EOTA

TECHNICAL REPORT

Evaluation of Anchorages in Concrete concerning Resistance to Fire

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1. General

This evaluation is for anchorages in normal weight concrete with a 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 1363-1:1999-10 [1] using the "Standard Temperature/Time 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 concrete.

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 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 prEN 1992-1-2 [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. Evaluation of metal anchors in concrete concerning Resistance to Fire

2.1. General

The following evaluation is only valid for metal anchors with an European Technical Approval (ETA), which can be used in cracked and non-cracked concrete

For bonded, bonded expansion and bonded undercut anchors see section 3.

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.

Two different design concepts are possible:

When using **the simplified design concept**[1] according to section 2.2 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 save side. Tests with fire exposure are not necessary when using the simplified design concept.

When using **the experimental determination** according to section 2.3 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.

The design of the anchorage under fire exposure has to be performed according to ETAG 001, Annex C [4]. The design of the anchorage under fire exposure has to be carried out as follows:

Eq. 2.1 $\mathbf{S_{d,fi} \leq R_{d,fi(t)}}$

Eq. 2.2 $\mathbf{S_{d,fi} = \gamma_{F,fi} \times S_{k,fi}}$

Eq. 2.3 $\mathbf{R_{d,fi(t)} = R_{k,fi(t)} / \gamma_{M,fi}}$

$S_{d,fi}$ = design value of action under fire exposure
$S_{k,fi}$ = characteristic value of action under fire exposure
$\gamma_{F,fi}$ = partial safety factor for action under fire exposure
$R_{d,fi(t)}$ = design value of resistance under fire exposure
$R_{k,fi(t)}$ = characteristic resistance under fire exposure, see Section 2.2 and 2.3
$\gamma_{M,fi}$ = partial safety factor for resistance under fire exposure (usually $\gamma_{M,fi}$ =1.0)

1 This **simplified design concept** is integrated in the informative Annex of the draft CEN/TC 250/SC 2/WG 2 "Design of Fastenings for use in concrete" [5]

2.2. Simplified design method for the determination of the duration of the fire resistance of anchorages in cracked and non-cracked concrete according to ETAG 001, Part 1-6

When the simplified method is used to design the resistance of single anchors under fire exposure, the steel failure is often decisive. This is due to the low tension strength considered when the anchor is unprotected. The other failure modes may be decisive when one or several of the following conditions are met:

- small embedment depth
- low $N_{Rk,p}$ value under normal temperature
- group of anchors with small spacing

2.2.1. Tension load

2.2.1.1. Steel failure

The characteristic resistance of an anchorages in case of steel failure under fire exposure (characteristic tension strength $\sigma_{Rk,s,fi}$) is given in the following Tables. These values are also valid for the unprotected steel parts of the anchor outside the concrete.

Table 2.1 contains the values for C-steel, normal carbon steel according to EN 10025 [6] and Table 2.2 contains the values for stainless steel of at least grade A4 according to ISO 3506 [7].

Table 2.1 Characteristic tension strength of an anchor made of C-steel under fire exposure

anchor bolt/thread diameter [mm]	anchorage depth h_{ef} [mm]	characteristic tension strength of an unprotected anchor made of C-steel in case of fire exposure in the time up to: $\sigma_{Rk,s,fi}$ [N/mm²]			
		30 min (R 15 to R30)	60 min (R45 and R60)	90 min (R90)	120 min (R120)
Ø 6 / M6	≥ 30	10	9	7	5
Ø 8 / M8	≥ 30	10	9	7	5
Ø 10 / M10	≥ 40	15	13	10	8
Ø 12 / M12 and greater	≥ 50	20	15	13	10

Table 2.2 Characteristic tension strength of an anchor made of stainless steel under fire exposure

anchor bolt/thread diameter [mm]	anchorage depth h_{ef} [mm]	characteristic tension strength of an unprotected anchor made of stainless steel in case of fire exposure in the time up to: $\sigma_{Rk,s,fi}$ [N/mm²]			
		30 min (R 15 to R30)	60 min (R45 and R60)	90 min (R90)	120 min (R120)
Ø 6 / M6	≥ 30	10	9	7	5
Ø 8 / M8	≥ 30	20	16	12	10
Ø 10 / M10	≥ 40	25	20	16	14
Ø 12 / M12 and greater	≥ 50	30	25	20	16

2.2.1.2. Pull-out failure

The characteristic resistance of an anchorages in case of pull-out failure under fire exposure up to 90 minutes (R90) and up to 120 minutes (R120) may be obtained by Eq. 2.4 and Eq. 2.5.

Eq. 2.4 $\mathbf{N_{Rk,p,fi(90)} = 0,25 \times N_{Rk,p}}$

Eq. 2.5 $\mathbf{N_{Rk,p,fi(120)} = 0,20 \times N_{Rk,p}}$

$N_{Rk,p,fi(90/120)}$ = characteristic resistance under fire exposure up to 90 minutes (≤ R90) or up to 120 minutes (≤ R 120) in case of pull-out failure in concrete C20/25 to C50/60

$N_{Rk,p}$ = characteristic resistance in cracked concrete C20/25 for pull-out failure under normal temperature given in the relevant ETA

2.2.1.3. Concrete cone failure

The characteristic resistance of an anchorages in case of concrete cone failure in concrete C20/25 to C50/60 under fire exposure up to 90 minutes (R90) and up to 120 minutes (R120) may be obtained using Equation Eq. 2.6 and Eq. 2.7.

Eq. 2.6 $$N^0_{Rk,c,fi(90)} = \frac{h_{ef}}{200} \times N^0_{Rk,c} \leq N^0_{Rk,c}$$

Eq. 2.7 $$N^0_{Rk,c,fi(120)} = 0,8 \times \frac{h_{ef}}{200} \times N^0_{Rk,c} \leq N^0_{Rk,c}$$

$N^0_{Rk,c,fi(90/120)}$ = Characteristic resistance of a single anchor not influenced by adjacent anchors or edges of the concrete member under fire exposure up to 90 minutes (≤ R90) or up to 120 minutes (≤ R 120) in case of concrete cone failure in concrete C20/25 to C50/60

h_{ef} = effective embedment depth in mm

$N^0_{Rk,c}$ = Characteristic resistance of a single anchor in cracked concrete C20/25 for concrete cone failure under normal temperature

The characteristic spacing and edge distance for anchorages near the edge under fire exposure are taken as follows $s_{cr,N} = 2\ c_{cr,N} = 4h_{ef}$.

2.2.1.4. Splitting failure

The assessment of splitting failure due to loading under fire exposure is not required, since the characteristic resistance for concrete cone failure and pull-out failure is calculated for cracked concrete and a reinforcement is assumed.

2.2.2. Shear load

2.2.2.1. Steel failure

a) Shear load without lever arm:

The behaviour under shear loading is similar to the behaviour under tension loading. According to test results under fire exposure, the relation between shear and tension strength increases.

Therefore the characteristic resistance of an anchorages in case of steel failure under fire exposure (characteristic shear strength $\tau_{Rk,s,fi}$) may be taken from the Tables 2.1 and 2.2 for characteristic tension strength. These values are also valid for the unprotected steel part of the anchor outside the concrete.

b) Shear load with lever arm:

The characteristic resistance of an anchor for shear load with lever arm under fire exposure may be calculated according to the design code. However the characteristic bending resistance of a single anchor under fire exposure is limited to the characteristic tension strength according to section 2.2.1.1. The characteristic bending resistance $M^{\circ}_{Rk,s,fi}$ may be taken from the following Equation.

Eq. 2.8 $$\mathbf{M^{0}_{Rk,s,fi} = 1{,}2 \times W_{el} \times \sigma_{Rk,s,fi}}$$

W_{el} = elastic section modulus of the relevant stressed cross section

$\sigma_{Rk,s,fi}$ = characteristic tension strength in case of steel failure under fire exposure according to Table 2.1 and Table 2.2.

2.2.2.2. Concrete pry-out failure

The characteristic resistance in case of concrete pry-out failure in concrete C20/25 to C50/60 under fire exposure up to 90 minutes (R90) and up to 120 minutes (R120) may be obtained using Eq. 2.9 and Eq. 2.10.

Eq. 2.9 $$\mathbf{V_{Rk,cp,fi(90)} = k \times N_{Rk,c,fi(90)}}$$

Eq. 2.10 $$\mathbf{V_{Rk,cp,fi(120)} = k \times N_{Rk,c,fi(120)}}$$

k = factor to be taken from the relevant ETA under normal temperature

$N_{Rk,c,fi(90/120)}$ = determined according to [4], Section 5.2.2.4 for the anchor loaded in shear, instead of $N^{0}_{Rk,c}$ the values $N^{0}_{Rk,c,fi(90)}$ and $N^{0}_{Rk,c,fi(120)}$ according to Eq. 2.6 and Eq. 2.7 respectively shall be taken

2.2.2.3. Concrete edge failure

The characteristic resistance of an anchorages in case of concrete edge failure in concrete C20/25 to C50/60 under fire exposure up to 90 minutes (R90) and up to 120 minutes (R120) may be obtained using Eq. 2.11 and Eq. 2.12.

Eq. 2.11 $$V^{0}_{Rk,c,fi(90)} = \mathbf{0{,}25} \times V^{0}_{Rk,c}$$

Eq. 2.12 $$V^{0}_{Rk,c,fi(120)} = \mathbf{0{,}20} \times V^{0}_{Rk,c}$$

$V^{0}_{Rk,c,fi(90/120)}$ = Initial value of the characteristic resistance of a single anchor loaded perpendicular to the edge in concrete C20/25 to C50/60 under fire exposure up to 90 minutes (R90) or up to 120 minutes (R120).

$V^{0}_{Rk,c}$ = Initial value of the characteristic resistance of a single anchor in cracked concrete C20/25 under normal temperature according to [4], Section 5.2.3.4a).

2.2.3. Combined tension and shear load

The interaction condition according to normal temperature of ETAG 001, Annex C, section 5.2.4 [2], may be taken with the characteristic resistance under fire exposure for the different loading directions for combined tension and shear loads.

2.3. Experimental determination of the duration of the fire resistance of anchorages in cracked and non-cracked concrete according to ETAG 001, Part 1-6

The tests have to be carried out according to [2], Annex A. However, the determinations of the following sections have to be considered. The drill hole has to be drilled with a drill-diameter of $d_{cut,m}$ and has to be cleaned according to the manufacturer's installation instructions. The anchor has to be set according to the manufacturer's installation instructions and prestressed with the installation moment T_{inst}, the moment has to be reduced to $0.5 \times T_{inst}$ after 10 min.

2.3.1. Behaviour under tension load

2.3.1.1. Steel failure

Test set-up:

The tests for the determination of the carrying capacity under steel failure have to be carried out in non-cracked concrete using an unloaded slab. The principle test set-up can be seen in Figure 2.1.

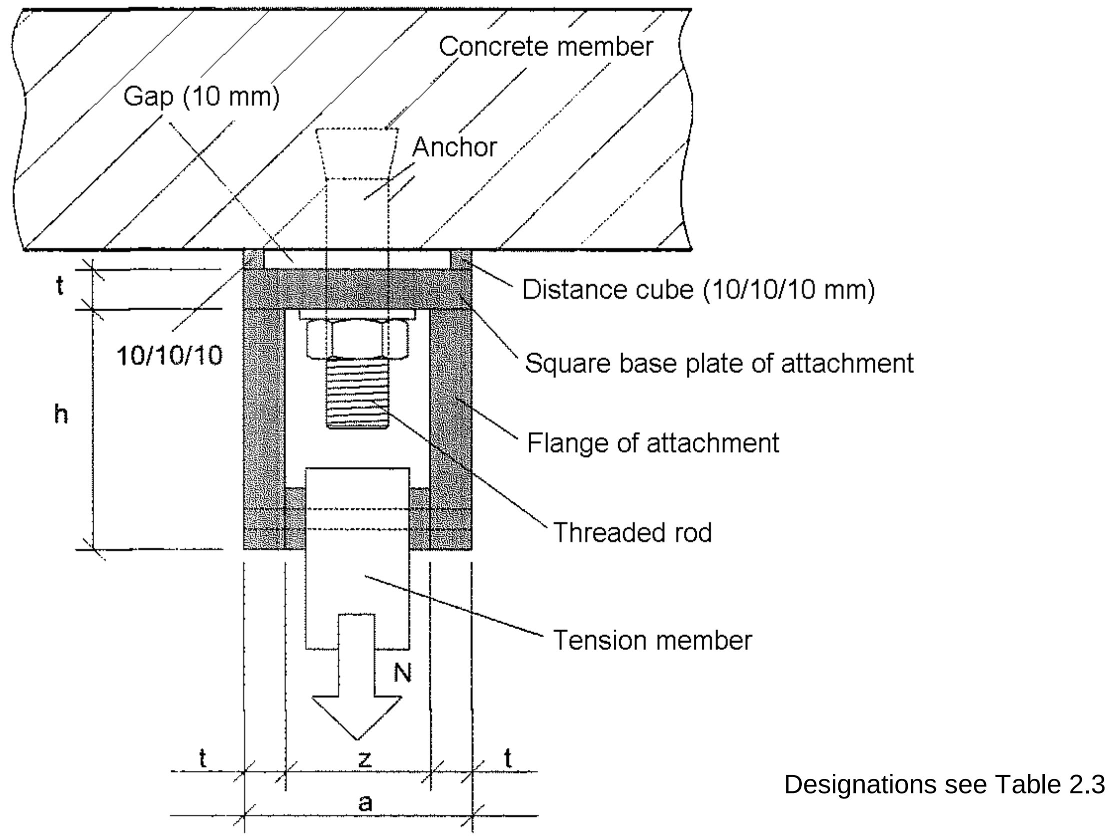


Figure 2.1 Test set-up for the determination of the steel failure under fire exposure

The dimensions of fixture have to be chosen depending on the load categories according to Table 2.3. The fixture has to provide a steel stress of 2 - 4 N/mm^2 in the relevant parts. Ordinary punched hole tapes can be used for the tests up to a load of 1,0 kN.

Table 2.3 Dimensions of the fixture during the test under fire exposure

Type of adapter	Load categories	Length of the square base plate	flange height/ width	profile thickness	distance between the flanges
	$N_{Rk,s,fi}$ [kN]	a [mm]	h / b [mm]	t [mm]	z [mm]
I	> 1 - ≤ 3	90	100 / 90	15	60
	> 3 - ≤ 5	90	100 / 90	15	60
II	> 5 - ≤ 7	110	120 / 110	20	70
	> 7 - ≤ 9	110	120 / 110	20	70
III	> 9 - ≤ 11	120	120 / 120	25	70
	> 11 - ≤ 13	120	120 / 120	25	70

Test procedure:
The anchor has to be loaded in tension during the test under fire exposure via the fixture which is defined in Table 2.3. The fire tests have to be carried out according to EN 1363-1:1999-10 [1].

At least 5 tests each using the smallest anchor size d_1 and the medium anchor size d_2 (≤ M12) have to be carried out. The duration of fire resistance must be more than 60 min in at least 4 tests per anchor size.

Test verification:

From the fire tests pair of variates [test load F / duration of failure t_u] shall be determined (existing test results in cracked concrete can be taken into account for the evaluation, if the failure appeared after more then 60 min). The test loads F shall be converted into steel stresses σ_s and drawn for each anchor size in a diagram depending on the determined fire resistance duration t_u (see Figure 2.2). By linear regression of the pair of variates σ_s / $(1/t_u)$ (see Figure 2.3) the formula (mean value curve) according to Eq. 2.13 shall be determined.

Eq. 2.13 $\sigma_{s1} = c_1 + c_2 / t_u$

The mean value curve according to Eq. 2.13 shall be reduced with an additional factor $c_3 < 1$ in such a way, that the curve runs through the pair of variates of the most unfavourable test result. As a result the lower limit value curve according to Eq. 2.14 is obtained.

Eq. 2.14 $\sigma_{s2} = c_3 (c_1 + c_2 / t_u)$

The characteristic steel stress for a duration of fire resistance of 60 min, 90 min and 120 min *can be calculated by* Eq. 2.14 as follows:

$$\sigma_{Rk,s,fi(60)} = c_3 (c_1 + c_2 / 60\text{min})$$
$$\sigma_{Rk,s,fi(90)} = c_3 (c_1 + c_2 / 90\text{min})$$
$$\sigma_{Rk,s,fi(120)} = c_3 (c_1 + c_2 / 120\text{min})$$

Using the two pair of variates t_u = 60min / $\sigma_{Rk,s,fi(60min)}$ and t_u = 90min / $\sigma_{Rk,s,fi(90min)}$ the following linear equation can be derived:

Eq. 2.15 $\sigma_{s3} = c_4 - c_5\, t_u$

The characteristic steel stress for a duration of fire resistance of 30 min can be calculated by Eq. 2.15 as follows:

$$\sigma_{Rk,s,fi(30)} = c_4 - c_5 \times 30\text{min}$$

If there are tests carried out with two anchor sizes only (d_1 and d_2), the characteristic steel stress for intermediate sizes ($d_1 \le d \le d_2$) can be calculated by linear interpolation without additional tests only (see Figure 2.4), if the ratio of the steel strength $\sigma_{Rk,s,d2} / \sigma_{Rk,s,d1}$ is not larger than about 2. For anchor sizes $d > d_2$, the characteristic steel stress calculated for d_2 can be taken.

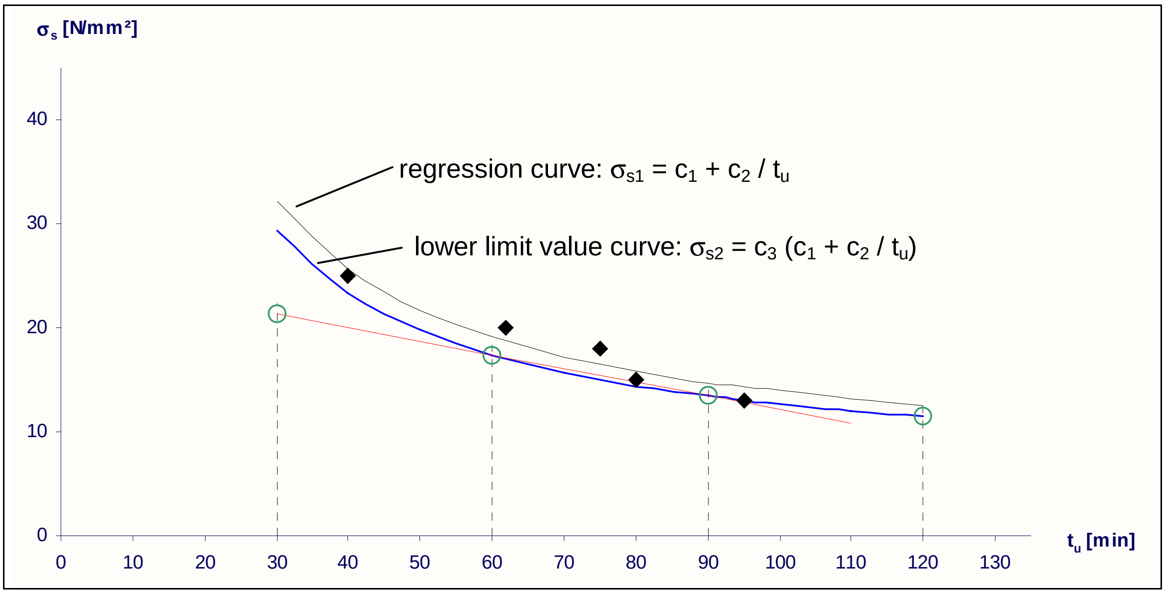


Figure 2.2 Determination of the characteristic steel stress

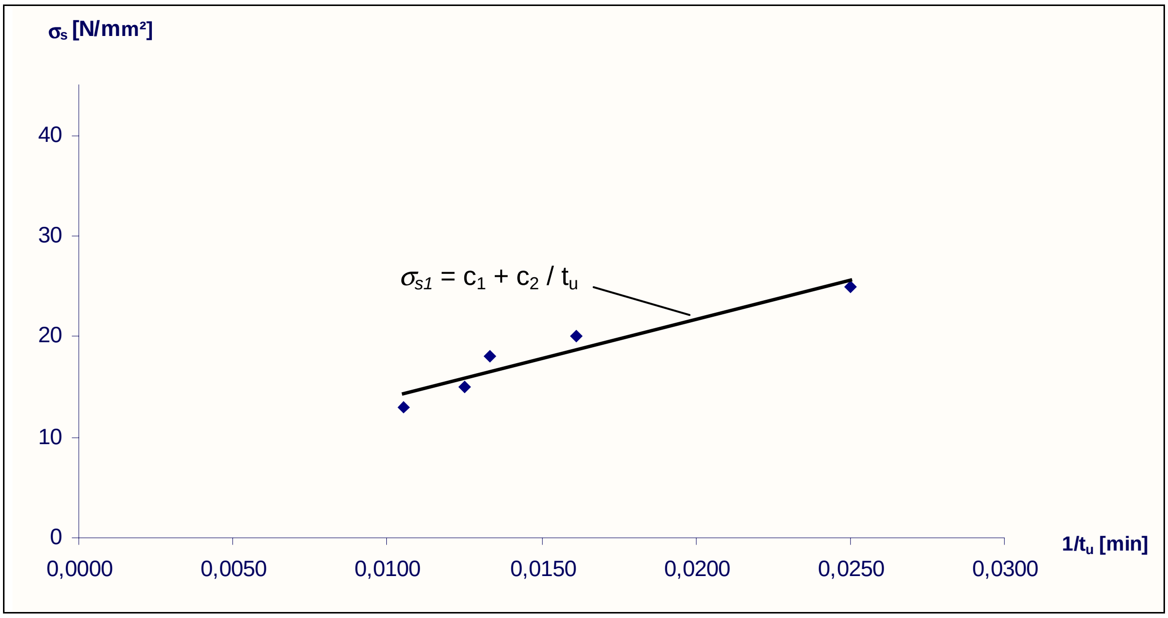


Figure 2.3 Determination of the regression equation

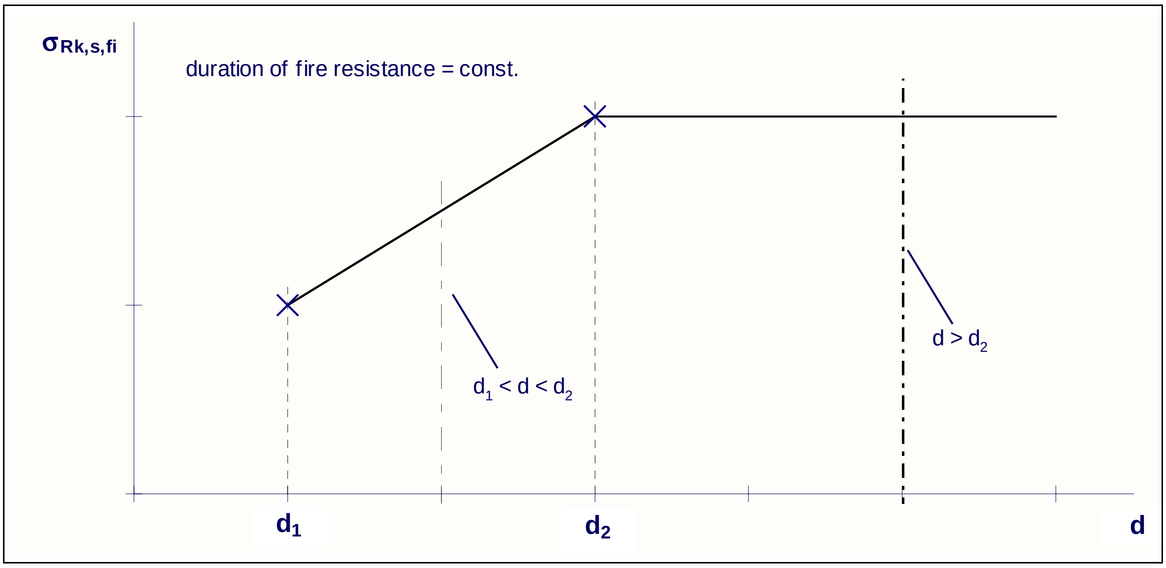
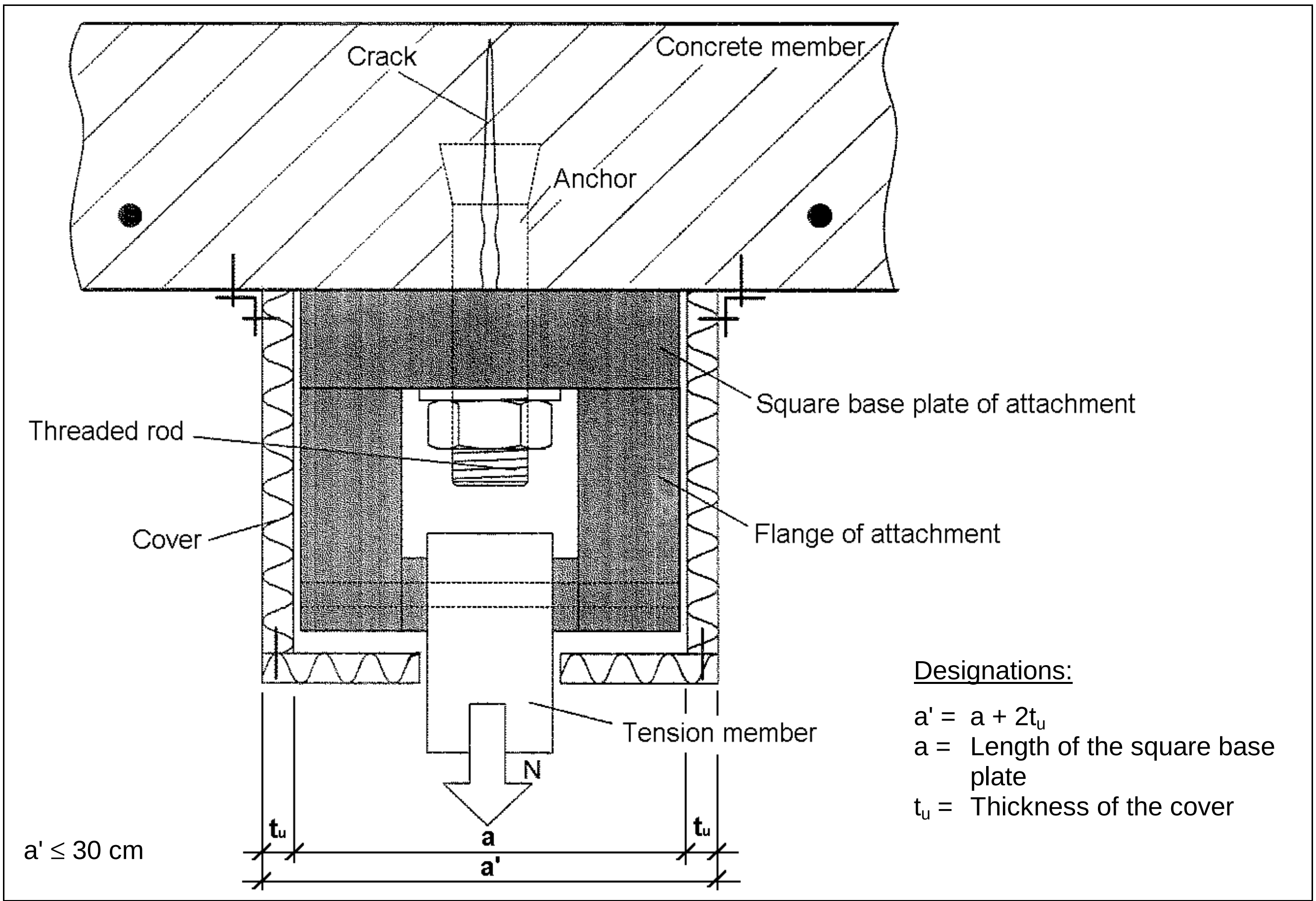


Figure 2.4 Interpolation of intermediate sizes

2.3.1.2. Pull-out failure

Test set-up:

The tests have to be carried out in an reinforced concrete slabs (C20/25) with an reinforcement of d_s = 12 mm / a = 150 mm and a degree of reinforcement of A_S / (b×d) of approximately 0,4%. Steel failure shall not occur, hence the fixation including the anchor must be lagged or protected. The fixation may be more compact than in the tests according to section 2.4.1.1. The reinforced concrete slab has to be at least designed for the desired duration of fire resistance. The thickness of the slab shall be ≥ 2 h_{ef} and at least be 250 mm. The test set-up can be seen in principle in Figure 2.4.



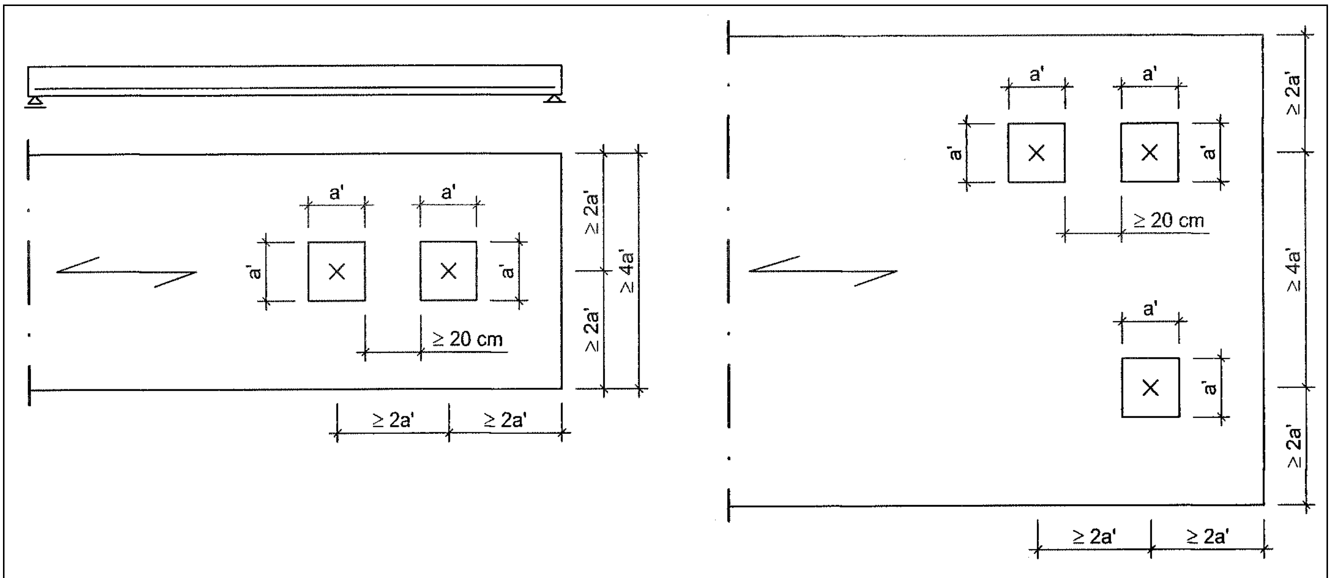


Figure 2.5 Test set-up for the determination of the characteristic resistance under fire exposure to pull-out failure

Test Procedure:

The reinforced concrete slab must be loaded until cracks appear. The anchor has to be set directly into the crack after the load release. Afterwards the slab has to be loaded again; up to a calculated reinforcement stress of approximately 270 $N/mm^2 \pm 20$ N/mm^2 in the anchor area. This will lead to crack widths of approximately 0,10 to 0,25mm. Next the anchor has to be loaded with the designated load for the fire test according to EN 1363-1 [1]. The steel stress of the reinforcement has to be held constant during the test.

At least 5 tests using anchors with the smallest anchor size, which have an effective anchorage depth h_{ef} of approximately 60 mm to 70 mm, have to be carried out for the determination of the limit value curve. The duration of the fire resistance shall be more than 60 min in at least 4 tests.

Test verification:

The test verification shall be carried out according to section 2.3.1.1 (steel failure). The relation between the characteristic pull-out load $N_{Rk,p,fi}$ for the duration of fire resistance of 30 min, 60 min, 90 min and 120 min and the characteristic pull-out load $N_{Rk,p}$ for cracked concrete C20/25 according to the ETA may be used for all anchor sizes of the evaluated system.

2.3.1.3. Concrete cone failure

There are no fire tests necessary for this failure mode. The characteristic resistance for concrete cone failure under fire exposure may be calculated according to section 2.2.1.3.

2.3.1.4. Splitting failure

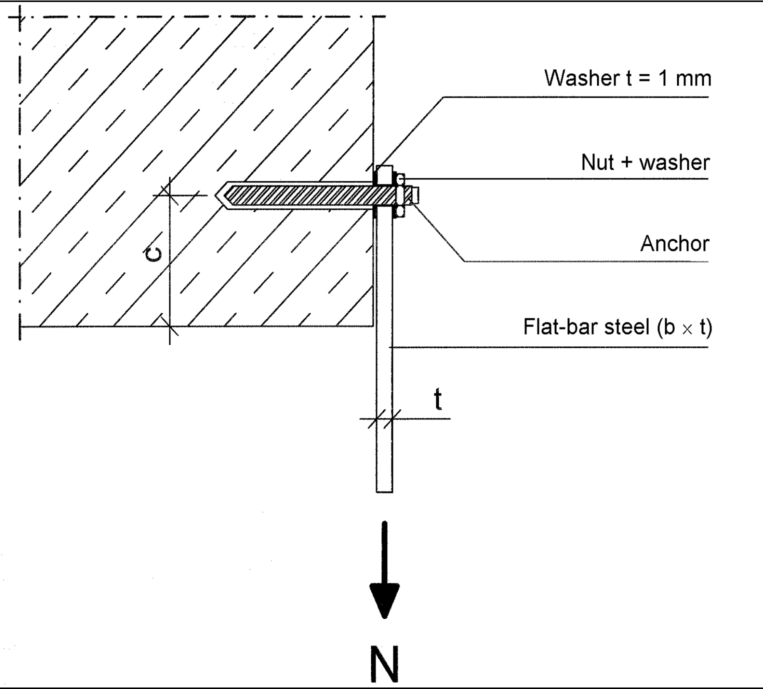
The verification of the failure mode concrete splitting under fire exposure is not necessary, since the verification of pull-out failure for cracked concrete has been carried out and a reinforcement is assumed.

2.3.2. Behaviour under shear load

2.3.2.1. Steel failure

The test procedure and the evaluation of the shall be done according to section 2.3.1.1. The shear load shall be applied via a flat-bar steel, which is adequate for a steel stress of 2 to 4 N/mm^2.

The test set-up can be seen in principle in Figure 2.6.



Designations:

c = edge distance
The edge distance c shall be chosen in such way, that steel failure occurs

t = thickness of the flat-bar steel
10 mm $\leq t \leq$ 20 mm

b = width of the flat-bar steel
$b = N / (t \times \sigma_{Rk,s,fi})$ with
2 $N/mm^2 \leq \sigma_{Rk,s,fi} \leq$ 4 N/mm^2

Figure 2.6 Test set-up for the determination of the characteristic resistance under fire exposure to steel failure due to shear loads

2.3.2.2. Concrete Pry-out failure

There are no fire tests necessary for this failure mode. The characteristic resistance for concrete pry-out failure under fire exposure may be calculated according to section 2.2.2.2.

2.3.2.3. Concrete edge failure

There are no fire tests necessary for this failure mode. The characteristic resistance for concrete edge failure may be taken from section 2.2.2.3

2.3.3. Behaviour under combined tension and shear load

The behaviour of anchors under combined tension and shear load under fire exposure may be determined according to the interaction condition at normal temperature of ETAG 001, Annex C, section 5.2.4 [2], in consideration of the determined resistances for each direction under fire exposure.

3. Evaluation of bonded anchors, bonded expansion anchors, and bonded undercut anchors concerning Resistance to Fire

Bonded anchors can only be evaluated regarding the carrying capacity of the steel according to this paper.

Bonded expansion anchors and bonded undercut anchors, that have an approval for cracked and non-cracked concrete can be evaluated according to this paper. However, an earlier pull-out of the anchor can occur, since the reduction of the strength of the bond mortar at higher temperatures may be decisive. Therefore, the characteristic resistance for pull-out failure shall always, also for the simplified design method according to 2.2, be determined for the certain product by fire tests according to 2.3.1.2. The anchor with the smallest anchorage depth shall be used for the tests.

4. Evaluation of plastic anchors concerning Resistance to Fire

Plastic anchor for use in a system that is required to provide a specific fire resistance class, may be determined by reference to the simplified design method according to chapter 2.2. However, an earlier pull-out of the anchor can occur, since the reduction of the strength of the plastic material at higher temperatures may be decisive. Therefore, the characteristic resistance shall always, also for the simplified design method according to 2.2, be determined for the certain product by fire tests according to 2.3.1.1.

It can be assumed that for fastening of facade systems the load bearing behaviour of the specific screwed in plastic anchor with a diameter 10mm and a metal screw with a diameter 7mm and a h_{ef} of 50mm and a plastic sleeve made of polyamide PA6 has a sufficient resistance to fire at least 90 minutes (R90) if the admissible load (no permanent centric tension load) is $\leq$ 0.8kN.

5. Literature

[1] EN 1363-1: 1999-10, Fire resistance tests - Part 1:General Requirements

[2] prEN 1992-1-2: Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design

[3] ETAG 001, Guideline for European Technical Approval of Metal Anchors for Use in Concrete, Edition 1997

[4] ETAG 001, Annex C of Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Design Methods for Anchorages, Edition 1997

[5] CEN/TC 250/SC 2/WG 2: Design of Fastenings for Use in Concrete, Draft 10, March 2004

[6] EN 10025: 1994-03, Hot rolled products of non-alloy structural steels, technical delivery conditions

[7] ISO 3506:1997, Mechanical properties of corrosion-resistant stainless steel fasteners