Anchor Bolts

Placement of bolts (1.16.1)
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.

Structural Details 1

Anchor Bolts: Projected Tension Area (1.16.2)

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.

Structural Details 2

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 $A_{pt}$.

Structural Details 3

Anchor Bolts: Groups

Approximate as a parabola

$A_{pt} = \pi t_b^2$

$x = \sqrt{(l_b)^2 - \left(\frac{t}{2}\right)^2} = \frac{1}{2} \sqrt{4(l_b)^2 - t^2}$

$Y = l_b - X$

$A_{pw} = (2X + Z)Y + l_b \left(\frac{\pi \theta}{180} - \sin \theta\right)$

$\theta = 2 \arcsin \left(\frac{t/2}{l_b}\right)$ degrees

Structural Details 4
Anchor Bolts: Projected Shear Area (1.16.3)

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

\( l_{be} \) = anchor bolt edge distance; measured in the direction of load from the edge of masonry to center of the cross section of anchor bolt. (1.16.7)

Anchor Bolts

Effective embedment length, \( l_b \) (1.16.4, 1.16.5)
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 (1.16.6)
Minimum embedment: \( \max\{4d_b, \text{2in.}\} \)

Edge Distance, \( l_{be} \) (1.16.7)
Distance in direction of load from edge of masonry to center of cross section of anchor bolt

Anchor Bolts: Testing

2.1.4.2.1 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.

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

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

Anchor Bolts - Tension

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Allowable Stress ( (2.1.4.3.1) )</th>
<th>Strength ( (3.1.6.3.1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry breakout</td>
<td>( B_{sbr} = 1.25 A_p \sqrt{\tau} )</td>
<td>( B_{sbr} = 4 A_p \sqrt{\tau} ) ( \phi = 0.5 )</td>
</tr>
<tr>
<td>Steel yielding</td>
<td>( B_{as} = 0.60 A_p f_y )</td>
<td>( B_{as} = A_p f_y ) ( \phi = 0.9 )</td>
</tr>
<tr>
<td>Anchor pullout (Only bent bar)</td>
<td>( B_{ap} = 0.6 f_m' \phi d_b + \left[ 120 \pi (l_b + c_b + d_b) d_b \right] )</td>
<td>( B_{ap} = 1.5 f_m' \phi d_b + \left[ 300 \pi (l_b + c_b + d_b) d_b \right] ) ( \phi = 0.65 )</td>
</tr>
</tbody>
</table>
Anchor Bolts: Tension Example

Given: 1/2 in. headed bolt ($f_y=36$ksi) embedded in side of 8 in. CMU wall; Type S mortar; assume that there are no edge effects.

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

Solution: $A_b=0.20\text{in}^2$

\[
B_{au} = A_b f_y = 0.20 \times 36 \text{ksi} = 7.2 \text{kips}
\]

\[
B_{au} = 0.9(7.2 \text{kips}) = 6.48 \text{kips}
\]

\[
B_{aub} = (\phi_y B_{au})/\phi_b = 6.48 \text{kips}/0.5 = 12.96 \text{kips}
\]

\[
B_{aub} = 4A_p \sqrt{f_m} \Rightarrow 12960lb = 4A_p \sqrt{1500 \text{psi}} \Rightarrow 
\]

\[
A_p = 83.6\text{in}^2 = \pi l_b^2 \Rightarrow l_b = 5.16\text{in}
\]

Use 5 1/4 in. of embedment to develop strength of bolt.

Anchor Bolts - Shear

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Allowable Stress (2.1.4.3.2)</th>
<th>Strength (3.1.6.3.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry breakout</td>
<td>$B_{vb} = 1.25 A_p \sqrt{f_m}$</td>
<td>$B_{vb} = 4A_p \sqrt{f_m}$</td>
</tr>
<tr>
<td></td>
<td>$\phi = 0.5$</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>$\phi = 0.5$</td>
<td>$\phi = 0.5$</td>
</tr>
<tr>
<td>Anchor bolt pryout</td>
<td>$B_{vpry} = 2.0B_{vb} = 2.5A_p \sqrt{f_m}$</td>
<td>$B_{vpry} = 2.0B_{aub} = 8A_p \sqrt{f_m}$</td>
</tr>
<tr>
<td></td>
<td>$\phi = 0.5$</td>
<td>$\phi = 0.5$</td>
</tr>
<tr>
<td>Steel yielding</td>
<td>$B_{vs} = 0.36A_b f_y$</td>
<td>$B_{vs} = 0.6A_b f_y$</td>
</tr>
<tr>
<td></td>
<td>$\phi = 0.9$</td>
<td>$\phi = 0.9$</td>
</tr>
</tbody>
</table>

Anchor Bolts - Combined Shear and Tension

<table>
<thead>
<tr>
<th>Allowable Stress: (2.1.4.3.3)</th>
<th>Strength: (3.1.6.3.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_u/b_a + b_s/b_r \leq 1$</td>
<td>$b_u/\phi B_{au} + b_s/\phi B_{au} \leq 1$</td>
</tr>
</tbody>
</table>
Anchor Bolts: Shear Example

Given: 1/2 in. bolt ($f_y=36ksi$) 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.  
\[ A_{pb} = \frac{\pi l_{be}^2}{2} = \frac{\pi (3.81\text{in.})^2}{2} = 22.8\text{in}^2 \]
\[ B_{vb} = 4A_{pb}\sqrt{f_{m}} = \phi B_{vb} = 0.5(3.53\text{kips}) = 1.77\text{kips} \]

Masonry crushing:
\[ B_{vc} = 1050\frac{f_m}{f_b}A_{pb} = \phi B_{vc} = 0.5(4.37\text{kips}) = 2.18\text{kips} \]

Solution, cont:

Anchor bolt pryout: $l_p = 6.0$ in.  
\[ A_{pt} = \pi l_p^2 = \pi (6\text{in.})^2 = 113.1\text{in}^2 \]
\[ B_{pv} = 2.0A_{pt}\sqrt{f_{m}} = \phi B_{pv} = 0.5(35.0\text{kips}) = 17.5\text{kips} \]

Steel yielding: 
\[ B_{sv} = 0.6A_{pb}f_y = \phi B_{sv} = 0.9(7.2\text{kips}) = 6.48\text{kips} \]

What is the allowable in-plane shear load?

Seismic Requirements

Seismic Design Category A (1.17.4.1)
Empirical design is acceptable

Seismic Design Category B (1.17.4.2)
Empirical design not allowed for lateral force resisting system

Seismic Design Category C (1.17.4.3)
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 C (1.17.4.3.2.4) Lateral stiffness — At each story level, at least 80 percent of the lateral stiffness shall be provided by lateral-force-resisting walls. Along each line of lateral resistance at a particular story level, at least 80 percent of the lateral stiffness shall be provided by lateral-force-resisting walls.

1.17.4.3.2.5 Design of columns, pilasters, and beams supporting discontinuous elements — Columns and pilasters that are part of the seismic force-resisting system and that support reactions from discontinuous stiff elements shall be provided with transverse reinforcement spaced at no more than one-fourth of the least nominal dimension of the column or pilaster. The minimum transverse reinforcement ratio shall be 0.0015. Beams supporting reactions from discontinuous walls shall be provided with transverse reinforcement spaced at no more than one-half of the nominal depth of the beam. The minimum transverse reinforcement ratio shall be 0.0015.
**Seismic Requirements**

**Seismic Design Category D (1.17.4.4)**
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
No Type N mortar or masonry cement mortar

**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.

**Seismic Design Category E and F (1.17.4.5)**
Additional requirements for stack bond masonry

**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

- **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

**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.
Infills

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

Embedded Plate

Angle welded to plate and anchored to bond beam

Concrete Beam

CMU Wall

Concrete Column

Bond Beam

Dovetail Anchor

SECTION A-A

Anchors (typ)

Reinforcing (typ)

SECTION B-B

ELEVATION