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TECHNICAL REPORT

DESIGN METHODS FOR ANCHORAGES WITH METAL INJECTION ANCHORS FOR USE IN MASONRY

TR 054

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Contents

1 SCOPE OF THE TECHNICAL REPORT

The design rules in this Technical Report (TR) are only valid for anchors with a European Technical Assessment (ETA) on basis of EAD 330076-00-0604 [1]. This document relies on characteristic resistances and distances which are stated in the ETA and referred to in this TR.

The design method applies to the design of injection anchors in masonry units of clay, calcium silicate, normal weight concrete, light weight concrete, autoclaved aerated concrete (AAC) or other similar materials.

The proof of local transmission of the anchor loads into the masonry units is delivered by using the design methods described in this document. Proof of transmission of anchor loads to the supports of the masonry members shall be done by the engineer of the construction works.

The design and construction of masonry structures in which the injection anchors are to be anchored shall be comparable with the structural rules for masonry, such as EN 1996 1-1:2005 + A1:2012 Clause 3 and Clause 8 [4] and the relevant national regulations.

1.1 Type of anchors, anchor groups and number of anchors

The essential characteristics of the specific anchor type (characteristic values of resistance, edge distances, spacing and group factors) 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 Base material

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), configuration of holes.

1.3 Type and direction of load

This Technical Report applies only to anchors subject to static or quasi-static actions in tension, shear or combined tension and shear or bending. The anchors are also intended to be used in areas with very low seismicity as defined in EN 1998-1:2004 + AC:2009, Clause 3.2.1 [5]. This Technical Report covers applications only where the masonry members in which the anchors are embedded are subject to static or quasi-static actions.

1.4 Specific terms used in this TR

Anchor	=	a manufactured, assembled component including bonding materials for achieving anchorage between the base material (masonry) and the fixture.
Anchor group	=	several anchors (working together)
Fixture	=	component to be fixed to the masonry
Anchorage	=	an assembly comprising base material (masonry), anchor or anchor group and component fixed to the masonry.

Anchors

The notations and symbols frequently used in this TR are given below. Further particular notation and symbols are given in the text.

b_{brick}	=	breadth of the brick
c	=	edge distance towards the free edge of the brick (edge of the wall or vertical joint not to be filled with mortar)
c_{cr}	=	edge distance for ensuring the transmission of the characteristic resistance of a single injection anchor
c_{min}	=	minimum allowable edge distance
d	=	anchor bolt/thread diameter
d_f	=	diameter of clearance hole in the fixture
d_{nom}	=	outside diameter of anchor
h	=	thickness of masonry member (wall)
h_{min}	=	minimum thickness of masonry member
h_{ef}	=	effective anchorage depth
h_{nom}	=	overall anchor embedment depth in the masonry
l_{brick}	=	length of the brick
h_{brick}	=	height of the brick
s	=	spacing of the injection anchor
s_{cr}	=	spacing for ensuring the transmission of the characteristic resistance of a single injection anchor
$s_{cr,II}$	=	s_{cr} parallel to the horizontal joint
$s_{cr,\perp}$	=	s_{cr} perpendicular to the horizontal joint
s_{min}	=	minimum allowable spacing
t_{fix}	=	thickness of fixture

Base materials (masonry) and metal parts of anchor

f_b	=	normalised mean compressive strength of masonry unit given in the ETA
f_{yk}	=	nominal characteristic steel yield strength
f_{uk}	=	nominal characteristic steel ultimate strength

Loads / Forces / Resistances

F	=	force in general
N	=	normal force (+N = tension force)
V	=	shear force
M	=	moment
N_{Rk},V_{Rk}	=	characteristic anchor resistance of a single anchor under tension or shear force
N_{Rk}^{g} , V_{Rk}^{g}	=	characteristic anchor resistance of an anchor group under tension or shear force
N_{Ed}^{g} , V_{Ed}^{g}	=	design value of actions acting on an anchor group
N_{Ed}^{h} , V_{Ed}^{h}	=	design value of actions acting on the highest loaded anchor

Displacementst

$\delta(\delta_N, \delta_V)$	=	displacement (movement) of the anchor at the masonry surface relative to the masonry surface in direction of the load (tension, shear) outside the failure area. The displacement includes the steel and masonry deformations and a possible anchor slip.
δ_0	=	displacement of the anchor under short term loading
δ_∞	=	displacement of the anchor under long term loading

2 DESIGN AND SAFETY CONCEPT

2.1 Design concept

The design of anchorages shall be in accordance with the general rules given in EN 1990:2002 + A1:2005 / AC:2010 [2]. It shall be shown that the value of the design actions S_d does not exceed the value of the design resistance R_d.

$$E_d \leq R_d \tag{1}$$

with: E_d = design value of action

R_d = design value of 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 1991:2002 + AC 2009 [3].

The partial safety factors for actions may be taken from national regulations or in the absence of them according to EN 1990:2002 + A1:2005 / AC:2010 [2].

The design resistance is calculated as follows:

$$R_d = R_k / \gamma_M \tag{2}$$

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

γ_M = partial safety factor for material

2.2 Ultimate limit state

The design resistance is calculated according to Equation (2).

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

Failure (rupture) of the metal part

Tension loading:

$$\gamma_{Ms} = \frac{1{,}2}{f_{yk} / f_{uk}} \geq 1{,}4 \tag{3a}$$

Shear loading of the anchor with and without lever arm:

$$\gamma_{Ms} = \frac{1{,}0}{f_{yk} / f_{uk}} \geq 1{,}25 \qquad f_{uk} \leq 800 \text{ N/mm}^2 \quad \text{and} \quad f_{yk} / f_{uk} \leq 0{,}8 \tag{3b}$$

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

Failure of the injection anchor

For use in masonry: $\gamma_{Mm} = 2{,}5$

For use in autoclaved aerated concrete: $\gamma_{MAAC} = 2{,}0$

2.3 Serviceability limit state

In the serviceability limit state it shall be shown that the displacements occurring under the characteristic actions (see chapter 5) 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 may be assumed to be equal 1,0 unless specified differently in the national regulations.

3 STATIC ANALYSIS

3.1 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.

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

3.2 Shear loads with or without lever arm

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

1. The fixture shall be made of metal and in the area of the anchorage be fixed directly to the base material without an intermediate layer or with a levelling layer of mortar with a compressive strength ≥ 30 N/mm^2 and a thickness $\leq d/2$.
2. The fixture is in contact with the anchor over a length of at least $0{,}5 \cdot t_{fix}$.
3. The diameter d_f of the hole in the fixture is not greater than the values d_f given in Table 1.

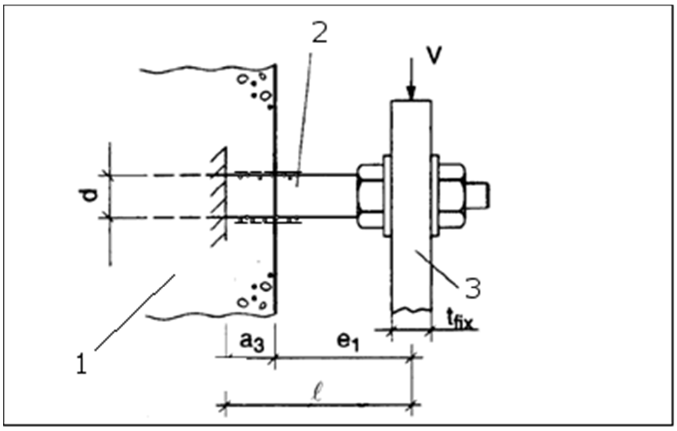
If these conditions are not fulfilled the lever arm is calculated according to following Equation (see Figure 1).

$$l = a_3 + e_1 \tag{4}$$

with: e_1 = distance between shear load and surface of the member

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

d = diameter of the anchor bolt



1 Masonry
2 Anchor bolt
3 Fixture

Figure 1 – Definition of lever arm

Table 1 – Diameter of clearance hole in the fixture

Outside anchor bolt or thread diameter d or d_{nom} (mm)	6	8	10	12	14	16	18	20	22	24	30
Diameter of clearance hole in the fixture d_f (mm)	7	9	12	14	16	18	20	22	24	26	33

4 ULTIMATE LIMIT STATE

4.1 General

For the design of anchorages in the ultimate limit state, there are two different design methods available. The general design method A is described in 4.2 and a simplified design method B is given in 4.3.

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

4.2 Design method A for use in masonry

In design method A it shall be shown that Equation (1) is observed for all loading directions (tension, shear) as well as all failure modes (steel failure, pull-out failure and brick failure).

In case of a combined tension and shear loading (oblique loading) the condition of interaction according to 4.2.3 shall be observed.

4.2.1 Resistance to tension loads

4.2.1.1 Required proofs

Failure of the metal part	$N^h_{Ed} \leq N_{Rk,s} / \gamma_{Ms}$	4.2.1.2
Pull-out failure of the anchor	$N^h_{Ed} \leq N_{Rk,p} / \gamma_{Mm}$	4.2.1.3
Brick breakout failure	$N_{Ed} \leq N_{Rk,b} / \gamma_{Mm}$ $N^g_{Ed} \leq N^g_{Rk,b} / \gamma_{Mm}$	4.2.1.4
Pull out of one brick	$N_{Ed} \leq N_{Rk,pb} / \gamma_{Mm}$	4.2.1.5
Influence of joints	$N^h_{Ed} \leq \alpha_j N_{Rk,p} / \gamma_{Mm}$ $N_{Ed} \leq \alpha_j N_{Rk,b} / \gamma_{Mm}$ $N^g_{Ed} \leq \alpha_j N^g_{Rk,b} / \gamma_{Mm}$	4.2.1.6

For anchorages in AAC the partial safety factor γ_{MAAC} is to be used instead of γ_{Mm}.

4.2.1.2 Failure of the metal part

The characteristic resistance of an anchor in case of failure of the metal part, $N_{Rk,s}$, is given in the relevant ETA. In case of no characteristic resistance is given in the ETA, the following equations may be applied.

$$N_{Rk,s} = A_s \cdot f_{uk} \tag{5}$$

with: A_s = decisive cross section of the anchor

f_{uk} = nominal characteristic steel ultimate strength

4.2.1.3 Pull-out failure of the anchor

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

4.2.1.4 Brick breakout failure

The characteristic resistance of one anchor in case of brick breakout failure $N_{Rk,b}$ and the corresponding values for spacing and edge distance $s_{cr,II}$, $s_{cr,\perp}$ and c_{cr} or c_{min} are given in the relevant ETA.

The characteristic resistance of a group of two or four injection anchors $N^g_{Rk,b}$ and the corresponding values for spacing and edge distance $s_{min,II}$, $s_{min,\perp}$ and c_{min} are given in the relevant ETA. Unless otherwise specified in the ETA, the characteristic resistance of a group with spacing smaller than $s_{cr,II}$ and $s_{cr,\perp}$ ($s_{min} \leq s \leq s_{cr}$) can be assumed to be at least the characteristic resistance of a corresponding single anchor.

4.2.1.5 Pull out of one brick

The characteristic resistance of an anchor or a group of anchors in case of pull out of one brick, $N_{Rk,pb}$, is calculated as follows:

Vertical joints are <u>not</u> filled with mortar

$$N_{Rk,pb} = 2 \cdot l_{brick} \cdot b_{brick} \; (0{,}5 \cdot f_{vko} + 0{,}4 \cdot \sigma_d) \qquad (6)$$

Vertical joints are filled with mortar

$$N_{Rk,pb} = 2 \cdot l_{brick} \cdot b_{brick} \; (0{,}5 \cdot f_{vko} + 0{,}4 \cdot \sigma_d) \; + \; 2 \cdot b_{brick} \cdot h_{brick} \cdot 0{,}5 \cdot f_{vko} \qquad (7)$$

with:
- $N_{Rk,pb}$ = characteristic resistance for pull out of one brick
- l_{brick} = length of the brick
- b_{brick} = breadth of the brick
- h_{brick} = height of the brick
- σ_d = minimum design compressive stress perpendicular to the shear
- f_{vko} = initial shear strength according to Table 2

Table 2
Initial shear strength according to EN 1996 1-1:2005 + A1:2012 [4], Table 3.4

Brick type	Mortar strength	f_{vko} [N/mm^2]
Clay brick	M2,5 to M9 M10 to M20	0,2 0,3
All other types	M2,5 to M9 M10 to M20	0,15 0,2

Note: The factor 0,5 regarding f_{vko} considers the difference between the shear strength of a wall given in the EN1996 1-1:2005 + A1:2012 [4], Table 3.4 and the shear strength of only one brick in case of pull out.

4.2.1.6 Influence of joints

The information on consideration of joints is given in the relevant ETA. In case of no information is given in the ETA following specification may be applied.

The characteristic resistance $N_{Rk,p,}$ $N_{Rk,b}$ and $N^g_{Rk,b}$ may be used if the joints of the masonry are completely filled with mortar.

If the joints of the masonry are not completely filled with mortar <u>and</u> the minimum edge distance to the joint is $c < c_{min}$ then the characteristic resistance $N_{Rk,p}$, $N_{Rk,b}$ and $N^g_{Rk,b}$ has to be reduced by the factor $\alpha_j = 0{,}75$.

4.2.2 Resistance to shear loads

4.2.2.1 Required proofs

Failure of the metal part, shear load without lever arm	$V_{Ed}^{h} \leq V_{Rk,s} / \gamma_{Ms}$	4.2.2.2
Failure of the metal part, shear load with lever arm	$V_{Ed}^{h} \leq V_{Rk,s} / \gamma_{Ms}$	4.2.2.3
Local brick failure	$V_{Ed} \leq V_{Rk,b} / \gamma_{Mm}$ $V_{Ed}^{g} \leq V_{Rk,b}^{g} / \gamma_{Mm}$	4.2.2.4
Brick edge failure	$V_{Ed} \leq V_{Rk,c} / \gamma_{Mm}$ $V_{Ed}^{g} \leq V_{Rk,c}^{g} / \gamma_{Mm}$	4.2.2.5
Pushing out of one brick	$V_{Ed} \leq V_{Rk,pb} / \gamma_{Mm}$	4.2.2.6
Influence of joints		4.2.2.7

For anchorages in AAC the partial safety factor γ_{MAAC} is to be used instead of γ_{Mm}.

4.2.2.2 Failure of the metal part, shear load without lever arm

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

In case of no characteristic resistance is given in the ETA, the following Equation may be applied.

$$V_{Rk,s} = 0,5 \cdot A_s \cdot f_{uk} \tag{8}$$

with: A_s = decisive cross section of the anchor

f_{uk} = nominal characteristic steel ultimate strength

4.2.2.3 Failure of the metal part, shear load with lever arm

The characteristic resistance of an anchor in case of failure of the metal part due to shear load with lever arm $V_{Rk,s}$ is given by following Equation:

$$V_{Rk,s} = \frac{M_{Rk,s}}{\ell} \tag{9}$$

with: ℓ = lever arm according to Equation (4)

$M_{Rk,s}$ = taken from the relevant ETA

4.2.2.4 Local brick failure

The characteristic resistance of one anchor in case of local brick failure $V_{Rk,b}$ and the corresponding values for spacing and edge distance $s_{cr,II}$, $s_{cr,\perp}$ and c_{cr} or c_{min} are given in the relevant ETA.

The characteristic resistance of a group of two or four injection anchors $V_{Rk,b}^{g}$ and the corresponding values for spacing and edge distance $s_{min,II}$, $s_{min,\perp}$ and c_{min} are given in the relevant ETA. Unless otherwise specified in the ETA, the characteristic resistance of a group with spacing smaller than $s_{cr,II}$ and $s_{cr,\perp}$ ($s_{min} \leq s \leq s_{cr}$) can be assumed to be at least the characteristic resistance of a corresponding single anchor.

4.2.2.5 Brick edge failure

The characteristic resistance for an anchor in the case of brick edge failure $V_{Rk,c}$ and the corresponding values for spacing and edge distance $s_{cr,II}$, $s_{cr,\perp}$ and c_{cr} or c_{min} are given in the relevant ETA.

In case no characteristic resistance is given in the ETA, the following equations may be applied.

For anchorages in solid masonry and AAC the following determination may be used:

$$V_{Rk,c} = k \cdot \sqrt{d_{nom}} \cdot (h_{nom} / d_{nom})^{0,2} \cdot \sqrt{f_b} \cdot c^{1,5} \quad (10)$$

with:
- k = 0,25 if load direction is to the free edge
- = 0,45 if load direction is parallel to the free edge
- c = edge distance closest to the edge in mm
  $c \geq c_{min}$
  If the load is directed to the free edge and no load transfer to other units in the wall is given then the following conditions shall be fulfilled:
  $c \leq h / 1,5$
  $c \leq h_{brick} / 3$
- d_{nom} = outside diameter of the anchor in mm
- h_{nom} = overall anchor embedment depth in mm
- f_b = normalized mean compressive strength of masonry unit in N/mm^2

For anchorages in hollow or perforated masonry the following values correspond to current experience and no further determination is required:

$V_{Rk,c}$ = 2,50 kN if load direction is parallel to the free edge with $c \geq 100$ mm and $c \geq 6\ d_0$ and if load direction is to the free edge with $c \geq 250$ mm

$V_{Rk,c}$ = 1,25 kN if load direction is to the free edge with $c \geq 100$ mm and $c \geq 6\ d_0$

Intermediate values can be interpolated.

The characteristic resistance of a group of two or four injection anchors $V^g_{Rk,c}$ and the corresponding values for spacing and edge distance $s_{min,II}$, $s_{min,\perp}$ and c_{min} are given in the relevant ETA. On the safe side the characteristic resistance of a group with spacing smaller than $s_{cr,II}$ and $s_{cr,\perp}$ ($s_{min} \leq s \leq s_{cr}$) can be assumed to be at least the characteristic resistance of a corresponding single anchor.

4.2.2.6 Pushing out of one brick

The characteristic resistance of an anchor or a group of anchors in case of pushing out of one brick on the free edge of a wall, $V_{Rk,pb}$, is calculated as follows:

$$V_{Rk,pb} = 2 \cdot l_{brick} \cdot b_{brick}\ (0,5 \cdot f_{vko} + 0,4 \cdot \sigma_d) \quad (11)$$

with:
- $V_{Rk,pb}$ = characteristic resistance for pushing out of one brick
- l_{brick} = length of the brick
- b_{brick} = breadth of the brick
- h_{brick} = height of the brick
- σ_d = minimum design compressive stress perpendicular to the shear
- f_{vko} = initial shear strength according to Table 2

Note: The factor 0,5 regarding f_{vko} considers the difference between the shear strength of a wall given in the EN1996 1-1:2005 + A1:2012 [4], Table 3.4 and the shear strength of only one brick in case of push out.

4.2.2.7 Influence of joints

The information on consideration of joints is given in the relevant ETA. In case of no information is given in the ETA following specification may be applied.

The characteristic resistance $V_{Rk,b}$, $V_{Rk,c}$, $V^{g}_{Rk,b}$ and $V^{g}_{Rk,c}$ may be used if the joints of the masonry are completely filled with mortar.

If the joints of the masonry are not completely filled with mortar then the joints have to be considered as a free edge and the minimum edge distance to the joint has to be $c \geq c_{min}$.

4.2.3 Resistance to combined tension and shear loads

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

$$\beta_N \leq 1{,}0 \quad (12a)$$

$$\beta_V \leq 1{,}0 \quad (12b)$$

$$\beta_N + \beta_V \leq 1{,}2 \quad \text{for solid masonry} \quad (12c)$$

$$\beta_N + \beta_V \leq 1{,}0 \quad \text{for perforated or hollow masonry} \quad (12d)$$

with β_N (β_V) = ratio between design action and design resistance for tension (shear) loading. In Equation (12) the largest value of β_N and β_V for the different failure modes shall be taken (see 4.2.1.1 and 4.2.2.1).

4.3 Design method B for use in masonry

Design method B is based on a simplified approach in which only one value for the design resistance F_{Rd} is given, independent of loading direction and mode of failure. The design resistance F_{Rd} is calculated by the lowest value under consideration of the characteristic resistances and the corresponding partial safety factors. The actual spacing and edge distance shall be equal to or larger than the values of s_{cr} and c_{cr}. F_{Rd}, s_{cr} and c_{cr} are given in the relevant ETA.

In case of shear load with lever arm the characteristic anchor resistance shall be calculated according to Equation (9). The smallest value of F_{Rd} or $V_{Rk,s} / \gamma_{Ms}$ according to Equation (9) governs.

The characteristic resistance of an anchor or a group of anchors in case of pull-out or push out of one brick and the influence of joints shall be considered according to 4.2.1.5, 4.2.1.6, 4.2.2.6 and 4.2.2.7 in every application.

5 SERVICEABILITY LIMIT STATE

5.1 Displacements

The characteristic displacement of the anchor under defined tension loads ($\delta_{N0;}$ $\delta_{N\infty}$) and shear loads ($\delta_{V0;}$ $\delta_{V\infty}$) 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.

5.2 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 shall be transferred by friction between the fixture and the base material (e.g. due to a sufficiently high permanent pre-stressing 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 to 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.

6 REFERENCE DOCUMENTS

As far as no edition date is given in the list of standards thereafter, the standard in its current version at the time of issuing the European Technical Assessment is of relevance.

[1] EAD 330076-00-0604: Metal injection anchors for use in masonry

[2] EN 1990:2002 + A1:2005 / AC:2010: Eurocode: Basis of structural design

[3] EN 1991:2002 + AC 2009: Actions on structures

[4] EN 1996-1-1:2005 + A1:2012: Design of masonry structures. Part 1-1: General rules for reinforced and unreinforced masonry structure

[5] EN 1998-1:2004 + AC:2009: Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings