EOTA

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SYSTEMS FOR POST-INSTALLED REBAR CONNECTIONS WITH MORTAR

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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) No 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1   SCOPE OF THE EAD

1.1   Description of the construction product

This EAD covers post-installed reinforcing bar (rebar) connections designed in accordance with EN 1992-1-1 [1] and EN 1992-1-2 [2]. The EAD deals with the preconditions, assumptions and the required tests and assessments for post-installed rebar.

The system for post-installed rebar connection comprises of a mortar and an embedded straight deformed reinforcing bar with properties according to EN 1992-1-1 [1] Annex C.

The product is not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

1.2   Information on the intended use(s) of the construction product

1.2.1   Intended use(s)

This EAD covers post-installed rebar connections in non-carbonated concrete C12/15 to C50/60 according to EN 206 [3], which are allowed with straight deformed cast-in bars according to EN 1992-1-1 [1]. This EAD covers post-installed rebars for which the minimum design bond strength for at least concrete strength class C12/15 in accordance with EN 1992-1-1 [1] applies.

This EAD covers post-installed rebar in well compacted concrete.

This EAD covers overlap joints with post-installed rebar for existing cast-in rebar, when the position of the existing rebar is known or is determined using a rebar detector suitable for this purpose.

Detailing and load transfer are to be accounted for as given in EN 1992-1-1 [1]. Examples for such rebar connections are as follows (taking into account the Note to Figures 1.1 to 1.5):

- an overlapping joint with existing reinforcement in a building component, see Figure 1.1 and Figure 1.2;
- anchoring of the reinforcement at a slab or beam support; end support/bearing of a slab designed as simply supported as well as its reinforcement for restraint forces, see Figure 1.3;
- anchoring of reinforcement of building components stressed primarily in compression, see Figure 1.4;
- anchoring of reinforcement to cover the line of acting tensile force, see Figure 1.5.

Actions

This EAD covers application of post-installed rebar connections in structures subject to static or quasi-static actions as well as exposure to fire. Qualification of post-installed rebar connections in structures loaded by fatigue, dynamic or seismic action is beyond the scope of this EAD.

Design

This EAD provides assessment requirements resulting in performance characteristics consistent with and to be used in the design provisions of EN 1992-1-1 [1] and EN 1992-1-2 [2].

Temperature

Concrete temperature range in service condition

The covered service temperature range of the concrete during the working life is specified by the manufacturer and given as intended use in the ETA.

T1: 24°C/40°C   =   temperature range from -40°C to +40°C, with a maximum long term temperature of +24°C, and a maximum short term temperature of +40°C;

T2: 50°C/80°C   =   temperature range from -40°C to +80°C, with a maximum long term temperature of +50°C, and a maximum short term temperature of +80°C;

T3: T_{lt}/T_{st} =   temperature range from -40°C to $+T_{st}$, with a maximum long term temperature $T_{lt} = 0,6$ to $1,0\ T_{st}$, and a maximum short term temperature of $T_{st} \geq 40°C$.

Durability

Corrosion resistance
Maximum allowable chloride contents of the concrete for the intended use according to EN 206 Table 15 [3].

- Cl 0,20
- Cl 0,40

Examples of post-installed rebar connections
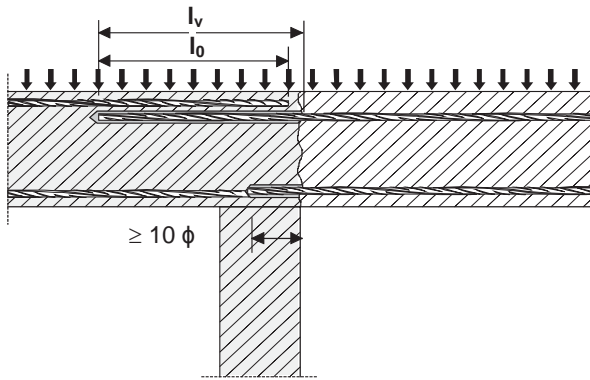
Figure 1.1 Overlap joint for rebar connections of slabs and beams
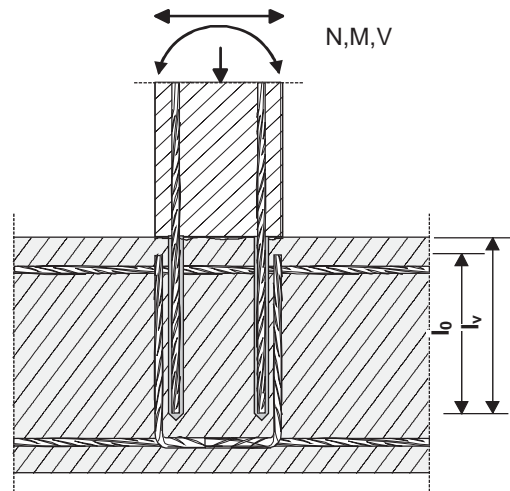
Figure 1.2 Overlap joint at a foundation of a column or wall where the rebar is stressed in tension
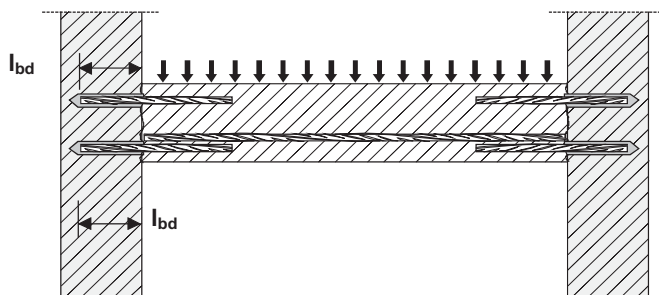
Figure 1.3 End anchoring of slabs or beams, designed as simply supported
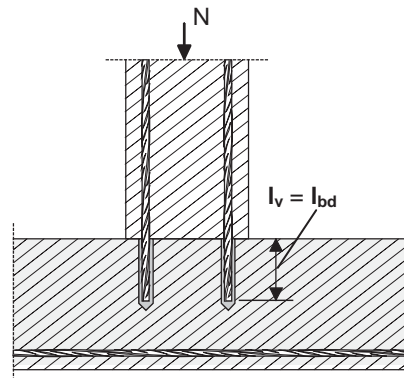
Figure 1.4 rebar connection for components stressed primarily in compression; rebar is stressed in compression
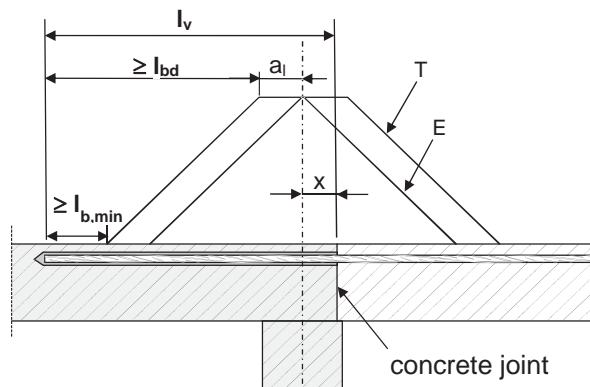
(only post-installed rebar is plotted)

Key to Figure 1.5

T   acting tensile force

E   envelope of $M_{ed}/z + N_{ed}$ (see EN 1992-1-1, Figure 9.2)

x   distance between the theoretical point of support and concrete joint

Note to Figure 1.1 to 1.5:

In the Figures no transverse reinforcement is plotted, the transverse reinforcement as required by EN 1992-1-1 shall be present.

The shear transfer between old and new concrete shall be designed according to EN 1992-1-1.

Figure 1.5 Anchoring of reinforcement to cover the line of acting tensile force

It is assumed that the product is installed in accordance with the manufacturer's product installation instructions (MPII).

The assessment methods of this EAD and the resulting performance characteristics are valid under the following conditions:

- Minimum concrete cover c_{min} as given in Table 1.1 and Table 1.2 are observed.
- Minimum clear spacing between two post-installed bars is a = 40 mm $\geq$ 4 ϕ. When using a drilling aid the requirement of 4 ϕ may be replaced by 2 ϕ.

Table 1.1   Minimum concrete cover c_{min}

Drilling method	Bar diameter ϕ	c_{min}
Hammer drilling or diamond drilling	< 25 mm	30 mm + 0,06 $\ell_v \geq$ 2 ϕ
	$\geq$ 25 mm	40 mm + 0,06 $\ell_v \geq$ 2 ϕ
Compressed air drilling	< 25 mm	50 mm + 0,08 ℓ_v
	$\geq$ 25 mm	60 mm + 0,08 $\ell_v \geq$ 2 ϕ

The factors 0,06 and 0,08 in Table 1.1 take into account the possible deviations during the drilling process. These factors might be smaller if drilling aid devices (see Figure 1.6) are used. When using such a drilling aid device the minimum concrete cover may be reduced as given in Table 1.2.

Table 1.2   Minimum concrete cover c_{min} when using a drilling aid

Drilling method	Bar diameter ϕ	With drilling aid: c_{min}
Hammer drilling or diamond drilling	< 25 mm	30 mm + 0,02 $\ell_v \geq$ 2 ϕ
	$\geq$ 25 mm	40 mm + 0,02 $\ell_v \geq$ 2 ϕ
Compressed air drilling	< 25 mm	50 mm + 0,02 ℓ_v
	$\geq$ 25 mm	60 mm + 0,02 $\ell_v \geq$ 2 ϕ
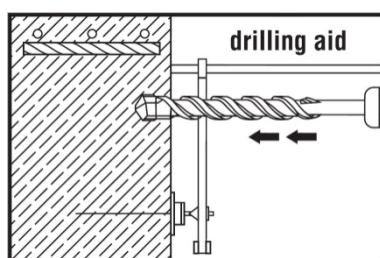
Figure 1.6   Example of drilling aid

1.2.2   Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the post-installed rebar connection for the intended use of 50 years when installed in the works (provided that the post-installed rebar connection is subject to appropriate installation (see 1.1)). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[1].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3   Specific terms used in this EAD

1.3.1   Abbreviations

MPII   = manufacturer's product installation instructions

1.3.2   Notation

a, b	=	exponential fitting curve constants for equation (2.12)
a_l	=	distance between the envelope of acting tensile force and moment curve (shift rule) according to EN 1992-1-1 [1] 6.2.2 (5) and 9.2.1.3 (2)
c_{min}	=	minimum concrete cover
cv	=	coefficient of variation
d_0	=	nominal diameter of drill hole
$d_{cut,m}$	=	medium cutting diameter of drill bit, see EOTA Technical Report TR 048
f_{bd}	=	design value of the ultimate bond stress according to EN 1992-1-1
$f_{bd,PIR}$	=	design value of the bond strength of a post-installed rebar
f_{bm}	=	mean value of ultimate bond strength for each concrete strength class
$f_{bm,cr,rqd}$	=	required mean value of bond strength in cracked concrete (test series according to Table A.1, line 3)
$f_{bm,cr,t}$	=	mean bond resistance in cracked concrete for the concrete strength class under consideration
$f_{bm,rqd}$	=	required mean bond resistance for post installed rebar for assessment as equivalent to cast-in reinforcing bars (see Table A.4)
$f_{bm,rqd,d}$	=	decisive required mean bond strength for specific concrete class equal to $f_{bm,rqd}$ for the assessment according to 2.2.2 a), but may be smaller than $f_{bm,rqd}$ for the assessment according to 2.2.2 b).
$f_{bm(\theta)}$	=	mean bond resistance at the temperature θ
$f_{bm(21°C)}$	=	mean bond strength at normal ambient temperature
$f_{bm,t}$	=	mean bond resistance calculated according to equation (A.2) in the relevant test series of Table A.1

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[1]   The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

$f_{bm,t,1}$	=	mean bond resistance according to equation (A.2) resulting from tests according to Table A.1 line 1
$f_{bm,t,2}$	=	mean bond resistance according to equation (A.2) resulting from tests according to Table A.1 line 2
$f_{bm,20;}$ $f_{bm,50}$	=	mean bond resistance for the post- installed rebar system in concrete C20/25 and C50/60, respectively
f_{bt}	=	bond stress in tests according to Table A.1 line 18
f_{ck}	=	nominal cylinder strength of concrete according to EN 206 [3]
$f_{c,20}$	=	characteristic concrete compressive strength for C20/25
$f_{c,50}$	=	characteristic concrete compressive strength for C50/60
$f_{c,t}$	=	concrete compressive cylinder strength of the test member
f_R	=	relative rib area of tested rebar acc. to EN ISO 15630-1:2010 [10]
f_{yk}	=	characteristic tensile (yield) strength of reinforcement
h	=	thickness of the concrete member
h_{sl}	=	measured thickness of a slice in a test
k_{fi}	=	temperature reduction factor
k_b	=	bond efficiency factor
l_{bd}	=	design anchorage length according to EN 1992-1-1 [1] 8.4.4
$l_{b,min}$	=	minimum anchorage length according to EN 1992-1-1 [1] 8.4.4
l_0	=	design lap length according to EN 1992-1-1 8.7.3
l_v	=	embedment length of the post-installed rebar
m	=	normalisation exponent taking into account the effect of concrete strength on bond
n	=	number of tests in a test series
N_{sust}	=	tension load applied during the sustained load test
N_{test}	=	tension load applied in the test for resistance to fire
$N_{u,fc}$	=	failure (peak) load in the test converted to nominal concrete strength
$N_{u,t}$	=	failure (peak) load in the tests
T	=	Temperature in tests according to Table A.1 line 14
α	=	reduction factor representing the ratio between tested failure load and corresponding reference, see equation (A.6)
α_{lb}	=	amplification factor for minimum anchorage length and splice length
β_{cv}	=	reduction factor resulting from large coefficients of variation
Δw	=	crack width for tests in cracked concrete
δ	=	displacement in tension tests
δ_1	=	limiting displacement
ϕ	=	nominal diameter of the reinforcing bar

ϕ_{max}	=	maximum diameter of rebar specified by the manufacturer of the post-installed rebar system
ϕ_{min}	=	minimum diameter of rebar specified by the manufacturer of the post-installed rebar system
τ_u	=	bond resistance in durability tests (tests according to Table A.1 line 16)
$\tau_{um(sto)}$	=	mean bond resistance of the mortar in the slices stored in alkaline fluid or in sulphureous atmosphere
$\tau_{um,ref}$	=	mean bond resistance of the comparison tests in slices stored under normal conditions
θ	=	temperature in fire resistance tests (tests according to Table A.1 line 18
θ_k	=	temperature in fire resistance tests (tests according to Table A.1 line 18) up to which the mortar maintains the full capacity
θ_{max}	=	maximum temperature in fire resistance tests, where the bond resistance of the mortar is lost

1.3.3 Indices

fi	=	under fire exposure
m	=	mean value
max	=	maximum
min	=	minimum
nom	=	nominal
rqd	=	required
t	=	test
20	=	normalised to cylinder strength of concrete for C20/25
50	=	normalised to cylinder strength of concrete for C50/60

1.3.4 Definitions

mortar	=	bonding material that is part of the post-installed rebar system
normal ambient temperature	=	temperature in the concrete: 21 °C ± 3 °C
rebar	=	deformed reinforcing bar

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of post-installed rebar connections with mortar is assessed in relation to the essential characteristics.

Table 2.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance (level, class, description)
Basic Works Requirement 1: Mechanical resistance and stability			
1	Characteristic resistance under static and quasi-static loading		
	Bond strength of post-installed rebar	2.2.1	$f_{bd,PIR}$ [N/mm²]
	Reduction factor	2.2.2	k_b [-]
	Amplification factor for minimum anchorage length	2.2.3	α_{lb} [-]
Basic Works Requirement 2: Safety in case of fire			
2	Reaction to fire	-	Class (A1)
3	Resistance to fire		
	Bond strength at increased temperature	2.2.4	$f_{bk,fi}(\theta)$ [N/mm²]; $k_{fi}(\theta)$ [-], θ_{max} [°C]

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

An overview of the test program for the assessment of the various essential characteristics of the product is given in Annex A.

Provisions valid for all tests and general aspects of the assessment are also given in Annex A.

2.2.1 Bond strength

2.2.1.1 Reference tension tests in uncracked concrete (test series 1 and 2)

Purpose of the test

The test is needed to assess the bond strength of the post-installed reinforcing bar system with the mortar and to establish reference for the assessment of the test series Table A.1, line 7,8,12 to 15.

Test procedure

The tension tests shall be performed in uncracked concrete C20/25 (test series 1) with an embedment length of the bar of 10 ϕ for all diameters ϕ and in uncracked concrete C50/60 (test series 2) with an embedment length of the bar of 7 ϕ for ~~all~~ the maximum rebar ~~diameters~~ ϕ_{max}. The range of tested sizes ϕ may be reduced to s/m/l (noting that reference tests with ϕ = 12 mm are required) if the installation system is consistent with respect to cleaning and injection effect (see note). The reduced range depends on the number of sizes given in the ETA per request by the applicant and is given in Table A.2.

The number of sizes shall be distributed equally in the range of sizes between ϕ_{min} and ϕ_{max}.

> *Note 1: Check the difference of drill bit diameter to rebar diameter, difference of outer brush diameter to nominal drill bit diameter, same material, thickness and density of bristles of the specified brushes, same type of blowing/vacuuming (e.g. hand pump, compressed air tool), same type of dispensers (e.g. manual, electric, pneumatic).*

Assessment

Failure loads of tension tests:

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15% (cv_F > 15%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.1.4.

Load displacement behaviour:

- Verify the criteria for loss of adhesion and determine the load N_{sl} [kN] according to A2.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5.

2.2.1.2 Robustness in dry concrete (test series 7)

Purpose of the test

The test series are required to check the influence of reduced cleaning effort in dry concrete (equilibrium moisture content)

Test procedure

The test series may be omitted if the reduction for this aspect has been determined for a reinforcing bar in accordance with EAD 330499. The tension tests shall be performed in concrete C20/25 with an effective embedment length of the bar of 10 ϕ and bar diameters in accordance with Table A.1 line 7.

To account for unfavourable cleaning conditions for larger embedment depths the installation of the fastener shall be carried out with an increased embedment depth as follows:

Use a test member consisting of two concrete blocks A and B stacked on the top of each other without a permanent connection as shown in Figure A.1 a). Drill the hole in accordance with the procedures described in the MPII. Clean the hole as described below. Install the mortar in accordance with the MPII to the limited depth of the bottom block B (Figure A.1 b)) with the equipment supplied by the manufacturer. Remove the upper block A and install the rebar element (Figure A.1c)). After curing perform the tension test.

The following cleaning process of the hole has to be carried out in the tests.

Clean the hole with the equipment supplied by the manufacturer using two blowing operations by hand pump or compressed air and one brushing operation, i.e. either blow-brush-blow or blow-blow-brush or brush-blow-blow. The type of blowing and the order of brushing/blowing shall be done as prescribed in the MPII. This test procedure is valid only if the MPII specify hole cleaning with at least four blowing and two brushing operations, meaning twice the operations given above. If the instructions specify less than this, the above requirement (2 blows + 1 brush) shall be reduced proportionately and the number of blows/brushes shall be lowered to the next whole number. Therefore where the MPII recommend two blowing and one brushing operations, the tests shall be carried out without the brushing operation and one blowing only.

If the MPII recommends a vacuum cleaning instead of a blowing operation, the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, the drilling shall be done without venting (meaning, airing out the dust by periodically

moving the drill bit out of the hole) during the drilling process. If the cleaning is performed with suction bit or a hollow drill bit, then the vacuum with the smallest specified maximum flow rate shall be used during the drilling process.

If precise instructions for hole cleaning are not provided by the MPII, the tests are carried out without hole cleaning.

The reference test series shall be performed with the same embedment length l_v.

Assessment

Failure loads of tension tests:

- Determine the mean value of failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5, converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% ($cv_F > 20\%$), determine the reduction factor for large scatter β_{cv} according to A2.1.4.
- Determine the reduction factor α according to Annex A, section A2.9 comparing the test results with reference test series according to Table A.1 line 1.
- If $\alpha < 0,80$ use the reduction factor α together with rqd. $\alpha = 0,80$ in Equations (2.6) and (2.7).

Load displacement behaviour:

- Verify the criteria for loss of adhesion and determine the load N_{sl} [kN] according to A2.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5.

2.2.1.3 Robustness in wet concrete (test series 8)

Purpose of the test

The test series are required to check the influence of reduced cleaning effort in water saturated concrete.

Test procedure

The test series may be omitted if the reduction for this aspect has been determined for a reinforcing bar in accordance with EAD 330499. The tension tests shall be performed in concrete C20/25 with an effective embedment length of the bar of 10 ϕ and bar diameters in accordance with Table A.1 line 8.

Hole drilling and cleaning as well as installation of the mortar and rebar element shall be carried out according to 2.2.1.2. However the concrete shall be water saturated when the hole is drilled, cleaned and the rebar is installed.

The following procedure may be applied to ensure a water saturated concrete in both concrete blocks A and B (see Figure A.1).

1. A hole with diameter approximately $0,5 \times d_0$ (d_0 = drill hole diameter of the tested rebar) is drilled in the concrete substrate to the recommended depth ,

2. The hole is filled with water and remains water-filled for 8 days until water has percolated into the concrete at a distance equal to 1,5 d to 2 d from the axis of the hole,

3. Water is removed from the hole,

4. The final hole is drilled at the recommended diameter d_0,

If methods other than those described above are used it shall be shown by appropriate methods that the concrete in the area of the anchorage is water saturated.

Clean the hole with the equipment supplied by the manufacturer using two blowing operations by hand pump or compressed air and one brushing operation, i.e. either blow-brush-blow or blow-blow-brush or brush-blow-blow. The type of blowing and the order of brushing/blowing shall be done as prescribed in the MPII. This test procedure is valid only if the MPII specify hole cleaning with at least four blowing and two brushing operations, meaning twice the operations given above. If the instructions specify less than this, the above requirement (2 blows + 1 brush) shall be reduced proportionately and the number of blows/brushes shall be lowered to the next whole number. Therefore where the MPII recommend two blowing and one brushing operation, the tests shall be carried out without the brushing operation and one blowing only.

If the MPII recommends a vacuum cleaning instead of a blowing operation, the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, the drilling shall be done without venting (meaning, airing out the dust by periodically moving the drill bit out of the hole) during the drilling process." If the cleaning is performed with suction bit or a hollow drill bit, then the vacuum with the smallest specified maximum flow rate shall be used during the drilling process.

If methods other than those described above are used it shall be shown by appropriate methods that the concrete in the area of the anchorage is water saturated.

The reference test series shall be performed with the same embedment length l_v.

Assessment

Failure loads of tension tests:

- Determine the mean value of failure loads $N_{u,m}$ [kN], and the corresponding mean bond resistance f_{bm} in accordance with A2.5 converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% ($cv_F > 20\%$), determine the reduction factor for large scatter β_{cv} according to A2.1.4.
- Determine the reduction factor α according to Annex A, section A2.9 comparing the test results with reference test series according to Table A.1 line 1.
- If $\alpha < 0,75$ use the reduction factor α together with rqd. $\alpha = 0,75$ in Equation (2.6) and (2.7).

Load displacement behaviour:

- Verify the criteria for loss of adhesion and determine the load N_{sl} [kN] according to A2.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5.

2.2.1.4   Installation at minimum and maximum installation temperature (test series 9, 10)

Purpose of the test

The test series are required to check if the rebar can be installed properly at maximum embedment depth before curing of the mortar.

The test series 9 may be omitted for minimum installation temperature > 0°C and minimum mortar temperature ≥5°C.

Test procedure

In the test it is checked whether a rebar with the maximum embedment depth can be installed correctly with the installation tools defined in the MPII (including drilling, cleaning, injection of the mortar and installation of the rebar). The tests are done with the maximum rebar diameter and the maximum embedment depth applied for. If during installation significant splitting forces are created (e.g. with capsule type systems where the rebar is hammered in), tests shall be done with minimum concrete cover. The temperature of the concrete, rebar and mortar shall comply with the installation conditions specified by the manufacturer at minimum (Table A.1 line 9) and maximum (Table A.1 line 10) specified installation temperature. The rebar is installed according to the MPII. The tests shall be done for each installation system (e.g. manual/electric/pneumatic dispensers) specified by the manufacturer.

Assessment

It shall be possible to install the rebar properly (required embedment depth is reached and the mortar comes out of the hole).

2.2.1.5   Correct injection (test series 11)

Purpose of the test

In the test it is checked if the injection of the mortar can be done properly without voids.

Test procedure

The injection tests are performed at the lowest installation temperature (of rebar, acryl tube and temperature of the test chamber and minimum storage temperature of the injection mortar) in acryl tubes

with an inner diameter equal to or 1 mm less than the drilling diameter. The tests are done in horizontal direction with the maximum rebar diameter and the maximum embedment depth applied for. During the injection of the mortar the acryl tube shall be covered so that the installer cannot see the flow of the injection mortar. After the injection insert the bar to the required depth.

> *Note 1:   acryl tubes are available with an inner diameter from 2 to 250 mm in steps of 2 mm; e.g. for drilling diameter $d_0 = 25$ mm an acryl tube of 24 mm is recommended*

Assessment

The mortar shall fill completely the gap between rebar and hole of the acryl tube over the entire embedment depth. Small voids are usually unavoidable. However, the size and number of these voids shall be such that they do not adversely affect the bond strength of the mortar and the corrosion resistance. Sagging of the rebar in the fresh mortar immediately after placing and adjustment shall be checked; significant sagging must not occur.

2.2.1.6   Installation direction (test series 12,13)

Purpose of the test

If the manufacturer allows in the MPII all installation directions, tension tests are needed with rebars installed vertically upwards only. If the manufacturer allows horizontal and vertical downward only, tension tests have to be done with rebars installed in horizontal direction. If special devices are used to maintain the rebar in place this shall be described in the MPII and in the ETA.

Test procedure

Test results may be taken from assessment based on EAD 330499 for this aspect for the same diameter. Perform a confined tension test without influence of edge distance and spacing in accordance with TR 048 [4].

The reference test series shall be performed with the same embedment length l_v.

Assessment

Failure loads of tension tests:

- Determine the mean value of failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5, converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% ($cv_F > 20\%$), determine the reduction factor for large scatter $ß_{cv}$ according to A2.1.4.
- Determine the reduction factor α according to Annex A, section A2.9 comparing the test results with reference test series according to Table A.1 line 1.
- If $\alpha < 0,90$ use the reduction factor α together with rqd. $\alpha = 0,90$ in Equations (2.6) and (2.7).

Load displacement behaviour:

- Verify the criteria for loss of adhesion and determine the load N_{sl} [kN] according to A2.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] and the corresponding mean bond resistance f_{bm} in accordance with A2.5.

2.2.1.7   Sustained loads (test series 14)

Purpose of the test

The tests are performed to check the creep behaviour of the loaded fastener at normal ambient temperature and at maximum long term temperature. The performance of the post-installed rebar shall not be adversely affected by long term temperatures within the service temperature range or by long term temperatures up to the maximum long term temperature.

Test procedure

The test series may be omitted if the reduction for this aspect is taken from assessment acc. to EAD 330499 for threaded rods. In this case any reduction factor gained with threaded rods shall be applied also for rebar.

The tests shall be carried out as confined tests in uncracked concrete C20/25, both at normal ambient concrete temperature and maximum long term concrete temperature as specified by the manufacturer (see 1.2.1). The permanent stress N_{sust} can be applied by a hydraulic jack, by springs or by dead loads, e.g. applied via a lever arm.

Install rebar at normal ambient temperature. Apply the load N_{sust} in accordance with (2.1).

$$N_{sust} = 0.55 \cdot f_{bm,t,1} \cdot \pi \cdot \phi \cdot l_v \cdot \left(\frac{f_{c,t}}{f_{c,20}} \right)^n \tag{2.1}$$

with $f_{bm,t,1} \leq 10.0$ N/mm²

For range T1 maintain load at N_{sust} and maintain temperature at normal ambient temperature (T = 21 °C) and measure the displacements until they appear to have stabilized, but at least for three months.

For range T2 or T3 maintain load at N_{sust} after curing and raise the temperature of the test chamber to maxim long term temperature at a rate of approximately 20 K per hour or at 5 K in the concrete in the area of the rebar. Maintain load at N_{sust} and maintain temperature and measure the displacements until they appear to have stabilized, but at least for three months (in special justified cases the TAB may allow a shorter duration for the sustained load test). Temperatures in the room may vary by ± 3 °C due to day/night and seasonal effects but the required test room temperature level shall be achieved as a mean over the test period. The frequency of monitoring displacements shall be chosen so as to demonstrate the characteristics of the fastener. As displacements are greatest in the early stages, the frequency shall be high initially and reduced with time. As an example, the following regime would be acceptable:

During first hour: every 10 minutes
During next 6 hours: every hour
During next 10 days: every day
From then on: every 5-10 days.

To check the remaining load capacity after the sustained load test, unload the rebar and carry out a confined tension test at maximum long term temperature.

The results of the residual load capacity test shall be compared with the load capacity of reference test series. The reference test series shall be performed with the same embedment length l_v.

Assessment

The displacements measured in the tests have to be extrapolated according to Equation (2.2) (Findley approach) to 50 years (tests at normal ambient concrete temperature), or 10 years (tests at maximum long term concrete temperature), respectively. The trend line according to Equation (2.2) may be constructed with data from not less than the last 20 days (minimum of 20 data points) of the sustained load test. The extrapolated displacements shall be less than the mean value of the displacements $s_{u,adh}$ in the corresponding reference tests at normal ambient concrete temperature or maximum long term concrete temperature respectively. $s_{u,adh}$ is the displacement at $N_{u,adh}$ (load at loss of adhesion, see A2.10).

$$s(t) \quad = s_o + a \bullet t^b \tag{2.2}$$

The applied sustained load in the test shall be assessed according to A2.8.

In the tension tests after the sustained loading the mean bond resistance shall be determined and the rqd.α has to be considered according to A2.9.

The result of the residual capacity tension tests at normal temperature as well as at maximum long term concrete temperature shall both be compared with the reference series according to Table A.1, line 1 (performed at normal ambient concrete temperature).

- Determine the mean value of the failure loads $N_{u,m}$ and the corresponding mean bond resistance f_{bm} in accordance with A2.5.
- Determine the reduction factor α according to Annex A, section A2.9 comparing the test results with reference test series according to Table A.1 line 1.
- If $\alpha < 0.90$ use the reduction factor α together with rqd. $\alpha = 0.90$ in Equations (2.6) and (2.7).

2.2.1.8   Freeze/thaw conditions (test series 15)

Purpose of the test

These tests are performed to determine the performance of the fastener under freeze/thaw conditions simulating service loads that are subject to variation over time.

Test procedure

The test series may be omitted if the reduction for this aspect and diameter is taken from assessment acc. to EAD 330499. Perform the tests with confined test setup. The tests are performed in uncracked freeze-thaw resistant concrete C50/60 in accordance with EN 206 [3]. As test member a cube with side length of 200 mm to 300 mm or 15d to 25d or a steel encased concrete cylinder shall be used and splitting of concrete shall be prevented.

Cover the top surface of the test member with tap water to a depth of 12 mm, other exposed surfaces shall be sealed to prevent evaporation of water.

The sustained load N_{sust} for the tests shall be determined according to equation (2.3).

$$N_{sust} = 0{,}4 \cdot f_{bm,t,2} \cdot \pi \cdot \phi \cdot l_v \cdot \left(\frac{f_{c,t}}{f_{c,50}} \right)^n \tag{2.3}$$

with $f_{bm,t,2} \leq 18{,}4$ N/mm²

Carry out 50 freeze/thaw cycles as follows:

- Raise temperature of chamber to $(+20 \pm 2)$ °C within 1 hour, maintain chamber temperature at $(+20 \pm 2)$ °C for 7 hours.

- Lower temperature of chamber to (-20 ± 2) °C within 2 hours, maintain chamber temperature at (-20 ± 2) °C for 14 hours (total of 16 hours).

If the test is interrupted, the samples shall always be stored at a temperature of $(+ 20 \pm 2)$ °C between the cycles.

The displacements shall be measured during the temperature cycles.

After completion of 50 cycles a confined tension test shall be carried out at normal ambient concrete temperature.

If no separate reference tests series is performed the test results shall be normalised to concrete strength C20/25 according to equation (A.1)

Assessment

The rate of displacement increase shall reduce with increasing number of freeze/thaw cycles to a value almost equal to zero.

The results of the residual load capacity test shall be assessed as follows:

- Determine the mean value of the failure loads $N_{u,m}$ and the corresponding mean bond resistance f_{bm} in accordance with A2.5.
- Determine the reduction factor α according to Annex A, section A2.9 comparing the test results with the reference tension test series at normal ambient concrete temperature with the same curing time.
- If $\alpha < 0{,}90$ use the reduction factor α together with rqd. $\alpha = 0{,}90$ in Equation (2.6) and (2.7)."

2.2.1.9   High alkalinity and sulphurous atmosphere (test series 16)

Purpose of the test

These tests are performed to determine the performance of the fastener under sulphurous atmosphere and high alkalinity. The test series may be omitted if the reduction for this aspect and diameter is taken from assessment acc. to EAD 330499.

Test specimen:

The concrete compressive strength class shall be C20/25. The diameter or side length of the concrete specimen shall be equal to or exceed 150 mm. The test specimen may be manufactured from cubes or

cylinders or may be cut from a larger slab. They can be cast; it is also allowed to diamond core concrete cylinders from slabs.

One steel element (medium size $\phi = 12$ mm or M12 or smallest size if the smallest size is larger than 12 mm) has to be installed per cylinder or cube on the central axis in dry concrete according to the MPII. The embedded part shall be made out of stainless steel.

After curing of the bonding material according to MPII the concrete cylinders or cubes are carefully sawn into 30 mm thick slices with a diamond saw. The top slice shall be discarded.

To gain sufficient information from the slice tests, at least 30 slices are necessary (10 slices for every environmental exposure test and 10 slices for the comparison tests under normal climate conditions).

Storage of the test specimen under environmental exposure:

The slices with bonding fasteners are subjected to water with high alkalinity and condensed water with sulphurous atmosphere. For comparison tests slices stored under normal climate conditions (dry / +21 °C $\pm$ 3 °C / relative humidity 50 $\pm$ 5%) for 2000 hours are necessary.

High Alkalinity:

The slices are stored under standard climate conditions in a container filled with an alkaline fluid (pH = 13.2). All slices shall be completely covered for 2.000 hours. The alkaline fluid is produced by mixing water with KOH (potassium hydroxide) powder or tablets until the pH-value of 13.2 is reached. The alkalinity of pH = 13.2 shall be kept as close as possible to 13.2 during the storage and not fall below a value of 13.0. Therefore the pH-value has to be checked and monitored in regular intervals (at least daily). The producing of alkaline fluid by mixing water with KOH (potassium hydroxide) powder or tablets could be given as an example. If other materials are used then it has to be shown that same results and comparable assessment are achieved.

Sulphurous atmosphere:

The tests in sulphurous atmosphere shall be performed according to EN ISO 6988 [8]. The slices are put into the test chamber, however in contrast to EN ISO 6988 the theoretical sulphur dioxide concentration shall be 0,67 % at beginning of a cycle. This theoretical sulphur dioxide concentration corresponds to 2 dm^3 of SO$_2$ for a test chamber volume of 300 dm^3. At least 80 cycles shall be carried out.

Slice tests

After the storage time, the thickness of the slices is measured and the metal segments of the bonded fasteners are pushed out of the slice, the slice is placed centrally to the hole of the steel rig plate. If slices are unreinforced then splitting may be prevented by confinement. Care shall be taken to ensure that the loading punch acts centrally on the fastener rod.

The results of at least 10 tests shall be taken for every environmental exposure and for comparison. Results with splitting failure shall be ignored.

Assessment

It shall be shown that the bond strength of the slices stored in an alkaline liquid and sulphurous atmosphere media is at least as high as that of the bond strength of the comparison tests on slices stored under normal conditions. To show compliance with this requirement the factor α_4 shall be calculated according to Equation (2.4).

$$\alpha_4 = min\left(\frac{\tau_{um,alkali}}{\tau_{um,r}}; \frac{\tau_{um,sulphour}}{0,9\tau_{um,r}}\right) \leq 1,0 \tag{2.4}$$

The reference bond strength $\tau_{um,r}$ is gained in the reference test series with unexposed slices.

The bond strength in the slice tests shall be calculated according to Equation (2.5).

$$\tau_u = \frac{N_u}{\pi \cdot d \cdot h_{sl}} \tag{2.5}$$

2.2.1.10 Corrosion resistance of rebar (test series 17)

Purpose of the test

Cast-in place rebars situated in non-carbonated concrete with limited chloride content according to EN 206 are protected by the alkalinity of the concrete, which develops a passive layer on the steel surface, along with the concrete cover.

No proof of the corrosion resistance of the rebar is needed if it is used in building components in dry surroundings according to exposure class X0 and XC1 of EN 1992-1-1. Also no proof is needed when only corrosion resistant rebars are specified for all applications.

In all other cases it has to be shown by the following tests that post-installed rebar connections provide the same corrosion resistance as cast-in-place rebar.

Test procedure

The test member is made of concrete C20/25. The mixture and storage is done as described in EOTA Technical report TR 048 with the following modifications:

-   the water/cement ratio shall be ≥ 0,6 (covering all exposure classes given in EN 206 [3], Table F.1 for which the test is required)
-   chlorides are added to the mix so that the chloride content of the concrete (expressed as mass proportion of chloride ions in cement) is 0,20 % or 0,40 % according to the class of chloride content according to EN 206 [3] Table 15.

The dimensions are either cubes of 150 mm x 150 mm x 150 mm or prism with a cross section of 150 x 150 mm and an arbitrary length. The age of the concrete cube at installation of the rebar shall be at least 21 days. Carbonated surfaces are to be removed. In minimum 3 rebars with the nominal diameter of 12 mm are to be used. They shall be cleaned in such a manner as to ensure no contamination of the rebar with other materials. A suitable method is to degrease with ethanol. They shall be ensured to be free from mill scale and other loose contaminants by cleaning methods recommended by the rebar manufacturer.

The installation of the rebar into the concrete is done according to the MPII for this size. The embedment depth is 70 mm (± 3 mm) and the edge distance is 75 mm. In case of prism the spacing between the rebars is at least 50 mm. The rebar is positioned so as to rest on the bottom of the drilled hole. The top side of the concrete member in the area of the post installed rebar is covered by epoxy resin to prevent carbonation.

After curing of the mortar, the concrete member is immersed into a container filled with artificial tap water (200 mg sodium sulphate and 200 mg sodium bicarbonate dissolved in 1 litre distilled water). By means of distance holder made of plastic, the concrete member is kept at least 1 cm above the bottom of the container. The water level shall be 10 mm above the bottom side of the installed rebar. For a height of the concrete member of 150 mm the water line should, therefore, be 90 mm above the bottom side of the concrete member. Each rebar is connected to a cathode with a 100 Ohm resistor (accuracy class ± 1%). The cathodes are L-shaped and made of stainless steel (EN 10088-1 [6] and EN 10088-3 [7]: 1.4404, 1.4435 or 1.4539). They are positioned directly on the bottom of the container. The surface of the cathodes in contact to the water is at least 100 cm^2. Previous to the test, the cathodes are degreased with ethanol, cleaned by exposing for 10 min in 5% Nitric acid and subsequent rinsing with distilled water. The cathodes have to be stored in the artificial tap water for at least 2 weeks, prior to run the test. The current between the rebar and the cathode is readily determined by measuring the potential drop over the resistor with a micro voltmeter with a resolution of 100 nV and an input resistance of at least 10 MOhm (eg. Keithley M2001).

Additionally, the corrosion potential of each rebar is measured by a Voltmeter with an input resistance of at least 10 MOhm and a resolution of 0,1 mV (e.g. Keithley M2001) against a reference electrode in the container. Ideally, a quasi-reference electrode is used. For example, a AgCl coated silver wire immersed in a container filled with a dilute chloride solution (200 mg sodium sulphate, 200 mg sodium bicarbonate and 58 mg sodium chloride dissolved in one litre distilled water) and an opening closed by a diaphragm can be used.

Alternatively an electrolyte bridge can be used to prevent significant pollution of the electrolyte with copper ions or chlorides. Every week the potential of the reference electrode has to be controlled with a saturated Cu/CuSO4 electrode (CSE).The measurement of the current flow and the potential shall be done continuously with intervals not greater than 1 hour.

The duration of the tests shall be at least 3 month. The measured current flow and the potential are plotted against the duration.

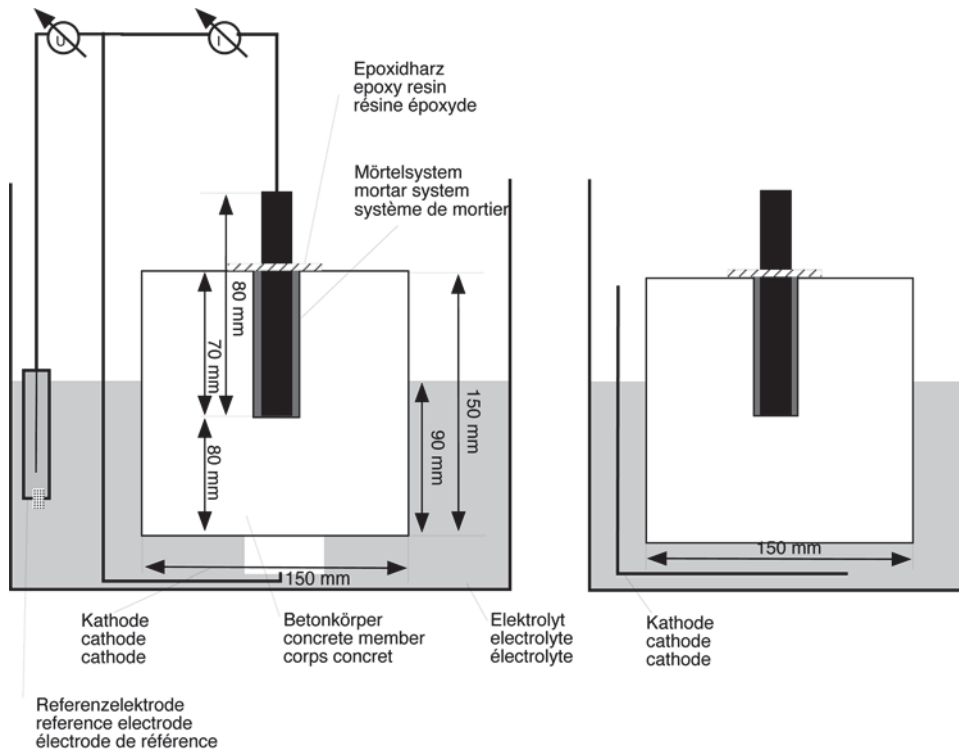The reference test series shall be performed with the same embedment length l_v.

Figure 2.1   Example of test setup in concrete cubes

Assessment

(a)   During the last third of the testing period the daily mean value of the current shall not exceed 0.28 µA and the potential shall not be below –0.2V CSE for all test samples.

(b)   The potential criterion may be omitted if the current criterion of 0.28 µA is fulfilled for all samples and the visual inspection of the rebar after the test does not show any corrosion products.

If either condition (a) or (b) is fulfilled the corrosion resistance of the post-installed rebar connection can be judged as being comparable with the corrosion resistance of cast-in-place rebar.

2.2.1.11 Determination of bond strength

The bond resistance for the assessment of the post-installed rebar shall be determined according to equations (2.6) and (2.7). Use $f_{bm,t,1}$ and $f_{bm,t,2}$ as determined in test series 1 and 2 of Table A.1.

C20/25: $f_{bm,20} = f_{bm,t,1} \cdot \alpha_4 \cdot \beta_{cv} \cdot min\left(\alpha_p; min\frac{\alpha}{rqd.\,\alpha}\right)$ (2.6)

C50/60: $f_{bm,50} = f_{bm,t,2} \cdot \alpha_4 \cdot \beta_{cv} \cdot min\left(\alpha_p; min\frac{\alpha}{rqd.\,\alpha}\right)$ (2.7)

$min\dfrac{\alpha}{rqd.\,\alpha}$ $= \ \leq 1,0$; minimum ratio of the tests Table A.1, line 7, 8, 12 to 15

2.2.2   Reduction factor k$_b$

This EAD covers post-installed rebar connections only where the mean bond resistance for low strength concrete and high strength concrete $f_{bm} \geq 7{,}1$ N/mm^2 for all rebar diameters as applied for.

The following assessment shall be made at least for the lowest mean bond strength $f_{bm,t,1}$ obtained from the range of the tested rebar diameters in the test series according to Table A.1 line 1. The results may be applied to all other sizes with higher mean bond strength.

The design value of the ultimate bond stress (design bond resistance) f$_{bd}$ for ribbed bars (rebars) according to EN 1992-1-1 depends on several National Determined Parameters. Therefore the design bond resistance for post-installed rebar is expressed in terms of the factor k$_b$, which shall be multiplied with the value of f$_{bd}$ according to EN 1992-1-1. The factor k$_b$ for each concrete class shall be determined as given in equation (2.8) and rounded to the nearest hundredth.

$$k_b = \frac{f_{bm,rqd,d}}{f_{bm,rqd}} \leq 1{,}0 \qquad\qquad (2.8)$$

a) Design according to EN 1992-1-1 for all concrete strength classes

If the mean bond resistance $f_{bm,20}$ determined according to equation (2.6) and the mean bond resistance $f_{bm,50}$ determined according to equation (2.7) reaches at least the required bond resistance $f_{bm,rqd}$ (i.e. 10,0 N/mm^2 for C20/25 and 18,4 N/mm^2 for C50/60), the post-installed rebar may be designed using the design values of the ultimate bond stress, f_{bd} for ribbed bars according to EN 1992-1-1 for the corresponding concrete strength class. In this case the decisive required bond strength f$_{bm,rqd,d}$ is equal to the required bond resistance f$_{bm,rqd}$ as given in Table A.1 for all concrete strength classes and hence, the factor k$_b$ = 1 for all concrete strength classes. An example is shown in Figure 2.2 and Table 2.2.
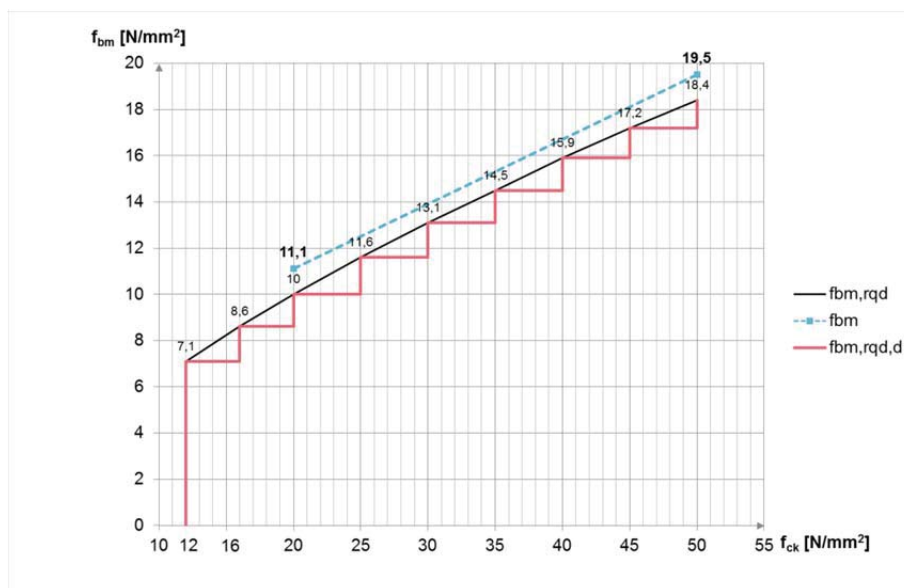

Figure 2.2   Example A: Design according to EN 1992-1-1 without reduction

Table 2.2   Determination of k_b for example A

Concrete class	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck} [N/mm²]	12	16	20	25	30	35	40	45	50
f_{bm} [N/mm²]	8,9	10,0	11,1	12,5	13,9	15,3	16,7	18,1	19,5
$f_{bm,rqd}$ [N/mm²]	7,1	8,6	10,0	11,6	13,1	14,5	15,9	17,2	18,4
$f_{bm,rqd,d}$ [N/mm²]	7,1	8,6	10,0	11,6	13,1	14,5	15,9	17,2	18,4
k_b [-]	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
$f_{bd,PIR}$ [N/mm²][*]	1,6	2,0	2,3	2,7	3,0	3,4	3,7	4,0	4,3

[*] *see footnote to Table A.1*

If the required bond resistance is not fulfilled in C20/25 and/or C50/60, the design may be carried out with deviations to EN 1992-1-1 using reduced design values of the ultimate bond stress determined according to b).

b) Design with deviations to EN 1992-1-1

If the required bond resistance in C20/25 and/or C50/60 is not fulfilled, the following procedure shall be carried out:

- Draw a straight line between the mean bond resistances $f_{bm,20}$ and $f_{bm,50}$
- Draw a step-shaped curve under this line with the given values of the required bond resistance $f_{bm,rqd}$ for the different concrete classes given in Table A.1 such, that this curve does not exceed the straight line.
- The values of the step-shaped curve represent the decisive required bond strength $f_{bd,rqd,d}$ for the corresponding concrete classes and provide the basis for the determination of the factor k_b.
- Determine the reduction factor k_b according to equation (2.8).

Example B: see Figure 2.3

Example B shows the determination of the design bond resistance in terms of the reduction factor k_b of a post-installed rebar where the mean bond resistance $f_{bm,50}$ does not reach the required bond resistance $f_{bm,rqd}$ for C50/60.
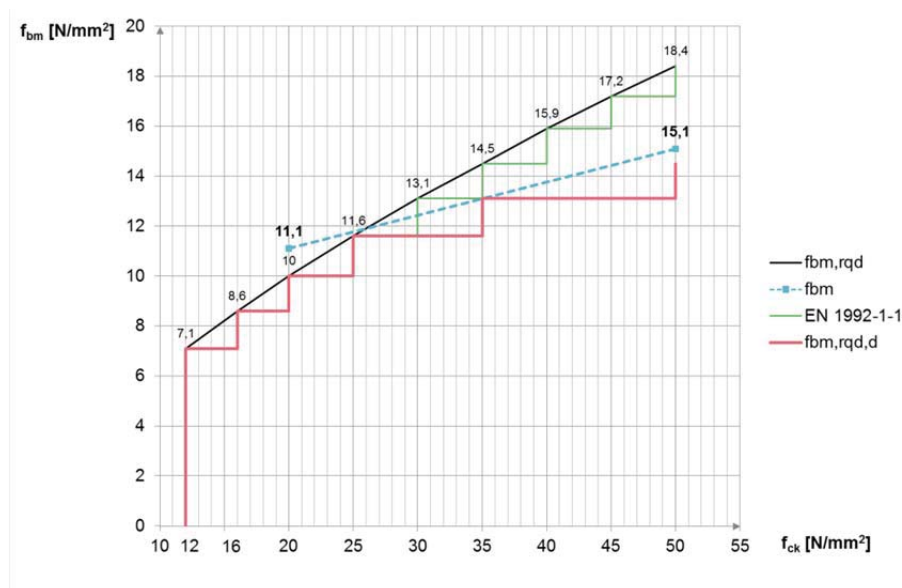

Figure 2.3   Example B, required bond resistance for C50/60 is not reached
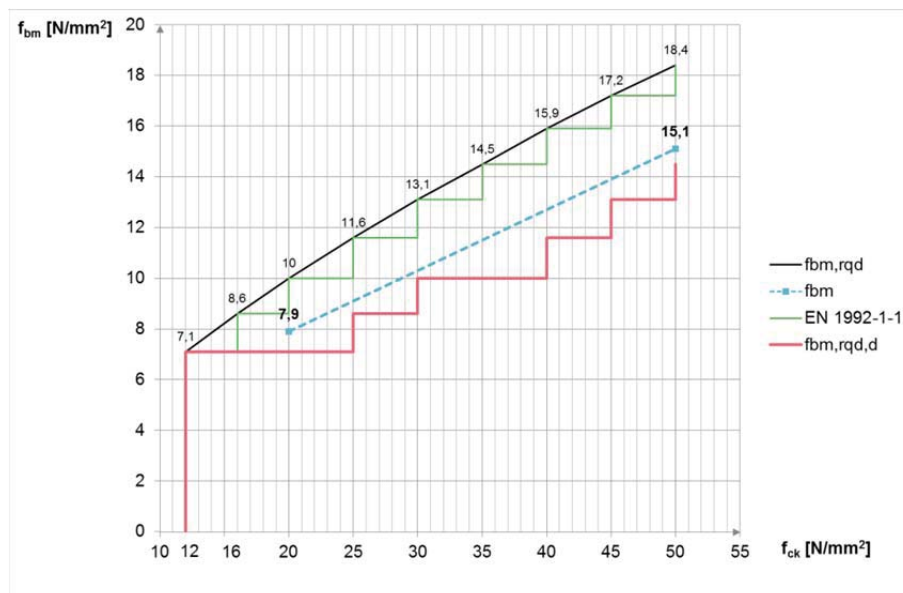
Table 2.3   Determination of k_b for example B

Concrete class	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck} [N/mm^2]	12	16	20	25	30	35	40	45	50
f_{bm} [N/mm^2]	-	-	11,1	11,8	12,4	13,1	13,8	14,4	15,1
$f_{bm,rqd}$ [N/mm^2]	7,1	8,6	10,0	11,6	13,1	14,5	15,9	17,2	18,4
$f_{bm,rqd,d}$ [N/mm^2]	7,1	8,6	10,0	11,6	11,6	13,1	13,1	13,1	14,5
k_b [-]	1,0	1,0	1,0	1,0	0,89	0,90	0,82	0,76	0,79
$f_{bd,PIR}$ [N/mm²][*]	1,6	2,0	2,3	2,7	2,7	3,0	3,0	3,0	3,4

[*] *see footnote to Table A.1*

Example C: see Figure 2.4

Example C shows the determination of the design bond resistance in terms of the reduction factor k_b where the mean bond resistances $f_{bm,20}$ and $f_{bm,50}$ do not reach the required bond resistances $f_{bm,rqd}$ for C20/25 and C50/60.

Figure 2.4   Example C, required bond resistances for C20/25 and C50/60 are not reached

Table 2.4   Determination of k_b for example C

Concrete class	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck} [N/mm^2]	12	16	20	25	30	35	40	45	50
f_{bm} [N/mm^2]	-	-	7,9	9,1	10,3	11,5	12,7	13,9	15,1
$f_{bm,rqd}$ [N/mm²]	7,1	8,6	10,0	11,6	13,1	14,5	15,9	17,2	18,4
$f_{bm,rqd,d}$ [N/mm^2]	-	-	7,1	8,6	10,0	10,0	11,6	13,1	14,5
k_b [-]	-	-	0,71	0,74	0,76	0,69	0,73	0,76	0,79
$f_{bd,PIR}$ [N/mm²][*]	-	-	1,6	2,0	2,3	2,3	2,7	3,0	3,4

[*] *see footnote to Table A.1*

The ETA shall explain the use of the reduction factor k_b for post-installed rebar:

$$f_{bd,PIR} = k_b \bullet f_{bd} \tag{2.9}$$

where

$f_{bd,PIR}$ = design bond strength of post-installed rebar

f_{bd} = design bond strength of cast-in rebar according to EN 1992-1-1

2.2.3 Amplification factor for minimum anchorage length

Test series 3 to 6

Purpose of the test

For post-installed rebar the minimum anchorage length $l_{b,min}$ and minimum lap length $l_{0,min}$ given in EN 1992-1-1 [1] for anchorages and overlap splices, respectively, shall be multiplied by an amplification factor α_{lb} to account for a difference in the performance between cast-in place and post-installed rebar in cracked concrete.

Cast-in place and post-installed rebars may show a different behaviour in cracked concrete. To account for this difference the minimum anchorage length and minimum splice length given in EN 1992-1-1 shall be multiplied by the amplification factor α_{lb}.

Investigations have shown that the bond resistance of cast-in-place rebar in cracked concrete is about 75% of the value valid for uncracked concrete [9]. For post-installed rebar the bond resistance in cracked concrete is about 50% of the value in uncracked concrete. For certain post-installed rebar systems, however, the influence of cracks on the bond resistance may be smaller. Therefore the increase in the minimum bond length for anchorages or overlap splices may be smaller or omitted at all under certain conditions.

Test procedure

The amplification factor α_{lb} may be determined through testing in cracked concrete (optional). The tension tests shall be performed in cracked concrete C20/25 and C50/60 ($\Delta w = 0,3$ mm) with an setting depth of the bar of $\ell_v = 10\ \phi$. The crack shall be constant throughout the member thickness. It shall be ensured (e.g. by an endoscope) that the crack runs throughout the whole setting depth. The tension tests shall be performed with a rebar diameter of $\phi = 12$ mm and $\phi = \phi_{max}$.

Assessment

If no tests according to Table A.1 line 3 in cracked concrete were performed, the following default levels for the amplification factor α_{lb} shall be used:

$\alpha_{lb} = 1,5$

$\alpha_{lb} = 1,0$ only if the bond strength in uncracked concrete is by a factor of 1,5 larger than the required bond resistance for post-installed rebar $f_{bm,rqd}$ as given in Table A.1 for low and high strength concrete, i.e. $f_{bm,20} > 15,0$ N/mm^2 and $f_{bm,50} > 27,6$ N/mm^2.

For the results of the tests performed in cracked concrete according to 2.2.3 the following assessment applies to determine the amplification factor α_{lb}.

The mean bond resistance in cracked concrete C20/25 and C50/60 is determined according to equation (A.2) resulting in $f_{bm,cr,t,20}$ and $f_{bm,cr,t,50}$, respectively. Using the same approach as in 2.2.2 b) the mean bond resistance in cracked concrete $f_{bm,cr,t}$ for intermediate concrete strength classes is calculated using linear interpolation (based on the concrete cylinder strength).

For each concrete strength class the required bond strength in cracked concrete shall be determined according to equation (2.10).

$$f_{bm,cr,rqd} = \frac{0,75 \cdot f_{bm,rqd,d}}{\beta_{cv} \cdot \min \dfrac{\alpha}{rqd.\alpha} \cdot \min \dfrac{\alpha_4}{rqd.\alpha_4}} \tag{2.10}$$

The amplification factor α_{lb} for each concrete strength class shall be calculated as given in equation (2.11) and rounded to the nearest tenth (meaning a factor 1,32 will be rounded to 1,3 and a factor 1,38 will be rounded to 1,4).

$$\alpha_{lb} = \frac{f_{bm,cr,rqd}}{f_{bm,cr,t}} \geq 1,0 \tag{2.11}$$

The ETA shall explain the use of the minimum anchorage length and minimum lap length of post-installed rebar:

Minimum anchorage length

$l_{bd,PIR} = \alpha_{lb} \bullet l_{b,min}$

$l_{b,min}$ – minimum anchorage length of cast-in rebar according to EN 1992-1-1

Minimum lap length

$l_{0,PIR} = \alpha_{lb} \bullet l_{0,min}$ *(minimum lap length)*

$l_{0,min}$ – minimum lap length of cast-in rebar according to EN 1992-1-1

2.2.4 Bond strength at increased temperature (test series 18)

Purpose of the test

The tests are intended to determine resistance to fire of the post-installed rebar connection with mortar. The assessment of resistance to fire is optional.

Test procedure

Test members

The tests are performed in uncracked concrete C20/25. The concrete used for testing shall comply with EN 206 and meet the requirements of Technical Report TR 048. The test setup is specified in Figure 2.5. Splitting of the concrete shall be prevented. Spalling of concrete shall not occur during the heating.

Dry concrete is required therefore concrete shall be dried before testing. (e.g. keep cylinders under indoor ambient conditions at least 3 months before testing, or store at maximum +80°C until constant weight).

Installation

Drill and clean the hole, inject the mortar and insert the rebar at normal ambient temperature in accordance with the MPII. The diameter of the rebar ϕ shall be equal to 12 mm. The embedment depth of the rebar shall be equal to 120 mm.

Two type K thermocouples (TC1 and TC2) shall be positioned along the rebar at 10 mm from the concrete surface for TC1 and at the bottom of the rebar (120 mm below the concrete surface) for TC2. To ensure accuracy on the position of the thermocouples, TC1 and TC2 shall be positioned on the rebar before installation. Figure 2.5 presents the test member during thermal and mechanical loading.
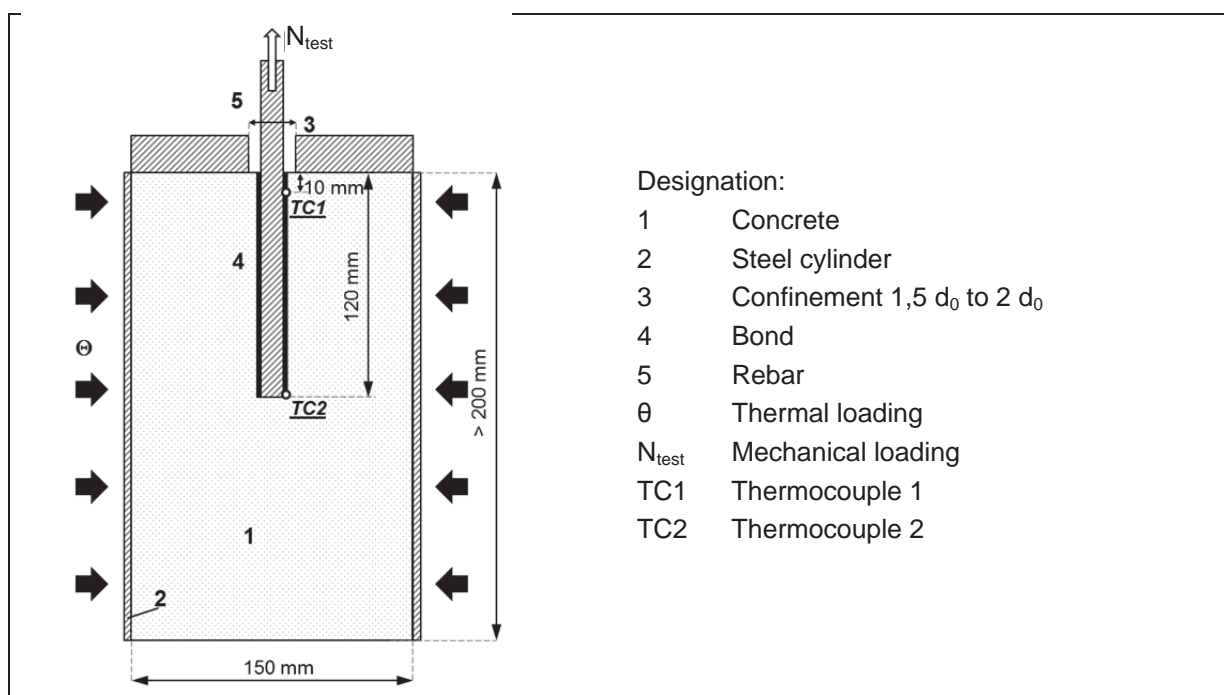
Figure 2.5   Test member during thermal and mechanical loading

Designation:
1   Concrete
2   Steel cylinder
3   Confinement $1,5\,d_0$ to $2\,d_0$
4   Bond
5   Rebar
θ   Thermal loading
N_{test} Mechanical loading
TC1   Thermocouple 1
TC2   Thermocouple 2

General description of the test

The tests shall be performed within 2 weeks after the specified minimum curing time of the mortar (bonding material) has been reached. During this time period the test specimen shall be stored at normal ambient temperature. Position the member inside the test device. Apply a constant tension load N_{test} (see below for load levels) on the rebar and maintain the load throughout the duration of the test. Ensure that the load is kept constant (no minus tolerance); a servo controlled hydraulic jack with load control or dead load are suitable. The tension load is applied using a confined test setup to avoid concrete cone failure according to TR 048 [4] Figure 3.4. Apply thermal loading on the lateral sides of the concrete cylinder to heat up the concrete member at a minimum rate of 5°C/min, while maintaining the load N_{test}. Heating shall be continuously applied until pull-out of the rebar occurs (caused by the increase of the temperature of the mortar).

The measurement of the load N_{test} and of the temperatures of the bond (at TC1 and TC2) shall be recorded continuously during the heating test until pull-out occurs. Additionally the temperatures of the oven shall be recorded during the test.

> Note 2:   test setup with pull-out tests at stabilized temperature are under investigation at the time of elaboration of this EAD. Pre-tests show that the test results are not conservative and research is being performed how to show the relationship.

The time of pull-out of the rebar shall be determined by the drop of load indicating failure and shall be recorded. The failure temperature $\theta_{failure}$ is calculated as the weighted average of the TC1 and TC2 temperatures when the pull-out occurs. The weighted average $\theta_{failure}$ is calculated as 1/3 of the higher measured temperature and 2/3 of the lower measured temperature. For each test, the failure temperature $\theta_{failure}$ is associated to the load N_{test} and corresponding bond stress $f_{b,t}$.

Thermal requirements

The main thermal flux shall be oriented towards the lateral side of the concrete cylinder. The non-bonded part of the rebar shall not be directly exposed to the heat source. This may be achieved by protecting the rebar with thermal insulating material.

The temperature of the oven shall be chosen to ensure the test duration of less than 3 hours in order to prevent excessive post curing of the mortar. Repeatability of the test procedure shall be ensured by using the same temperature increase of the oven for every test.

For average measured temperatures at the surface of the rebar between 21 °C and ≤ 50 °C, the difference between the temperatures of TC1 and TC2 shall not exceed 10°C.

> *Note 3:   At temperatures higher than 50 °C at the locations TC1 and TC2 water vaporization at the outer layers of the concrete specimen (close to the encasing steel cylinder) can lead to temperature differences between TC1 and TC2 that can be higher than 10°C.*

Load values

A minimum number of 20 tests shall be carried out. The tests shall be performed at different load levels. For each applied load N_{test} the corresponding bond stress $f_{b,t}$ is calculated according to equation (A.2), with N_{test} and $f_{b,t}$ replacing $N_{u,fc,m}$ and $f_{bm,t}$, respectively. The load levels shall be selected to ensure

a) a maximum difference of the applied bond stress $f_{b,t}$ between two neighbouring data points in the interval [1 N/mm^2; $f_{bm(21°C)}$] of ≤ 1 N/mm^2 and

b) a maximum difference of two neighbouring failure temperatures $\theta_{failure}$ of ≤ 50 °C; and

c) that the resulting fitting curve in the assessment provides the bond resistance at ambient temperature of ≥ $f_{bm,rqd.}$

The confined pull-out tests at ambient temperature shall be carried out.

Figure 2.6 presents an example of the loads in terms of bond stress $f_{b,t}$ that may be used to establish the bond resistance vs. temperature relationship in the case of $f_{bm(21°C)} > 10$ N/mm².

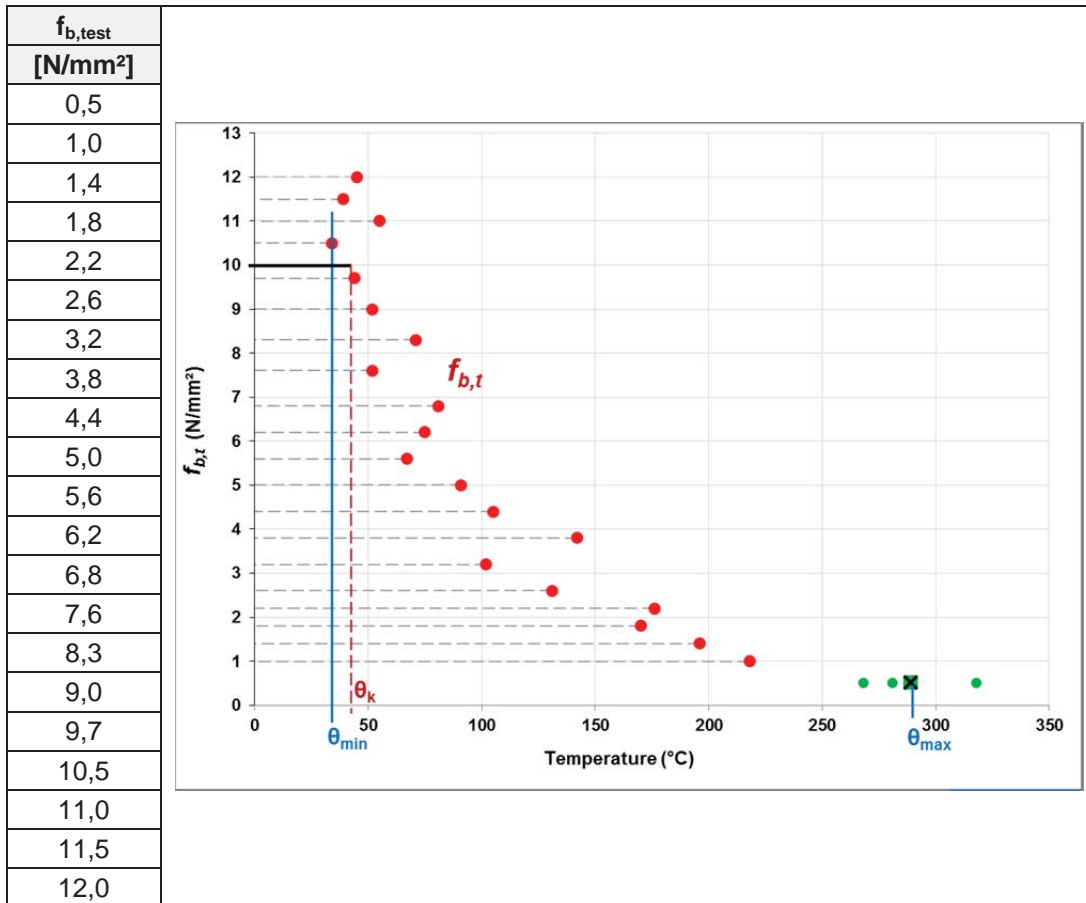| $f_{b,test}$ [N/mm²] |
|---|
| 0,5 |
| 1,0 |
| 1,4 |
| 1,8 |
| 2,2 |
| 2,6 |
| 3,2 |
| 3,8 |
| 4,4 |
| 5,0 |
| 5,6 |
| 6,2 |
| 6,8 |
| 7,6 |
| 8,3 |
| 9,0 |
| 9,7 |
| 10,5 |
| 11,0 |
| 11,5 |
| 12,0 |

Figure 2.6   Example for bond stress $f_{b,t}$ vs. temperature at failure θ

Assessment of test results

Fitting curve

a) If $f_{bm(21°C)} \geq 10$ N/mm², plot the variation of bond resistance vs. temperature. Determine the mean bond resistance f_{bm} with a best fitting trend function (exponential or power function are recommended; as an example exponential function is given in Equation (2.12)) using the least square fitting method. For low temperatures the fitting curve is cut to 10 N/mm². No extrapolation of the fitting curve shall be done beyond maximal temperatures θ_{max} measured during the tests.

b) If $f_{bm(21°C)} < 10$ N/mm², add the 3 bond resistances measured at 21 °C to the bond resistance vs. temperature plot established with the high temperature tests. Determine the mean bond resistance f_{bm} with a trend function (exponential or power function are recommended; as an example exponential function is given in Equation (2.12)) using the least square fitting method. For low temperatures the fitting curve is cut to $f_{bm,rqd}$ of concrete strength class C20/25. No extrapolation of the fitting curve shall be done beyond the maximal temperature θ_{max} measured during the tests.

$$f_{bm(\theta)} = a \cdot e^{-b \cdot \theta} \left[N/mm^2 \right] \tag{2.12}$$

The coefficient of variation cv shall be calculated as the relative deviation from the fitting curve according to equation (2.13).

$$cv = \sqrt{\frac{1}{n_{test} - 1} \sum_{i=1}^{n_{test}} \left(\frac{f_{b,t,i}}{f_{bm}(\theta_i)} - 1 \right)^2} \tag{2.13}$$

The coefficient of variation shall be cv ≤ 45 %. Increase of number of tests is allowed for better representation of the behaviour of the product

Figure 2.7 presents an example of the $f_{bm}(\theta)$ exponential curve fitted to the test data in the case where $f_{bm(21°C)} > 10$ N/mm².
The function may be chosen for best fit to test results:
Requirements for the chosen function

- No negative bond strength
- No increase of bond strength at high temperature
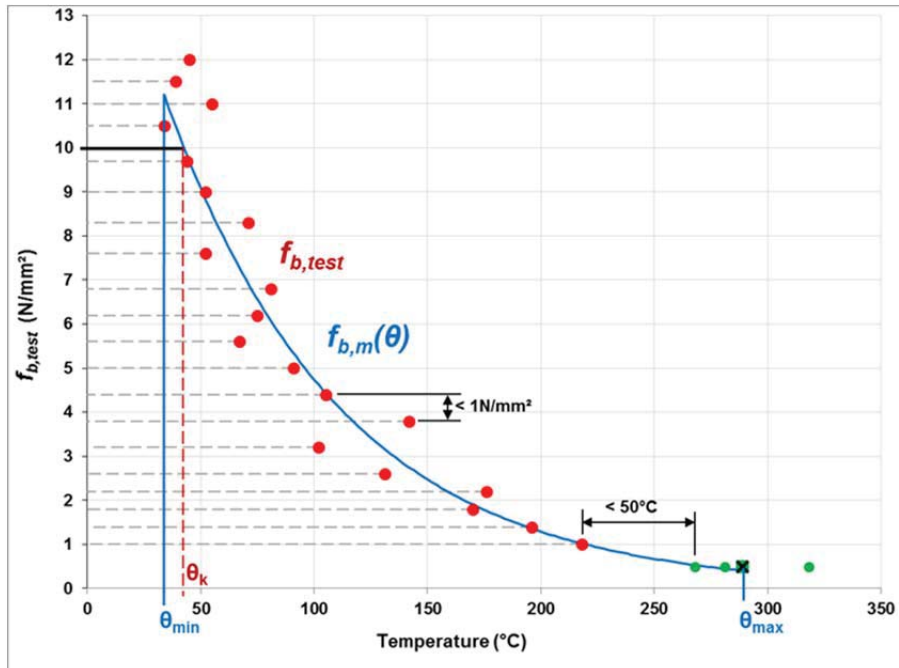- No overestimation at high temperature

Figure 2.7   Example for determination of bond strength f$_{bm}$ as a function of temperature θ

Temperature reduction factor

The temperature reduction factor k$_{fi}$(θ) shall be determined according to the following equations:

$$k_{fi}(\theta) = f_{bm}(\theta)/(f_{bd,PIR} \cdot 4,3) \leq 1,0 \quad \text{for } 21 \text{ °C} \leq \theta \leq \theta_{max} \tag{2.14}$$

$$k_{fi}(\theta) = 0 \qquad\qquad \text{for} \quad \theta > \theta_{max} \tag{2.15}$$

No extrapolation on test temperatures is allowed. For temperatures higher than the maximal measured temperature during the tests (θ$_{max}$), the reduction factor k$_{fi}$(θ) is equal to zero.

Figure 2.8 presents an example of the temperature reduction factor k$_{fi}$(θ) in the case where f$_{bm(21°C)}$ > 10 N/mm². In this figure θ$_k$ is the temperature up to which the mortar maintains the full capacity.
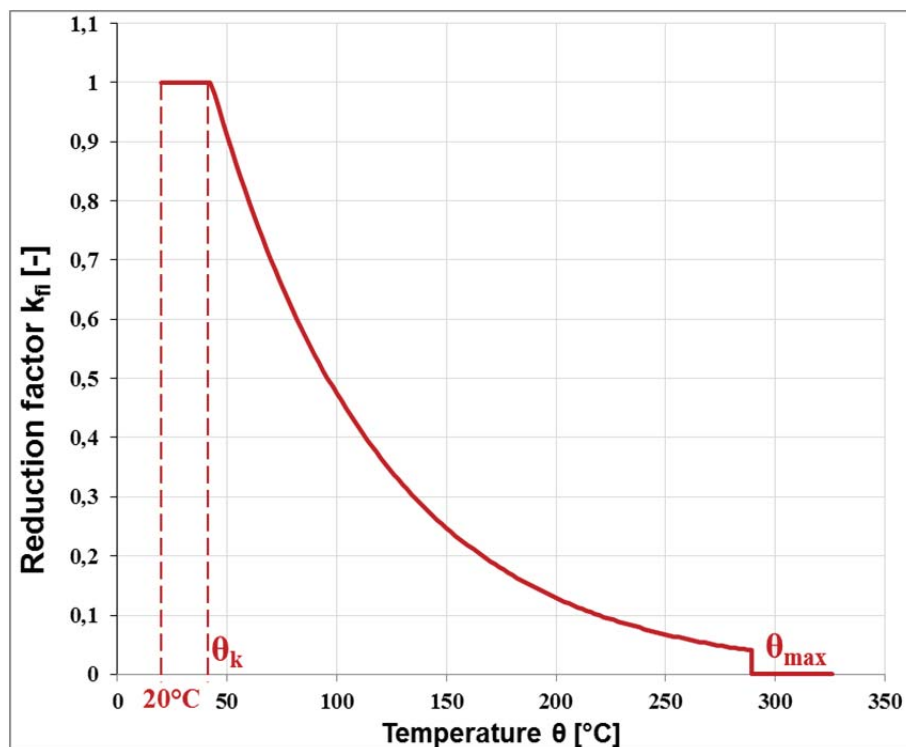
Figure 2.8   Example of the graph of reduction factor $k_{fi}(\theta)$ for concrete strength class C20/25 for good bond conditions

Test report

As a minimum requirement, the test report shall include at least the following information:

- The plots presenting the evolutions of the oven temperature, TC1 temperature, TC2 temperature and sustained load during the heating for each test.
- The test duration and the temperatures θ_{TC1} and θ_{TC2} at failure).
- If $f_{bm(21°C)} < 10$ N/mm², the bond resistances measured from the 3 tension tests performed at ambient temperature;
- The general data and information on test members, rebar installation and testing equipment described in Technical Report TR 048.

Evaluation report

As a minimum requirement, the evaluation report shall include at least the following information:
- The plot presenting bond stress vs. temperature with the exponential fitting curve and the analytic equation of the fitting curve.
- The plot of the temperature reduction factor $k_{fi}(\theta)$ and the analytic equations that describe the variation of $k_{fi}(\theta)$ with temperature.
- The general data and information on test members, rebar installation and testing equipment described in Technical Report TR 048.

ETA content

As a minimum requirement, the ETA shall include at least the following information:
- The plot of the temperature reduction factor $k_{fi}(\theta)$ and the analytic equations that describe the variation of $k_{fi}(\theta)$ with temperature.
- $f_{bk,fi}(\theta) = k_{fi}(\theta) \cdot f_{bd,PIR} \cdot \gamma_c / \gamma_{M,fi}$
- Reduction $k_{fi}(\theta)$ as a function of temperature
- limited by 1,0 and
- Temperature θ_{max} as determined in Figure 2.8.

The anchorage length shall be determined in accordance with EN 1992-1-1 [1] equation (8.3) using the bond strength $f_{bk,fi}(\theta)$.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is: Decision 1996/582/EC

The system is: 1

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.1.

Table 3.1 gives guidance; the control plan depends on the individual manufacturing process and has to be established between TAB and manufacturer for each product.

Table 3.1   Control plan for the manufacturer; corner stones

No	Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method *(refer to 2.2 or 3.4)*	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) **[including testing of samples taken at the factory in accordance with a prescribed test plan]***					
1	Batch number and expiry date	visual check	Laid down in control plan	1	Each batch
2	Components	check material and the mass of components acc. to recipe			
3	Specific gravity / Density	Standardized method proposed by the manufacturer			Every shift or 8 hours of production per machine
4	Viscosity				
5	Reactivity (gel time, where relevant: max. reaction temperature, time to max reaction temperature)				Each batch
6	Properties of raw material	(e.g. by infrared analysis)			initial testing and each change of batch
7	Performance of the cured bonding material	(e.g. tension test to failure)		3	Each batch

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for systems for post-installed rebar connections with mortar are laid down in Table 3.2.

Table 3.2   Control plan for the notified body; corner stones

No	Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method *(refer to 2.2 or 3.4)*	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control *(for systems 1+, 1 and 2+ only)*					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the mortar		Laid down in control-plan		1
Continuous surveillance, assessment and evaluation of factory production control *(for systems 1+, 1 and 2+ only)*					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan		Laid down in control-plan		1/year

4   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]	EN 1992-1-1:2004 + AC 2010, EC 2	Design of concrete structures – Part 1-1: General rules and rules for buildings
[2]	EN 1992-1-2:2004 + AC 2008, EC 2	Design of concrete structures - Part 1-2: General rules - Structural fire design
[3]	EN 206:2013 + A1:2016	Concrete - Specification, performance, production and conformity
[4]	EOTA TR 048	Details of tests for post-installed fasteners in concrete", August 2016
[5]	EOTA EAD 330499	Bonded fasteners for use in concrete
[6]	EN 10088-1:2014	Stainless steels - Part 1: List of stainless steels
[7]	EN 10088-3:2014	Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes
[8]	ISO 6988:1997	Metallic and other non-organic coatings - Sulfur dioxide test with general condensation of moisture
[9]	Spieth, H.A.	Tragverhalten und Bemessung von eingemörtelten Bewehrungsstäben (Behavior and Design of Post-installed Bonded Rebar Connections), Dissertation, Universität Stuttgart, 2002 (German)
[10]	EN ISO 15630-1:2010	Steel for the reinforcement and prestressing of concrete - Test methods - Part 1: Reinforcing bars, wire rod and wire (ISO 15630-1:2010)
[11]	EN 13501-1:2017	Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests

A   ANNEX   TEST PROGRAM AND GENERAL ASPECTS OF ASSESSMENT

A1   TEST PROGRAM

As far as applicable Technical Report TR 048 [4]shall be followed for test members, test setup and details of tests. Modifications are addressed in section 2.2.1, which overrule conflicting provisions in Technical Report TR 048.

If the temperature is not specified for a test series, normal ambient temperature (21 °C ± 3 °C) of the concrete member during the tests applies.

The required tests are given in Table A.1 as an overview. All tension tests shall be performed with confined test setup according to Technical Report TR 48. The members shall be chosen such that splitting of the concrete is avoided (e.g. dimensions of member, steel encased concrete cylinder).

All mandatory tests are done with deformed rebar with properties according to Annex C of EN 1992-1-1 [1] with $f_{yk} \geq 500$ N/mm² and a relative rib area f_R between 0,05 and 0,10 in uncracked concrete C20/25 and C50/60. For the optional test series (Table A.1 line 3) cracked concrete is to be used. Deformed rebar with the same geometrical properties made of steel with higher strength may be used for the tests (except for the test series according to Table A.1 line 17).

In all tests the holes are drilled with the diameter $d_{cut,m}$ according to the specifications of the manufacturer. The holes are cleaned according to the MPII with the cleaning equipment specified by the manufacturer. Exceptions see "sensitivity to hole cleaning" tests according to Table A.1 lines 7 and 8. The mortar and the rebar are installed according to the MPII with the equipment specified in the MPII.

Installation in water-filled hole is not covered by this EAD.

The tests shall be done using each drilling method applied for by the manufacturer. However, if the tests are done using hammer drilling, the results of the tests can also be used for compressed air drilling or rock drilling.

The tests shall be performed within 5 days after the specified minimum curing time of the mortar has been reached unless specified differently in the following sections.

Some test series and corresponding assessment of post-installed reinforcing bars are identical with the assessment methods for bonded fasteners. The assessment of bonded fasteners is given in EAD 330499. As far as applicable product characteristics which are already determined in accordance with EAD 330499 can be used and the relevant test series need not be repeated.

Table A.1   Test program for post-installed rebar connections

Line	Purpose of test	Concrete strength class [1]	Rebar size [2] ϕ [mm]	Setting depth [3] l_v [mm]	Minimum number of tests	Criteria	Test procedure / assessment
Basic tension tests							
1	Reference tension tests in uncracked concrete	C20/25	all[10]	10 ϕ	5 each	$f_{bm} \geq 7{,}1$ [N/mm²] [14]	2.2.1.1
2		C50/60	ϕ_{max}	7 ϕ	5		
3	Reference tension tests in cracked concrete ($\Delta w = 0{,}3$ mm) [4]	C20/25	12	10 ϕ	5	-	2.2.2
4			ϕ_{max}		5		
5		C50/60	12	7 ϕ	5		
6			ϕ_{max}		5		

Line	Purpose of test	Concrete strength class [1]	Rebar size [2] ϕ [mm]	Setting depth [3] l_v [mm]	Minimum number of tests	Criteria	Test procedure / assessment
Functioning under tension load with respect to							
7	Robustness in dry concrete [5] [10]	C20/25	s/m/l	10 ϕ	5 each	rqd. α $\geq$ 0,8	2.2.1.2
8	Robustness in wet concrete [6] [10]	C20/25	s/m/l	10 ϕ	5 each	rqd. α $\geq$ 0,75	2.2.1.3
9	Installation at minimum installation temperature [15]	C20/25	ϕ_{max}	max l_v	3		2.2.1.4
10	Installation at maximum installation temperature	C20/25	ϕ_{max}	max l_v	3		2.2.1.4
11	Correct injection	-	ϕ_{max}	max l_v	3		2.2.1.5
12	Vertical upwards installation direction [7] [13]	C20/25	ϕ_{max}	10 ϕ	5	rqd.α $\geq$ 0,9	2.2.1.6
13	Horizontal installation direction [8]	C20/25	ϕ_{max}	10 ϕ	5	rqd.α $\geq$ 0,9	
14	Sustained loads [9] [13]	C20/25	12	10 ϕ	5	rqd.α $\geq$ 0,9	2.2.1.7
15	Freeze/thaw conditions [13]	C50/60	12	7 ϕ	5	rqd.α $\geq$ 0,9	2.2.1.8
16	High alkalinity and sulphurous atmosphere [13]	C20/25	12[11]	-	3 x 10		2.2.1.9
17	Corrosion resistance of rebar [12]	C20/25	12	70 mm	3		2.2.1.10
Resistance to fire							
18	Bond strength at increased temperature [4] [9]	C20/25	12	10 ϕ	20		2.2.4

[1] All tests performed in uncracked concrete except test series line 3-6.
[2] Diameter of the rebar ϕ; ϕ_{max} = maximum diameter of the rebar specified by the manufacturer;
[3] 10 ϕ and 7 ϕ shall be reduced in case of steel failure mode. The reduction shall be the same in all test series. It is the objective of these tests to determine bond resistance.
[4] This test series is optional.
[5] This test series may be omitted if no cleaning is specified in the MPII.
[6] Test series may be omitted if no cleaning is specified in the MPII for mortars based on cement only.
[7] This test series may be omitted if this installation direction is excluded in the MPII.
[8] This test series may be omitted if only downward installation is allowed in the MPII.
[9] If more than one drilling diameter is given in the MPII for the same rebar diameter, drilling shall be done with the largest drilling diameter.
[10] The test series may be omitted if the assessment for this aspect is taken from assessment acc. to ETAG 001-5 with TR 023.
[11] This test series may be performed with threaded rods of size M12. High alkalinity tests are not required for mortars based on cement only.
[12] No proof of the corrosion resistance of the rebar is needed if post-installed rebar is used in building components in dry surroundings according to exposure class X0 and XC1 of EN 1992-1-1. Also no proof is needed when only corrosion resistant rebar is specified for all application.
[13] The test series may be omitted if the assessment for this aspect ~~and rebar diameter~~ is taken from assessment acc. to EAD 330499.
[14] The requirement accounts for the lowest concrete strength class C12/15 in accordance with EN 1992-1-1 [1] (see also 2.2.1 of this EAD)
[15] The test series 9 may be omitted for minimum installation temperature > 0°C and minimum mortar temperature ≥5°C.

For certain test series according to Table A.1 a reduced range of tested sizes, indicated by "s/m/l" may be used. The number of diameters to be tested in this case depends on the number of requested sizes and is given in Table A.2.

Table A.2   Reduced range of tested sizes

Number of requested sizes	Numbers of diameters to be tested
≤ 5	3
6 to 8	4
9 to 11	5

A2   PROVISIONS FOR ALL TEST SERIES

As far as applicable the Technical Report 048 shall be followed with respect to the test members, test setup and performance of the tests. Modifications are addressed in the following sections, which overrule conflicting provisions in the Technical Report 048.

It is recommended that handling of tests and calibration items are performed in accordance with EN ISO/IEC 17025 [13].

To avoid "steel failure" in the tests rebar of a higher strength may be used as long as the functioning is not influenced. This condition is fulfilled if the geometry of the rebar of higher strength steel is identical with the specified rebar.

In cases where the use of high strength rebar is insufficient to prevent "steel failure" the embedment depth shall be reduced. This principle may overrule the required embedment depth given in Table A.1 except for the test series concerning sensitivity to installation (Table A.1 lines 7 and 8). To avoid steel failure in the tests with maximum embedment depth for injection type systems or nominal embedment depth for capsule type systems the following test procedure may be employed.

For the robustness tests (test series according to Table A.1, lines 7 and 8) larger embedment length for the cleaning procedure is required. For these tests use a test member consisting of two concrete blocks A and B stacked on the top of each other without a permanent connection as shown in Figure A.1 a). Drill the hole in accordance with the procedures described in the MPII. Clean the hole as described below for the specific test. Install the bonding material and the element (for capsule type systems) or the bonding material only (for injection type systems) in each case in accordance with the MPII with the equipment supplied by the manufacturer as shown in Figure A.1 b). Remove the upper block A and for injection type systems install the metal part (Figure A.1 c)). After curing perform the confined tension test. In this context $h_{ef,red}$ represents the reduced embedment, for which steel yielding of a high strength metal part is just avoided. For capsule type systems the test setup shall be adapted accordingly.
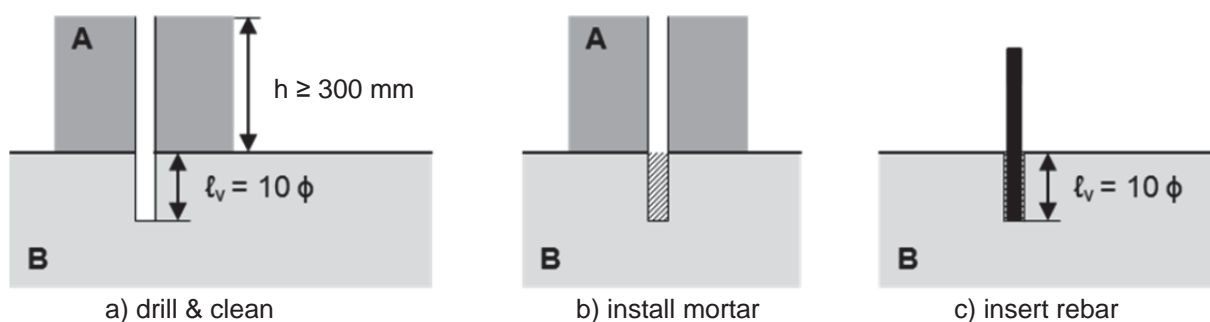

a) drill & clean   b) install mortar   c) insert rebar

Figure A.1   Test set up to avoid steel failure

Reference tension tests shall be performed because they are needed for the evaluation of the results of the test series for resistance to pull-out failure and to take account of the influence of certain parameters on the resistance of bonded fasteners to tension load. They shall be made in each batch. All reference tests shall be carried out as follows:

- in dry concrete
- at normal ambient temperature (T = + 21° C ± 3 °C)
- installation in accordance with the manufacturer's published instructions
- as confined test; they shall be made at approximately the same curing time as the corresponding tests.

The reference tests should be made in the same concrete batch as the tests to which they shall be compared. The reference tests shall be made in uncracked concrete (cracked concrete: Δw = 0,3 mm), if their results shall be compared with results of tests in uncracked concrete (cracked concrete).

It is necessary to carry out at least 5 reference tests in each test series for each concrete batch. The coefficient of variation of the failure loads in one (each) test series of reference tests shall meet the same requirement as for service condition tests. Hence, the number of reference tests may need to be increased until the coefficient of variation meets the requirement.

If the assessment covers more than one drilling technique, all tests shall be done with all drilling techniques. If different sizes of packages, types of nozzles and dispensers will be used for one system, equal mixing of the bonding material components must be proven for all sizes of the packages and with all admissible types of nozzles and dispensers both for coaxial and shuttle cartridges.

A2.1 Installation

The fastener shall be installed in accordance with the MPII.

A2.2 Concrete strength and concrete age

The tests are performed for the assessment in "low strength concrete C20/25" and "high strength concrete C50/60". Therefore the concrete strength at the time of testing the fasteners shall be within the following limits:

C20/25: $25 \leq f_{c,cube} \leq 35$ [N/mm²]

C50/60: $60 \leq f_{c,cube} \leq 70$ [N/mm²]

The concrete test member shall be at least 21 days old at the time of installation of the fastener and testing.

A2.3 Assessment of the failure mode

The test lab shall identify and report the initial failure mode for any test:

Tension tests:
- splitting (sp) – test condition for tests in uncracked concrete in case when a first crack of the concrete is observed
- bond failure between element and bonding material (be)
- bond failure between bonding material and bore hole (bb) (mixed bond failure between element and bonding material as well as between bonding material and bore hole (bbe) may occur)
- steel failure (s)

A2.4 Conversion of failure loads to nominal strength

The failure loads shall be converted as follows:

$$N_{u,fc} = N_{u,t} \, (f_{ck} / f_{c,t})^m \tag{A.1}$$

For pullout failure m = 0,3 may be taken as a default value. Lower values shall be determined by comparison of test results in low strength and high strength concrete for diameters ϕ_{min}, 12 mm and ϕ_{max}.

A2.5 Mean bond resistance

The mean bond resistance for each tension test series according to Table A.1 lines 1 to 8, 12 to 15 and 18 is calculated from the results of the tension tests according to equation (A.2).

$$f_{bm,t} = \frac{N_{u,fc,m}}{\pi \cdot \phi \cdot l_v} \cdot \left(\frac{0,08}{f_R} \right)^{0,4} \qquad\qquad (A.2)$$

The parameter $N_{u,fc,m}$ is the mean value of the failure loads $N_{u,fc}$ in the test series. The failure (peak) load $N_{u,fc}$ of an individual test is determined as follows taking into account the limiting displacement δ_1 as given in Table A.3:

- If the peak load is reached at a displacement $\delta \leq \delta_1$, the peak load shall be used as failure load for the determination of $N_{u,fc,m}$.
- If the peak load is reached at a displacement $\delta > \delta_1$, use the load at δ_1 as failure load.
- Convert the failure load to the nominal strength (C20/25 or C50/60 depending on the test series) in accordance with A2.4.

Table A.3   Limiting displacement δ_1

ϕ [mm]	δ_1 [mm]
< 25	1,5
25 to 40	2,0
> 40	3,0

Note 4:   The limiting displacements $\delta 1$ are derived in [9].
Note 5:   The displacements $\delta 1$ are the mean values of a cast-in rebar at peak load. If peak load is reached at a displacement $\delta > \delta 1$, the deformation of the post-installed rebar is larger than for a cast-in rebar and the basic assumptions (Bernoulli hypothesis) for the design.

A2.6 Criteria for bond strength

If the system has been assessed for use of rebar as fastener according to EAD 330499 these results may be used for assessment of post-installed rebar taking into account all relevant reduction factors and the required stress level.

The bond strength of the post-installed rebar system as assessed in section 2.2.1.1 to 2.2.1.10 shall be compared to the values given in Table A.4. Tests in which steel failure or steel yielding is observed shall not be considered for the assessment.

Table A.4   Bond strength of cast-in rebar

Concrete strength class	Bond strength $f_{bm,rqd}$ [N/mm^2]	Design value of the ultimate bond stress according to EN 1992-1-1 [**]f_{bd} [N/mm²]
C12/15	7,1	1,6
C16/20	8,6	2,0
C20/25	**10,0**	2,3
C25/30	11,6	2,7
C30/37	13,1	3,0
C35/45	14,5	3,4
C40/50	15,9	3,7
C45/55	17,2	4,0
C50/60	**18,4**	4,3

**) Design values for the ultimate bond stress, f_{bd}, for ribbed bars (rebars) are determined based on Nationally Determined Parameters given in the National annex; the recommended values given here are calculated using equation (8.2) in clause 8.4.2 of EN 1992-1-1 [1], i.e. $f_{bd} = 2,25\,\eta_1\,\eta_2\,f_{ctd}$, inserting the recommended basic values for η_1, α_{ct} and γ_c given in EN 1992-1-1 as well as $\eta_2 = 1$.

Note 6:   The bond strength $f_{bm,rqd}$ is based on large number of tests with cast-in-place rebar following the test regime of Table A.1 lines 1 and 2 and using concrete mixed according Technical Report TR 048.

Note 7:   The bond strength $f_{bm,rqd}$ is based on the design value of ultimate bond stress according to EN 1992-1-1 [1]. According to [9] the value includes the following increasing factors taking into account the recommended material safety factor for concrete ($\gamma_{Mc} = 1,5$), the ratio of mean value to 5% fractile (1/0,75), the effect of uncracked concrete to bond in cracked concrete (1/0,75), the effect of large edge distance and spacing (1/0,7), and the influence of distribution of bond stress for short embedment as used in tests to long embedment (40 ϕ) according to EN 1992-1-1 [1] (1/0,8). The requirement given in Table A.1 line 1 corresponds to for the lowest concrete strength class C12/15 according to EN 1992-1-1.

A2.7   Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any test series according to Table A.1 lines 1, 2 and 3 exceeds 15% and is not larger than 20%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 15)} \leq 1{,}0 \tag{A.3}$$

If the coefficient of variation of the failure load in any test series according to Table A.1 lines 7, 8, 12 to 15 exceeds 20% and is not larger than 30%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 20)} \leq 1{,}0 \tag{A.4}$$

The smallest result min ß$_{cv}$ in any test shall be taken for assessment.

A2.8 Sustained loads

If the stress applied on the rebar τ_p during a test series according to Table A.1, lines 14 and 15 is smaller than the required load, the reduction factor α_p shall be taken into account in the assessment. The smallest value α_p in any of these test series applies.

$$\alpha_p = \frac{\tau_{p,t}}{\tau_p} \leq 1{,}0 \tag{A.5}$$

with

$\tau_{p,t}$ actual stress applied on the rebar in the respective test series

τ_p stress required for the respective test series

A2.9 Failure loads (reduction factors α)

For test series according to Table A.1 lines 7, 8 and 12 to 15 the mean failure loads shall be compared with the corresponding reference test series of basic tension test series according to Table A.1:

$$\alpha = F_{u,m,t} / F_{u,m,r} \leq 1{,}0 \tag{A.6}$$

A2.10 Loss of adhesion

With bonded fasteners uncontrolled slip occurs when the bonding material with the embedded part is pulled out of the drilled hole (because then the load displacement behaviour depends significantly on irregularities of the drilled hole). The corresponding load when uncontrolled slip starts is called load at loss of adhesion $N_{u,adh}$.

The load at loss of adhesion $N_{u,adh}$ shall be evaluated for every test from the measured load displacement curve. The load at loss of adhesion is characterised by a significant change of stiffness, see Figure A.2). If the change in stiffness at a defined load is not so obvious, e.g. the stiffness is smoothly decreasing, the load at loss of adhesion shall be evaluated as follows:

1) Compute the tangent to the load-displacement curve at a load $0{,}3\ N_u$ (N_u = peak load in test). The tangent stiffness can be taken as the secant stiffness between the points 0/0 and $0{,}3\ N_u/\delta_{0,3}$ ($\delta_{0,3}$: displacement at $N = 0{,}3\ N_u$).
2) Divide the tangent stiffness with a factor of 1,5.
3) Draw a line through the point 0/0 with the stiffness as calculated in 2).
4) The point of intersection between this line and the measured load-displacement curve gives the load $N_{u,adh}$ where the adhesion fails, see Figure A.3.
5) If there is a peak in the load-displacement curve, to the left side of this line, which is higher than the load at intersection, $N_{u,adh}$ is taken as the peak load, see
6) Figure A.4.
7) If there is a very stiff load-displacement curve at the beginning ($\delta_{0,3} \leq 0{,}05$mm) the drawing of the line for the calculation can be shifted to the point ($0{,}3\ N_u / \delta_{0,3}$), see Figure A.5.

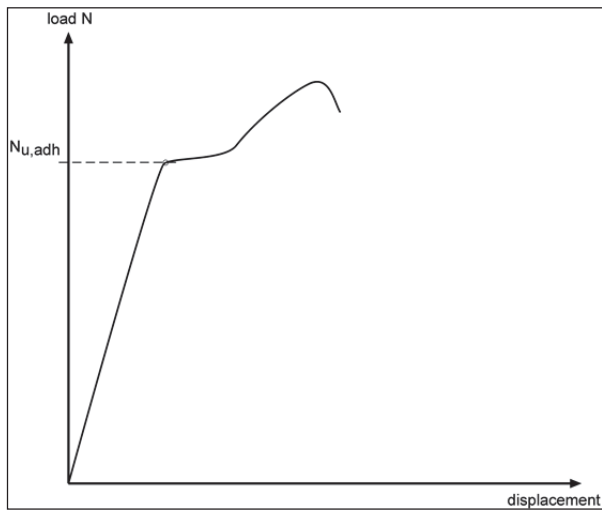**Examples of load-displacement curves**

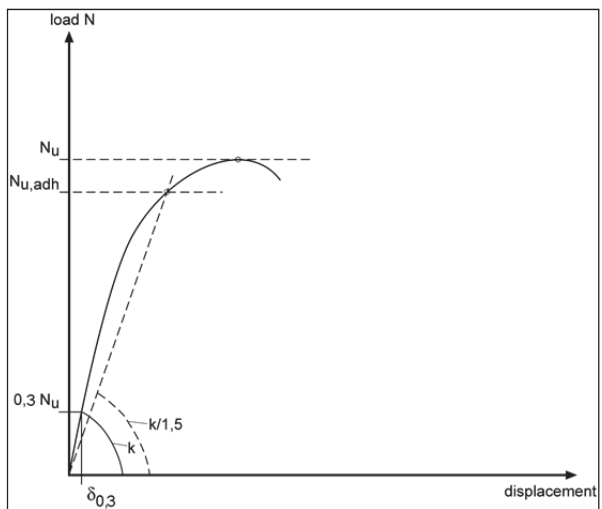**Figure A.2   Load at loss of adhesion by a significant change of stiffness**

Figure A.3   Evaluation of load at loss of adhesion

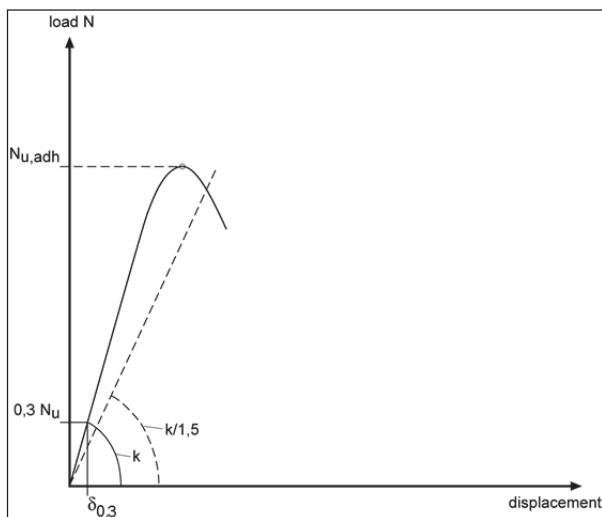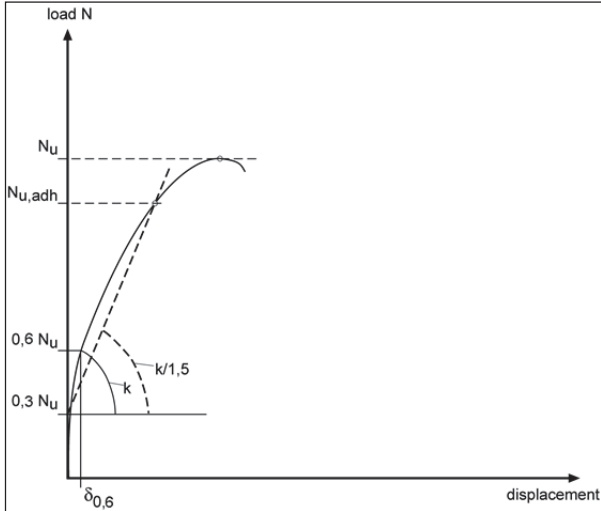**Figure A.4   Evaluation of load at loss of adhesion**

Figure A.5   Evaluation of load at loss of adhesion