Masonry Construction: beams & columns

Office Hours

• 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

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

\[ \rho = \frac{A_s}{bd} \]

Masonry Materials

- units
  - stone, brick, concrete block, clay tile

Masonry Materials

- mortar
  - water, masonry cement, sand, lime
  - types:
    - $M$ higher strength – 2500 psi (ave.)
    - $N$ medium high strength – 1800 psi
    - $O$ medium strength – 750 psi
    - $W$ 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

Masonry Walls

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

Allowable Masonry Stresses

- tension - unreinforced only
  - Table 2.2.3.2 — Allowable flexural tensile stresses for clay and concrete masonry, psi (MPa)

- flexure
  - $F_D = 1/3 f'_m$ (unreinforced)
  - $F_b = 0.45 f'_m$ (reinforced)

- shear, unreinforced masonry
  - $F_v = 1.5 \sqrt{f'_m} \leq 120$ psi

- 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 \( F_s = 20 \text{ ksi} \)
  - 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, \( M_s \)**

\[
\Sigma M = A_s f_s = f_m b \frac{kd}{2}
\]

**Masonry Lintels**

- **distributed load**
  – triangular or trapezoidal

\[
\Sigma M = f_m b \frac{kd}{2} \text{ jd} = 0.5 f_m b d^2 j f_s
\]

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 $k, j$
    - $bd^2 = \frac{M}{\rho j F'_s}$
    - get $b & d$ in nice units
  - size reinforcement (bar size & #): $A_s = \frac{M}{F_s j d}$
  - check design: $M_s = A_s F_s j d > M$
  - $f_b = \frac{M}{0.5bd^2 jk} < F_b$

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

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

Design

- **masonry columns and walls** (unreinforced)
  \[
  \frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0 \quad \text{and} \quad f_b - f_a \leq F_t
\]

  - \( h/r < 99 \)
    \[
    F_a = 0.25 f'_m \left( 1 - \left( \frac{h}{140r} \right)^2 \right)
    \]
  
  - \( h/r > 99 \)
    \[
    F_a = 0.25 f'_m \left( \frac{70r^2}{h} \right)
    \]

  - \( F_b = 0.33 f'_m \)

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
  \[ f_a + f_b \leq F_b \] provided \[ f_a \leq F_a \]

BENDING STRESS

\[ f_{m} = \frac{f_{w}(k_d/2)}{I_{s}} \]

AXIAL STRESS

\[ I_{s} = \frac{P}{A} \]

for equilibrium:
\[ \sum F = C_{m} - T_{s} \]

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 (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