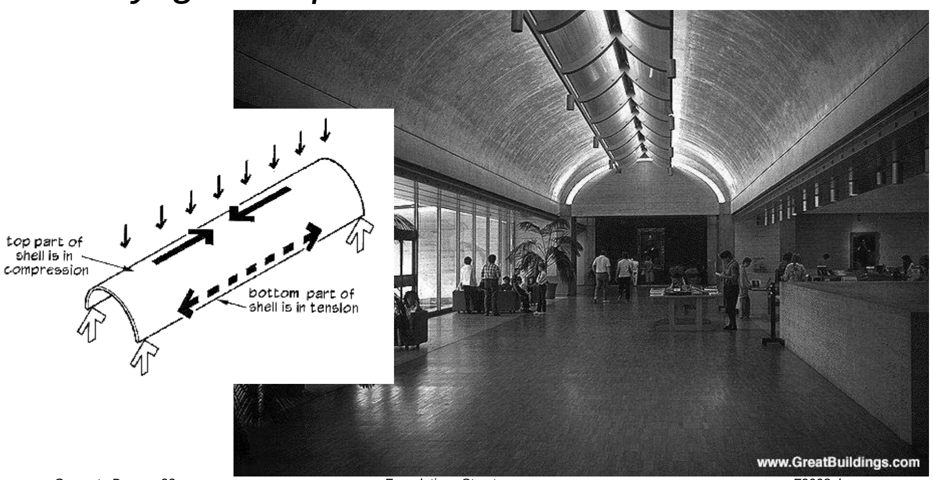
- outer shell edges





Kimball Museum, Kahn 1972

- *skylights at peak*



Approximate Depths