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

\[ T_s = A_s f_s \]
\[ C_m = f_m b (kd) / 2 \]
\[ \rho = \frac{A_s}{bd} \]

Masonry Materials

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

- 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
  - fire resistant

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

Not allowed in MSJC code

tension parallel to bed joints

strong units

weak units

Allowable Masonry Stresses

- tension - unreinforced only

<table>
<thead>
<tr>
<th>Direction of flexural stress and masonry type</th>
<th>Member type</th>
<th>Portland cement or mortar masonry</th>
<th>Masonry cement or air-entrained portland cement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M or S</td>
<td>N</td>
<td>M or S (standard)</td>
</tr>
<tr>
<td>Normal to bed joints</td>
<td>Solid units</td>
<td>53 (366)</td>
<td>46 (327)</td>
</tr>
<tr>
<td></td>
<td>Hollow units</td>
<td>55 (393)</td>
<td>48 (345)</td>
</tr>
<tr>
<td></td>
<td>Unground and partial</td>
<td>55 (393)</td>
<td>48 (345)</td>
</tr>
<tr>
<td></td>
<td>Fully ground</td>
<td>55 (393)</td>
<td>48 (345)</td>
</tr>
<tr>
<td>Parallel to bed joints in running bond</td>
<td>Solid units</td>
<td>106 (751)</td>
<td>66 (461)</td>
</tr>
<tr>
<td></td>
<td>Hollow units</td>
<td>106 (751)</td>
<td>66 (461)</td>
</tr>
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<td></td>
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<td>106 (751)</td>
<td>66 (461)</td>
</tr>
<tr>
<td>Parallel to bed joints in masonry on bed in running bond</td>
<td>133 (917)</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Continuous grout section parallel to bed joints</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

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

- flexure
  - $F_b = \frac{1}{3} f_m'$ (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 \( F_s = 20 \text{ ksi} \)
  - 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, \( M_s \)

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

\[
\Sigma M \text{ about } C_m: \quad M_s = A_s f_s d = p b d^2 j f_s
\]

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

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

Reinforcement, \( M_m \)

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

\[
\Sigma M \text{ about } T_s: \quad M_m = f_m b \frac{kd}{2} d = 0.5 f_m b d^2 j k
\]

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**
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 $k, j$
  • get $b, d$ in nice units
  – size reinforcement (bar size & #): $A_s = \frac{M}{F_s j d}$
  – check design: $M_s = A_s F_s j d > M$
  \[
f_b = \frac{M}{0.5bd^2 jk} < F_b
  \]

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

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

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

- \( h = \) 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 Walls (unreinforced)

- allowable axial stresses

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

Design

- masonry columns and walls (unreinforced)

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

- \( h/r < 99 \)

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

- \( h/r > 99 \)

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

\[ F_b = 0.33 f'_m \]

Design

- masonry columns and walls - loading

- wind loading
- eccentric axial load
- “virtual” eccentricity, \( e_1 \)

\[ \text{virtual eccentricity} \]

\[ e_1 = \frac{M}{P} \]
Design
• masonry columns and walls – with rebar
  – wall reinforcement usually at center and ineffective in compression
  \[ f_a + f_b \leq F_b \quad \text{provided} \quad f_a \leq F_a \]
  BENDING STRESS
  \[ f_m = f_{m0} (kd)/2 \]
  AXIAL STRESS
  \[ t_a = P/A \]
  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