Verification example – Anchor bolts in tension and shear

Type of connection: Base plate subjected to pure tension

Unit system: Metric

Designed acc. to: CSA S14-16 and CSA A23.3-14

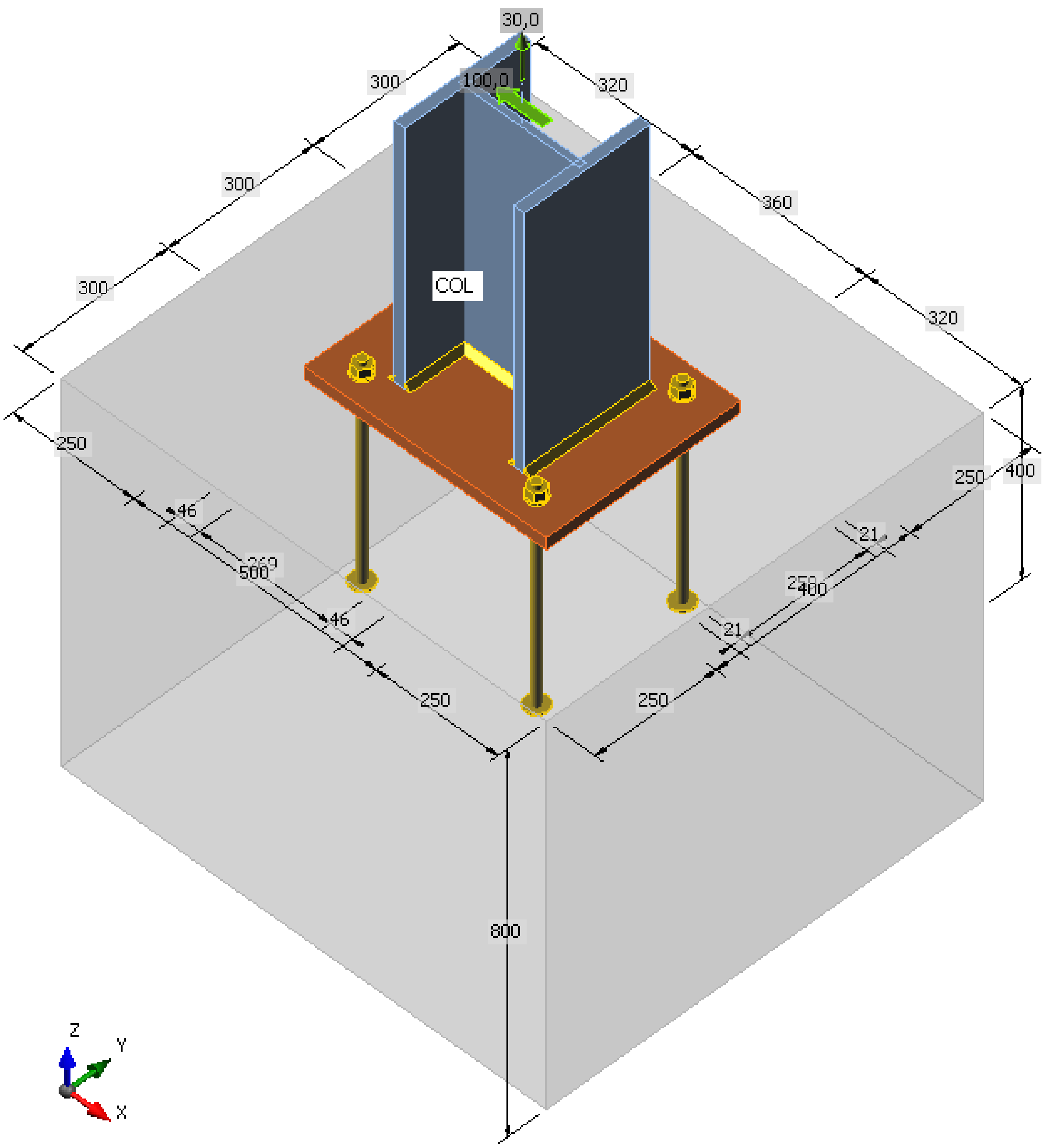
Investigated: Anchor bolts in tension

Plate Materials: 350W

Base plate thickness: 25.4 mm

Anchor bolts: 3/4, grade A325, standard holes with diameter 21 mm, circular heads with diameter 45 mm, embedment length 400 mm

Geometry:



Applied forces:

N = 30 kN

V = 100 kN

M = 0 kNm

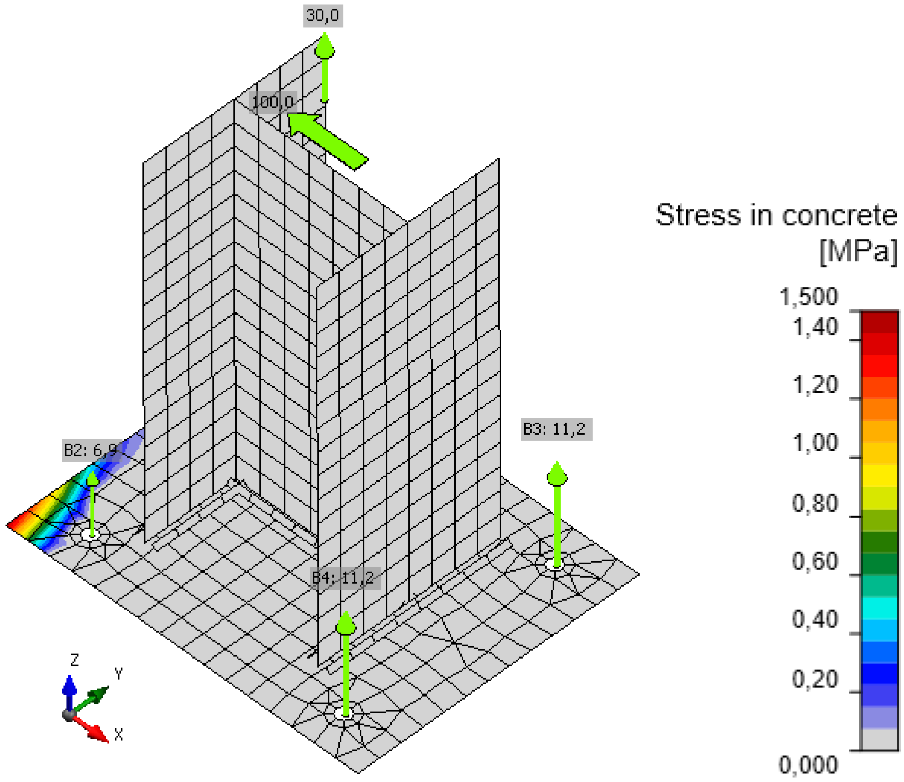
Procedure:

Anchor bolts in tension are designed according to Concrete Capacity Method in A23.3-14 Design of concrete structures – Annex D. The concrete pad is assumed as unreinforced and cracked. Shear force is assumed to be transferred via all anchor bolts for all failure modes and the concrete cone in shear is assumed as the closest to the concrete edge.

IDEA StatiCa uses a Winkler subsoil model for concrete foundation pad as simplification.

IDEA StatiCa Connection

According to Canadian customs, the base plate should not yield. The maximum von Mises stress reached on the base plate is 49.3 MPa. The combination of tensile and shear force causes a slight bending of the column base. The base plate is inclined and is in contact with the concrete which increases the tensile forces in anchors no. 3 and 4. The shear forces are affected by the normal force; the tensile force deforms the base plate and the shear vectors with magnitude 0.9 kN aim to the centre of the base plate.



Check of anchors for extreme load effect

Item	Loads	Nf [kN]	V [kN]	Nsar [kN]	Ncbr [kN]	Ncpr [kN]	Nsbr [kN]	Vsar [kN]	Vcpr [kN]	Vcbr [kN]	Utt [%]	Uts [%]	Utts [%]	Status
A1	LE1	6,9	24,5	119,9	49,7	140,4	220,2	67,5	99,3	26,4	14,0	92,7	91,9	✓
A2	LE1	6,9	24,5	119,9	49,7	140,4	220,2	67,5	99,3	26,4	14,0	92,7	91,8	✓
A3	LE1	11,2	25,6	119,9	49,7	140,4	220,2	67,5	99,3	0,0	22,6	37,9	28,2	✓
A4	LE1	11,2	25,6	119,9	49,7	140,4	220,2	67,5	99,3	0,0	22,6	37,9	28,2	✓

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Anchors in tension and shear

Material:

Material of concrete: $f'_c := 20.7\ \mathrm{MPa}$

Modification factor for lightweight concrete: $\lambda_a := 1$

Material of anchors: $f_{ya} := 634.3\ \mathrm{MPa}$
$f_{uta} := 825\ \mathrm{MPa}$

Resistance factor for concrete: $\phi_c := 0.65$

Resistance factor for steel: $\phi_s := 0.85$

Geometry:

Width of the concrete pad: $a_c := 1000\ \mathrm{mm}$

Depth of the concrete pad: $b_c := 900\ \mathrm{mm}$

Height of the concrete pad: $h_c := 800\ \mathrm{mm}$

Width of the base plate: $a_{bp} := 450\ \mathrm{mm}$

Depth of the base plate: $b_{bp} := 350\ \mathrm{mm}$

Thickness of the base plate: $t_{bp} := 25.4\ \mathrm{mm}$

Anchor spacing: $s_1 := 360\ \mathrm{mm}$
$s_2 := 300\ \mathrm{mm}$

Distance to concrete edge: $c_1 := \dfrac{(a_c - s_1)}{2} = 320\ \mathrm{mm}$
$c_2 := \dfrac{(b_c - s_2)}{2} = 300\ \mathrm{mm}$

Number of anchors: $n := 4$

Anchor diameter: $d_a := 19.05\ \mathrm{mm}$

Effective cross-sectional area of anchor in tension: $A_{seN} := 0.75 \cdot \pi \cdot \dfrac{d_a^{\ 2}}{4} = 214\ \mathrm{mm}^2$

Loading:

Normal tensile force: $N := 30\ \mathrm{kN}$

Shear force: $V := 100\ \mathrm{kN}$

Steel resistance of anchor in tension:

Resistance modification factor: $R := 0.8$

$N_{sar} := A_{seN} \cdot \phi_s \cdot f_{uta} \cdot R = 119.9 \text{ kN}$

Utilization: $\dfrac{\frac{N}{n}}{N_{sar}} = 6\%$

Concrete breakout resistance of anchor in tension:

Resistance modification factor: $R := 1$

Embedment depth of anchor in concrete pad: $h_{emb} := 500 \text{ mm}$

Effective embedment depth of anchor in concrete pad: $h_{ef} := min\left(h_{emb}, \max\left(\frac{c_1}{1.5}, \frac{c_2}{1.5}, \frac{s_1}{3}, \frac{s_2}{3}\right)\right) = 213 \text{ mm}$

Smallest distance from the anchor to the edge: $c_{amin} := min(c_1, c_2) = 300 \text{ mm}$

Modification factor for edge distance: $\psi_{edN} := min\left(0.7 + 0.3 \cdot \frac{c_{amin}}{1.5 \cdot h_{ef}}, 1\right) = 1$

Modification factor for concrete conditions: $\psi_{cN} := 1$

Factor: $k_c := 10$

Concrete breakout cone area of a single anchor not influenced by edges: $A_{Nco} := 9 \cdot h_{ef}^2 = 409600 \text{ mm}^2$

Concrete breakout cone area of a group of anchors: $A_{Nc} := a_c \cdot b_c = 900000 \text{ mm}^2$

Basic concrete breakout resistance: $N_{br} := k_c \cdot \phi_c \cdot \lambda_a \cdot \sqrt{f'_c} \cdot h_{ef}^{1.5} \cdot R \cdot \sqrt{1000} \cdot \frac{\text{kg}^{\frac{1}{2}}}{\text{s}} = 92.1 \text{ kN}$

$N_{cbr} := \frac{A_{Nc}}{A_{Nco}} \cdot \psi_{edN} \cdot \psi_{cN} \cdot \frac{N_{br}}{n} = 49.7 \text{ kN}$

Utilization: $\dfrac{\frac{N}{n}}{N_{cbr}} = 15\%$

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Concrete pullout resistance of headed anchor in tension:

Resistance modification factor: $R:=1$

Modification factor for concrete conditions: $\psi_{cP}:=1$

Anchor head diameter: $d_h:=45\ \mathrm{mm}$

Bearing area of the head: $A_{brg}:=\pi\cdot\frac{{d_h}^2-{d_a}^2}{4}=1305\ \mathrm{mm}^2$

Basic pullout resistance: $N_{pr}:=8\cdot A_{brg}\cdot\phi_c\cdot f'_c\cdot R=140.5\ \mathrm{kN}$

$N_{cpr}:=\psi_{cP}\cdot N_{pr}=140.5\ \mathrm{kN}$

Utilization: $\frac{\frac{N}{n}}{N_{cpr}}=5\%$

Concrete side-face blowout resistance:

Resistance modification factor: $R:=1$

Reduction due to concrete edge: $red_c:=\max\left(0.5,min\left(1,\frac{1+\frac{\max(c_1,c_2)}{min(c_1,c_2)}}{4}\right)\right)=0.517$

Reduction due to anchor spacing: $red_s:=min\left(1,\frac{\left(1+\frac{min(s_1,s_2)}{6\cdot min(c_1,c_2)}\right)}{2}\right)=0.583$

$N_{sbr}:=min(red_c,red_s)\cdot13.3\cdot min(c_1,c_2)\cdot\sqrt{A_{brg}}\cdot\phi_c\cdot\lambda_a\cdot\sqrt{f'_c}\cdot R\cdot\frac{1000\cdot\sqrt{\mathrm{kg}}}{\sqrt{\mathrm{m}}\cdot\mathrm{s}}=220.3\ \mathrm{kN}$

Utilization: $\frac{\frac{N}{n}}{N_{sbr}}=3\%$

Utilization: $Ut_t:=\max\left(\frac{\frac{N}{n}}{N_{sar}},\frac{\frac{N}{n}}{N_{cbr}},\frac{\frac{N}{n}}{N_{cpr}},\frac{\frac{N}{n}}{N_{sbr}}\right)=15\%$

Steel resistance of anchor in shear:

Effective cross-sectional area of an anchor in shear: $A_{seV}:=0.75\cdot\pi\cdot\frac{{d_a}^2}{4}=214\ \mathrm{mm}^2$

Resistance modification factor: $R:=0.75$

$V_{sar}:=A_{seV}\cdot\phi_s\cdot0.6\cdot f_{uta}\cdot R=67.5\ \mathrm{kN}$

Utilization: $\frac{\frac{V}{n}}{V_{sar}}=37\%$

Concrete breakout resistance of anchor in shear:

Distance to the edge: $c_{a1} := min\left(c_1, \max\left(\frac{c_2}{1.5}, \frac{h_c}{1.5}, \frac{s_2}{3}\right)\right) = 320\ \text{mm}$

Projected concrete failure area of one anchor when not limited by corner influences, spacing or member thickness: $A_{Vc0} := 4.5 \cdot {c_{a1}}^2 = 460800\ \text{mm}^2$

Projected concrete failure area of an anchor or group of anchors divided by number of anchors in this group: $A_{Vc} := \frac{b_c \cdot 1.5 \cdot c_{a1}}{2} = 216000\ \text{mm}^2$

Modification factor for edge effect: $\psi_{edV} := min\left(0.7 + 0.3 \cdot \frac{c_2}{1.5 \cdot c_{a1}}, 1\right) = 0.888$

Modification factor for concrete condition: $\psi_{cV} := 1$

Modification factor for anchor in thin member: $\psi_{hV} := \max\left(\sqrt{\frac{1.5 \cdot c_{a1}}{h_c}}, 1\right) = 1$

Load-bearing length of the anchor for shear: $l_e := min\left(8 \cdot d_a, h_{ef}\right) = 152.4\ \text{mm}$

Resistance modification factor: $R := 1$

Factored concrete breakout resistance in shear of a single anchor in cracked concrete:

$$V_{br1} := 0.58 \cdot \left(\frac{l_e}{d_a}\right)^{0.2} \cdot \sqrt{d_a} \cdot \phi_c \cdot \lambda_a \cdot \sqrt{f'_c} \cdot {c_{a1}}^{1.5} \cdot 1000\ \frac{\text{kg}^{\frac{1}{2}}}{\text{m}^{\frac{1}{2}} \cdot \text{s}} = 65\ \text{kN}$$

$$V_{br2} := 3.75 \cdot \lambda_a \cdot \phi_c \cdot \sqrt{f'_c} \cdot {c_{a1}}^{1.5} \cdot R \cdot \sqrt{1000} \cdot \frac{\text{kg}^{\frac{1}{2}}}{\text{s}} = 63.5\ \text{kN}$$

$$V_{br} := min\left(V_{br1}, V_{br2}\right) = 63.5\ \text{kN}$$

$$V_{cbr} := \frac{A_{Vc}}{A_{Vc0}} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV} \cdot V_{br} = 26.4\ \text{kN}$$

Utilization: $\frac{\frac{V}{n}}{V_{cbr}} = 95\%$

Concrete pryout resistance of anchor in shear:

Coefficient for pryout resistance: $k_{cp} := 2$

Cast-in anchors: $N_{cpr} := N_{cbr} = 49.7\ \text{kN}$

$V_{cpr} := k_{cp} \cdot N_{cpr} = 99.3\ \text{kN}$

Utilization: $\dfrac{\frac{V}{n}}{V_{cpr}} = 25\%$

Utilization: $Ut_s := \max\left(\dfrac{\frac{V}{n}}{V_{sar}}, \dfrac{\frac{V}{n}}{V_{cbr}}, \dfrac{\frac{V}{n}}{V_{cpr}}\right) = 95\%$

Interaction of tensile and shear forces:

Utilization: $Ut_{ts} := Ut_t^{\frac{5}{3}} + Ut_s^{\frac{5}{3}} = 96\%$

Comparison

The resistances of anchors in tension – steel resistance of the anchor, concrete breakout resistance, concrete pullout resistance, and side-face blowout resistance – and in shear – steel resistance of the anchor, concrete breakout resistance, and concrete pryout resistance – are completely the same as using the manual check according to A23.3-14 – Annex D. The difference is between the loading, the forces acting on anchors are slightly higher due to the prying forces which are not expected in the manual assessment. The difference in anchor utilization is therefore 3 %. The difference varies with the plate thickness and the normal force. Concrete capacity method assumes rigid base plate while CBFEM uses force distribution which is closer to reality.