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

- 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
- 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

Allowable Masonry Stresses

- tension - unreinforced only

<table>
<thead>
<tr>
<th>Direction of flexural tensile stress and masonry type</th>
<th>Mortar types</th>
<th>M or S</th>
<th>N</th>
<th>M or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal to bed joints</td>
<td>Portland cement/mortar cement</td>
<td>53 (369)</td>
<td>37 (271)</td>
<td>30 (213)</td>
</tr>
<tr>
<td>Hollow units</td>
<td>Masonry cement or air entrained</td>
<td>33 (229)</td>
<td>20 (139)</td>
<td>12 (87)</td>
</tr>
<tr>
<td>Unevenly ground</td>
<td></td>
<td>84 (593)</td>
<td>81 (559)</td>
<td>77 (531)</td>
</tr>
<tr>
<td>Parallel to bed joints in running bond</td>
<td></td>
<td>106 (731)</td>
<td>64 (441)</td>
<td>40 (276)</td>
</tr>
<tr>
<td>Solid units</td>
<td></td>
<td>66 (455)</td>
<td>40 (276)</td>
<td>25 (172)</td>
</tr>
<tr>
<td>Hollow units, unevenly ground</td>
<td></td>
<td>106 (731)</td>
<td>64 (441)</td>
<td>40 (276)</td>
</tr>
<tr>
<td>Parallel to bed joints in masonry not bed in running bond</td>
<td></td>
<td>133 (917)</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Continuously gr^-jec section parallel to bed joints</td>
<td></td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

For partially ground masonry, allowable stresses shall be determined on the basis of base reciprocities between finely ground hollow units and segmental hollow units based on cement content (percentage) of graving.
Masonry Walls

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

Not allowed in MSJC code

Strong units

Weak units

Allowable Masonry Stresses

- **flexure**
  - \( F_b = \frac{1}{3} f_m' \) (unreinforced)
  - \( F_b = 0.45 f_m' \) (reinforced)

- **shear, unreinforced masonry**
  - \( F_v = 150 \text{ psi} \leq 120 \text{ psi} \)

- **shear, reinforced masonry**
  - \( M/Vd \leq 0.25: \quad F_v = \)
  - \( M/Vd \geq 1.0: \quad F_v = \)

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, \( M_s \)

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

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

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

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

\[ C_m = f_m(bkd)/2 \]

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

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

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

MSJC \( F_b = 0.33f'_m \)

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**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 \( k, j \)
    - \( bd^2 = \frac{M}{\rho j F_x} \)
    - get \( b \) & \( d \) in nice units
  - size reinforcement (bar size & #): \( A_s = \frac{M}{F_s jd} \)
  - 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
    - \( \beta_1, \beta_2 \)
    - ex. earthquake loads
Masonry Columns and Pilasters

• must be reinforced

![Diagram of Masonry Columns and Pilasters]

Figure 9.2 Columns and pilaster details.

Masonry Columns

– allowable axial load

\[
P_a = \begin{cases} 
0.25 f'_m A_n + 0.65 A_{st} F_s \left( 1 - \frac{h}{140r} \right)^2 & \text{if } h/r \leq 99 \\
0.25 f'_m A_n + 0.65 A_{st} F_s \left( \frac{70r}{h} \right)^2 & \text{if } h/r > 99 
\end{cases}
\]

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 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 Walls (unreinforced)

– allowable axial stresses

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

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

h/r ≤ 99

h/r > 99

100% solid unit
100% solid unit
100% solid unit

Vertical Cross-Section, Masonry Spanning Horizontally

Horizontal Cross-Section, Masonry Spanning Vertically

Figure 9—Horizontal and Vertical Cross-Sections

Masonry Construction 17
Lecture 28
Foundations Structures
ARCH 331
F2008abn

Masonry Construction 18
Lecture 28
Foundations Structures
ARCH 331
F2008abn

Masonry Construction 19
Lecture 28
Foundations Structures
ARCH 331
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Masonry Construction 20
Lecture 28
Foundations Structures
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Masonry Construction 18
Lecture 28
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ARCH 331
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Masonry Construction 20
Lecture 28
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6
Design

- masonry columns and walls (unreinforced)

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

- \( h/r < 99 \)

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

- \( h/r > 99 \)

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

\[
F_b = 0.33 f'_m
\]

Design

- masonry columns and walls - loading

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

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