$$N_{\mathrm{Rd,a}}^{0} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{\mathrm{bd}}}{\alpha_1 \cdot \alpha_2} \leq A_{\mathrm{s,re}} \cdot f_{\mathrm{yk,re}} \cdot \frac{1}{\gamma_{\mathrm{Ms,re}}} \tag{7.33}$$

l_1 is the anchorage length in the break-out body (see Figure 7.2); l_1 shall be larger than the minimum anchorage length in 7.2.1.2 (2)d);

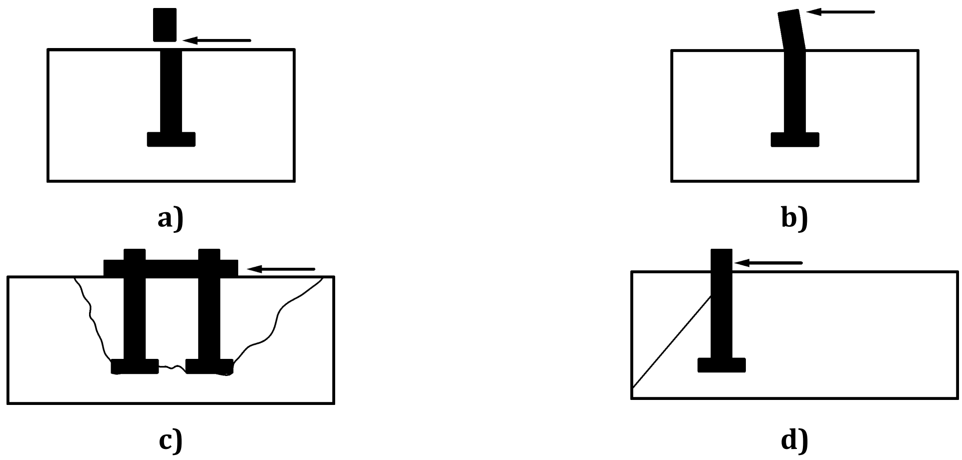
f_{bd} is the design bond strength according to EN 1992–1-1:2004, 8.4.2;

α_1, α_2 are the influencing factors according to EN 1992–1-1:2004, 8.4.4.

7.2.2 Shear load

7.2.2.1 Required verifications

The verifications of Table 7.2 apply. The failure modes addressed are given in Figure 7.9:



Key

a) steel failure without lever arm

b) steel failure with lever arm

c) concrete pry-out failure

d) concrete edge failure

Figure 7.9 — Failure modes of headed and post-installed fasteners under shear load

Table 7.2 — Required verifications for headed and post-installed fasteners in shear

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	**Steel failure of fastener without lever arm**	$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	$V_{Ed}^{h} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	
2	**Steel failure of fastener with lever arm**	$V_{Ed} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V_{Ed}^{h} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	
3	**Concrete pry-out failure**	$V_{Ed} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$		$V_{Ed}^{g} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$ [a]
4	**Concrete edge failure**	$V_{Ed} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$		$V_{Ed}^{g} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$
5	**Steel failure of supplementary reinforcement** [b]	$N_{Ed,re} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Ed,re}^{h} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
6	**Anchorage failure of supplementary reinforcement** [b]	$N_{Ed,re} \leq N_{Rd,a}$	$N_{Ed,re}^{h} \leq N_{Rd,a}$	

[a] Exception see 7.2.2.4 (4).

[b] The tension force acting on the reinforcement is calculated from V_{Ed} according to Formula (6.6).

7.2.2.2 Detailing of supplementary reinforcement

(1) When the design relies on supplementary reinforcement, concrete edge failure according to Table 7.2 and 7.2.2.5 need not to be verified but the supplementary reinforcement shall be designed according to 7.2.2.6 to resist the total load. The supplementary reinforcement may be in the form of a surface reinforcement (see Figure 7.10 a)) or in the shape of stirrups or loops (see Figure 7.10 b) and c)).

(2) The supplementary reinforcement shall be anchored outside the assumed failure body with an anchorage length l_{bd} according to EN 1992-1-1. In reinforced concrete members the tension in the anchored reinforcing bar shall be transferred to the reinforcement in the member by adequate lapping. Otherwise the load transfer from the supplementary reinforcement to the structural member shall be verified by an appropriate model, e.g. strut and tie model.

(3) If the shear force is taken up by a reinforcement according to Figure 7.10 a), the bars shall only be assumed to be effective if the following requirements are fulfilled.

a) Where supplementary reinforcement has been sized for the most loaded fastener, the same reinforcement is provided around all fasteners considered effective for concrete edge failure.

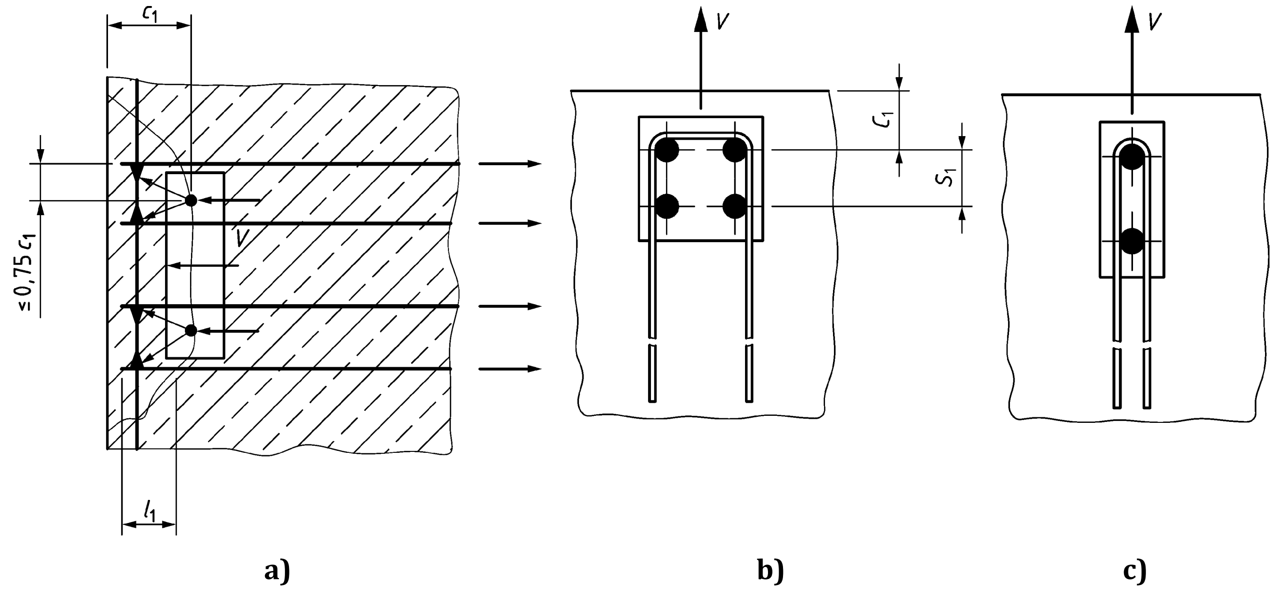
b) The supplementary reinforcement consists of ribbed bars with $f_{yk} \leq 600\ \text{N/mm}^2$ and the diameter ϕ is not larger than 16 mm. The mandrel diameter, ϕ_m, complies with EN 1992-1-1.

c) Bars are within a distance of $0{,}75c_1$ from the fastener.

d) The anchorage length l_1 in the concrete breakout body is at least min $l_1 = 10\phi$ for straight bars with or without welded transverse bars and $\min l_1 = 4\phi$ for bars with a hook, bend or loop. Exception see 7.2.2.2 (4).

e) The breakout body assumed should be the same as that for calculating the resistance for concrete edge failure (see 6.2.2.2 and 7.2.2.5).

f) Reinforcement along the edge of the member is provided and designed for the forces according to an appropriate strut and tie model. As a simplification an angle of the compression struts of 45° may be assumed.



Key

a) surface reinforcement to take up shear forces with simplified strut and tie model to design edge reinforcement

b) supplementary reinforcement in the shape of stirrups

c) supplementary reinforcement in the shape of loops

Figure 7.10 — Reinforcement to take up shear forces acting on a fastening

(4) If the shear forces are taken up by a supplementary reinforcement detailed in the shape of stirrups or loops (see Figure 7.10 b) and c)), the reinforcement shall enclose and be in contact with the shaft of the fastener and be positioned as closely as possible to the fixture, because direct force transfer from the fastener to the supplementary reinforcement is assumed and therefore no verification of the anchorage length in the breakout body is required.

7.2.2.3 Steel failure of fastener

7.2.2.3.1 Shear load without lever arm

(1) The characteristic resistance of a single fastener in case of steel failure $V^0_{\text{Rk,s}}$ is given in the relevant European Technical Product Specification.

NOTE For a single fastener made out of carbon steel without sleeve in the sheared section (threaded rod) and without significant reduction in cross-section along its total length $V^0_{\text{Rk,s}}$ can be calculated as follows:

$$V_{\mathrm{Rk,s}}^{0} = k_6 \cdot A_\mathrm{s} \cdot f_\mathrm{uk} \tag{7.34}$$

where

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

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

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

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

$$V_{\mathrm{Rk,s}} = k_7 \cdot V_{\mathrm{Rk,s}}^{0} \tag{7.35}$$

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 $V_{\mathrm{Rk,s}}$ in uncracked concrete is:

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

7.2.2.3.2 Shear load with lever arm

The characteristic resistance in case of steel failure $V_{\mathrm{Rk,s,M}}$ shall be obtained from Formula (7.37):

$$V_{\mathrm{Rk,s,M}} = \frac{\alpha_\mathrm{M} \cdot M_{\mathrm{Rk,s}}}{l_\mathrm{a}} \tag{7.37}$$

with

α_M, l_a see 6.2.2.3 (3)

$$M_{\mathrm{Rk,s}} = M_{\mathrm{Rk,s}}^{0} \cdot \left(1 - N_\mathrm{Ed} / N_{\mathrm{Rd,s}}\right) \tag{7.38}$$

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

The characteristic resistance under tension load in case of steel failure $N_{Rk,s}$, the partial factor γ_{Ms} and the characteristic bending resistance of a single fastener $M^0_{Rk,s}$ are given in the relevant European Technical Product Specification where applicable.

Formula (7.38) can only be used for tension load N_{Ed}; where N_{Ed} is a compression load the fastener should be designed as a steel element according to EN 1993-1-8.

7.2.2.4 Concrete pry-out failure

(1) Fastenings may fail due to a concrete pry-out failure at the side opposite to load direction. Pull-out failure may also occur due to a tension force introduced in the fasteners by the shear load. For reason of simplicity this effect is not verified explicitly, but implicitly accounted for in the verification for pry-out failure, where relevant.

NOTE The tension force is caused by the eccentricity between the applied shear force and the resultant of the resistance in the concrete.

(2) The corresponding characteristic resistance $V_{Rk,cp}$ shall be calculated for fastenings with headed or mechanical post-installed fasteners as follows:

— for fastenings without supplementary reinforcement

$$V_{Rk,cp} = k_8 \cdot N_{Rk,c} \quad (7.39a)$$

— for fastenings with supplementary reinforcement

$$V_{Rk,cp} = 0,75 \cdot k_8 \cdot N_{Rk,c} \quad (7.39b)$$

where

k_8 is a factor to be taken from the relevant European Technical Product Specification

$N_{Rk,c}$ is determined according to 7.2.1.4 for a single fastener or all fasteners in a group loaded in shear.

(3) The characteristic resistance $V_{Rk,cp}$ shall be calculated for fastenings with bonded fasteners as follows:

— for fastenings without supplementary reinforcement

$$V_{Rk,cp} = k_8 \cdot \min\{N_{Rk,c}\,;\, N_{Rk,p}\} \quad (7.39c)$$

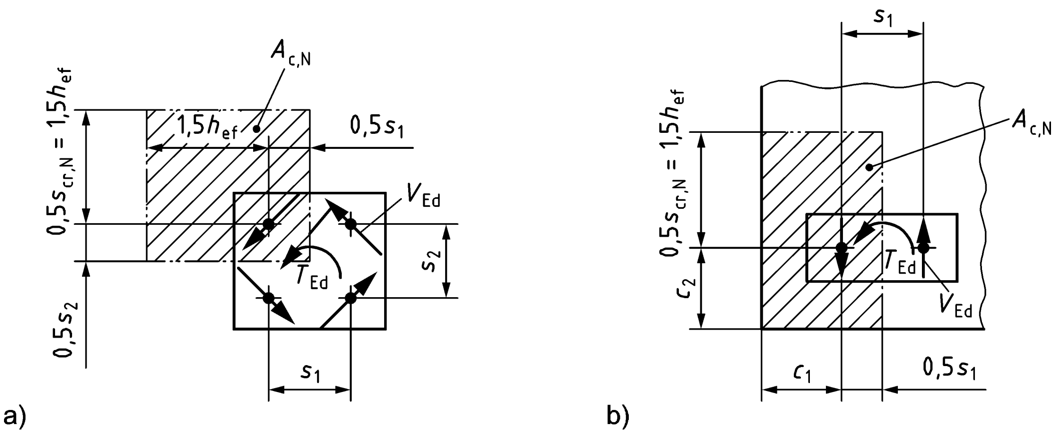
— for fastenings with supplementary reinforcement

$$V_{Rk,cp} = 0,75 \cdot k_8 \cdot \min\{N_{Rk,c}\,;\, N_{Rk,p}\} \quad (7.39d)$$

where

$N_{Rk,p}$ is determined according to 7.2.1.6 for a single fastener or all fasteners in a group loaded in shear.

(4) For anchor groups of fasteners with shear forces (or components thereof) on the individual fasteners in opposing directions (e.g. fastenings loaded predominantly by a torsion moment), the most unfavourable fastener shall be verified. When calculating the areas $A_{c,N}$ and $A_{p,N}$ it shall be assumed that there is a virtual edge (c = 0,5s) in the direction of the neighbouring fastener(s) (see Figure 7.11).



Key

a) group of four fasteners without edge influence

b) group of two fasteners located in a corner

Figure 7.11 — Calculation of area $A_{c,N}$ for pryout failure for a group of fasteners with shear load (or components thereof) on fasteners acting in opposing directions – Examples, assuming $s_{cr,N} = 3h_{ef}$

7.2.2.5 Concrete edge failure

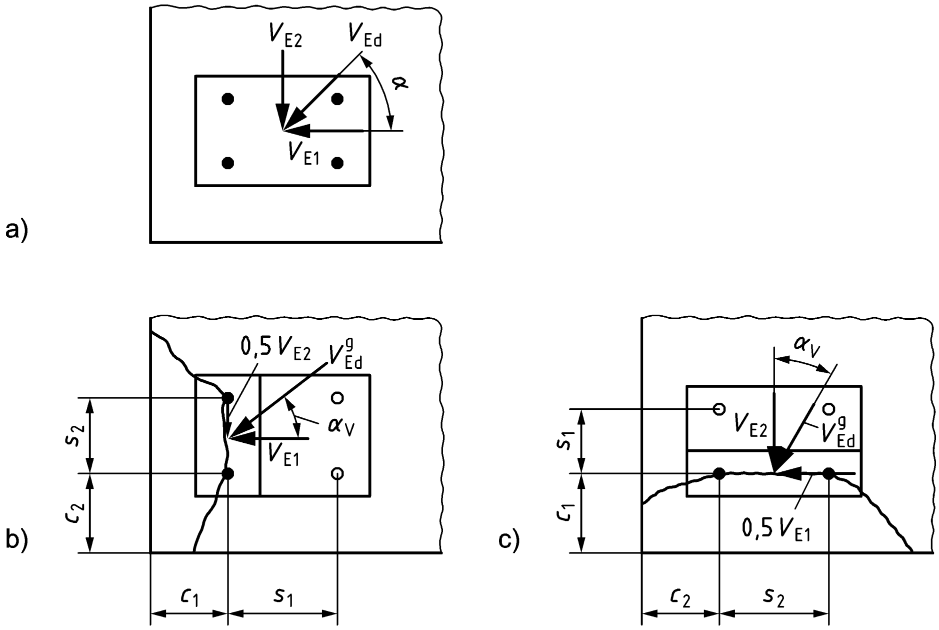
(1) For embedded base plates with an edge distance in direction of the shear load $c \leq \max\left\{10\ h_{ef}\ ;\ 60\ d\right\}$ the provisions are valid only if the thickness t of the base plate in contact with the concrete is smaller than 0,25 h_{ef}. For fastenings where the shear load acts with lever arm, the provisions are valid if $c > \max\left\{10\ h_{ef}\ ;\ 60\ d\right\}$.

NOTE In case of fastenings located close to an edge and loaded by a shear load with lever arm the effect of an overturning moment on the concrete edge resistance is not considered in the following provisions.

(2) Only the fasteners located closest to the edge are used for the verification of concrete edge failure (see Figure 7.12). For load distribution see 6.2.2.2.

(3) For fastenings with more than one edge (see Figure 7.12), the verification shall be carried out for all edges.

(4) The minimum spacing of fasteners in a group should be $s_{min} \geq 4d_{nom}$.



Key

$V_{E1} = V_{Ed} \cos\alpha$

$V_{E2} = V_{Ed} \sin\alpha$

a) applied action

b) verification for the left edge

c) verification for the bottom edge

● fastener in a); loaded fastener in b) and c)

○ unloaded fastener in b) and c)

Figure 7.12 — Verification for a quadruple fastening with hole clearance at a corner – Example

(5) The characteristic resistance $V_{Rk,c}$ of a fastener or a group of fasteners loaded towards the edge is:

$$V_{Rk,c} = V_{Rk,c}^{0} \cdot \frac{A_{c,V}}{A_{c,V}^{0}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \psi_{\alpha,V} \cdot \psi_{re,V} \quad (7.40)$$

The different factors of Formula (7.40) are given below.

(6) The initial value of the characteristic resistance of a fastener loaded perpendicular to the edge is calculated as:

$$V_{Rk,c}^{0} = k_9 \cdot d_{nom}^{\alpha} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1,5} \quad (7.41)$$

with

k_9 = 1,7 for cracked concrete

= 2,4 for uncracked concrete

$$\alpha = 0,1 \cdot \left(\frac{l_f}{c_1}\right)^{0,5} \quad (7.42)$$

$$\beta = 0{,}1 \cdot \left(\frac{d_{nom}}{c_1}\right)^{0{,}2} \tag{7.43}$$

l_f = h_{ef} in case of a uniform diameter of the shank of the headed fastener and a uniform diameter of the post-installed fastener

$\leq 12\, d_{nom}$ in case of $d_{nom} \leq 24$ mm

$\leq \max\left\{8\, d_{nom}; 300 \text{ mm}\right\}$ in case of $d_{nom} > 24$ mm

The values d_{nom} and l_f are given in the relevant European Technical Product Specification.

(7) The ratio $A_{c,V}/A^0_{c,V}$ takes into account the geometrical effect of spacing as well as of further edge distances and the effect of thickness of the concrete member on the characteristic resistance.

$A^0_{c,V}$ is the reference projected area, see Figure 7.13

$$= 4{,}5\, c_1^2 \tag{7.44}$$

$A_{c,V}$ is the area of the idealized concrete break-out body, limited by the overlapping concrete cones of adjacent fasteners $(s \leq 3\, c_1)$ as well as by edges parallel to the assumed loading direction $(c_2 \leq 1{,}5\, c_1)$ and by member thickness $(h < 1{,}5\, c_1)$. Examples for the calculation of $A_{c,V}$ are given in Figure 7.14.

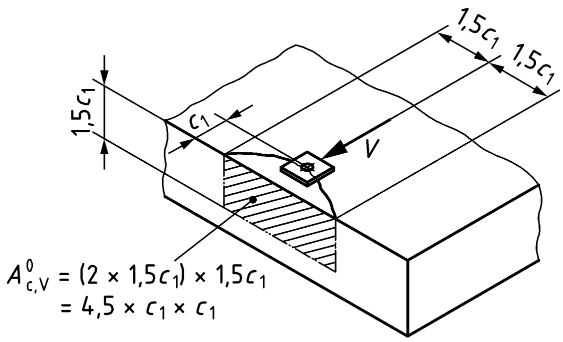
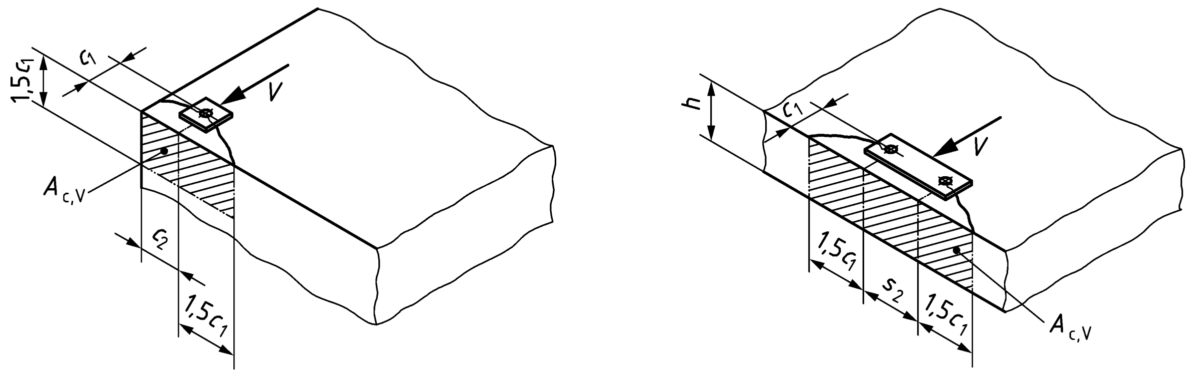


Figure 7.13 — Idealized concrete break-out body and area $A^0_{c,V}$ for a single fastener



$A_{c,V} = 1{,}5\, c_1 (1{,}5\, c_1 + c_2)$

$h \geq 1{,}5\, c_1$

$c_2 \leq 1{,}5\, c_1$

a) Single fastener at a corner

$A_{c,V} = (2 \cdot 1{,}5\, c_1 + s_2) \cdot h$

$h < 1{,}5\, c_1$

$s_2 \leq 3\, c_1$

b) Group of fasteners at an edge in a thin concrete member

Figure 7.14 — Examples of actual projected areas $A_{c,V}$ of the idealized concrete break-out bodies for different fastener arrangements under shear loading

(8) Resistance calculated in accordance with Formula (7.40) may be unconservative for concrete edge failure in cases where the fastenings comprising two fasteners are subject to torsion resulting in shear in opposite directions in the fasteners due to overlapping of the concrete breakout bodies. If the ratio between the concrete edge breakout resistance (verified edge) to the concrete breakout resistance of the second fastener (pry-out or edge failure) is larger than 0,7 and $s_2 \leq s_{crit}$, $V_{Rk,c}$ according to Formula (7.40) should be multiplied by a factor of 0,8 which is assumed to be conservative. Herein, s_{crit} is defined as follows:

— $s_{crit} = 1{,}5 h_{ef} + 1{,}5 c_1$, if the second fastener is governed by pry-out failure;

— $s_{crit} = 1{,}5 c_1$, if the second fastener is governed by concrete edge failure with respect to a second edge (perpendicular to the verified edge).

(9) The factor $\psi_{s,V}$ takes account of the disturbance of the distribution of stresses in the concrete due to further edges of the concrete member on the shear resistance. For fastenings with two edges parallel to the direction of loading (e.g. in a narrow concrete member) the smaller value of these edge distances shall be used for c_2 in Formula (7.45).

$$\psi_{s,V} = 0{,}7 + 0{,}3 \cdot \frac{c_2}{1{,}5\, c_1} \leq 1 \tag{7.45}$$

(10) The factor $\psi_{h,V}$ takes account of the fact that the concrete edge resistance does not decrease proportionally to the member thickness as assumed by the ratio $A_{c,V} / A^0_{c,V}$ (Figure 7.14 b)).

$$\psi_{h,V} = \left(\frac{1{,}5 c_1}{h} \right)^{0{,}5} \geq 1 \tag{7.46}$$

(11) The factor $\psi_{ec,V}$ takes into account a group effect when different shear loads are acting on the individual fasteners of a group (see Figure 7.15).

$$\psi_{ec,V} = \frac{1}{1 + 2 \cdot e_V / (3c_1)} \leq 1 \qquad (7.47)$$

where

e_V is the eccentricity of the resulting shear load acting on the fasteners relative to the centre of gravity of the fasteners loaded in shear

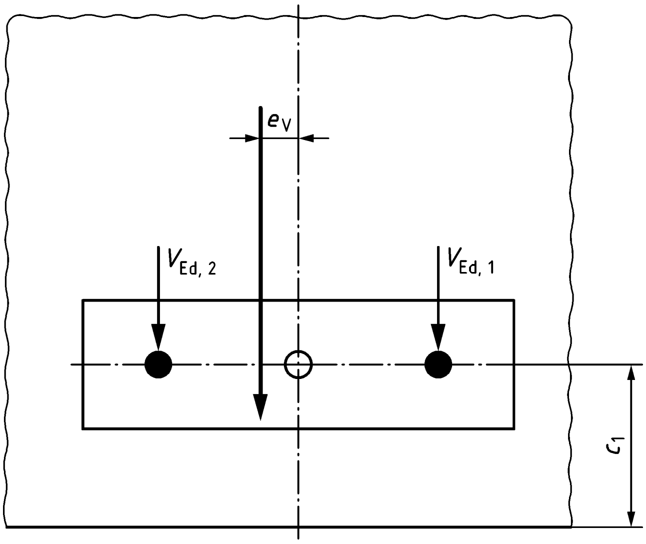


Figure 7.15 — Resolving unequal shear components into an eccentric shear load resultant – Example

(12) The factor $\psi_{\alpha,V}$ takes account of the influence of a shear load inclined to the edge under consideration on the concrete edge resistance.

$$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos \alpha_V)^2 + (0{,}5 \cdot \sin \alpha_V)^2}} \geq 1 \qquad (7.48)$$

where

α_V is the angle between design shear load V_{Ed} (single fastener) or V_{Ed}^{g} (group of fasteners) and a line perpendicular to the verified edge, $0° \leq \alpha_V \leq 90°$, see Figure 7.12.

(13) The factor $\psi_{re,V}$ takes account of the effect of the reinforcement located on the edge.

$\psi_{re,V} = 1{,}0$ fastening in uncracked concrete and fastening in cracked concrete without edge reinforcement or stirrups

$\psi_{re,V} = 1{,}4$ fastening in cracked concrete with edge reinforcement (see Figure 7.10) and closely spaced stirrups or wire mesh with a spacing $a \leq 100$ mm and $a \leq 2c_1$.

A factor $\psi_{\text{re,V}} > 1$ for applications in cracked concrete shall only be applied, if the embedment depth h_{ef} of the fastener is at least 2,5 times the concrete cover of the edge reinforcement.

(14) For fastenings in a narrow, thin member with $c_{2,\max} \leq 1,5\, c_1$ and $h \leq 1,5\, c_1$ (see Figure 7.16) the calculation according to Formula (7.40) leads to conservative results. More precise results are achieved if c_1 is replaced by:

$$c_1' = \max\left\{\frac{c_{2,\max}}{1,5}; \frac{h}{1,5}\right\} \text{ in case of single fasteners} \tag{7.49}$$

or

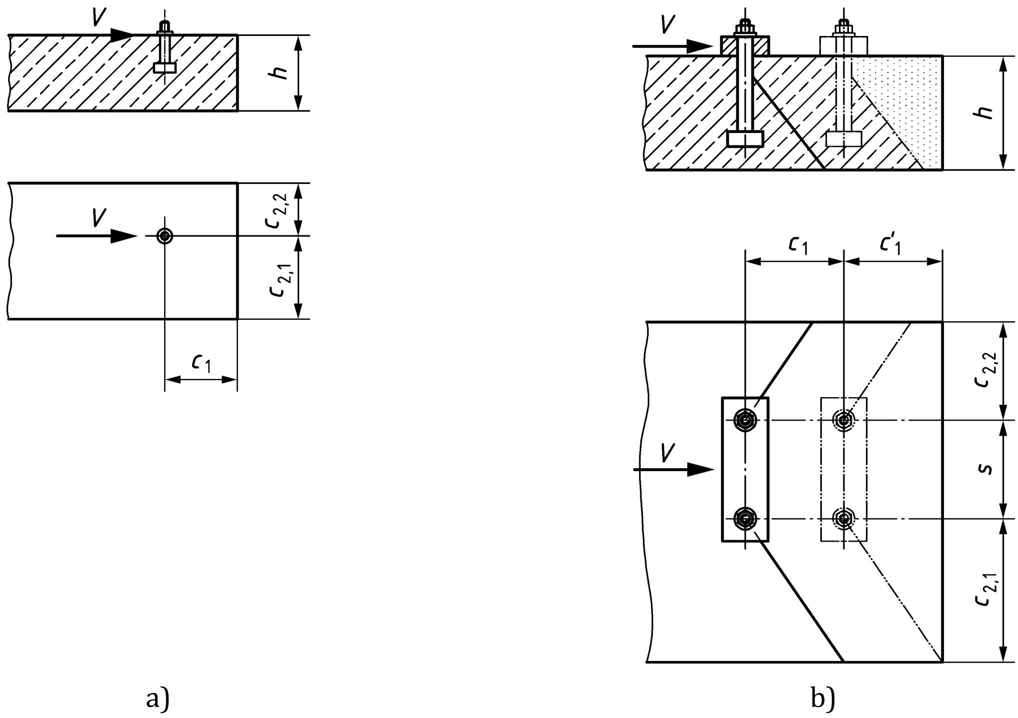
$$c_1' = \max\left\{\frac{c_{2,\max}}{1,5}; \frac{h}{1,5}; \frac{s_{2,\max}}{3}\right\} \text{ in case of groups} \tag{7.50}$$

where

$c_{2,\max}$ is the larger of the two distances to the edges parallel to the direction of loading; and

$s_{2,\max}$ is the maximum spacing in direction 2 between fasteners within a group.

The value of c_1' instead of c_1 is used in Formulae (7.41) to (7.47) as well as in the determination of the areas $A_{\text{c,V}}^0$ and $A_{\text{c,V}}$ according to Figures 7.13 and 7.14.



$\max\{c_{2,1}; c_{2,2}\} < 1,5\, c_1$ and $h < 1,5\, c_1$

$s = 100$ mm, $c_1 = 200$ mm, $h = 120 \text{ mm} < 1,5 \cdot 200 \text{ mm}$,

$c_{2,1} = 150 \text{ mm} \leq 1,5 \cdot 200 \text{ mm}$, $c_{2,2} = 100 \text{ mm} < 1,5 \cdot 200 \text{ mm}$,

$c_1' = \max\{150/1,5; 120/1,5; 100/3\} = 100$ mm

Figure 7.16 — Fasteners in thin, narrow members where the value c_1' may be used