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EAD **332402-00-0601**

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European Assessment Document for

Post-installed reinforcing bar (rebar) connections with improved bond-splitting behaviour

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 with improved bond-splitting behaviour. The system for post-installed rebar connections is composed of a mortar and an embedded straight deformed reinforcing bar with properties according to Annex C of EN 1992-1-1[1] [1].

This EAD covers post-installed rebar connections with improved bond-splitting behaviour with a mean bond strength, $f_{bm,20}$ and $f_{bm,50}$, $f_{bm,20,100y}$ and $f_{bm,50,100y}$ for all rebar sizes equal to or larger than 10 N/mm^2 for the concrete strength class C20/25 and equal to or larger than 18,4 N/mm^2 for the concrete strength class C50/60.

Note: Assessment methods to determine the mean bond strength are provided by EAD330087-01-0601 [3] clauses 2.2.1.11 and 2.2.1.12 (equations (2.6), (2.7), (2.8) and (2.9))

This EAD is applicable to products which exhibit a sufficiently steady load-displacement behaviour and for which the scatter in the tests does not exceed the following values:

- $cv_F \leq 20\%$ and $cv_\delta \leq 25\%$ (test series L1 to L9, G1 to G4 and P1 to P4 according to Annex A, Table A.1.1)

where cv_F is the coefficient of variation for loads and cv_δ is the coefficients of variation for displacements. This EAD does not cover post-installed rebar connections that do not fulfil the requirements above.

This EAD is applicable to post-installed rebar connections where the following conditions are fulfilled:

- Minimum concrete cover, c_{min}, as given in Table 1.1.1 and Table 1.1.2.
- Minimum clear spacing between two post-installed bars is a = 40 mm ≥ 4·ϕ.

Table 1.1.1 Minimum concrete cover, c_{min}

Drilling method	Bar diameter ϕ	c_{min}
Hammer drilling or diamond drilling	< 25 mm	max (30 mm + 0,06 l_b; 2·ϕ)
	≥ 25 mm	max (40 mm + 0,06 l_b; 2·ϕ)
Compressed air drilling	< 25 mm	max (50 mm + 0,08 l_b; 2·ϕ)
	≥ 25 mm	max (60 mm + 0,08 l_b; 2·ϕ)

The factors 0,06 and 0,08 in Table 1.1.1 take into account the possible inherent tolerances of the drilling process. These factors might be smaller if drilling aid devices (see Figure 1.1.1) are used. When using such a drilling aid device the minimum concrete cover may be reduced as given in Table 1.1.2.

Table 1.1.2 Minimum concrete cover, c_{min}, when using a drilling aid

Drilling method	Bar diameter ϕ	c_{min}
Hammer drilling or diamond drilling	< 25 mm	max (30 mm + 0,02 l_b; 2·ϕ)
	≥ 25 mm	max (40 mm + 0,02 l_b; 2·ϕ)
Compressed air drilling	< 25 mm	max (50 mm + 0,02 l_b; 2·ϕ)
	≥ 25 mm	max (60 mm + 0,02 l_b; 2·ϕ)

1 All undated references to standards or to EADs in this EAD are to be understood as references to the dated versions listed in chapter 4.

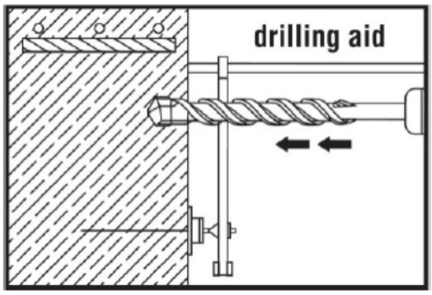


Figure 1.1.1 Example of drilling aid

The product is not covered by a harmonised European standard (hEN) and is not fully covered by the following harmonised technical specification:

- EAD 330499-01-0601 [2], because fasteners according to EAD 330499-01-0601 [2] have a different intended use regarding load directions and different essential characteristics and assessment methods due to different failure modes.
- EAD 330087-01-0601 [3], because it does not include an assessment method for the bond-splitting strength of post-installed rebar connections but only the equivalency to cast-in rebars is considered with limited bond strength. The construction product is the same in EAD 330087-01-0601 [3] and in EAD 332402-00-0601, but the intended uses are different.

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 of the construction product

1.2.1 Intended use

Post-installed rebar connections are intended to be used in reinforced or unreinforced normal weight, non-carbonated concrete without fibres C20/25 to C50/60 according to EN 206 [5] and which are allowed with straight deformed post-installed reinforcing bars (rebars) according to EOTA TR 069 [4].

The EAD applies for cracked and uncracked concrete.

Maximum allowable chloride contents of the concrete for the intended use according to EN 206 Table 15 [5] are

- Cl 0,20
- Cl 0,40

Post-installed rebar connections are intended to be applied in well compacted concrete.

Use in exposure classes according to EN 1992-1-1 [1] shall be as assessed in accordance with EAD 330087-01-0601 [3], clause 2.2.1.10.

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

This EAD provides assessment requirements resulting in performance characteristics consistent with and to be used in the design provisions of EOTA TR 069 [4].

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 $T_{st} \geq 40°C$.

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 connections for the intended use of 50 and/or 100 years[2] when installed in the works (provided that the post-installed rebar connections are subject to appropriate installation (see clause 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[3].

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

BET = Beam End Test

MPII = Manufacturer's Product Installation Instructions

1.3.2 Notation

A	=	Minimum rebar spacing
A_k	=	Characteristic fitting factor for equations (2.2.1.1.1) and (2.2.1.1.2)
A_{st}	=	Cross-sectional area of one stirrup leg
$c_{cr,N}$	=	Characteristic edge distance for concrete cone failure in tension
c_d	=	Minimum between clear concrete cover and half of the clear spacing from the closest neighbouring reinforcing bar
c_{min}	=	Minimum concrete cover
c_{max}	=	Maximum between clear concrete cover and half of the clear spacing from the closest neighbouring reinforcing bar
cv_F	=	Coefficient of variation of forces or bond strengths
cv_δ	=	Coefficient of variation of displacements
$d_{cut,m}$	=	Medium cutting diameter of drill bit, see clause B.2
En	=	Dissipated energy calculated as the area under the monotonic load-displacement curve or under the envelope of the cyclic curve

2 Based on the application of the manufacturer the assessment may be based on 50 years working life, or based on 100 years working life or both 50- and 100-years working life.

3 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}	=	Mean bond strength of the post-installed rebar connection
f_{ck}	=	Nominal cylinder strength of concrete according to EN 206 [5]
$f_{c,cube}$	=	Characteristic cube compressive strength of concrete
$f_{c,t}$	=	Concrete compressive cylinder strength of the test member
f_R	=	Relative rib area of tested rebar according to EN ISO 15630-1 [6]
f_{yk}	=	Characteristic tensile (yield) strength of reinforcement
$k_{cr,N}$	=	Factor for resistance to concrete failure in cracked concrete
$k_{ucr,N}$	=	Factor for resistance to concrete failure in uncracked concrete
k_m	=	Factor for the effectiveness of transverse reinforcement
k_s	=	Factor for the determination of the 5% fractile value
K_{tr}	=	Normalised ratio to consider the amount of transverse reinforcement crossing a potential splitting surface, equation (2.2.1.1.3) in accordance with fib Model Code 2010 [13]
l_b	=	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_b	=	Number of anchored or lapped rebars in the potential splitting surface
n_t	=	Number of legs of confining reinforcement crossing a potential splitting surface
N_u	=	Failure load
$N_{u,m}$	=	Mean value of failure loads
$N_{u,t}$	=	Failure (peak) load in the tests
r	=	Correlation coefficient for trend lines according to Table 2.2.1.1.2
s_b	=	Spacing between the confining reinforcement
s_{max}	=	Maximum displacement of the unloaded end of the rebar applied in cyclic tests
sp1, sp2, sp3, sp4 and *lb1*	=	Curve fitting exponents of equations (2.2.1.1.1) and (2.2.1.1.2)
T	=	Temperature
α_{cr}	=	Ratio between bond resistances in uncracked and cracked concrete, see equation (2.2.2.1)
α_i	=	Bond strength degradation in the cycle i vs. the cycle no. 1 in the series S1 and S2 according to Table A.1.1
$\alpha_{ref,i}$	=	Factor that takes into account the sensitivity of each specific concrete batch
$\alpha_{rqd,i}$	=	Required bond strength degradation in the cycle i vs. the cycle no. 1
β_{cv}	=	Reduction factor resulting from large coefficients of variation
δ	=	Displacement in tension tests
δ_1	=	Limiting displacement
$\delta_{0.5Nu,m}$	=	Displacement at 50% of the mean failure load

Δw_{cr}	=	Crack width for tests in cracked concrete
ϕ	=	Nominal diameter of the reinforcing bar
ϕ_{max}	=	Maximum diameter of rebar specified by the manufacturer of the post-installed rebar system
γ_{inst}	=	Factor accounting for the sensitivity to installation (used in design according to EOTA TR 069 [4])
τ	=	Bond resistance
$\tau_{c1=0,3mm}$	=	Bond strength at which the crack C1 reaches a width of 0,3 mm (refer to Annex A, Figure A.2.3.3.1)
$\tau_{c2=0,15mm}$	=	Bond strength at which the crack C2 reaches a width of 0,15 mm (refer to Annex A, Figure A.2.3.3.1)
τ_{Rk}	=	Characteristic bond resistance
$\tau_{u,m}$	=	Mean ultimate bond strength
Ω_{cr}	=	Factor to account for the influence of cracked concrete on resistance to combined pull-out and concrete failure

1.3.3 Definitions

Confined test setup	=	Close spacing of the supports according to Figure B.5.3.1
Long-term temperature	=	Temperature of the concrete within the service temperature range, which will be approximately constant over significant periods of time
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 Deformed rebars have surface deformations/projections such as ribs or lugs that increase its bond strength when used in reinforced concrete
Service temperature range	=	Range of ambient temperatures in the area of the post-installed rebar after installation and during the lifetime of the connection
Short-term temperature	=	Temperature of the concrete within the service temperature range which vary over short intervals, e.g., day/night and freeze/thaw cycles
Unconfined test setup	=	Wide spacing of the supports according to Figure B.5.2.1

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of the post-installed rebar connections is assessed in relation to the essential characteristics.

Table 2.1.1 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
Basic Works Requirement 1: Mechanical resistance and stability			
Characteristic resistance to tension load (static and quasi-static loading)			
1	Resistance to combined pull-out and concrete failure in uncracked concrete	EAD 330499-01-0601 [2] Clause 2.2.2 and C.5	Level $\tau_{Rk,ucr}$ [N/mm²], ψ^0_{sus} [-] $\tau_{Rk,ucr,100}$ [N/mm²]
		EAD 330499-01-0601-v01 [12] Clause 2.2.1	Level $\psi^0_{sus,100}$ [-]
2	Resistance to concrete cone failure	EAD 330499-01-0601 [2] clause 2.2.3	Level $c_{cr,N}$ [mm], $k_{ucr,N}$ [-], $k_{cr,N}$ [-]
3	Robustness	EAD 330499-01-0601 [2] clause 2.2.5	Level γ_{inst} [-]
4	Resistance to bond-splitting failure	2.2.1	Level A_k [-], sp1 [-], sp2 [-], sp3 [-], sp4 [-], lb1 [-]
5	Influence of cracked concrete on resistance to combined pull-out and concrete failure	2.2.2	Level Ω_{cr} [-]
Characteristic resistance to tension load (seismic loading)			
6	Resistance to bond-splitting failure under cyclic loading	2.2.3	Level $\alpha_{eq,sp}$ [-]
7	Influence of increased crack width on resistance to pull-out failure	2.2.4	Level $\Omega_{cr,05}$ [-], $\Omega_{cr,08}$ [-]
8	Resistance to pull-out failure in uncracked concrete under cyclic loading	2.2.5	Level $\alpha_{eq,p}$ [-]
9	Maximum embedment depth	2.2.6	Level $l_{b,max}$ [mm]
Basic Works Requirement 2: Safety in case of fire			
10	Reaction to fire	2.2.7	Class

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

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

An overview of the test programme 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 (determination of 5%-fractile values of resistance, determination of reduction factors, etc.) are also given in Annex A.

2.2.1 Resistance to bond-splitting failure

Purpose of the assessment

The purpose of these tests is to determine the parameters of the equation used to determine the bond-splitting strength of the system. Tests shall be performed with the deformed reinforcing bars and the mortar system for which the manufacturer applies. The purpose of each test series is the derivation of the constant A_k and of the exponents sp1, sp2, sp3, sp4 and lb1 for the determination of the characteristic bond-splitting resistance $\tau_{Rk,sp}$ as per TR 069 [4].

The characteristic bond-splitting resistance $\tau_{Rk,sp}$ as per TR 069 [4] is given in equations (2.2.1. 1) and (2.2.1. 2) (basic equations without taking into account additional influencing factors as per TR 069 [4]):

$$\tau_{Rk,sp} = A_k \cdot \left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_d}{\phi}\right)^{sp3} \cdot \left(\frac{c_{\max}}{c_d}\right)^{sp4} + k_m \cdot K_{tr}\right] \cdot \left(\frac{7\phi}{l_b}\right)^{lb1} \leq \tau_{Rk,ucr} \qquad (2.2.1.1)$$

for $7\phi \leq l_b \leq 20\phi$

$$\tau_{Rk,sp} = A_k \cdot \left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_d}{\phi}\right)^{sp3} \cdot \left(\frac{c_{\max}}{c_d}\right)^{sp4} + k_m \cdot K_{tr}\right] \cdot \left(\frac{7\phi}{l_b}\right)^{lb1} \leq \tau_{Rk,ucr} \cdot \left(\frac{20\phi}{l_b}\right)^{lb1} \qquad (2.2.1.2)$$

for $l_b > 20\phi$

Where

$\tau_{Rk,ucr}$ is the characteristic bond strength in uncracked concrete for the rebar element assessed according to the EAD 330499-01-0601 [2] [N/mm²] and taking into account the appropriate installation and service conditions,

A_k is the characteristic fitting factor calculated with equations (2.2.1.5) to (2.2.7),

f_{ck} is the characteristic cylinder compressive strength of concrete [N/mm²],

ϕ is the diameter of the test rebar [mm],

c_d is the minimum clear concrete cover of the test rebar [mm] (refer to Figure 2.2.1.1),

c_{max} is the maximum clear concrete cover of the test rebar [mm] (refer to Figure 2.2.1.1),

k_m is the factor for the effectiveness of transverse reinforcement defined according to fib Model Code 2010 [13] and fib Bulletin 72 [14].

k_m = 12 where rebars are confined inside a bend of links passing round the bar of at least 90°.

k_m = 6 where a rebar is more than 125 mm and more than 5 bar diameters from the nearest vertical leg of a link crossing the splitting plane in an approximately perpendicular direction

k_m = 0 if a splitting crack would not intersect transverse reinforcement, either because the transverse reinforcement is positioned inside the rebars, or the clear spacing between anchored or pairs of lapped rebars is less than 4 times the bottom cover, and hence a crack through the plane of the rebars would form without intersecting transverse reinforcement

Note: for the series L1 to L7 of Annex A, Table A.1.1 k_m = 6 applies. For the series L8 and L9 of Annex A, Table A.1.1, the post-installed rebar is closer to the bend of the confining stirrups and, therefore, k_m is equal to 12. In all series L1 to L9 the specimen shown in Figure 2.2.1.1 shall be used and only the stirrup close to the load application point may be considered as effective.

sp1, sp2, sp3, sp4 and lb1 are curve fitting exponents.

l_b is the embedment length of the post-installed rebar.

K_{tr} is the normalised ratio to consider the amount of transverse reinforcement crossing a potential splitting surface defined and calculated according to fib Model Code 2010 [13] as follows:

$$K_{tr} = (n_t \cdot A_{st}) / (n_b \cdot \phi \cdot s_b) \leq 0{,}05 \qquad (2.2.1.3)$$

Where

n_t is the number of legs of confining reinforcement crossing a potential splitting surface

A_{st} is the cross-sectional area of one stirrup leg

n_b is the number of anchored or lapped rebars in the potential splitting surface

ϕ is the diameter of the anchored rebar considered [mm]

s_b is the spacing between the confining reinforcement

Note: Equations (2.2.1.1) and (2.2.1.2) are based on the formulation proposed by the fib Model Code 2010 [13] *for the determination of the bond-splitting performance of cast-in rebars and adapted to take into account the different characteristic product performance of post-installed rebar systems. Furthermore, the upper bounds defined in equations (2.2.1.1) and (2.2.1.2) are following the assumptions of a uniform bond stress ($\tau_{Rk,ucr}$) distribution for embedment lengths up to 20ϕ and a bond stress degradation for embedment lengths beyond 20ϕ.*

Assessment method

a) Test series L1 to L9 (*Annex A, Table A.1.1)*

The tests of the series L1 to L9 shall be performed in uncracked concrete using the beam-end test specimen (BET, Figure 2.2.1.1) and an unconfined setup according to Annex B, clause B.5.2 (Figure B.5.2.1).

Note: For a correct installation of the post-installed rebar connections in the beam-end test specimens (series L1 to L9 in Annex A, Table A.1.1) refer to the procedure described in Annex C.

The test setup according to Figure 2.2.1.1 fulfils the following requirements:

(a) unconfined test setup

(b) minimum transverse reinforcement

(c) the displacements can be measured at the unloaded end of the rebar

(d) all stirrups shall be ϕ6 mm and longitudinal bars ϕ16 mm. To test rebars with diameter ϕ>20 mm and in cases where high concrete splitting resistance is expected, it is recommended to increase the diameter of the longitudinal bars. Alternatively, or in combination with this measure the dimensions of the test specimen may be enlarged.

(e) tolerance for the positioning of the post-installed rebar is ± 3 mm with a maximum inclination of 2°.

Concrete splitting failure shall be ensured.

Note: The use, in the assessment, of test results where pull-out instead of splitting failure is observed leads to a conservative derivation of the exponents in equations (2.2.1.1) and (2.2.1.2).

The test procedure shall fulfil the requirements of Annex B, clause B.4.

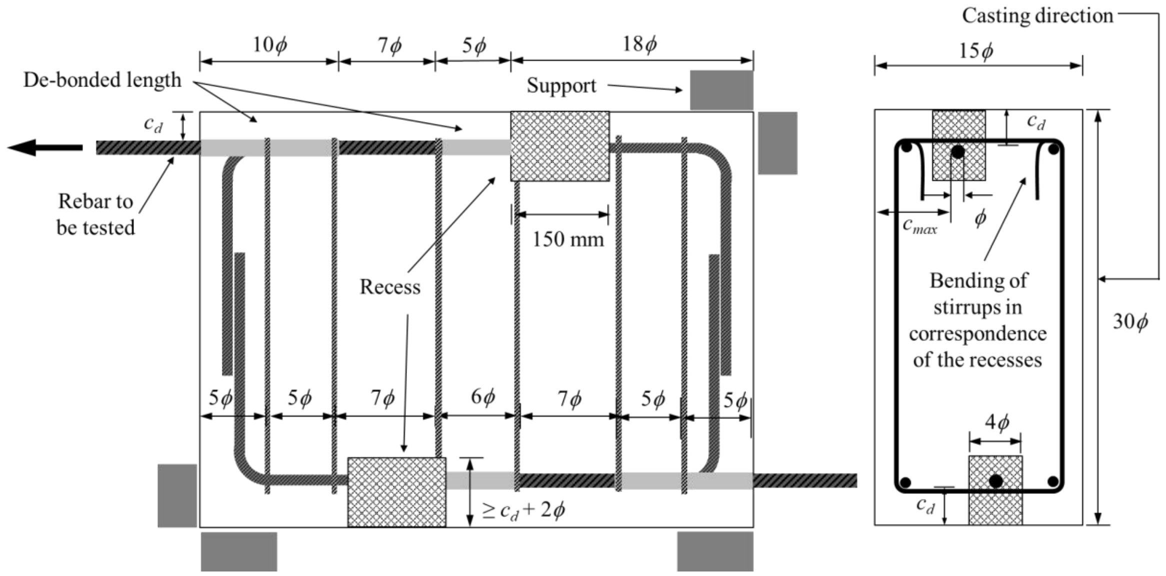


Figure 2.2.1.1 Typical beam-end test specimen to be used in the test series L1 to L9

b) Test series G1 to G4 Annex A, Table A.1.1

The tests of the series G1 to G4 shall be performed with a confined test setup according to Annex B, clause B.5.3 (Figure B.5.3.1). A schematic representation of the specimen and of the test setup is given in Figure 2.2.1.2.

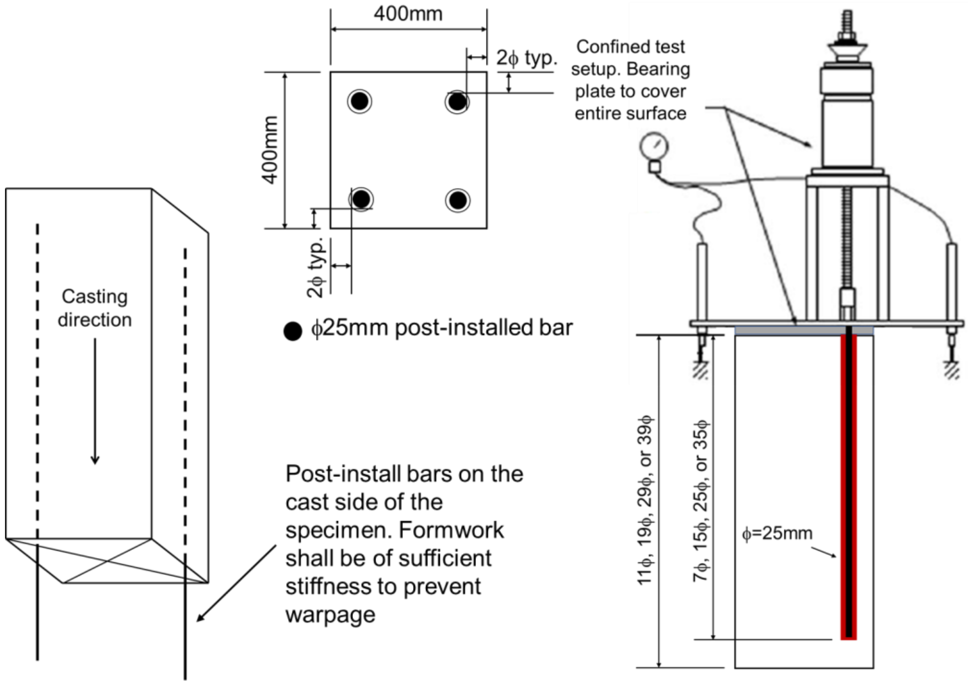


Figure 2.2.1.2 Typical specimen and setup to be used in the test series G1, G2, G3, and G4 (tolerance on bar position is ± 3 mm)

Each test series shall be assessed as follows:

a) Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], normalised to the nominal concrete compressive strength according to clause A.2.3.2 and accounting for concrete batch influence according to clause A.2.3.3 and A.2.3.4.
- Determine the coefficient of variation of failure loads, cv_F [%]. If the coefficient of variation of loads exceeds 15% (cv_F > 15%), determine the reduction factor for large scatter β_{cv} according to A.2.3.5.

b) Load displacement behaviour

- Determine the displacements at 50% of the mean failure load, $\delta_{0.5Nu,m}$ [mm], in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load, cv_δ [%]. If the displacements at 50% of the failure load are smaller than 0,4 mm, cv_δ may exceed 25 %.

c) Exponents of equations (2.2.1.1) and (2.2.1.2)

The exponents in equations (2.2.1.1) and (2.2.1.2) shall be determined individually (i.e., one parameter at a time) from the test series reported in Table 2.2.1.1 and assuming no correlation between different influencing parameters. The results of the corresponding test series shall be used to fit the best (power) curve as per equation (2.2.1.4) based on the R^2 method to obtain the individual exponents (see Figure 2.2.1.3):

$$\tau_{u,m,sp} = a \cdot x^b \qquad (2.2.1.4)$$

Where

$\tau_{u,m,sp}$ is the mean bond-splitting resistance

a is a constant value

x is the varied parameter

b is the derived exponent to be used in the equations (2.2.1.1) and (2.2.1.2)

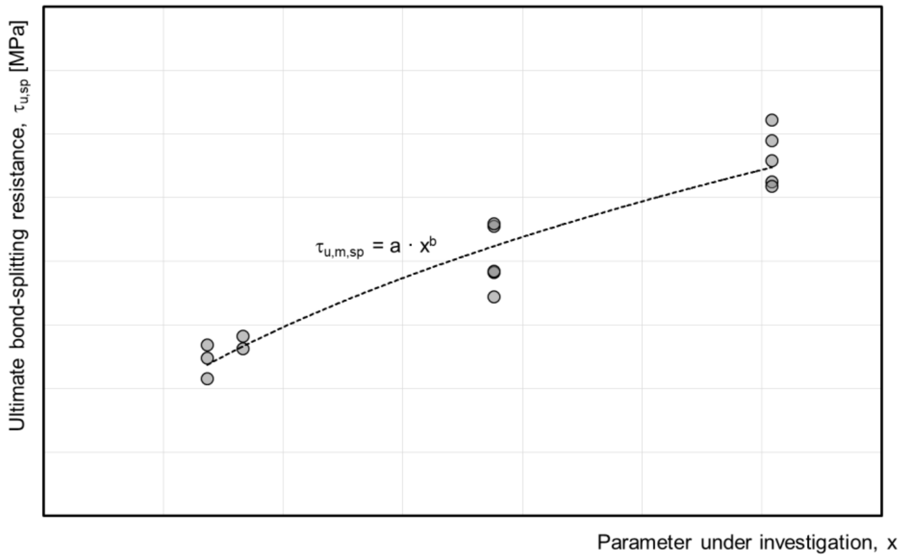


Figure 2.2.1.3 Example of best fit (least squares) power function

In particular:

1. The exponent to consider the influence of concrete strength, sp1, is obtained by correlating the test failure loads with the concrete compressive strength measured in the tests.

2. The exponent to consider the influence of rebar diameter, sp2, is obtained by correlating the test failure loads with the diameter of the rebar used for testing, ϕ.

3. The exponent to consider the influence of minimum concrete cover, sp3, is obtained by correlating the test failure loads with the concrete cover used for testing. The assessment of sp3 may be conducted after the normalisation with respect to sp4.

4. The exponent to consider the influence of side concrete cover, sp4, is obtained by correlating the test failure loads with the side concrete cover used for testing.

5. The exponent to consider the influence of the anchorage length, lb1, is obtained by correlating the test failure loads with the anchorage length used for testing, l_b.

Table 2.2.1.1 Parameter/Exponents of equations (2.2.1.1) and (2.2.1.2) and relative test series

Exponent	Meaning	Test series
A_k	Fitting factor	L1 to L9
sp1	Influence of concrete strength	L1, L4 and L5
sp2	Influence of rebar diameter	L1, L6 and L7
sp3	Influence of minimum concrete cover	L1, L2 and L3
sp4	Influence of side concrete cover	L1, L8 and L9
lb1	Influence of the anchorage length	G1, G2, G3 and G4

d) Parameter A_k in equations (2.2.1.1) and (2.2.1.2)

Once the individual exponents sp1, sp2, sp3 and sp4 are determined, results of all the test series L1 to L9 shall be assessed together to determine the fitting parameter A_k according to equations (2.2.1.5) to (2.2.1.7).

The results of the series G1 to G4 are not considered in the determination of the factor A_k, because obtained with a different test setup. The mean bond strength obtained from series G1 shall be at least 95 % of the calculated mean values using equation (2.2.1.1) with the parameters derived from the series L1 to L9.

Using the values of the exponents obtained individually, the value of the parameter A_t shall be determined correlating the splitting strength values obtained from the experimental results with those calculated using equations (2.2.1.1) and (2.2.1.2) to fit the best curve based on the R^2 method.

$$A_t = \frac{\tau_{u,t,sp}}{\left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_d}{\phi}\right)^{sp3} \cdot \left(\frac{c_{\max}}{c_d}\right)^{sp4} + k_m \cdot K_{tr}\right]} \quad (2.2.1.5)$$

$$A_m = \frac{1}{n}\sum_{t=1}^{n} A_t \quad (2.2.1.6)$$

$$A_k = \min \beta_{CV} \cdot A_m \cdot (1 - k_s \cdot cv_F) \quad (2.2.1.7)$$

Where

$\tau_{u,t,sp}$ is the bond-splitting strength of the single test

n is the total number of tests available (series L1 to L9)

min β_{CV} is evaluated from the test series L1 to L9 and G1 to G4 according to Annex A, A.2.3.5

cv_F is the coefficient of variation of A_t obtained from the evaluation of all test results of the series L1 to L9

k_s according to Annex A, clause A.2.3.6

e) Interpolation criteria and technical limitations on parameters

The following criteria shall be fulfilled for the definition of the function which interpolates the test results for the derivation of the exponents sp1, sp2, sp3, sp4 and lb1 in equations (2.2.1.1) and (2.2.1.2):

a. The coefficient of variation associated with the trend line shall fulfil the requirements of A.2.3.5.
b. The value of the correlation coefficient (r) associated with the trend line fitted to the experimental data shall be equal to or greater than the value given in Table 2.2.1.2 for a given data population (n). It is permitted to calculate r as the square root of the coefficient of determination, R^2. For values of n between the tabular values, the value of r shall be taken from as the next higher value.
c. The value of the slope of the trend line shall not change in sign.
d. A minimum of three evenly distributed parameters shall be tested to develop the trend line.
e. Values for parameters outside of the tested parameter range shall not be extrapolated.

Note: Extrapolation is allowed only for the assessment of rebar diameters smaller than 12 mm. This means than the bond-splitting performance of the rebar with diameter 12 mm can be used also for the diameter 8 mm and 10 mm. However, no increase in the performance is allowed.

Table 2.2.1.2 Minimum values of the correlation coefficient for trend line of model validation

n	r_{min}	n	r_{min}	N	r_{min}	n	r_{min}
4	0,999	14	0,780	24	0,629	50	0,451
5	0,991	15	0,760	25	0,618	60	0,414
6	0,974	16	0,742	26	0,607	70	0,385
7	0,951	17	0,725	27	0,597	80	0,361
8	0,925	18	0,708	28	0,588	90	0,341
9	0,898	19	0,693	29	0,579	100	0,324
10	0,872	20	0,679	30	0,570	200	0,231
11	0,847	21	0,665	35	0,532	300	0,189
12	0,823	22	0,652	40	0,501	400	0,164
13	0,801	23	0,640	45	0,474	500	0,147

Table 2.2.1.2 illustrates the limits on the parameters of equations (2.2.1.1) and (2.2.1.2) based on current experience and knowledge.

Table 2.2.1.3 Limits for the fitting factor and exponents in equation (2.2.1.1) and (2.2.1.2)

Parameter/Exponent	Limit	Technical justification
A_k	≤ 8,0	Prevention of very high splitting strength values for very low strength concrete and small concrete cover conditions
sp1	≤ 0,50	Avoid stronger influence compared to the tensile strength of concrete
sp2	≥ 0,00	Prevention of negative size effect
sp3	≤ 0,67	Prevention of very high splitting strength values for very low strength concrete and small concrete cover conditions
sp4	≤ 0,33	Prevention of very high splitting strength values for very low strength concrete and small concrete cover conditions
lb1	≥ 0,45	Avoid an unconservative degradation of the bond-splitting strength

Note: In the assessment, a rounding to the decimal digit is recommended for A_k and to the hundredth digit for the other exponents (possibly 5 or 10 hundredth).

Expression of results

A_k [-], sp1 [-], sp2 [-], sp3 [-], sp4 [-], lb1 [-]

2.2.2 Influence of cracked concrete on resistance to combined pull-out and concrete failure

Purpose of the assessment

These tests are performed to assess the sensitivity of the rebar bond strength in cracked concrete with a crack width of 0,3 mm. These tests can be omitted if the parameter Ω_{cr} is assigned a default value equal to 0,5 (Ω_{cr} =0,5).

Assessment method

The tests series P1 to P4 (Annex A, Table A.1.1) shall be performed with rebar sizes s/m/l according to Annex A, Table A.1.2 in concrete C20/25 and C50/60 with a confined test setup according to Annex B, clause B.5.3.

Each test series shall be assessed as follows:

a) Failure loads

- Determine the mean value of failure loads, $N_{u,m}$ [kN], normalised to the nominal concrete compressive strength according to clause A.2.3.2 and accounting for concrete batch influence according to clause A.2.3.3 and A.2.3.4.
- Determine the 5% fractile of the failure loads, $N_{u,5\%}$ [kN], normalised to the nominal concrete compressive strength and accounting for concrete batch influence according to clause A.2.3.4 and A.2.3.6.
- Determine the coefficient of variation of failure loads, cv_F [%]. If the coefficient of variation exceeds 15 % (cv_F > 15 %), determine the reduction factor for large scatter β_{cv} according to A.2.3.5.

b) Load displacement behaviour

- Determine the displacements at 50 % of the mean failure load, $\delta_{0.5Nu,m}$ [mm], in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load, cv_δ [%]. If the displacements at 50 % of the failure load are smaller than 0,4 mm, cv_δ may exceed 25 %.

The factor Ω_{cr}, to be reported in the ETA, shall be derived as follows:

$$\Omega_{cr} = 1 - \alpha_{cr} \cdot \Delta w_{cr} \qquad (2.2.2.1)$$

Where

Δw_{cr} is the crack width under consideration

= 0,3 mm

α_{cr} is the parameter representing the sensitivity of the tested post-installed rebar system to the crack width under consideration

= 1,67 if no tests in cracked concrete are conducted

= $(1 - \tau_{u,m,cr}/\tau_{u,m,ucr})/0,3$

The factor α_{cr} shall be derived for C20/25 and C50/60 in accordance with Annex A, clause A.2.3.7, and the maximum of the two shall be used for the derivation of the factor Ω_{cr}. The factor α_{cr} may vary with varying rebar diameter. A trend line may be derived and in this case the requirements of clause 2.2.1 above shall be fulfilled.

Expression of results

Ω_{cr} [-]

2.2.3 Resistance to bond-splitting failure under cyclic loading

Purpose of the assessment

The purpose is to verify comparability between the cyclic and monotonic test results in case of splitting failure. The comparability is established in terms of ultimate strength, energy dissipation, and residual load.

General provisions valid for test specimens and setup

The tests shall be performed with a test setup according to Figure 2.2.1.1 that fulfils the requirements of clause 2.2.1

The test procedure for monotonic tests shall fulfil the requirements of clause B.4, with the following deviations:

1) the test shall be carried out with displacement control and continued beyond the peak of the load/displacement curve to at least s_{max} defined as the minimum between:
   a) the displacement level where the load value drops down to 80% of its peak value in the post-peak region of the average load-displacement curve;
   b) 3,0 mm.
2) A minimum recording frequency of 10 Hz of test data is required.
3) The time to reach the peak load may be increased beyond 3 minutes to ensure a reliable displacement control of the test especially in the descending branch of the load-displacement curve.

The tests can be either controlled using as a feedback signal the displacement of the actuator or the slip value evaluated as the measurement at the rear end. All instruments shall fulfil the requirements of clause B.3. If the displacement control of the tests cannot be fully ensured right after reaching of the peak load due to the high brittleness of the failure, an additional criterion for the determination of s_{max} shall be considered for all tests of the series. Figure 2.2.3.1 provides guidance for the calculation of s_{max} in this case, i.e., if the displacement corresponding to 80% of the peak load in the post-peak region cannot be determined $s_{max} = 2s_u$ shall be taken (compare Figure 2.2.3.1.a), b). For the calculation of the dissipated energy the descending branch of the load-displacement curve can be linearly approximated in the range where the readings of the instrumentation are not reliable.

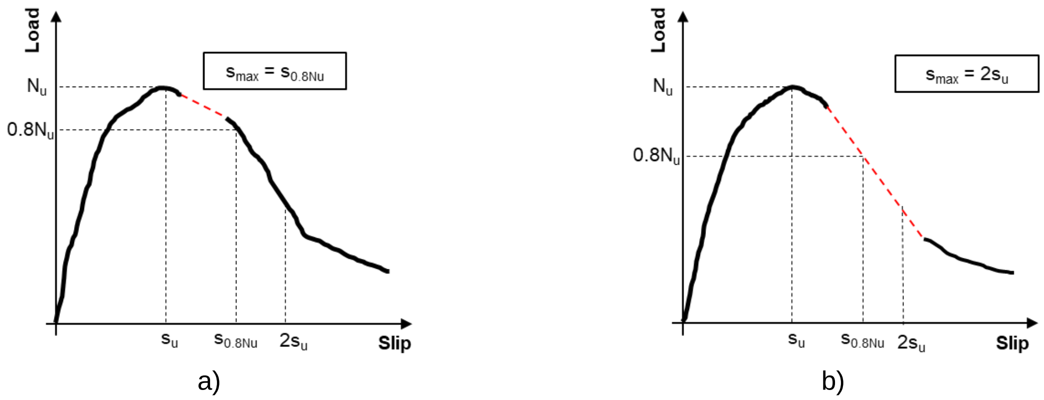


Figure 2.2.3.1: Assessment of s_{max} including situations where the displacement control is not reliable after reaching the peak load

In the cyclic tests, the same displacement rate as in the corresponding monotonic tests shall be used for the first cycle at each displacement step, while for the 2nd and 3rd cycles as well as for the descending branches the rate can be increased up to 10 times that rate, but not faster than 3 mm/min measured at the rear end of the tested rebar.

The same displacement rate shall be adopted for all tests of a series.

2.2.3.1 Monotonic reference tests

The tests are required to provide a monotonic reference to the cyclic tests to quantify the effect of cyclic loading in scenarios where splitting failure is decisive.

Assessment method

The test specimen and setup shown in Figure 2.2.1.1 shall be used. During the test the load shall be recorded as a function of the displacement. The configurations in terms of rebar diameter and concrete strength to be tested are listed in Table A.1.1 (Series L1-S, L5-S, L6-S and L7-S).

Each test series shall be assessed as follows:

a) Failure loads

- Determine the mean value of failure loads, $N_{um,mon}$ [kN], normalised to the nominal concrete compressive strength according to Annex A, clause A.2.3.2 and the corresponding bond strength, $\tau_{um,mon}$ [N/mm²] according to Annex A, clause A.2.3.3.
- Determine the coefficient of variation of failure loads, cv_F [%]. If the coefficient of variation exceeds 15% ($cv_F > 15\%$), determine the reduction factor for large scatter β_{cv} according to equation A.2.3.5.1 indicated in Annex A, clause A.2.3.5.

b) Load displacement behaviour

- Determine the mean displacement s_{max} [mm].
- If the scatter associated to s_{max} is higher than 40%, the number of repetitions shall be increased until this requirement is met.

c) Energy dissipation

- Calculate the energy dissipated under monotonic loading, En_{mon} [J] as the area under the load-displacement curve between s = 0 and s = s_{max}.

2.2.3.2 Cyclic tests

These test series are meant to assess the cyclic bond performance of the product in near edge conditions, where the splitting failure mode is decisive.

Assessment method

The tests according to Table A.1.1, Series L1-S, L5-S, L6-S and L7-S are required to be carried out with the same concrete and rebar batches of the monotonic reference tests to ensure full comparability. These test series shall be performed using the beam-end test specimen (BET, Figure 2.2.1.1).

The tests shall be performed in displacement control with the indications given at the beginning of clause 2.2.3. The test protocol consists of three half cycles at each of the following displacement steps (in case where s_{max} = 3,0 mm):

0,1; 0,25; 0,5; 0,75; 1,0; 1,25; 1,5; 2,0; 2,5; 3,0 mm

If s_{max} < 3,0 mm the test shall be stopped at the correspondent displacement level.

Three half cycles between s = 0 mm and s = s_{max} at each displacement level shall be conducted as shown in Figure 2.2.3.2.1. The cyclic test may be stopped when the displacement level s_{max} obtained from the monotonic reference tests is reached and the residual tension strength of the rebars shall be determined.

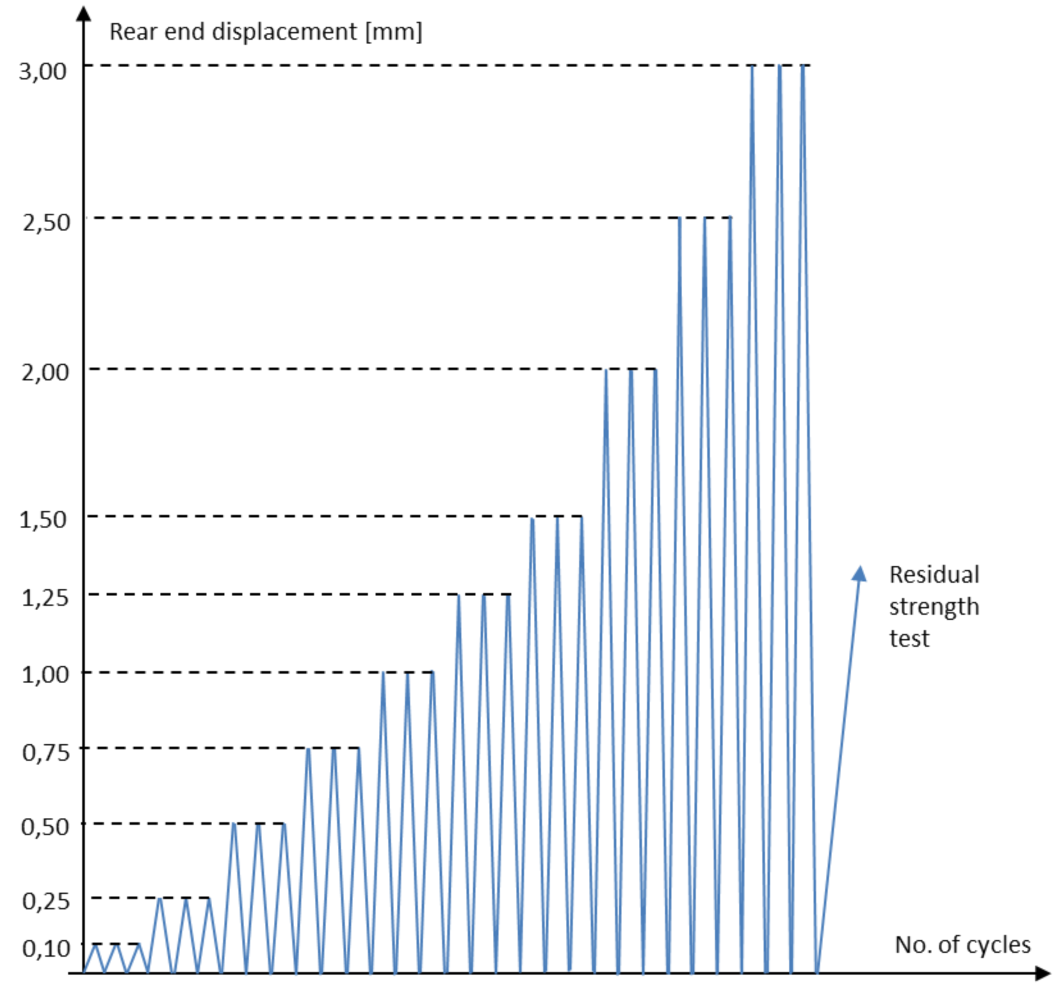


Figure 2.2.3.2.1: Displacement-controlled loading history in case where s_{max} = 3,0 mm

Each test series shall be assessed as follows:

a) Failure loads

- Determine the mean value of peak loads, $N_{u,m,cyc}$ [kN], normalised to the nominal concrete compressive strength according to Annex A, clause A.2.3.2 and the corresponding bond strength, $\tau_{u,m,cyc}$ [N/mm^2] according to Annex A, clause A.2.3.3.
- Determine the coefficient of variation of peak loads, cv_F [%]. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $\beta_{cv,sp}$ according to Annex A, clause A.2.3.5.
- Determine the mean residual failure load after the completion of the displacement cycles $N_{u,m,res}$ [kN], normalised to the nominal concrete compressive strength according to Annex A, clause A.2.3. 2 and the corresponding bond strength, $\tau_{u,m,res}$ [N/mm^2] according to Annex A, clause A.2.3.3.
- Determine the coefficient of variation, cv_F [%] of the residual strength. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $\beta_{cv,sp}$ according to Annex A, clause A.2.3.5.

b) Energy dissipation

- The envelope of the cyclic load (or bond stress) displacement curves obtained from the tests shall be plotted by joining the peaks of the first cycles of each loading step (see Figure 2.2.3.2.1). An example of the derivation of the envelope from the cyclic test results is shown in Figure 2.2.3.2.2 (continuous red line).
- Calculate the mean energy dissipated under cyclic loading, En_{cyc} as the area under the envelope curve between s = 0 and s = s_{max}.

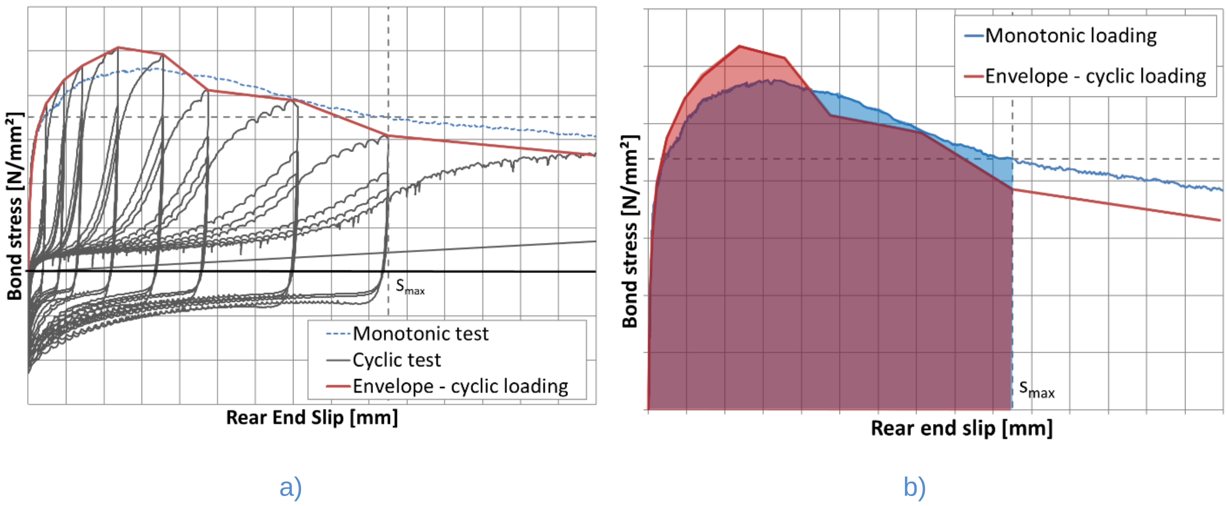


Figure 2.2.3.2.2: Load-displacement curves. a) Monotonic curve (dashed blue line) and envelope curve (continuous red line) derived from cyclic load-displacements curves; b) area under the monotonic curve and under the envelope curve.

2.2.3.3 Derivation of reduction factor $\alpha_{eq,sp}$

The reduction factor $\alpha_{eq,sp}$ is derived according to equation (2.2.3.3.1) The minimum value of $\alpha_{eq,sp}$ derived from all the series shall be reported in the ETA:

$$\alpha_{eq,sp} = \min \beta_{CV,sp} \cdot \min\left(\frac{\tau_{u,m,cyc}}{(0{,}95 \cdot \tau_{u,m,mon})}; \frac{En_{cyc}}{(0{,}95 \cdot En_{mon})}; \frac{\tau_{u,m,res}}{(0{,}4 \cdot \tau_{u,m,mon})}; 1{,}0\right) \qquad (2.2.3.3.1)$$

where min $\beta_{CV,sp}$ is the minimum among all reduction factors for large scatter of peak loads and residual strength.

Expression of results

$\alpha_{eq,sp}$ [-]

2.2.4 Influence of increased crack width on resistance to pull-out failure

Purpose of the assessment

These tests are performed to assess the sensitivity of the rebar bond strength in cracked concrete with a crack width of 0,5 and 0,8 mm in concrete strength classes C20/25 (Table A.1.1), series B10 and C2.1a) and C50/60 (Table A.1.1, series B11 and C2.1b).

Assessment method

The tests shall be performed with a confined setup according to clause B.5.3. The test results of the test series B10 and C2.1a, B11 and C2.1b shall be compared with the results of the series P1 and P2 according to Table A.1.1.

Each test series shall be assessed as follows:

a) Failure loads

- Determine the mean value of failure loads, $N_{u,m}$ [kN], normalised to the nominal concrete compressive strength according to Annex A, clause A.2.3.2 and the corresponding bond strength, $\tau_{u,m}$ [N/mm^2], according to clause A.2.3.3 and accounting for concrete batch influence according to Annex A, clause A.2.3.4.
- Determine the coefficient of variation of failure loads, cv_F [%]. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factors for large scatter $\beta_{cv,05}$ and $\beta_{cv,08}$ according to Annex A, clause A.2.3.5.
- Determine the reduction factors $\Omega_{cr,05}$ and $\Omega_{cr,08}$ for C20/25 and C50/60 according to Annex A, clause A.2.3.7. The minimum of the values in low and high strength concrete shall be reported in the ETA. The factors $\Omega_{cr,05}$ and $\Omega_{cr,08}$ may vary with varying rebar diameter. A trend line may be derived and in this case the requirements of clause 2.2.1 e) shall be fulfilled.

Note: If in the assessment according to clause 2.2.1 no tests were performed and the default value Ω_{cr} = 0,5 (i.e., $\Omega_{cr} = \Omega_{cr,03}$) was taken, an inconsistency between the values of $\Omega_{cr,03}$ and $\Omega_{cr,05}$ may occur (e.g., $\Omega_{cr,05} > \Omega_{cr,03}$). In such cases the values $\Omega_{cr,03}$ shall be considered as equal to $\Omega_{cr,05}$.

b) Load displacement behaviour

- Determine the displacements at 50% of the mean failure load, $\delta_{0.5Nu,m}$ [mm], in each test.
- Determine the coefficient of variation of the displacements at 50% of the mean failure load, cv_δ [%]. If the displacements at 50% of the failure load are smaller than 0,4 mm, cv_δ may exceed 40 %. If cv_δ exceeds 40% the number of tests shall be increased to meet this limit.

Expression of results

$\Omega_{cr,05}$ [-], $\Omega_{cr,08}$ [-]

2.2.5 Resistance to pull-out failure in uncracked concrete under cyclic loading

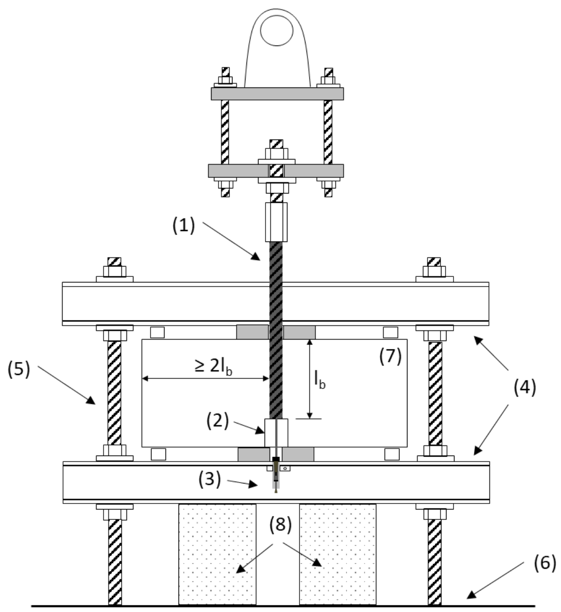
Purpose of the assessment

Scope of the test is the assessment of the pull-out resistance under cyclic loading through the determination of the efficiency factor $\alpha_{eq,p}$.

Assessment method

These test series are performed with post-installed rebars in concrete strength classes C20/25 (Table A.1.1, series S1) and C50/60 (Table A.1.1, series S2) for which the assessment is sought. The test is designed based on the assumption of general comparability to bond properties of cast-in rebar in terms of degradation with increasing displacement cycles.

The tests shall be performed with rebar sizes ϕ_{min}, ϕ_{medium} and ϕ_{max} (see Table A.1.1). The cyclic tests with post-installed rebars shall be performed in uncracked concrete using a confined setup according to clause B.5.3. The displacements shall be measured at the unloaded end of the rebar as shown, for example, in Figure 2.2.5.1 (3).



(1) Rebar to be tested
(2) PVC-tubes with inner diameter $\phi \approx 2 \cdot \phi_{rebar}$
(3) Transducer to measure the displacement at the unloaded end of the rebar
(4) Support beams
(5) Prestressed rods to connect to strong floor (or side supports, if the specimen is placed horizontally)
(6) Strong floor (or side supports, if the specimen is placed horizontally)
(7) Test specimen
(8) Supports

Note: more than one rebar can be tested in one specimen, if a spacing of at least $4 \cdot l_b$ is provided

Figure 2.2.5.1: Example of pull-out test setup with displacement measurements at the unloaded end of the rebar

The tests shall be performed in displacement control using the required slip protocol and the general procedure reported in clause 2.2.4 (*Assessment method*) of EAD 330087-01-0601.

Each test series shall be assessed as follows:

a) Loads

- Determine the mean value of the maximum loads measured after cycle 1 in all tests of test series S1 and S2, $N_{um,1}$ [kN], normalised to the nominal concrete compressive strength according to Annex A, clause A.2.3.2 and converted into bond strength, $\tau_{um,1}$ [N/mm²] according to Annex A, clause A.2.3.3.
- Repeat this procedure for the maximum loads measured after cycles 2, 5, 10 and the residual load test.
- Determine the coefficient of variation cv_F of the maximum loads, cv_F [%] after cycles 1, 2, 5, 10 and the residual load test. If the coefficient of variation exceeds 20% ($cv_F > 20\%$), determine the reduction factor for large scatter $\beta_{cv,p}$ according to Annex A, clause A.2.3.5.

b) Displacements

- Determine the coefficient of variation of the displacement at peak of the residual failure load test (cv_δ). If cv_δ exceeds 40% the number of tests shall be increased to meet this limit.

The factor $\alpha_{eq,p}$, to be reported in the ETA, shall be derived as follows:

$$\alpha_i = \tau_{um,i} / \tau_{um,1} \quad (2.2.5.1)$$

$$\alpha_{eq,p,i} = \alpha_i / \alpha_{rqd,i} \leq 1,0 \quad (2.2.5.2)$$

$$\alpha_{eq,p} = \min \beta_{CV,p} \cdot \min (\alpha_{eq,p,i}) \quad (2.2.5.3)$$

With:

i = 2, 5 and 10

$\alpha_{rqd,i}$ according to Table 2.5 of EAD 330087-01-0601.

Expression of results

$\alpha_{eq,p}$ [-]

2.2.6 Maximum embedment length

Purpose of the assessment

The assessment is required to check if the rebar can be installed properly at maximum embedment depth before curing of the mortar and if the injection of the mortar can be done properly without voids.

Assessment method

$$l_{b,max} = l_v \quad (2.2.6.1)$$

With:

l_v = maximum embedment length assessed according to EAD 330087-01-0601 [3], clause 2.2.1.4 and 2.2.1.5.

Expression of results

$l_{b,max}$ [mm]

2.2.7 Reaction to fire

The post-installed rebar is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the product is class A1.

The injection mortar is considered as a small component embedded in the concrete. In the end use of the application the reaction to fire class of the concrete is not influenced. Separate testing and classification are not necessary.

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 Commission Decision 96/582/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 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	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	According to control plan	1	Each batch
2	Components	Check material and the mass of components according to recipe	According to control plan	1	Each batch
3	Specific gravity / Density	According to control plan	According to control plan	1	Every shift or 8 hours of production per machine
4	Viscosity	According to control plan	According to control plan	1	Every shift or 8 hours of production per machine
5	Reactivity (gel time, where relevant: max. reaction temperature, time to max reaction temperature)	According to control plan	According to control plan	1	Each batch
6	Properties of raw material	According to control plan (e.g., by infrared analysis)	According to control plan	1	Initial testing and each change of batch
7	Performance of the cured bonding material	According to control plan (e.g., tension test to failure)	According to control plan	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 the post-installed rebar connections with improved bond-splitting behaviour are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	The notified body shall ascertain that, in accordance with the control plan, the manufacturing plant of the product manufacturer, in particular personnel and equipment, and the factory production control are suitable to ensure a continuous and orderly manufacturing of the bonding material.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	As defined in the control plan	As defined in the control plan	At the beginning of the contract between NB and Manufacturer
Continuous surveillance, assessment and evaluation of factory production control					
2	The notified body shall ascertain that the system of factory production control and the specified manufacturing process are maintained in accordance with the control plan in order to ensure the constancy of product performance.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1.	As defined in the control plan	As defined in the control plan	Once per year

4 REFERENCE DOCUMENTS

[1] EN 1992-1-1:2004/AC:2010/A1:2014	Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings
[2] EAD 330499-01-0601	Bonded fasteners for use in concrete
[3] EAD 330087-01-0601	Systems for post-installed rebar connections with mortar
[4] EOTA TR 069:2021-06	Design method for anchorage of post-installed reinforcing bars (Rebars) with improved bond-splitting behavior as compared to EN1992-1-1
[5] EN 206:2013+A2:2021	Concrete: Specification, performance, production and conformity
[6] EN ISO 15630-1:2019	Steel for the reinforcement and prestressing of concrete - Test methods - Part 1: Reinforcing bars, wire rod and wire (ISO 15630-1:2019)
[7] EN ISO/IEC 17025:2017	General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2017)
[8] ISO 6783:1982	Coarse aggregates for concrete; Determination of particle density and water absorption; Hydrostatic balance method
[9] EN 197-1:2011	Cement - Part 1: Composition, specifications and conformity criteria for common cements
[10] EN 13791:2019	Assessment of in-situ compressive strength in structures and precast concrete components
[11] ISO 5468:2017	Rotary and rotary impact masonry drill bits with hard metal tips - Dimensions
[12] EAD 330499-01-0601-v01	Bonded fasteners for use in concrete - Variant for sustained tension load factor for 100 years working life

Further information and background for assessment methods is given in the following documents:

[13] fib Model Code 2010	fib Model Code for Concrete Structures 2010
[14] fib Bulletin 72:2014	Bond and Anchorage of embedded reinforcement: Background to the fib Model Code for Concrete Structures 2010.
[15] R. Lewandowski	R, Lewandowski, Beurteilung von Bauwerksfestigkeiten an Hand von Betongütewürfeln und –bohrproben, Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig, Heft 3, Werner Verlag, Düsseldorf, 1971
[16] Spieth, H.A.	Tragverhalten und Bemessung von eingemörtelten Bewehrungsstäben (Behavior and Design of Post-installed Bonded Rebar Connections), Dissertation, Universität Stuttgart, 2002 (in German)

ANNEX A TEST PROGRAM AND GENERAL ASPECTS OF ASSESSMENT

A.1 Test program

All test series shall be conducted with concrete members at normal ambient temperature (21°C ± 3 °C).

An overview of the tests is given in Table A.1.1.

All tests shall be 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 according to EN ISO 15630-1 [6] in uncracked concrete C20/25 and C50/60. If required, in order to have a correct experimental assessment of the product (i.e., to avoid steel failure), it is possible to use deformed rebars with $f_{yk} \geq 600$ N/mm².

For the test series P3 and P4 (Table A.1.1) cracked concrete shall be used.

In all tests the holes shall be drilled with the diameter $d_{cut,m}$ according to the specifications of the manufacturer. The holes shall be cleaned according to the MPII with the cleaning equipment specified by the manufacturer.

The tests shall be performed using each drilling method applied for by the manufacturer. If the equivalency of two different drilling methods has been shown in the assessment in accordance with the EAD 330499-01-0601 [2] and EAD 330087-01-0601 [3], only the proof of the equivalency of the bond-splitting behaviour in the series L1 of Table A.1.1 is sufficient.

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

For the test series S1 and S2 the results of the series carried out according to EAD 330087-01-0601 can be used for the assessment according to this EAD. The results of the series S1 in concrete strength class C16/20 according to EAD 330087-01-0601 can be used also for the assessment in concrete C20/25 according to this EAD. If the series S2 according to EAD 330087-01-0601 was carried out in concrete strength class smaller than C50/60, it can be used for the assessment according to this EAD, but in this case the intended use shall also be limited accordingly to the maximum concrete strength class tested.

For the test series B10, B11, C2.1a and C2.1b (see Table A.1.1) cracked concrete shall be used. Results of corresponding series carried out according to EAD 330499-01-0601 (Table A.1 for test series B10 and B11 and Table E.4 for test series C2.1a and C2.1b) with rebar elements can be used for the assessment according to this EAD.

The tests shall be performed using each drilling method applied for by the manufacturer. However, the test programme given in Table A.1.1 for an alternative drilling method can be reduced as follows:

1) If the equivalency of two different drilling methods has been shown in the assessment in accordance with the EAD 330499-01-0601 [2] and EAD 330087-01-0601 [3], only the proof of the equivalency of the bond-splitting behaviour in the series L1-S of Table A.1.1 is sufficient to check splitting under cyclic loading comparing it with reference tests carried out with the primary drilling method;

2) For the series B10, B11, C2.1a and C2.1b the number of sizes to be tested can be reduced from “s/m/l” to “ϕ_{min}; ϕ_{medium}; ϕ_{max}”; and

3) If equivalency in terms of bond strengths between the first and the alternative drilling method is shown in the series C2.1a and C2.1b, the series B10 and B11 may be omitted.

Table A.1.1 Test programme

Series No.	Purpose of test series	Rebar ϕ[1]	Concrete cover c_d [mm]	Concrete cover c_{max} [mm]	Concrete strength	Transverse reinforcement Ø/spacing	Setting depth l_b [mm]	Minimum no. of tests	Clause
Derivation of local bond/splitting model (using BET specimens)									
L1	Reference series	20	2 ϕ	7 ϕ	C20/25	6/7 ϕ	7 ϕ	5	2.2.1
L2	Influence of concrete cover	20	3,5 ϕ [2]	7 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
L3		20	5 ϕ [2]	7 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
L4	Influence of concrete strength	20	2 ϕ	7 ϕ	C35/45	6/7 ϕ	7 ϕ	5	
L5		20	2 ϕ	7 ϕ	C50/60	6/7 ϕ	7 ϕ	5	
L6	Influence of rebar diameter	12	2 ϕ	7 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
L7		ϕ_{max}	2 ϕ	7 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
L8 [3]	Influence of c_{max}/c_d	20	2 ϕ	2 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
L9 [3]		20	2 ϕ	4 ϕ	C20/25	6/7 ϕ	7 ϕ	5	
Derivation of global bond-splitting model (using confined splitting specimens)									
G1	Influence of bond length	25±2	2 ϕ	2 ϕ	C20/25	-	7ϕ	5	2.2.1
G2		25±2	2 ϕ	2 ϕ	C20/25	-	15 ϕ	5	
G3		25±2	2 ϕ	2 ϕ	C20/25	-	25 ϕ	5	
G4		25±2	2 ϕ	2 ϕ	C20/25	-	35 ϕ	5	

Resistance to pull-out failure in cracked concrete

Line	Purpose of test	Rebar ϕ[1]	Concrete strength	Crack width [mm]	Setting depth l_b[4] [mm]	Minimum no. of tests	clause
P1	Bond strength in uncracked concrete	s/m/l	C20/25	0,0	7 ϕ	5	2.2.2
P2		s/m/l	C50/60	0,0	7 ϕ	5	
P3	Bond strength in cracked concrete	s/m/l	C20/25	0,3	7 ϕ	5	
P4		s/m/l	C50/60	0,3	7 ϕ	5	

1) Diameter of the rebar ϕ; ϕ_{max} = maximum diameter of the rebar specified by the manufacturer. If the diameter 20 mm is not applied for, the closest rebar diameter applied for shall be tested.

2) These values may be reduced if the pull-out resistance of the rebar or steel yielding is reached.

3) For this test series the longitudinal cast-in rebar as per Figure 2.2.1.1 in the corner close to the post-installed rebar may be omitted. In such case, a longitudinal rebar may be added to increase confinement, but it shall be positioned at a distance of minimum 4ϕ from the post installed rebar, to avoid interferences (lap-splice) with it.

4) The embedment depth can be reduced to avoid steel failure.

Table A.1.1 Test programme (continued)

<table>
<tr><th colspan="9">Influence of cyclic loading on splitting (using BET specimens)</th></tr>
<tr><th>Series No.</th><th>Purpose of test</th><th>Rebar ϕ [2)]</th><th>Concrete strength</th><th>Concrete cover c_d [mm]</th><th>Transverse reinforcement Ø/spacing [mm] [6)]</th><th>Setting depth l_b [mm]</th><th>Minimum no. of tests</th><th>Section</th></tr>
<tr><td>L1-S</td><td>Reference series</td><td>20</td><td>C20/25</td><td>2 ϕ</td><td>6/7 ϕ</td><td>7 ϕ</td><td>5+5R [4)]</td><td rowspan="4">2.2.3</td></tr>
<tr><td>L5-S</td><td>Influence of concrete strength</td><td>20</td><td>C50/60</td><td>2 ϕ</td><td>6/7 ϕ</td><td>7 ϕ</td><td>5+5R [4)]</td></tr>
<tr><td>L6-S</td><td rowspan="2">Influence of rebar diameter</td><td>12</td><td>C20/25</td><td>2 ϕ</td><td>6/7 ϕ</td><td>7 ϕ</td><td>5+5R [4)]</td></tr>
<tr><td>L7-S</td><td>ϕ_{max}</td><td>C20/25</td><td>2 ϕ</td><td>6/7 ϕ</td><td>7 ϕ</td><td>5+5R [4)]</td></tr>
<tr><th colspan="9">Influence of increased crack width on pull-out resistance</th></tr>
<tr><th>Series No. [1)]</th><th>Purpose of test</th><th>Rebar ϕ [2)]</th><th>Concrete strength</th><th colspan="2">Crack width [mm]</th><th>Setting depth l_b [3)] [mm]</th><th>Minimum no. of tests</th><th>Section</th></tr>
<tr><td>B10</td><td rowspan="2">Bond strength in cracked concrete</td><td>s/m/l [5)]</td><td>C20/25</td><td colspan="2">0,5</td><td>7 ϕ</td><td>5</td><td rowspan="4">2.2.4</td></tr>
<tr><td>B11</td><td>s/m/l [5)]</td><td>C50/60</td><td colspan="2">0,5</td><td>7 ϕ</td><td>5</td></tr>
<tr><td>C2.1a</td><td rowspan="2">Bond strength in cracked concrete</td><td>s/m/l [5)]</td><td>C20/25</td><td colspan="2">0,8</td><td>7 ϕ</td><td>5</td></tr>
<tr><td>C2.1b</td><td>s/m/l [5)]</td><td>C50/60</td><td colspan="2">0,8</td><td>7 ϕ</td><td>5</td></tr>
<tr><th colspan="9">Influence of alternating cyclic loading on pull-out resistance</th></tr>
<tr><td>S1</td><td rowspan="2">Bond strength under cyclic loading</td><td rowspan="2">ϕ_{min}; ϕ_{medium}; ϕ_{max}</td><td>C20/25</td><td colspan="2">0,0</td><td>7 ϕ</td><td>5</td><td rowspan="2">2.2.5</td></tr>
<tr><td>S2</td><td>C50/60</td><td colspan="2">0,0</td><td>7 ϕ</td><td>5</td></tr>
</table>

1) Numbering of series consistent with that of EAD 330499-01-0601 (B10, B11, C2.1a and C2.1b) and EAD 330087-01-0601 (S1 and S2)
2) ϕ_{max} (ϕ_{min}) = maximum (minimum) diameter of the rebar specified by the manufacturer $\phi_{medium} \approx (\phi_{max}+\phi_{min})/2$. If the diameters 12 and/or 20 mm are not applied for, the closest rebar diameters applied for shall be tested.
3) The embedment depth can be reduced to avoid steel failure.
4) Reference monotonic test in the same concrete and rebars batches
5) "s/m/l" according to Table A.1.2
6) This spacing represents the distance between the stirrups in Figure 2.2.1.1.

For the test series P1 to P4 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.1.2.

Table A.1.2 Reduced range of tested sizes s/m/l

Number of requested sizes	Number of diameters to be tested
Up to 5	3
6 to 8	4
9 to 11	5
More than 11	6

A.2 Provisions for all test series

As far as applicable, Annex B shall be followed with respect to the test members, test setup and performance of the tests.

It is recommended that handling of tests and calibration items are performed in accordance with EN ISO/IEC 17025 [7].

For the assessment of a post-installed rebar the test series L1 to L9 shall be carried out including at least the following minimum number of different concrete batches within the programme of testing:

Assessment for C20/25	on at least 2 different batches, if the concrete comes from different concrete suppliers.
	on at least 3 different batches, if the concrete comes from the same concrete supplier.

If concrete batches come from the same concrete supplier, it shall be ensured that each batch is made from a different delivery of either cement or aggregates.

A.2.1 Installation

The rebar shall be installed in accordance with the MPII. The installation shall be conducted at normal ambient temperature (21°C ± 3°C).

For more indications see Annex B, clause B.2.

A.2.2 Concrete strength and concrete age

The tests are performed for the assessment in "low strength concrete C20/25" and "high strength concrete C50/60" as well as in C35/45. Therefore, the concrete strength at the time of testing the rebars shall be within the following limits:

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

C35/45: $45 \leq f_{c,cube} \leq 55$ [N/mm²]

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

For more indications about test members see Annex B, clause B.1.

A.2.3 Analysis of ultimate loads

A.2.3.1 Assessment of the failure mode

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

Tension tests:

- concrete cone failure (cc) – give diameter and depth of concrete cone
- splitting (sp) – test condition for tests in uncracked concrete characterized by first cracking along the rebar
- 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)
- combined bond and concrete failure in unconfined tests (bc)
- steel failure (s) – define position of the steel rupture over length of the rebar

If initial failure is not clear, a combination of failure modes may be reported.

A.2.3.2 Conversion of failure loads to concrete nominal strength

The conversion of failure loads shall be done according to Equations (A.2.3.2.1) to (A.2.3.2.4) depending on the failure mode.

Bond failure	$N_{u,p} = N_{u,t} \cdot \left(\frac{f_{ck}}{f_{c,t}}\right)^{m}$ with $\frac{f_{ck}}{f_{c,t}} \leq 1.0$	(A.2.3.2.1)
Confined uncracked [1)]	$m = \frac{\log(N_{u,m,P2} / N_{u,m,P1})}{\log(f_{c,P2} / f_{c,P1})} \leq 0.5$	(A.2.3.2.2)
Confined cracked [1)]	$m = \frac{\log(N_{u,m,P4} / N_{u,m,P3})}{\log(f_{c,P4} / f_{c,P3})} \leq 0.5$	(A.2.3.2.3)
Splitting failure [2)]	$N_{u,sp} = N_{u,t} \cdot \left(\frac{f_{ck}}{f_{c,t}}\right)^{sp1}$ with $\frac{f_{ck}}{f_{c,t}} \leq 1.0$	(A.2.3.2.4)

1) The exponent m derived in the assessment according to EAD 330499-01-0601 [2] shall be used.
2) Exponent sp1 according to equation 2.2.1.1

A.2.3.3 Conversion of failure load to bond strength

Pull-out failure

Failure loads of the tests, where pull-out failure occur shall be converted to bond strength related to the nominal diameter of the metal part according to equation (A.2.3.3.1).

$$\tau_{u,t} = \frac{N_{u,t}}{\pi \cdot \phi \cdot l_b} \left(\frac{0.08}{f_R}\right)^{0.4} \quad \text{(A.2.3.3.1)}$$

The failure (peak) load $N_{u,t}$ of an individual test shall be determined as follows taking into account the limiting displacement δ_1 as given in Table A.2.3.3.1:

- If the peak load is reached at a displacement $\delta \leq \delta_1$, the peak load shall be used as failure load.
- 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 A.2.3.2

Table A.2.3.3.1 Limiting displacement δ_1

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

Note 1: The limiting displacements δ_1 are derived in [16].
Note 2: The displacements δ_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 do not apply.

Splitting failure

The measured ultimate load reached in tests where splitting failure occurs shall be converted into bond resistance according to equation (A.2.3.3.2) and shall be normalised to the minimum characteristic concrete strength in accordance with A.2.3.2.

$$\tau_{u,t,sp} = \frac{N_{u,t,sp}}{\pi \cdot \phi \cdot l_b} \quad \text{(A.2.3.3.2)}$$

To limit the crack widths under service loads, in the series L1 to L9 the bond strength under service loads shall meet equation (A.2.3.3.3). If the requirement of equation (A.2.3.3.3) is not fulfilled, min ($\tau_{c1=0,3mm}$; $\tau_{c2=0,15mm}$) shall be taken as $\tau_{u,t}$.

$$min\left(\frac{\tau_{c1=0,3mm}}{\tau_{u,m}}; \frac{\tau_{c2=0,15mm}}{\tau_{u,m}}\right) \geq 0,5 \quad \text{(A.2.3.3.3)}$$

Where

$\tau_{u,m}$ is the mean ultimate bond strength for any given test series

$\tau_{c1=0,3mm}$ is the bond strength at which the crack C1 (refer to Figure A.2.3.3.1) reaches a width of 0,3 mm.

$\tau_{c2=0,15mm}$ is the bond strength at which the crack C2 (refer to Figure A.2.3.3.1) reaches a width of 0,15 mm.

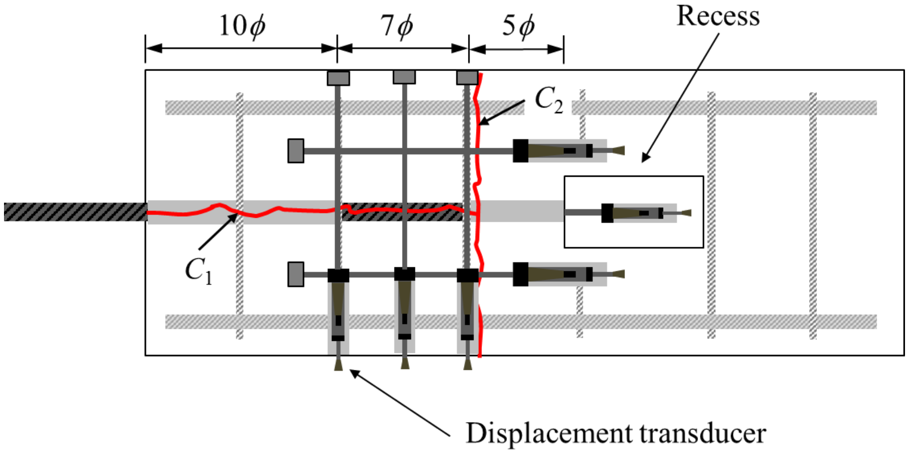


Figure A.2.3.3.1 Measurement of crack widths during the test for verification of serviceability limit state (C_1, longitudinal splitting crack; C_2, transversal splitting crack)

A.2.3.4 Conversion of failure load to account for concrete batch influence

Splitting failure

The conversion of failure loads for all the tests of the series L1 to L9 carried out in the i-batch $N_{u,t,i}$ shall be done according to equation (A.2.3.4.1).

$$N_{u,t,sp} = N_{u,t,i} \cdot \alpha_{ref,i} \quad \text{(A.2.3.4.1)}$$

The factor $\alpha_{ref,i}$ takes into account the sensitivity of each specific concrete batch using the results of reference tests (series L1) and it shall be:

$$\alpha_{ref,i} = \frac{\min \tau_{u,m,L1}}{\tau_{u,m,i,L1}} \leq 1.0 \quad \text{(A.2.3.4.2)}$$

The series L1 shall be conducted with at least 2 batches of concrete C20/25 used for the tests according to Table A.1.1.

If the coefficient of variation of the ultimate bond-splitting resistance of all results in the test series L1 to L9 is cv ≤ 15 %, the assessment according to equation (A.2.3.4.2) may be omitted and $\alpha_{ref,i}$ = 1,0 may be used. In this case the characteristic value of the bond-splitting resistance must be determined with a coefficient of variation of 15 %.

Pull-out failure

The conversion of failure loads for all the tests of the series P1 to P4 shall be carried out following the requirements of the EAD 330499-01-0601 [2] in this regard.

A.2.3.5 Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any test series according to Table A.1.1, lines L1 to L9, G1 to G4 and P1 to P4 exceeds 15%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03\,(cv_F - 15)} \leq 1{,}0 \qquad \text{(A.2.3.5.1)}$$

If the maximum limit for the coefficient of variation of the failure loads of 20 % is exceeded, the number of tests may be increased to meet this limit.

If the coefficient of variation of the failure load in any test series according to Table A.1.1, lines L1-S, L5-S, L6-S, L7-S, B10, B11, C2.1a, C2.1b, S1 and S2 exceeds 20 % (except for the monotonic reference tests for the series L1-S, L5-S, L6-S and L7-S), the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03\,(cv_F - 20)} \leq 1{,}0 \qquad \text{(A.2.3.5.2)}$$

If the maximum limit for the coefficient of variation of the failure loads of 30 % is exceeded, the number of tests may be increased to meet this limit.

The smallest result, min β_{cv}, in any test series shall be taken for assessment

A.2.3.6 Establishing 5 % fractile of bond-splitting resistance

The 5 %-fractile value of the ultimate bond resistance measured in a test series shall be calculated according to statistical procedures for a confidence level of 90 %. A test series can consist of more than one diameter of the rebar tested under the same conditions. If a precise verification does not take place, a normal distribution and an unknown standard deviation of the population shall be assumed; equations (A.2.3.6.1) and (A.2.3.6.2) apply.

$$\tau_{u,5\%} = \tau_{u,m}\,(1 - k_s \cdot cv_F) \qquad \text{(A.2.3.6.1)}$$

$$N_{u,95\%} = N_{u,m}\,(1 + k_s \cdot cv_F) \qquad \text{(A.2.3.6.2)}$$

e.g.,
n = 5 tests: k_s = 3,40
n = 10 tests: k_s = 2,57
n = 15 tests: k_s = 2,33
n = 20 tests: k_s = 2,21
n = 25 tests: k_s = 2,13
n = 30 tests: k_s = 2,08
n = 40 tests: k_s = 2,01
n = 50 tests: k_s = 1,97
n = 60 tests: k_s = 1,93
n= ∞ tests: k_s = 1,65

A.2.3.7 Failure loads (factors α_{cr} and Ω_{cr})

For test series P1 to P4 the mean failure loads and 5 %-fractile of failure loads shall be compared with the corresponding reference test series according to:

$$\alpha_{cr,20} = \beta_{cv} \cdot \max\{(1-N_{u,m,P3} / N_{u,m,P1})/0{,}3;\ (1-N_{u,5\%,P3} / N_{u,5\%,P1})/0{,}3\} \geq 0{,}0 \quad \text{in C20/25} \qquad \text{(A.2.3.7.1)}$$

$$\alpha_{cr,50} = \beta_{cv} \cdot \max\{(1-N_{u,m,P4} / N_{u,m,P2})/0{,}3;\ (1-N_{u,5\%,P4} / N_{u,5\%,P2})/0{,}3\} \geq 0{,}0 \quad \text{in C50/60} \qquad \text{(A.2.3.7.2)}$$

The comparison of the 5 %-fractile may be omitted for any number of tests in a test series when the coefficient of variation of the test series is smaller than or equal to the coefficient of variation of the reference test series or if the coefficient of variation in both test series is smaller than 15 %.

For test series B10, B11, C2.1a and C2.1b the mean failure loads shall be compared with the corresponding reference test series (i.e., series P1 and P2) according to:

$$\Omega_{cr,05,20} = \min \beta_{cv,05} \cdot N_{um,B10} / \left(0{,}9 \cdot N_{um,P1}\right) \leq 1{,}0 \quad \text{in C20/25} \qquad \text{(A.2.3.7.1)}$$

$\Omega_{cr,05,50} = \min \beta_{cv,05} \cdot N_{um,B11}/\left(0{,}9 \cdot N_{um,P2}\right) \leq 1{,}0$ in C50/60 (A.2.3.7.2)

$\Omega_{cr,08,20} = \min \beta_{cv,08} \cdot N_{um,C2.1a}/\left(0{,}9 \cdot N_{um,P1}\right) \leq 1{,}0$ in C20/25 (A.2.3.7.3)

$\Omega_{cr,08,50} = \min\beta_{cv,08} \cdot N_{um,c2.1b}/\left(0{,}9 \cdot N_{um,P2}\right) \leq 1{,}0$ in C50/60 (A.2.3.7.4)

ANNEX B DETAILS OF TESTS FOR POST-INSTALLED REBARS IN CONCRETE

B.1 Test members

B.1.1 General

Concrete members shall be made of compacted normal weight concrete without fibres with strength classes in the range of C20/25 - C50/60 in accordance with EN 206 [5].

The test members shall comply with the following:

B.1.2 Aggregates

Aggregates shall be of natural occurrence (i.e., non-artificial) and with a grading curve falling within the boundaries given in Figure B.1.2.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2,0 and 3,0 t/m³ (see EN 206 [5] and ISO 6783 [8]).

The boundaries reported in Figure B.1.2.1 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries may be adopted, if previously agreed with the responsible TAB.

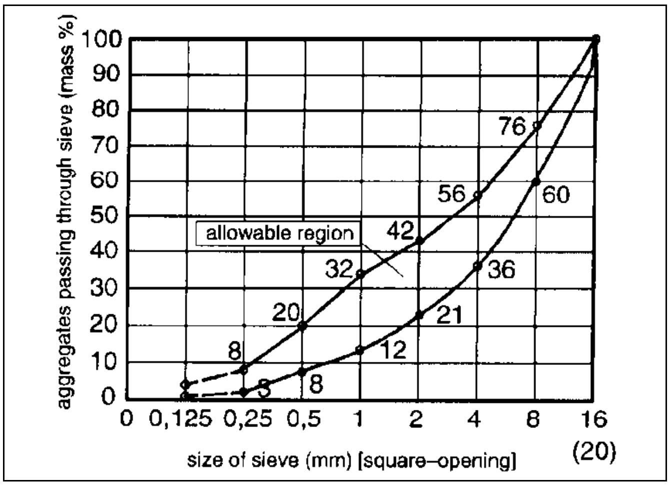


Figure B.1.2.1 Admissible region for the grading curve

B.1.3 Cement

The concrete shall be produced using Portland cement Type CEM I or Portland-Composite cement Type CEM II/A-LL, CEM II/B-LL (see EN 197-1 [9]).

B.1.4 Water/ cement ratio and cement content

The water/cement ratio shall not exceed 0,75 and the cement content shall be at least 240 kg/m³.

No additives likely to change the concrete properties (e.g., fly ash or silica fume or other powders) shall be included in the mixture.

B.1.5 Concrete strength

The concrete compressive strength shall be measured either on cylinders with a diameter of 150 mm and height of 300 mm, or on cubes of 150 mm.

The following conversion factors for concrete compressive strength from cube to cylinder shall be used:

C20/25 $$f_c = \frac{1}{1,25} f_{cube} \quad \text{(B.1.5.1)}$$

C50/60 $$f_c = \frac{1}{1,20} f_{cube} \quad \text{(B.1.5.2)}$$

For other dimensions, the concrete compressive strength may be converted as follows:

$$f_{cube100} = \frac{1}{0,95} f_{cube} \quad \text{(B.1.5.3)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \quad \text{(B.1.5.4)}$$

$f_{cube} = f_{core100}$ (according to EN 13791 [10], clause 7.1) (B.1.5.5)

Note: Additional literature for conversion is given by R. Lewandowski [15].

For every concreting operation, specimens (cylinder, cube) shall be prepared having the dimensions conventionally employed in the member country. The specimens shall be made, cured and conditioned in the same way as the test members.

Generally, the concrete control specimens shall be tested on the same day as the rebars to which they relate. If a test series takes a number of days, the specimens shall be tested at a time giving the best representation of the concrete strength at the time of the rebar tests, e.g., at the beginning and at the end of the tests. In this case the concrete strength at the time of testing can be determined by interpolation.

The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

If, when evaluating the test results, there should be doubts whether the strength of the control specimens represents the concrete strength of the test members, at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores may be converted into the strength of cubes by equation (B.1.5.5).

B.1 6 Test members for tests in cracked concrete

The tests shall be carried out on test members with unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. The thickness of the test member shall be $h \geqq 2\ l_b$ but at least 100 mm. To control cracking, so-called 'crack-formers' may be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure B.1.6.1

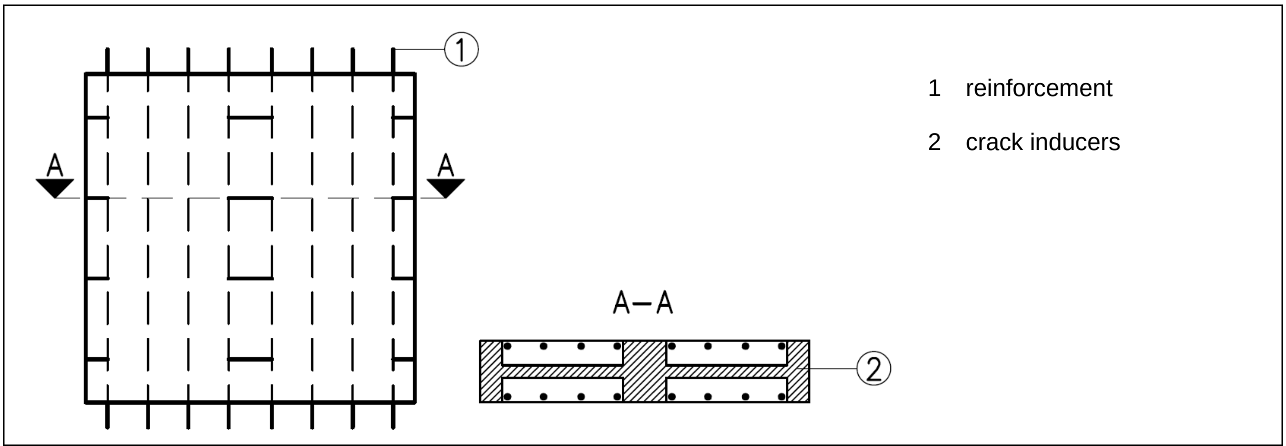


Figure B.1.6.1 Example of a test member for rebars tested in cracked concrete

B.1.7 Test members for tests in uncracked concrete

Generally, the tests shall be carried out on unreinforced test members. In cases where the test member contains reinforcement to allow handling or for the distribution of loads transmitted by the test equipment, the reinforcement shall be positioned such as to ensure that the loading capacity of the tested rebars is not affected. This requirement will be met if the reinforcement is located outside the zone of concrete cones having a vertex angle of 120°.

B.1.8 Casting and curing of test members

The test members shall be cast horizontally. They may also be cast vertically if the maximum height is 1,5 m and complete compaction is ensured.

Test members and concrete specimens (cylinders, cubes) shall be cured and stored indoors for seven days. Thereafter they may be stored outside provided they are protected such that frost, rain and direct sun does not cause a deterioration of the concrete compression and tension strength. When testing the rebars the concrete shall be at least 21 days old.

Test members and concrete specimen shall be stored in the same way.

B.2 Installation of rebars

The tested rebars shall be installed in a concrete surface that has been cast against a form of the test member.

The rebar shall be installed in accordance with the manufacturer's product installation instructions (MPII), except where special conditions are specified in the EAD for the test series.

When testing in cracked concrete, rebars are placed in the middle of hairline cracks. It shall be verified that the rebar is placed over the entire anchoring zone in the crack by suitable methods (e.g., borescope).

The holes for rebars shall be perpendicular (± 5° deviation) to the surface of the concrete member.

In the tests the drilling tools specified by the manufacturer for the rebars shall be used. If hard metal hammer-drill bits are required, these bits shall meet the requirements laid down in ISO 5468 [11] with regard to dimensional accuracy, symmetry, symmetry of insert tip, height of tip and tolerance on concentricity.

The diameter of the cutting edges as a function of the nominal drill bit diameter is given in Figure B.2.1.

The diameter of the drill bit shall be checked every 10 drilling operations to ensure continued compliance.

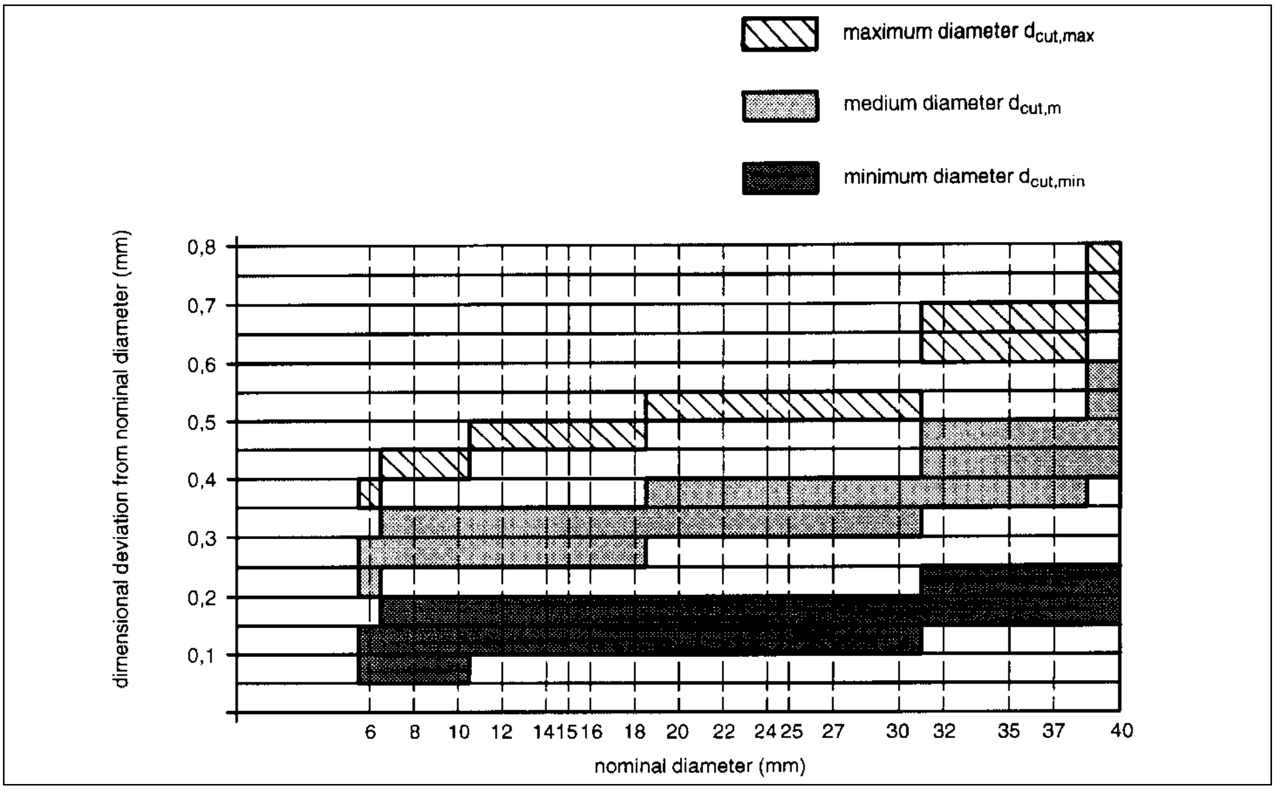


Figure B.2.1 Cutting diameter of hard metal hammer-drill bits

B.3 Test equipment

Tests shall be carried out using measuring equipment having a documented calibration according to international standards. The load application equipment shall be designed to avoid sudden increase in load especially at the beginning of the test. The measurement bias of the measuring chain of the load shall not exceed 2 % of the measured quantity value.

Displacements shall be recorded continuously (e.g., by means of electrical displacement transducers) with a measuring bias not greater than 0,020 mm or 2,0 % for displacements > 1 mm.

For unconfined tests the test rigs shall allow the formation of an unrestricted rupture cone. For this reason, the distance between the support reaction and a rebar shall be at least 2 l_b (tension test) as shown in Figure B.5.2.1.

During all tests, the load shall be applied to the rebar by a fixture representing the conditions found in practice.

In tests on single rebars without edge and spacing influences the centre-to-centre distance and the distances from free edges shall be large enough to allow the formation of an unrestricted rupture cone of vertex angle 120° in the concrete.

During tension tests the load shall be applied concentrically to the rebar. To achieve this, hinges shall be incorporated between the loading device and the rebar. An example of a tension test rig is illustrated in Figure B.5.2.1.

B.4 Test procedure – general aspects

The rebars shall be installed in accordance with the MPII, except where special conditions are specified in the EAD for the test series.

The tests in cracked concrete shall be undertaken in unidirectional cracks. The required crack width Δw is the difference between the crack width when loading the rebar and the crack width at rebar installation. After installation of the rebar the crack shall be widened to the required crack width while the rebar is unloaded. The initial crack width shall be set to within +10 % of the specified value. However, the mean value of a series shall reflect the specified value.

Use one-sided tolerance for crack width.

Then the rebar shall be subjected to load while the crack width is controlled, either

- at a constant width, for example, by means of a servo system, or
- limited to a width close to the initial value by means of appropriate reinforcement and depth of the test member.

In both cases the crack width at the face opposite to that through which the rebar is installed be maintained at a value larger than or equal to the specified value.

The load shall be increased in such a way that the peak load occurs after 1 to 3 minutes from commencement. Load and displacement shall be recorded continuously. The tests may be carried out with load, displacement or hydraulic control. In case of displacement control the test shall be continued beyond the peak of the load/displacement curve to at least 75 % of the maximum load to be measured (to allow the drop of the load/displacement curve). In case of displacement-controlled test setup the speed shall be kept constant.

The data shall be collected with a frequency of 3 Hz – 5 Hz.

B.5 Tension tests

B.5.1 General

After installation, the rebar shall be connected to the test rig and loaded to failure. The displacements of the rebar relative to the concrete surface shall be measured by use of either one displacement transducer on the head of the rebar or by use of at least two displacement transducers on either side at a distance of ≥ 1,5 l_b from the rebar; the mean value of the transducer readings shall be recorded in the latter case.

When testing in cracked concrete, the crack width shall be regularly measured during the test on both sides of the rebar at a distance of approximately 1,0 l_b and at least on the face of the test member in which the rebars are installed.

B.5.2 Unconfined test setup

Unconfined tests allow an unrestricted formation of the rupture concrete cone. An example for an unconfined test setup is shown in Figure B.5.2.1.

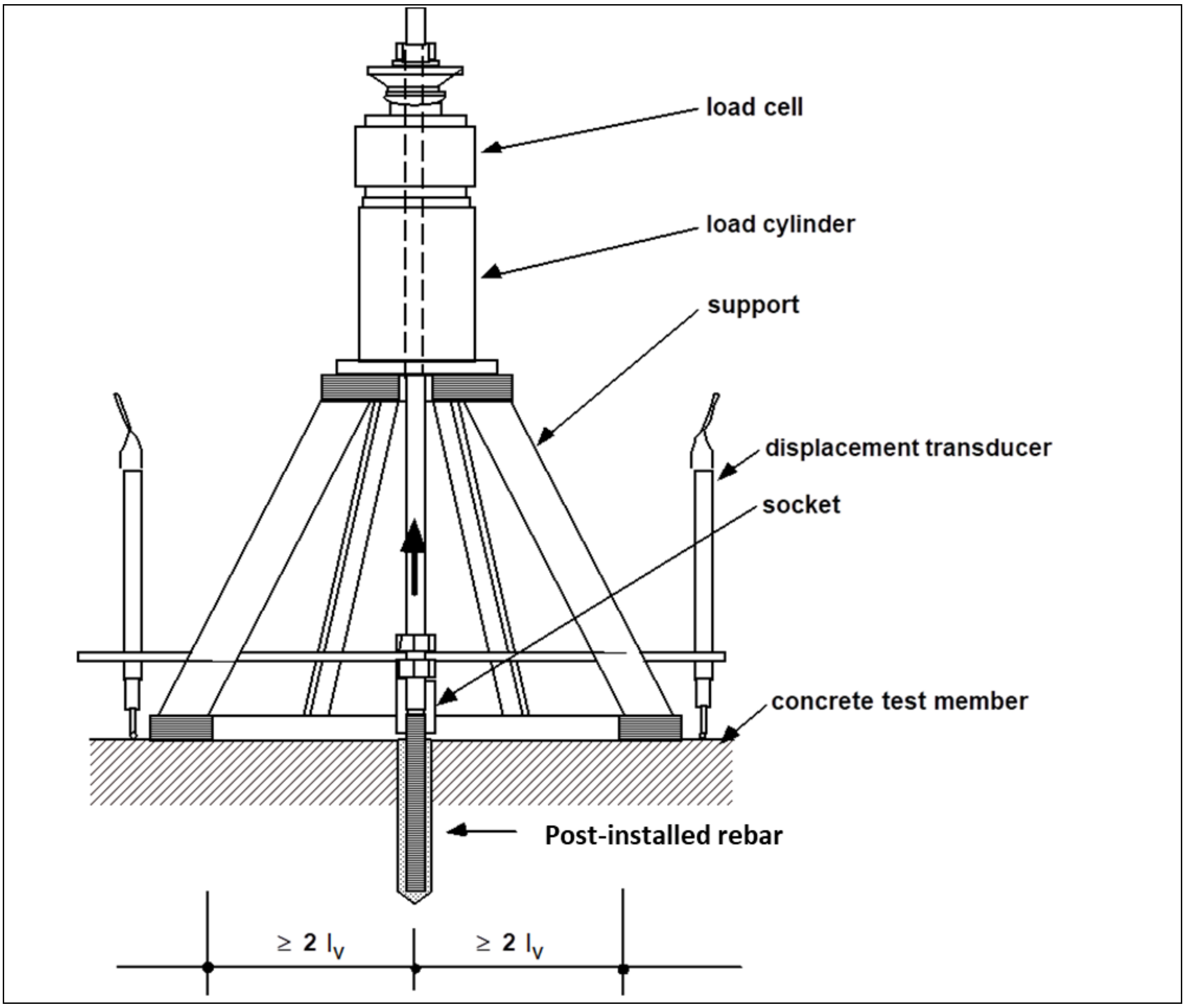


Figure B.5.2.1 Example of a tension test rig for unconfined tests (l_v =l_b= embedment depth

B.5.3 Confined test setup

Confined tests are performed when concrete cone failure shall be excluded (e.g., for bond resistance of bonded rebars). In confined tests concrete cone failure is eliminated by transferring the reaction force close to the rebar into the concrete.

An example of the test setup is shown in Figure B.5.3.1. The rig/steel plate shall be stiff and the area of support large to avoid high compression of the concrete. Recommendation: compression strength under the steel plate < 0,7 of the concrete compression strength.

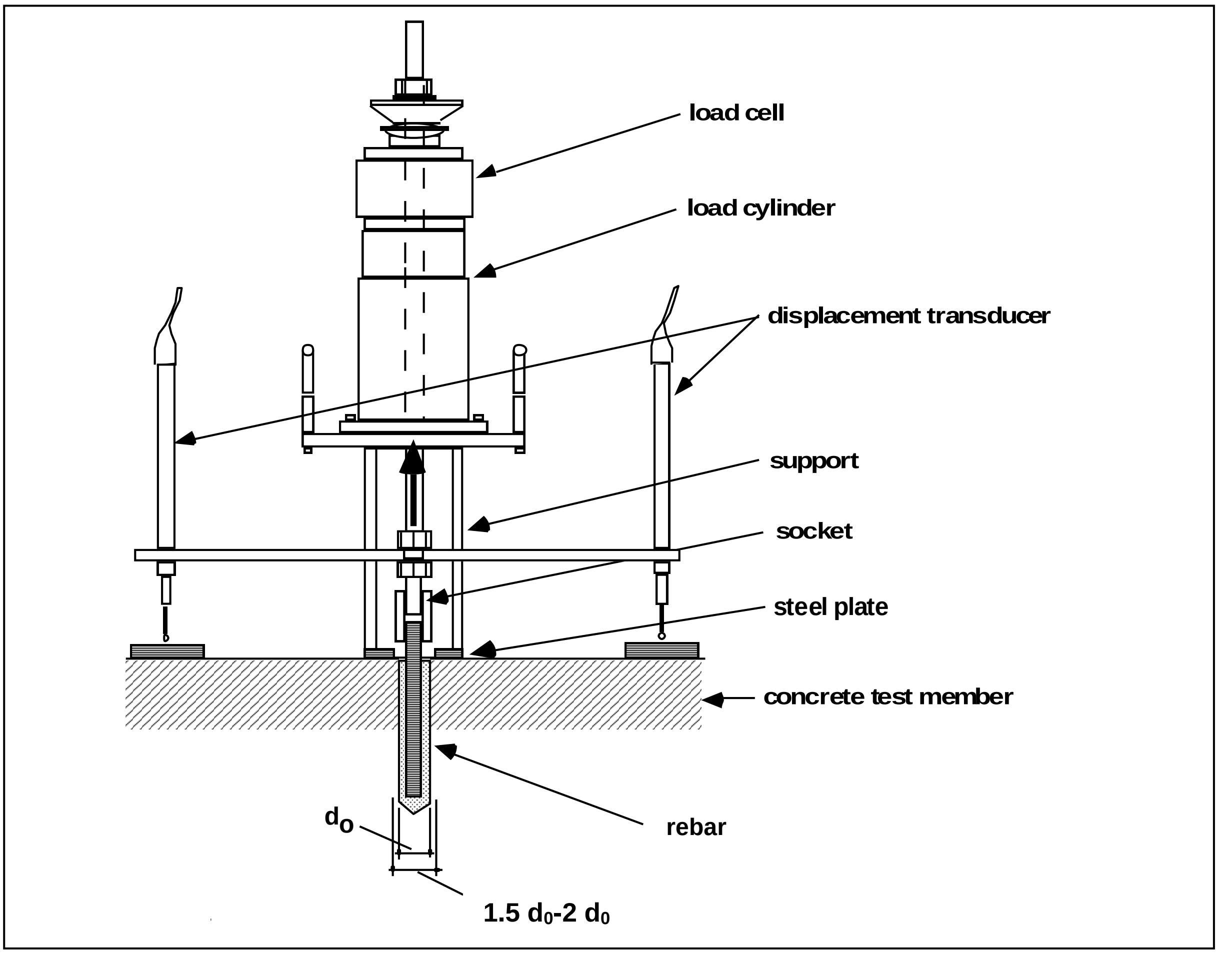


Figure B.5.3.1 Example of a tension test rig for <u>confined</u> tests

ANNEX C INSTALLATION OF POST-INSTALLED REBARS IN THE SPECIMENS OF THE TEST SERIES L1 TO L9

C.1 Preparation of tubes for post-installed rebars

For tests of the series L1 to L9, a tube (e.g., made of PVC) shall be cast in order to create a pilot hole to avoid deviations of the borehole axis during drilling. In both test specimens, the rebars show three different parts (see Figure C.1.1 and Figure C.4.1), an initial debonded length (l_{db1}), followed by the bond length (l_b) and another debonded length at the rear end (l_{db2}). Before casting, both rebar and tube shall be prepared in the same way. The steps of preparation of the rebars/tubes are described in Table C.1.1.

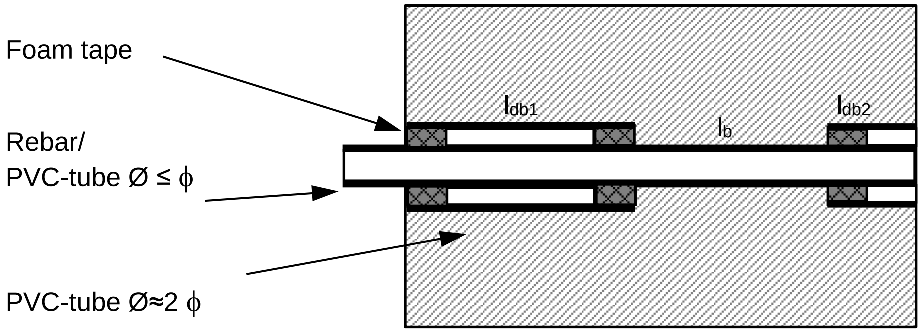


Figure C.1.1 Bonded and debonded parts of the rebars in the test specimen

Table C.1.1 Preparation of cast-in rebars/tubes

1	In the debonded parts the rebar/tube shall be covered by a tube with diameter of approximately 2 times the rebar diameter. The distance between the rebar/tube and the larger tubes in the debonded parts shall be sealed with a foam tape.	
2	The foam tape for cast-in rebars can be adhered directly to the rebar. In case of post-installed rebars, the foam tape can only be directly adhered to the inner tube in the initial debonded length (l_{db1}). In the second debonded length (l_{db2}), the foam tape needs to be movable on the tube surface, because the tube is pulled out before curing of the concrete.	
3	After preparation, the rebars/tubes shall be installed in the formwork. The covering tube of l_{db2} can be fixed at the recess. Therefore, it is recommended to use a wooden panel at least for this surface of the recess.	
4	To ensure secure positioning, the covering tube of l_{db1} can go through a hole in the formwork	

C.2 Casting of specimens

Before casting, all dimensions need to be checked, especially the thickness of the concrete cover and correct length and position of the bonded and debonded parts. When the concrete is poured in the formwork, it shall not directly fall on the installed tubes/rebars to ensure that they stay in the correct position. During cast-in of the specimen, the concrete shall be properly compacted with internal vibrators. This needs to be conducted very carefully, because the vibrator shall not touch the installed rebars/tubes. The tubes that were installed to create a pilot hole for post-installed rebars shall be removed after the concrete starts to cure.

C.3 Preparation of post-installed rebars Preparation of post-installed rebars

Before installation, post-installed rebars shall be prepared as shown in Table C.3.1 in order to create clearly defined bonded and debonded parts.

Table C.3.1 Preparation of post-installed rebars

1	Along the debonded part at the backside (l_{db2}) the ribs of the rebar shall be removed by turning using a lathe and hence the diameter of the rebar is reduced.	
2	The smoothed (e.g., reduced area) portion of the rebar shall be covered with a PVC tube of the nominal diameter of the rebar. During installation no mortar shall flow between rebar and tube. In some cases, it might, therefore, be necessary to adjust the diameter of the reduced part of the rebars to account for differences in the inner diameter of the tube using adhesive tape.	
3	The debonded part at the front side (l_{db1}) of the rebar shall be covered with a tube with a nominal diameter corresponding to the nominal drill bit diameter and sealed with hot melting glue.	 
4	An additional layer of adhesive foam tape can be applied around this tube.	

C.4 Installation procedure of post-installed rebars Installation procedure of post-installed rebars

All steps of the installation of post-installed rebars are explained in Table C.4.1. The flow of the adhesive (red colour) is schematically shown in Figure C.4.1. With this procedure, at least one weak layer between rebars and concrete is provided in both debonded parts. Thus, the load transfer in the debonded parts is reduced to a minimum for tension and compression loading, no matter if the failure of the bond happens between steel and mortar or between mortar and concrete.

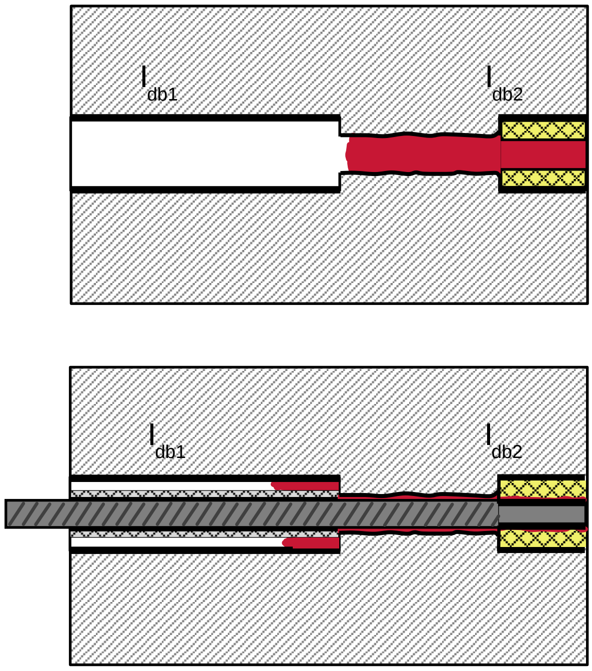


Figure C.4.1 Installation procedure (flow of the adhesive)

Table C.4.1 Description of the installation procedure

1	Drilling of the borehole. The pilot hole formed by the tube during casting shall be enlarged by drilling. A special rig shall be used to ensure that the hole is drilled perpendicular to the concrete surface. This technique, in addition to the provided pilot hole, ensures the correct borehole position. Additionally, the pilot hole helps to reduce spalling at the end of the borehole significantly After drilling, prior to the bore hole cleaning it shall be checked if the foam tape, which stayed in the concrete in debonded part l_{db2}, is completely removed. If it is not the case the tape shall be removed manually.	
2	Bore hole cleaning in accordance with the manufacturer's product installation instruction (MPII).	
3	Prior to injection of the mortar, a cylinder made of polystyrene shall be inserted in the tube at the unloaded end of the rebar (l_{db2}). Afterwards, the backside of the hole shall be sealed with a block of polystyrene.	  
4	The mortar shall be injected using a dispenser and a rebar prepared as explained in clause C.3 can be installed.	