ANCHOR BOLT DESIGN  Combined Tension and Shear

Result Summary

Anchor Rod Embedment, Spacing and Edge Distance

Min Required Anchor Reinft. Development Length ratio = 0.87 OK

Overall ratio = 0.75 OK

Seismic Design

Tension = OK

Shear = OK

Design Code Reference

Anchor bolt design based on

ACI 318-11 Building Code Requirements for Structural Concrete and Commentary Appendix D

PIP STE05121 Anchor Bolt Design Guide-2006

AISC Design Guide 1: Base Plate and Anchor Rod Design 2nd Ed

Anchor Bolt Data

Factored tensile force

Nu = 20.00 [kips]

Factored shear force

Vu = 25.00 [kips]

Concrete strength

f'c = 5.2 [ksi]

Anchor bolt material

F1554 Grade 3

Anchor bolt tensile strength

futa = 58.0 [ksi]

Anchor is ductile steel element D.1

Anchor bolt diameter

da = 1 [in]

Anchor bolt has sleeve

No

Anchor bolt embedment depth

hfe = 14.00 [in]

12.00 OK

Page A -1 Table 1

Pedestal height

ha = 18.00 [in]

17.00 OK

Pedestal width

bc = 16.00 [in]

Pedestal depth

dc = 16.00 [in]
Anchor bolt edge distance \( c_1 \) = 5.00 [in] 4.50 OK
Anchor bolt edge distance \( c_2 \) = 5.00 [in] 4.50 OK
Anchor bolt edge distance \( c_3 \) = 5.00 [in] 4.50 OK
Anchor bolt edge distance \( c_4 \) = 5.00 [in] 4.50 OK

Outermost bolt line spacing \( s_1 \) = 6.00 [in] 4.00 OK
Outermost bolt line spacing \( s_2 \) = 6.00 [in] 4.00 OK

To be considered effective for resisting anchor tension, vertical reinforcing bars shall be located within \( 0.5h_{ef} \) from the outmost anchor’s centerline.

Avg ver. bar center to anchor rod center distance \( d_{ar} \) = 4.00 [in]
No of ver. rebar that are effective for resisting anchor tension \( n_v \) = 4.0
Ver. rebar size No. 8 [\( \geq 1.000 \) [in] dia single rebar area \( A_s \) = 0.790 [in\(^2\)]
Ver. rebar top anchorage option 180 Degree Hook or Hairpin

To be considered effective for resisting anchor shear, hor. reinft shall be located within \( \min(0.5c_1, 0.3c_2) \) from the outmost anchor’s centerline.

\( \min(0.5c_1, 0.3c_2) \) = 1.50 [in]
No of tie leg that are effective to resist anchor shear \( n_{leg} \) = 2.0
No of tie layer that are effective to resist anchor shear \( n_{lay} \) = 2
Hor. tie rebar size No. 4 [\( \geq 0.500 \) [in] dia single rebar area \( A_t \) = 0.200 [in\(^2\)]
For anchor reinf shear breakout strength calc 100% hor. tie bars develop full yield strength

Rebar yield strength - ver. rebar \( f_{y-v} \) = 60.0 [ksi]
Rebar yield strength - hor. rebar \( f_{y-h} \) = 60.0 [ksi]
No of anchor bolt carrying tension \( n_t \) = 4.0
No of anchor bolt carrying shear \( n_s = 4.0 \)

For side-face blowout check use

No of anchor bolt along width edge \( n_{bw} = 2.0 \)
No of anchor bolt along depth edge \( n_{bd} = 2.0 \)

Anchor bolt head type [Heavy Hex]

Anchor effective cross section area \( A_{se} = 0.606 \) [in\(^2\)]

Anchor bolt head bearing area \( A_{brg} = 1.501 \) [in\(^2\)]

Anchor bolt 1/8" (3mm) corrosion allowance = No
Provide built-up grout pad? = Yes

Seismic design category SDC >= C = Yes
Anchor bolt load E <= 0.2U
Tensile = No
Shear = No

Anchor bolt satisfies option
Tensile = Option 4
Shear = Option 3

Strength reduction factors
Anchor reinforcement \( \phi_s = 0.75 \)
Anchor rod - ductile steel \( \phi_{r,s} = 0.75, \phi_{v,s} = 0.65 \)
Concrete - condition A \( \phi_{t,c} = 0.75, \phi_{v,c} = 0.75 \)

**CONCLUSION**

Anchor Rod Embedment, Spacing and Edge Distance

Min Required Anchor Reinf. Development Length ratio = 0.87

Overall ratio = 0.75

Tension

Anchor Rod Tensile Resistance ratio = 0.19
Anchor Reinf Tensile Breakout Resistance  ratio=0.18  OK
Anchor Pullout Resistance  ratio=0.15  OK
Side Blowout Resistance  ratio=0.21  OK

Shear
Anchor Rod Shear Resistance  ratio=0.57  OK
Anchor Reinf Shear Breakout Resistance
  Strut Bearing Strength  ratio=0.45  OK
  Tie Reinforcement  ratio=0.69  OK
Conc. Pryout Not Govern When h_{ef} >= 12d_a  OK

Seismic Design
Tension  Applicable  OK  D.3.3.4
Seismic SDC>=C and E>0.2U , Option 4 is selected to satisfy additional seismic requirements as per D.3.3.4.3

Assumptions
1. Concrete is cracked  D.5.2.6, D5.3.6, D.6.2.7
2. Condition A - supplementary reinforcement is provided  D.4.3 (c)
3. Load combinations shall be per ACI 318-11 9.2  D.4.3
4. Anchor reinft strength is used to replace concrete tension / shear breakout strength as per ACI 318-11 Appendix D clause D.5.2.9 and D.6.2.9
5. For tie reinft, only the top most 2 or 3 layers of ties (2" from TOC and 2x3" after) are effective
6. Strut-and-Tie model is used to anlyze the shear transfer and to design the required tie reinft
7. Anchor reinft used in structures with SDC>=C shall meet requirements specified in D.3.3.7
8. Anchor bolt washer shall be tack welded to base plate for all anchor bolts to transfer shear  AISC Design Guide 1 Section 3.5.3

CACULATION
Anchor Rod Tensile Resistance  ACI 318-11
\[ \phi t_s N_{sa} = \phi t_s n_t A_{se} f_{uta} \geq 105.44 \text{ [kips]} \]
\[ \text{ratio} = 0.19 \]

Anchor Reinf Tensile Breakout Resistance  ACI 318-11
Min required full yield tension $l_{dh} = 180$ degree hook case

Actual development length

$$l_a = h_{ef} - c \times (2 \text{ in}) - d_{br} \times \tan 35$$

$$= 9.2 \text{ [in]}$$

> 8.00 OK 12.5.1

Anchor reinf breakout resistance

$$\phi_s N_n = \phi_s \times f_{y-v} \times n_x \times A_x \times (l_a / l_d, \text{if } l_a < l_d) = 112.30 \text{ [kips]}$$

Ratio = 0.18

$> N_u$ OK

Anchor Pullout Resistance

Single bolt pullout resistance

$$N_P = 8 A_{brg} f_{c'} = 62.44 \text{ [kips]}$$

$$\phi_{t,c} N_{p} = \phi_{t,c} n_t \Psi_{c,p} N_P = 174.84 \text{ [kips]}$$

$\Psi_{c,p} = 1$ for cracked conc

$\phi_{t,c} = 0.70$ pullout strength is always Condition B

Seismic design strength reduction

$$= x 0.75 \text{ applicable}$$

$$> N_u$$ OK

Side Blowout Resistance

Failure Along Pedestal Width Edge

Tensile load carried by anchors close to edge which may cause side-face blowout along pedestal width edge

$$N_{bijv} = N_u \times n_{bij} / n_t$$

$$= 10.00 \text{ [kips]}$$

$c = \min (c_1, c_3)$

$s = 5.00 \text{ [in]}$

$s = 6.00 \text{ [in]}$

Check if side blowout applicable

$$h_{ef} = 14.00 \text{ [in]}$$

$> 2.5c$ side blowout is applicable

Single anchor SB resistance

$$\phi_{t,c} N_{sb} = \phi_{t,c} \left( 160 \frac{c}{A_{brg}} \right) \sqrt{f_{c'}}$$

$$= 53.01 \text{ [kips]}$$

Multiple anchors side blowout work as group

$$\phi_{t,c} N_{sb} = (1 + s / 6c) \times \phi_{t,c} N_{sb}$$

$$= 63.61 \text{ [kips]}$$

Seismic design strength reduction

$$= x 0.75 \text{ applicable}$$

$$> N_{bijv}$$ OK
Failure Along Pedestal Depth Edge

Tensile load carried by anchors close to edge which may cause side-face blowout along pedestal depth edge

\[ N_{bud} = N_u \times n_{bd} / n_t \]
\[ c = \min (c_2, c_4) \]
\[ s = s_1 \]

Check if side blowout applicable

\[ h_{ef} = 14.00 \text{ [in]} \]
\[ > 2.5c \text{ side blowout is applicable} \]

Single anchor SB resistance

\[ \phi_{t,c} N_{sb} = \frac{160 c \sqrt{A_{bdg}}}{c \sqrt{f_c}} \]
\[ = 53.01 \text{ [kips]} \]

Multiple anchors side blowout

work as group

\[ \phi_{t,c} N_{sb,gd} = (1 + s / 6c) \times \phi_{t,c} N_{sb} \]
\[ = 63.61 \text{ [kips]} \]

Seismic design strength reduction

\[ = x 0.75 \text{ applicable} \]
\[ \text{ratio} = 0.21 \]
\[ > N_{bud} \text{ OK} \]

Group side blowout resistance

\[ \phi_{t,c} N_{sbg} = \phi_{t,c} \min \left( \frac{N_{deg,w}}{n_{bdg}}, \frac{N_{deg,d}}{n_t} \right) \]
\[ = 95.41 \text{ [kips]} \]

Govern Tensile Resistance

\[ N_r = \min (\phi N_{sa}, \phi N_n, \phi N_{pn}, \phi N_{sbg}) \]
\[ = 95.41 \text{ [kips]} \]

Anchor Rod Shear Resistance

\[ \phi_{v,s} V_{sa} = \phi_{v,s} n_b A_{se} f_{uta} \]
\[ = 54.83 \text{ [kips]} \]

Reduction due to built-up grout pad

\[ = x 0.8 \text{, applicable} \]
\[ \text{ratio} = 0.57 \]
\[ > V_u \text{ OK} \]

Anchor Reinf Shear Breakout Resistance

Strut-and-Tie model is used to analyze the shear transfer and to design the required tie reinf

STM strength reduction factor

\[ \phi_{st} = 0.75 \]
Strut-and-Tie model geometry

\[ d_v = 2.250 \text{ [in]} \]
\[ d_h = 2.250 \text{ [in]} \]
\[ \theta = 45 \]
\[ d_t = 3.182 \text{ [in]} \]

Strut compression force

\[ C_s = 0.5 \frac{V_u}{\sin \theta} \]
\[ = 17.68 \text{ [kips]} \]

**Strut Bearing Strength**

Strut compressive strength

\[ f_{ce} = 0.85 f'_c \]
\[ = 4.4 \text{ ksi} \] (A-3)

* Bearing of anchor bolt

Anchor bearing length

\[ l_e = \min(8d_a, h_{ef}) \]
\[ = 8.00 \text{ [in]} \] (D.6.2.2)

Anchor bearing area

\[ A_{brg} = l_e \times d_a \]
\[ = 8.00 \text{ [in}^2] \]

Anchor bearing resistance

\[ C_r = n_s \times \phi_{st} \times f_{ce} \times A_{brg} \]
\[ = 106.08 \text{ [kips]} \]

\[ > V_u \text{ OK} \]

* Bearing of ver reinft bar

Ver bar bearing area

\[ A_{brg} = (l_e + 1.5 \times d_t - d_a/2 - d_b/2) \times d_b \]
\[ = 11.77 \text{ [in}^2] \]

Ver bar bearing resistance

\[ C_r = \phi_{st} \times f_{ce} \times A_{brg} \]
\[ = 39.03 \text{ [kips]} \]

\[ \text{ratio} = 0.45 \]

\[ > C_s \text{ OK} \]

**Tie Reinforcement**

* For tie reinft, only the top most 2 or 3 layers of ties (2" from TOC and 2x3" after) are effective

* For enclosed tie, at hook location the tie cannot develop full yield strength \( f_y \). Use the pullout resistance in tension of a single hooked bolt as per ACI 318-11 Eq. (D-15) as the max force can be developed at hook \( T_h \)

* Assume 100% of hor. tie bars can develop full yield strength

Total number of hor tie bar

\[ n = n_{leg} \times n_{lay} \]
\[ = 4 \] (ACI 318-11)
Pull out resistance at hook

\[ T_h = \phi_{t,c} 0.9 f'_c e_n d_a \]

\[ e_n = 4.5 \text{ d}_b \]

\[ = 3.95 \text{ kips} \quad \text{D.5.3.5 (D-15)} \]

\[ = 2.250 \text{ [in]} \]

Single tie bar tension resistance

\[ T_r = \phi_s f_{y-h} A_s \]

\[ = 9.00 \text{ [kips]} \]

Total tie bar tension resistance

\[ \phi_s V_n = 1.0 x n x T_r \]

\[ \text{ratio}=0.69 \quad > V_u \quad \text{OK} \]

\[ = 36.00 \text{ [kips]} \quad \text{D.3.3.5.4 & D.6.2.9} \]

**Conc. Pryout Shear Resistance**

The pryout failure is only critical for short and stiff anchors. It is reasonable to assume that for general cast-in place headed anchors with \( h_{ef} \geq 12d_a \), the pryout failure will not govern

\[ 12d_a = 12.00 \quad \text{[in]} \]

\[ h_{ef} = 14.00 \quad \text{[in]} \]

\[ > 12d_a \quad \text{OK} \]

**Govern Shear Resistance**

\[ V_r = \min ( \phi_{v,s} V_{sa}, \phi_s V_n ) \]

\[ = 36.00 \quad \text{[kips]} \]

**Tension Shear Interaction**

ACI 318-11

Check if \( N_u > 0.2 \phi N_n \) and \( V_u > 0.2 \phi V_n \)

\[ = \text{Yes} \quad \text{D.7.1 & D.7.2} \]

\[ N_u / \phi N_n + V_u / \phi V_n \]

\[ = 0.90 \quad \text{D.7.3 (D-42)} \]

\[ \text{ratio}=0.75 \quad < 1.2 \quad \text{OK} \]

**Seismic Design**

**Tension**

Applicable \quad \text{OK}

Option 4 is selected.

ACI 318-11

User has to ensure that the tensile load \( N_u \) user input above includes the seismic load \( E \), with \( E \) increased by multiplying overstrength factor \( \Omega_o \)

Seismic SDC\( = C \) and \( E > 0.2U \), Option 4 is selected to satisfy additional seismic requirements as per D.3.3.4.3

**Shear**

Applicable \quad \text{OK}

Option 3 is selected.

ACI 318-11

User has to ensure that the shear load \( V_u \) user input above includes the seismic load \( E \), with \( E \) increased by multiplying overstrength factor \( \Omega_o \)

Seismic SDC\( = C \) and \( E > 0.2U \), Option 3 is selected to satisfy additional seismic requirements as per D.3.3.5.3