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GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL

of

PLASTIC ANCHORS FOR MULTIPLE USE IN CONCRETE AND MASONRY FOR NON-STRUCTURAL APPLICATIONS

Annex C:

DESIGN METHODS FOR ANCHORAGES

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ANNEX C:
DESIGN METHODS FOR ANCHORAGES

INTRODUCTION

The design method for anchorages is intended to be used for the design of anchorages under due consideration of the safety and design concept within the scope of the European Technical Approvals (ETA) of plastic anchors.

The design method given in Annex C is based on the assumption that the required tests for assessing the admissible service conditions given in the relevant Parts of this Guideline have been carried out. Therefore Annex C is a pre-condition for assessing and judging of plastic anchors. The use of other design methods will require reconsideration of the necessary tests.

The plastic anchors shall be used for multiple fixings. By multiple anchor use it is assumed that in the case of excessive slip or failure of one anchor the load can be transmitted to neighbouring anchors without significantly violating the requirements on the fixture in the serviceability and ultimate limit state.

Therefore the design of the fixture shall specify the number n_1 of fixing points to fasten the fixture and the number n_2 of anchors per fixing point. Furthermore the design value of actions N_{Sd} on a fixing point to a value $\leq n_3$ (kN) is specified up to which the strength and stiffness of the fixture are fulfilled and the load transfer in the case of excessive slip or failure of one anchor need not be taken into account in the design of the fixture.

The following default values for n_1, n_2 and n_3 should be taken:

$\mathbf{n_1 \geq 4}$; $\mathbf{n_2 \geq 1}$ and $\mathbf{n_3 \leq 4{,}5\ kN}$ (Figure 1.1) or

$\mathbf{n_1 \geq 3}$; $\mathbf{n_2 \geq 1}$ and $\mathbf{n_3 \leq 3{,}0\ kN}$. (Figure 1.2)

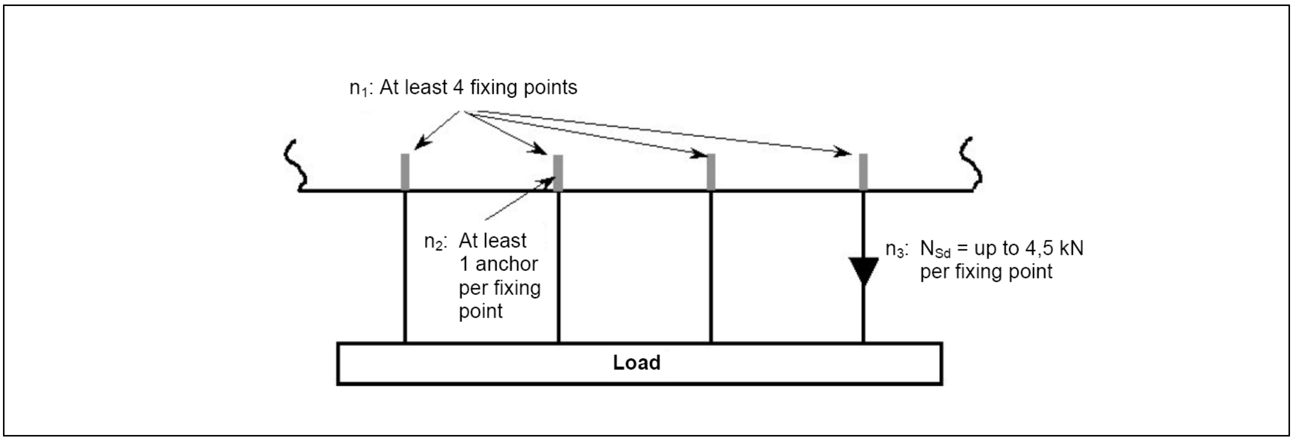

Figure 1.1: $n_1 \geq 4$; $n_2 \geq 1$ and $n_3 \leq 4{,}5$ kN

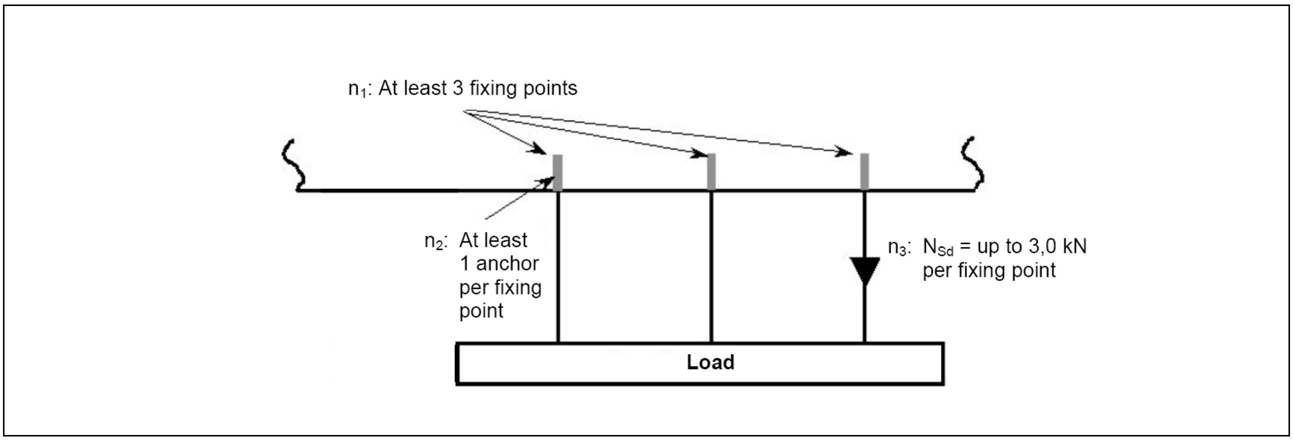

Figure 1.2: $n_1 \geq 3$; $n_2 \geq 1$ and $n_3 \leq 3{,}0$ kN

1. SCOPE

1.1. Type of anchors, anchor groups and number of anchors

The design method applies to the design of plastic anchors in normal weight concrete, different masonry and autoclaved aerated concrete using anchors which fulfil the requirements of this Guideline. The characteristic values are given in the relevant ETA.

The design method is valid for single anchors and anchor groups with two or four anchors. In an anchor group only anchors of the same type, size and length shall be used.

1.2. Member

1.2.1. Concrete member

The concrete member shall be of normal weight concrete of at least strength class C12/15 according to EN 206 [5] and shall be subjected to only predominantly static loads. The design method is valid for cracked and non-cracked concrete.

If the edge distance of an anchor is smaller than the edge distance $c_{cr,N}$, then a longitudinal reinforcement of at least ∅ 6 mm shall be provided at the edge of the member in the area of the anchorage depth.

1.2.2. Solid and hollow or perforated masonry

The masonry member shall be of solid or hollow or perforated masonry units made of clay or calcium silicate or normal weight concrete or lightweight concrete.

The detailed information of the corresponding base material is given in the ETA [e.g. *Base material, size of units, normalised compressive strength; volume of all holes (% of the gross volume); volume of any hole (% of the gross volume); minimum thickness in and around holes (web and shell); combined thickness of webs and shells (% of the overall width)*].

1.2.3. Autoclaved aerated concrete

The autoclaved aerated concrete member shall be according to EN 771-4 [9] "Autoclaved aerated concrete masonry units" or EN 12602 [10] "Reinforced components of autoclaved aerated concrete".

1.3. Type and direction of load

This design method applies to plastic anchors subject to static or quasi-static actions in tension, shear or combined tension and shear or bending; it is not applicable to plastic anchors loaded in compression or subject to fatigue, impact, or seismic actions.

2. TERMINOLOGY AND SYMBOLS

2.1. Plastic anchors

The notations and symbols frequently used are given below.

a	=	spacing between outer anchors of adjoining groups or between single anchors
a_1	=	spacing between outer anchors of adjoining groups or between single anchors in direction 1
a_2	=	spacing between outer anchors of adjoining groups or between single anchors in direction 2
c	=	edge distance
c_1	=	edge distance in direction 1; in case of anchorages close to an edge loaded in shear c_1 is the edge distance in direction of the shear load
c_2	=	edge distance in direction 2; direction 2 is perpendicular to direction 1
$c_{cr,N}$	=	edge distance for ensuring the transmission of the characteristic tensile resistance of a single plastic anchor
c_{min}	=	minimum allowable edge distance
d	=	nominal diameter of the anchor
d_{nom}	=	outside diameter of anchor
h	=	thickness of member (wall)
h_{ef}	=	effective anchorage depth
h_{nom}	=	overall anchor embedment depth in the base material
s	=	spacing of the plastic anchor
s_{min}	=	minimum allowable spacing

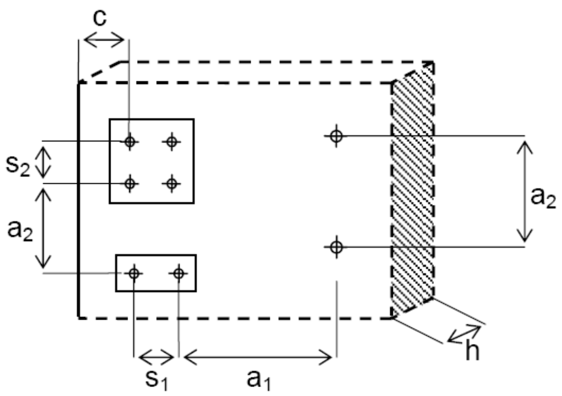

Figure 2.1: Member, anchor spacing and edge distance

2.2. Base material

$f_{ck,cube}$	=	nominal characteristic concrete compression strength (based on cubes)
f_{yk}	=	nominal characteristic steel yield strength
f_{uk}	=	nominal characteristic steel ultimate strength

2.3. Actions and resistances

F	=	force in general (resulting force)
N	=	normal force (positive: tension force, negative: compression force)
V	=	shear force
M	=	moment

$\mathbf{F_{Sk}}$ ($\mathbf{N_{Sk}}$; $\mathbf{V_{Sk}}$; $\mathbf{M_{Sk}}$; $\mathbf{M_{T,Sk}}$)	=	characteristic value of actions acting on a single anchor or the fixture of an anchor group (normal load, shear load, bending moment, torsion moment)
$\mathbf{F_{Sd}}$ ($\mathbf{N_{Sd}}$; $\mathbf{V_{Sd}}$; $\mathbf{M_{Sd}}$, $\mathbf{M_{T,Sd}}$)	=	design value of actions acting on a single anchor or the fixture of an anchor group (normal load, shear load, bending moment, torsion moment)

$\mathbf{N^{h}_{Sd}}$ ($\mathbf{V^{h}_{Sd}}$)	=	design value of tensile load (shear load) acting on the most stressed anchor of an anchor group
$\mathbf{N^{g}_{Sd}}$ ($\mathbf{V^{g}_{Sd}}$)	=	design value of the sum (resultant) of the tensile (shear) loads acting on the tensioned (sheared) anchors of a group
$\mathbf{F_{Rk}}$ ($\mathbf{N_{Rk}}$; $\mathbf{V_{Rk}}$)	=	characteristic value of resistance of a single anchor or an anchor group (normal force, shear force)
$\mathbf{F_{Rd}}$ ($\mathbf{N_{Rd}}$; $\mathbf{V_{Rd}}$)	=	design value of resistance of a single anchor or an anchor group (normal force, shear force)

2.4. Indices

S	=	action
R	=	resistance
M	=	material
k	=	characteristic value
d	=	design value
s	=	steel
pol	=	polymeric
c	=	concrete
m	=	masonry
AAC	=	autoclaved aerated concrete
cp	=	concrete pry-out
p	=	pull-out
u	=	ultimate
y	=	yield

3. DESIGN AND SAFETY CONCEPT

3.1. General

The design of anchorages shall be in accordance with the general rules given in EN 1990 [20]. It shall be shown that the value of the design actions S_d does not exceed the value of the design resistance R_d.

$$\mathbf{S_d \leq R_d} \qquad \textbf{(3.1)}$$

with:

S_d = value of design action

R_d = value of design resistance

Actions to be used in design may be obtained from national regulations or in the absence of them from the relevant parts of EN 1991 [21].

The partial safety factors for actions may be taken from national regulations or in the absence of them according to EN 1990 [20].

The design **resistance** is calculated as follows:

$$\mathbf{R_d = R_k / \gamma_M} \qquad \textbf{(3.2)}$$

with:

R_k = characteristic resistance of a single anchor or an anchor group

γ_M = partial safety factor for material

3.2. Ultimate limit state

3.2.1. Design resistance

The design resistance is calculated according to Equation (3.2).

3.2.2. Partial safety factors for resistances

In the absence of national regulations the following partial safety factors shall be used:

3.2.2.1. Failure (rupture) of the expansion element

a) Metal expansion element:

- Tension loading:

$$\gamma_{Ms} = \frac{1{,}2}{f_{yk} / f_{uk}} \geq 1{,}4 \qquad \textbf{(3.3a)}$$

- Shear loading of the anchor with and without lever arm:

$$\gamma_{Ms} = \frac{1{,}0}{f_{yk} / f_{uk}} \geq 1{,}25 \qquad f_{uk} \leq 800\ N/mm^2 \quad \text{and} \quad f_{yk} / f_{uk} \leq 0{,}8 \qquad \textbf{(3.3b)}$$

$$\gamma_{Ms} = 1{,}5 \qquad f_{uk} > 800\ N/mm^2 \quad \text{or} \quad f_{yk} / f_{uk} > 0{,}8$$

b) Polymeric expansion element:

γ_{Mpol} = 2,5

(also valid for rupture of the polymeric sleeve)

3.2.2.2. Failure of the plastic anchor

a) For use in concrete

γ_{Mc} = 1,8

b) For use in masonry

γ_{Mm} = 2,5

c) For use in autoclaved aerated concrete

γ_{MAAC} = 2,0

3.3. Serviceability limit state

In the serviceability limit state it shall be shown that the displacements occurring under the characteristic actions (see 6) are not larger than the permissible displacements. The permissible displacements depend on the application in question and shall be evaluated by the designer.

In this check the partial safety factors on actions and on resistances shall be assumed to be equal 1,0.

4. STATIC ANALYSIS

4.1. Loads acting on anchors

Distribution of loads acting on anchors shall be calculated according to the theory of elasticity.

For steel failure under tension and shear and for pull-out failure under tension the load acting on the highest loaded anchor shall be determined. For concrete failure under tension and shear the load on the group shall be calculated.

In case of concrete edge failure the shear force is assumed to act on the anchor(s) closest to the edge.

4.2. Shear loads with lever arm

Shear loads acting on an anchor may be assumed to act without lever arm if both of the following conditions are fulfilled:

a) The fixture shall be made of metal and in the area of the anchorage be fixed directly to the base material either without an intermediate layer or with a levelling layer of mortar with a thickness $\leq$ 3 mm.

b) The fixture shall be in contact with the anchor over its entire thickness.

If these two conditions are not fulfilled the lever arm is calculated according to Equation (4.1) (see Figure 4.1).

$$\mathbf{l = a_3 + e_1} \qquad \textbf{(4.1)}$$

with:

e_1 = distance between shear load and surface of the member

a_3 = $0{,}5 \cdot d$

d = nominal diameter of the anchor

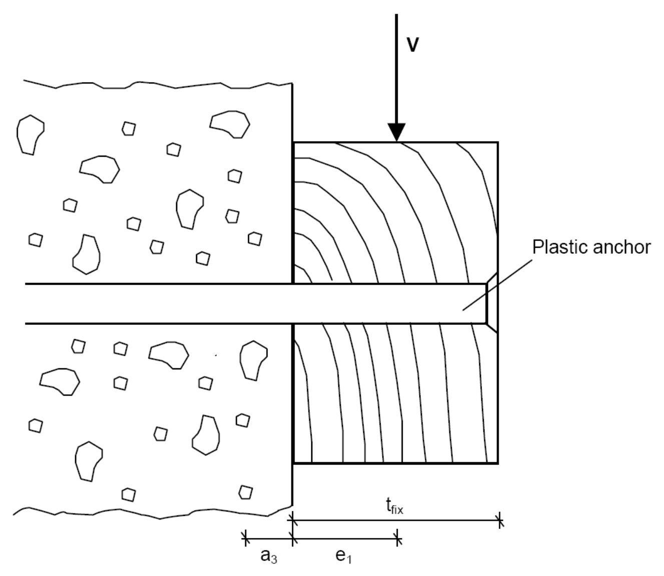

Figure 4.1: Definition of lever arm

5. ULTIMATE LIMIT STATE

5.1. General

The characteristic resistances of plastic anchors in the ultimate limit state for use in concrete are given in 5.2. The characteristic resistances and the corresponding specific conditions for the design of plastic anchors for use in masonry and aerated concrete are listed in 5.3.

In general, it is assumed that anchor groups have the same resistance as single anchors under tension loads, shear loads and combined tension and shear loads independent of the spacing between the anchors.

Spacing, edge distance as well as thickness of member shall not remain under the given minimum values.

5.2. Ultimate limit state for use in concrete

5.2.1. Resistance to tension loads

5.2.1.1. Required proofs

		single anchor	anchor group	
failure of the expansion element	metal	$N_{Sd} \le N_{Rk,s} / \gamma_{Ms}$	$N^{h}_{Sd} \le N_{Rk,s} / \gamma_{Ms}$	
	polymeric **(1)**	$N_{Sd} \le N_{Rk,pol} / \gamma_{Mpol}$	$N^{h}_{Sd} \le N_{Rk,pol} / \gamma_{Mpol}$	
pull-out failure		$N_{Sd} \le N_{Rk,p} / \gamma_{Mc}$	$N^{h}_{Sd} \le N_{Rk,p} / \gamma_{Mc}$	
concrete cone failure		$N_{Sd} \le N_{Rk,c} / \gamma_{Mc}$		$N^{g}_{Sd} \le N_{Rk,c} / \gamma_{Mc}$

(1) also valid for rupture of the polymeric sleeve

5.2.1.2. Failure of the expansion element

The characteristic resistance of an anchor in case of failure (rupture) of the expansion element, $N_{Rk,s}$ or $N_{Rk,pol}$ is given in the relevant ETA.

5.2.1.3. Pull-out failure

The characteristic resistance in case of failure by pull-out, $N_{Rk,p}$, shall be taken from the relevant ETA.

5.2.1.4. Concrete cone failure

The characteristic resistance of an anchor or a group of anchors in case of concrete cone failure is:

$$N_{Rk,c} = 7{,}2 \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1,5} \cdot \frac{c}{c_{cr,N}} \qquad (5.1)$$

$f_{ck,cube}$ [N/mm²]; h_{ef} [mm]; $\left(\frac{c}{c_{cr,N}}\right) \leq 1{,}0$

with:

$$h_{ef}^{1,5} = \frac{N_{Rk,p}}{7{,}2 \cdot \sqrt{f_{ck,cube}}} \qquad (5.2)$$

$N_{Rk,p}$ = given in the ETA; $N_{Rk,p}$ [N]

c = edge distance of the outer anchor of the group

$c_{cr,N}$ = edge distance to ensure the transmission of the characteristic resistance; given in the ETA

$f_{ck,cube}$ = nominal characteristic concrete compressive strength (based on cubes) value for C50/60 at most

5.2.2. Resistance to shear loads

5.2.2.1. Required proofs

		single anchor	anchor group	
Failure of the expansion element, shear load without lever arm	metal	$V_{Sd} \leq V_{Rk,s} / \gamma_{Ms}$	$V_{Sd}^{h} \leq V_{Rk,s} / \gamma_{Ms}$	
	polymeric	$V_{Sd} \leq V_{Rk,pol} / \gamma_{Mpol}$	$V_{Sd}^{h} \leq V_{Rk,pol} / \gamma_{Mpol}$	
Failure of the expansion element, shear load with lever arm	metal	$V_{Sd} \leq V_{Rk,s} / \gamma_{Ms}$	$V_{Sd}^{h} \leq V_{Rk,s} / \gamma_{Ms}$	
	polymeric	$V_{Sd} \leq V_{Rk,pol} / \gamma_{Mpol}$	$V_{Sd}^{h} \leq V_{Rk,pol} / \gamma_{Mpol}$	
concrete edge failure		$V_{Sd} \leq V_{Rk,c} / \gamma_{Mc}$		$V_{Sd}^{g} \leq V_{Rk,c} / \gamma_{Mc}$

5.2.2.2. Failure of the expansion element, shear load without lever arm

The characteristic resistance of an anchor in case of failure of the expansion element due to shear load without lever arm $V_{Rk,s}$ or $V_{Rk,pol}$ shall be taken from the relevant ETA.

5.2.2.3. Failure of the expansion element, shear load with lever arm

The characteristic resistance of an anchor in case of failure of the expansion element due to shear load with lever arm $V_{Rk,s}$ or ($V_{Rk,pol}$) is given by Equation (5.3).

$$\mathbf{V_{Rk,s} = \frac{M_{Rk,s}}{l} \quad [N]} \qquad \textbf{(5.3a)}$$

$$\mathbf{V_{Rk,pol} = \frac{M_{Rk,pol}}{l} \quad [N]} \qquad \textbf{(5.3b)}$$

with:

l	=	lever arm according to Equation (4.1)
$M_{Rk,s}$ or $M_{Rk,pol}$	=	to be taken from the relevant ETA

5.2.2.4. Concrete edge failure

The characteristic resistance for an anchor or an anchor group in the case of concrete cone failure at edges corresponds to:

$$\mathbf{V_{Rk,c} = 0{,}45 \cdot \sqrt{d_{nom}} \cdot (h_{nom}/d_{nom})^{0.2} \cdot \sqrt{f_{ck,cube}} \cdot c_1^{1,5} \cdot \left(\frac{c_2}{1{,}5c_1}\right)^{0,5} \cdot \left(\frac{h}{1{,}5c_1}\right)^{0,5}} \qquad \textbf{(5.4)}$$

$V_{Rk,c}$ [N]; d_{nom}, h_{nom}, h, c_1, c_2 [mm]; $f_{ck,cube}$ [N/mm²]; $\left(\frac{c_2}{1{,}5c_1}\right)^{0,5} \leq 1{,}0$ and $\left(\frac{h}{1{,}5c_1}\right)^{0,5} \leq 1{,}0$

with:

c_1	=	edge distance closest to the edge in loading direction
c_2	=	edge distance perpendicular to direction 1
$f_{ck,cube}$	=	nominal characteristic concrete compressive strength (based on cubes) value for C50/60 at most

5.2.3. Resistance to combined tension and shear loads

For combined tension and shear loads the following Equations shall be satisfied:

$$\boldsymbol{\beta_N \leq 1} \qquad \textbf{(5.5a)}$$

$$\boldsymbol{\beta_V \leq 1} \qquad \textbf{(5.5b)}$$

$$\boldsymbol{\beta_N + \beta_V \leq 1{,}2} \qquad \textbf{(5.5c)}$$

β_N (β_V) ratio between design action and design resistance for tension (shear) loading.

In Equation (5.5) the largest value of β_N and β_V for the different failure modes shall be taken (see 5.2.1.1 and 5.2.2.1).

5.3. Ultimate limit state for use in masonry and in autoclaved aerated concrete

The following specific conditions for the design method in masonry and in autoclaved aerated concrete shall be taken into account:

(1) The ETA contains only <u>one</u> characteristic resistance $\mathbf{F_{Rk}}$ independent of the load direction and the mode of failure. The appropriated partial safety factor and the corresponding values c_{min} and s_{min} for this characteristic resistance are also given in the ETA.

In case of shear load with lever arm the characteristic anchor resistance shall be calculated according to Equation (5.3a) and (5.3b). The smallest value of F_{Rd} or $V_{Rk,s}/\gamma_{Ms}$ (metal) or $V_{Rk,pol}/\gamma_{Mpol}$ (polymeric) governs.

(2) The characteristic resistance $\mathbf{F_{Rk}}$ for a single plastic anchor shall also be taken for a group of two or four plastic anchors with a spacing equal or larger than the minimum spacing s_{min}.

The distance between single plastic anchors or a group of anchors is a ≥ 250mm.

(3) The position of the plastic anchors with respect to the joints of a masonry wall (use categories b, c and d) and the kind of joint according to EN 1996-1-1: Eurocode 6 [8], 8.1.5 have to be taken into account for the design of the anchorage in masonry. Joints may be visible (e.g. unplastered wall) or not visible (e.g. a wall with rendering). Appropriate reduction factors are given in Table 7.1 depending on the kind of joint and the visibility of the joints on construction site.

Table 7.1: Characteristic resistance in masonry (use categories b, c and d) depending on visibility and condition of the joints

	1	2	3
1	**Joints**	**Characteristic resistance depending on the joints (a)** **joints are visible**	 **joints are <u>not</u> visible**
2	**filled with mortar (b)** (perpend/vertical and bed/horizontal joints)	F_{Rk}	$0{,}5 \cdot F_{Rk}$
3	**<u>not</u> filled with mortar (b)** (perpend/vertical joints)	$0{,}5 \cdot F_{Rk}$ **(c)** and $N_{Sd} \leq 2{,}0$ kN **(d)**	$0{,}5 \cdot F_{Rk}$ and $N_{Sd} \leq 2{,}0$ kN **(d)**
4	**interlocking units** (perpend/vertical joints)	F_{Rk}	$0{,}5 \cdot F_{Rk}$
5	**glued together** (only bed/horizontal joints in AAC)	F_{Rk}	$0{,}5 \cdot F_{Rk}$

(a) F_{Rk} = characteristic resistance given in the ETA for the individual masonry units

(b) The condition of the joint shall be determined from the design of the wall (e.g. joints of the wall are designed to be filled with mortar) or from a representative assessment for existing constructions.

(c) The characteristic resistance does not have to be reduced to $0{,}5 \cdot F_{Rk}$ if the minimum edge distance c_{min} to the vertical joints is observed. The minimum edge distance c_{min} is given in the ETA for the individual masonry units.

(d) N_{Sd} has to be limited to 2,0 kN to ensure that a pull-out of one brick of the wall will be prevented.

(4) For prefabricated reinforced components made of autoclaved aerated concrete the following has to be taken into account as well, if no special tests or calculation for the resistance of the member made of AAC have been carried out:

- The design value of shear resistance in the member caused by the anchorage is less than or equal to 40 % of the design value of resistance of the member in the critical cross section.
- The edge distance c is ≥ 150 mm for slabs of width ≤ 700 mm.
- The spacing of fixing points in general is a ≥ 250 mm. For prefabricated reinforced floor units the spacing of fixing points is a ≥ 600 mm. Fixing points are single anchors or groups of 2 or 4 anchors.

6. SERVICEABILITY LIMIT STATE

6.1. Displacements

The characteristic displacement of the anchor under defined tension and shear loads shall be taken from the ETA. It may be assumed that the displacements are a linear function of the applied load. In case of a combined tension and shear load, the displacements for the tension and shear component of the resultant load shall be geometrically added.

In case of shear loads the influence of the hole clearance in the fixture on the expected displacement of the whole anchorage shall be taken into account.

6.2. Shear load with changing sign

If the shear loads acting on the anchor change their sign several times, appropriate measures shall be taken to avoid a fatigue failure of the anchor (e.g. the shear load should be transferred by friction between the fixture and the base material (e.g. due to a sufficiently high permanent prestressing force)).

Shear loads with changing sign can occur due to temperature variations in the fastened member (e.g. facade elements). Therefore, either these members are anchored such that no significant shear loads due to the restraint of deformations imposed on the fastened element will occur in the anchor or in shear loading with lever arm the bending stresses in the most stressed anchor $\Delta\sigma = \max\sigma - \min\sigma$ in the serviceability limit state caused by temperature variations shall be limited to 100 N/mm^2 for steel.