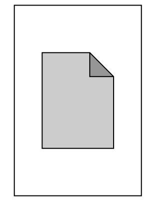
Applied Architectural Structures:
Structural Analysis and Systems
ARCH 631
Dr. Anne Nichols
Fall 2012

lecture
twenty three

masonry construction

Bright Football Complex
www.tamu.edu

Learning Evaluation



Masonry

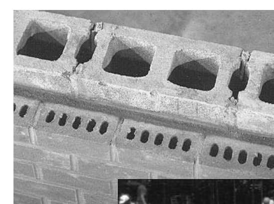
- columns
- beams
- arches
- walls
- footings

www.archiplanet.org

http://www.bluffton.edu

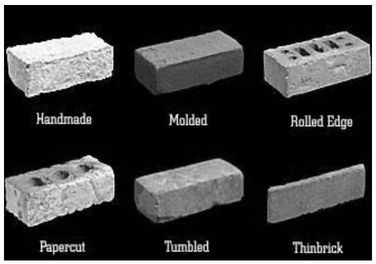
Masonry Construction

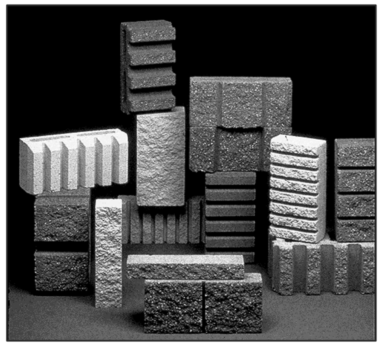
- solid, grouted, hollow
- unreinforced
- reinforced
- prestressing



Masonry Materials

- brick
- concrete masonry units



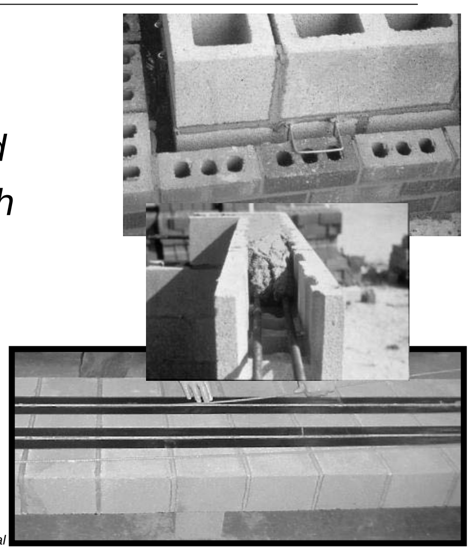


Masonry Materials

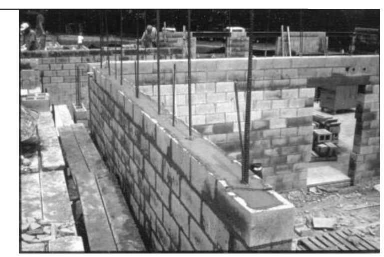
- mortar
  - water, masonry cement, sand, lime
  - types:
    - M higher strength – 2500 psi (ave.)
      A
    - S medium high strength – 1800 psi
      O
    - N medium strength – 750 psi
      W
    - O medium low strength – 350 psi
      R
    - K low strength – 75 psi

Masonry Materials

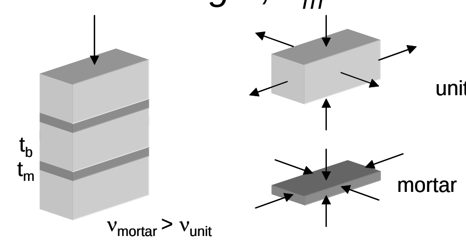
- reinforcement
  - deformed bars
  - prestressing strand
  - development length
  - anchorage
  - splices
  - ties
- steel or composite



Masonry Materials

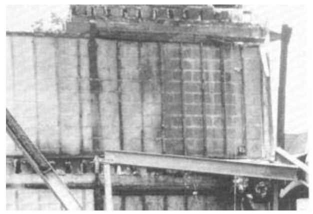


- grout
  - high slump concrete
  - fills voids and fixes rebar
- prisms
  - used to test strength, f'_m



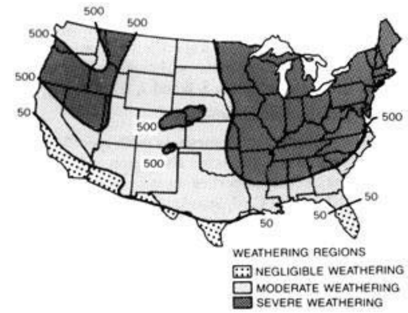
Masonry Materials

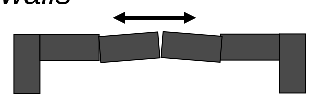
- fire resistance
  - fire-resistive structural material
  - details important to prevent leaks or cracks
  - retains strength if exposure not too long
    - mortar and cmu's dehydrate
    - loses 30-60% after that
  - no toxic fumes
  - cover necessary to protect steel



Masonry Materials

- moisture resistance
  - weathering index for brick
  - bond and detailing
  - expansion or shrinking from water
    - provide control joints
    - parapets, corners, long walls





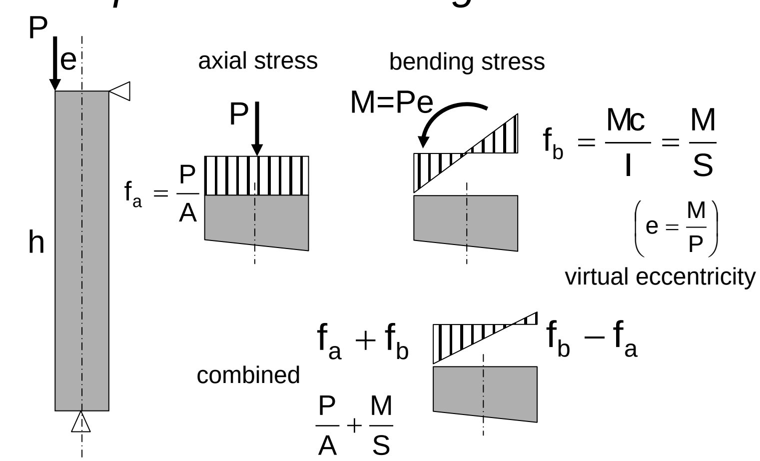
parapet with no control joint

Masonry Walls

- based on empirical requirements for minimum wall thickness and height
  - h/t < 25 (UBC 2105.2 h/t<35)
- wall thicknesses often increased by 4"/story
- bearing walls > 3-5 stories uneconomical, steel or concrete frames used
- strength design limit states:
  - serviceability: deflection
  - ultimate: compression & tension

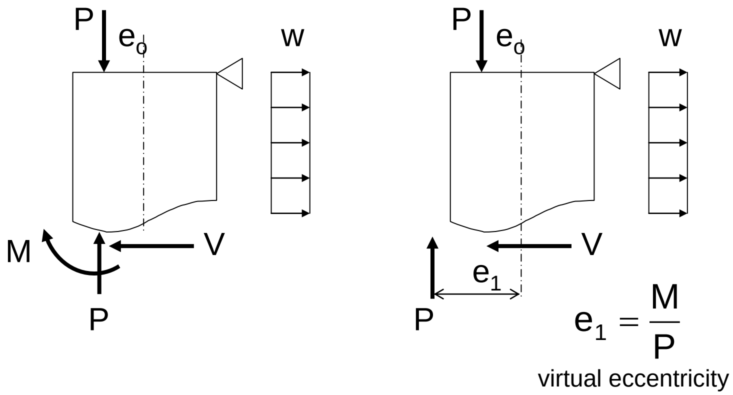
Masonry Walls

- compression + bending



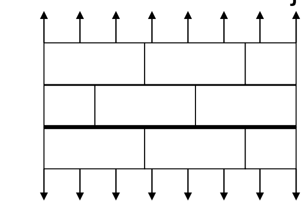
Masonry Walls

- *equivalent eccentricity with lateral load*



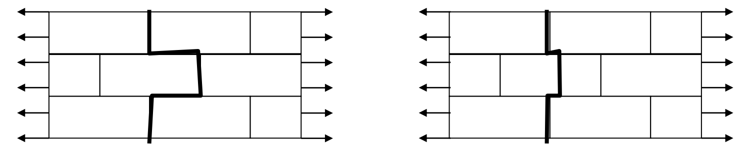
Masonry Walls

tension normal to bed joints



Not allowed in MSJC code

tension parallel to bed joints



Masonry Beam & Wall Design

- *MSJC (ACI, ASCE, TMS)*
  - *limit tensile stress in mortar*
  - *working stress design (ASD)*
    - *linear stresses in masonry*
    - *no tension in masonry when reinforced*
    - *elastic stress in steel < f_y*
    - *additional compression in walls*
  - *masonry strength = f'_m*

Masonry Beam & Wall Design

- *reinforcement increases capacity & ductility*

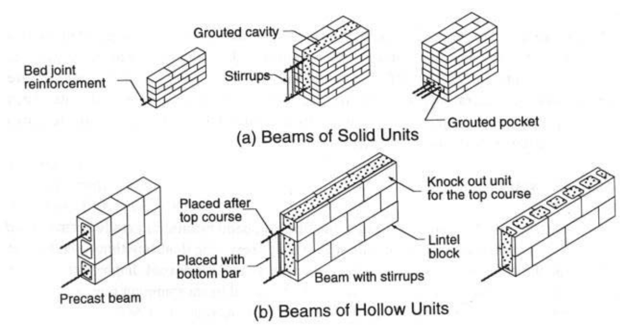
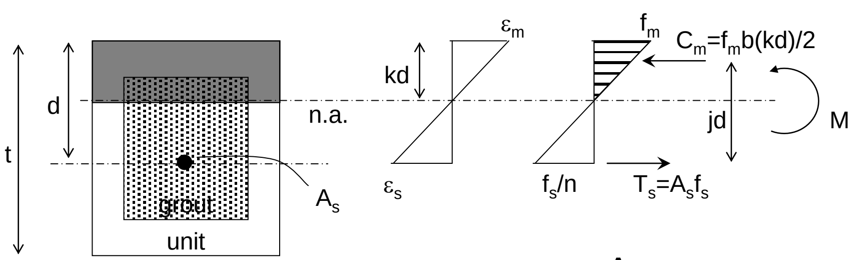


Figure 2.10 Reinforced masonry beams and lintels.

Masonry Design

- f_s is not the yield stress
- f_m is the stress in the masonry



$$\rho = \frac{A_s}{bd}$$

BIA Teknote 17 series

Allowable Masonry Stresses

- tension - unreinforced only

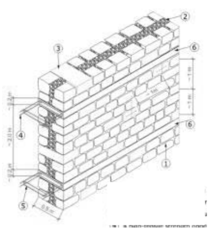
Table 2.2.3.2 — Allowable flexural tensile stresses for clay and concrete masonry, psi (kPa)

Direction of flexural tensile stress and masonry type	Mortar types			
	Portland cement/lime or mortar cement		Masonry cement or air entrained portland cement/lime	
	M or S	N	M or S	N
Normal to bed joints				
Solid units	53 (366)	40 (276)	32 (221)	20 (138)
Hollow units[1]				
Ungrouted	33 (228)	25 (172)	20 (138)	12 (83)
Fully grouted	86 (593)	84 (579)	81 (559)	77 (531)
Parallel to bed joints in running bond				
Solid units	106 (731)	80 (552)	64 (441)	40 (276)
Hollow units				
Ungrouted and partially grouted	66 (455)	50 (345)	40 (276)	25 (172)
Fully grouted	106 (731)	80 (552)	64 (441)	40 (276)
Parallel to bed joints in masonry not laid in running bond				
Continuous grout section parallel to bed joints	133 (917)	133 (917)	133 (917)	133 (917)
Other	0 (0)	0 (0)	0 (0)	0 (0)

1 For partially grouted masonry, allowable stresses shall be determined on the basis of linear interpolation between fully grouted hollow units and ungrouted hollow units based on amount (percentage) of grouting.

Allowable Masonry Stresses

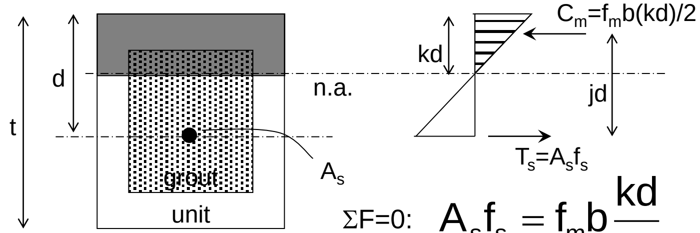
- flexure
  - $F_b = 1/3\ f'_m$ (unreinforced)
  - $F_b = 0.45\ f'_m$ (reinforced)
- shear, unreinforced masonry
  - $F_v = 1.5\sqrt{f'_m} \leq 120$ psi
- shear, reinforced masonry
  - $M/Vd \leq 0.25$: $F_v = 3.0\sqrt{f'_m}$
  - $M/Vd \geq 1.0$: $F_v = 2.0\sqrt{f'_m}$



Allowable Reinforcement Stress

- tension
  - a) Grade 40 or 50 F_s = 20 ksi
  - b) Grade 60 F_s = 24 ksi
  - c) Wire joint F_s = 30 ksi
- *no allowed increase by 1/3 for combinations with wind & earthquake
  - did before 2011 MSJC

Reinforcement, M_s



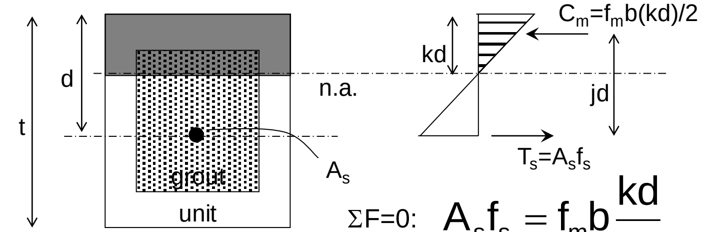
ΣF=0: $$A_sf_s = f_mb\frac{kd}{2}$$

ΣM about C_m: $$M_s = A_sf_sjd = \rho bd^2jf_s$$

if $f_s=F_s$ (allowable) the moment capacity is limited by the steel

MSJC: F_s = 20 ksi, 24 ksi or 30 ksi by type

Reinforcement, M_m



ΣF=0: $$A_sf_s = f_mb\frac{kd}{2}$$

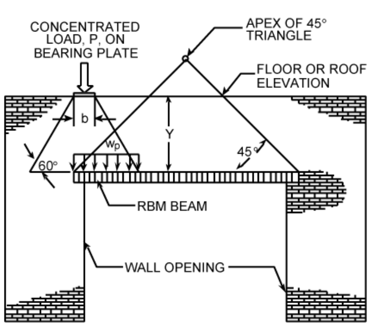
ΣM about T_s: $$M_m = f_mb\frac{kd}{2}jd = 0.5f_mbd^2jk$$

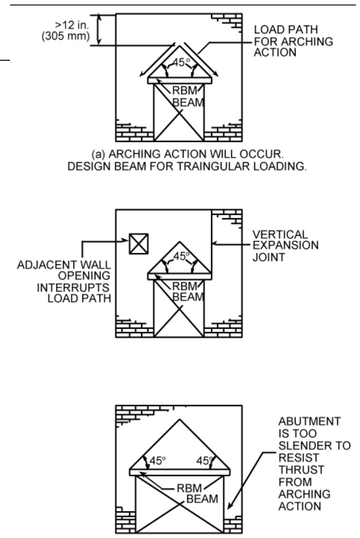
if $f_s=F_s$ (allowable) the moment capacity is limited by the steel

MSJC $F_b=0.33f'_m$

Masonry Lintels

- *distributed load*
  - *triangular or trapezoidal*





(a) ARCHING ACTION WILL OCCUR. DESIGN BEAM FOR TRAINGULAR LOADING.

(b) ARCHING ACTION WILL NOT OCCUR. DESIGN BEAM FOR ENTIRE WALL AREA.

Strategy for RM Flexural Design

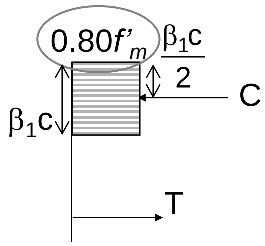
- *to size section and find reinforcement*
  - *find ρ_b knowing f'_m and f_y*
  - *size section for some $\rho < \rho_b$*
    - *get k, j*
    - $bd^2 = \dfrac{M}{\rho jF_s}$
    - *get b & d in nice units*

    } *needs to be sized for shear also*
  - *size reinforcement (bar size & #):* $A_s = \dfrac{M}{F_sjd}$
  - *check design:* $M_s = A_sF_sjd > M$

$$f_b = \frac{M}{0.5bd^2jk} < F_b$$

Ultimate Strength Design

- LRFD
- like reinforced concrete
- useful when beam shear is high
- improved inelastic model
  - ex. earthquake loads



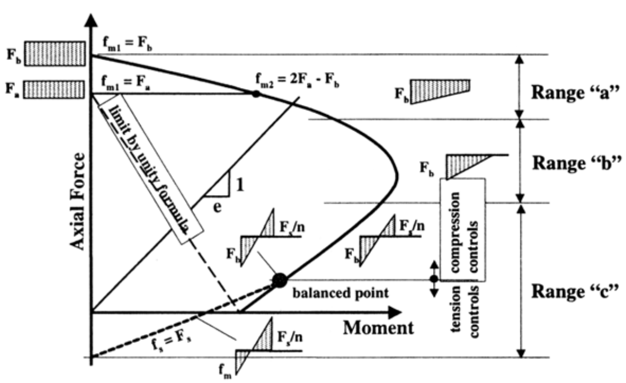
Masonry Walls

- one-way or two-way bending
- usually use hollow units (< 75% solid)
- reinforcement grouted
  - into cells if hollow units
  - between wythes if solid
- reinforcement usually at center
- reinforcement in compression ineffective
- avoid stirrups
- desirable in seismic zones

Masonry Walls

- axial force-moment interaction diagram

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \le 1$$



Masonry Shear Walls

- bearing, bending, and shear
  - compression increases resistance

$$f_v = \frac{VQ}{I_n b} \quad \text{or} \quad \frac{V}{A_{nv}} \le F_v$$

unreinforced   reinforced

- unreinforced stress limit $1.5\sqrt{f'_m} \le 120$ psi

Masonry Shear Walls

- *(and beams)*
  - *reinforcement strength included:*

$$F_v = F_{vm} + F_{vs}$$

  - *where*

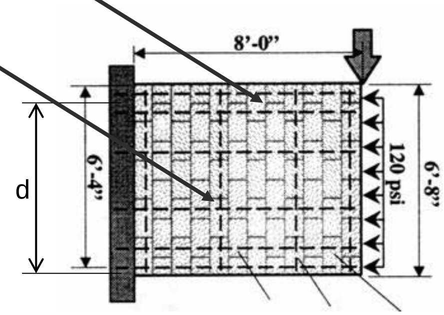
$$F_{vm} = \frac{1}{2}\left[\left(4.0 - 1.75\left(\frac{M}{Vd}\right)\right)\sqrt{f'_m}\right] + 0.25\frac{P}{A_n}$$

$$F_{vs} = 0.5\left(\frac{A_v F_s d}{A_{nv} s}\right)$$

  - *stress limit depends on ratio of bending moment to overturning moment: M/Vd*
  - *spacing limits*

Masonry Shear Walls

- *model as deep cantilever beam*
  - *flexure reinforcement*
  - *shear stirrups*



Masonry Columns and Pilasters

- *must be reinforced*

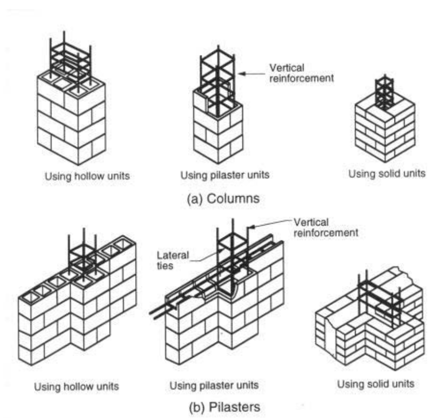


Figure 9.2 Columns and pilaster details.

Masonry Columns and Pilasters

- *considered a column when b/t<3 and h/t>4*
- *slender is*
  - *8" one side*
  - *h/t* $\leq$ *25*
- *needs ties*
- *eccentricity*
  - *10% of side dimension required*
  - *interaction diagrams like r/c*

Masonry Columns

– allowable axial load

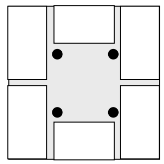
$$P_a = \left[0.25 f'_m A_n + 0.65 A_{st} F_s\right]\left[1 - \left(\frac{h}{140r}\right)^2\right]$$

$h/r \leq 99$

(unreinforced A_{st} = 0)

$$P_a = \left[0.25 f'_m A_n + 0.65 A_{st} F_s\right]\left(\frac{70r}{h}\right)^2$$

$h/r > 99$



h = effective length

r = radius of gyration

A_n = effective area of masonry

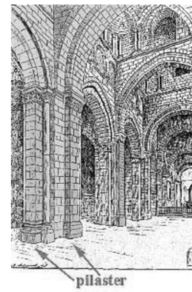
A_{st} = effective area of column reinforcement

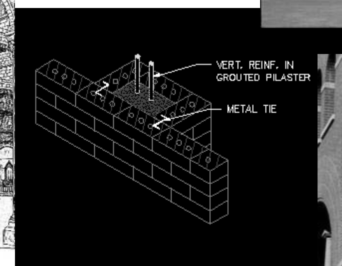
F_s = allowable compressive stress in column reinforcement

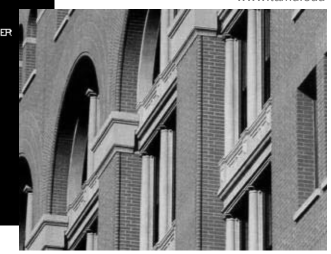
Masonry Pilasters, Arches

- column in wall
  – increase bearing area and stiffness

www.tamu.edu







Construction Supervision

- proper placement of all reinforcement
- prism construction
  – masonry
  – mortar
- hot/cold weather protection