SEISMIC AND FIRE CONSIDERATIONS

2. Seismic and accidental fire design situation

2.1. General

In many countries around the world, fire and seismic considerations are becoming increasingly important, as fire events and earthquakes are causing severe damages to buildings and a high number of casualties. Post-installed anchors have to be fit for those extraordinary events as they are incorporated in the structural and non-structural elements of a building, and are used to fix the services and essential lifelines of a building.

Post-installed anchors are assessed based on the valid European Assessment Documents (EAD). The different product behaviour of mechanical, bonded and concrete screw anchors, is incorporated in their specifically related EADs. This relates also to the tests for the assessment of the product behaviour under accidental loads. In this Design Manual, we give information based on the European guidelines. Information based on American guidelines would be equivalent. Only post-installed anchors that are qualified for cracked concrete and seismic applications are considered in this chapter.

Chapter 9 of the EN 1992-4 provides the requirements for the design of post-installed fasteners under seismic actions. Annex C of the same code provides more detailed information on the design method and requirements. The design explanations of part 2.5 of this chapter are primarily based on the EN 1992-4 and its annexes.

A manufacturer of post-installed anchors is not responsible for the structural verifications of an anchorage, but should provide information about the relevant and related topics to design and establish safe anchorage. Therefore, and as we consider the topic about combination of actions important, we start here with a short summary.

2.2. Design values of actions

The design concept and the required verification considering a limit state of rupture or excessive deformation based on EN 1990 clause 6.4 was briefly explained in our previous chapter. This chapter elaborates on the combinations of actions as a matter of principle. It is assumed that the structural engineer will detail particular verifications with the relevant National Standard.

2.2.1. Combinations of actions for persistent or transient design situations (fundamental combinations)

For each critical load case, the design values of the effects of actions E_d shall be determined by combining the values of actions that are considered to occur simultaneously.

$$E_d = \sum_{j\geq 1} \gamma_{G,j}\, G_{k,j} + \gamma_{Q,1} Q_{k,1} + \sum_{i>1} \gamma_{Q,i}\, \psi_{o,i} Q_{k,i}$$

Effects of actions that cannot exist simultaneously due to physical or functional reasons should not be considered together in combinations of actions. Depending on its uses and the form and the location of a building, the combinations of actions may be based on not more than two variable actions.

The combination factors ψ are given in Annexes of EN 1990.

Table 1: $\gamma_{G,j}$ & $\gamma_{Q,1}$ factors for permanent and variable actions

Persistent and transient design situations	Permanent action	Variable action
favourable	$\gamma_{G,j} = 1.00$	$\gamma_{Q,1} = \gamma_{Q,i} = 0$
unfavourable	$\gamma_{G,j} = 1.35$	$\gamma_{Q,1} = \gamma_{Q,i} = 1.50$

2.2.2. Combinations of actions for accidental design situations

Combinations of actions for accidental design situations should either involve an explicit accidental action A_d (fire or impact), or refer to a situation after an accidental event ($A_d = 0$).

$$E_d = \sum_{j\geq 1} G_{k,j} + A_d + \psi_{1,1} Q_{k,1} + \sum_{i>1} \psi_{2,i} Q_{k,i}.$$

2.2.3. Combinations of actions for seismic design situations

$$E_d = \sum_{j\geq1} G_{k,j} + P_{Ed} + \sum_{i>1} \psi_{2,i} Q_{k,i}.$$

2.3. Structural verifications under seismic design situations and design values of the anchor resistances for the respective failure modes

Anchors are assessed for their seismic performance characteristics according to the product relevant EAD. Only anchors, which proved their suitability for the use in cracked concrete, are accepted and qualified in seismic performance categories C1 and/or C2.

The two seismic performance categories C1/C2 are distinguished by the stringency of the tests, with C2 qualification being the more demanding. The recommended use of the C1/C2 is given in the EN 1992-4.

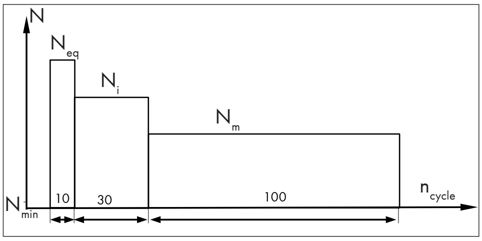
The performance category C1 provides fastener capacities in terms of strength (forces), while C2 in terms of both strength (forces) and displacements. Both cases take into consideration concrete cracking. In the case of C1, the maximum crack width is taken as $\Delta w = 0.5$ mm and in C2 as $\Delta w = 0.8$ mm. For C2, the performance is assessed with a test where cracks open and close (see figure 5) in addition.

The following table provides the reader with the qualification tests for each performance category:

Table 2: Seismic Qualification Tests of Fasteners

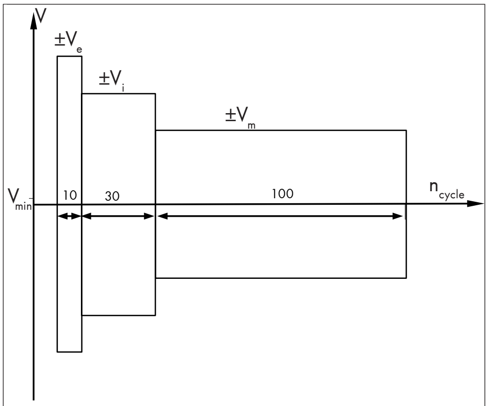
C1 Category	C2 Category
1. Pulsating tension load 2. Alternating shear loads	1 Tests up to failure 2. Pulsating tension load 3. Alternating shear load 4. Crack cycling

2.3.1. Qualification of anchors for category C1



$N_{eq} = 0.5 \cdot N_{u,m,ref}$
$N_i = 0.375 \cdot N_{u,m,ref}$
$N_m = 0.25 \cdot N_{u,m,ref}$
$N_{u,m,ref}$ = normalized mean tension capacity for C20/25, $\Delta w = 0.5$mm

Figure 1: Tests under pulsating tension load

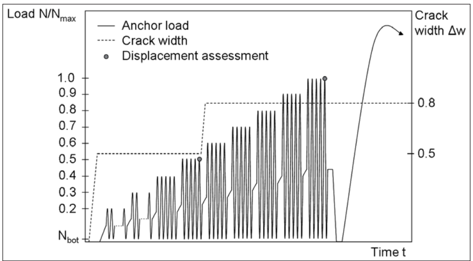


$V_{eq} = 0.5 \cdot V_{u,m,ref}$
$V_i = 0.375 \cdot V_{u,m,ref}$
$V_m = 0.25 \cdot V_{u,m,ref}$
$V_{u,m,ref}$ = normalized mean shear capacity for C20/25, $\Delta w = 0.5$mm

Figure 2: Tests under alternating shear load

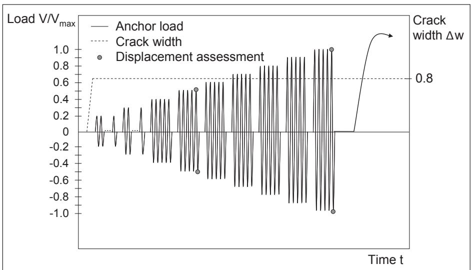
SEISMIC AND FIRE CONSIDERATIONS

2.3.2. Qualification of anchors for category C2



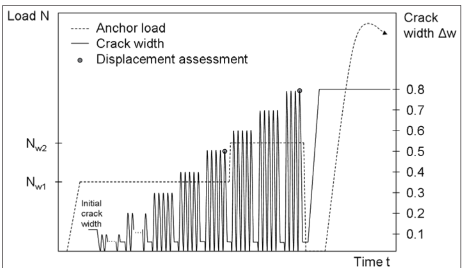
N_{max} = $0.75 \cdot N_{u,m,ref}$
$N_{u,m,ref}$ = normalized mean tension capacity for C20/25, Δw = 0.8mm

Figure 3: Tests under pulsating tension load



V_{max} = $0.85 \cdot V_{u,m,ref}$
$V_{u,m,ref}$ = normalized mean shear capacity for C20/25, Δw = 0.8mm

Figure 4: Tests under alternating shear load



N_{w1} = $0.4 \cdot N_{u,m,ref}$
N_{w2} = $0.5 \cdot N_{u,m,ref}$
$N_{u,m,ref}$ = normalized mean shear capacity for C20/25, Δw = 0.8mm

Figure 5: Tests under crack cycling

2.4. Recommended seismic performance categories for anchors

The seismic performance of anchors subjected to seismic loading is categorized by the performance categories C1 and C2. Seismic performance category C1 provides anchor capacities only in terms of resistances at ultimate limit state, while seismic performance category C2 provides anchor capacities in terms of both resistances at ultimate limit state and displacements at damage limitation state and ultimate limit state. The following tables relate to the seismic performance categories C1 and C2 to the seismicity level and building importance class. The level of seismicity is defined as a function of the product $a_g \cdot S$, where a_g is the design ground acceleration on Type A ground and S the soil factor both in accordance with EN 1998-1.

Table 3: Importance classes for buildings

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

Note: Importance classes I, II, III or IV correspond roughly to consequences classes CC1, CC2, CC3, respectively, defined in EN 1990:2002, Annex B.

2.5. Connections between structural elements of primary and/or secondary seismic members

Table 4: Recommended seismic performance categories for fasteners

	Seismicity level [a]		Importance class acc. to EN 1998-1:2004, 4.2.5			
1	Class	$a_{g.}S^{c}$	I	II	III	IV
2	Very low [b]	$a_{g.}S \leq 0.05$ g	No seismic performance category required			
3	low [b]	0.05 g $< a_{g.}S \leq 0.1$ g	C1	C1[d] or C2[e]		C2
4	> low	$a_{g.}S > 0.1$ g	C1	C2		

[a] The values defining the seismicity levels are subject to a National Annex. The recommended values are given here.
[b] Definition according to EN 1998-1:2004. 3.2.1.
[c] a_g = design ground acceleration on type A ground (see EN 1998-1:2004, 3.2.1),
S = soil factor (see EN 1998-1:2004, 3.2.2).
[d] C1 for fixing non-structural elements to structures
[e] C2 for fixing structural elements to structures

2.6. Design options and criteria

In the design of fastenings one of the following options shall be satisfied:

a1) Capacity design
a2) Elastic design
b) Design with requirements on the ductility of the anchors

2.6.1. Design 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.

a1) Capacity design

The anchor or 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. For both connections between structural elements of primary and/or secondary seismic members and attachments of non-structural elements, the fastening is designed for the maximum load that can be transmitted to the fastening based either on the development of a ductile yield mechanism in the attached steel component (see Figure 6) or in the steel base plate (see Figure 7) taking into account material over-strength effects, or on the capacity of a non-yielding attached component or structural element (see Figure 8). The assumption of a plastic hinge in the fixture (Figure 7) 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 and the low cycle fatigue behaviour of the fixture.

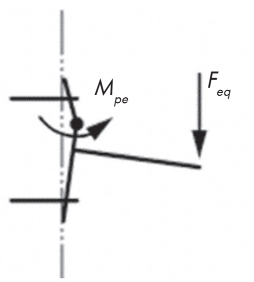


Figure 6: Yielding in attached element

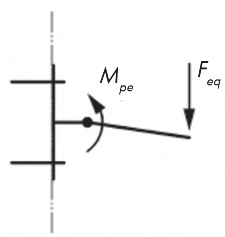


Figure 7: Yielding in baseplate

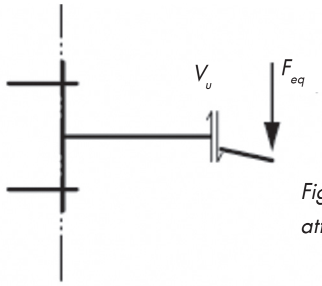


Figure 8: Capacity of attached element

a2) Elastic design

The fastening is designed for the maximum load obtained from the design load combinations that include seismic actions $A_{E,d}$ corresponding to the ultimate limit state (EN 1998-1) assuming an elastic behaviour of the fastening and of the structure. Furthermore uncertainties in the model to derive seismic actions on the fastening shall be taken into account.

The action effects for connections between structural elements of primary and/or secondary seismic members shall be derived according to EN 1998-1 with a behaviour factor q = 1.0.

For attachments of non-structural elements the action effects shall be derived with a behaviour factor q_a = 1.0 for the attached element.

If action effects are derived in accordance with the simplified approach given in EN 1998-1:2004, 4.3.5, those types with a behaviour factor q_a = 1.0 shall be multiplied by an amplification factor equal to 1.5. If the action effects are derived from a more precise model this further amplification may be omitted.

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.

The horizontal effects of the seismic action of non-structural elements are determined according to Equation (4.24) of EN 1998-1.

$$F_a = \frac{S_a \cdot W_a \cdot \gamma_a}{q_a}$$

F_a = horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavourable direction,

W_a = weight of the element,

S_a = seismic coefficient pertinent to non-structural elements,

γ_a = importance factor of the element.
For the following non-structural elements the importance factor γa shall not be chosen less than 1.5:
- Anchorage of machinery and equipment required for life safety systems.
- Tanks and vessels containing toxic or explosive substances considered to be hazardous to the safety of the general public.

In all other cases the importance factor γ_a of a non-structural element may be assumed γ_a = 1.0.

q_a = behaviour factor of the element

The seismic coefficient may be calculated as follows:

$$S_a = \alpha \cdot S \cdot \left[\left(1 + \frac{z}{H}\right) \cdot A_a - 0.5\right]$$

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

S = soil factor,

A_a = Amplification factor

$$A_a = \frac{3}{(1 + (1 - T_a/T_1)^2)}$$

or taken from Table below if one of the fundamental vibration periods is not known,

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

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

z = height of the non-structural element above the level of application of the seismic action,

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

The behaviour factor q_a and seismic amplification factor A_a may be taken from the following table:

Table 5: behaviour factor q_a and seismic amplification factor A_a

Type of non-structural element	q_a	A_a
Cantilevering parapets or ornamentations	1.0	3.0
Signs and billboards		3.0
Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height		3.0
Hazardous material storage, hazardous fluid piping		3.0
Exterior and interior walls	2.0	1.5
Partitions and facades		1.5
Chimneys, masts and tanks on legs acting as unbraced cantilevers along less than one half of their total height, or braced or guyed to the structure at or above their centre of mass		1.5
Elevators		1.5
Computer access floors, electrical and communication equipment		3.0
Conveyors		3.0
Anchorage elements for permanent cabinets and book stacks supported by the floor		1.5
Anchorage elements for false (suspended) ceilings and light fixtures		1.5
High pressure piping, fire suppression piping		3.0
Fluid piping for non-hazardous materials		3.0
Computer, communication and storage racks		3.0

b) Design with requirements on the ductility of the anchors.

The anchor or group of anchors is designed for the design actions including the seismic actions $A_{E,d}$ corresponding to the ultimate limit state (EN 1998-1). The tension steel capacity of the fastening shall be smaller than the tension capacity governed by concrete related failure modes. Sufficient elongation capacity of the anchors is required. The fastening shall not be accounted for energy dissipation in the global structural analysis or in the analysis of a non-structural element unless proper justification is provided by a non-linear time history (dynamic) analysis (according to EN 1998-1) and the hysteretic behaviour of the anchor is provided by an ETA. This approach is applicable only for the tension component of the load acting on the anchor.

Note: Option b) may not be suitable for the fastening of primary seismic members (EN 1998-1) due to the possible large non-recoverable displacements of the anchor that may be expected. It is recommended to use option b) for the fastening of secondary seismic members. Furthermore, unless shear loads acting on the fastening are resisted by additional means, additional anchors should be provided and designed in accordance with option a1) or a2).

- Only valid for anchor of seismic category C2,
- Anchor needs to comply with a list of requirements that to ensure ductility (e.g. stretch length of 8d),
- Recommended for secondary seismic members and non-structural attachments, may not be suitable for primary seismic members (considering possibly large non-recoverable displacements of the anchor),
- In order to ensure the steel failure, additional checks must be done (comparison between the concrete and steel resistance).

SEISMIC AND FIRE CONSIDERATIONS

2.6.3. Vertical effects

For the design of the anchors in connections between structural elements of primary and/or secondary seismic members the vertical component of the seismic action shall be taken into account according to EN 1998-1, Section 4.3.3.5.2 (2) to (4) if the vertical design ground acceleration a_{vg} is greater than 2.5 m/s².

The vertical effects of the seismic action F_{va} for non-structural elements may be neglected for the fastener when the vertical component of the design ground acceleration a_{vg} is less than 2.5 m/s² and the gravity loads are transferred through direct bearing of the fixture on the structure. The determination of the vertical seismic action effects of non-structural elements for use in a Country may be found in its National Annex to this EN. The recommended rule is the application of the formula:

$$F_{Va} = \frac{S_{Va} \cdot W_a \cdot \gamma_a}{q_a}$$

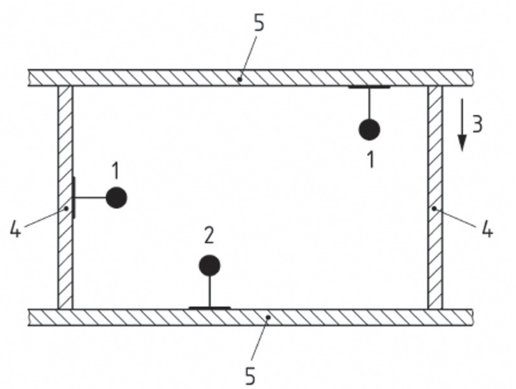


Figure 9: Vertical effects of the seismic action - Example

Key

1 include F_{Va}

2 neglect F_{Va} if $a_{Vg} \leq 2.5$ m / s²

3 gravity force

4 wall

5 ceiling or floor

2.7. Resistances and required verifications

2.7.1. General provisions

- Limited to the anchor configurations of EN 1992-4
- Stand-off installations (grouted or not) are out of scope
- If the seismic contribution to the design load combination is ≤ 20% no explicit seismic design is needed. However, a seismic approved anchor is still required
- Cracked concrete must be considered unless proven otherwise
- The maximum value of each action effect (tension and shear component of forces for an 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
- An annular gap between an anchor and its fixture should be avoided in seismic design situations. For fastenings of non-structural elements in minor non-critical applications an annular gap (diameter d_f) of the clearance hole in the fixture not larger than the value given in EN 1992-4 is allowed. The effect of the annular gap on the behaviour of fastenings shall be taken into account
- Loosening of the nut or screw shall be prevented by appropriate measures

2.7.2. Required verifications

Table 6: Required verifications

	Failure mode	Single anchor	Anchor group	
			most loaded	anchor group
Tension	Steel failure	$N_{Sd,seis} \leq N_{Rd,s,seis}$	$N^h_{Sd,seis} \leq N^h_{Rd,s,seis}$	
	Pull-out failure	$N_{Sd,seis} \leq N_{Rd,p,seis}$	$N^h_{Sd,seis} \leq N^h_{Rd,p,seis}$	
	Combined pull-out and concrete failure[1)]	$N_{Sd,seis} \leq N_{Rd,p,seis}$		$N^g_{Sd,seis} \leq N^g_{Rd,p,seis}$
	Concrete cone failure	$N_{Sd,seis} \leq N_{Rd,c,seis}$		$N^g_{Sd,seis} \leq N^g_{Rd,c,seis}$
	Splitting [3)]	$N_{Sd,seis} \leq N_{Rd,sp,seis}$		$N^g_{Sd,seis} \leq N^g_{Rd,sp,seis}$
Shear	Steel failure, shear load without lever arm[2)]	$V_{Sd,seis} \leq V_{Rd,s,seis}$	$V^h_{Sd,seis} \leq V^h_{Rd,s,seis}$	
	Concrete pry-out failure	$V_{Sd,seis} \leq V_{Rd,cp,seis}$		$V^g_{Sd,seis} \leq V^g_{Rd,cp,seis}$
	Concrete edge failure	$V_{Sd,seis} \leq V_{Rd,c,seis}$		$V^g_{Sd,seis} \leq V^g_{Rd,c,seis}$

[1)] Verificaton for bonded anchors only.
[2)] Steel failure for shear loads with lever arm is not covered.
[3)] Verification is not required if cracked concrete is assumed and reinforcement resists the splitting forces.

2.7.3. Design Resistance

The seismic design resistance $R_{d,seis}$ ($N_{Rd,seis}$, $V_{Rd,seis}$) of a fastening is given by:

$$R_{d,seis} = \frac{R_{k,seis}}{\gamma_{M,seis}}$$

The characteristic seismic resistance $R_{k,seis}$ ($N_{Rk,seis}$, $V_{Rk,seis}$) of a fastening shall be calculated for each failure mode

$$R_{k,seis} = \alpha_{gap} \cdot \alpha_{seis} \cdot R^0_{k,seis}$$

where

a_{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 ETA;

Note: The forces on the anchors are amplified in presence 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 a_{gap} may be used. These values are based on a limited number of tests.

a_{gap} = 1.0 in case of no hole clearance between anchor and fixture;
= 0.5 in case of connections with hole clearance according to the following table

SEISMIC AND FIRE CONSIDERATIONS

External diameter d or d_{nom} [1]	[mm]	6	8	10	12	14	16	18	20	22	24	27	30
Diameter d_f of clearance hole in fixture	[mm]	7	9	12	14	16	18	20	22	24	26	30	33

[1] diameter *d* if bolt bears against fixture; diameter d_{nom} if sleeve bears against the fixture

a_{seis} = reduction factor to take into account the influence of large cracks and scatter of load displacement curves, see the following table

Table 7: Reduction factor a_{eq}

Loading	Failure mode	Single fastener[1]	Fastener group
Tension	Steel failure	1.00	1.00
	Concrete cone failure	0.85	0.75
	Pull-out failure	1.00	0.85
	Combined pull-out and concrete cone failure (bonded fastener)	1.00	0.85
	Concrete splitting failure	1.00	0.85
	Concrete blow-out failure	1.00	0.85
Shear	Steel failure	1.00	0.85
	Concrete pry-out failure	0.85	0.75
	Concrete edge failure	1.00	0.85

[1] This also applies where only one fastener in a group is subjected to tension load.

$R^0_{k,seis}$ = basic characteristic seismic resistance for a given failure mode determined as follows:

	Failure mode	ETA values (C1 or C2)	Calculated value as per EN 1992-4
Tension	Steel failure	$N^0_{Rk,s,seis}$ | $\gamma_{Ms,seis}$	
	Pull-out failure	$N^0_{Rk,p,seis}$ | $\gamma_{Mp,seis}$	
	Combined pull-out and concrete failure	$\tau_{Rk,seis}$ | $\gamma_{Mp,seis}$	$N^0_{Rk,p,seis}$
	Concrete cone failure	$\gamma_{Mc,seis}$	$N^0_{Rk,c,seis}$
	Splitting	$\gamma_{Msp,seis}$	$N^0_{Rk,sp,seis}$
Shear	Steel failure, shear load without lever arm	$V^0_{Rk,s,seis}$ | $\gamma_{Ms,seis}$	
	Concrete pry-out failure	$\gamma_{Mc,seis}$	$V^0_{Rk,cp,seis}$
	Concrete edge failure	$\gamma_{Mc,seis}$	$V^0_{Rk,c,seis}$

2.7.4. Displacements

The anchor displacement under tensile and shear load at damage limitation state (DLS) shall be limited to a value $\delta_{N,req(DLS)}$ and $\delta_{V,req(DLS)}$ 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 to a rigid support condition is considered to be in the range of 3 mm.*

If deformations (displacements or rotations) are relevant for the design of the connection (such as, for example, on secondary seismic members or façade elements) it shall be demonstrated that these deformations can be accommodated by the anchors.

If the anchor displacements $\delta_{N,Seis(DLS)}$ under tension loading and/or $\delta_{V,Seis(DLS)}$ under shear loading provided in the relevant ETA (for anchors qualified for seismic performance category C2) 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 (5.11) and (5.12) to meet the required displacement limits.

$$N_{Rd,seis,reduced} = N_{Rd,seis} \cdot \frac{\delta_{N,req(DLS)}}{\delta_{N,seis(DLS)}}$$

$$V_{Rd,seis,reduced} = V_{Rd,seis} \cdot \frac{\delta_{V,req(DLS)}}{\delta_{V,seis(DLS)}}$$

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

Combined Tension and Shear

Table 8: Required verifications for post-installed fasteners without supplementary reinforcement subjected to a combined tension and shear load

	Failure mode	Verification
1	**Steel failure of fastener** [a]	$\left(\frac{N_{Ed}}{N_{Rd,seis}}\right)^2 + \left(\frac{V_{Ed}}{V_{Rd,seis}}\right)^2 \leq 1$ If N_{Ed} and V_{Ed} are different for the individual fasteners of the group, the interaction shall be verified for all fasteners.
2	**Failure modes other than steel failure**	$\left(\frac{N_{Ed}}{N_{Rd,i,seis}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i,seis}}\right)^{1.5} \leq 1$ or $\left(\frac{N_{Ed}}{N_{Rd,i,seis}}\right) + \left(\frac{V_{Ed}}{V_{Rd,i,seis}}\right) \leq 1.2$ With $N_{Ed} / N_{Rd,i} \leq 1$ and $V_{Ed} / V_{Rd,i} \leq 1$ The largest value of $N_{Ed} / N_{Rd,i}$ and $V_{Ed} / V_{Rd,i}$ for the different failure modes shall be taken.

[a] This verification is not required in case of shear load with lever arm

SEISMIC AND FIRE

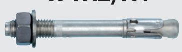
SEISMIC AND FIRE CONSIDERATIONS

Injection anchors

Anchor type	Size	Performance	
		C1	C2
WIT-VIZ S 	M8		
	M10	✓	✓
	M12	✓	✓
	M16	✓	✓
	M20	✓	✓
	M24	✓	✓
WIT-VIZ A4 	M8		
	M10	✓	✓
	M12	✓	✓
	M16	✓	✓
	M20	✓	✓
	M24	✓	✓
WIT-UH 300 M 	M8	✓	
	M10	✓	
	M12	✓	✓
	M16	✓	✓
	M20	✓	✓
	M24	✓	✓
	M27	✓	
	M30	✓	
WIT-UH 300 R 	Ø8	✓	
	Ø10	✓	
	Ø12	✓	
	Ø14	✓	
	Ø16	✓	
	Ø20	✓	
	Ø24	✓	
	Ø25	✓	
	Ø28	✓	
	Ø32	✓	

Anchor type	Size	Performance	
		C1	C2
WIT-PE 1000 M 	M8	✓	
	M10	✓	
	M12	✓	✓
	M16	✓	✓
	M20	✓	✓
	M24	✓	✓
	M27	✓	
	M30	✓	
WIT-PE 1000 R 	Ø8	✓	
	Ø10	✓	
	Ø12	✓	
	Ø14	✓	
	Ø16	✓	
	Ø20	✓	
	Ø24	✓	
	Ø25	✓	
	Ø28	✓	
	Ø32	✓	
WIT-VM 250 M 	M8	✓	
	M10	✓	
	M12	✓	
	M16	✓	
	M20	✓	
	M24	✓	
	M27	✓	
	M30	✓	
WIT-VM 250 R 	Ø8	✓	
	Ø10	✓	
	Ø12	✓	
	Ø14	✓	
	Ø16	✓	
	Ø20	✓	
	Ø25	✓	
	Ø28	✓	
	Ø32	✓	

Mechanical anchors

Anchor type	Size	Standard Effective anchorage depth (mm)	Performance	
			C1	C2
W-BS 	Ø6	55	✓	✓ 1)
	Ø8	65	✓	✓ 1)
	Ø10	85	✓	✓ 1)
	Ø12	100	✓	✓ 1)
	Ø14	115	✓	✓ 1)
W-FAZ/S 	M8	46	✓	✓
	M10	60	✓	✓
	M12	70	✓	✓
	M16	85	✓	✓
	M20	100	✓	✓
	M24	115		
	M27	125		
W-FAZ/A4 	M8	46	✓	✓
	M10	60	✓	✓
	M12	70	✓	✓
	M16	85	✓	✓
	M20	100	✓	✓
	M24	125		
W-HAZ/S 	10/M6	76	✓	✓
	12/M8	100	✓	✓
	15/M10	110	✓	✓
	18/M12	130	✓ 2)	✓ 2)
	24/M16	114	✓ 2)	✓ 2)
	24/M16L	150	✓ 2)	✓ 2)
	28/M20	185	✓ 2)	✓ 2)
	32/M24	210	✓ 2)	✓ 2)
W-HAZ/A4 	12/M8	100	✓	✓
	15/M10	110	✓	✓
	18/M12	130	✓	✓
	24/M16	150	✓ 2)	✓ 2)

1) Only for the galvanized version. C2 is not suitable for A4 and HCR

2) Not suitable for W-HAZ-SK

SEISMIC AND FIRE CONSIDERATIONS

2.8. Structural verifications under fire exposure and design values of the anchor resistances for the respective failure modes

In general, the duration of the fire resistance of anchorages depends mainly on the configuration of the structure itself (base materials, anchorage including the fixture). It is not possible to classify an anchor for its fire resistance. This evaluation concept includes the behaviour of the anchorage in concrete and the parts outside the concrete. The influence of the fixation is considered unfavourable.

The following information is for anchorages in normal weight concrete with a compressive strength of at least C 20/25 and at most C 50/60 used for normal structures under fire exposure. The determination of the duration of the fire resistance is according to the conditions given in EN 13501-2 using the "Standard ISO time-temperature Curve" (STC). This evaluation can be used as a basis for including a fire resistance class in European Technical Approvals (ETA) for metal anchors for use in cracked concrete. The base material (reinforced concrete), in which the anchor shall be anchored, shall have at least the same duration of fire resistance as the anchorage itself.

Local spalling is possible at fire attack. To avoid any influence of the spalling on the anchorage, the concrete member must be designed according to EN 1992-1-2. The members shall be made of concrete with quartzite additives and have to be protected from direct moisture; and the moisture content of the concrete has to be like in dry internal conditions respectively. The anchorage depth has to be increased for wet concrete by at least 30 mm compared to the given value in the approval.

2.8.1. Design concepts

When using the **Simplified design concept** for all load directions and failure modes the limit values must be observed (characteristic resistance in ultimate limit state under fire exposure $F_{Rk,fi(t)}$), which were developed by general test series and are on the safe side. Tests with fire exposure are not necessary when using the simplified design concept.

When using the **Experimental determination** for all load directions and failure modes the required investigations are given. The duration of fire resistance of the anchor can be determined from the results.

A combination of the design concepts is possible. For example: the duration of the fire resistance for individual failure modes (e.g. steel failure) can be determined by tests and for other failure modes (e.g. pull-out and concrete failure) the limit values can be determined using the simplified design method.

	Simplified Design Concept	**Experimental Determination**
Metal anchors	✔	✔
Bonded anchors	evaluation only for steel failure (special experimental determination)	special experimental determination

It can be assumed that for fastening of facade systems, the load bearing behaviour of the specific screwed in plastic anchor with a diameter 10 mm and a metal screw with a diameter 7 mm and a h_{ef} of 50 mm and a plastic sleeve made of polyamide has a sufficient resistance to fire at least 90 minutes (R90) if the applied load (no permanent tension load) is ≤ 0.8kN.

General provisions:

- Valid for anchors with an European Technical Approval (ETA), which can be used in cracked and non-cracked concrete
- The determination covers anchors with a fire attack from one side only. If the fire attack is from more than one side, the design method may be taken only, if the edge distance of the anchor is $c \geq 300$ mm and $\geq 2\,h_{ef}$
- The determination is valid for unprotected anchors
- The characteristic spacing and edge distance for anchorages near the edge under fire exposure are taken as follows $s_{cr,N} = 2c_{cr,N} = 4h_{ef}$

- $\gamma_{M,fi}$ = 1.0 for steel failure and concrete related failure modes under shear loading. For concrete related failure modes under tension $\gamma_{M,fi}$ = 1.0 γ_{inst}
- $N_{Rk,p}$, $N^0_{Rk,c}$, $V^0_{Rk,c}$ characteristic resistances of a single anchor in cracked concrete C20/25 for concrete cone failure under normal temperature

2.8.2. Resistance

2.8.2.1. Fire resistance capacity in tension and shear

The following table provides a summary of the resistances to fire according to the various failure modes of fasteners. The overview shows values from the simplified design concept, which should be used if no values are provided in the corresponding European Technical Product Specification. The values of the simplified design concept are considered conservative. For more details on the resistance equations, please refer to annex D of the EN 1992-4.

Table 9: Fire resistance under the different failure modes

	Failure mode	Simplified Design Concept	Experimental Determination
Tension	Steel failure	$N_{Rk,s,fi} = A_s \cdot \sigma_{Rk,s,fi}$	given in ETA
	Pull-out failure	$N_{Rk,p,fi(90)} = 0.25 \cdot N_{Rk,p}$ $N_{Rk,p,fi(120)} = 0.2 \cdot N_{Rk,p}$	given in ETA
	Concrete cone failure	$N^0_{Rk,c,fi(90)} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$ $N^0_{Rk,c,fi(120)} = 0.8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$	$N^0_{Rk,c,fi(90)} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$ $N^0_{Rk,c,fi(120)} = 0.8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$
Shear	Steel failure, shear load without lever arm	$V_{Rk,s,fi} = A_s \cdot \sigma_{Rk,s,fi}$	given in ETA
	Steel failure, shear load with lever arm	$M^0_{Rk,s,fi} = 1.2 \cdot W_{el} \cdot \sigma_{Rk,s,fi}$	given in ETA
	Concrete pry-out failure	$V^0_{Rk,cp,fi(t)} = k \cdot N^0_{Rk,c,fi(t)}$	$V^0_{Rk,cp,fi(t)} = k \cdot N^0_{Rk,c,fi(t)}$
	Concrete edge failure	$V^0_{Rk,c,fi(90)} = 0.25 \cdot V^0_{Rk,c}$ $V^0_{Rk,c,fi(120)} = 0.2 \cdot V^0_{Rk,c}$	$V^0_{Rk,c,fi(90)} = 0.25 \cdot V^0_{Rk,c}$ $V^0_{Rk,c,fi(120)} = 0.2 \cdot V^0_{Rk,c}$

SEISMIC AND FIRE CONSIDERATIONS

Table 10: Characteristic tension strength of an unprotected anchor made of C-steel according to EN 10025 in case of fire exposure

Fastener bolt / thread diameter	Embedment depth	Characteristic tension strength			
	h_{ef}	$\sigma_{Rk,s,fi(t)}$			
mm	mm	N/mm²			
		30 min (R15 to R30)	60 min (R45 and R60)	90 min (R90)	120 min (≤ R120)
⌀ 6 / M6	≥ 30	10	9	7	5
⌀ 8 / M8	≥ 30	10	9	7	5
⌀ 10 / M10	≥ 40	15	13	10	8
≥ ⌀ 12 / M12	≥ 50	20	15	13	10

Table 11: Characteristic tension strength of an unprotected anchor made of at least steel grade A4 according to the EN ISO 3506 series in case of fire exposure

Fastener bolt / thread diameter	Embedment depth	Characteristic tension strength			
	h_{ef}	$\sigma_{Rk,s,fi}$			
mm	mm	N/mm²			
		30 min (R15 to R30)	60 min (R45 and R60)	90 min (R90)	120 min (≤ R120)
⌀ 6 / M6	≥ 30	10	9	7	5
⌀ 8 / M8	≥ 30	20	16	12	10
⌀ 10 / M10	≥ 40	25	20	16	14
≥ ⌀ 12 / M12	≥ 50	30	25	20	16

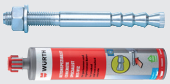
2.8.2.2. Required verifications for combined tension and shear loads

	Failure mode	Verification
1	**Steel failure of fastener [a]**	$$\left(\frac{N_{Ed}}{N_{Rd,fi}}\right)^2 + \left(\frac{V_{Ed}}{V_{Rd,fi}}\right)^2 \leq 1$$ If N_{Ed} and V_{Ed} are different for the individual fasteners of the group, the interaction shall be verified for all fasteners.
2	**Failure modes other than steel failure**	$$\left(\frac{N_{Ed}}{N_{Rd,i,fi}}\right)^{1.5} + \left(\frac{V_{Ed}}{V_{Rd,i,fi}}\right)^{1.5} \leq 1$$ or $$\left(\frac{N_{Ed}}{N_{Rd,i,fi}}\right) + \left(\frac{V_{Ed}}{V_{Rd,i,fi}}\right) \leq 1.2$$ With $N_{Ed} / N_{Rd,i} \leq 1$ and $V_{Ed} / V_{Rd,i} \leq 1$ The largest value of $N_{Ed} / N_{Rd,i}$ and $V_{Ed} / V_{Rd,i}$ for the different failure modes shall be taken.

[a] This verification is not required in case of shear load with lever arm

SEISMIC AND FIRE CONSIDERATIONS

Fire loads Bonded Anchors

Anchor type	Size	Effective anchorage depth (mm)	Max tensile loading (kN) for specified fire resistance time [1) 2)]				Authority / No.
			R30	R60	R90	R120	
WIT-BS 	Ø10		4.40	3.30	2.30	1.70	Z-21.1-2075
	Ø12		7.30	5.80	4.20	3.40	
	Ø14		10.30	8.20	5.90	4.80	
WIT-VIZ S 	M8	50	1.04	0.47	-	-	MFPA Leipzig Nr. GS 3.2/ 18-075-1
	M10	60	2.50	1.45	0.39	-	
	M12	80	5.80	3.80	1.81	0.81	
	M16	125	7.62	5.81	4.01	3.11	
	M20	170	13.02	9.75	6.48	4.84	
	M24	170	13.02	9.75	6.48	4.84	
WIT-VIZ A4 	M8	50	1.04	0.47	-	-	MFPA Leipzig Nr. GS 3.2/ 18-075-1
	M10	60	2.50	1.45	0.39	-	
	M12	80	5.80	3.80	1.81	0.81	
	M16	125	7.62	5.81	4.01	3.11	
	M20	170	13.02	9.75	6.48	4.84	
	M24	170	13.02	9.75	6.48	4.84	
WIT-UH 300 M [3)] 	M8	80	0.71	0.56	0.41	0.32	Ingenieur-büro Thiele 21807de 9.12.2018
	M10	90	1.42	1.11	0.79	0.61	
	M12	110	3.03	2.28	1.60	1.18	
	M16	125	5.65	4.24	2.98	2.20	
	M20	170	8.82	6.62	4.66	3.43	
	M24	210	12.71	9.53	6.71	4.94	
	M27	240	16.52	12.39	8.72	6.43	
	M30	270	20.20	15.15	10.66	7.85	
WIT-PE 1000 M [3)] 	M8	80	1.10	0.88	0.33	0.00	Ingenieur-büro Thiele 22022e 14.05.2020
	M10	90	1.74	1.39	0.65	0.00	
	M12	110	3.03	2.28	1.60	0.88	
	M16	125	5.65	4.24	2.77	1.54	
	M20	170	8.82	6.62	4.66	3.43	
	M24	210	12.71	9.53	6.71	4.94	
	M27	240	16.52	12.39	8.72	6.43	
	M30	270	20.20	15.15	10.66	7.85	

Anchor type	Size	Effective anchorage depth (mm)	Max tensile loading (kN) for specified fire resistance time [1] [2]				Authority / No.
			R30	R60	R90	R120	
WIT-VM 250 M [4] 	M8	≥ 80	1.60	1.10	0.60	0.30	Technische Universität Kaiserslautern Project Number EBB 170019_6de
	M10	≥ 90	2.60	1.80	0.90	0.50	
	M12	≥ 110	3.40	2.60	1.80	0.50	
	M16	≥ 125	6.20	4.80	3.40	2.70	
	M20	≥ 170	9.80	7.50	5.30	4.20	
	M24	≥ 210	14.00	10.80	7.60	6.00	
	M27	≥ 250	18.30	14.10	9.90	7.90	
	M30	≥ 280	22.30	17.20	12.10	9.60	

[1] All values are for reinforced concrete as base material of strength classes from C20/25 to C50/60
[2] Data valid for steel failure. See approval for other failure modes
[3] Values are for standard effective anchorage depths values in cracked concrete. Check the fire test report for the complete list of values
[4] Values are for non-cracked concrete

SEISMIC AND FIRE CONSIDERATIONS

Fire loads Mechanical Anchors

Anchor type	Size	Effective anchorage depth (mm)	Max tensile loading (kN) for specified fire resistance time 1) 2)				Authority / No.
			R30	R60	R90	R120	
W-BS 	Ø6	31	0.90	0.80	0.60	0.40	ETA-16/0043
		44	0.90	0.80	0.60	0.40	
	Ø8	35	2.40	1.70	1.10	0.70	
		43	2.40	1.70	1.10	0.70	
		52	2.40	1.70	1.10	0.70	
	Ø10	43	4.40	3.30	2.30	1.70	
		60	4.40	3.30	2.30	1.70	
		68	4.40	3.30	2.30	1.70	
	Ø12	50	7.30	5.80	4.20	3.40	
		67	7.30	5.80	4.20	3.40	
		80	7.30	5.80	4.20	3.40	
	Ø14	58	10.30	8.20	5.90	4.80	
		79	10.30	8.20	5.90	4.80	
		92	10.30	8.20	5.90	4.80	
W-FAZ/S 	M8	46	1.50	1.10	0.80	0.70	ETA-99/0011
	M10	60	2.60	1.90	1.40	1.20	
	M12	70	4.10	3.00	2.40	2.20	
	M16	85	7.70	5.60	4.40	4.00	
	M20	100	9.40	8.20	6.90	6.30	
	M24	115	13.60	11.80	10.00	9.10	
	M27	125	17.60	15.30	13.00	11.80	
W-FAZ/A4 	M8	46	3.80	2.90	2.00	1.60	ETA-99/0011 of 2 October 2018
	M10	60	6.90	5.30	3.60	2.80	
	M12	70	12.70	9.40	6.10	4.50	
	M16	85	23.70	17.60	11.50	8.40	
	M20	100	33.50	25.00	16.40	12.10	
	M24	125	48.20	35.90	23.60	17.40	

Anchor type	Size	Effective anchorage depth (mm)	Max tensile loading (kN) for specified fire resistance time [1) 2)]				Authority / No.
			R30	R60	R90	R120	
W-HAZ/S 	10/M6		1.00	0.80	0.60	0.40	ETA-02-0031
	12/M8		1.90	1.50	1.00	0.80	
	15/M10		4.30	3.20	2.10	1.50	
	18/M12		6.30	4.60	3.00	2.00	
	24/M16		11.60	8.60	5.00	3.10	
	24/M16L		11.60	8.60	5.00	3.10	
	28/M20		18.30	13.50	7.70	4.90	
	32/M24		26.30	19.50	12.60	9.20	
W-HAZ/A4 	12/M8		6.10	4.40	2.60	1.80	ETA-02-0031
	15/M10		10.20	7.30	4.30	2.80	
	18/M12		15.70	11.10	6.40	4.10	
	24/M16		29.20	20.60	12.00	7.70	
W-FA/S 	M6/40		0.90	0.50	0.30	0.25	IBMB Braunschweig 7260/2018
	M8		1.40	0.80	0.50	0.40	
	M10		2.20	1.20	0.80	0.60	
	M12		3.20	1.80	1.20	0.90	
	M16		6.00	3.40	2.20	1.70	
	M20		10.00	5.25	3.60	2.75	
W-FA/A4 **W-FA/HCR** 	M6/40		0.90	0.50	0.30	0.25	IBMB Braunschweig 3067/2013
	M8		2.30	1.70	1.40	1.30	
	M10		3.60	2.60	2.20	2.00	
	M12		5.20	3.80	3.20	2.90	
	M16		9.70	7.00	6.00	5.40	
	M20		15.00	10.20	8.20	7.00	
W-ED/S 	M6		1.70	0.70	0.40	0.30	IBMB Braunschweig 3067/2013
	M8x30		1.70	0.70	0.40	0.30	
	M8x40		3.00	1.50	0.80	0.60	
	M10		4.70	2.40	1.30	1.00	
	M12		6.90	2.40	1.30	1.00	
	M16		12.50	5.60	3.50	2.50	
	M20		18.00	8.50	5.50	4.40	
W-ED/A4 	M6		1.70	0.70	0.40	0.30	IBMB Braunschweig 3067/2013
	M8x30		1.70	0.70	0.40	0.30	
	M8x40		3.00	1.50	0.80	0.60	
	M10		4.70	2.40	1.30	1.00	
	M12		6.90	2.40	1.30	1.00	
	M16		12.50	5.60	3.50	2.50	
	M20		18.00	8.50	5.50	4.40	

[1)] All values are for reinforced concrete as base material of strength classes from C20/25 to C50/60
[2)] Data valid for steel failure. See approval for other failure modes