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

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.)
    - $S$: medium high strength – 1800 psi
    - $N$: medium strength – 750 psi
    - $O$: medium low strength – 350 psi
    - $K$: low strength – 75 psi

- rebar
  - 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

 Allowable Masonry Stresses

- tension - unreinforced only

### Table 2.2.3 - Allowable flexural tensile stresses for clay and concrete masonry, psi (kPa)

<table>
<thead>
<tr>
<th>Direction of flexural tensile stress and masonry type</th>
<th>Portland cement/concrete or mortar cement</th>
<th>Masonry cement or air cured or portland cement/concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal to bed joints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid units</td>
<td>51 (366)</td>
<td>40 (276)</td>
</tr>
<tr>
<td>Hollow units</td>
<td>51 (366)</td>
<td>40 (276)</td>
</tr>
<tr>
<td>Ungrouted</td>
<td>33 (238)</td>
<td>21 (146)</td>
</tr>
<tr>
<td>Fully grouted</td>
<td>84 (593)</td>
<td>84 (579)</td>
</tr>
<tr>
<td>Parallels to bed joints in running bond</td>
<td>106 (753)</td>
<td>64 (446)</td>
</tr>
<tr>
<td>Solid units</td>
<td>106 (753)</td>
<td>64 (446)</td>
</tr>
<tr>
<td>Hollow units</td>
<td>68 (476)</td>
<td>68 (476)</td>
</tr>
<tr>
<td>Ungrounded and partially grouted</td>
<td>68 (476)</td>
<td>68 (476)</td>
</tr>
<tr>
<td>Fully grouted</td>
<td>68 (476)</td>
<td>68 (476)</td>
</tr>
<tr>
<td>Parallels to bed joints in masonry not laid in poking bond</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Continuous grooves section parallel to bed joints</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Other</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Fm or Fm</td>
<td>3.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

1. For fully grouted masonry, allowable stress 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
  - walls
  - Not allowed in MSJC code
- tension parallel to bed joints

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 \( F_s = 20 \text{ ksi} \)
  
  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, \( M_s \)**

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

\[
\sum M \text{ about } T_s: \quad M_s = A_s f_s j d = \rho b d^2 j f_s
\]

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

MSJC: \( F_s = 20 \text{ ksi}, 32 \text{ ksi or } 30 \text{ ksi by type} \)

**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 \( k, j \)
    • \( bd^2 = \frac{M}{\rho F'_c} \) needs to be sized for shear also
    • get \( b \) & \( d \) in nice units
  – size reinforcement (bar size & #): \( A_s = \frac{M}{F'_c j d} \)
  – check design: \( M_{s} = A_s F'_c j d > M \)
    \[ f_b = \frac{M}{0.5bd^2 jk} < F_b \]

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

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

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

Masonry Walls (unreinforced)

- allowable axial stresses

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

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, \( e_1 \)

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

virtual eccentricity
Design

• masonry columns and walls – with rebar
  – wall reinforcement usually at center and ineffective in compression
  \[ f_a + f_b \leq F_b \quad \text{provided} \quad f_a \leq F_a \]

BENDING STRESS
AXIAL STRESS

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