Verification example – Anchor bolts in tension

Type of connection: Base plate subjected to pure tension

Unit system: Metric

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

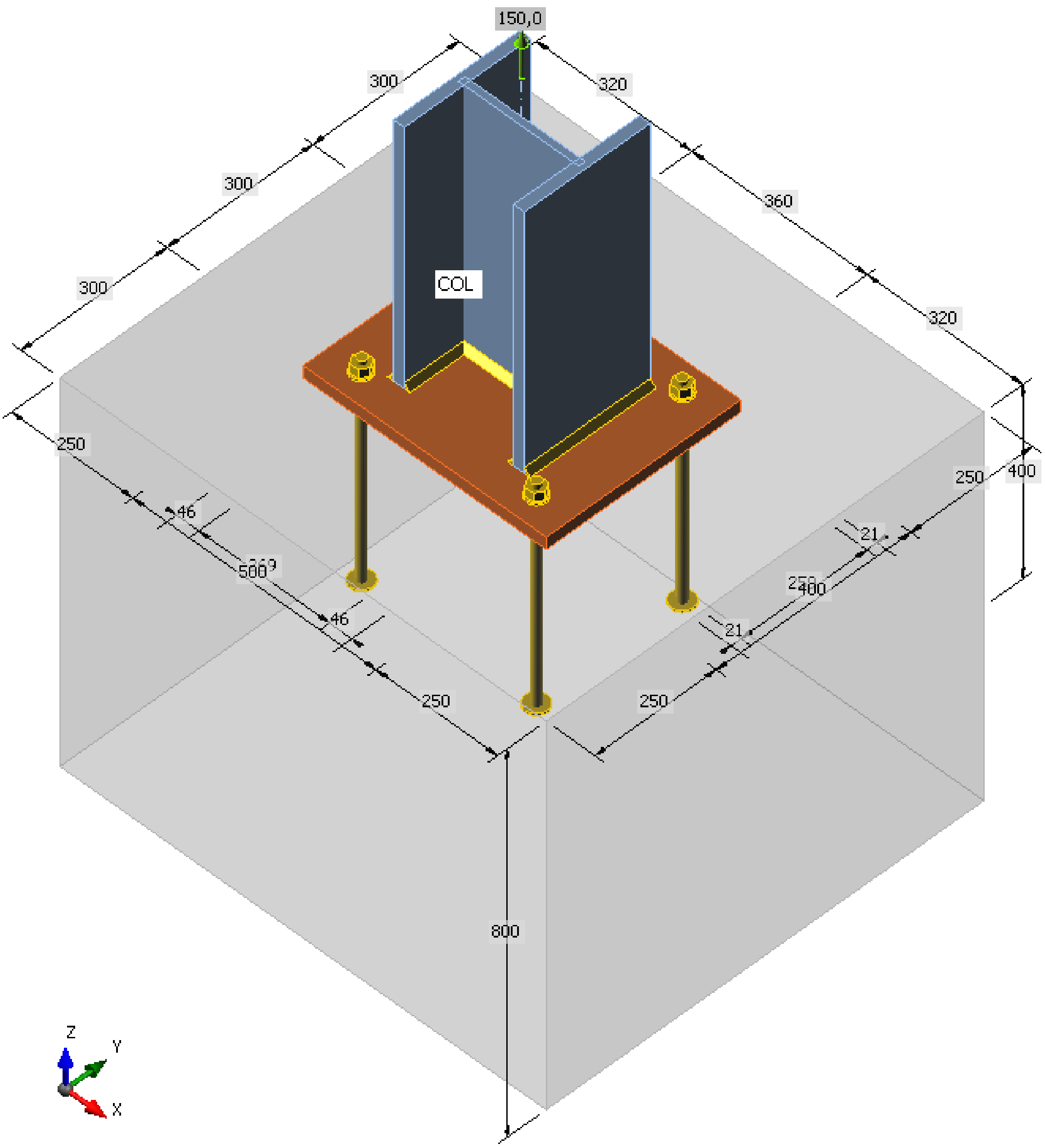
Investigated: Anchor bolts in tension

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 = 150 kN

V = 0 kN

M = 0 kNm

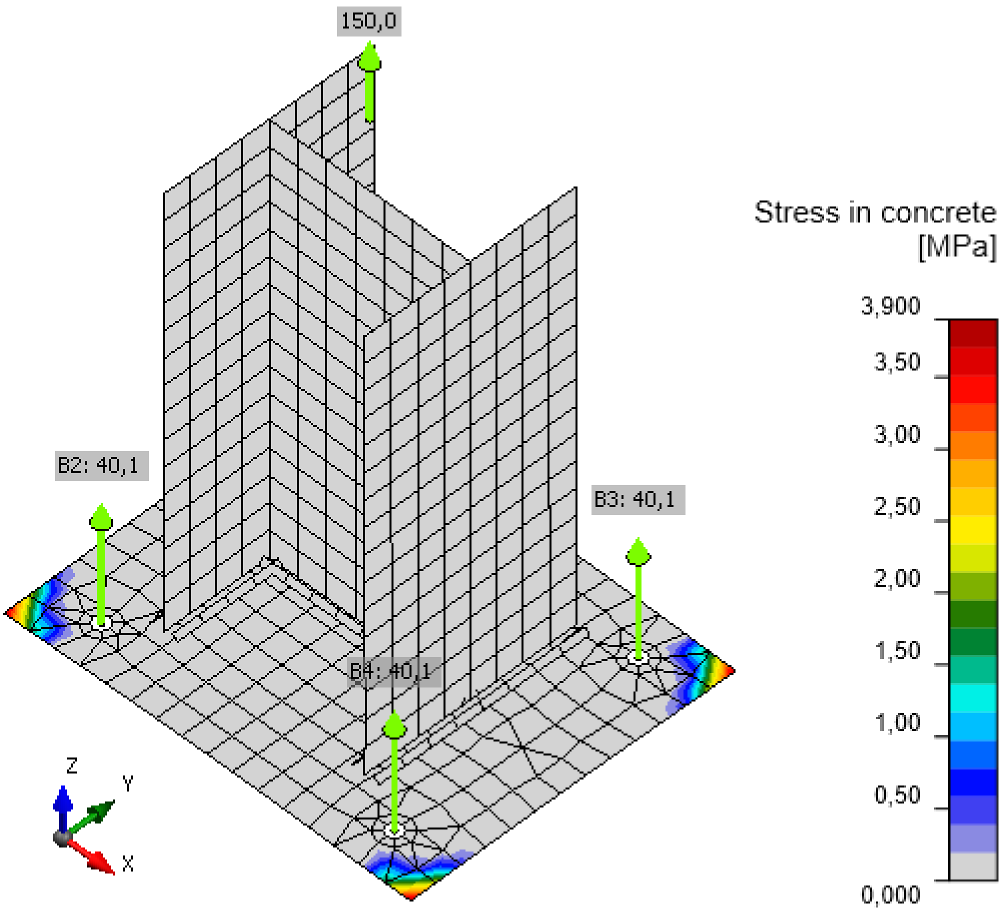
Procedure:

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.

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 77.7 MPa. The forces in anchor bolts are increased by 7 % by prying forces as can be seen from the following picture.



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	40,1	4,5	119,9	49,7	140,4	220,2	67,5	99,3	0,0	80,7	6,7	71,0	✓
	⊞	A2	LE1	40,1	4,5	119,9	49,7	140,4	220,2	67,5	99,3	0,0	80,7	6,7	71,1	✓
	⊞	A3	LE1	40,1	4,5	119,9	49,7	140,4	220,2	67,5	99,3	0,0	80,7	6,7	71,0	✓
	⊞	A4	LE1	40,1	4,5	119,9	49,7	140,4	220,2	67,5	99,3	0,0	80,7	6,7	71,1	✓

CISC

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Anchors in tension

Material:

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

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

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

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

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

Geometry:

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

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

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

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

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

Thickness of the base plate: $t_{bp} := 25\ \text{mm}$

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

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

Number of anchors: $n := 4$

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

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

Loading:

Normal tensile force: $N := 150\ \text{kN}$

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: $\dfrac{\frac{N}{n}}{N_{sar}} = 31\%$

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: $c_{amin} := min\left(c_1, c_2\right) = 300 \text{ mm}$

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: $N_{br} := k_c \cdot \phi_c \cdot \lambda_a \cdot \sqrt{f'_c} \cdot h_{ef}^{\ 1.5} \cdot R \cdot \dfrac{1}{\sqrt{\text{MPa}} \cdot \text{mm}^{1.5}} = 92148.1$

$N_{cbr} := \dfrac{A_{Nc}}{A_{Nco}} \cdot \psi_{edN} \cdot \psi_{cN} \cdot \dfrac{N_{br}}{n} \cdot \dfrac{\text{kN}}{1000} = 49.7 \text{ kN}$

Utilization: $\dfrac{\frac{N}{n}}{N_{cbr}} = 75\%$

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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: $A_{brg}:=\pi\cdot\dfrac{{d_h}^2-{d_a}^2}{4}=1305\ \mathrm{mm}^2$

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: $\dfrac{\frac{N}{n}}{N_{cpr}}=27\%$

Concrete side-face blowout resistance:

Resistance modification factor: $R:=1$

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

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

$N_{sbr}:=min(red_c,red_s)\cdot 13.3\cdot min(c_1,c_2)\cdot\sqrt{A_{brg}}\cdot\phi_c\cdot\lambda_a\cdot\sqrt{f'_c}\cdot R\cdot\dfrac{1000\cdot\sqrt{\mathrm{kg}}}{\sqrt{\mathrm{m}}\cdot\mathrm{s}}=220.3\ \mathrm{kN}$

Utilization: $\dfrac{\frac{N}{n}}{N_{sbr}}=17\%$

Utilization: $Ut_t:=\max\left(\dfrac{\frac{N}{n}}{N_{sar}},\dfrac{\frac{N}{n}}{N_{cbr}},\dfrac{\frac{N}{n}}{N_{cpr}},\dfrac{\frac{N}{n}}{N_{sbr}}\right)=75\%$

Comparison

The resistances of anchors – steel resistance of the anchor, concrete breakout resistance, concrete pullout resistance and side-face blowout 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 5 % to the safe side.