BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF CIVIL ENGINEERING

Anchorage Design


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Author
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Education

2006–2010 – Brno University of Technology, bachelor

2010–2013 – BUT, master (Structures and Traffic Constructions)

2011–2012 – Technical university in Denmark, ERASMUS

2013–2018 – BUT, Ph.D. (Strengthening of steel columns under load)

Experience

2013–now – Brno University of Technology, Research assistant

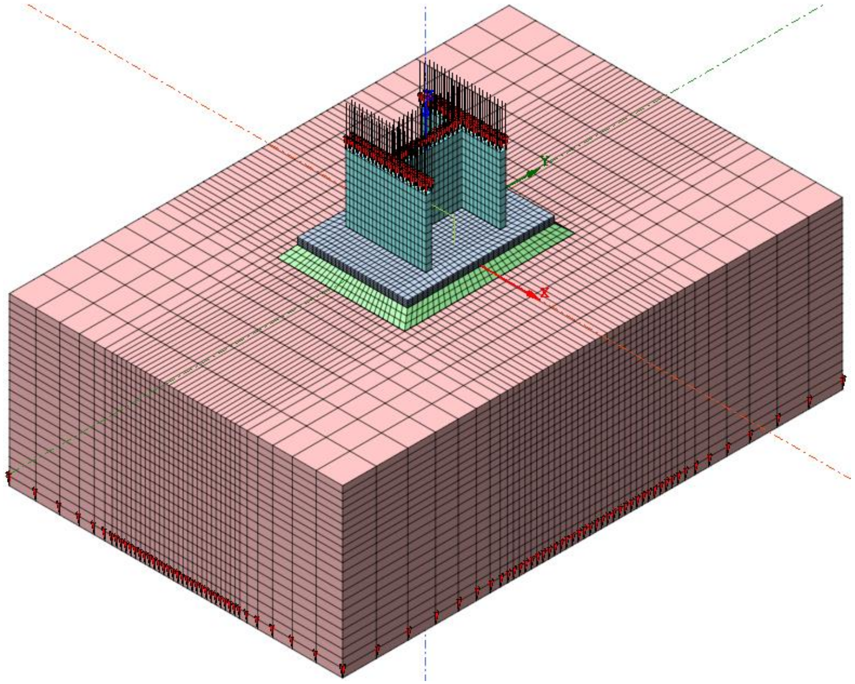
2017–now – IDEA StatiCa, Product Development Engineer

IDEA StatiCa®

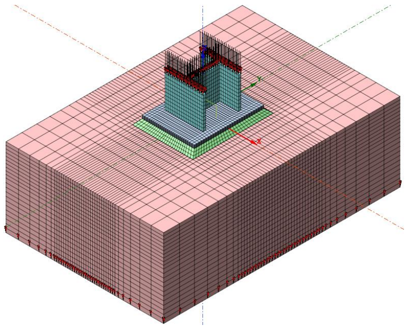
Calculate yesterday's estimates

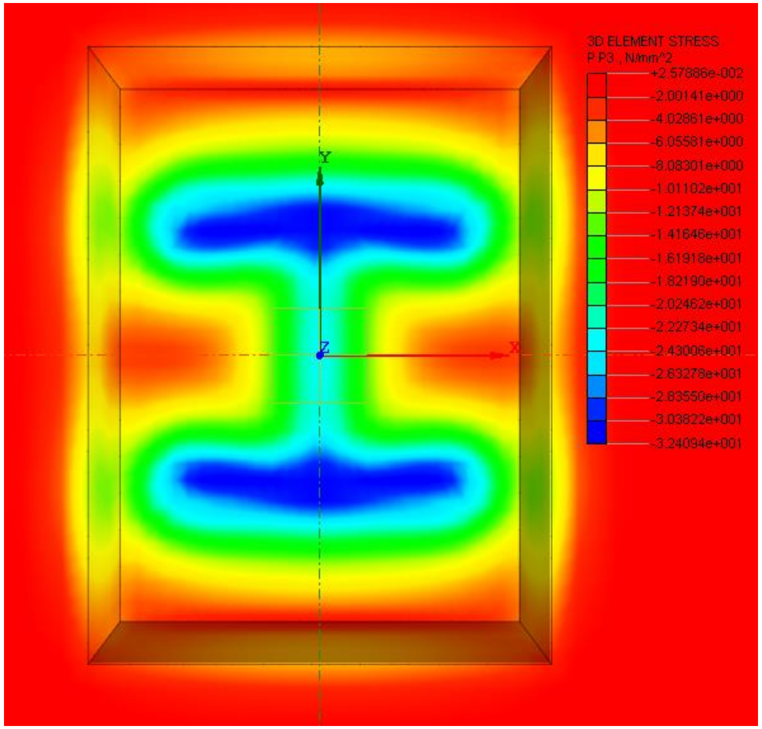
Contents

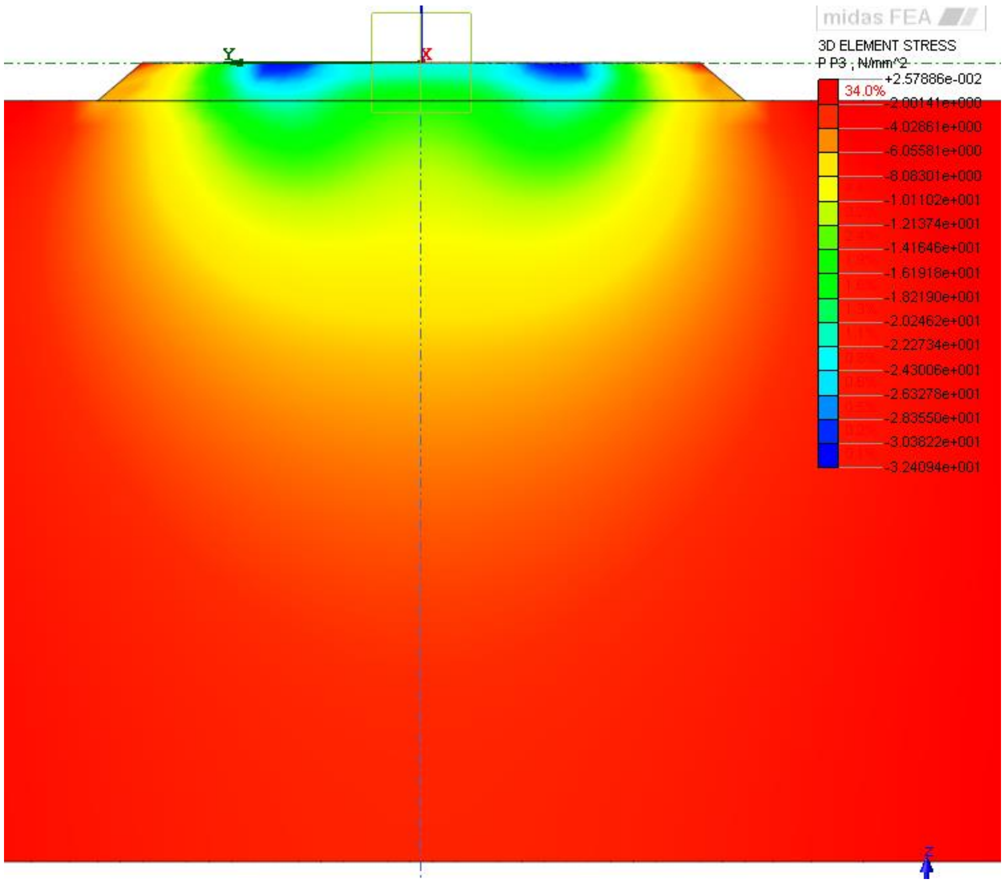
- Concrete in bearing
- Anchors
  - Loaded in tension
  - Loaded in shear
- Stand-off anchors
- Shear transfer
  - Friction
  - Anchors
  - Shear lug



Concrete in bearing





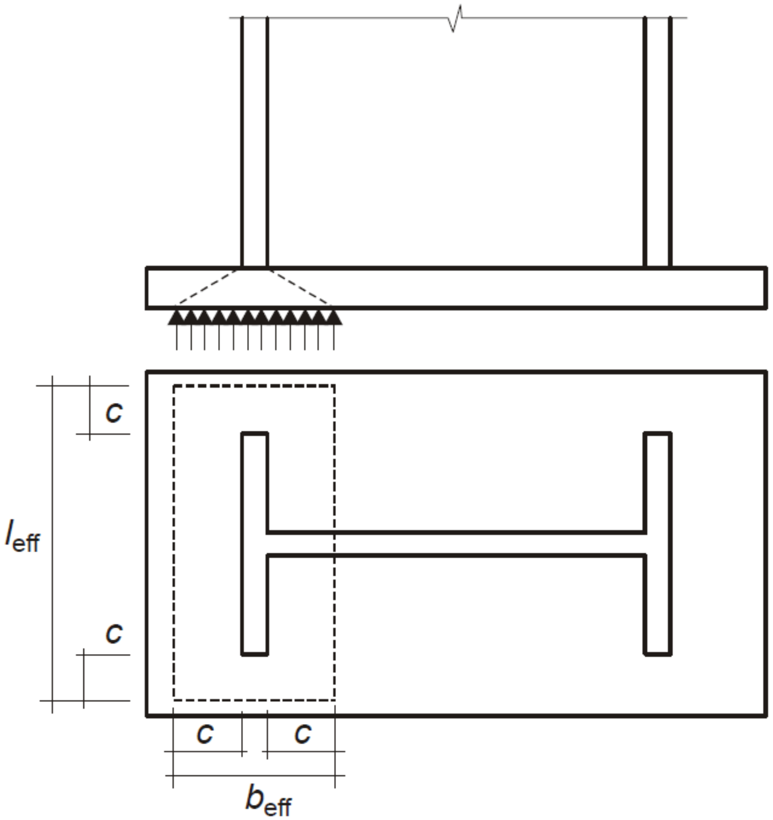


Concrete in bearing

- Codes:
  - EN 1993-1-8 – Cl. 6.2.5
  - EN 1992-1-1 – Cl. 6.7

Equivalent T-stub in compression

$$c = t\sqrt{\frac{f_y}{3 f_{jd} \gamma_{M0}}}$$



Concrete in bearing

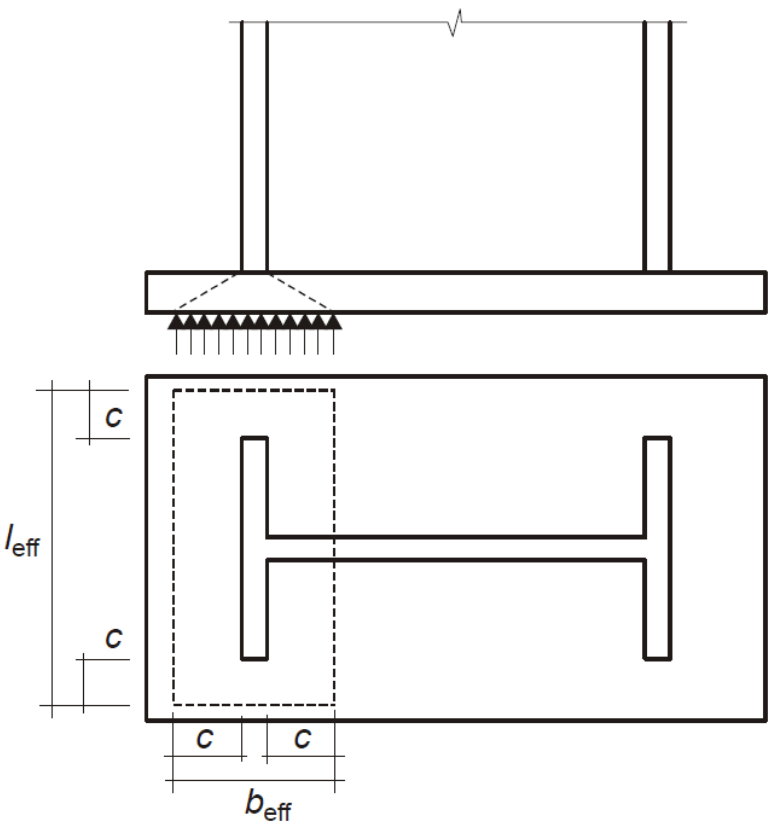
$$f_{jd} = \frac{F_{Rdu}}{A_{eff}}$$

$$\beta_j = 2/3$$

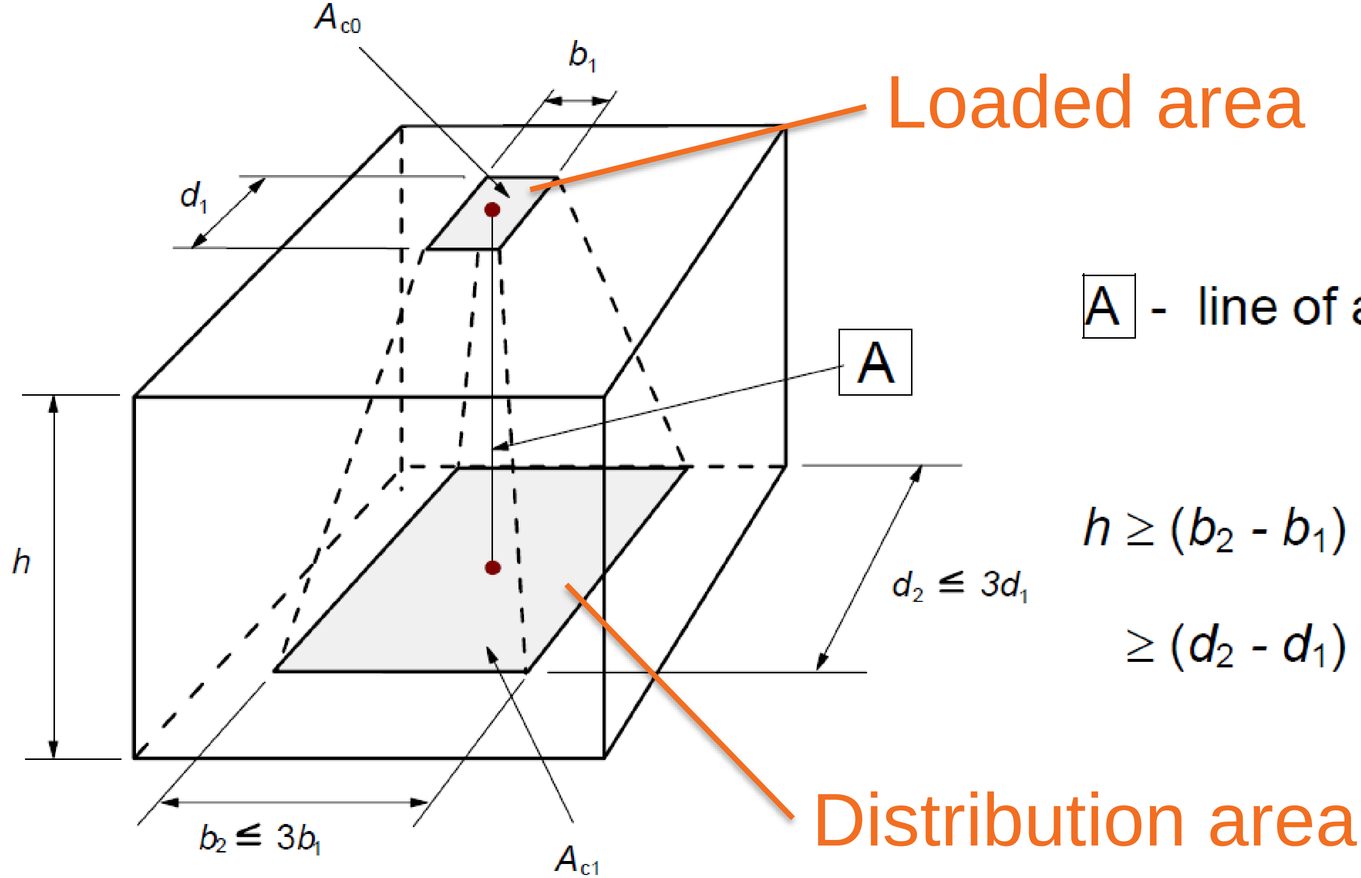
$$k_j = \sqrt{\frac{A_{c1}}{A_{eff}}} \leq 3.0$$

$$f_{jd} = \beta_j k_j f_{cd}$$

$$N_{c,Rd} = f_{jd} A_{eff}$$



Concrete in bearing – EN



$$k_j = \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3$$

A - line of action

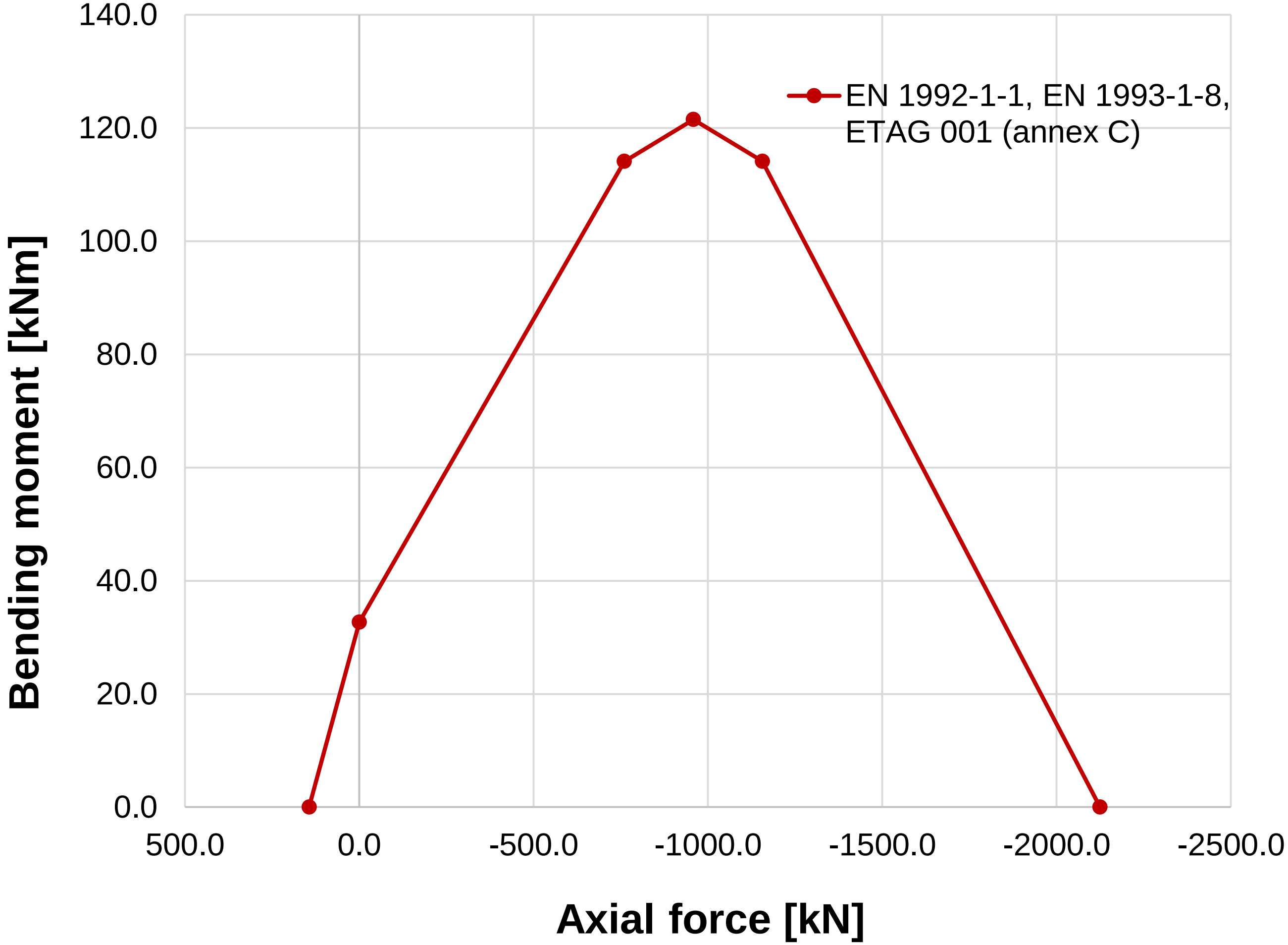
$h \geq (b_2 - b_1)$ and

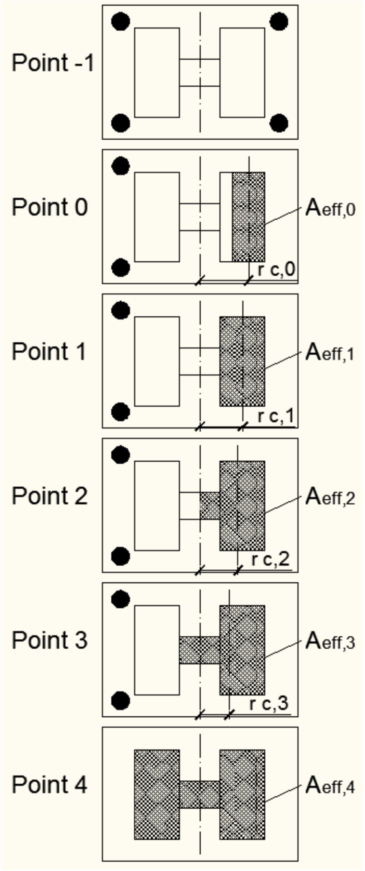
$\geq (d_2 - d_1)$

https://resources.ideastatica.com/Content/02_Steel/Verifications/EN/Concrete%20in%20compression/Concrete%20in%20compression.htm

Interaction diagram

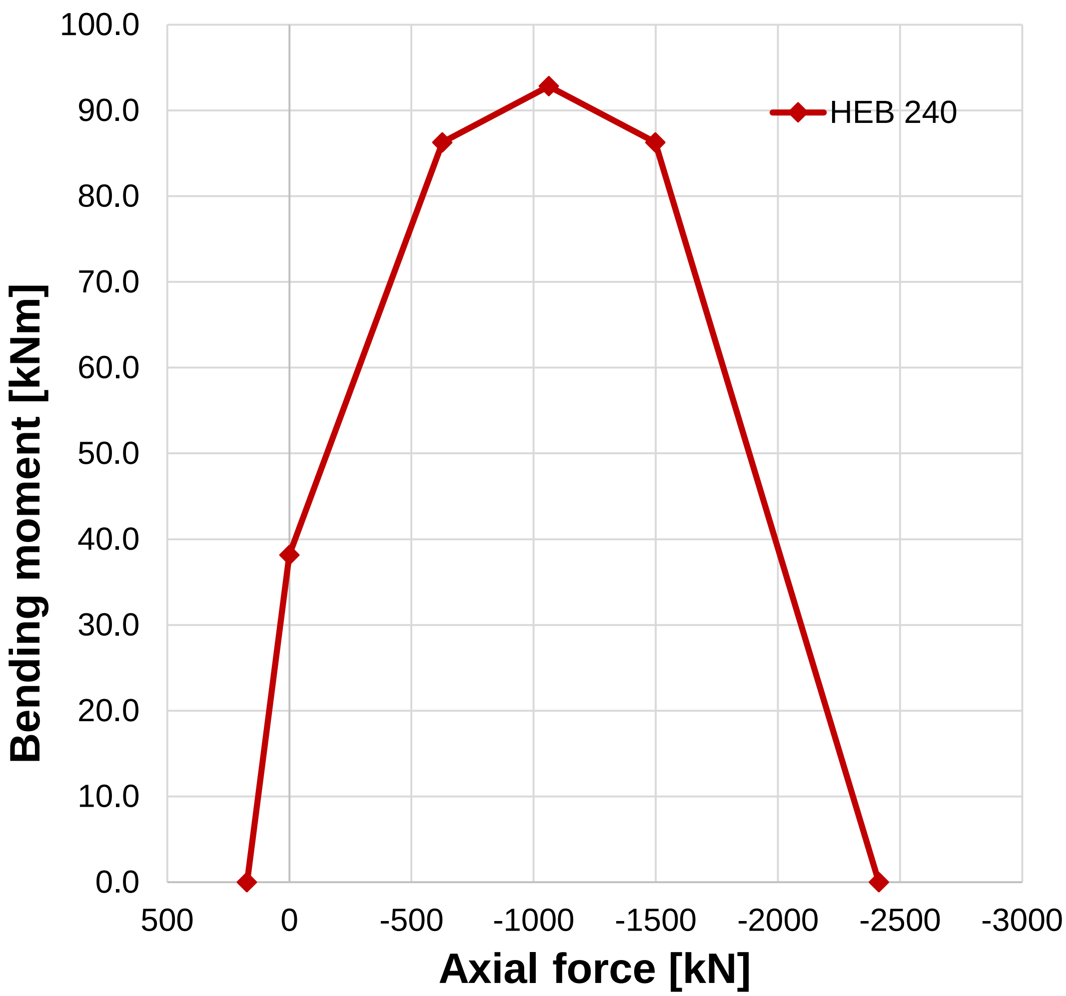
major axis

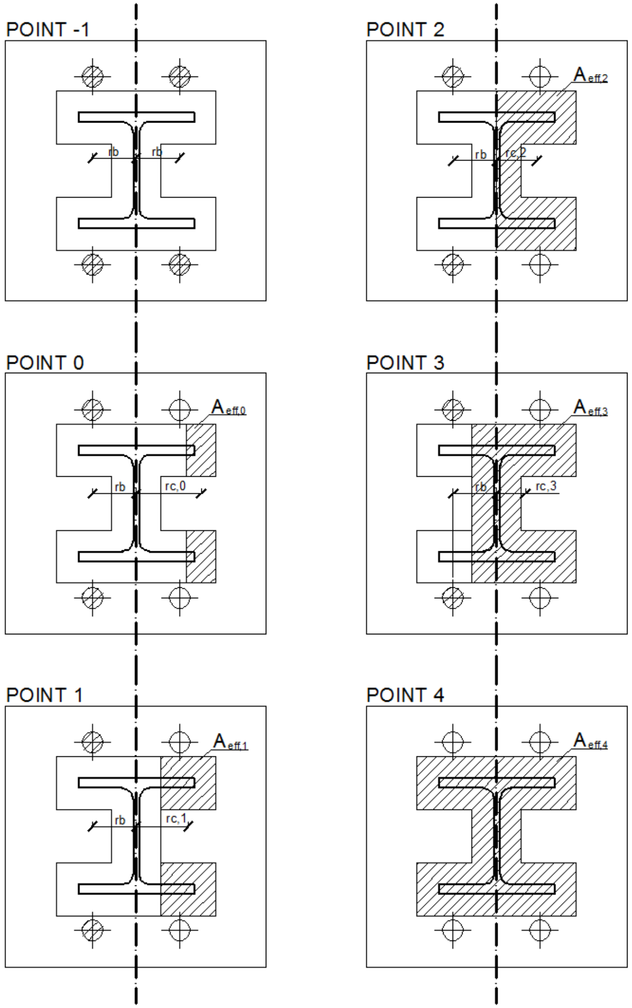




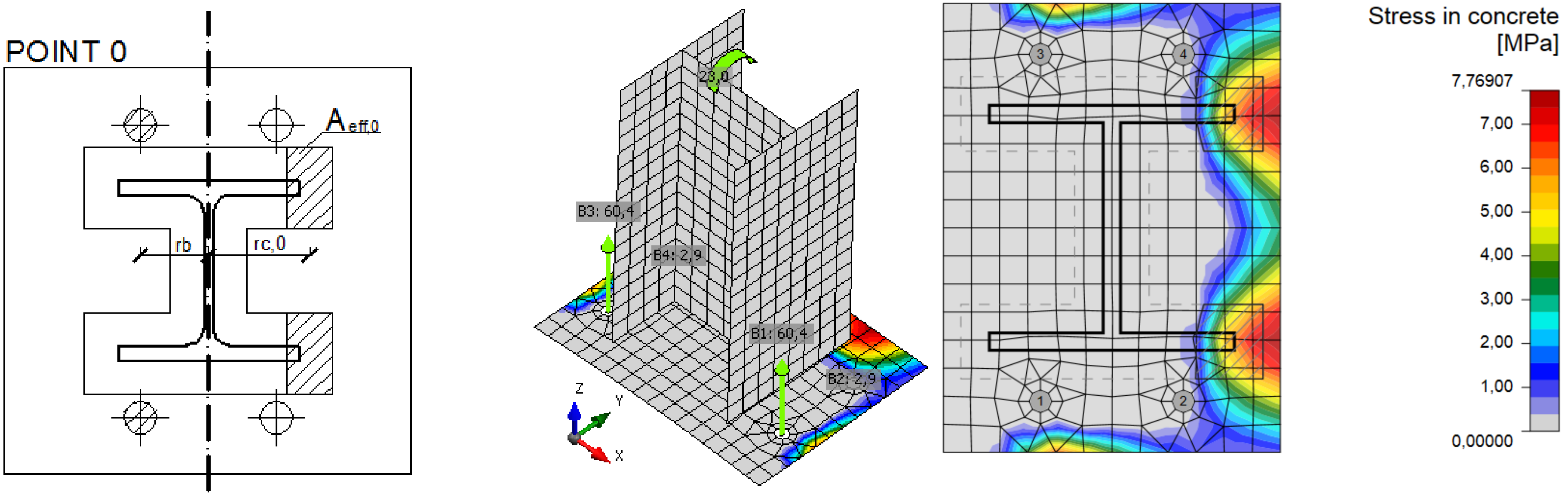
Interaction diagram

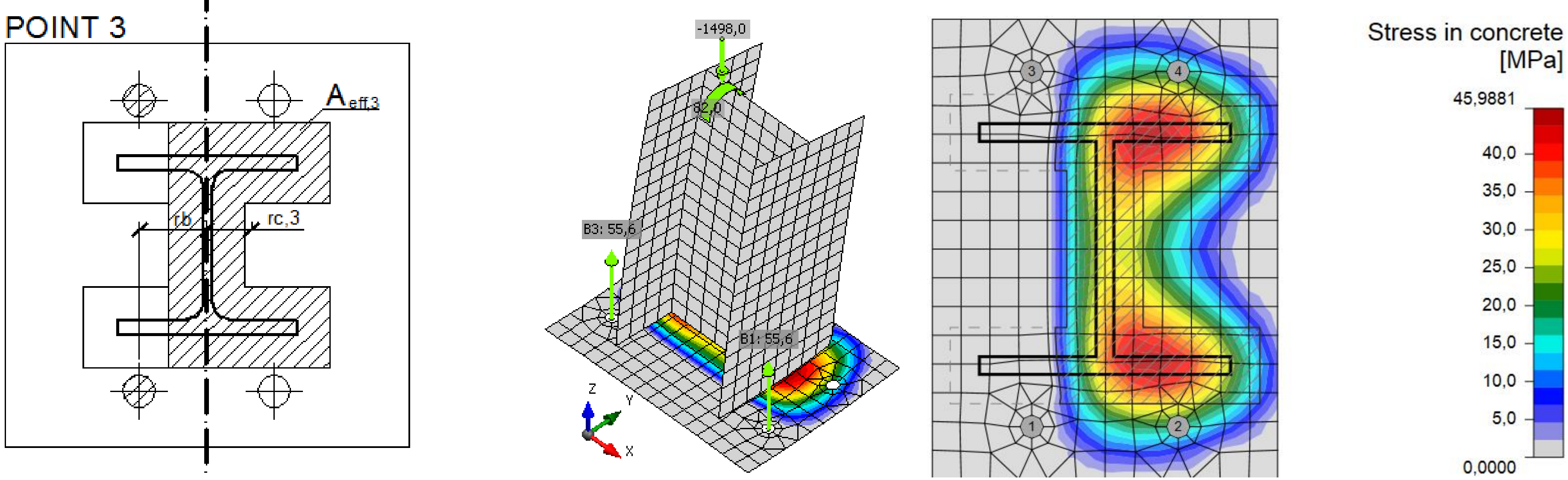
minor axis



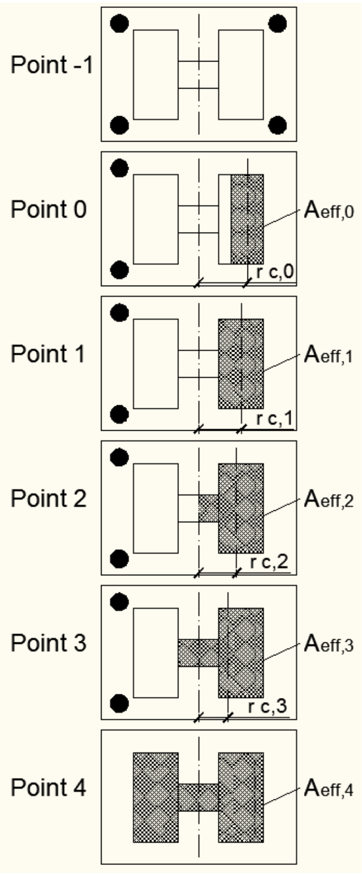


Concrete in bearing – EN





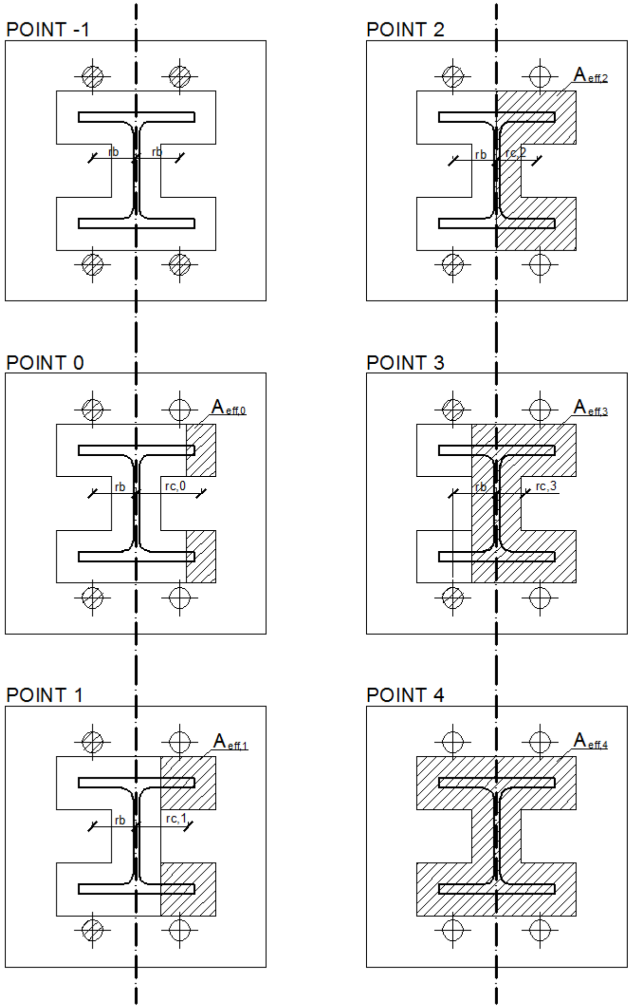
Interaction diagram



$$N_{\mathrm{c,Rd}} = A_{\mathrm{eff}} f_{\mathrm{jd}}$$

$$M_{\mathrm{Rd}} = A_{\mathrm{eff}} f_{\mathrm{jd}} r_{\mathrm{c}} + F_{\mathrm{b,Rd}} r_{\mathrm{b}}$$

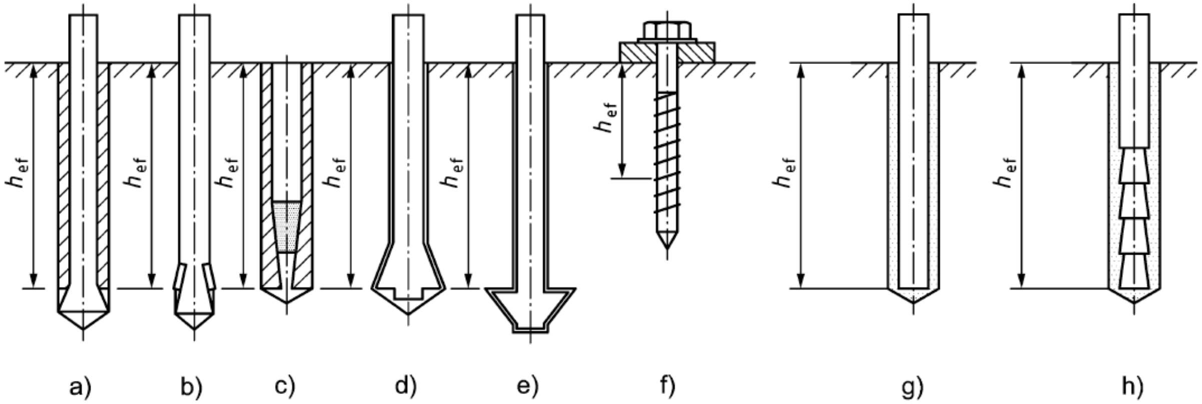
Assumption:
Concrete is fully utilized
Anchors are fully utilized
Axis is in the middle (wrong)



Checks – ANCHORS

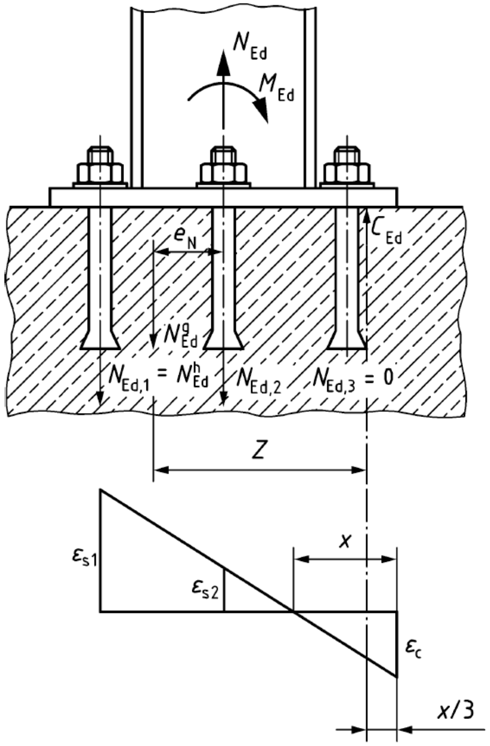
- Concrete Capacity Method (prof. Eligehausen)
- Same checks all over the world
- Newer code → more advanced
- ETAG → EN 1992-4 in 11/2018

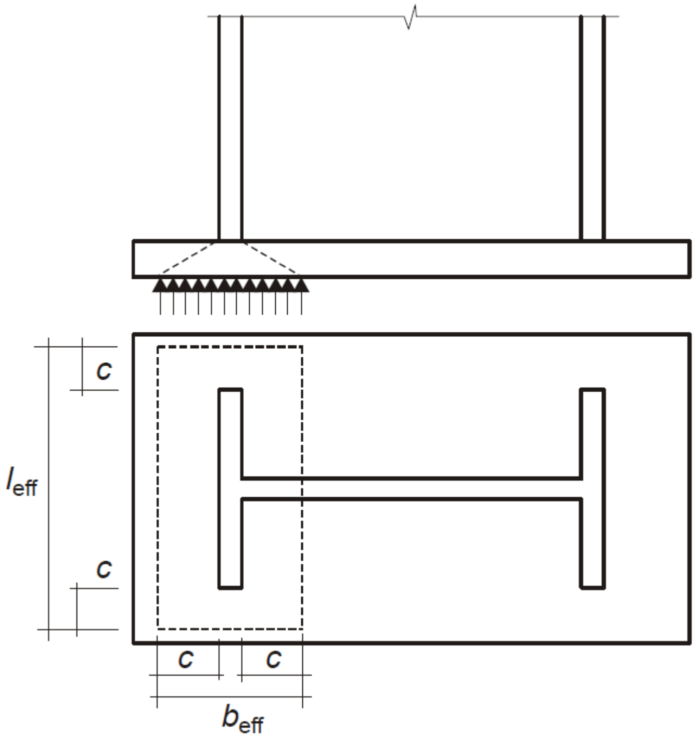
Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete



Checks – ANCHORS

- EN 1992-4 assumes RIGID base plate
- EN 1993-1-8 assumes PLASTIC b. p.

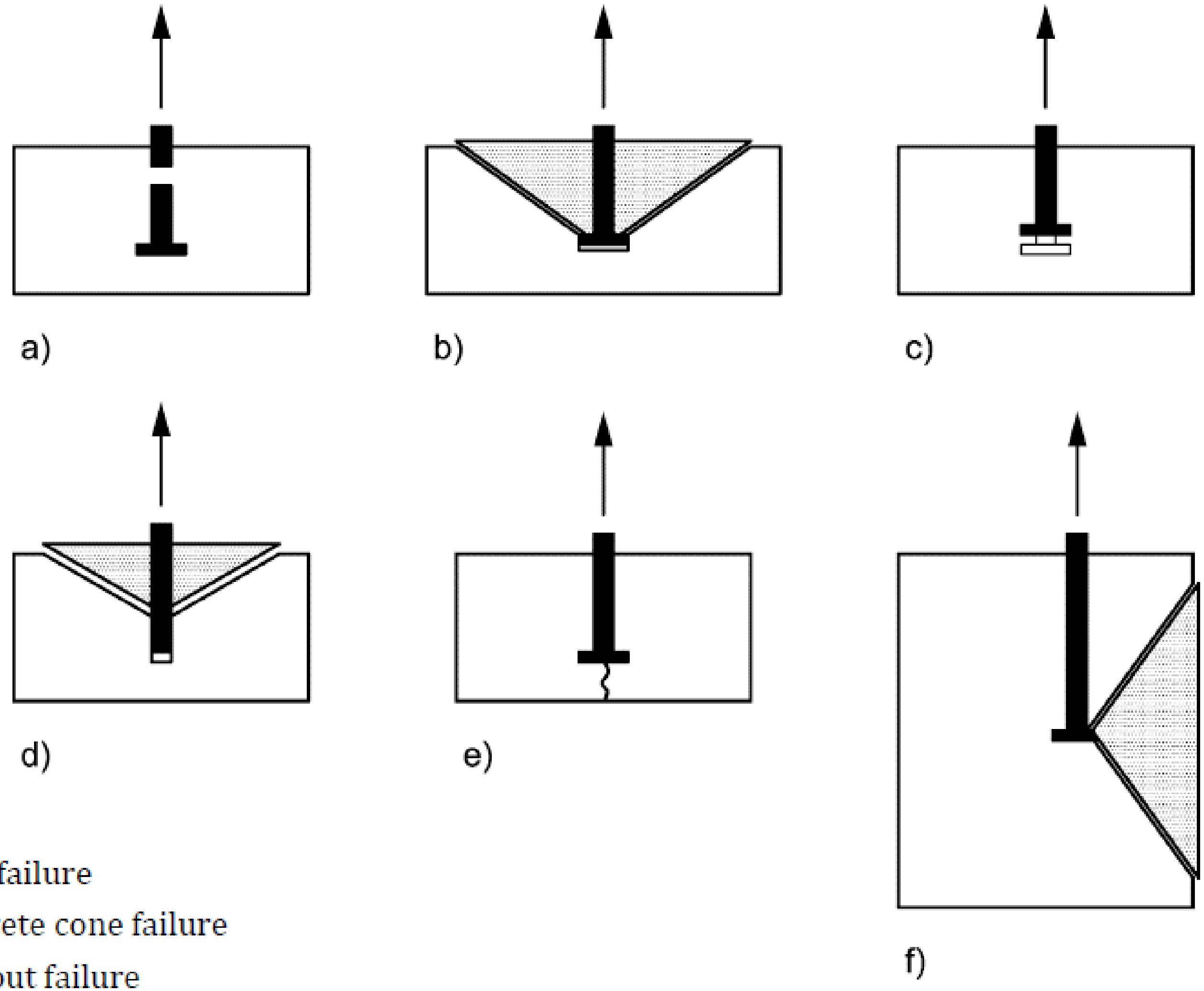




Checks – ANCHORS

- Single anchor
  - Steel failure in tension
  - Steel failure in shear
  - Pull-out failure
  - Combined pullout and concrete failure of bonded anchors
  - Concrete splitting failure
- Group of anchors
  - Concrete cone failure
  - Concrete blow-out failure
  - Concrete edge failure
  - Concrete pry-out failure
- Combined tension and shear

Checks ANCHORS Tension



Key

a) steel failure

b) concrete cone failure

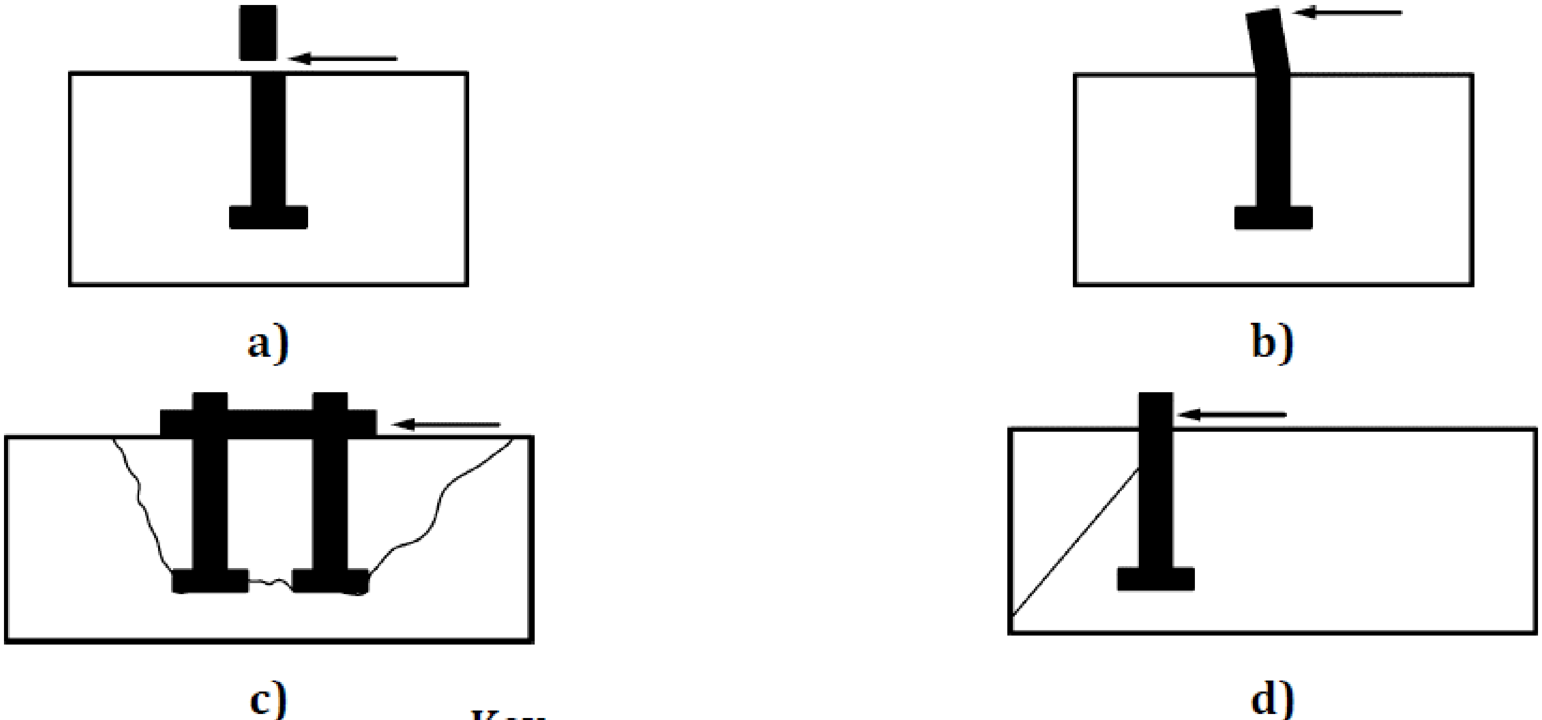
c) pull-out failure

d) combined pull-out and concrete failure of bonded fasteners

e) concrete splitting failure

f) concrete blow-out failure

Checks – ANCHORS – Shear



Key

a) steel failure without lever arm

b) steel failure with lever arm

c) concrete pry-out failure

d) concrete edge failure

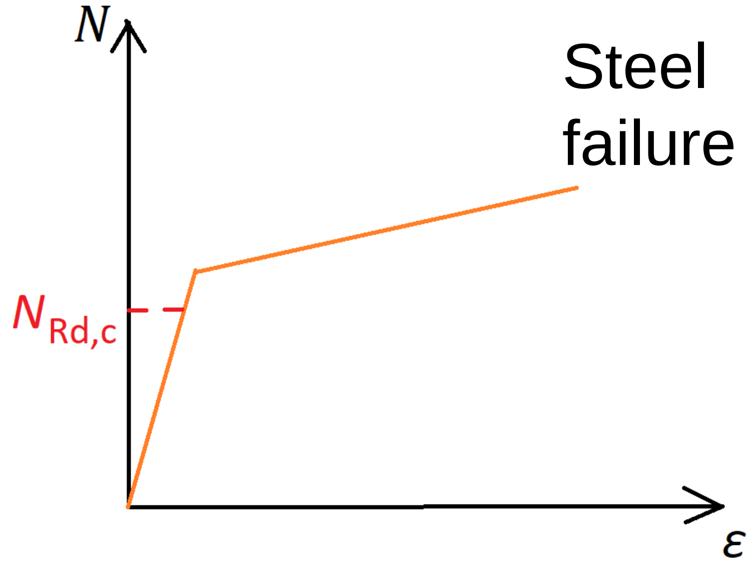
Checks – ANCHORS

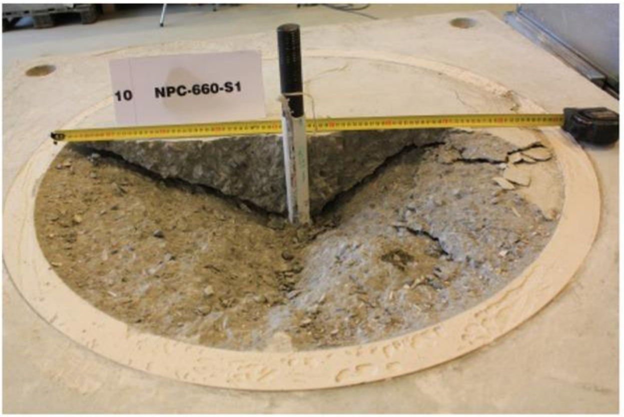
Base plate:

- Single anchor
  - Bolts in bearing – shear
  - Punching shear (EN only) – tension

Checks – ANCHORS

- Concrete failures are brittle



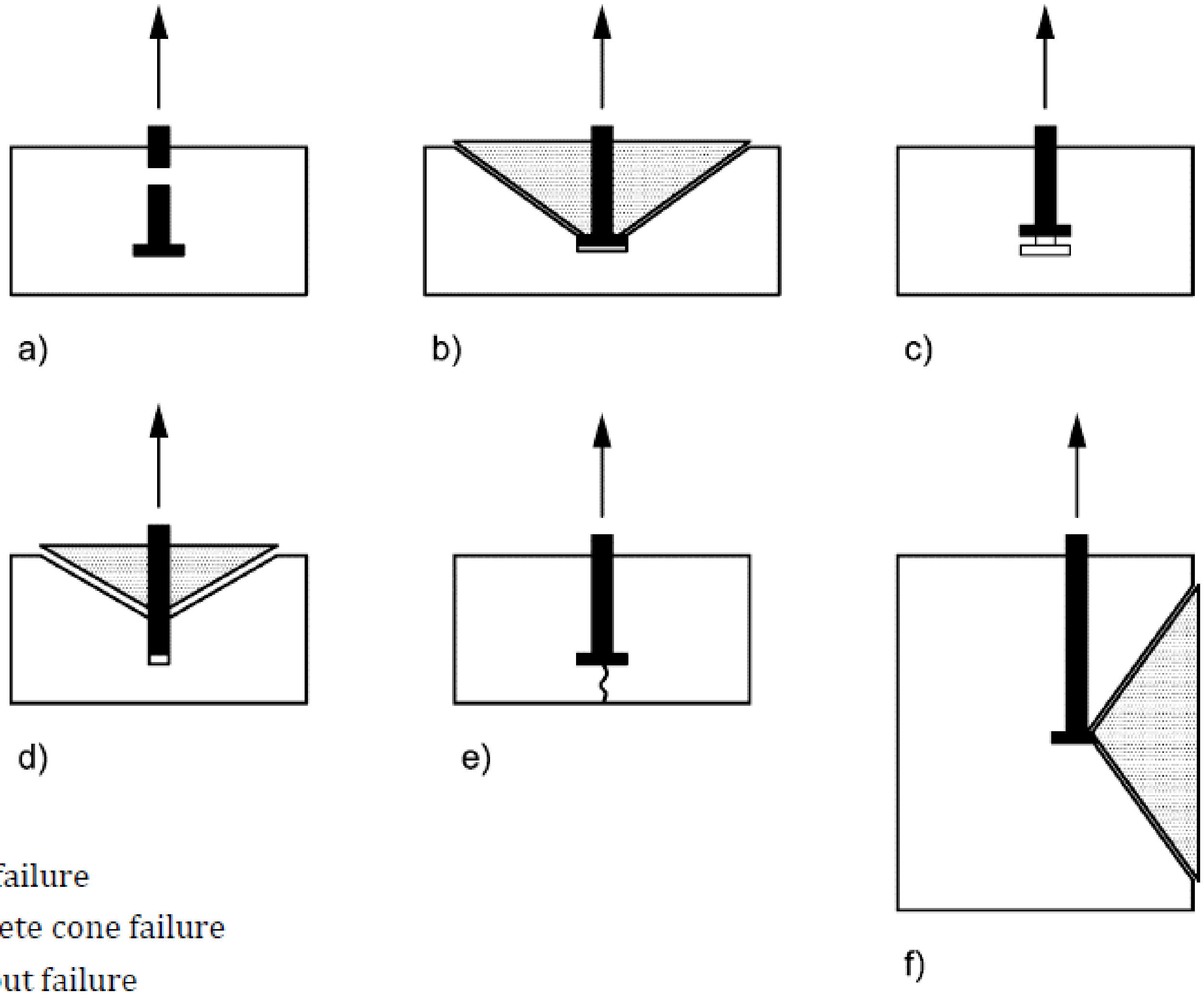


(a)

(b)

(c)

Checks ANCHORS Tension



Key

a) steel failure

b) concrete cone failure

c) pull-out failure

d) combined pull-out and concrete failure of bonded fasteners

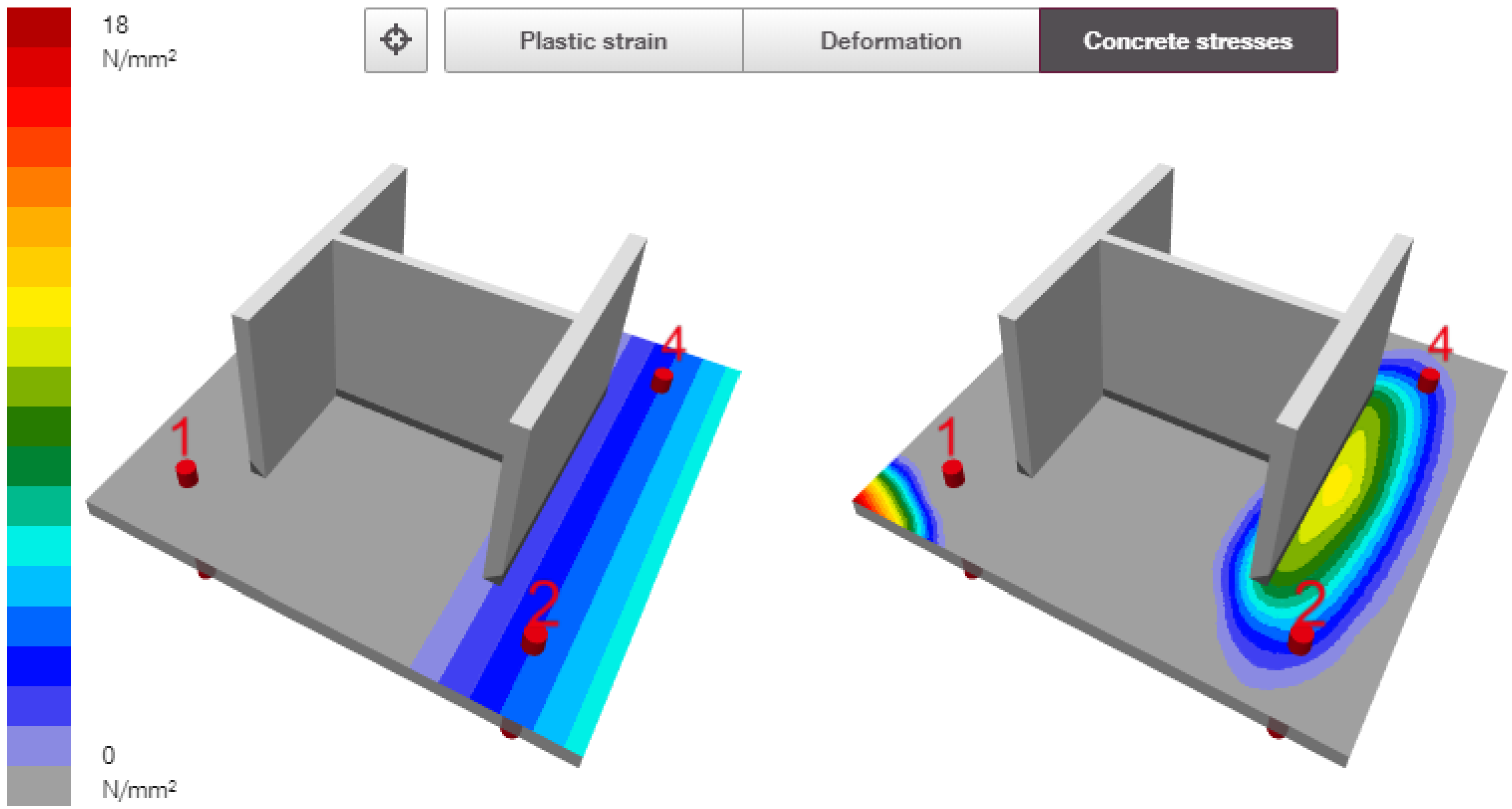
e) concrete splitting failure

f) concrete blow-out failure

Rigid base plate assumption

- Rigid base plate
  - assumption is not correct
  - easy to calculate tensile forces in anchors, compression in concrete
  - in all anchorage codes
- Elasto-plastic base plate
  - in EN 1993-1-8, in CBFEM
  - generally is safer (higher forces in anchors)
  - Hilti Profis Engineering, IDEA StatiCa

Click for more details



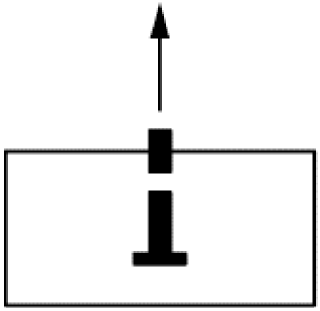
	Equivalent rigid baseplate (FEM)	Flexible baseplate (FEM)
Anchor tension forces		
Anchor 1	21.8 kN	33.7 kN (55%)
Anchor 2	0 kN	0 kN (-%)
Anchor 3	21.8 kN	33.7 kN (55%)
Anchor 4	0 kN	0 kN (-%)
Baseplate plastic strain (max)	None	0.07%
Baseplate deformation (max)	0.2 mm	0.7 mm

- prying forces
- lesser lever arm

Steel failure in tension

EN 1992-4 – Table 7.1

$$N_{Ed} \leq N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}} \qquad N_{Rk,s} = A_s \cdot f_{ub}$$



a)

EN 1993-1-8 – Table 3.4

$$F_{t,Rd} = \frac{k_2 \; f_{ub} \; A_s}{\gamma_{M2}}$$

where $k_2 = 0{,}63$ for countersunk bolt,
otherwise $k_2 = 0{,}9$.

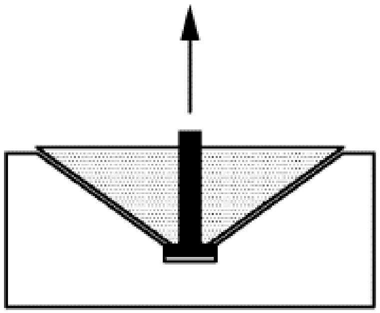
EN 1993-1-8 – Cl. 3.6.1

For bolts with cut threads, such as anchor bolts or tie rods fabricated from round steel bars where the threads comply with EN 1090, the relevant values from Table 3.4 should be used. For bolts with cut threads where the threads do not comply with EN 1090 the relevant values from Table 3.4 should be multiplied by a factor of 0,85.

Concrete cone failure

EN 1992-4 – Table 7.1

$$N_{Ed} \leq N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$



$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

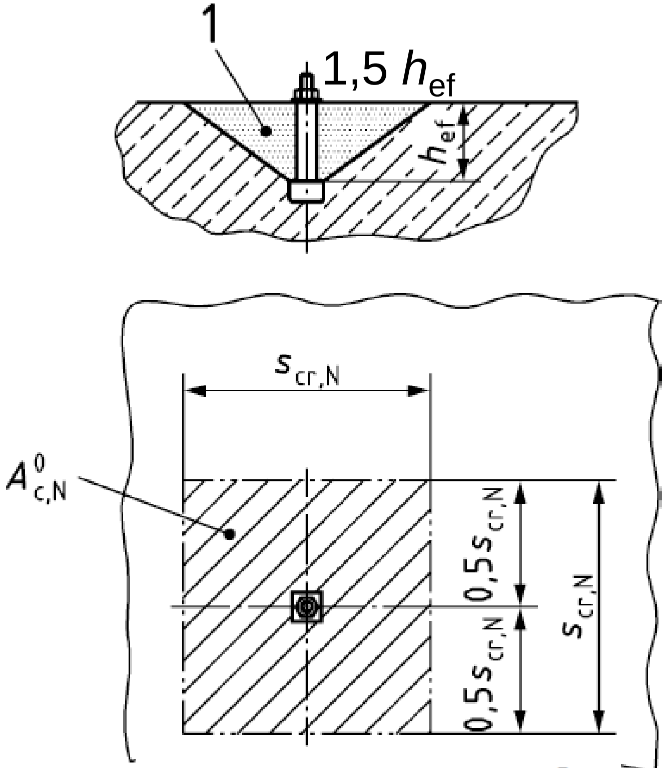
$$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1,5}$$

	Post-installed	Cast-in
Cracked	$k_{cr,N} = 7,7$	$k_{cr,N} = 8,9$
Uncracked	$k_{ucr,N} = 11,0$	$k_{ucr,N} = 12,7$

Geometry of upper surface

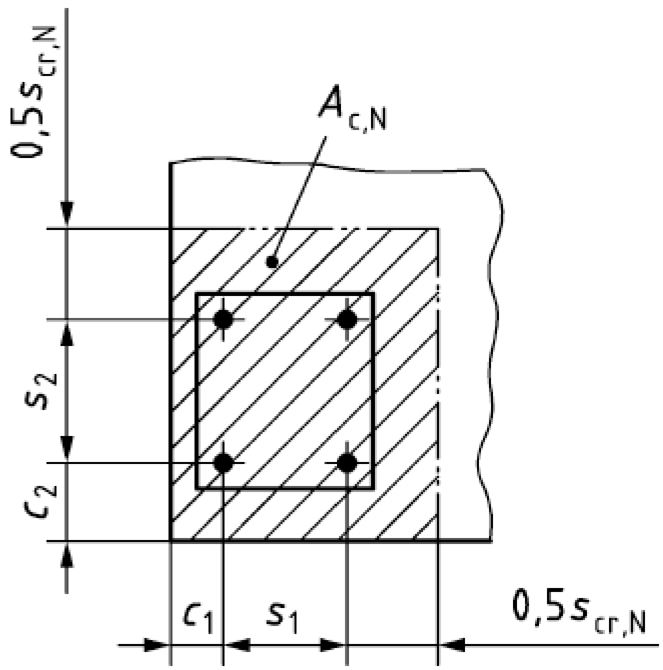
$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

reference projected area $A^0_{c,N}$



$s_{cr,N} = 2\ c_{cr,N} = 3\ h_{ef}$

actual projected area $A_{c,N}$



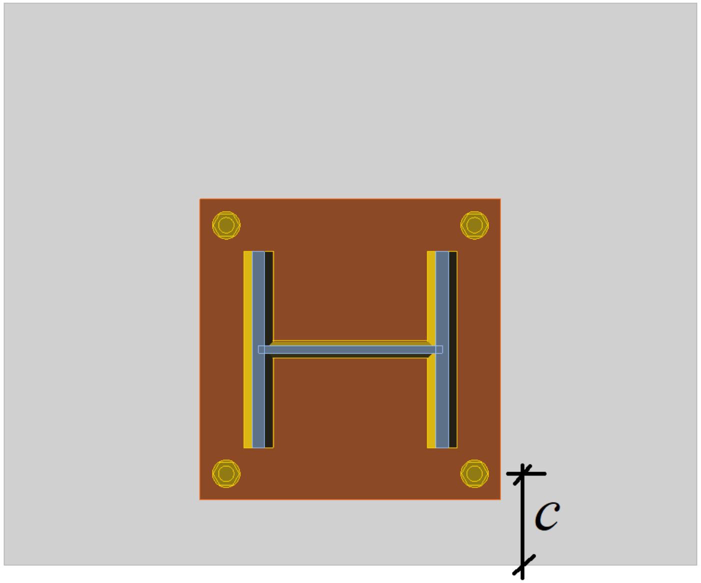
Concrete edge proximity

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

disturbance of the distribution of stresses in the concrete due to the proximity of an edge of the concrete member

$$\psi_{s,N} = 0,7 + 0,3 \cdot \frac{c}{c_{cr,N}} \leq 1$$

$$c_{cr,N} = 1,5\, h_{ef}$$



Shell spalling factor

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \boxed{\psi_{re,N}} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

The shell spalling factor applies when $h_{ef} < 100$ mm and accounts for the effect of dense reinforcement between which the fastener is installed:

$$\psi_{re,N} = 0,5 + \frac{h_{ef}}{200} \leq 1$$

The factor $\psi_{re,N}$ may be taken as 1,0 in the following cases:

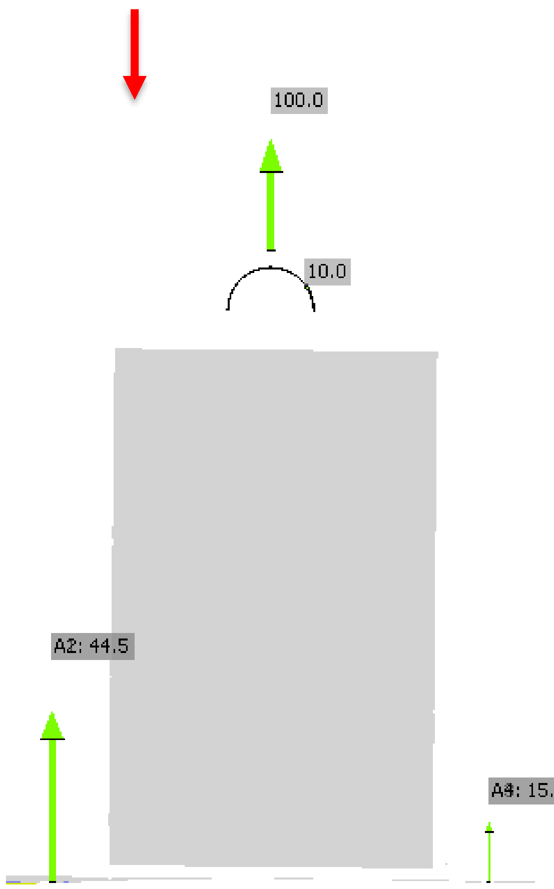
a) reinforcement (any diameter) is present at a spacing ≥ 150 mm, or

b) reinforcement with a diameter of 10 mm or smaller is present at a spacing ≥ 100 mm.

The conditions a) or b) shall be fulfilled for both directions in case of reinforcement in two directions.

Load eccentricity

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \boxed{\psi_{ec,N}} \cdot \psi_{M,N}$$



group effect when different tension loads are acting on the individual fasteners of a group

$$\psi_{ec,N} = \frac{1}{1 + 2 \cdot \left(e_N / s_{cr,N}\right)} \leq 1$$

Where there is an eccentricity in two directions, $\psi_{ec,N}$ shall be determined separately for each direction and the product of both factors shall be inserted in Formula (7.1).

Bending moment loading

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

effect of a compression force between fixture and concrete in cases of bending moments with or without axial force

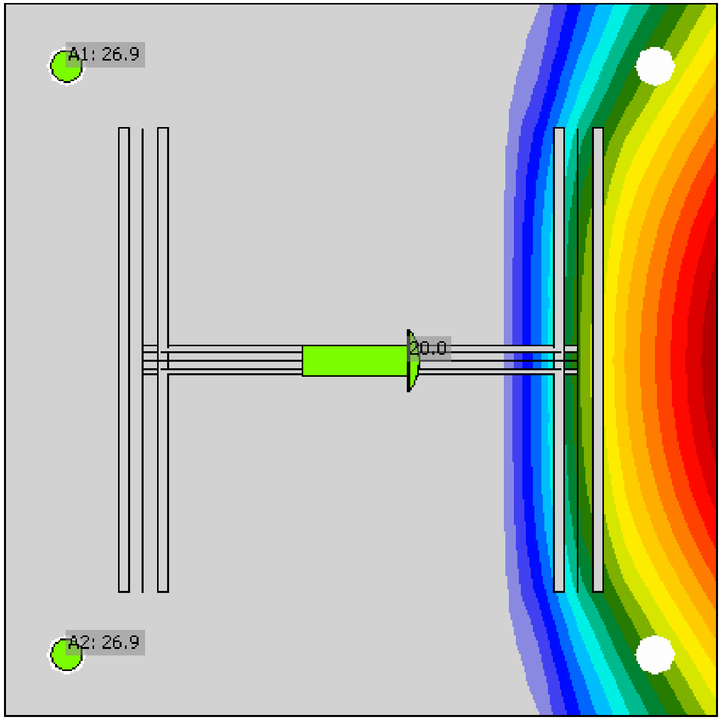
$$\psi_{M,N} = 2 - \frac{z}{1,5\, h_{ef}} \geq 1$$

$\psi_{M,N} = 1$ for:

$$c < 1,5\, h_{ef}$$

$$C_{Ed} / N_{Ed} < 0,8$$

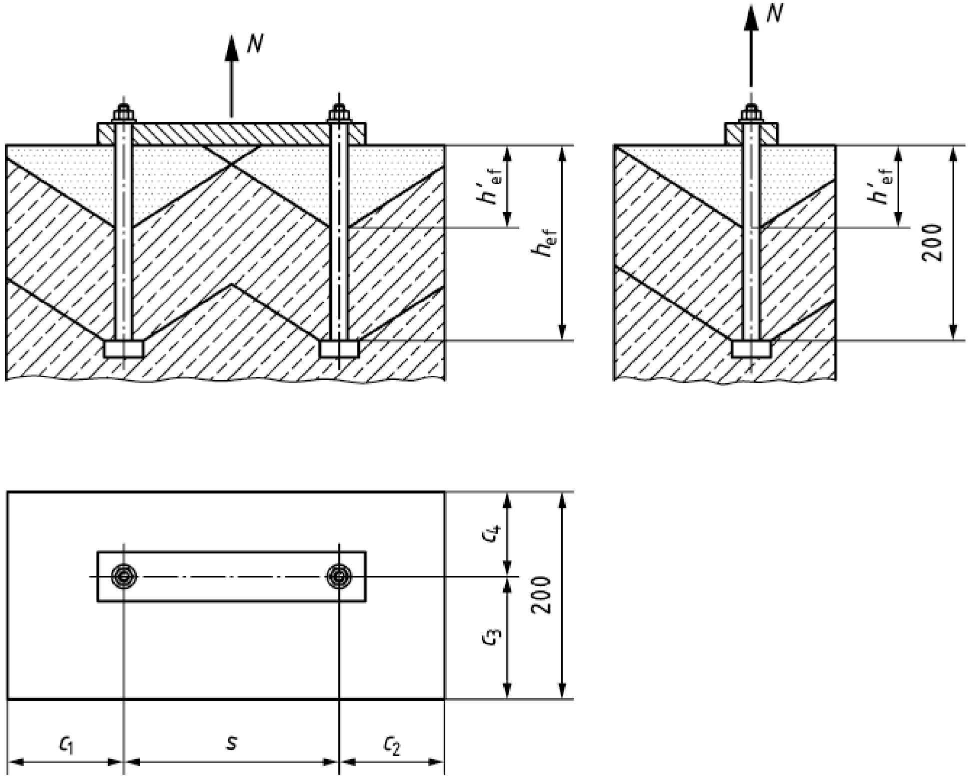
$$z / h_{ef} \geq 1,5$$

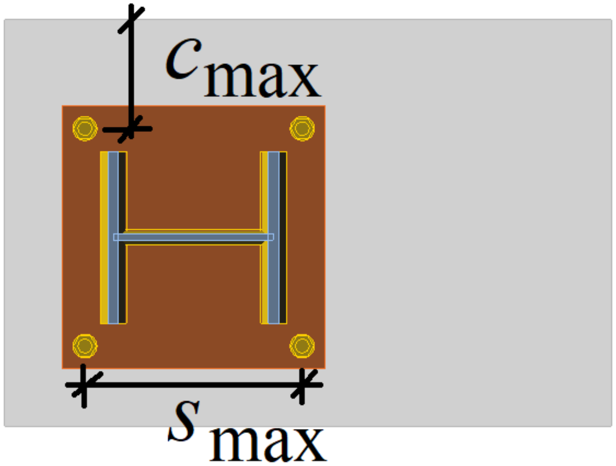


Edge of thin member

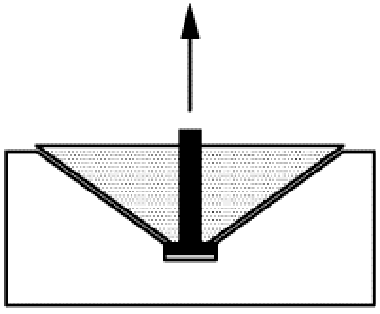
Longer anchor → decrease in load resistance: Nonsense

Effective length h_{ef} is limited: $h'_{ef} = \max\left\{\frac{c_{\max}}{c_{\mathrm{cr,N}}} \cdot h_{ef} \, ; \, \frac{s_{\max}}{s_{\mathrm{cr,N}}} \cdot h_{ef}\right\}$





Concrete cone failure



Checked as a group
Very often governing resistance

$$N_{\mathrm{Rk,c}} = N^{0}_{\mathrm{Rk,c}} \cdot \frac{A_{\mathrm{c,N}}}{A^{0}_{\mathrm{c,N}}} \cdot \psi_{\mathrm{s,N}} \cdot \psi_{\mathrm{re,N}} \cdot \psi_{\mathrm{ec,N}} \cdot \psi_{\mathrm{M,N}}$$

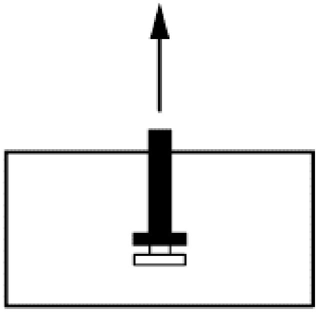
Basic resistance

Group effect

Factors

Pullout failure

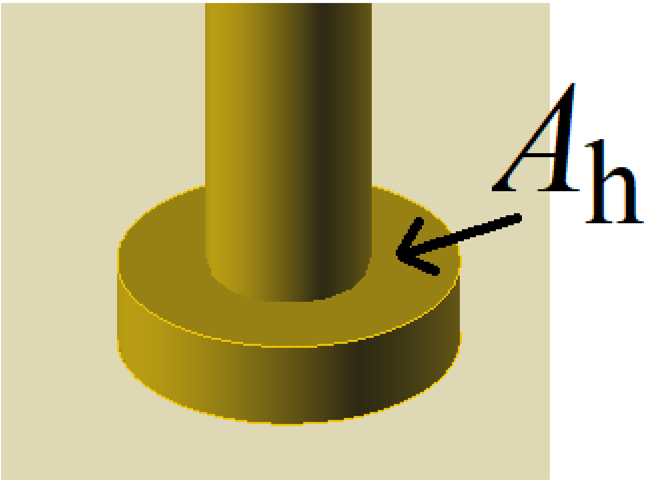
EN 1992-4 – Table 7.1


c)

$$N_{\mathrm{Ed}} \leq N_{\mathrm{Rd,p}} = \frac{N_{\mathrm{Rk,p}}}{\gamma_{\mathrm{Mp}}}$$

$$N_{\mathrm{Rk,p}} = k_2 \cdot A_{\mathrm{h}} \cdot f_{\mathrm{ck}}$$

	Headed fastener
Cracked	$k_2 = 7{,}5$
Uncracked	$k_2 = 10{,}5$

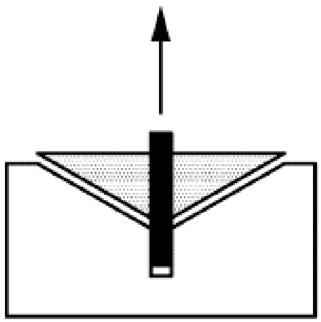


Other anchors – according to manufacturer
Hooked anchors – not recommended

Bonded anchors

Combined pull-out and concrete cone

EN 1992-4 – Table 7.1



d)

$$N_{\mathrm{Ed}} \leq N_{\mathrm{Rd,p}} = \frac{N_{\mathrm{Rk,p}}}{\gamma_{\mathrm{Mp}}}$$

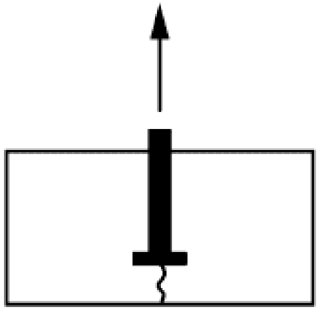
$$N_{\mathrm{Rk,p}} = N_{\mathrm{Rk,p}}^{0} \cdot \frac{A_{\mathrm{p,N}}}{A_{\mathrm{p,N}}^{0}} \cdot \psi_{\mathrm{g,Np}} \cdot \psi_{\mathrm{s,Np}} \cdot \psi_{\mathrm{re,N}} \cdot \psi_{\mathrm{ec,Np}}$$

Bond strength necessary, use software of the manufacturer

Concrete splitting failure

Post-installed mechanical anchors

EN 1992-4 – Table 7.1



e)

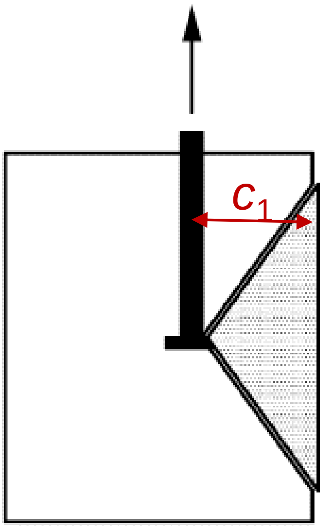
$$N_{\mathrm{Ed}} \leq N_{\mathrm{Rd,sp}} = \frac{N_{\mathrm{Rk,sp}}}{\gamma_{\mathrm{Msp}}}$$

Edge distance necessary, use software of the manufacturer

Concrete blow-out failure

Anchors near the edge; headed and post-installed mechanical

EN 1992-4 – Table 7.1

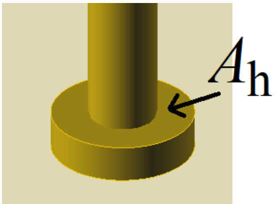


f)

$$N_{\mathrm{Ed}} \leq N_{\mathrm{Rd,cb}} = \frac{N_{\mathrm{Rk,cb}}}{\gamma_{\mathrm{Mc}}}$$

$$N_{\mathrm{Rk,cb}} = N^0_{\mathrm{Rk,cb}} \cdot \frac{A_{\mathrm{c,Nb}}}{A^0_{\mathrm{c,Nb}}} \cdot \psi_{\mathrm{s,Nb}} \cdot \psi_{\mathrm{g,Nb}} \cdot \psi_{\mathrm{ec,Nb}}$$

$$N^0_{\mathrm{Rk,cb}} = k_5 \cdot c_1 \cdot \sqrt{A_{\mathrm{h}}} \cdot \sqrt{f_{\mathrm{ck}}}$$



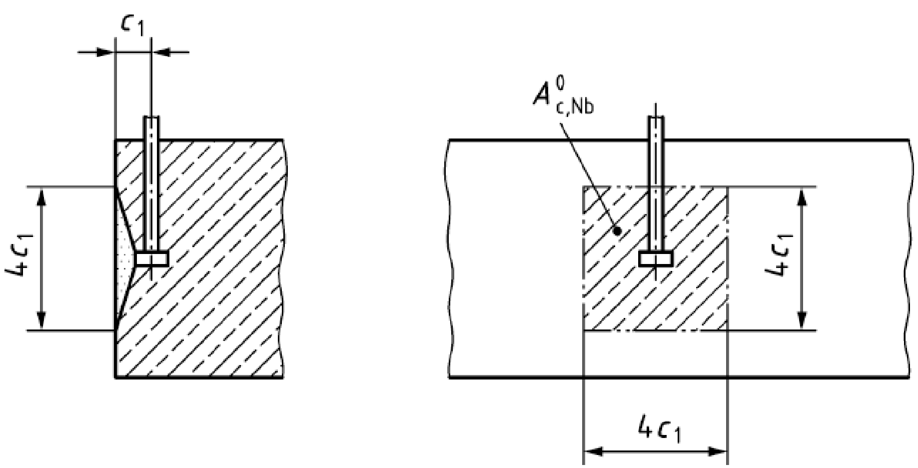
Cracked	$k_5 = 8{,}7$
Uncracked	$k_5 = 12{,}2$

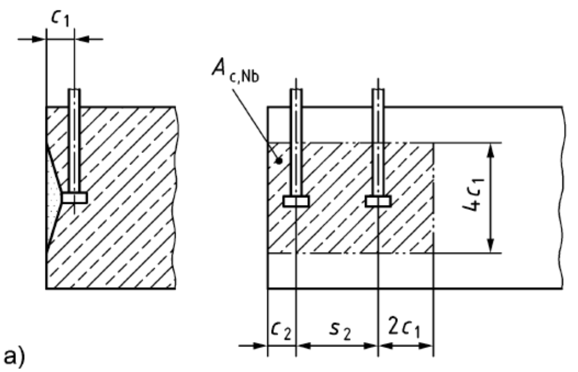
Geometry of side surface

$$N_{\mathrm{Rk,cb}} = N^0_{\mathrm{Rk,cb}} \cdot \frac{A_{\mathrm{c,Nb}}}{A^0_{\mathrm{c,Nb}}} \cdot \psi_{\mathrm{s,Nb}} \cdot \psi_{\mathrm{g,Nb}} \cdot \psi_{\mathrm{ec,Nb}}$$

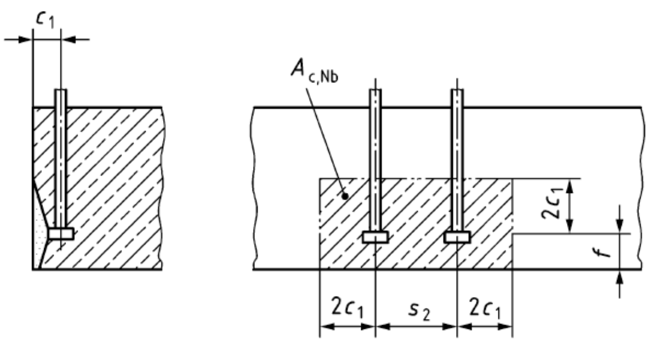
reference projected area $A^0_{\mathrm{c,Nb}}$

actual projected area $A_{\mathrm{c,Nb}}$





a)



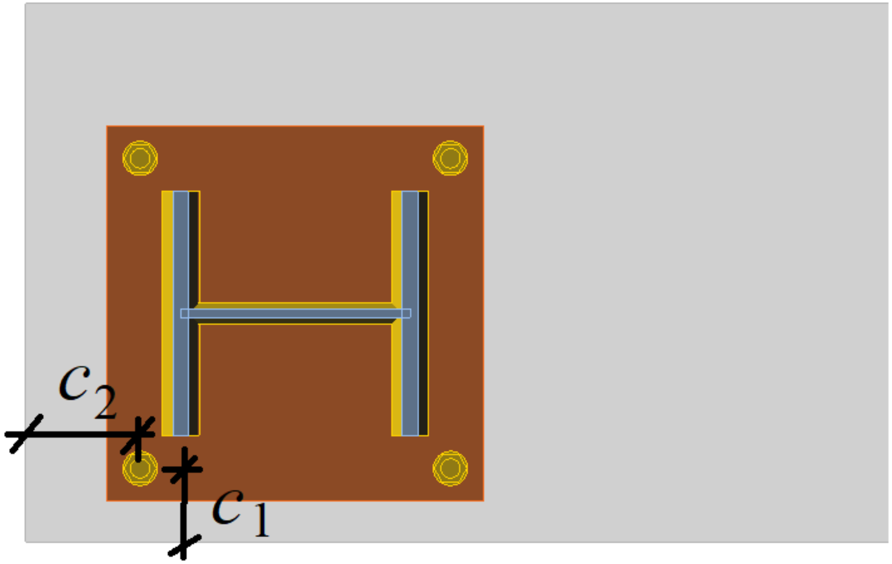
b)

Proximity of a corner

$$N_{Rk,cb} = N^0_{Rk,cb} \cdot \frac{A_{c,Nb}}{A^0_{c,Nb}} \cdot \psi_{s,Nb} \cdot \psi_{g,Nb} \cdot \psi_{ec,Nb}$$

disturbance of the distribution of stresses in the concrete due to the proximity of a corner of the concrete member

$$\psi_{s,Nb} = 0,7 + 0,3 \cdot \frac{c_2}{2c_1} \leq 1$$



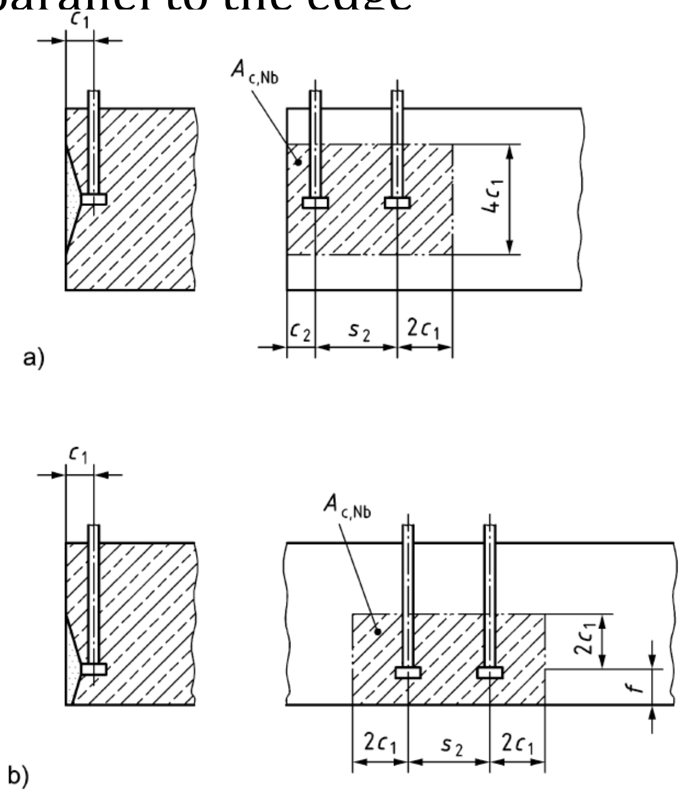
Number of anchors

$$N_{Rk,cb} = N^0_{Rk,cb} \cdot \frac{A_{c,Nb}}{A^0_{c,Nb}} \cdot \psi_{s,Nb} \cdot \psi_{g,Nb} \cdot \psi_{ec,Nb}$$

group effect of a number of fasteners n in a row parallel to the edge

$$\psi_{g,Nb} = \sqrt{n} + \left(1 - \sqrt{n}\right) \cdot \frac{s_2}{4\,c_1} \geq 1$$

$$s_2 \leq 4c_1$$

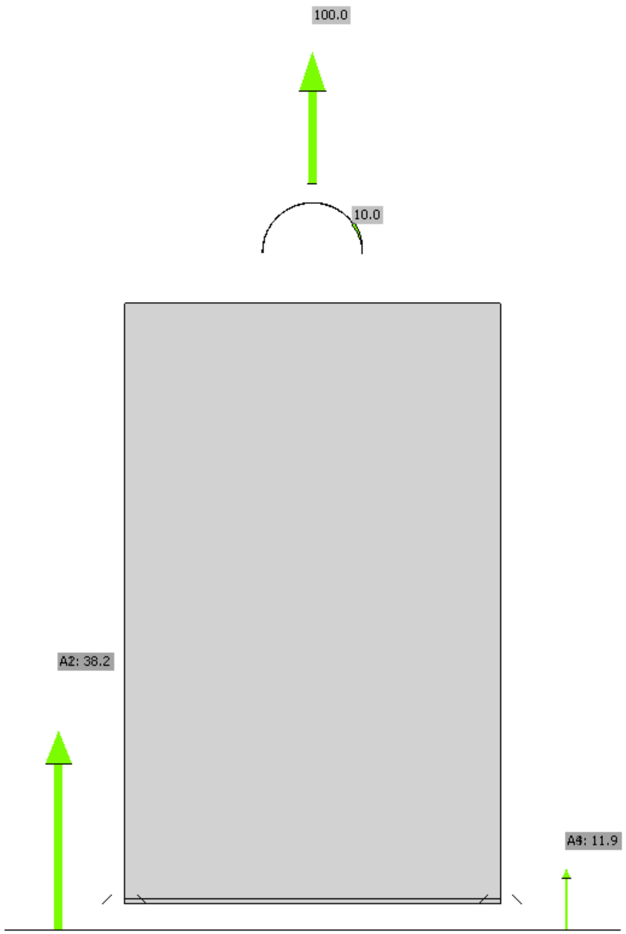


Load eccentricity

$$N_{\mathrm{Rk,cb}} = N^0_{\mathrm{Rk,cb}} \cdot \frac{A_{\mathrm{c,Nb}}}{A^0_{\mathrm{c,Nb}}} \cdot \psi_{\mathrm{s,Nb}} \cdot \psi_{\mathrm{g,Nb}} \cdot \psi_{\mathrm{ec,Nb}}$$

different loads are acting on the individual fasteners of a group

$$\psi_{\mathrm{ec,Nb}} = \frac{1}{1 + 2 \cdot e_{\mathrm{N}} / \left(4c_1\right)}$$



Supplementary reinforcement

Reinforcement instead of concrete cone resistance

Steel failure

$$N_{\mathrm{Ed,re}} \leq N_{\mathrm{Rd,re}} = \frac{N_{\mathrm{Rk,re}}}{\gamma_{\mathrm{Ms,re}}}$$

$$N_{\mathrm{Rk,re}} = \sum_{i=1}^{n_{\mathrm{re}}} A_{\mathrm{s,re,i}} \cdot f_{\mathrm{yk,re}}$$

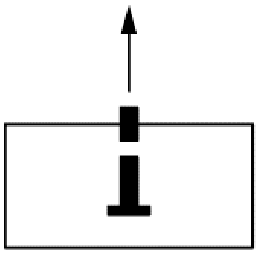
Anchorage failure

$$N_{\mathrm{Ed,re}} \leq N_{\mathrm{Rd,a}}$$

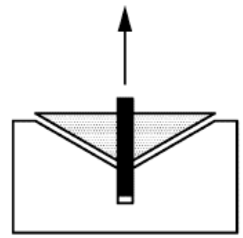
$$N_{\mathrm{Rd,a}} = \sum_{i=1}^{n_{\mathrm{re}}} N^0_{\mathrm{Rd,a,i}}$$

$$N^0_{\mathrm{Rd,a}} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{\mathrm{bd}}}{\alpha_1 \cdot \alpha_2} \leq A_{\mathrm{s,re}} \cdot f_{\mathrm{yk,re}} \cdot \frac{1}{\gamma_{\mathrm{Ms,re}}}$$

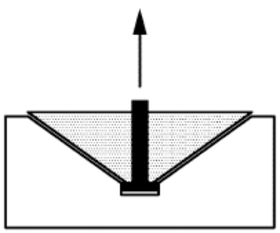
Summary – ANCHORS – Tension



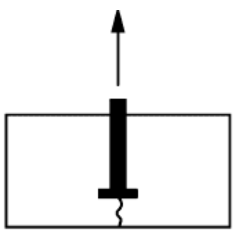
Steel failure



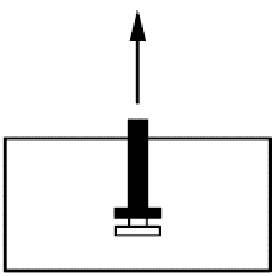
Combined pull-out and concrete failure of bonded anchors



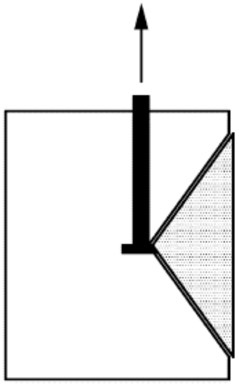
Concrete cone failure



Concrete splitting failure

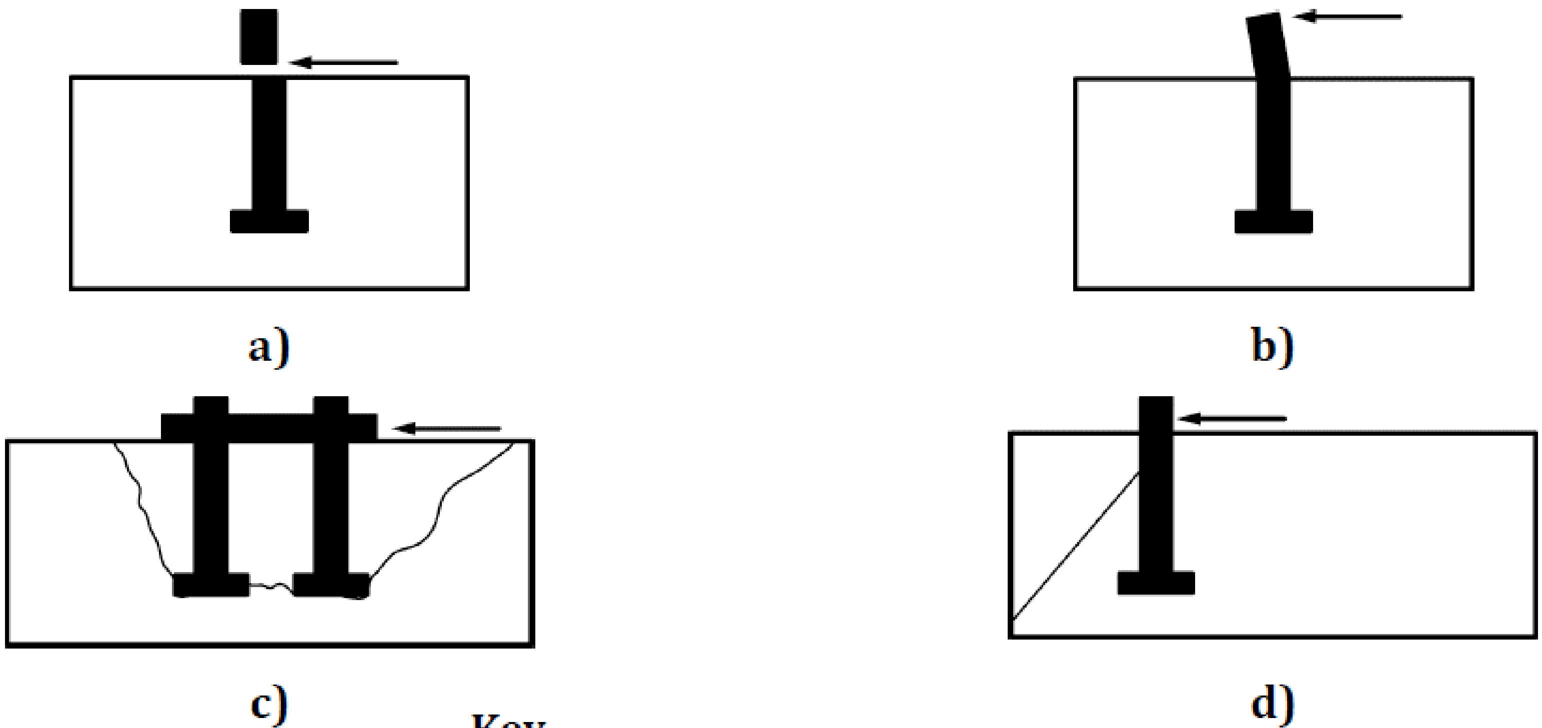


Pull-out failure



Concrete blow-out failure

Checks – ANCHORS – Shear



Key

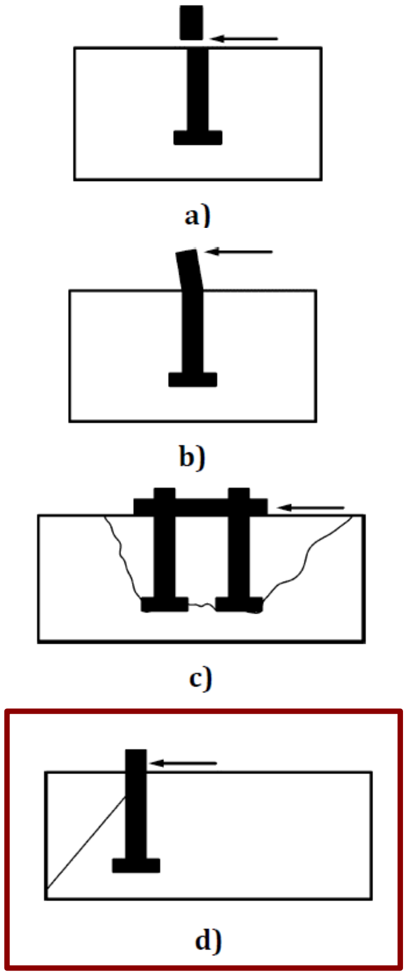
a) steel failure without lever arm

b) steel failure with lever arm

c) concrete pry-out failure

d) concrete edge failure

Load distribution in shear



V/n

V/n

V/n

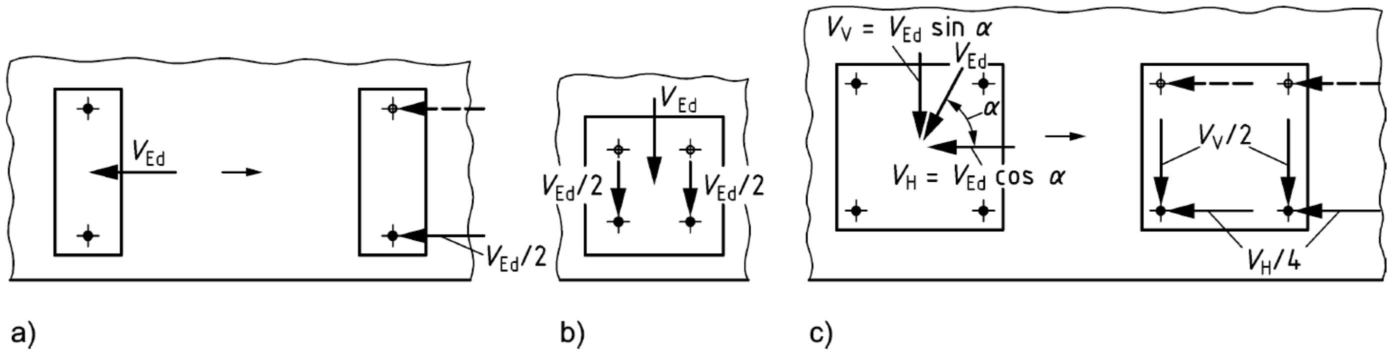
Requirement: hole clearance

Table 6.1 — Hole clearance

Dimensions in millimetres

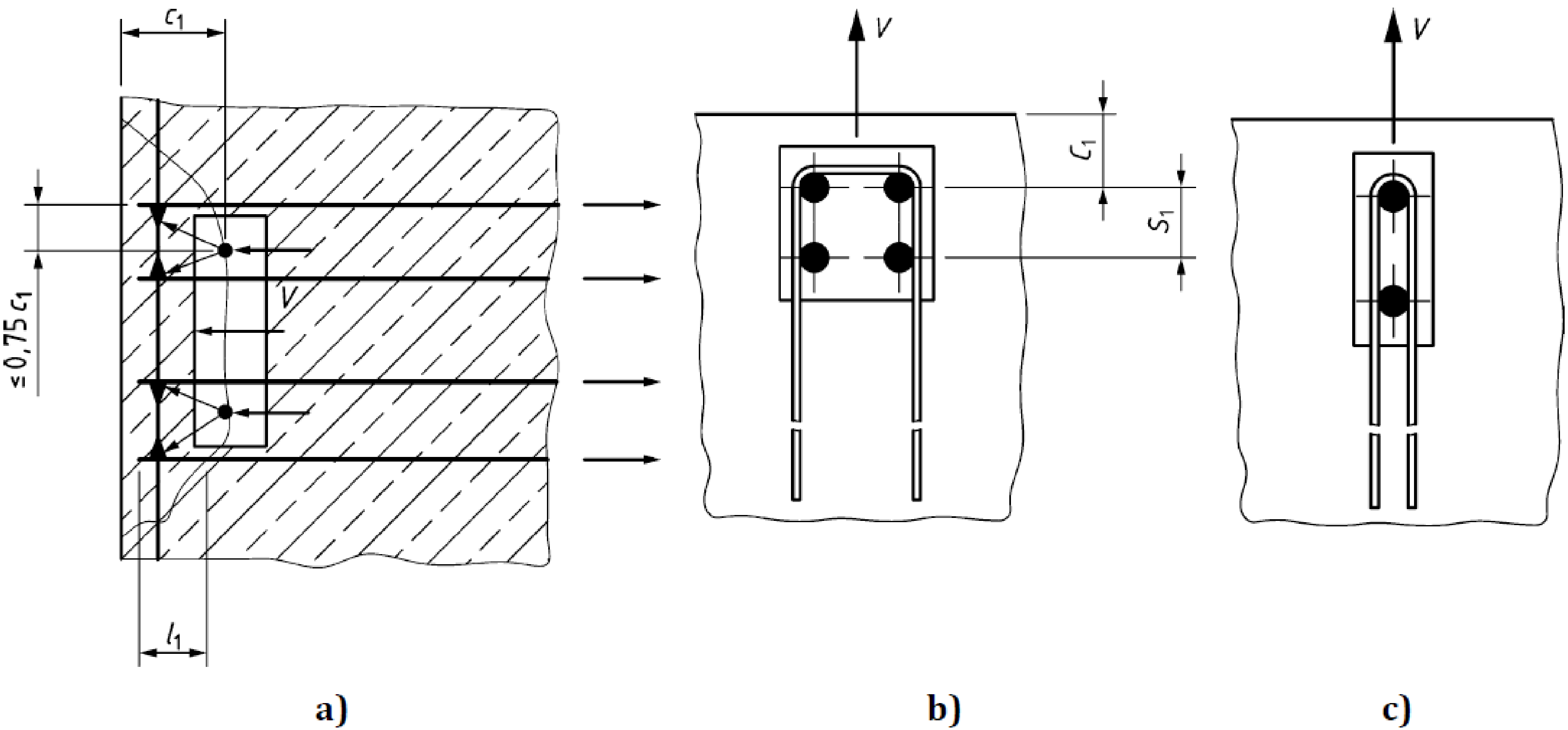
1	external diameter of fastener d[a] or d_{nom}[b]	6	8	10	12	14	16	18	20	22	24	27	30	> 30
2	diameter d_f of clearance hole in the fixture	7	9	12	14	16	18	20	22	24	26	30	33	$d + 3$ or $d_{nom} + 3$

[a] If bolt bears against the fixture.
[b] If sleeve bears against the fixture.



Supplementary reinforcement

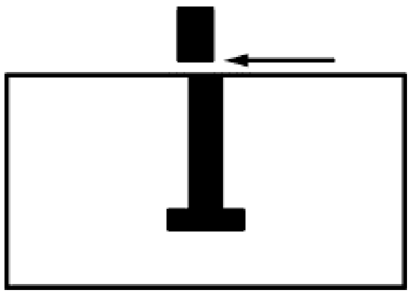
Several requirements to allow transfer shear forces by reinforcement instead by concrete edge resistance



Without lever arm

EN 1992-4 – Table 7.2

$$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$



Standard anchor (threaded rod)

$$V^0_{Rk,s} = k_6 \cdot A_s \cdot f_{uk}$$

k_6 = 0,6 for $f_{uk} \leq 500\ N/mm^2$

= 0,5 for $500\ N/mm^2 < f_{uk} \leq 1\ 000\ N/mm^2$

Without lever arm

For fasteners with a ratio $h_{ef} / d < 5$ and a concrete compressive strength class $<$ C20/25 the characteristic resistance $V^0_{Rk,s}$ should be multiplied by a factor of 0,8.

(2) The characteristic resistance of a fastener $V_{Rk,s}$ accounting for ductility of the fastener in a group and including a possible grout layer with a thickness $t_{grout} \leq d / 2$ is:

$$V_{Rk,s} = k_7 \cdot V^0_{Rk,s} \qquad (7.35)$$

where

for single fasteners $k_7 = 1$;

for fasteners in a group k_7 is given in the relevant European Technical Product Specification.

NOTE For fasteners in a group the factor k_7 for ductile steel can be assumed as $k_7 = 1$, for steel with a rupture elongation $A_5 \leq 8\%$ a value $k_7 = 0{,}8$ can be used.

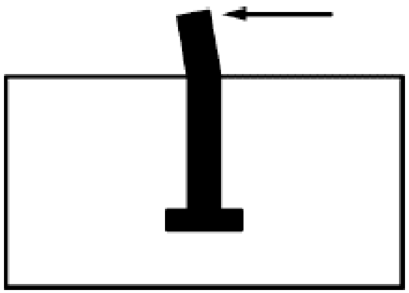
(3) If the conditions given in 6.2.2.3 (2) are fulfilled, the characteristic resistance of one fastener $V_{Rk,s}$ in uncracked concrete is:

$$V_{Rk,s} = \left(1 - 0{,}01 \cdot t_{grout}\right) \cdot k_7 \cdot V^0_{Rk,s} \qquad (7.36)$$

With lever arm

EN 1992-4 – Table 7.2

$$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$



b)

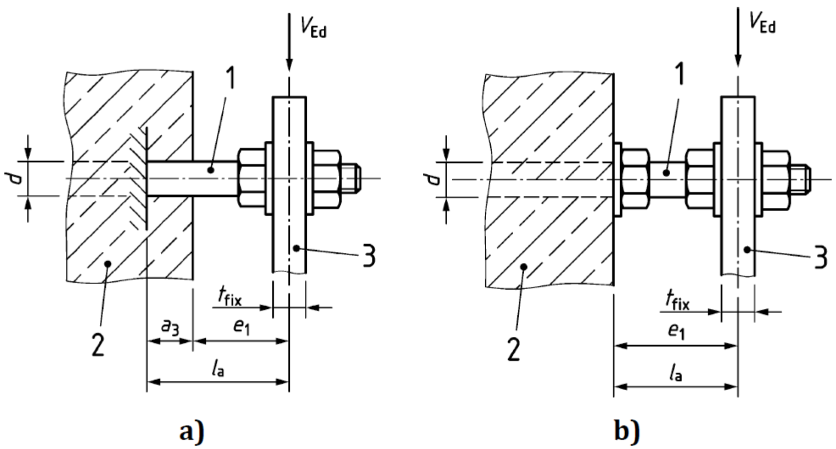
Standard anchor (threaded rod)

Actually, not a shear check but: Linear interaction of bending moment and tensile force

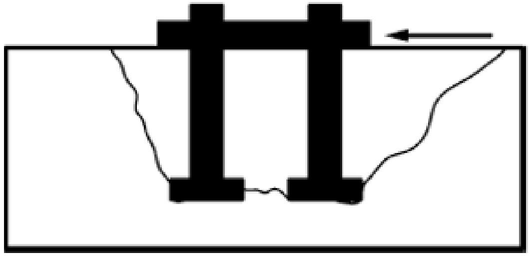
$$V_{Rk,s,M} = \frac{\alpha_M \cdot M_{Rk,s}}{l_a}$$

$$M_{Rk,s} = M^0_{Rk,s} \cdot \left(1 - N_{Ed} / N_{Rd,s}\right)$$

$$N_{Rd,s} = N_{Rk,s} / \gamma_{Ms}$$



Concrete pryout failure



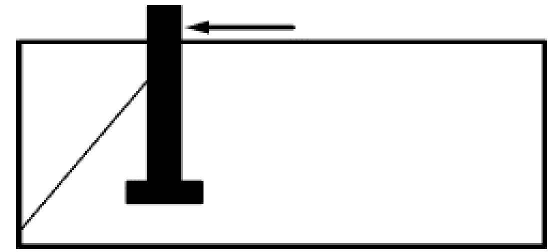
No supplementary reinforcement:

- $V_{\mathrm{Rk,cp}} = N_{\mathrm{Rd,c}} \cdot k_8$
  Concrete cone breakout × 2
- All anchors are assumed in tension in concrete cone breakout check

With supplementary reinforcement:

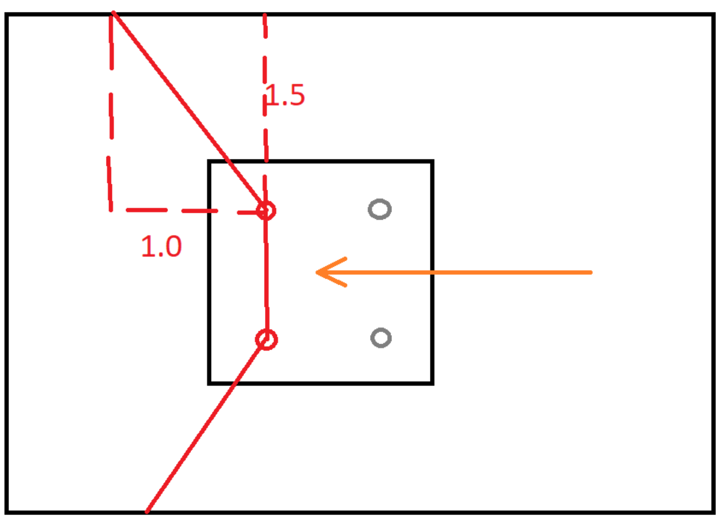
$$V_{\mathrm{Rk,cp}} = 0,75 \cdot k_8 \cdot N_{\mathrm{Rk,c}}$$

Concrete edge failure

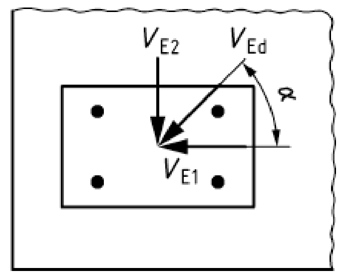


d)

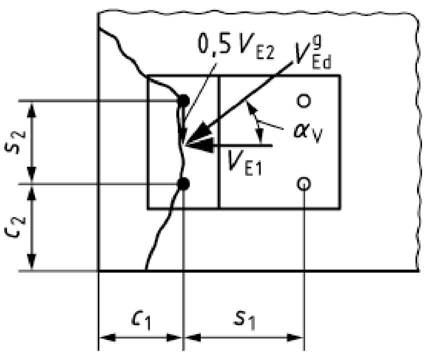
Brittle failure → Only anchors near the edge transfer shear load



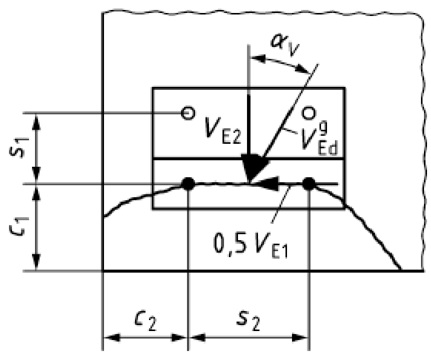
a)



b)

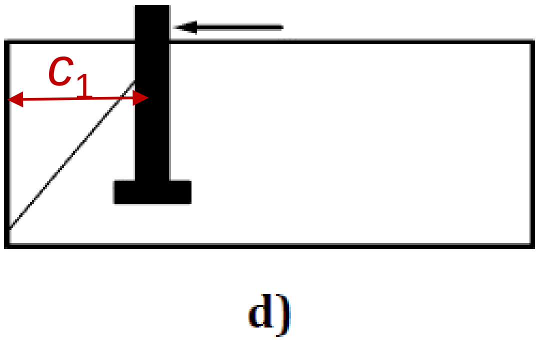


c)



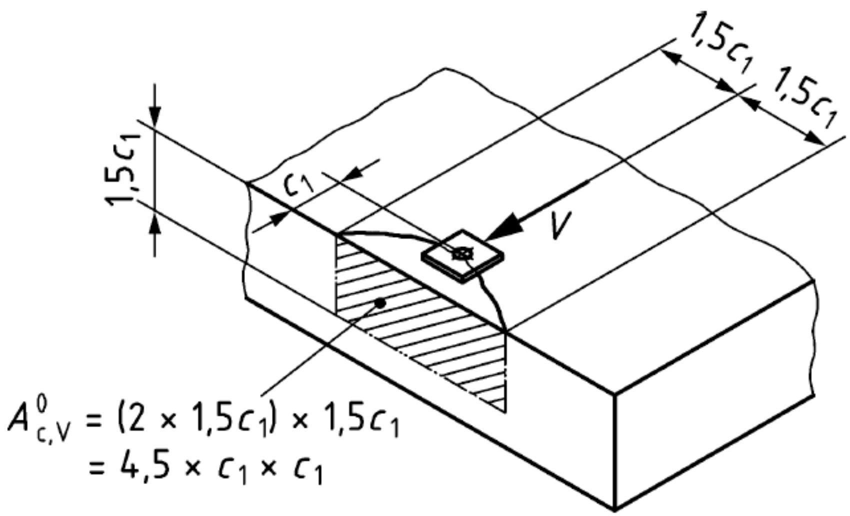
Concrete edge failure

$$V_{Ed}^{g} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$$



$$V_{Rk,c} = V_{Rk,c}^{0} \cdot \frac{A_{c,V}}{A_{c,V}^{0}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \psi_{\alpha,V} \cdot \psi_{re,V}$$

$$V_{Rk,c}^{0} = k_9 \cdot d_{nom}^{\alpha} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1,5}$$



k_9 = 1,7 for cracked concrete

= 2,4 for uncracked concrete

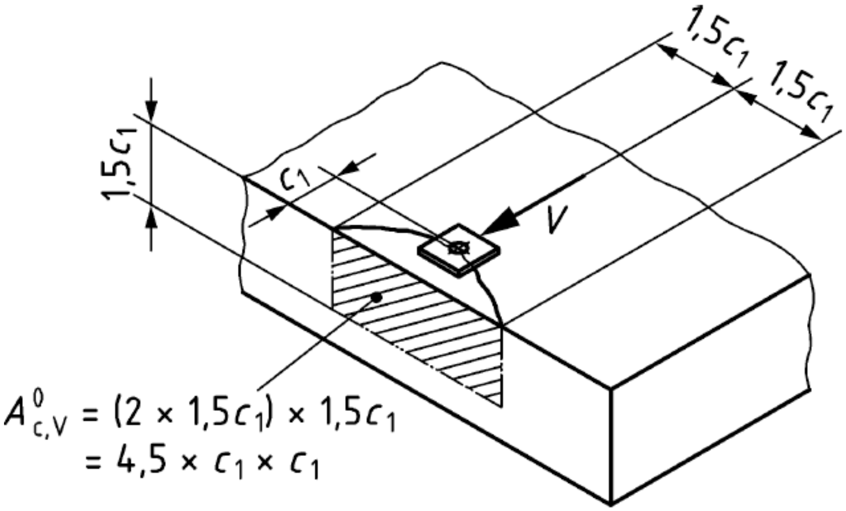
$$\alpha = 0,1 \cdot \left(\frac{l_f}{c_1}\right)^{0,5} \qquad \beta = 0,1 \cdot \left(\frac{d_{nom}}{c_1}\right)^{0,2} \qquad l_f \leq h_{ef}$$

Geometry of side surface

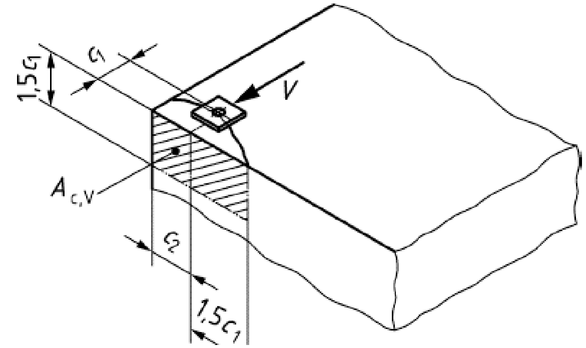
$$V_{Rk,c} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \psi_{\alpha,V} \cdot \psi_{re,V}$$

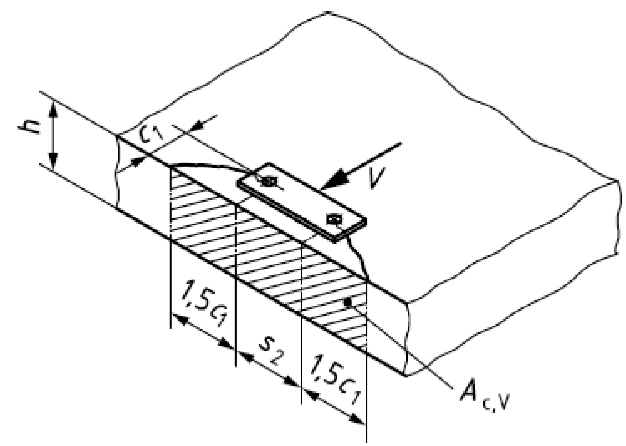
reference projected area $A^0_{c,V}$

$$A^0_{c,V} = 4{,}5 c_1^2$$



actual projected area $A_{c,V}$



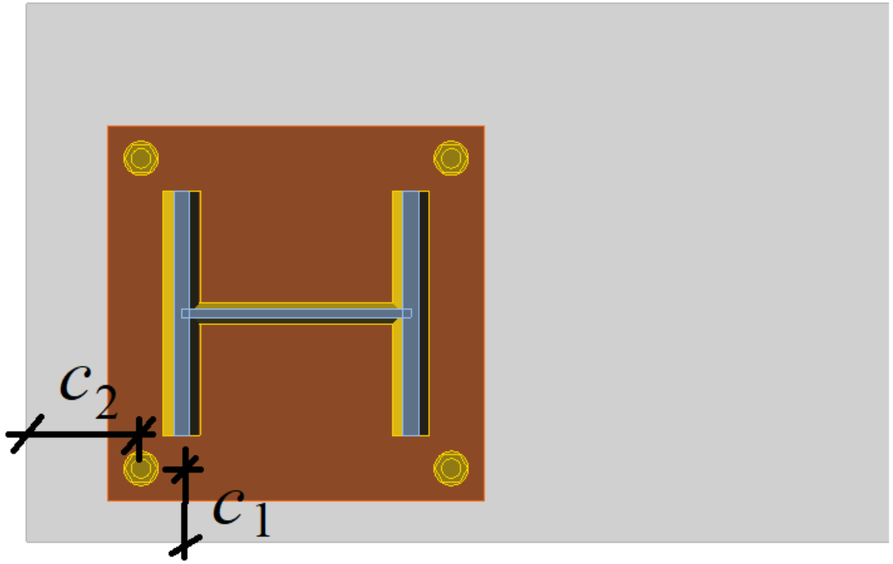


Corner proximity

$$V_{\mathrm{Rk,c}} = V^{0}_{\mathrm{Rk,c}} \cdot \frac{A_{\mathrm{c,V}}}{A^{0}_{\mathrm{c,V}}} \cdot \psi_{\mathrm{s,V}} \cdot \psi_{\mathrm{h,V}} \cdot \psi_{\mathrm{ec,V}} \cdot \psi_{\alpha,\mathrm{V}} \cdot \psi_{\mathrm{re,V}}$$

disturbance of the distribution of stresses in the concrete due to further edges of the concrete member on the shear resistance

$$\psi_{\mathrm{s,V}} = 0,7 + 0,3 \cdot \frac{c_2}{1,5\, c_1} \leq 1$$

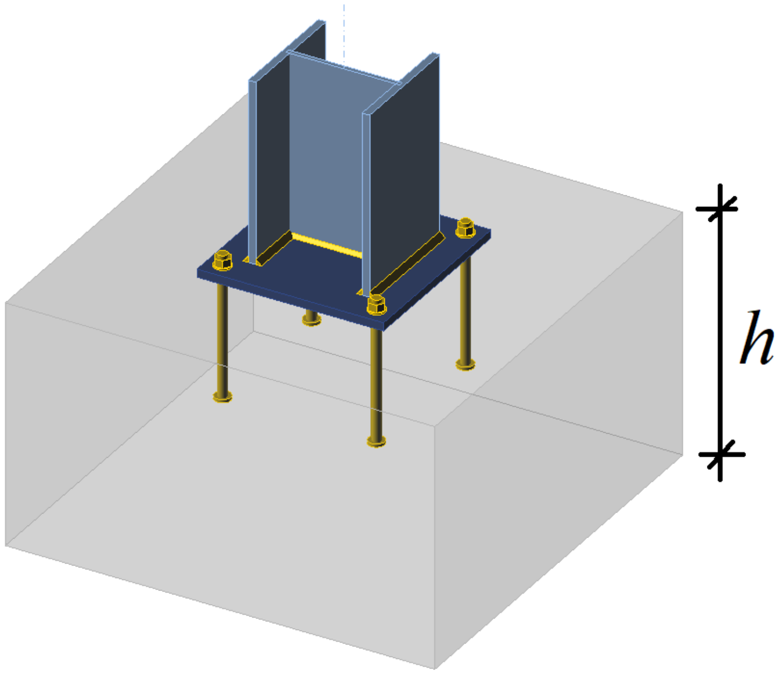


Concrete pad thickness

$$V_{\text{Rk,c}} = V^0_{\text{Rk,c}} \cdot \frac{A_{\text{c,V}}}{A^0_{\text{c,V}}} \cdot \psi_{\text{s,V}} \cdot \boxed{\psi_{\text{h,V}}} \cdot \psi_{\text{ec,V}} \cdot \psi_{\alpha,\text{V}} \cdot \psi_{\text{re,V}}$$

concrete edge resistance does not decrease proportionally to the member thickness as assumed by the ratio $\frac{A_{\text{c,V}}}{A^0_{\text{c,V}}}$

$$\psi_{\text{h,V}} = \left(\frac{1{,}5c_1}{h}\right)^{0{,}5} \geq 1$$

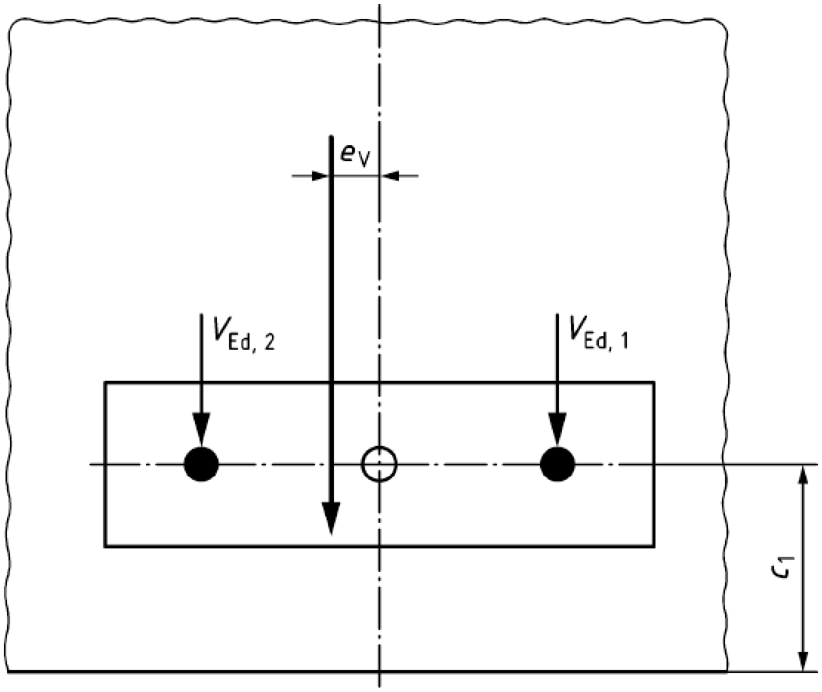


Load eccentricity

$$V_{\mathrm{Rk,c}} = V^0_{\mathrm{Rk,c}} \cdot \frac{A_{\mathrm{c,V}}}{A^0_{\mathrm{c,V}}} \cdot \psi_{\mathrm{s,V}} \cdot \psi_{\mathrm{h,V}} \cdot \boxed{\psi_{\mathrm{ec,V}}} \cdot \psi_{\alpha,\mathrm{V}} \cdot \psi_{\mathrm{re,V}}$$

group effect when different shear loads are acting on the individual fasteners of a group

$$\psi_{\mathrm{ec,V}} = \frac{1}{1 + 2 \cdot e_{\mathrm{V}} / \left(3 c_1\right)} \leq 1$$

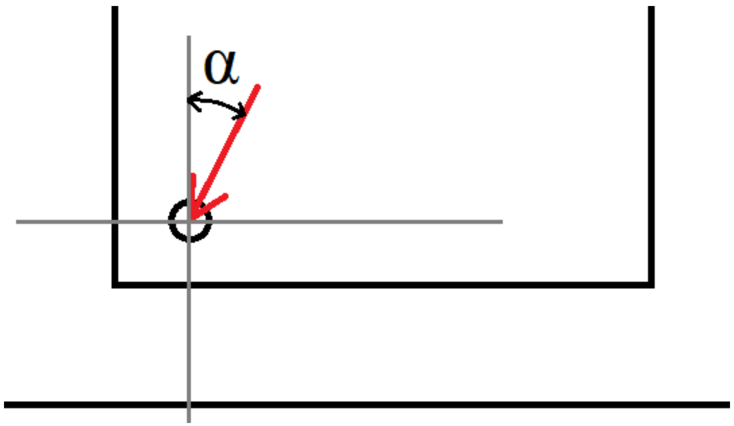


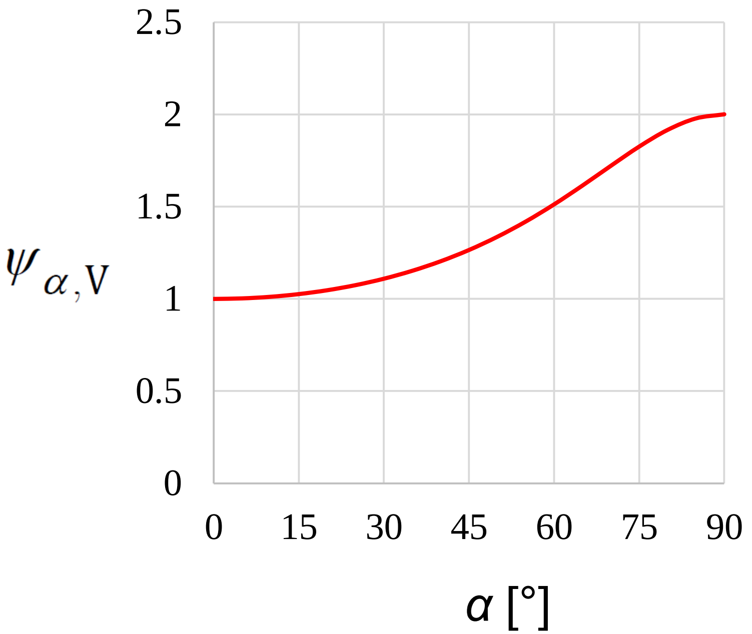
Load eccentricity

$$V_{Rk,c} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \boxed{\psi_{\alpha,V}} \cdot \psi_{re,V}$$

group effect when different shear loads are acting on the individual fasteners of a group

$$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos\alpha_V)^2 + (0,5 \cdot \sin\alpha_V)^2}} \geq 1$$





Reinforcement

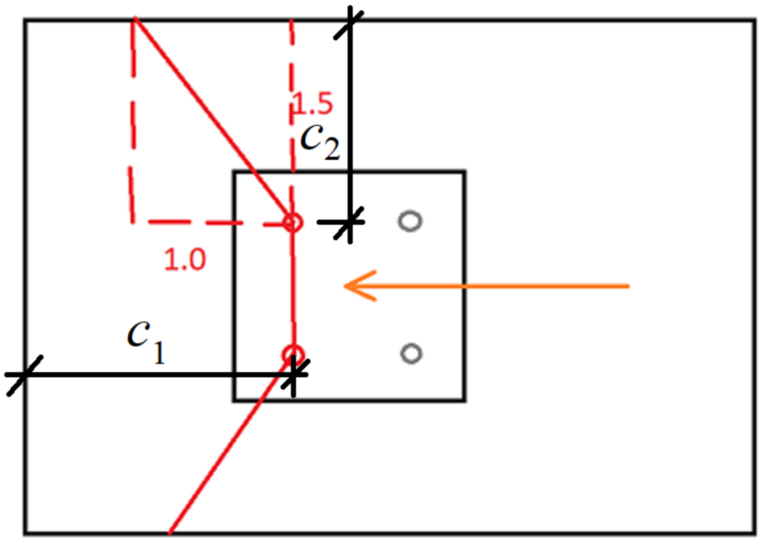
$$V_{\mathrm{Rk,c}} = V^{0}_{\mathrm{Rk,c}} \cdot \frac{A_{\mathrm{c,V}}}{A^{0}_{\mathrm{c,V}}} \cdot \psi_{\mathrm{s,V}} \cdot \psi_{\mathrm{h,V}} \cdot \psi_{\mathrm{ec,V}} \cdot \psi_{\alpha,\mathrm{V}} \cdot \psi_{\mathrm{re,V}}$$

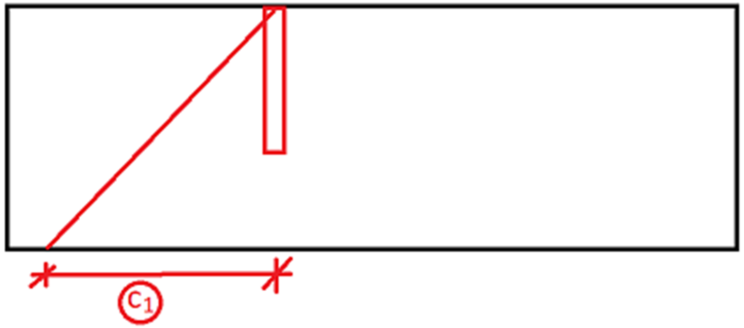
effect of the reinforcement located on the edge

$\psi_{\mathrm{re,V}} = 1{,}0$ without edge reinforcement or stirrups

$\psi_{\mathrm{re,V}} = 1{,}4$ cracked concrete with edge reinforcement and stirrups; $h_{ef} \geq 2{,}5$ concrete cover of edge reinforcement

Thin, narrow concrete pad





- Increase in c_1 → decrease in load resistance
  $A_{c,V}$ is increasing slower than $A_{c,V}^0$

$$c'_1 = \max\left\{\frac{c_{2,\max}}{1,5}; \frac{h}{1,5}; \frac{s_{2,\max}}{3}\right\}$$

Supplementary reinforcement

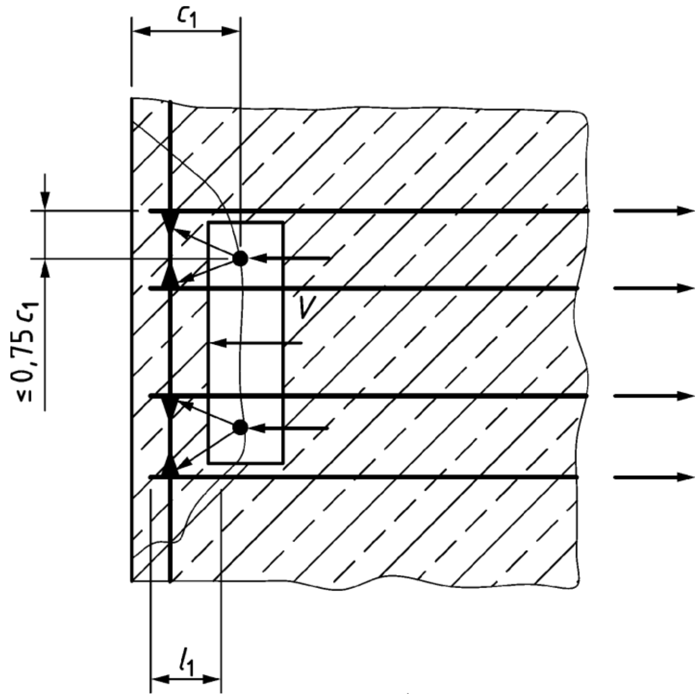
Steel failure

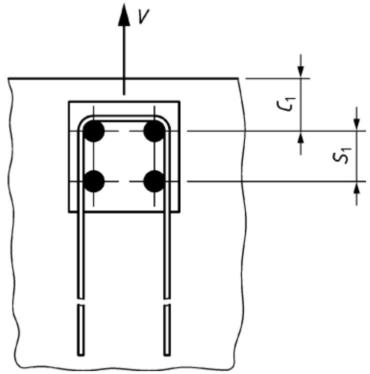
$$N_{\mathrm{Rk,re}} = k_{10} \sum_{i=1}^{n_{\mathrm{re}}} A_{\mathrm{s,re,i}} \cdot f_{\mathrm{yk,re}}$$

Anchorage failure

$$N_{\mathrm{Rd,a}} = \sum_{i=1}^{n_{\mathrm{re}}} N^{0}_{\mathrm{Rd,a}}$$

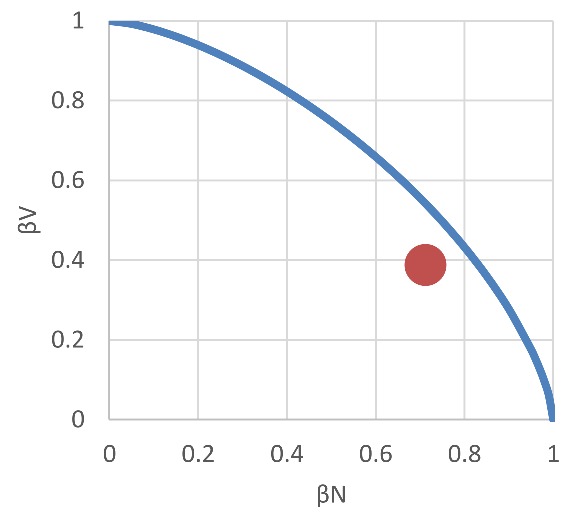
$$N^{0}_{\mathrm{Rd,a}} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{\mathrm{bd}}}{\alpha_1 \cdot \alpha_2} \le A_{\mathrm{s,re}} \cdot f_{\mathrm{yk,re}} \cdot \frac{1}{\gamma_{\mathrm{Ms,re}}}$$





Combined tension and shear

Without reinforcement:



Steel failure $$\left(\frac{N_{\mathrm{Ed}}}{N_{\mathrm{Rd,s}}}\right)^2 + \left(\frac{V_{\mathrm{Ed}}}{V_{\mathrm{Rd,s}}}\right)^2 \leq 1$$

Concrete failure $$\left(\frac{N_{\mathrm{Ed}}}{N_{\mathrm{Rd,i}}}\right)^{1,5} + \left(\frac{V_{\mathrm{Ed}}}{V_{\mathrm{Rd,i}}}\right)^{1,5} \leq 1$$

With reinforcement:

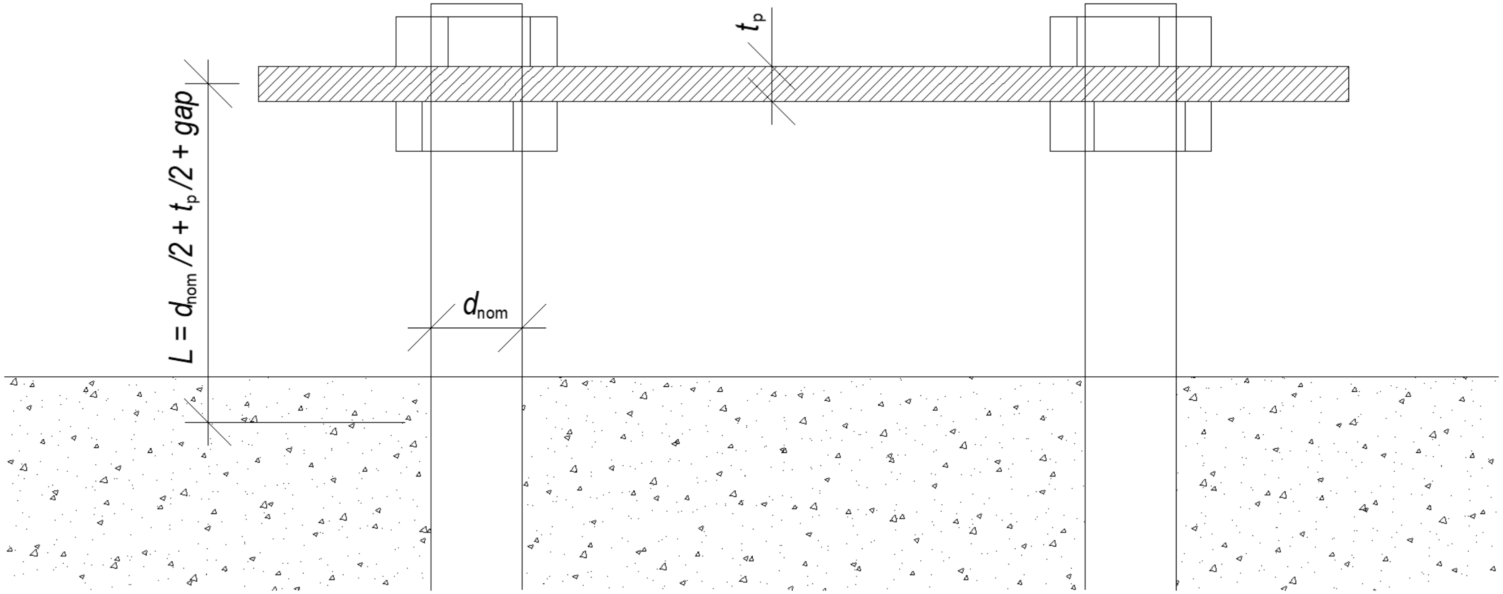
$$\left(\frac{N_{\mathrm{Ed}}}{N_{\mathrm{Rd,i}}}\right)^{k_{11}} + \left(\frac{V_{\mathrm{Ed}}}{V_{\mathrm{Rd,i}}}\right)^{k_{11}} \leq 1$$

$$k_{11} = 2/3$$

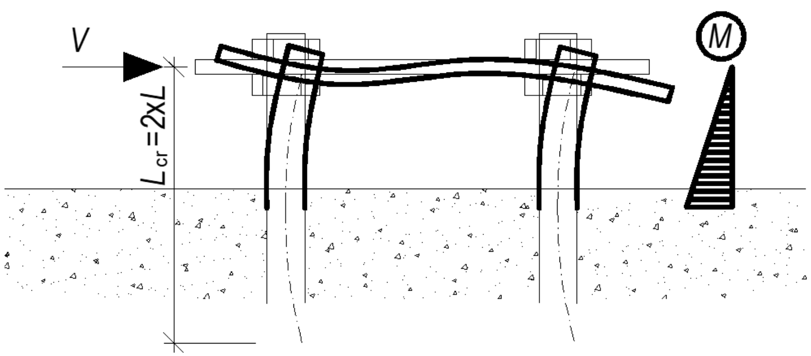
Concrete checks

- Cracked concrete should be assumed unless proven otherwise
- EN 1992-4 and other anchorage codes are for short anchors, not much reinforced concrete
- If EN 1992-4 does not pass →
  use EN 1992-1-1 (strut and tie method)

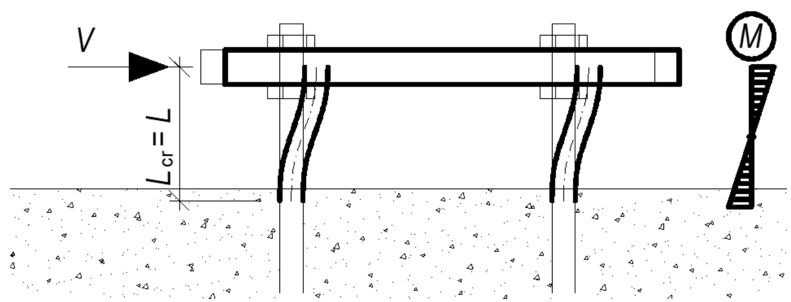
Stand-off anchors



Stiff anchors SAFE

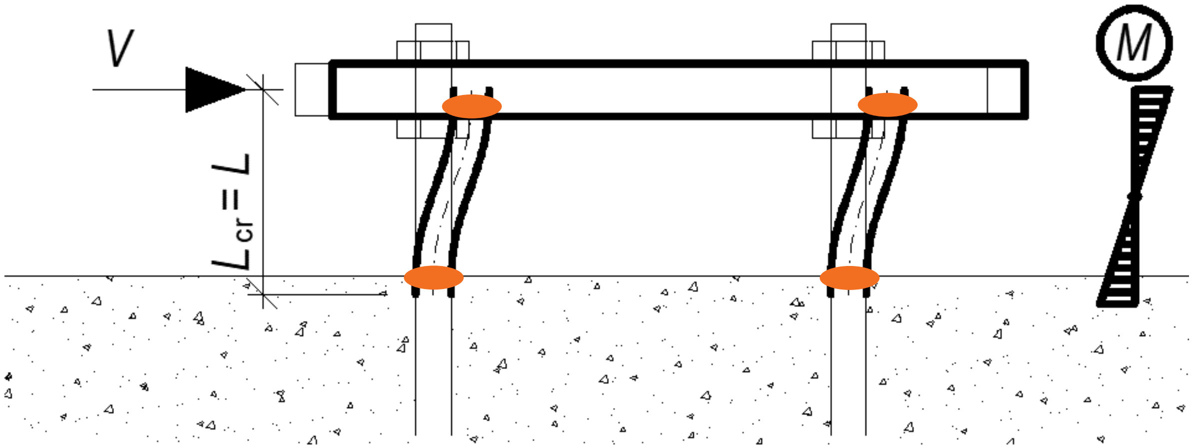


Stiff base plate REALISTIC



Stand-off anchors

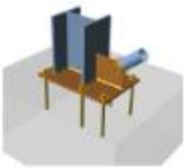
- Bar elements – beam theory
- Assumed circular cross-section reduced by threads
- Two plastic hinges may form

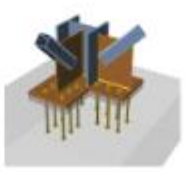


Stand-off anchors

- Steel checks
  - Bending
  - Shear
  - Tension
  - Compression (incl. buckling)
  - Linear interaction of loading
- Concrete checks

Column base – Shear



- Friction
- Anchors
- Shear lug

- No combination = safest
- Combination of friction and anchors
  - EN 1993-1-8
  - only under certain circumstances (FIB 58)
    - the thickness of the grout layer exceeds one-half the anchor diameter,
    - the anchorage capacity is governed by a near-edge condition,
    - the anchorage is intended to resist earthquake loads.

Column base – Shear – Friction

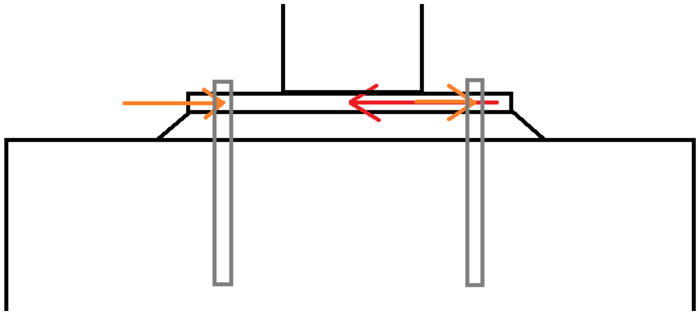
$$F_{\mathrm{f,Rd}} = N_{\mathrm{c,Ed,inf}} \cdot C_{\mathrm{fd}}$$

Minimal design compressive force

Friction coefficient

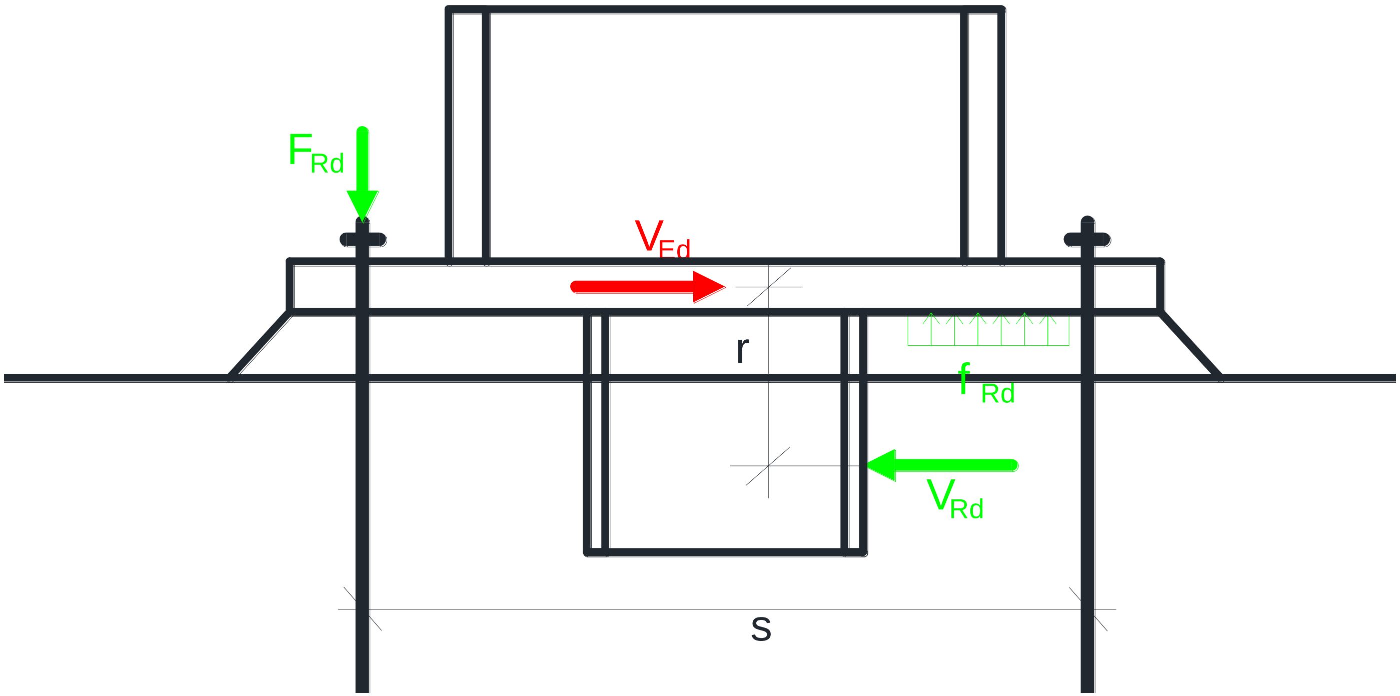
Anchors

Shear force taken by anchors

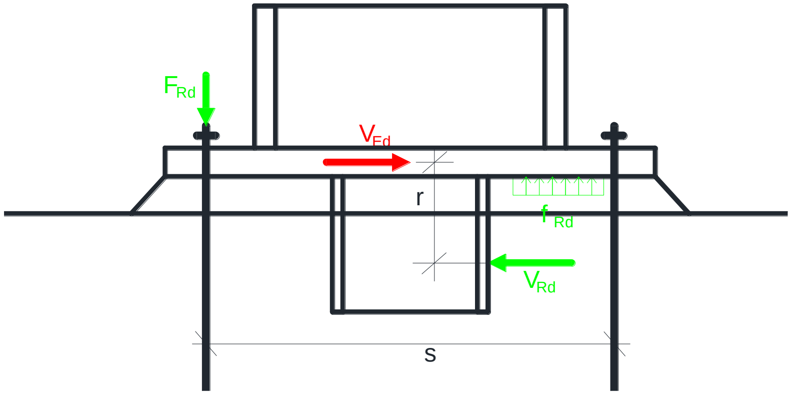


Column base – Shear
Shear lug

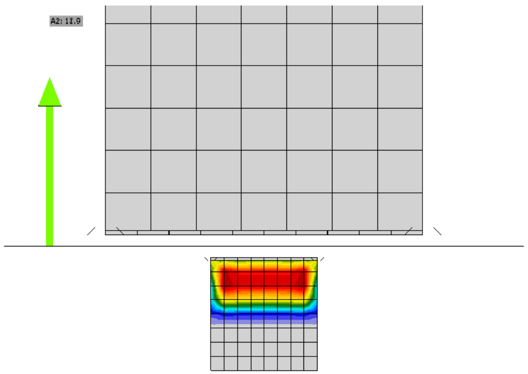
- Tensile forces in anchors – force equilibrium



Shear lug
Steel check



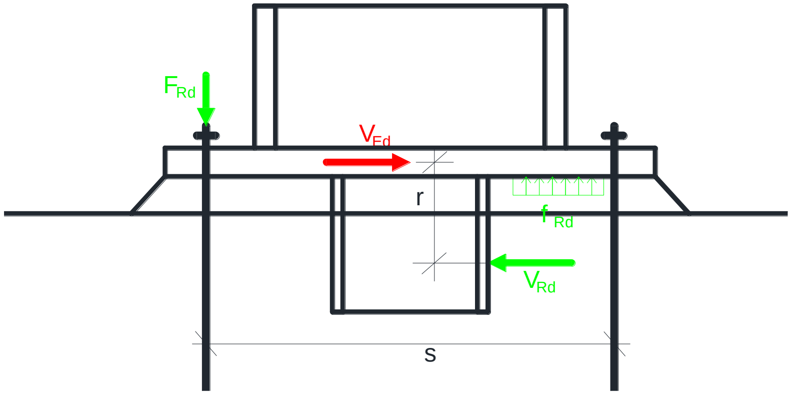
- Beam theory:
  - simple, incorrect, safe
  - shear lug is short



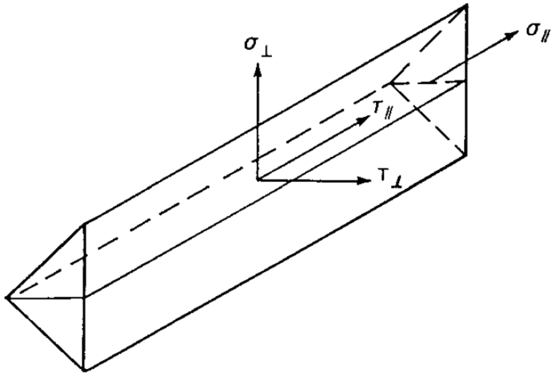
$$V_{pl,Rd} = \frac{A_v \left(f_y / \sqrt{3}\right)}{\gamma_{M0}}$$

$$\rho = \left(\frac{2\,V_{Ed}}{V_{pl,Rd}} - 1\right)^2 \qquad (1-\rho)\,f_y \qquad M_{pl,Rd} = \frac{W_{pl}\,f_y}{\gamma_{M0}}$$

Shear lug
Weld check

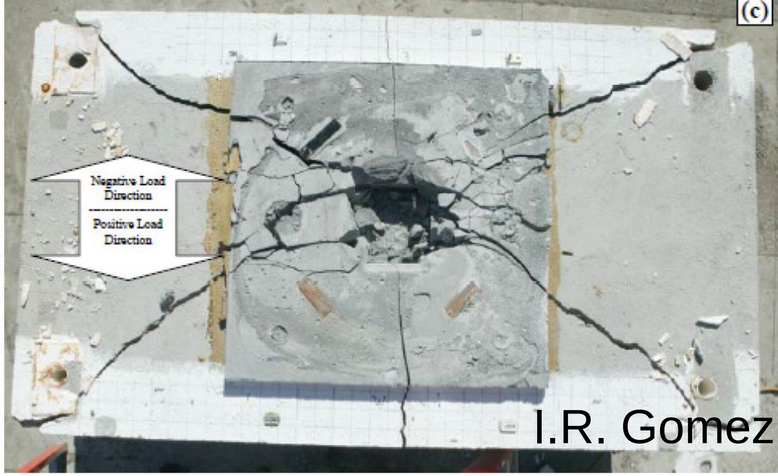


- Beam theory:
  - simple, incorrect, safe
  - shear lug is short
- Weld loaded by
  - shear $\rightarrow \tau_{ll}$
  - bending moment $\rightarrow \sigma_{\perp}, \tau_{\perp}$



$$[\sigma_{\perp}^2 + 3\,(\tau_{\perp}^2 + \tau_{\parallel}^2)]^{0,5} \leq f_u / (\beta_w\, \gamma_{M2}) \quad \text{and} \quad \sigma_{\perp} \leq 0.9\, f_u / \gamma_{M2}$$

Shear lug
Concrete check



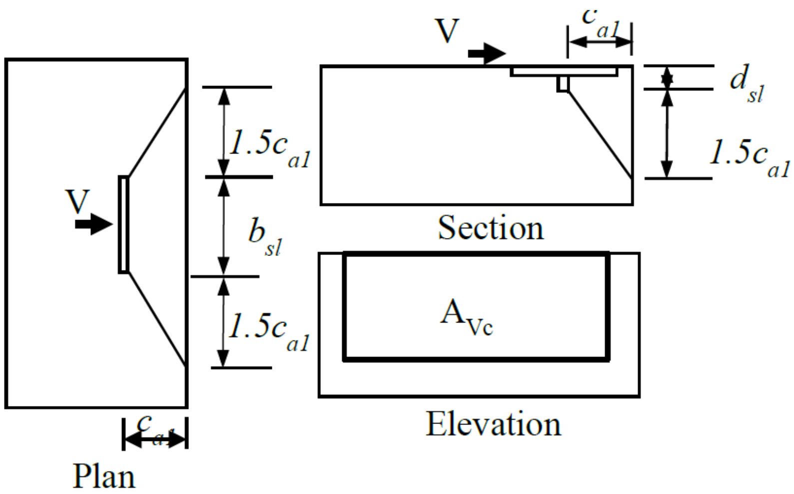
- Bearing: $V_{c,Rd} = A\sigma_{Rd,max}$

  $$\sigma_{Rd,max} \cong f_{cd}$$

- Concrete edge failure:
  - missing in EC

$$V_{cb,sl} = \frac{A_{Vc}}{A_{Vco}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$$

$$V_b = 7\sqrt{f_c'}\, c_{a1}^{1.5}$$



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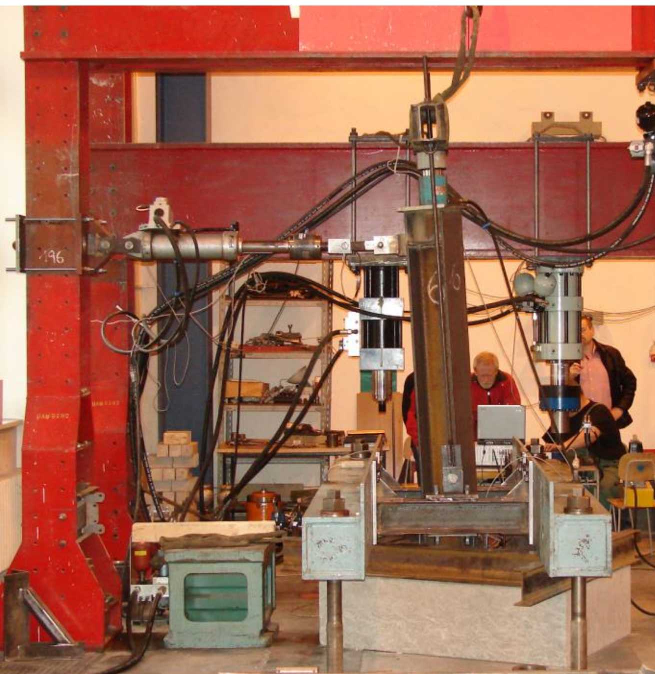
Thank you for your attention



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