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TECHNICAL REPORT

Design of plastic anchors for fixing façade claddings through angle brackets in masonry and concrete under seismic action

TR 080

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EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT

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Contents

1 SCOPE OF THE TECHNICAL REPORT

1.1 General

This Technical Report provides a design method for the anchorage of façade claddings under seismic actions through angle brackets in concrete or masonry with plastic anchors featuring a European Technical Assessment (ETA) in accordance with EAD 331151-01-0604 [1]. This document relies on characteristic resistances and distances which are stated in the ETA and referred to in this Technical Report.

The anchorages are intended to be used only as redundant non-structural systems (statically indeterminate fixing with more than two supports).

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.

1.2 Specifics for seismic design

In structures subjected to earthquake ground motions, cracking is expected to be widespread and to be more severe in regions, such as e.g. in the diagonals of shear walls. In buildings subjected to earthquake ground motions, cracking may occur both in primary or secondary seismic members and in masonry infills.

A precondition for seismic anchor design is, therefore, a seismic design of the members where anchors will be installed, including the potential identification of regions mentioned above. The results of these design procedures are strongly depending on the assumptions used for the design of a building and shall be performed by an engineer experienced in anchorages and concrete and masonry work under seismic actions or under their supervision. Only redundant applications shall be allowed, and single fastener installations shall be avoided by increasing the number of fixing points or fasteners per fixing point to enable load redistribution to neighbouring fasteners in case of excessive slip or premature failure of one anchor.

This Technical Report relies on the assessment of fasteners capacity as given in EAD 331151-00-0604 [1], where the effects of cyclic actions are evaluated in uncracked concrete or masonry. Because of the specific application for façade cladding, it is considered that the redundancy of the anchorage points is fulfilled and is high enough to ensure that no more than one fixing point may be located in a crack such that failure at the fixing point may occur. Consequently, at the remaining fixing points, it is assumed that:

a. When fastening in concrete, crack width is not higher than the one for which the fastener is qualified according to EAD 330284-00-0604 for quasi-static or static actions;
b. When fastening in masonry, no crack can occur prior to a load level which induces failure of the member where fasteners are installed.

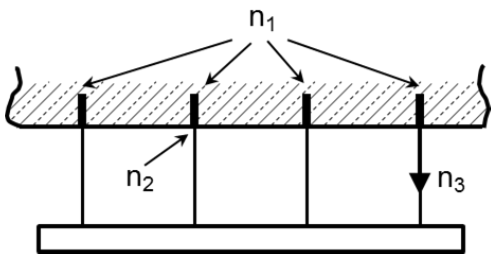
1.3 Type of anchors, anchor groups and number of anchors

The design rules in this Technical Report (TR) rely on essential characteristics of the specific anchor type (characteristic values of resistance and group factors), which are stated in the relevant ETA and referred to in this TR.

The design methods are valid for single anchors and anchor groups with two or four anchors with spacing s_{cr} or s_{min} and edge distances c_{cr} or c_{min} as given in the relevant ETA. In case of an anchor group the loads are applied to the individual anchors of the group by means of a bracket. The diameter d_f of the clearance hole in the bracket should not be larger than the value given in the ETA. In an anchor group only anchors of the same type, size and length shall be used.

The definition of redundant systems in the context of this Technical Report 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, the load transfer in the case of excessive slip of one anchor needs to be considered in the design of the fixture.

The redistribution of loads in case of excessive slip or premature failure of one anchor shall be considered for the verification of the fastening.



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

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

Figure 1.1 Examples of a redundant non-structural systems

1.4 Base material

This design method applies to the design of anchorage of façade claddings through angle brackets in masonry units made of clay, calcium silicate or normal weight concrete.

The design and construction of concrete structures in which the injection anchors are to be anchored shall be comparable with the structural rules for concrete, such as EN 1992 1-1 Clause 3 and Clause 8 [4] and - in case of seismic actions - EN 1998-1 Clause 9 [5], and the relevant national regulations.

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 Clause 3 and Clause 8 [4] and - in case of seismic actions - EN 1998-1 Clause 9 [5], and the relevant national regulations.

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.

1.5 Type and direction of load

This Technical report applies only to anchors subject to seismic actions in tension, shear or combined tension and shear.

Anchors featuring an ETA according to EAD 331151-00-0604 [1] may be used in areas with seismicity higher than very low as defined in EN 1998-1 [5]. They shall be designed according to section 3 of this TR.

1.6 Specific terms used in this TR

Definitions and abbreviations

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.

DLS = Damage Limitation State (see EN 1998-1 [5], 2.2.1)

ULS = Ultimate Limit State (see EN 1998-1 [5], 2.2.1)

Indices

E = action

M = material

N = tension

R = resistance

V = shear

c = edge

d = design value

eq = seismic (earthquake)
k = characteristic value
m = masonry
p = anchor pull-out or pushing out
pl = plastic
s = steel
u = ultimate
y = yielding

Superscripts

g = load on or resistance of a group of anchors
h = most loaded anchor of a group

Anchors

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

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 anchor
s_{cr} = spacing for ensuring the transmission of the characteristic resistance of a single injection anchor
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

A_a = seismic amplification factor
E_d = design action
E_{Ed} = design value of the effect of seismic actions as given in EN 1998-1 [5]
F = force in general
N = normal force (+N = tension force)
V = shear force
M = moment
R_d = design resistance
R_k = characteristic resistance

N_{Rk}, V_{Rk}	=	characteristic anchor resistance of a single anchor under tension or shear force
$N^{g}_{Rk}E_{d}$, V^{g}_{Rk}	=	characteristic anchor resistance of an anchor group under tension or shear force
N^{g}_{Ed} , V^{g}_{Ed}	=	design value of actions acting on an anchor group
N^{h}_{Ed} , V^{h}_{Ed}	=	design value of actions acting on the highest loaded anchor
γ_{M}	=	partial safety factor for material

Displacements

$\delta_{sf,N,DLS}$	=	Displacement for serviceability limit state under tension loading
$\delta_{sf,V,DLS}$	=	Displacement for serviceability limit state under shear loading

2 GENERAL DESIGN AND SAFETY CONCEPT

The design of anchorages shall be in accordance with the general rules given in EN 1990 [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.

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

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 safety factors for actions may be taken from national regulations or in the absence of them according to EN 1990 [2].

The design resistance is calculated as follows:

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

with:

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

γ_M = partial safety factor for material

3 DESIGN OF ANCHORAGES UNDER SEISMIC ACTIONS

3.1 General

This section provides requirements for the design of plastic anchors used to transmit seismic actions by means of tension, shear, or a combination of tension and shear load to concrete and masonry members.

3.2 Design and safety concept

3.2.1 Ultimate limit state

Partial safety factors for actions shall be in accordance with EN 1990 [2].

The design resistance under seismic actions is calculated according to Equation (3.5).

In the absence of national regulations, the recommended values for partial safety factors for fastenings under seismic loading $\gamma_{M,eq}$ are identical to the corresponding values for static loading (see EOTA TR 064) [7]:

Failure (rupture) of the metal part

Tension loading:

$$\gamma_{Ms} = \frac{1{,}2}{f_{yk}/f_{uk}} \geq 1{,}4 \tag{3.1}$$

Shear loading of the anchor with and without lever arm:

$$\gamma_{Ms} = \frac{1{,}0}{f_{yk}/f_{uk}} \geq 1{,}25 \qquad f_{uk} \leq 800\ \text{N/mm}^2 \qquad \text{and} \qquad f_{yk} / f_{uk} \leq 0{,}8 \tag{3.2}$$

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

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

$$\gamma_{Mpol} = 2{,}5$$

Failure (rupture) of the masonry unit:
For use in base material group a:

$$\gamma_{Mc} = 1{,}8 \tag{3.3}$$

For use in base material group b and c:

$$\gamma_{Mm} = 2{,}5 \tag{3.4}$$

3.2.2 Damage limitation state

In the damage limitation state, it shall be shown that the displacements occurring under the relevant actions are not larger than the admissible displacement. The admissible displacement depends on the application under consideration and shall be evaluated by the design engineer.

3.3 Requirements

Anchors used to resist seismic actions shall meet all applicable requirements for non-seismic applications.

Only anchors qualified according to EAD 331151-00-0604 [1] shall be used.

The provisions in this section do not apply to the design of fastenings in regions of structure members where cracks might occur during seismic events as e.g. in the diagonals of shear walls.

Loosening of the nut or screw shall be prevented by appropriate measures.

Fastenings where shear loads act on anchors with a lever arm, such as e.g. in stand-off installation or with a grout layer ≥ 0,5·d, are not covered (compare section 1).

3.4 Design options

In the design of fastenings one of the following options a) or b) shall be satisfied:

The design shall be carried out without requirements on the ductility of the anchors. It shall be assumed that anchors are non-dissipative elements, and they are not able to dissipate energy by means of ductile hysteretic behaviour and that they do not contribute to the overall ductile behaviour of the structure, therefore two design options are possible:

a. Elastic design: The fastening is designed for the maximum load obtained from the design load combinations that include seismic actions $E_{E,d}$ corresponding to the ultimate limit state (see EN 1998-1 [5]) assuming elastic behavior of the fastening and of the structure. Furthermore, uncertainties in the model to derive seismic actions on the fastening shall be considered.
b. Capacity design: The group of anchors is designed for the maximum tension and/or shear load that can be transmitted to the fastening based on either the development of a ductile yield mechanism in the fixture or the attached element taking into account strain hardening and material over-strength or the capacity of a non-yielding attached element according to Capacity Design Rules as given in EN 1998-1 [5]. The assumption of a plastic hinge in the fixture requires to take into account specific aspects including e.g. the redistribution of loads to the individual anchors of a group, the redistribution of the loads in the structure.

As for case (b), when the resistance and the energy-dissipation capacity of the attached element are evaluated through a behaviour factor q_a (see EN 1998-1 [5]) , the action effects for the fasteners shall be derived assigning q_a = 2,0 to the attached element according to EN 1998-1 [5]. If action effects are derived in accordance with the simplified approach given in 3.5.3 with q_a = 2,0, they shall be multiplied by an amplification factor equal to 1,5. If the action effects are derived from a more precise model, this additional amplification may be omitted.

3.5 Derivation of forces action on anchors

3.5.1 General

The design value of the effect of seismic actions $E_{E,d}$ acting on the fixture shall be determined according to EN 1998-1 [5] and section 3.4 as applicable. Provisions in addition to EN 1998-1 [5] including vertical seismic actions acting on non-structural elements are provided in this Section.

The maximum value of each action effect (tension and shear component of forces per anchor) shall be considered to act simultaneously if no other more accurate model is used for the estimation of the probable simultaneous value of each action effect.

3.5.2 Addition to EN 1998-1: 2004, 4.3.5.1

In the design of fastenings for non-structural elements subjected to seismic actions, any beneficial effects of friction due to gravity loads should be ignored.

3.5.3 Addition and alterations to EN 1998-1:2004, 4.3.5.2

The horizontal effects of the seismic action of non-structural elements are determined according to Equation (4.24) of EN 1998-1 [5]. However, the behaviour factor q_a may be taken from Table 3.1.

Note: Table 3.1 includes information in addition to the values q_a given in EN 1998-1 [5], Table 4.4.

Table 3.1 Values of q_a and A_a for non-structural elements

Type of non-structural element	q_a	A_a
Partitions and facades	2,0	1,5

Equation (4.25) of EN 1998-1 [5] for the seismic coefficient S_a may be rearranged as:

$$S_a=\alpha\cdot S\cdot\left[\left(1+\frac{z}{H}\right)\cdot A_a-0,5\right] \tag{3.1}$$

Where:

α = ratio of the design ground acceleration on type A ground, a_g, to the acceleration of gravity g;

S = soil factor;

z = height of the non-structural element above the level of application of the seismic action (foundation or top of a rigid basement);

H = building height measured from the foundation or from the top of a rigid basement;

$$A_a = \frac{3}{1+\left(1-\frac{T_a}{T_1}\right)^2} \tag{3.2}$$

T_a = fundamental vibration period of the non-structural element;

T_1 = fundamental vibration period of the building in the relevant direction.

The seismic amplification factor A_a may be calculated according to Equation (3.2) or taken from Table 3.1 if one of the fundamental vibration periods is not known.

Note: When calculating the forces acting on non-structural elements according to Equation (4.25) of EN 1998-1 [5], it can often be difficult to establish with confidence the fundamental vibration period T_a of the non-structural element. Table 3.1 provides a pragmatic approach and may not be conservative in all cases.

The vertical effects of the seismic action should be determined by applying to the non-structural element a vertical force F_{Va} acting at the centre of mass of the non-structural element which is defined as follows:

$$F_{Va} = (S_{Va} \cdot W_a \cdot \gamma_a)/q_a \tag{3.3}$$

where

S_{Va} = $\alpha_V \cdot A_a$

α_V = ratio of the vertical ground acceleration on type A ground, a_{vg}, to the acceleration of gravity g;

W_a = weight of the element;

γ_a = importance factor of the element, see EN 1998-1 [5], Section 4.3.5.3;

q_a, A_a may be assumed to be equal to the values valid for horizontal forces.

Note: The vertical effects of the seismic action F_{Va} for non-structural elements may be neglected for the anchor when the ratio of the vertical component of the design ground acceleration a_{vg} to the acceleration of gravity g is less than 0,25 and the gravity loads are transferred through direct bearing of the fixture on the structure.

3.6 Resistances

3.6.1 Required verifications

For the seismic design situation the verifications $F_{Ed,eq} \leq F_{Rd,eq}$ shall be performed for all loading directions (tension, shear, combined tension and shear) as well as all failure modes (see Table 3.2).

Table 3.2 Required verifications

Loading	Failure mode	Single anchor	Anchor group	
			most loaded anchor	anchor group
tension	Failure of the metal part	$N_{Ed,eq} \leq N_{Rd,s,eq}$	$N^h_{Ed,eq} \leq N_{Rd,s,eq}$	-
	Pull-out failure of the anchor	$N_{Ed,eq} \leq N_{Rd,p,eq}$	$N^h_{Ed,eq} \leq N_{Rd,p,eq}$	-
	Brick breakout failure	$N_{Ed,eq} \leq N_{Rd,b,eq}$	-	$N^g_{Ed,eq} \leq N^g_{Rd,b,eq}$
shear	Failure of the metal part, shear load without lever arm [1)]	$V_{Ed,eq} \leq V_{Rd,s,eq}$	$V^h_{Ed,eq} \leq V_{Rd,s,eq}$	-
	Local brick failure	$V_{Ed,eq} \leq V_{Rd,b,eq}$	-	$V^g_{Ed,eq} \leq V^g_{Rd,b,eq}$
	Brick edge failure	$V_{Ed,eq} \leq V_{Rd,c,eq}$	-	$V^g_{Ed,eq} \leq V^g_{Rd,c,eq}$

[1)] Steel failure for shear loads with lever arm is not covered for seismic actions (see Section 3.3).

3.6.2 Design resistance

The seismic design resistance $R_{d,eq}$ of a fastening is given by:

$$R_{d,eq} = \frac{R_{k,eq}}{\gamma_{M,eq}} \tag{3.5}$$

with $\gamma_{M,eq}$ (i.e. $\gamma_{Ms,eq}$, $\gamma_{Mm,eq}$, γ_{Mpol}) in accordance with 3.2.1.

The characteristic seismic resistance $R_{k,seis}$ of a fastening shall be determined as follows:

$$R_{k,eq} = \alpha_{gap} \cdot\cdot R^0_{k,eq} \tag{3.6}$$

where

α_{gap} = reduction factor to take into account inertia effects due to an annular gap between anchor and fixture in case of shear loading; given in the relevant European Technical Product Specification;

$R^0_{k,eq}$ = basic characteristic seismic resistance determined as follows:
For steel, brick breakout failure under tension load and steel, local brick and brick edge failure under shear load (if evaluated in tests) $R^0_{Rk,eq}$ shall be taken from the relevant ETA (i.e. $N_{Rk,sf}$, $V_{Rk,sf}$).

The forces on the anchors are amplified in presence of an annular gap under shear loading due to a hammer effect on the anchor. For reasons of simplicity this effect is considered only in the resistance of the fastening. In absence of information in the ETA the following values α_{gap} may be used, which are based on a limited number of tests in concrete.

Shear loading:

α_{gap} = 1,0, no hole clearance between anchor and fixture (general case, see 3.1)
= 0,5, connections with hole clearance

3.6.3 Interaction – resistance to combined tension and shear loads

The verification for interaction between tension and shear forces shall be carried out according to Equation (3.7).

$$\left(\frac{N_{Ed}}{N_{Rd,i,eq}}\right) + \left(\frac{V_{Ed}}{V_{Rd,i,eq}}\right) \leq 1 \tag{3.7}$$

In Equation (3.7) the largest ratios $N_{Sd}/N_{Rd,i,eq}$ and $V_{Sd}/V_{Rd,i,eq}$ for the different failure modes shall be inserted, where N_{Sd} and V_{Sd} are the design actions on the anchors including seismic effects.

3.7 Displacements

The displacement of an anchor under tensile and shear loads at damage limitation state (DLS) shall be limited to a value $\delta_{sf,N,DLS}$ and $\delta_{sf,V,DLS}$ to meet requirements regarding e.g. functionality and assumed support conditions. These values shall be selected based on the requirements of the specific application. When assuming a rigid support in the analysis the designer shall establish the limiting displacement compatible to the requirement for the structural behaviour.

Note: In a number of cases, the acceptable displacement associated with a rigid support condition is considered to be in the range of 3 mm.

If the anchor displacements $\delta_{sf,N,DLS}$ under tension loading and/or $\delta_{sf,V,DLS}$ under shear loading provided in the relevant ETA are higher than the corresponding required values $\delta_{N,req(DLS)}$ and/or $\delta_{V,req(DLS)}$, the design resistance may be reduced according to Equations (3.8) and/or (3.9) to meet the required displacement limits.

$$N_{Rd,eq,red} = N_{Rd,eq} \cdot \frac{\delta_{N,req(DLS)}}{\delta_{sf,N,DLS}} \tag{3.8}$$

$$V_{Rd,eq,red} = V_{Rd,eq} \cdot \frac{\delta_{V,req(DLS)}}{\delta_{sf,V,DLS}} \tag{3.9}$$

If fastenings and attached elements shall be operational after an earthquake, the relevant displacements have to be taken into account.

4 ADDITIONAL RULES FOR VERIFICATION OF MASONRY MEMBERS DUE TO LOADS APPLIED BY FASTENINGS

The proof of the local transmission of the anchor loads into the masonry member is delivered by using the design methods described in this document.

Safe transmission of the anchor loads to the supports of the masonry member shall be demonstrated for the ultimate limit state and the damage or serviceability limit state according to EN 1996 1-1 [4] and EN 1998-1 [5].

5 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 331151-01-0604: Plastic anchors for fixing façade claddings through angle brackets in masonry and concrete under seismic action, September 2017

[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

[6] EN 1998-3:2005 + AC:2010: Eurocode 8: Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings

[7] TR 064: Design of plastic anchors in concrete and masonry. European Organisation for Technical Assessment (EOTA), Brussels, Belgium, 2018.