Masonry
- columns
- beams
- arches
- walls
- footings

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.)
    - S medium high strength – 1800 psi
    - N medium strength – 750 psi
    - O medium low strength – 350 psi
    - 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 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 Materials

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

Masonry Walls

- **compression + bending**
  - $f_a = \frac{P}{A}$
  - axial stress
  - $f_b = \frac{M}{S}$
  - bending stress
  - $e = \frac{M}{P}$
  - virtual eccentricity
  - combined
Masonry Walls

• equivalent eccentricity with lateral load

\[ e_1 = \frac{M}{P} \]

virtual eccentricity

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 Walls

tension normal to bed joints

Not allowed in MSJC code

tension parallel to bed joints

strong units

weak units

Masonry Beam & Wall Design

• reinforcement increases capacity & ductility
**Masonry Design**

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

**Allowable Masonry Stresses**

- **tension - unreinforced only**

  ![Diagram of masonry design and stress-strain relationship]

  \[ \rho = \frac{A_s}{bd} \]

**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**
  - $M/V_d \leq 0.25$: $F_V = 3.0 \sqrt{f'_m}$
  - $M/V_d \geq 1.0$: $F_V = 2.0 \sqrt{f'_m}$

**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, $M_s$

\[
\Sigma F = 0: \quad A_s f_s = f_m b \frac{kd}{2}
\]

\[
\Sigma M \text{ about } C_m: \quad M_s = A_s f_s jd = \rho bd^2 j f_s
\]

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

Masonry Lintels

- distributed load
  - triangular or trapezoidal

Strategy for RM Flexural Design

- to size section and find reinforcement
  - find $\rho_b$ knowing $f'_m$ and $f_y$
  - size section for some $\rho < \rho_b$
    - get $k$, $j$
    - $bd^2 = \frac{M}{\rho j F}$
    - get $b$ & $d$ in nice units
  - size reinforcement (bar size & #): $A_s = \frac{M}{F_s jd}$
  - check design: $M_s = A_j F_s j d > M$
    \[
f_b = \frac{M}{0.5bd^2 j k} < F_b
\]
**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
  \[
  \frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1
  \]

**Masonry Shear Walls**
- bearing, bending, and shear
  - compression increases resistance
    \[
    f_v = \frac{VQ}{I_n b} \quad \text{or} \quad \frac{V}{A_{nv}} \leq F_v
    \]
    - unreinforced
    - reinforced
  - unreinforced stress limit \(1.5 \sqrt{f_m} \leq 120\) psi
Masonry Shear Walls

- (and beams)
  - reinforcement strength included:
    \[ F_v = F_{vm} + F_{vs} \]
  - where
    \[ F_{vm} = \frac{1}{2} \left[ 4.0 - 1.75 \left( \frac{M}{Vd} \right) \right] \sqrt{f'_m} + 0.25 \frac{P}{A_n} \]
    \[ F_{vs} = 0.5 \left( \frac{A_s f_v d}{A_{mv} s} \right) \]
  - stress limit depends on ratio of bending moment to overturning moment: \( M/Vd \)
  - spacing limits

Masonry Columns and Pilasters

- must be reinforced

Masonry Shear Walls

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

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**

\[
P_a = \begin{cases} 
0.25 f_m' A_n + 0.65 A_{st} F_s & \text{if } h/r \leq 99 \\
0.25 f_m' A_n + 0.65 A_{st} F_s \left( \frac{70r}{h} \right)^2 & \text{if } h/r > 99 
\end{cases}
\]

(unreinforced \( A_{st} = 0 \))

- \( h = \) 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

### Construction Supervision

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