ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN
ARCH 331
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SUMMER 2015

lecture twenty four

masonry construction: beams & columns

Masonry Construction 1
Lecture 24

Architectural Structures
ARCH 331

Su2015abn
### Office Hours

**Professor Anne Nichols (845-6540)**

**link to posted schedule**

[http://faculty.arch.tamu.edu/anichols/schedule/](http://faculty.arch.tamu.edu/anichols/schedule/)
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

International Masonry Institute (Brian Trimble)
Masonry Beam & Wall Design

- *reinforcement increases capacity & ductility*

![Diagram of reinforced masonry beams and lintels.](image)
Masonry Design

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

\[ M = A_s f_m \]

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

\[ T_s = A_s f_s \]

\[ \rho = \frac{A_s}{bd} \]
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
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
Allowable Masonry Stresses

- **tension - unreinforced only**

<table>
<thead>
<tr>
<th>Table 2.2.3.2 — Allowable flexural tensile stresses for clay and concrete masonry, psi (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction of flexural tensile stress and masonry type</strong></td>
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<tr>
<td></td>
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<tr>
<td>Normal to bed joints</td>
</tr>
<tr>
<td>Solid units</td>
</tr>
<tr>
<td>Hollow units¹</td>
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<tr>
<td>Ungrooted</td>
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<tr>
<td>Fully grouted</td>
</tr>
<tr>
<td>Parallel to bed joints in running bond</td>
</tr>
<tr>
<td>Solid units</td>
</tr>
<tr>
<td>Hollow units</td>
</tr>
<tr>
<td>Ungrooted and partially grouted</td>
</tr>
<tr>
<td>Fully grouted</td>
</tr>
<tr>
<td>Parallel to bed joints in masonry not laid in running bond</td>
</tr>
<tr>
<td>Continuous grout section parallel to bed joints</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

¹ For partially grouted masonry, allowable stresses 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

Not allowed in MSJC code

tension parallel to bed joints

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**
  - \( F_v = 1.5 \sqrt{f'_m} \leq 120 \text{ psi} \)

- **shear, reinforced masonry**
  - \( M/Vd \leq 0.25: \quad F_v = 3.0 \sqrt{f'_m} \)
  - \( M/Vd \geq 1.0: \quad F_v = 2.0 \sqrt{f'_m} \)
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, $M_s$

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

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

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

MSJC: $F_s = 20 \text{ ksi}, 32 \text{ ksi or } 30 \text{ ksi by type}$
Reinforcement, $M_m$

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

$\Sigma M$ about $T_s: \quad M_m = f_m b \frac{kd}{2} j d = 0.5 f_m b d^2 j k$

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

$MSJC \quad F_b = 0.33 f'_m$
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 $k$, $j$
    • $bd^2 = \frac{M}{\rho j F_s}$ needs to be sized for shear also
    • get $b$ & $d$ in nice units
  – size reinforcement (bar size & #): $A_s = \frac{M}{F_s j d}$
  – check design: $M_s = A_s F_s j d > M$
    $$f_b = \frac{M}{0.5bd^2jk} < F_b$$
Ultimate Strength Design

- LRFD
- like reinforced concrete
- useful when beam shear is high
- improved inelastic model
  - ex. earthquake loads

\[ 0.80f'_m \frac{\beta_1 c}{2} \]
Masonry Columns and Pilasters

- must be reinforced

Figure 9.2  Columns and pilaster details.
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

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

- \( h \) = 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 Walls (unreinforced)

- allowable axial stresses

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

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

- masonry columns and walls  (unreinforced)

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

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

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

\[
F_b = 0.33 f'_m
\]
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: \[ M = f_m C_m = f_m b (kd) / 2 \]

AXIAL STRESS: \[ f_a = P / A \]

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 (continue):
  – 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-Δ, 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