TECHNICAL REPORT

DESIGN OF
PLASTIC ANCHORS
IN CONCRETE AND MASONRY

TR 064
May 2018

Contents

1.   SCOPE OF THE TECHNICAL REPORT

The design rules in this Technical Report (TR) are valid for plastic anchors for redundant non-structural systems in concrete and masonry with a European Technical Assessment (ETA) in accordance with EAD 330284-00-0604 [1]. This document relies on characteristic resistances and distances which are stated in the ETA and referred to in this TR.

This TR covers the design of plastic anchors for redundant non-structural systems in concrete and/or masonry.

Redundant non-structural systems mean applications in which multiple fastener support elements that are capable to redistribute the load to neighbouring anchors without significantly violating the requirements on the fixture in the serviceability and ultimate limit state in the case of excessive slip or failure of one anchor.

The definition of redundant non-structural systems is given in terms of the number n_1 of fixing points to fasten the fixture and the number n_2 of anchors per fixing point. Furthermore n_3 (kN) specifies the upper limit of the design value of actions on a fixing point 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 to be taken into account in the design of the fixture.

The redistribution of loads in case of excessive slip or failure of one fastener is considered in the static verification of the fastening.

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

$$n_1 \geq 3; \ n_2 \geq 1 \ \text{ and } n_3 \leq 3,0 \text{ kN} \qquad \qquad \qquad \qquad \qquad \qquad (1.2)$$
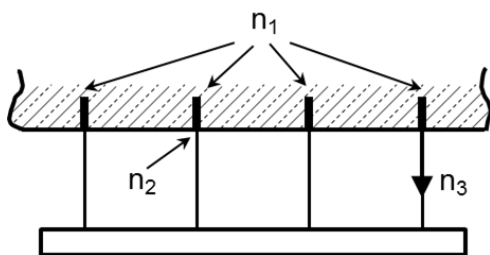

Figure 1.1   Example of a redundant non-structural system

The design method applies to the design of plastic anchors in normal weight concrete, masonry units of clay, calcium silicate, normal weight concrete, light weight concrete, autoclaved aerated concrete.

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

The design and construction of masonry structures in which the plastic anchors are to be anchored shall be comparable with the structural rules for masonry, such as EN 1996 1-1 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

Table 1   Definition of base material groups

Base material group	Base material	Remark
a	Normal weight concrete	Cracked and non-cracked compacted normal weight concrete without fibres with strength classes C12/15 and higher according to EN 206 [6].
		Thin skins (weather resistant skin)
		Precast prestressed hollow core slab
		If the edge distance of an anchor is smaller than the edge distance $c_{cr,N}$, then a longitudinal reinforcement of at least $\varnothing$ 6 mm shall be provided at the edge of the member in the area of the anchorage depth.
b	Solid masonry	Masonry units consisting of solid units according to EN 771-1,2,3 and 5 [7], which in general do not have any holes or cavities other than those inherent in the material.
		However, solid masonry units may have a vertical perforation of up to 15 % of the cross section.
		The characteristic resistances given in the ETA are valid only for the brick sizes which are given in the ETA or for larger brick sizes.
c	Hollow or perforated masonry	Hollow or perforated units according to EN 771-1,2,3 and 5 [7], which have a certain volume percentage of voids which pass through the masonry unit.
		The characteristic resistances given in the ETA are valid for the bricks and blocks only which are given in the ETA regarding base material, size of units, compressive strength and configuration of the voids.
d	Autoclaved aerated concrete (AAC)	Autoclaved aerated concrete masonry units according to EN 771-4 [7] and reinforced components of autoclaved aerated concrete (prefabricated reinforced members) according to EN 12602 [8].

Masonry:
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. 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

Anchors

The notations and symbols frequently used are given below.

a	=	spacing between outer anchors of adjoining groups or between single anchors
a₁	=	spacing between outer anchors of adjoining groups or between single anchors in direction 1
a₂	=	spacing between outer anchors of adjoining groups or between single anchors in direction 2
c	=	edge distance
c₁	=	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
c₂	=	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
e₁	=	distance between shear load and surface of the base material
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 of an anchor group
s_min	=	minimum allowable spacing
s_cr	=	spacing for ensuring the transmission of the characteristic resistance of a single anchor
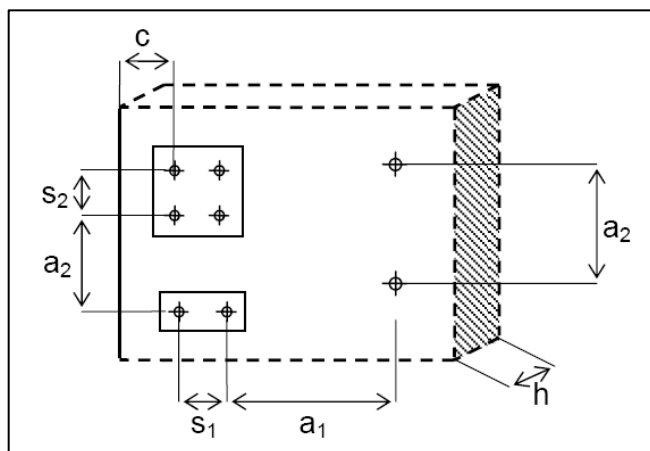
Figure 1.2   Member, anchor spacing and edge distance

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

Actions and resistance

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

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

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

N^h_{Ed} (V^h_{Ed}) = design value of tensile load (shear load) acting on the most stressed anchor of an anchor group

N^g_{Ed} (V^g_{Ed}) = design value of the sum (resultant) of the tensile (shear) loads acting on the tensioned (sheared) anchors of a group

F_{Rk} (N_{Rk} ; V_{Rk}) = characteristic value of resistance of a single anchor or an anchor group (normal force, shear force)

F_{Rd} (N_{Rd} ; V_{Rd}) = design value of resistance of a single anchor or an anchor group (normal force, shear force)

Indices

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

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 E_d does not exceed the value of the design resistance R_d.

$$E_d \quad \leq \quad R_d \tag{2.1}$$

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 [3].

The partial 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:

$$R_d \quad = \quad \frac{R_k}{\gamma_M} \tag{2.2}$$

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

γ_M =   partial factor for material

2.2   Ultimate limit state

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

Failure (rupture) of the metal expansion element

Tension loading:

$$\gamma_{Ms} \quad = \quad \frac{1,2}{\frac{f_{yk}}{f_{uk}}} \quad \geq \quad 1,4 \tag{2.3}$$

Shear loading of the anchor with and without lever arm:

$$\gamma_{Ms} \quad = \quad \frac{1,0}{\frac{f_{yk}}{f_{uk}}} \quad \geq \quad 1,25 \quad f_{uk} \leq 800 \,\frac{N}{mm^2} \quad \text{and} \quad \frac{f_{yk}}{f_{uk}} \leq 0,8 \tag{2.4}$$

$$\gamma_{Ms} \quad = \quad 1,5 \qquad\qquad f_{uk} > 800 \,\frac{N}{mm^2} \quad \text{or} \quad \frac{f_{yk}}{f_{uk}} > 0,8 \tag{2.5}$$

Failure (rupture) of the polymeric expansion element and/or sleeve

$$\gamma_{Mpol} \quad = \quad 2,5 \tag{2.6}$$

Failure of the plastic anchor

For use in base material group a:

$$\gamma_{Mc} \quad = \quad 1,8 \tag{2.7}$$

For use in base material group b and c:

$$\gamma_{Mm} \quad = \quad 2,5 \tag{2.8}$$

For use in base material group d:

$$\gamma_{MAAC} \quad = \quad 2,0 \tag{2.9}$$

2.3   Serviceability limit state

In the serviceability limit state it shall be shown that the displacements occurring under the characteristic actions (see chapter 4) 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 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 of a group 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 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 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 ≤ 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 (3.1) (see Figure 3.1).

$$ l \qquad = \quad a_3 + e_1 \tag{3.1}$$

with: e_1 =   distance between shear load and surface of the base material
$$e_1 = 0,5 \cdot t_{fix} + t_{tol}$$
a_3 = $0,5 \cdot d$
d =   nominal diameter of the anchor
t_{tol} =   thickness of mortar layer
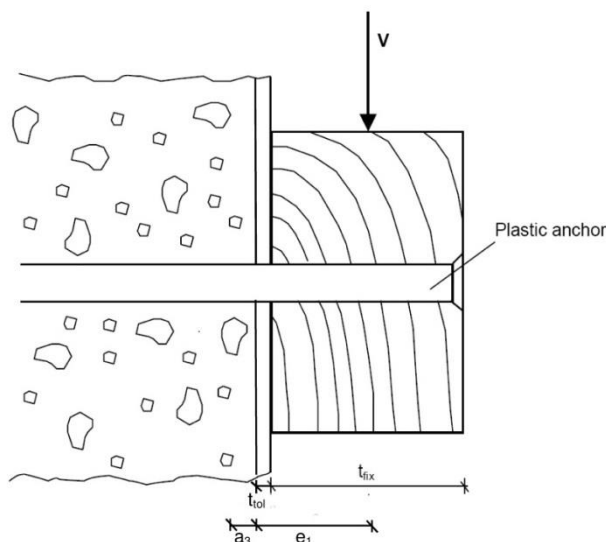t_{fix} =   thickness of fixture

Figure 3.1   Definition of lever arm

4.   ULTIMATE LIMIT STATE

4.1   General

The characteristic resistances of plastic anchors in the ultimate limit state for use in concrete are given in 4.2. The characteristic resistances and the corresponding specific conditions for the design of plastic anchors for use in masonry and aerated concrete are listed in 4.3.

4.2   Ultimate limit state for use in concrete

4.2.1   Resistance to tension loads

4.2.1.1 Required proofs

Table 2

		single anchor	anchor group	
failure of the expansion element	metal	$N_{Ed} \leq N_{Rk,s} / \gamma_{Ms}$	$N^h_{Ed} \leq N_{Rk,s} / \gamma_{Ms}$	
	polymeric [(1)]	$N_{Ed} \leq N_{Rk,pol} / \gamma_{Mpol}$	$N^h_{Ed} \leq N_{Rk,pol} / \gamma_{Mpol}$	
pull-out failure		$N_{Ed} \leq N_{Rk,p} / \gamma_{Mc}$	$N^h_{Ed} \leq N_{Rk,p} / \gamma_{Mc}$	
concrete cone failure		$N_{Ed} \leq N_{Rk,c} / \gamma_{Mc}$		$N^g_{Ed} \leq N_{Rk,c} / \gamma_{Mc}$

[(1)]   also valid for rupture of the polymeric sleeve, $N_{Rk,pol}$ only given in ETA if failure is caused by rupture polymeric sleeve.

4.2.1.2 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.

4.2.1.3 Pull-out failure

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

4.2.1.4 Concrete cone failure

The characteristic resistance of a single anchor in case of concrete cone failure is:

$$N_{Rk,c} \quad = \quad 7,2 \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1,5} \cdot \frac{c}{c_{cr,N}} \tag{4.1}$$

$$\left(\frac{c}{c_{cr,N}} \right) \quad \leq \quad 1,0 \tag{4.2}$$

$$h_{ef}^{1,5} \quad = \quad \frac{N_{Rk,p}}{7,2 \cdot \sqrt{f_{ck,cube}}} \tag{4.3}$$

with: $N_{Rk,p}$ = 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 shall not exceed 60 N/mm² (corresponding to concrete strength class C50/60) in N/mm²

h_{ef} = effective anchorage depth in mm

Anchors with a spacing $s \leq s_{cr}$ are considered as a group with a characteristic resistance to concrete cone failure $N_{Rk,c}$ according to equation (4.1) for the whole group.

For a spacing $s > s_{cr}$ the anchors are considered as single anchors, each with a characteristic resistance to concrete cone failure $N_{Rk,c}$.

4.2.2   Resistance to shear loads

4.2.2.1 Required proofs

Table 3

		single anchor	anchor group	
Failure of the expansion element, shear load **without** lever arm	metal	$V_{Ed} \leq V_{Rk,s} / \gamma_{Ms}$	$V^h_{Ed} \leq V_{Rk,s} / \gamma_{Ms}$	
	polymeric	$V_{Ed} \leq V_{Rk,pol} / \gamma_{Mpol}$	$V^h_{Ed} \leq V_{Rk,pol} / \gamma_{Mpol}$	
Failure of the expansion element, shear load **with** lever arm	metal	$V_{Ed} \leq V_{Rk,s} / \gamma_{Ms}$	$V^h_{Ed} \leq V_{Rk,s} / \gamma_{Ms}$	
	polymeric	The shear load shall be applied without lever arm. A stand-off installation is not covered.		
concrete edge failure		$V_{Ed} \leq V_{Rk,c} / \gamma_{Mc}$		$V^g_{Ed} \leq V_{Rk,c} / \gamma_{Mc}$

4.2.2.2 Failure of the metal part or polymeric part, 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.

4.2.2.3 Failure of the expansion element, shear load with lever arm

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

$$V_{Rk,s} \quad = \quad \frac{M_{Rk,s}}{l} \qquad \text{[N]} \tag{4.4}$$

with: l = lever arm according to equation (3.1)

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

4.2.2.4 Concrete edge failure

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

$$V_{Rk,c} \quad = \quad 0{,}45 \cdot \sqrt{d_{nom}} \cdot \left(\frac{h_{nom}}{d_{nom}} \right)^{0,2} \cdot \sqrt{f_{ck,cube}} \cdot c_1^{1,5} \cdot \left(\frac{c_2}{1{,}5 \cdot c_1} \right)^{0,5} \cdot \left(\frac{h}{1{,}5 \cdot c_1} \right)^{0,5} \tag{4.5}$$

$$\left(\frac{c_2}{1{,}5 \cdot c_1} \right)^{0,5} \quad \leq \ 1{,}0 \tag{4.6}$$

and

$$\left(\frac{h}{1{,}5 \cdot c_1} \right)^{0,5} \quad \leq \ 1{,}0 \tag{4.7}$$

with: c_1 = edge distance closest to the edge in loading direction in mm

c_2 = edge distance perpendicular to direction 1 in mm

$f_{ck,cube}$ = nominal characteristic concrete compressive strength (based on cubes) value shall not exceed 60 N/mm² (corresponding to concrete strength class C50/60) in N/mm²

Anchors with a spacing $s \leq s_{cr}$ are considered as a group with a characteristic resistance to concrete edge failure $V_{Rk,c}$ according to equation (4.1) for the whole group.

For a spacing $s > s_{cr}$ the anchors are considered as single anchors, each with a characteristic resistance to concrete edge failure $V_{Rk,c}$.

4.2.3   Resistance to combined tension and shear loads

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

$$\beta_N \qquad \leq \qquad 1{,}0 \qquad\qquad\qquad (4.8)$$

$$\beta_V \qquad \leq \qquad 1{,}0 \qquad\qquad\qquad (4.9)$$

$$\beta_N + \beta_V \qquad \leq \qquad 1{,}2 \qquad\qquad\qquad (4.10)$$

with β_N (β_V) = ratio between design action and design resistance for tension (shear) loading.
In equations (4.8) to (4.10) 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   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 **F_{Rk}** independent of the load direction and the mode of failure. The appropriated partial 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 (4.4) and (4.5). The smallest value of F_{Rd} or $_{Rk,s}/\gamma_{Ms}$ (metal) or $V_{Rk,pol}/\gamma_{Mpol}$ (polymeric) governs.

(2)   The characteristic resistance **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 between groups of anchors is $a \geq 250mm$ and $a > s_{min}$.

(3)   The position of the plastic anchors with respect to the joints of a masonry wall (base material group b, c and d) and the kind of joint according to EN 1996-1-1: Eurocode 6 [4], 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 4 depending on the kind of joint and the visibility of the joints on construction site.

Table 4 Characteristic resistance in masonry (base material group b, c and d) depending on visibility and condition of the joints

1	Joints	Characteristic resistance depending on the joints (a)	
		joints are visible	joints are <u>not</u> visible
2	**filled with mortar** (perpend/vertical and bed/horizontal joints)	F_{Rk}	$0,5 \cdot F_{Rk}$ **(b)**
3	**<u>not</u> filled with mortar** (perpend/vertical joints)	$0,5 \cdot F_{Rk}$ **(c)** and $N_{Ed} \leq 2,0$ kN **(d)**	$0,5 \cdot F_{Rk}$ and $N_{Ed} \leq 2,0$ kN **(b) (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_{Ed} 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 $a \geq 250$ mm. For prefabricated reinforced floor units the spacing of fixing points is $a \geq 600$ mm. Fixing points are single anchors or groups of 2 or 4 anchors.

5. SERVICEABILITY LIMIT STATE

5.1 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.

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 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.

6. REFERENCE DOCUMENTS

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

[1]   EAD 330284-00-0604
      Plastic anchors for redundant non-structural systems in concrete and masonry

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

[3]   EN 1991: Actions on structures

[4]   EN 1996-1-1:2005 + A1:2012 Eurocode 6 - Design of masonry structures
      Part 1-1: General rules for reinforced and unreinforced masonry structure

[5]   EN 206:2000-12/A1:2004/A2:2005: Concrete
      Part 1: Specification, performance, production and conformity

[6]   EN 206:2013+A1:2016: Concrete - Specification, performance, production and conformity

[7]   EN 771-1 to 5:2011-07+A1:2015: Specification for masonry units

[8]   EN 12602:2016: Prefabricated reinforced components of autoclaved aerated concrete