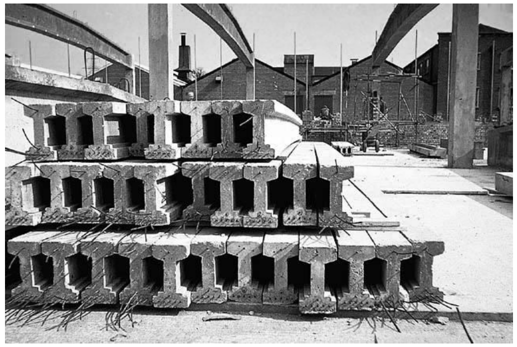
ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 331

DR. ANNE NICHOLS

SUMMER 2014

lecture
nineteen

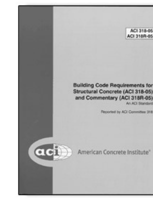


http:// nisee.berkeley.edu/godden

concrete construction:
materials & beams

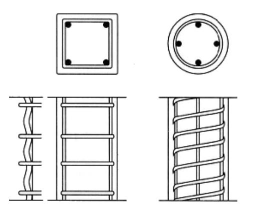
Concrete Beam Design

- 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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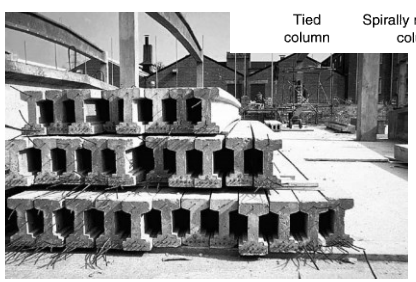

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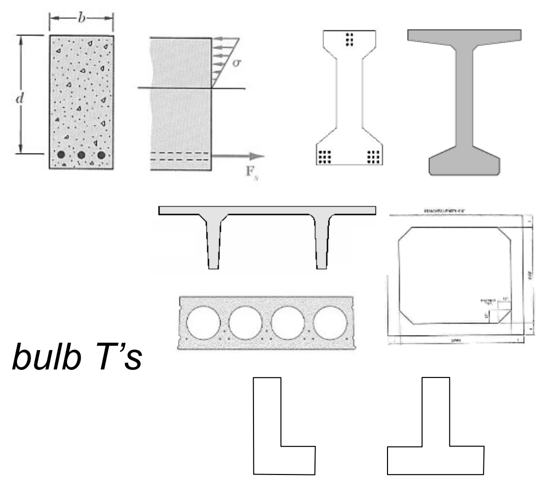
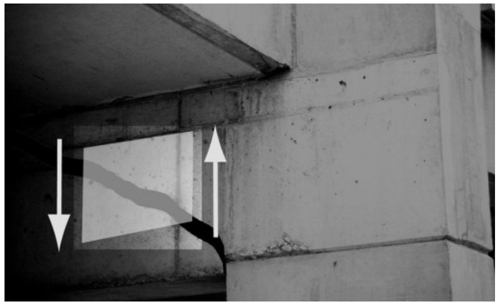
Concrete Beams

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

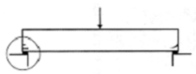


Concrete Beams

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

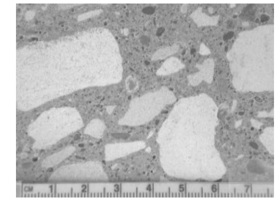


http://urban.arch.virginia.edu



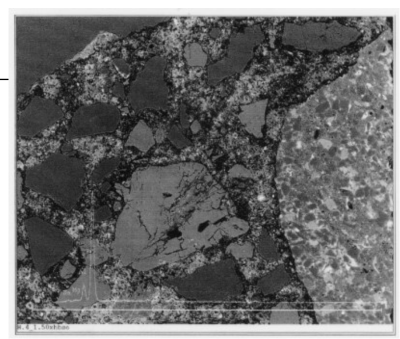
Concrete

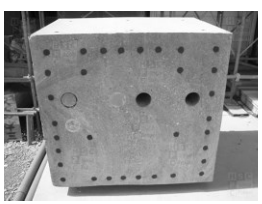
- low strength to weight ratio
- relatively inexpensive
  - Portland cement
    - types I - V
  - aggregate
    - course & fine
  - water
  - admixtures
    - air entraining
    - superplasticizers



Concrete

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





jci-web.jp

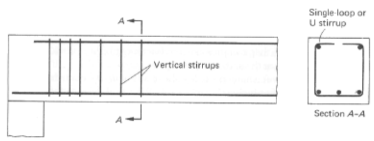
Concrete

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

Reinforcement

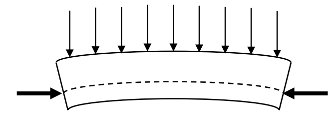
- deformed steel bars (rebar)
  - Grade 40, F_y = 40 ksi
  - Grade 60, F_y = 60 ksi - most common
  - Grade 75, F_y = 75 ksi
  - US customary in # of 1/8" ϕ (nominal)

- longitudinally placed
  - bottom
  - top for compression reinforcement



Reinforcement

- prestressing strand
- post-tensioning



- stirrups
- detailing
  - development length
  - anchorage
  - splices

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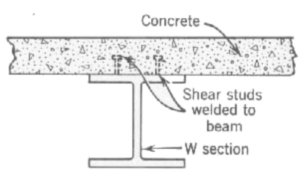
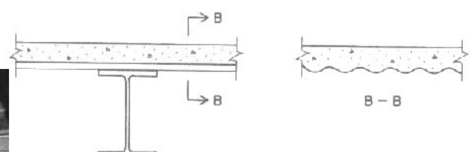
Composite Beams

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



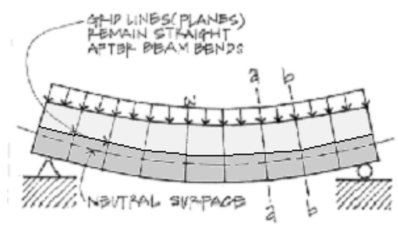
(c) Composite beam.

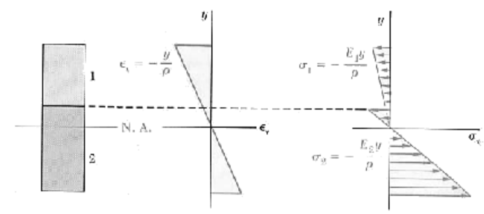


(b)

Behavior of Composite Members

- plane sections remain plane
- stress distribution changes

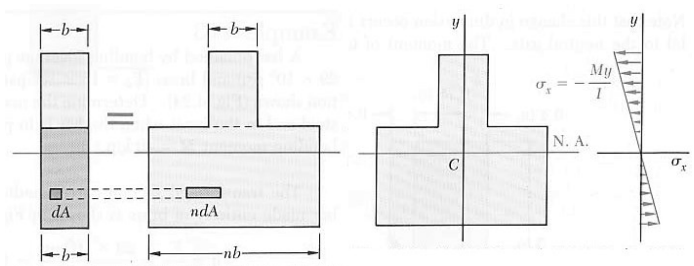




$$f_1 = E_1\varepsilon = -\frac{E_1 y}{\rho} \qquad f_2 = E_2\varepsilon = -\frac{E_2 y}{\rho}$$

Transformation of Material

- n is the ratio of E's $n = \dfrac{E_2}{E_1}$
- 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

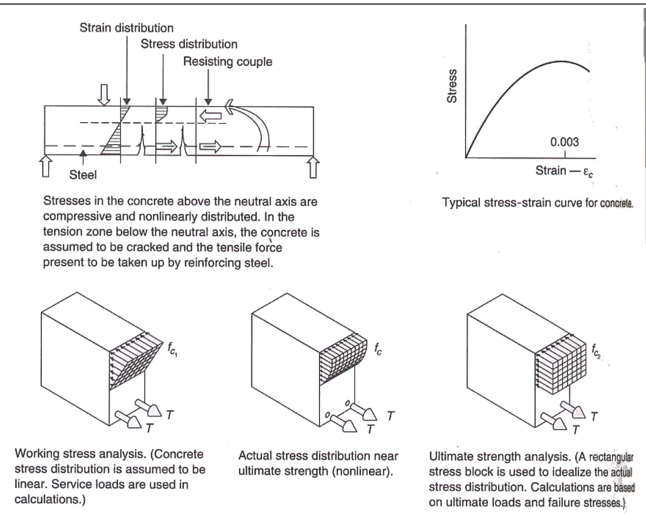
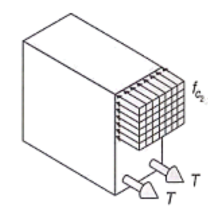


FIGURE 6-37 Reinforced concrete beams.

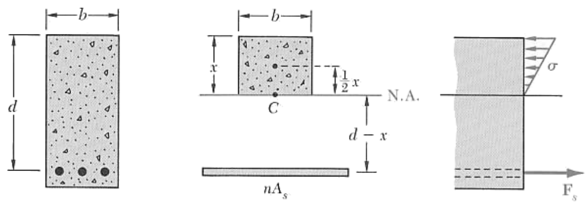
Reinforced Concrete Analysis

- 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.

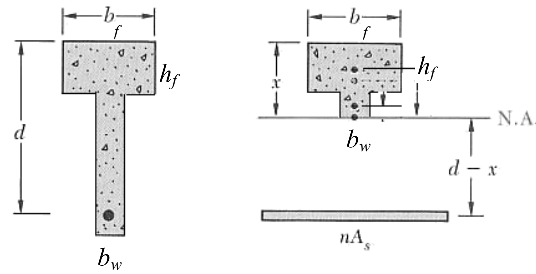
- ignore concrete below n.a.
- transform steel
- same area moments, solve for x



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

T sections

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



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

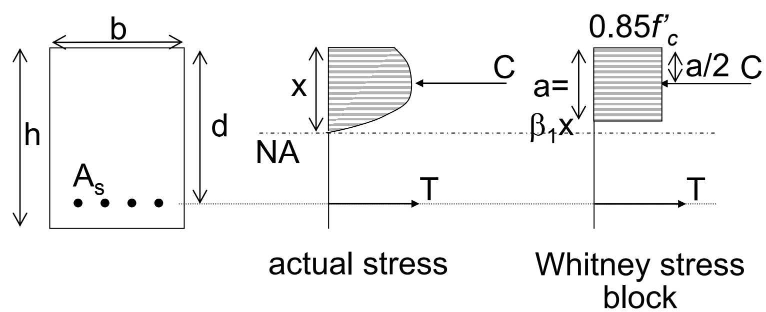
ACI Load Combinations*

- 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

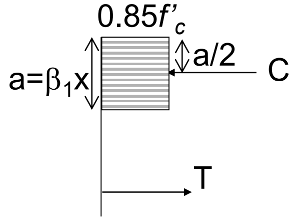
- stress distribution in bending



Wang & Salmon, Chapter 3

Force Equations

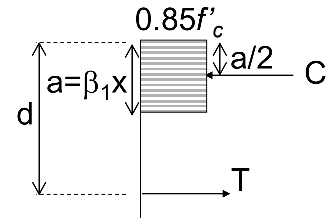
- $C = 0.85\ f'_c ba$
- $T = A_s f_y$
- where
  - f'_c = concrete compressive strength
  - a = height of stress block
  - β_1 = factor based on f'_c
  - x = location to the n.a.
  - b = width of stress block
  - f_y = steel yield strength
  - A_s = area of steel reinforcement



$$\beta_1 = 0.85 - \left(\frac{f'_c - 4000}{1000}\right)(0.05) \geq 0.65$$

Equilibrium

- $T = C$
- $M_n = T(d\text{-}a/2)$
  - d = depth to the steel n.a.
- with A_s
  - $a = \dfrac{A_s f_y}{0.85 f'_c b}$

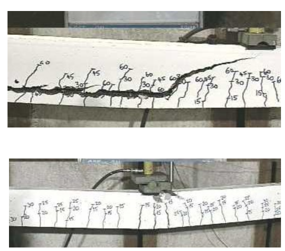


$$*\phi = 0.65 + (\varepsilon_t - \varepsilon_y)\frac{0.25}{(0.005 - \varepsilon_y)} \geq 0.65$$

  - $M_u \leq \phi M_n$ $\phi = 0.9$ 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 $\varepsilon_{steel} \geq 0.004$ (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. $A_s = \dfrac{0.85 f'_c ba}{f_y}$
    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.

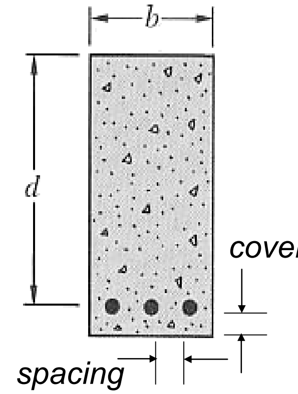
A_s for a Given Section (cont)

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

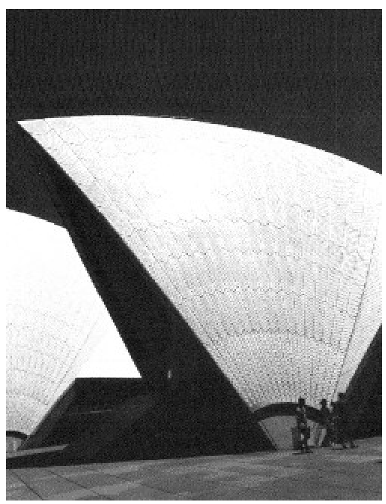
    1. calculate $R_n = \dfrac{M_n}{bd^2}$
    2. find curve for f'_c and f_y to get ρ
    3. calculate A_s and a
- *simplify by setting h = 1.1d*

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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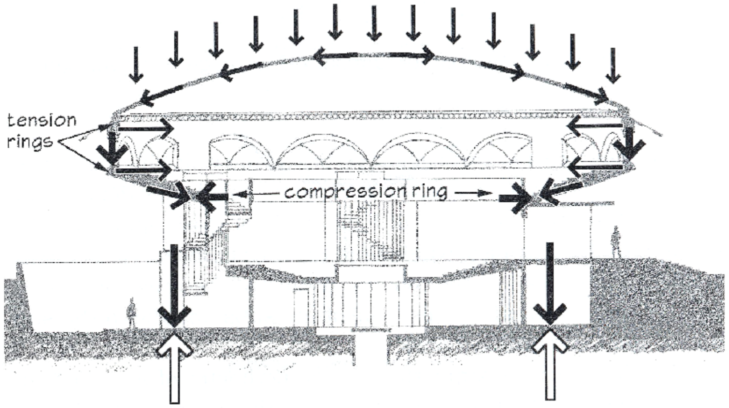
Annunciation Greek Orthodox Church

- *Wright, 1956*

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

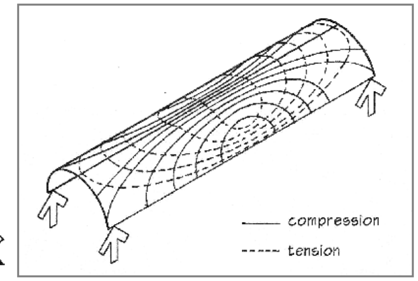
Annunciation Greek Orthodox Church

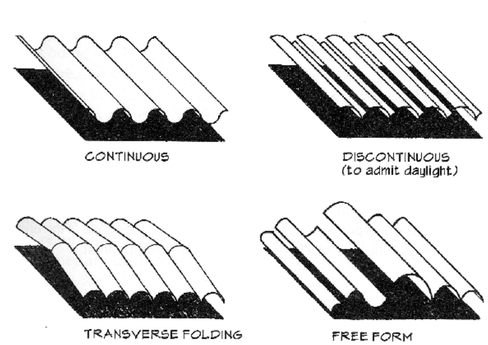
- Wright, 1956



Cylindrical Shells

- can resist tension
- shape adds "depth"



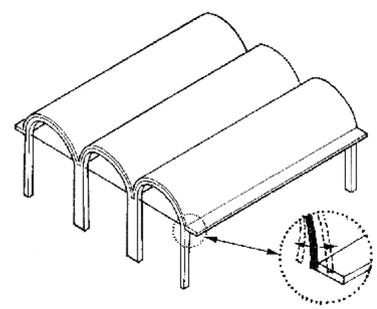


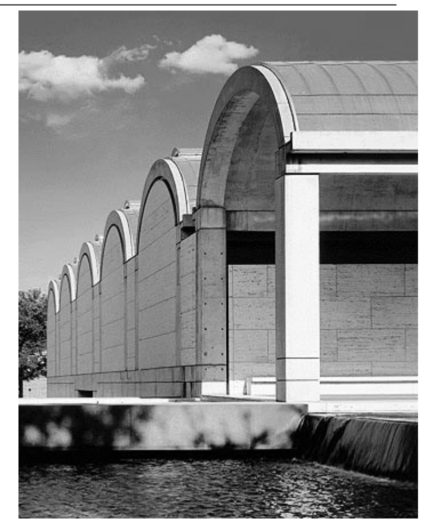
- not vaults
- barrel shells

Kimball Museum, Kahn 1972

Kimball Museum, Kahn 1972

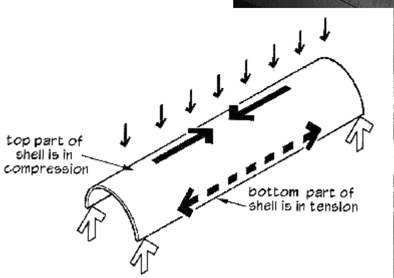
- outer shell edges





Kimball Museum, Kahn 1972

- *skylights at peak*



Approximate Depths