Masonry Construction

- columns
- beams
- arches
- walls
- footings

Learning Evaluation
**Masonry Materials**

- brick
- concrete masonry units

**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**

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

**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

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 Materials

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

Masonry Walls

• compression + bending

\[
P = \frac{M}{I} = \frac{M}{S}
\]

axial stress

\[
f_a = \frac{P}{A}
\]

virtual eccentricity

combined

\[
f_a + f_b = \frac{M}{A + S} - f_a
\]
**Masonry Walls**

- equivalent eccentricity with lateral load

\[ e_{\text{eq}} = \frac{M}{P} \]

\[ e_{1} = \frac{M}{P} \]

**Masonry Walls**

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

**Masonry Beam & Wall Design**

- **MSJC (ACI, ASCE, TMS)**
  - 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

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

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

![Diagram of Masonry Design](image)

$$p = \frac{A_s}{bd}$$

Allowable Masonry Stresses

- **tension** - unreinforced only

<table>
<thead>
<tr>
<th>Table 3.2.3.2</th>
<th>Allowable flexural tensile stresses for dry and mortarless masonry, psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction of flexural tensile stress and masonry type</td>
<td>Mortar type</td>
</tr>
<tr>
<td>Portland cement/linseed or mortarless masonry cement</td>
<td>Masonry cement or air entrained, Portland cement</td>
</tr>
<tr>
<td>M or 5</td>
<td>N</td>
</tr>
</tbody>
</table>
| Normal masonry joints | Saturated Hollow units | Ungrouted Hollow units | Grouted Hollow units | Parallel to bed joints in masonry bonded in mortar \( d \leq 1.5 \sqrt{f_m} \leq 120 \text{ psi} \)
| 50/206 (202) | 80/153 (1032) | 64/145 (453) | 40/93 (293) | 40/93 (293) |
| 60/249 (269) | 96/210 (607) | 80/181 (547) | 60/136 (346) | 60/136 (346) |
| 75/375 (333) | 120/271 (835) | 100/236 (852) | 80/193 (852) | 80/193 (852) |
| 100/505 (440) | 160/333 (1451) | 125/272 (1032) | 100/236 (852) | 100/236 (852) |
| 125/637 (1727) | 200/413 (876) | 150/345 (1451) | 125/272 (1032) | 125/272 (1032) |
| 150/797 (1727) | 250/539 (1117) | 200/413 (876) | 150/345 (1451) | 150/345 (1451) |
| 175/913 (1584) | 300/617 (1451) | 250/539 (1117) | 200/413 (876) | 200/413 (876) |
| 200/1025 (1406) | 350/755 (1584) | 250/539 (1117) | 200/413 (876) | 200/413 (876) |
| 225/1138 (1584) | 400/853 (1666) | 300/617 (1451) | 250/539 (1117) | 250/539 (1117) |
| 250/1250 (1666) | 450/927 (1584) | 350/755 (1584) | 300/617 (1451) | 300/617 (1451) |

- **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
  - 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: $F_s = 20$ ksi, 24 ksi or 30 ksi by type

**Masonry Lintels**

- **Distributed load**
  - Triangular or trapezoidal

**Reinforcement, $M_m$**

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

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

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

MSJC $F_b = 0.33 f'_m$

**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 $k, j$
    - $bd^2 = \frac{M}{\rho j F}$
      - Needs to be sized for shear also
    - Get $b$ & $d$ in nice units
  - Size reinforcement (bar size & #): $A_s = \frac{M}{F_s jd}$
  - Check design: $M_s = A_s f_s jd > M$
    - $f_b = \frac{M}{0.5 bd^2 jk} < F_b$
**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 Walls**

- axial force-moment interaction diagram
  \[
  \frac{f_u}{F_a} + \frac{f_b}{F_b} \leq 1
  \]

**Masonry Shear Walls**

- bearing, bending, and shear
  - compression increases resistance

\[
    f_v = \frac{VQ}{I_n b} \quad \text{or} \quad \frac{V}{A_{nv}} \leq F_v
\]

- unreinforced stress limit \(1.5\sqrt{f_m} \leq 120 \text{ psi}\)
Masonry Shear Walls

• (and beams)
  
  – reinforcement strength included:

\[
F_v = F_{vm} + F_{vs}
\]

  – where

\[
F_{vm} = \frac{1}{2} \left( 4.0 - 1.75 \left( \frac{M}{Vd} \right) \sqrt{f_m'} \right) + 0.25 \frac{P}{A_n}
\]

\[
F_{vs} = 0.5 \left( \frac{A_F}{A_{nv,s}} \right)
\]

  – 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 ≤ 25

  • needs ties

  • eccentricity

    – 10% of side dimension required

    – interaction diagrams like r/c
Masonry Columns

- allowable axial load

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

\( h = \) 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 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