Unreinforced Masonry

Code Sections, 9.2
- 9.2.1 Scope
- 9.2.2 Design criteria
- 9.2.3 Design assumptions
- 9.2.4 Nominal flexural and axial strength
- 9.2.5 Axial tension
- 9.2.6 Nominal shear strength

Key design equation:  
\[ f_t = \frac{Mc}{I} - \frac{P}{A} \]

Interaction Diagram

Axial strength limit, Section 9.2.4.2  
\[ P_n = 0.80[0.80f'_m A_n] \left[ 1 - \left( \frac{h}{140r} \right)^2 \right] \quad \text{for } \frac{h}{r} \leq 99 \]
\[ P_n = 0.80[0.80f'_m A_n] \left( \frac{20r}{h} \right)^2 \quad \text{for } \frac{h}{r} > 99 \]

Compression controlled: Compression stress does not exceed 0.80\( f'_m \)

\[ f_a + f_b \leq \phi (0.8f'_m) \]

Tension controlled: Tension stress does not exceed modulus of rupture, Table 9.1.9.2

\[ -f_a + f_b \leq \phi F_t \]

\[ \phi = 0.6 \]
Moment Magnification

Design for magnified moment: \( M_u = \psi M_{u,0} \)

\[
\psi = \frac{1}{1 - \frac{P_u}{P_{e}}} = \frac{1}{1 - \frac{P_u}{A_n f_m' \left(\frac{70r}{h}\right)^2}}
\]

- Can take \( \psi = 1 \) if \( h/r \leq 45 \)
- Can take \( \psi = 1 \) if \( 45 < h/r \leq 60 \) and nominal strength reduced by 10%

Lateral Load Example

Given: 12 ft high wall; 8 in. hollow light weight concrete masonry units with Type S masonry cement mortar; face shell bedding; no grout. Superimposed dead load of 1 kip/ft and roof live load of 0.5 kip/ft at an eccentricity of 3 in. (toward inside). Out-of-plane wind load of 24 psf (pressure or suction).

Required: Check adequacy of wall

Solution: \( f_m' = 2000 \text{ psi}; \ A_n = 30.0 \text{ in.}^2/\text{ft}; \ S_n = 81.0 \text{ in.}^3/\text{ft}; \ r = 2.84 \text{ in.} \)

Load Combinations

1.4D  
1.2D + 1.6L_r  
1.2D + 1.0W + 0.5L_r  
0.9D + 1.0W

\[
\frac{h}{r} = \frac{144 \text{in.}}{2.84 \text{in.}} = 50.7
\]

Wall weight = 30 psf
Lateral Load Example

Which load combination do you think will control?
A. 1.2D + 1.0W + 0.5L_r Wind pressure (compression on outside)
B. 1.2D + 1.0W + 0.5L_r Wind suction (compression on inside)
C. 0.9D + 1.0W Wind pressure (compression on outside)
D. 0.9D + 1.0W Wind suction (compression on inside)

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Tensile Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2D + 1.0W + 0.5L_r wind pressure</td>
<td></td>
</tr>
<tr>
<td>1.2D + 1.0W + 0.5L_r wind suction</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>0.9D + 1.0W wind suction</td>
<td></td>
</tr>
</tbody>
</table>

0.9D + 1.0W  
Wind suction (compression on inside face of wall)

Factored axial load, $P_u$

$$P_u = 0.9 \left( 1000 \frac{lb}{ft} + 31 \frac{lb}{ft^2} \left( \frac{62.6 \text{in.}}{12 \text{in./ft}} \right) \right) = 1046 \frac{lb}{ft}$$

Moment at top of wall, $M_{uf}$

$$M_{uf} = P_u e = 0.9 \left( 1000 \frac{lb}{ft} \right) (3.0 \text{in.}) = 2700 \frac{lb \cdot \text{in.}}{ft}$$

Location of max moment, $x$

$$x = \frac{h}{2} - \frac{M_{uf}}{w_u h} = \frac{144 \text{in.}}{2} - \frac{2700 \frac{lb \cdot \text{in.}}{ft}}{24 \frac{lb}{ft^2} \left(12 \text{ft} \right)^2} = 62.6 \text{in.}$$

$$M_{u,0} = \frac{M_{uf}}{2} + \frac{w_u h^2}{8} + \frac{M_{uf}^2}{2w_u h^2}$$

Maximum moment, $M_{u,0}$

$$= \frac{2700 \frac{lb \cdot \text{in.}}{ft}}{2} + \frac{24 \frac{lb}{ft^2} \left(12 \text{ft} \right)^2 \left( 12 \text{in./ft} \right)}{8} + \frac{\left( 2700 \frac{lb \cdot \text{in.}}{ft} \right)^2}{2 \left( 24 \frac{lb}{ft^2} \right) \left(12 \text{ft} \right)^2 \left( 12 \text{in./ft} \right)}$$

$$= 1350 + 5184 + 88 = 6622 \frac{lb \cdot \text{in.}}{ft}$$
Lateral Load Example

Moment Magnifier: \[ \psi = \frac{1}{1 - \frac{P_u}{A_n f' m \left( \frac{70 ft}{h} \right)^2}} = \frac{1}{1 - \frac{1046 \text{ lb}}{1046 \text{ lb/ft}^2}} = 1.009 \]

Tension: \[ -\frac{P_u}{A_n} + \frac{\psi M_{u,0}}{S_n} = \]

Nominal Strength = Design Strength =

Compression: \[ \frac{P_u}{A_n} + \frac{\psi M_{u,0}}{S_n} = \frac{1046 \text{ lb/ft}}{30 \text{ in}^2/\text{ft}^2} + \frac{1.009 \left(6622 \text{ lb-in}/\text{ft}^2\right)}{810 \text{ in}^3/\text{ft}^2} = 34.9 + 82.5 = 117.4 \text{ psi} \]

Nominal Strength = 0.8(2000 psi) = 1600 psi
Design Strength = 0.6(1600 psi) = 960 psi

OK

Unreinforced Masonry

Lateral Load Example

Moment Magnifier: \[ \psi = \frac{1}{1 - \frac{P_u}{A_n f' m \left( \frac{70 ft}{h} \right)^2}} = \frac{1}{1 - \frac{1046 \text{ lb}}{1046 \text{ lb/ft}^2}} = 1.009 \]

Tension: \[ -\frac{P_u}{A_n} + \frac{\psi M_{u,0}}{S_n} = -\frac{1046 \text{ lb/ft}}{30 \text{ in}^2/\text{ft}^2} + \frac{1.009 \left(6622 \text{ lb-in}/\text{ft}^2\right)}{810 \text{ in}^3/\text{ft}^2} = -34.9 + 82.5 = 47.6 \text{ psi} \]

Nominal Strength = 51 psi
Design Strength = 0.6(51 psi) = 30.6 psi

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Compression: \[ \frac{P_u}{A_n} + \frac{\psi M_{u,0}}{S_n} = \frac{1046 \text{ lb/ft}}{30 \text{ in}^2/\text{ft}^2} + \frac{1.009 \left(6622 \text{ lb-in}/\text{ft}^2\right)}{810 \text{ in}^3/\text{ft}^2} = 34.9 + 82.5 = 117.4 \text{ psi} \]

Nominal Strength = 0.8(2000 psi) = 1600 psi
Design Strength = 0.6(1600 psi) = 960 psi

OK
Lateral Load Example

What to do to make wall work? (short of reinforcing wall)

1.
2.
3.
4.

In-Plane Shear (9.2.6)

Failure modes:

- strong mortar, weak units
- weak mortar, strong units

Nominal strength is smallest of:

\[ 3.8A_{nv}\sqrt{f_m} \]
\[ (300 \text{ psi})A_{nv} \]
Running bond not solidly grouted and stack bond with open end units grouted solid
Running bond solidly grouted
Other stack bond

\[ (56 \text{ psi})A_{nv} + 0.45N_u \]
\[ (90 \text{ psi})A_{nv} + 0.45N_u \]
\[ (23 \text{ psi})A_{nv} \]

\[ \phi = 0.8 \]
Example: In-Plane Shear

Given: 12 ft high wall; 8 in. hollow concrete masonry units with Type S masonry cement mortar; face shell bedding; no grout. Wall is 10 ft long and subjected to a 1 kip/ft vertical dead load.

Required: In-plane wind load

Solution: $f_m' = 2000 \text{ psi}$

\[ A_{nv} = 2(1.25 \text{ in.})(120 \text{ in.}) = 300 \text{ in.}^2 \]
\[ V_n = \min\{3.8\sqrt{f_m'A_{nv}}, 300A_{nv}, 56A_{nv} + 0.45N_u\} \]
\[ 3.8\sqrt{2000 \text{ psi}(300 \text{ in.}^2)} = 51.0 \text{kips} \]
\[ 300 \text{ psi}(300 \text{ in.}^2) = 90 \text{kips} \]
\[ 56(300 \text{ in.}^2) + 0.45(0.9)(1000 \frac{\text{lb}}{\text{ft}})(10 \text{ ft}) = 20.8 \text{kips} \]

\[ V_{u,max} = \phi V_n = 0.8(20.8 \text{kips}) = 16.7 \text{kips} \]

Example: Overturning

9.1.9.2 Modulus of rupture values same as for out-of-plane bending

Section properties:
only face shell bedding is considered, although full bedding is required at the first course

\[ S_n = \frac{bd^2}{6} = \frac{2.5 \text{ in.}(120 \text{ in.})^2}{6} = 6000 \text{ in.}^3 \]

Tension include wall weight of 31 psf(12 ft high)(10 ft long) = 3720 lb

\[ P_u = 0.9(10 \text{ kip} + 3.72 \text{ kips}) = 12.35 \text{kips} \]

\[ \frac{-P_u}{A_n} + \frac{V_{uh}}{S_n} = \phi F_t \]
\[ \frac{12350 \text{ lb}}{300 \text{ in.}^2} + \frac{V_u(144 \text{ in.})}{6000 \text{ in.}^3} = -41.2 \text{ psi} + 0.024V_u = 0.6(51 \text{ psi}) = 30.6 \text{ psi} \]

\[ V_{u,max} = 2.99 \text{ kips} \]
12 ft high wall; 8 in hollow CMU with Type S masonry cement mortar