ELEMENTS OF ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 614
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SPRING 2019

lecture
twenty seven


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masonry construction:
beams & columns

Masonry Design

- *Masonry Standards Joint Committee*
  - *ACI, ASCE, TMS*
  - *ASD (+empirical)*
    - *linear-elastic stresses*
  - *LRFD added in 2002*
  - *referenced by IBC*
  - *unreinforced allows tension in flexure*
  - *reinforced - all tension in steel*
  - *walls are also in compression*

International Masonry Institute (Brian Trimble)

Masonry Beam & Wall Design

- *reinforcement increases capacity & ductility*

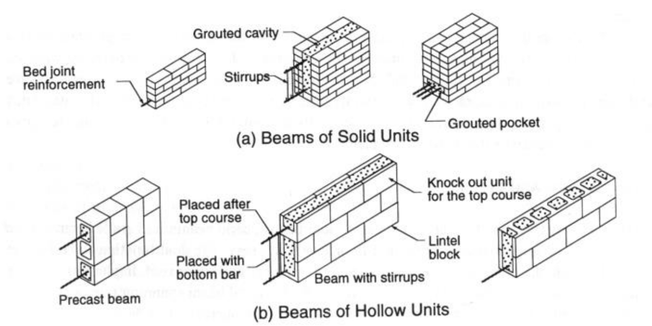
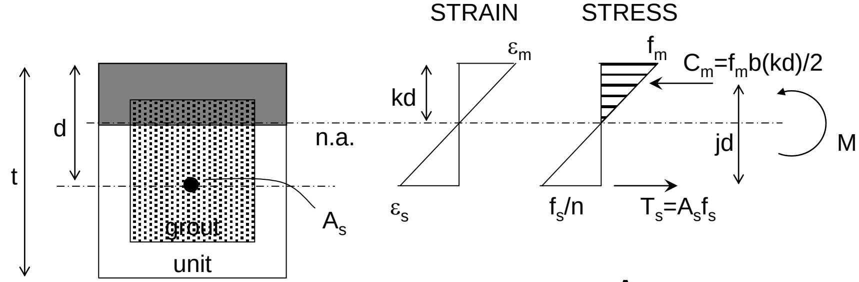


Figure 2.10 Reinforced masonry beams and lintels.

Masonry Design

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

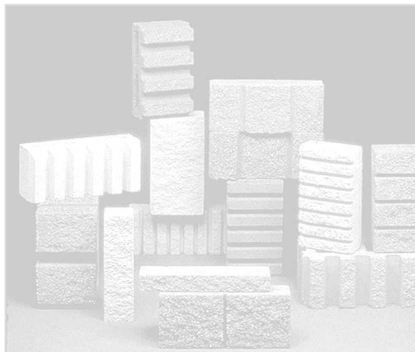


$$\rho = \frac{A_s}{bd}$$

BIA Teknote 17 series

Masonry Materials

- *units*
  - *– stone, brick, concrete block, clay tile*



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*

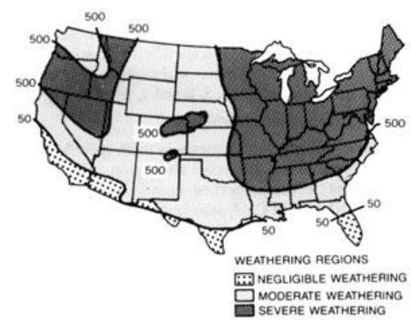
      R
    - *K* *low strength – 75 psi*

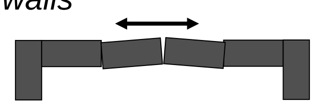
Masonry Materials

- *rebar*
- *grout*
  - *– fills voids and fixes rebar*
- *prisms*
  - *– used to test strength,* f'_m
- *fire resistant*

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

Allowable Masonry Stresses

- *tension - <u>unreinforced</u> only*

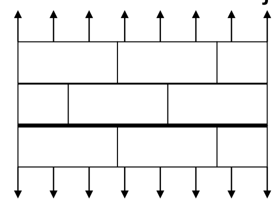
Table 2.2.3.2 — Allowable flexural tensile stresses for clay and concrete masonry, psi (kPa)

Direction of flexural tensile stress and masonry type	Mortar types: Portland cement/lime or mortar cement		Mortar types: 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.

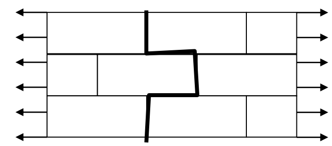
Masonry Walls

tension normal to bed joints

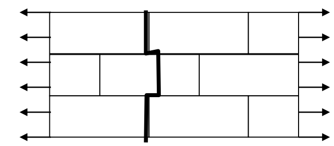


Not allowed in MSJC codes

tension parallel to bed joints



strong units



weak units

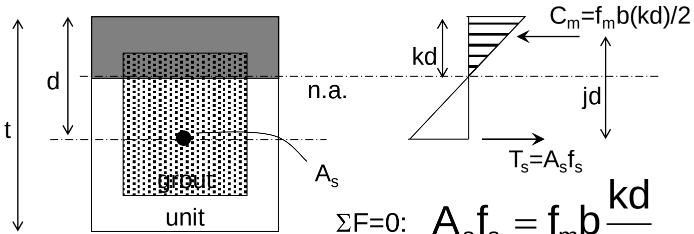
Allowable Masonry Stresses

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

Allowable Reinforcement Stress

- *tension*
  - a) Grade 40 or 50 $F_s = 20$ ksi
  - b) Grade 60 $F_s = 32$ ksi
  - c) Wire joint $F_s = 30$ ksi
- **no allowed increase by 1/3 for combinations with wind & earthquake*
  - *did before 2011 MSJC code*

Reinforcement, M_s



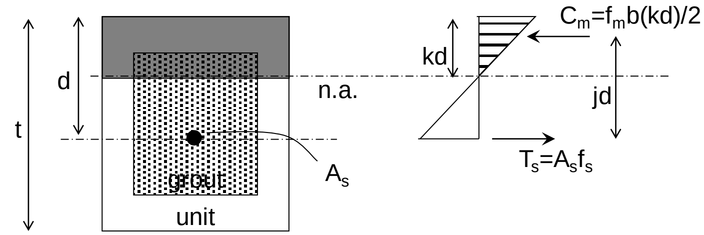
$\Sigma F=0$: $$A_s f_s = f_m b \frac{kd}{2}$$

ΣM about C_m: $$M_s = A_s f_s jd = \rho b d^2 j f_s$$

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

MSJC: F_s = 20 ksi, 32 ksi or 30 ksi by type

Reinforcement, M_m



for equilibrium:

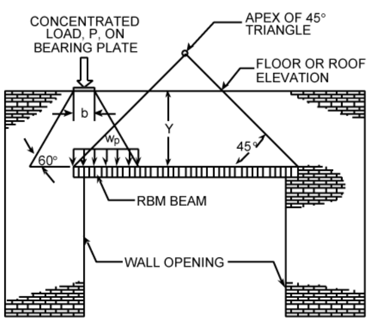
$$\sum M = 0 \text{ about } F_s \qquad M_m = f_m b \frac{kd}{2} jd = 0.5 f_m b d^2 jk$$

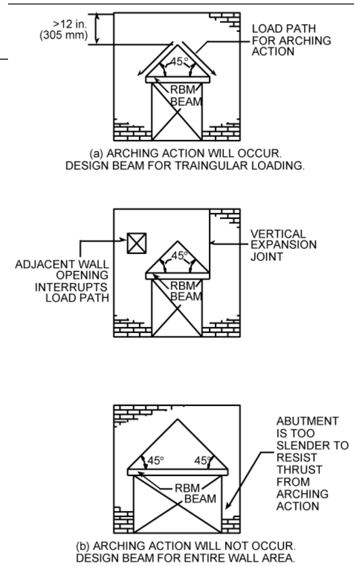
if $f_m=F_b$ (allowable) the moment capacity is limited by the masonry

MSJC $F_b = 0.33f'_m$

Masonry Lintels

- *distributed load*
  - *triangular or trapezoidal*





Strategy for RM Flexural Design

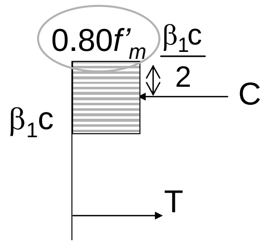
- *to size section and find reinforcement*
  - *find ρ_b knowing f'_m and f_y*
  - *size section for some $\rho < \rho_b$*
    - *get k, j*
    - $bd^2 = \dfrac{M}{\rho j F_s}$
    - *get b & d in nice units*

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

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

Ultimate Strength Design

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



Masonry Columns and Pilasters

- must be reinforced

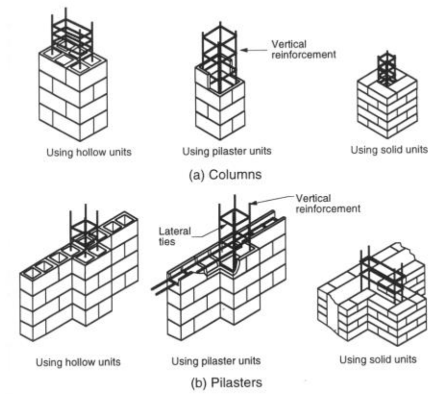


Figure 9.2 Columns and pilaster details.

Masonry Columns and Pilasters

- considered a column when b/t<3 and h/t>4
  - b is width of "wall"
  - t is thickness of "wall"
- slender is
  - 8" one side
  - $h/t \leq 25$
- needs ties
- eccentricity may be required

Masonry Columns

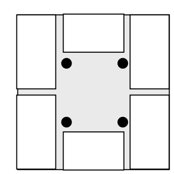
– allowable axial load

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

$h/r \leq 99$

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

$h/r > 99$



h = effective length

A_n = effective area of masonry

A_{st} = effective area of column reinforcement

F_s = allowable compressive stress in column reinforcement (lesser of $0.4f_y$ or 24 ksi)

Masonry Walls (unreinforced)

– *allowable axial stresses*

$$F_a = 0.25 f'_m \left[1 - \left(\frac{h}{140r}\right)^2\right] \qquad F_a = 0.25 f'_m \left(\frac{70r}{h}\right)^2$$

h/r $\leq$ *99*   *h/r > 99*

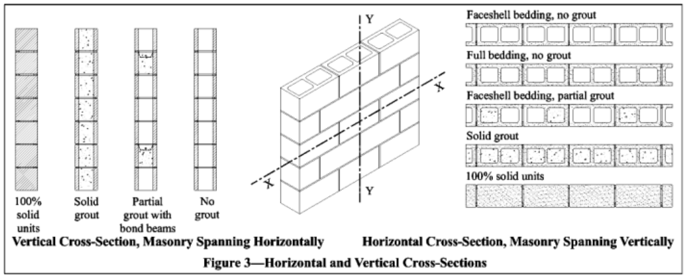


Figure 3—Horizontal and Vertical Cross-Sections

Design

- *masonry columns and walls* *(unreinforced)*

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0 \quad \textit{and} \quad f_b - f_a \leq F_t$$

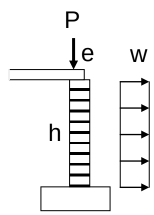
– *h/r < 99* $\quad F_a = 0.25 f'_m \left[1 - \left(\frac{h}{140r}\right)^2\right]$

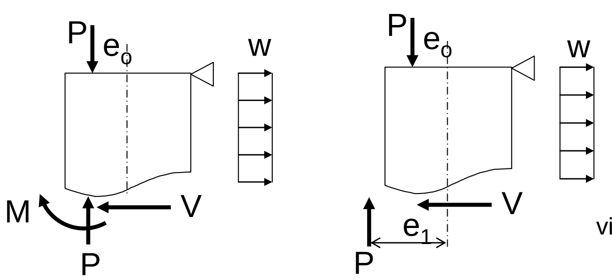
– *h/r > 99* $\quad F_a = 0.25 f'_m \left(\frac{70r}{h}\right)^2$

$$F_b = 0.33 f'_m$$

Design

- *masonry columns and walls - loading*
  - *wind loading*
  - *eccentric axial load*
  - *"virtual" eccentricity, e_1*





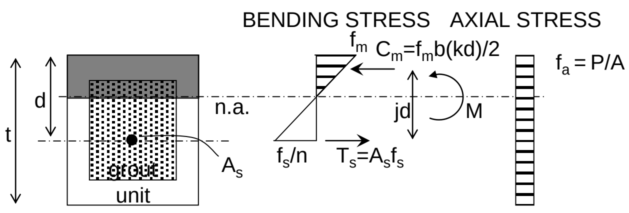
$$e_1 = \frac{M}{P}$$

virtual eccentricity

Design

- *masonry columns and walls – with rebar*
  - *wall reinforcement usually at center and ineffective in compression*

$$f_a + f_b \leq F_b \quad \textit{provided} \quad f_a \leq F_a$$



for equilibrium: $\sum F = P = C_m - T_s$

Design Steps Knowing Loads

1. *assume limiting stress*
   - *buckling, axial stress, combined stress*
2. *solve for r, A or S*
3. *pick trial section*
4. *analyze stresses*
5. *section ok?*
6. *stop when section is ok*