Design of Masonry Walls to Resist Shear

Failure Mechanisms

Sliding Along Shear Plane

Sliding is resisted by:
- strength of mortar
- friction due to vertical stress

Friction exists only when interface is under compressive stress

\( F_v = \min \left[ \frac{F_t}{A_{nt}}, \frac{Nu}{A_{nt}} \right] \)

- 15 psi if not running bond or not open end units
- 37 psi if running bond, not grouted solid
- 60 psi if running bond, grouted solid

\( F_t < F_{t'} \) in Table 2.2.3.2, pg. C-26
when flexural tension is not small ($F_t > F_t^{*}$) (Table 2.2.3.2)

- no friction to resist sliding
- flexural-shear cracking occurs

![Graphs showing flexure stress, shear stress, tensile strength, and shear strength](Image)

Failure when $\sigma_t = $ tensile strength

Failure when $\sigma_t = $ tensile strength

Shear strength of masonry affected by relative magnitude of flexure
code uses $\frac{M}{N} = \frac{M}{V} \frac{M}{M_{max}}$
ACI Masonry code conservatively sets shear resistance, \( F_v \), when \( f_t > F_t \). Table 2.7.3.2 to:

Shear resistance of masonry only or shear resistance of reinforcement only but not both at the same time

**Design to Resist Shear**
- See flowchart, pg. CE-39 in ACI

**Example - Out-of-Plane Shear (Corely a factor)**

- 8" CMU, ungrouted, Type M
- \( f_m = 1500 \text{ psi} \), running bond

\( f_v \) at top of wall: Table 2.7.2

\[ M_u = 0 \rightarrow f_t = 0 < 25 \text{ psi} \]

\[ V_u = (30 \text{ psi})(\frac{18'}{2}) = 270 \text{ psi} \]

\[ f_v = \frac{1}{2} \sqrt{\frac{V_u}{A}} \text{ since } f_t < F_t \]

\[ f_v = \frac{1}{2} \sqrt{\frac{270}{30 \text{ in}^2}} = 10.5 \text{ psi} \]

\[ F_v = \min \left[ 1.5 \sqrt{f_m}, \frac{(20 \text{ psi})}{V + 15 \sqrt{N_y}}, \frac{1500}{A} \right] \]

\[ F_v = \min \left[ 1.5 \sqrt{1500}, \frac{120}{30 \text{ in}^2}, \frac{37 \text{ psi}}{20 \text{ psi}} \right] \]
\[
F_v = \min [58.1 \text{ psi}, 120 \text{ psi}, 105.6 \text{ psi}] = 58 \text{ psi}; \\
F_v = 93.5 \text{ psi}; < 58 \text{ psi}; = F_v, \text{ OK}
\]

**Example - Same problem except base of wall is fixed**

\[
P_0 = 200 \text{ psi}
\]

\[
W = 30 \text{ psi}
\]

\[
M = \frac{W L^2}{8} = \frac{(30 \text{ psi})(18')^2}{8} = 1215(\frac{144}{12}) = 1215 \frac{16}{\text{ in}} = 1, 215 \frac{16}{\text{ ft}}
\]

\[
V = \frac{5 W L}{8} = \frac{(5)(30 \text{ psi})(18')}{8} = 337.5 \frac{16}{\text{ ft}}
\]

**Base of wall:**

\[
f_t = \frac{-P}{A} + \frac{M}{S} = \frac{-2000(16/\text{ ft})}{30 \text{ in}^2/\text{ ft}} + \frac{(1215(\frac{16}{\text{ in}})(12 \text{ in}/\text{ ft}))}{81.0 \text{ in}^2/\text{ ft}}
\]

\[
f_t = -66.9 \text{ psi} + 180.0 \text{ psi} = 113.3 \text{ psi}
\]

\[
f_t = 113.3 \text{ psi} > 25 \text{ psi}; \text{ (Table 2.2.3.2)}, \text{ flexural reinforcement req'd}
\]

Use a 6 e 32" placed in center of cell

\[
f_v = \frac{V}{b d} \text{ (ACI 2-19)}
\]

\[
f_v = \frac{337.5(16/\text{ ft}) \times 32"}{(8.3(25"))(3.8(25"))}
\]
\[ F_v = 28.4 \text{ psi} \]

\( F_v \text{ (check } F_v \text{ masonry only first)} \leq \text{ no shear rent.} \)

\[ F_v = \sqrt{f_{\text{min}} \leq 500 \text{ psi for flexural memb. }} \checkmark \]

\[ F_v = \frac{51500 \text{ psi}}{\sqrt{1}} = 58.7 \text{ psi} \]

\[ F_v = 28.4 \text{ psi} < 58.7 \text{ psi} = F_v, \text{ OK} \]

**Example — in-plane shear**

8" cm w, Type M masonry

\[ f_{\text{min}} = 1500 \text{ psi, running bond} \]

(a) \( V = 500 \text{ lb} \)

At base of wall:

\[ \rho = G \frac{V (f_{\text{min}} h + l)}{L \phi A_y} \text{ lb. ft.} \]

\[ \rho = 5440 \text{ lb. ft.} \]

\[ M = V \times h = 500 \times 16 = 8000 \text{ lb. ft.} \]

\[ A = 2 \times FST \times L \]

\[ A = 2 (1.25") (10 \times 12") = 300 \text{ in}^2 \]

\[ S = \frac{1}{6} (2 \times FST)(L)^2 = \frac{1}{6} (2 \times 1.25") (10 \times 12")^2 \]

\[ S = 6000 \text{ in}^3 \]
\[ f_t = - \frac{P}{A} + \frac{M}{S} = - \frac{5440 \text{ lb}}{300 \text{ in}^2} + \frac{38,000 \text{ lb} \cdot \text{in}}{6 \text{ cfs} \cdot \text{in}^3} \]

\[ f_t = -1811 \text{ psi} + 16,100 \text{ psi} = 2289 \text{ psi} \]

\[ f_t = 2289 \text{ psi}, \text{ compression, OK, no tension allowed in unreinforced masonry} \text{, in-plane} \]

\[ f_c < f_t \text{ by inspection} \]

\[ F_v = \frac{A}{2} \frac{V}{A} \text{ for rectangular sections} \]

\[ F_v = \frac{(1.5)(500 \text{ ft})}{300 \text{ in}^2} = 2.5 \text{ psi} \]

\[ F_v = \text{min} \left[ 1.5 \sqrt{f_v}, 120 \text{ psi}, V + 0.5 \frac{Vu}{A_{\text{min}}} \right] \]

\[ F_v = \text{min} \left[ 1.5 \sqrt{500 \text{ psi}}, 120 \text{ psi}, 37 \text{ psi} + 0.5 \frac{5440 \text{ lb}}{300 \text{ in}^2} \right] \]

\[ F_v = \text{min} \left[ 58 \text{ psi}, 120 \text{ psi}, 45 \text{ psi} \right] = 45 \text{ psi} \]

\[ F_v = 2.5 \text{ psi} < 45 \text{ psi} \text{, } F_v \text{, OK} \]

b) \[ V = 1 \text{ cfs} \cdot \text{in} \]

\[ M = 1 \text{ cfs} \cdot \text{in} \cdot 10' = 16,000 \text{ lb} \cdot \text{ft} \]

\[ f_t = -\frac{P}{A} + \frac{M}{S} = -\frac{5440 \text{ lb}}{300 \text{ in}^2} + \frac{16,000 \text{ lb} \cdot \text{ft}}{6 \text{ cfs} \cdot \text{in}^3} \]

\[ f_t = 14 \text{ psi} \text{, NG since no tension allowed in-plane} \]

\[ b = 2 \times FST = 2.5' \]

\[ d = 10' \times 12'' - 4'' = 116'' \]

\[ n = \frac{29,000}{1,350} = 21.5 \]
try #6 in end cells

from spreadsheet $f_m = -57$ psi, $f_s = 556$ psi, ok

$$F_v = \frac{V}{bd} = \frac{11,000 \text{ lb}}{(2.5'')(112'')} = 3.4 \text{ psi}$$

$$\frac{M}{Vd} = \frac{Vh}{Vd} = \frac{h}{d} = \frac{16' \times 2''}{112''} = 1.66 > 1$$

$$F_v = \min \left[ \sqrt{f_m, 35 \text{ psi}} \right] = \min \left[ \sqrt{1500 \text{ psi, 35 psi}} \right]$$

$$F_v = \min \left[ 39 \text{ psi, 35 psi} \right] = 35 \text{ psi}$$

$$F_v = 4 \text{ psi} < 35 \text{ psi} = F_v, \text{ ok}$$

b) $V = 11,000 \text{ lb}$

$$M = 11,000 \text{ lb} \times 16' = 176,000 \text{ lb} \cdot \text{ft}$$

from spreadsheet, need #7 in end 2 cells

$$d = 16' \times 12'' / 8'' = 112''$$

$$A_5 = 2 \times 60 \text{ in}^2 = 120 \text{ in}^2$$

$$f_m = -463 \text{ psi}, \ f_s = 16,000 \text{ psi}, \text{ ok}$$

$$F_v = \frac{V}{bd} = \frac{11,000 \text{ lb}}{(2.5'')(112'')} = 39.3 \text{ psi}$$

$$\frac{M}{Vd} = \frac{h}{d} = \frac{16' \times 2''}{112''} = 1.71$$

$$F_v = 39 \text{ psi} > 35 \text{ psi} = F_v \text{ for no shear restraint.}$$

$$\text{需 shear restraint.}$$
\[
F_v \text{ w/ shear reinf} = \min \left[ 1.5 \sqrt{f_{m}}, 7.5 \text{ psi} \right]
\]
\[
F_v = \min \left[ 1.5 \sqrt{1500 \text{ psi}}, 7.5 \text{ psi} \right]
\]
\[
F_v = \min \left[ 58 \text{ psi}, 7.5 \text{ psi} \right] = 58 \text{ psi}
\]
\[
F_v = 39 \text{ psi} < 58 \text{ psi} = F_v \text{ w/ shear reinf, OK}
\]

**Shear Reinf:**

Use grade 60 rebar, \( F_s = 29,000 \text{ psi} \)

\[
A_v = \frac{V_s}{F_s \cdot d}
\]

\[
5 \text{-to-provide } A_v = \frac{A_v F_s d}{V_s} \cdot 
\]

\[
5 \text{-for } A_v = \frac{0.20 \text{ in}^2 \cdot (24,000 \text{ psi}) \cdot (112\text{")}}{11,000 \text{ in}}
\]

\[
5 \text{-for } A_v = 48.9 \text{ in}
\]

\[
\max s = \min \left[ \frac{d}{2}, 48\text{"} \right], \text{ ACI 2.3.5.3.1}
\]

\[
\max s = \min \left[ \frac{112\text{"}}{2}, 48\text{"} \right] = \min \left[ 56\text{"}, 48\text{"} \right] = 48\text{"}
\]

Use *4* bars @ 4' o.c. vertically

\[
\text{end of wall panel}
\]

\[
\text{+4 @ 48" o.c.}
\]

\[
\text{+4 in 2 end cells}
\]