Masonry Construction

- columns
- beams
- arches
- walls
- footings

Masonry Construction

- solid, grouted, hollow
- unreinforced
- reinforced
- prestressing
Masonry Construction 4
Lecture 26
ARCH 631
F2007abn

Masonry Materials

- brick
- concrete masonry units

Masonry Construction 5
Lecture 26
ARCH 631
F2007abn

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 Construction 6
Lecture 26
ARCH 631
F2007abn

Masonry Materials

- reinforcement
  - deformed bars
  - prestressing strand
  - development length
  - anchorage
  - splices
  - ties
- steel or composite

Masonry Construction 7
Lecture 26
ARCH 631
F2007abn

Masonry Materials

- grout
  - high slump concrete
  - fills voids and fixes rebar
- prisms
  - used to test strength, $f_m$
**Masonry Materials**

- **fire resistance**
  - fire-resistive structural material
  - details important to prevent leaks or cracks
  - retains strength if exposure not too long
    - mortar and cmu’s dehydrate
    - loses 30-60% after that
  - no toxic fumes
  - cover necessary to protect steel

- **moisture resistance**
  - weathering index for brick
  - bond and detailing
  - expansion or shrinking from water
    - provide control joints
    - parapets, corners, long walls

**Masonry Walls**

- based on empirical requirements for minimum wall thickness and height
  - h/t < 25 (UBC 2105.2 h/t<35)
- wall thicknesses often increased by 4”/story
- bearing walls > 3-5 stories uneconomical, steel or concrete frames used
- strength design limit states:
  - serviceability: deflection
  - ultimate: compression & tension

**Masonry Walls**

- compression + bending

\[ P = f_a A \]

axial stress

\[ f_b = \frac{M}{S} \]

bending stress

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

virtual eccentricity

\[ f_a + f_b = \frac{P}{A + M/S} \]

combined
**Masonry Walls**

- equivalent eccentricity with lateral load

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

\[ e_1 = \text{virtual eccentricity} \]

**Masonry Walls**

- tension normal to bed joints
- Not allowed in MSJC code
- tension parallel to bed joints
- strong units
- weak units

**Masonry Beam & Wall Design**

- limit tensile stress in mortar
- working stress design (ASD)
  - linear stresses in masonry
  - no tension in masonry when reinforced
  - elastic stress in steel < \( f_y \)
  - additional compression in walls
- masonry strength = \( f'_m \)

**Masonry Beam & Wall Design**

- reinforcement increases capacity & ductility

---

*Figure 2.10* Reinforced masonry beams and lintels.
Masonry Design

- $f_s$ is not the yield stress
- $f_m$ is the stress in the masonry

Allowable Masonry Stresses

- tension - unreinforced only

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>N or S</th>
<th>N or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement/mortar</td>
<td>37 (256)</td>
<td>72 (511)</td>
</tr>
<tr>
<td>Masonry cement or air entrained</td>
<td>70 (479)</td>
<td>77 (533)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>N or S</th>
<th>N or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal to bed joints</td>
<td>40 (279)</td>
<td>12 (83)</td>
</tr>
<tr>
<td>Solid units</td>
<td>25 (172)</td>
<td>12 (83)</td>
</tr>
<tr>
<td>Hollow units</td>
<td>25 (172)</td>
<td>12 (83)</td>
</tr>
<tr>
<td>Fully grouted</td>
<td>25 (172)</td>
<td>12 (83)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>N or S</th>
<th>N or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel to bed joints in running bond</td>
<td>64 (441)</td>
<td>40 (279)</td>
</tr>
<tr>
<td>Solid units</td>
<td>64 (441)</td>
<td>40 (279)</td>
</tr>
<tr>
<td>Hollow units</td>
<td>64 (441)</td>
<td>40 (279)</td>
</tr>
<tr>
<td>Fully grouted</td>
<td>64 (441)</td>
<td>40 (279)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mortar type</th>
<th>N or S</th>
<th>N or S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel to bed joints in masonry not bed in running bond</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Continuous grout sections parallel to test points</td>
<td>133 (917)</td>
<td>133 (917)</td>
</tr>
<tr>
<td>Other</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

- $f_m = 1/3 f_m$ (unreinforced)
- $f_m = 0.45 f_m$ (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 $F_s = 20$ ksi
  - b) Grade 60 $F_s = 24$ ksi
  - c) Wire joint $F_s = 30$ ksi

- *no allowed increase by 1/3 for combinations with wind & earthquake
  - did before 2011 MSJC
Reinforcement, $M_s$

\[
\Sigma F = 0: \quad A_s f_s = f_m b \frac{kd}{2} \\
\Sigma M \text{ about } C_m: \quad M_s = A_s f_s jd = \rho bd^2 j f_s
\]

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

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

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 $k, j$ and $\rho j f_s'$
    - $bd^2 = \frac{M}{\rho j f_s'}$
    - 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
  - ex. earthquake loads

**Masonry Walls**

- one-way or two-way bending
- usually use hollow units (< 75% solid)
- reinforcement grouted
  - into cells if hollow units
  - between wythes if solid
- reinforcement usually at center
- reinforcement in compression ineffective
- avoid stirrups
- desirable in seismic zones

**Masonry Shear Walls**

- bearing, bending, and shear
  - compression increases resistance
  \[ f_v = \frac{VQ}{I_n b} \]
  or
  \[ \frac{V}{A_{nv}} \leq F_v \]
  - unreinforced stress limit 1.5\( \sqrt{f_m'} \) \leq 120 psi

**Masonry Walls**

- axial force-moment interaction diagram
  \[ \frac{f_a + f_b}{F_a + F_b} \leq 1 \]
Masonry Shear Walls

• (and beams)
  – reinforcement strength included:
    \[ F_v = F_{vm} + F_{vs} \]
  – where
    \[ F_{vm} = \frac{1}{2} \left[ 4.0 - 1.75 \left( \frac{M}{Vd} \right) \sqrt{f_m'} \right] + 0.25 \frac{P}{A_n} \]
    \[ F_{vs} = 0.5 \left( \frac{A_F d}{A_{m,s}} \right) \]
  – stress limit depends on ratio of bending moment to overturning moment: \( M/Vd \)
  – spacing limits

Masonry Columns and Pilasters

• must be reinforced

Masonry Shear Walls

• model as deep cantilever beam
  – flexure reinforcement
  – shear stirrups

Masonry Columns and Pilasters

• considered a column when \( b/t < 3 \) and \( h/t > 4 \)
  – slender is
    – 8” one side
    – \( h/t \leq 25 \)
  • needs ties
  • eccentricity
    – 10% of side dimension required
    – interaction diagrams like r/c
Masonry Columns

- allowable axial load

\[ P_a = \left[ 0.25 f'_m A_n + 0.65 A_{st} F_s \right] \left[ 1 - \left( \frac{h}{140r} \right)^2 \right] \]

\( h/r \leq 99 \)  
\( h/r > 99 \)  
(unreinforced \( A_{st} = 0 \))

\[ P_a = \left[ 0.25 f'_m A_n + 0.65 A_{st} F_s \right] \left( \frac{70r}{h} \right)^2 \]

\( h = \) 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 Pilasters, Arches

- column in wall

- increase bearing area and stiffness

Construction Supervision

- proper placement of all reinforcement
- prism construction
  - masonry
  - mortar
- hot/cold weather protection