**Anchor Bolts**

**Placement of bolts (6.2.1)**

Anchor bolts grouted in place

- 1/4 in. bolts permitted to be placed in 1/2 in. mortar bed joints
- Coarse grout: at least 0.5 in. grout between bolt and masonry
- Fine grout: at least 0.25 in. grout between bolt and masonry
- Clear distance between anchor bolts: not less than nominal diameter or 1 in.

**Anchor Bolts: Projected Tension Area (6.2.2)**

Projected area reduced by that falling in an open cell, core, or outside the wall.

When projected areas overlap, projected area reduced so no portion of the masonry included more than once.

**Anchor Bolts: Groups**

When the projected areas of two or more anchors overlap, the anchors with overlapping projected areas should be treated as an anchor group. The projected areas of the anchors in the group are summed, this area is adjusted for overlapping areas, and the capacity of the anchor group is calculated using the adjusted area in place of $A_{pt}$.

**Anchor Bolts: Groups**

\[ A_{pt} = \pi t_b^2 \]
**Anchor Bolts: Projected Shear Area (6.2.3)**

\[ A_{pv} = \frac{\pi l_{be}^2}{2} \]

- \( l_{be} \) = anchor bolt edge distance; measured in the direction of load from the edge of masonry to center of the cross section of anchor bolt. (6.2.7)

**Anchor Bolts**

Effective embedment length, \( l_b \) (6.2.4, 6.2.5)
- Plate or headed anchor bolts: Length to bearing surface
- Bent bar anchor bolts: Length to bearing surface of bend minus \( d_b \)

Minimum embedment length (6.2.6)
- Minimum embedment: \( \max\{4d_b, 2\text{in.}\} \)

**Edge Distance, \( l_{be} \) (6.2.7)**
- Distance in direction of load from edge of masonry to center of cross section of anchor bolt

**Anchor Bolts: Testing**

8.1.3.2.1 Anchors shall be tested in accordance with ASTM E 488 under stresses and conditions representing intended use, except that a minimum of five tests shall be performed.

8.1.3.2.2 Allowable loads shall not exceed 20 percent of the average tested strength.

9.1.6.2.2 Anchor bolt nominal strengths used for design shall not exceed 65 percent of the average failure load from the tests.

5th-percentile value, assuming a coefficient of variation of 20%

**Anchor Bolts - Tension**

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Allowable Stress (8.1.3.3.1)</th>
<th>Strength (9.1.6.3.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry breakout</td>
<td>( B_{stab} = 1.25 A_{pb} \sqrt{f_m} )</td>
<td>( B_{stab} = 4 A_{pb} \sqrt{f_m} )  ( \phi = 0.5 )</td>
</tr>
<tr>
<td>Steel yielding</td>
<td>( B_{as} = 0.60 A_{pb} f_y )</td>
<td>( B_{as} = A_{pb} f_y )  ( \phi = 0.9 )</td>
</tr>
<tr>
<td>Anchor pullout (Only bent bar)</td>
<td>( B_{ap} = 0.6 f_m^* e_b d_b + \left[ 10 \pi l_b (e_b + d_b) d_b \right] )</td>
<td>( B_{ap} = 1.5 f_m^* e_b d_b + \left[ 300 \pi (e_b + d_b) d_b \right] )  ( \phi = 0.65 )</td>
</tr>
</tbody>
</table>
**Anchor Bolts – Bolt Area**

\[ A_b = \frac{\pi}{4} \left( d_b - \frac{0.9743}{n_t} \right)^2 \]

- \( A_b \) = effective tensile stress area
- \( d_b \) = nominal anchor diameter
- \( n_t \) = number of threads per inch

<table>
<thead>
<tr>
<th>Bolt</th>
<th>( A ) (in²)</th>
<th>( A_b ) (in²)</th>
<th>( A_b / A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 - 13</td>
<td>0.196</td>
<td>0.142</td>
<td>0.723</td>
</tr>
<tr>
<td>5/8 - 11</td>
<td>0.307</td>
<td>0.226</td>
<td>0.737</td>
</tr>
<tr>
<td>3/4 - 10</td>
<td>0.442</td>
<td>0.334</td>
<td>0.757</td>
</tr>
<tr>
<td>7/8 - 9</td>
<td>0.601</td>
<td>0.462</td>
<td>0.768</td>
</tr>
<tr>
<td>1 - 8</td>
<td>0.785</td>
<td>0.606</td>
<td>0.771</td>
</tr>
</tbody>
</table>

Suitable approximation: \( A_b = 0.75 \) (nominal area)

---

**Anchor Bolts: Tension Example**

Given: 1/2 in. headed bolt (\( f_y = 36 \text{kpsi} \)) embedded in side of 8 in. CMU wall, Type S mortar.

Required: Embedment depth to develop tensile capacity of anchor bolt.

Solution:

\[ B_{au} = A_b f_y = 0.142 \text{ in}^2 (36 \text{kpsi}) = 5.11 \text{kips} \]

\[ \phi B_{au} = 0.9 (7.2 \text{kips}) = 4.60 \text{kips} \]

\[ B_{au} = (\phi B_{au}) / \phi_p = 4.60 \text{kips} / 0.5 = 9.20 \text{kips} \]

\[ B_{au} = 4 A_{pt} \sqrt{f_m'} \Rightarrow 9200 \text{lb} = 4 A_{pt} \sqrt{1500 \text{psi}} \Rightarrow A_{pt} = 59.4 \text{in}^2 \]

\[ A_{pt} = \frac{\pi l^2_b}{4} \Rightarrow 59.4 \text{in}^2 = \frac{\pi l^2_b}{4} \Rightarrow l_b = 4.35 \text{in} \]

Cone falls outside edge of masonry

---

**Anchor Bolts: Tension Example**

Required: Determine required embedment for J- or L-bolt with \( e_b = 2.0 \text{in.} \)

Solution:

\[ B_{uap} = (\phi B_{au}) / \phi_p = 5.11 \text{kips} / 0.65 = 7.86 \text{kips} \]

\[ B_{uap} = 1.5 f_m' e_b d_b + [300 \pi (l_b + e_b + d_b) l_b] \]

\[ 7.86k = 1.5 (1.5 \text{kpsi}) (2.0 \text{in})(0.50 \text{in}) + [0.3 \pi (l_b + 2.0 \text{in} + 0.50 \text{in}) 0.50 \text{in}] \]

\[ 7.86k = 2.25k + 0.471 (l_b + 2.5 \text{in}) \]

\[ l_b = 9.41 \text{in} \]

Forget using L- or J- bolts in tension
### Anchor Bolts - Shear

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Allowable Stress (8.1.3.3.2)</th>
<th>Strength (9.1.6.3.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry breakout</td>
<td>$B_{vb} = 1.25A_{pv} \sqrt{f_{m}'}$</td>
<td>$B_{vnb} = 4A_{pv} \sqrt{f_{m}'}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\phi = 0.5$</td>
</tr>
<tr>
<td>Masonry crushing</td>
<td>$B_{vc} = 350\sqrt{f_{m}'}A_{b}$</td>
<td>$B_{vc} = 1050\sqrt{f_{m}'}A_{b}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\phi = 0.5$</td>
</tr>
<tr>
<td>Anchor bolt pryout</td>
<td>$B_{spry} = 2.0B_{ab} = 2.5A_{pv} \sqrt{f_{m}'}$</td>
<td>$B_{supry} = 2.0B_{amb} = 8A_{pv} \sqrt{f_{m}'}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\phi = 0.5$</td>
</tr>
<tr>
<td>Steel yielding</td>
<td>$B_{va} = 0.36A_{b}f_{y}$</td>
<td>$B_{vsa} = 0.6A_{b}f_{y}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\phi = 0.9$</td>
</tr>
</tbody>
</table>

### Anchor Bolts - Combined Shear and Tension

Allowable Stress: (8.1.3.3.3)

$$\frac{b_{u} + b_{v}}{B_{u} + B_{v}} \leq 1$$

Strength: (9.1.6.3.3)

$$\frac{b_{sf} + b_{vf}}{\phi B_{us} + \phi B_{uns}} \leq 1$$

### Anchor Bolts: Shear Example

Given: 1/2 in. bolt ($f_{y} = 36$ksi) embedded 6 inch in top center of 8 in. CMU wall; threads excluded from shear plane; Type S mortar.

Required: Shear strength of anchor bolt for out-of-plane loads.

Solution:

Masonry breakout: $l_{be} = 3.81$ in. $A_{pv} = \frac{\pi l_{o}^2}{2} = \frac{\pi (3.81in)^2}{2} = 22.8in^2$

$$B_{vb} = 4A_{pv} \sqrt{f_{m}'} = \phi B_{vb} = 0.5(3.53kips) = 1.77kips$$

Masonry crushing:

$$B_{vc} = 1050\sqrt{f_{m}'}A_{b} = \phi B_{vc} = 0.5(4.37kips) = 2.18kips$$

Solution, cont:

Anchor bolt pryout: $B_{supry} = 2.0B_{amb} = 8A_{pv} \sqrt{f_{m}'} = \phi B_{supry} = 0.5(35.0kips) = 17.5kips$

Steel yielding: $B_{vsa} = 0.6A_{b}f_{y} = \phi B_{vsa} = 0.9(7.2kips) = 6.48kips$

Design Shear Load = 1.77 kips

What is the design shear load for an in-plane shear load?
Seismic Requirements

Seismic Design Category A (7.4.1)
Empirical design is acceptable

Seismic Design Category B (7.4.2)
Empirical design not allowed for lateral force resisting system

Seismic Design Category C (7.4.3)
Non-participating elements (partitions, screen walls, etc.)
- Isolated from the structure
- Reinforced either in the horizontal or vertical direction
  - Horizontal: 2-W1.7 wires every 16 in. or #4 at 48 in.
  - Vertical: #4 at 120 in.; bar within 16 in. of end of wall
- Shear walls reinforced (ordinary, intermediate, or special)

Seismic Design Category D (7.4.4)
Non-participating elements (partitions, screen walls, etc.):
- Isolated from the structure
- Reinforced either in the horizontal or vertical direction; spacing of vertical reinforcing in non-participating elements reduced to 48 in.
- Only special reinforced shear walls allowed
- Mortar
  - Fully grouted walls: Type S or M mortar; any kind
  - Partially grouted walls: Type S or M cement-lime or mortar cement

Seismic Design Category E an F (7.4.5)
Additional requirements for stack bond masonry

Seismic Observations

Parapets: Quite vulnerable to earthquakes. One of earliest and most successful retrofit programs was to brace parapets.

Anchorage of walls to diaphragms:
Primary cause of failure of older masonry construction is inadequate anchorage of masonry walls to roof and floors. Successful retrofit has been to attach the walls at the diaphragm.

Pictures from Nisqually earthquake, 2001
Seismic Observations

Chimneys:
- Quite vulnerable in earthquakes. Fail by overturning or breaking at roof line.
- Successful reinforcing has been:
  - 4-#4 vertical bars in chimneys up to 40 in. wide; add 2-#4 for additional 40 in. or additional flue
  - 1/4 in. ties at 18 in.; two ties at each bend in vertical steel
  - 2 anchorage straps at each floor or roof level

Infills

Isolated Infills
- Anchor against out-of-plane movements but unrestrained against in-plane movements.
- Need sufficient gap to accommodate frame movement. Seismic drifts:
  - 2.5% story height (3in. for 10 ft. story), Use Group I, structures designed to accommodate drift.
  - 2.0% story height (2.4in. for 10 ft. story), Use Group I, all other structures.
  - 1.0% story height (1.2in. for 10 ft. story), Use Group III, all other structures.

Non-isolated infills
- Tight infill will function structurally.
- Can be primary load resisting system for older buildings.
- Buildings in downtown LA had shaking on order of 0.15-0.20g during Northridge earthquake. Older buildings with unreinforced infills experienced some damage, but remained open and usable after the earthquake.

Problems with Non-isolated infills
- Infills on upper floors, with open lower floor
- Non-symmetrical infills which create torsion in building
- Partial height infills which lead to premature shear failures in columns

Out-of-Plane Loading
- Typical erroneous assumption is unreinforced masonry infills are vulnerable to out-of-plane failure due to
  - Inadequate anchorage
  - Cracking of masonry
- Resistance mechanism is arching; thus, significant strength after cracking.
- No anchors are needed; anchors can reduce capacity by causing localized damage and compromising the integrity of the boundary.
- Infills with height/thickness < 25 should have adequate out-of-plane strength.

SERF Infill Details

ELEVATION

Anchors (typ)

Reinforcing (typ)
SERF Infill Details

SECTION B-B

Dovetail Anchor

Concrete

Column CMU Wall

Embedded Plate

Concrete Beam

Angle welded to plate and anchored to bond beam

Bond Beam

SECTION A-A

Embedded Plate

Concrete Beam

Angle welded to plate and anchored to bond beam

Bond Beam

SECTION B-B

Concrete Column

CMU Wall

Dovetail Anchor