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

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

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

Masonry Materials

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

Masonry Materials

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

Masonry Walls

- tension normal to bed joints
- tension parallel to bed joints

Allowable Masonry Stresses

- tension - unreinforced only

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Flexural Tension Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>$F_b = 1/3 f'_m$ (unreinforced)</td>
</tr>
<tr>
<td>Weak</td>
<td>$F_b = 0.45 f'_m$ (reinforced)</td>
</tr>
</tbody>
</table>

- shear, unreinforced masonry
  - $F_v = 1.5 \sqrt{f'_m} \leq 120 \text{ psi}$

- 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 \( F_s = 20 \text{ ksi} \)
  - b) Grade 60 \( F_s = 32 \text{ ksi} \)
  - c) Wire joint \( F_s = 30 \text{ ksi} \)

- *no allowed increase by 1/3 for combinations with wind & earthquake*
  – did before 2011 MSJC code

**Reinforcement, \( M_s \)**

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

\[
\sum M \text{ about } C_m: \quad M_s = A_s f_s jd = pbd^2 jf_s
\]

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

MSJC: \( F_s = 20 \text{ ksi}, 24 \text{ ksi or 30 ksi by type} \)

**Reinforcement, \( M_m \)**

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

\[
\sum M \text{ about } T_s: \quad M_m = f_m b \frac{kd}{2} jd = 0.5 f_m bd^2 jk
\]

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

MSJC \( F_B = 0.33 f_m \)

**Masonry Lintels**

- **distributed load**
  – triangular or trapezoidal

MSJC: \( F_s = 20 \text{ ksi}, 24 \text{ ksi or 30 ksi by type} \)
**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 $k, j$
  - size section for some $\rho < \rho_b$
  - get $b & d$ in nice units
- size reinforcement (bar size & #): $A_s = \frac{M}{F_s,jd}$
- check design: $f_b = \frac{M}{0.5bd^2j} < F_b$

**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

**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

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

\[
h = \text{effective length} \\
r = \text{radius of gyration} \\
A_n = \text{effective area of masonry} \\
A_{st} = \text{effective area of column reinforcement} \\
F_s = \text{allowable compressive stress in column reinforcement}
\]

Masonry Walls (unreinforced)

- allowable axial stresses

\[
F_a = \begin{cases} 
0.25f'_m \left[ 1 - \left( \frac{h}{140r} \right)^2 \right] & \frac{h}{r} \leq 99 \\
0.25f'_m \left( \frac{70r}{h} \right)^2 & \frac{h}{r} > 99 
\end{cases}
\]

Design

- masonry columns and walls (unreinforced)

\[
\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0 \quad \text{and} \quad f_b - f_a \leq F_t
\]

\[
\begin{align*}
&- h/r < 99 \\
&\quad F_a = 0.25f'_m \left[ 1 - \left( \frac{h}{140r} \right)^2 \right] \\
&- h/r > 99 \\
&\quad F_a = 0.25f'_m \left( \frac{70r}{h} \right)^2 \\
&\quad F_b = 0.33f'_m
\end{align*}
\]

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

\[
f_a + f_b \leq F_b \quad \text{provided} \quad f_a \leq F_a
\]

\[
f_a = \frac{F_m}{C_m} = \frac{f_m b (k d)}{2}
\]

\[
t = \frac{P}{A}
\]

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

Final Exam Material

- my list:
  - systems
    - components & levels
    - design considerations
  - equilibrium - \( \Sigma F \) & \( \Sigma M \)
    - supports, trusses, cables, beams, pinned frames, rigid frames
  - materials
    - strain & stress \( E \), temperature, constraints

Final Exam Material

- my list (continued):
  - beams
    - distributed loads, tributary width, V&M, stresses, design, section properties \( I \) & \( S \), pitch, deflection
  - columns
    - stresses, design, section properties \( I \) & \( r \)
  - frames
    - \( P, V \) & \( M, P-\Delta \), effective length with joint stiffness, connection design, tension member design
Final Exam Material

• my list (continued):
  – foundations
    • types
    • sizing & structural design
    • overturning and sliding
  – design specifics
    • steel (ASD & LRFD)
    • concrete
    • wood
    • masonry