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

\[
\begin{align*}
\text{STRAIN} & \quad \varepsilon_m \\
\text{STRESS} & \quad f_m = f_m(k_d)/2 \\
\text{n.a.} & \quad \text{t} \\
& \quad \text{d} \\
& \quad A_s \quad \rho = \frac{A_s}{b_d}
\end{align*}
\]
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

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
  • parapet with no control joint

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Allowable Masonry Stresses

- **tension** - unreinforced only

<table>
<thead>
<tr>
<th>Direction of Reversed tensile stress and Masonry Type</th>
<th>Mortar Type</th>
<th>Perforated concrete or mortar</th>
<th>Perforated concrete or mortar cement or air entrained cement or air entrained</th>
<th>M or S</th>
<th>N</th>
<th>M or S</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal to bed joints</td>
<td></td>
<td></td>
<td></td>
<td>106(731)</td>
<td>80(552)</td>
<td>66(455)</td>
<td>90(645)</td>
</tr>
<tr>
<td>Parallel to bed joints in running bond:</td>
<td></td>
<td></td>
<td></td>
<td>133(917)</td>
<td>133(917)</td>
<td>133(917)</td>
<td>133(917)</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td>0(0)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>0(0)</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 pointing.

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Masonry Walls

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

- **Not allowed in MSJC codes**

- **Strong units**
- **Weak units**

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Allowable Masonry Stresses

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

- **shear, unreinforced masonry**
  - \( F_v = 1.5\sqrt{f'_m} < 120 \text{ psi} \)

- **shear, reinforced masonry**
  - \( M/Vd \leq 0.25: \quad F_v = 3.0\sqrt{f'_m} \)
  - \( M/Vd \leq 0.25: \quad F_v = 2.0\sqrt{f'_m} \)

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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, $M_s$

\[ C_m = f_m b (kd)/2 \]

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

$\Sigma M$ about $C_m$: \[ M_s = A_s f_s j d = \rho bd^2 j f_s \]

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

MSJC: $F_s = 20$ ksi, 32 ksi or 30 ksi by type

Reinforcement, $M_m$

for equilibrium: \[ \sum M = 0 \] about $F_s$ \[ M_m = f_m b \frac{kd}{2} j d = 0.5 f_m bd^2 j k \]

If $f_m = F_b$ (allowable) the moment capacity is limited by the masonry

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 $k$, $j$
    - $bd^2 = \frac{M}{\rho j F_y}$
    - get $b$ & $d$ in nice units
  - size reinforcement (bar size & #): $A_s = \frac{M}{F_s j d}$
  - check design: \[ M_s = A_s F_s j d > M \] \[ \frac{M}{F_s j d} > f'_b = \frac{0.5 bd^2 j k}{F_b} \]
Ultimate Strength Design
• LRFD
• like reinforced concrete
• useful when beam shear is high
• improved inelastic model
  – ex. earthquake loads

Masonry Columns and Pilasters
• must be reinforced

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

Figure 9.2: Columns and pilaster details.
Masonry Walls (unreinforced)

- allowable axial stresses

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

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

\[ \frac{h}{r} \leq 99 \]

\[ \frac{h}{r} > 99 \]

Design

- masonry columns and walls (unreinforced)

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

\[ - h/r < 99 \quad F_a = 0.25 f_m' \left[ 1 - \left( \frac{h}{140r} \right)^2 \right] \]

\[ - h/r > 99 \quad F_a = 0.25 f_m' \left( \frac{70r}{h} \right)^2 \]

\[ F_b = 0.33 f_m' \]

Design

- masonry columns and walls - loading

- wind loading

- eccentric axial load

- “virtual” eccentricity, \( e_1 \)

Design

- masonry columns and walls – with rebar

- wall reinforcement usually at center and ineffective in compression

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