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EAD **330387-00-0601**

October 2017

European Assessment Document for

Glass fibre-reinforced plastic connectors for use in sandwich and element walls made of concrete

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 No (EU) 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 European Assessment Document (EAD) covers connectors made of glass fibre-reinforced plastic (GFRP) for use in sandwich and element walls made of concrete (in the following generally referred to as connectors).

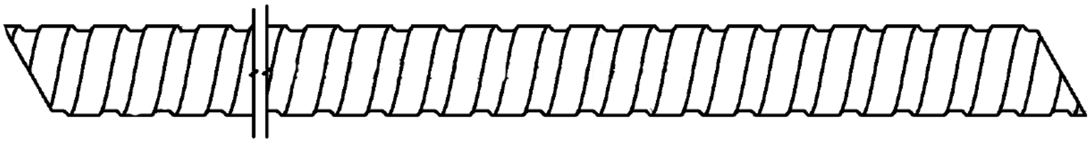
The construction product consists of a straight pin produced of unidirectional glass fibres embedded in plastic matrix optional with a collar made of plastic as illustrated in Figures 1.1.1 a) and b). The single glass fibres are bundled in rovings and orientated parallel to the pin.

Typical cross sections of connectors, surfaces and shapes of the ends of the pins are shown in Figures 1.1.2 to Figure 1.1.4 (examples).

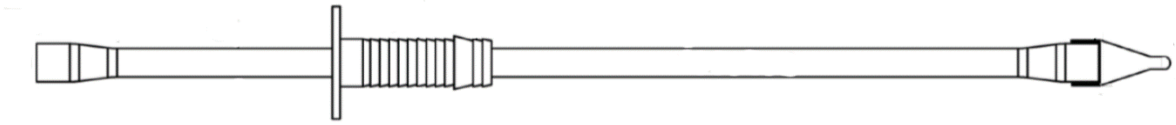
The assessment methods in this EAD apply to connectors with diameter of the pin between 6 mm and 16 mm for a round or quasi round cross section.

Both sides of a squared cross section are between 5 mm and 15 mm. The ratio between both sides of a squared cross section is not larger than 1,7.

The minimum and/or maximum dimensions are based on relevance in practice. All assessment methods have been developed / adjusted to these dimensions based on experiences and tests. Other dimensions could cause other failure modes, other stiffnesses and other mechanical models which are not assessed according to this EAD.

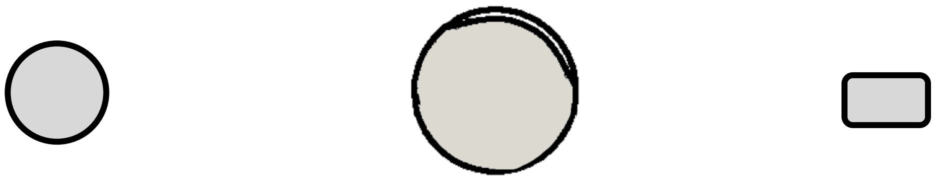


a) Pin without collar.



b) Pin with collar

Figure 1.1.1: Examples of pins



a) Round b) Quasi round c) Rectangular

Figure 1.1.2: Examples of cross sections

a) Smooth b) Ribbed

Figure 1.1.3: Examples of surfaces

a) Straight b) Dovetail shaped

Figure 1.1.4: Examples of shapes of ends of pin

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

The product is not covered by EAD 330389-00-0601[1]. Compared to EAD 330389-00-0601 this EAD covers linear (one-dimensional) GFRP-bars with unidirectional glass fibres used as fastener and designed in principle according to EN 1992-4 [3].

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

The connectors are intended to be used to connect cover layers to structural layers for sandwich walls with 3 layers and element walls according to Figure 1.2.1.1. The cover layer is supported.

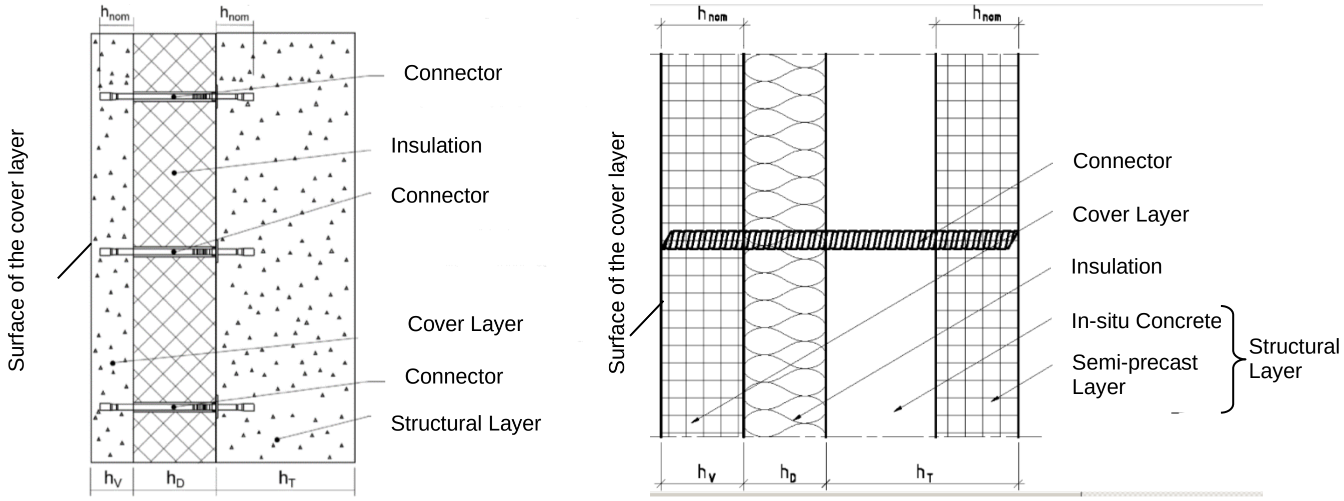
Sandwich walls consist of a precast cover layer, an insulation layer and a precast structural layer. Element walls consist of a precast cover layer, an insulation layer and a structural layer. The structural layer consists of an outer precast part and an inner in situ poured part.

The cover and structural layers are made of compacted normal-weight concrete without fibres with strength classes in the range of C20/25 to C50/60 in accordance with EN 206 [4].

The connector is intended to be used in cracked and uncracked concrete.

The connector is pushed through the insulation layer into the wet concrete of the cover layer and afterwards this layer is compacted. No material of the insulation layer is pressed into the concrete.

Walls are precast in horizontal position. Primarily the cover layer is poured (reverse manufacturing). For sandwich walls the structural layer is poured directly on top of the insulation layer. For element walls the cover layer and the insulation layer including the connectors are turned into the wet concrete of the structural layer. For both wall types the structural layer is compacted after cast-in of the connectors.



a) Connector in sandwich wall

b) Connector in element wall

Figure 1.2.1.1: Examples of walls

The connector is anchored in concrete by mechanical interlock or bond. The connector is intended to be cast in only once.

The connectors are intended to be used subject to static or quasi-static loads. The loads may be permanent.

The connector is intended to be used to transmit tensile or compression loads, shear loads or any combination of these loads into the concrete.

The connector is intended to be used with a temperature on the surface of the concrete cover layer between +65 °C and -20 °C (maximum short-term temperature of +65 °C and maximum long-term temperature of 40°C).

In this EAD the assessment is made to determine characteristic values of the mechanical fastener for calculation analogous to EN 1992-4 [3].

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 connector for the intended use of 50 years when installed in the works (provided that the connector is subject to appropriate installation (see 1.1)). These provisions are based upon the current state of the art and the available knowledge and experience.

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

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

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

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

MPII = manufacturer’s product installation instructions

1.3.2 Notation

A = area (cross section) of a connector

c_{min} = minimum allowable edge distance

c_{nom} = nominal concrete cover according to EN 1992-1-1 [12]

cv_F = coefficient of variation related to loads

d = connector diameter

$d_{failure\ cone}$ = maximum value of diameter of failure cone

e_{max} = maximum distance between outer connector and fixpoint of the concrete layer (see Figure 2.2.3.3.1)

$\mathrm{E_N}$ = modulus of elasticity under normal force

$\mathrm{E_M}$ = modulus of elasticity under bending load

F = force in general (for the relevant test series N or V applies)

$F_{u,m}$ = mean value failure(ultimate) load of a test series

$F_{5\%}$ = 5% fractile of failure (ultimate) loads

$F_{u,t}$ = failure loads in a test series

$F_{u,c}$ = converted failure loads

f_c = concrete compressive strength measured on cylinders

$f_{c,t}$ = compressive strength of concrete at the time of testing

h_{nom} = overall connector embedment depth in the concrete (measured rectangular to the concrete surface)

$\mathrm{h_{D,max}}$ = maximum thickness of insulation layer

$\mathrm{h_{D,min}}$ = minimum thickness of insulation layer

$\mathrm{h_{T,min}}$ = minimum thickness of structural layer

$\mathrm{h_{V,max}}$ = maximum thickness of cover layer

$\mathrm{h_{V,min}}$ = minimum thickness of cover layer

$\mathrm{I_y}$ = area moment of inertia in y direction

$\mathrm{I_z}$ = area moment of inertia in z direction

$\mathrm{k_S}$ = tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90%, in general derived from a Gaussian distribution for which the population standard deviation is unknown

N = normal force (+N = tension force)

$\mathrm{N_{Rk,GFRP}}$ = characteristic resistance to GFRP failure under tension load

$\mathrm{N_{Rk,\ GFRP,0}}$ = basic value of characteristic resistance to GFRP failure under tension load

$N_{Rk, GFRP,ref}$ = reference value for characteristic resistance to GFRP failure under tension load

$N_{sust,test}$ = sustained tension load for tests

$N_{Rk, GFRP,D}$ = characteristic resistance to GFRP failure under compression load

$N_{Rk, GFRP,w}$ = residual tension resistance to GFRP failure after cyclic shear deformation

$N_{Rk,c,cr}$ = characteristic resistance to concrete failure in cracked concrete under tension load

$N_{Rk,c,cr,0}$ = basic value of characteristic resistance to concrete failure in cracked concrete under tension load

$N_{Rk,c,cr,ref}$ = reference value for characteristic resistance to concrete failure in cracked concrete under tension load

$N_{Rk,c,D}$ = characteristic resistance to concrete failure under compression load

$N_{Rk,c,N}$ = residual tension resistance to concrete failure after cyclic tension load

$N_{Rk,c,ucr}$ = characteristic resistance to concrete failure in uncracked concrete under tension load

$N_{Rk,c,ucr,0}$ = basic value of characteristic resistance to concrete failure in uncracked concrete under tension load

N_o = upper value of cyclic tension load

$N_{Rk,c,w}$ = residual tension resistance to concrete failure after cyclic shear deformation

n = number of tests of a test series

s_{min} = minimum allowable spacing

V = shear force

$V_{Rk, GFRP}$ = characteristic resistance to GFRP failure under shear load

$V_{Rk, GFRP,0}$ = basic value of characteristic resistance to GFRP failure under shear load

$V_{Rk, GFRP,ref}$ = reference value for characteristic resistance to GFRP failure under shear load

$V_{sust,test}$ = sustained shear load for tests

$V_{Rk, GFRP,w}$ = residual shear resistance to GFRP failure after cyclic shear deformation

$V_{Rk,c}$ = characteristic resistance to concrete failure under shear load

$V_{Rk,c,0}$ = basic value of characteristic resistance to concrete failure under shear load

$V_{Rk,c,ref}$ = reference value for characteristic resistance to concrete failure under shear load

$V_{Rk,c,w}$ = residual shear resistance to concrete failure after cyclic shear deformation

w_{max} = maximum acceptable shear deformation

$\alpha_{N, GFRP,w}$ = ratio of residual to reference tension resistance for GFRP failure after cyclic shear deformation

$\alpha_{N,c,w}$ = ratio of residual to reference tension resistance capacity for concrete failure after cyclic shear deformation

$\alpha_{V, GFRP,w}$ = ratio of residual to reference shear resistance for GFRP failure after cyclic shear deformation

$\alpha_{V,c,w}$ = ratio of residual to reference shear resistance for concrete failure after cyclic shear deformation

α_1 = reduction factor for cyclic shear deformation

α_2 = reduction factor for cyclic tension load

α_3 = reduction factor for sustained tension load

α_4 = reduction factor for sustained shear load

α_c = linear coefficient of thermal expansion

ΔT = temperature difference between cover layer and structural layer

1.3.3 Indices

cr = cracked concrete

ref = reference tests

t = tested result

u = ultimate – situation when failure occurs

ucr = uncracked concrete

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 connector 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			
1	Resistance to GFRP failure under compression load	2.2.1	Level $N_{Rk, GFRP,D}$ [kN]
2	Resistance to concrete failure under compression load	2.2.2	Level $N_{Rk,c,D}$ [kN]
3	Resistance to GFRP failure under tension load	2.2.3	Level $N_{Rk, GFRP}$ [kN]
4	Resistance to concrete failure (cracked and uncracked concrete) under tension load	2.2.4	Level $N_{Rk,c,cr}$ [kN], $N_{Rk,c,ucr}$ [kN]
5	Resistance to GFRP failure under shear load	2.2.5	Level $V_{Rk, GFRP}$ [kN]
6	Resistance to concrete failure under shear load	2.2.6	Level $V_{Rk,c}$ [kN]
7	Maximum acceptable shear deformation	2.2.7	Level w_{max} [mm]
8	Minimum edge distances and spacing	2.2.8	Level c_{min} [mm], s_{min} [mm]
9	Modulus of Elasticity	2.2.9	Level E_N, E_M [N/mm^2]
10	Geometric parameters	2.2.10	Level A [mm^2], I_y, I_z [mm^4]

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 program for the assessment of the various essential characteristics of the product is given in Annex A. Provisions valid for all tests are also given in Annex A. General aspects of the assessment are given in Annex B.

2.2.1 Resistance to GFRP failure under compression load (test series C1)

Purpose: Determination of the characteristic resistance to GFRP failure of the connector.

Required tests: Perform the tests according to Table A.1, line C1, until failure.

Test conditions: The test is carried out on connectors without collar cast into or not cast into concrete. Test results of tests with connectors not cast into concrete are on the safe side, test results of tests with connectors cast into concrete are more realistic. In case of dispute, tests with connectors not cast into concrete shall be performed. The samples shall be chosen out of different production batches. Both ends of the connector are supported sufficiently restraint according to Figure A.2.3.3.1 a) to cause failure of the connector. The clear distance between the supports is the maximum thickness of the thermal insulation plus the diameter of the bar. Report the failure load and failure mode of each test.

Assessment: Assessment of failure loads according to Annex B, B.2, and determination of the characteristic resistance according to the following Equation. The characteristic resistance shall be rounded down to 0,1 kN steps.

$$N_{Rk,\,GFRP,D} = F_{5\%}\,(C1) \qquad (2.2.1.1)$$

with: $F_{5\%}$ (C1) = 5%-fractile of the failure loads of test series C1

2.2.2 Resistance to concrete failure under compression load (test series C2)

Purpose: Determination of the characteristic resistance to concrete failure (punching).

Required tests: Perform the tests according to Table A.1, line C2, until failure

Test conditions: The tests are carried out on connectors embedded in uncracked concrete with the load applied to the connector (see also A.2.3.3). The thickness of the concrete member is $h_{V,min}$ and the connector is cast into concrete with the maximum overall connector embedment depth so that the minimum concrete cover c_{nom} in the direction of the load is given. The support of the concrete member does not influence the concrete cone. No thermal insulation is used. Report the failure load, failure mode and, if applicable, the concrete cone diameter of each test.

Assessment: Assessment of failure loads according to Annex B, B.1 and B.2, and determination of the characteristic resistance according to the following Equation. The characteristic resistance shall be rounded down to 0,1 kN steps.

$$N_{Rk,c,D} = F_{5\%}\,(C2) \qquad (2.2.2.1)$$

with: $F_{5\%}$ (C2) = 5%-fractile of the converted failure loads of test series C2

2.2.3 Resistance to GFRP failure under tension load

2.2.3.1 Short-term failure (test series N1)

Purpose: Determination of short-term behaviour

Required tests: Perform the tests according to Table A.1, line N1, until failure.

Test conditions: Test specimens shall be stored in the testing hall for such a long time that they assumed the temperature and humidity of the testing hall. The test is carried out on connectors not cast into concrete. Both ends of the connector are supported sufficiently restraint to cause tensile failure of the connector. Report the failure load and failure mode and location of each test.

Assessment: Assessment of failure loads according to Annex B, B.2, and determination of the reference tension resistance according to the following Equation:

$$N_{Rk,\,GFRP,ref} = F_{5\%}\,(N1) \qquad (2.2.3.1.1)$$

with: $F_{5\%}$ (N1) = 5%-fractile of the failure loads of test series N1

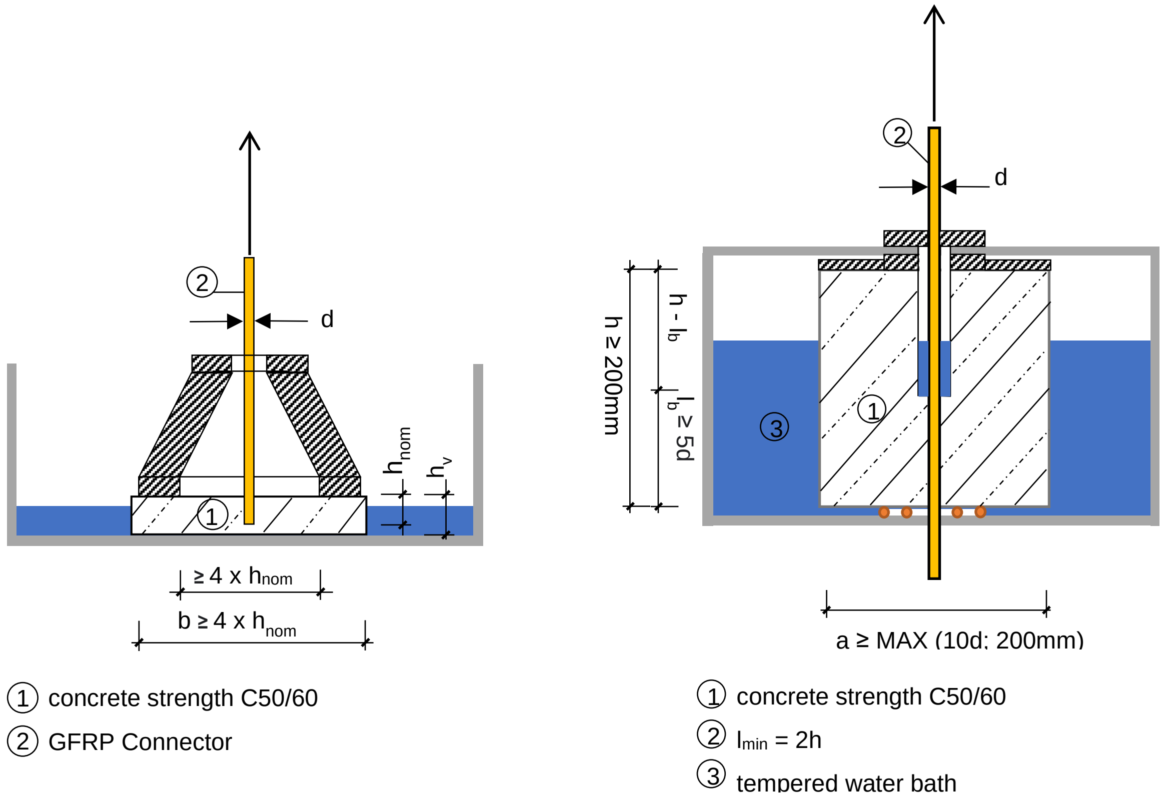
2.2.3.2 Sustained load (test series N2)

Purpose: Determination of the characteristic tension resistance of the connector for permanent loads.

Required tests: Perform the tests according to Table A.1, line N2, 60 °C

There are two different test conditions and evaluation of test results: Method A and B. One of the two methods can be selected.

Method A results in time-to-failure curves (more precise results). Method B is a simplified method without failure (safe side). If an assumption of a reduction factor α_3 for sustained loads for method B (see equation 2.2.3.2.1) is not possible, method A shall be used.



a) in concrete layer

b) in concrete cube according to RILEM

Figure 2.2.3.2.1: Examples for test setups for pull-out test under sustained tension load

Preconditioning and loading of test specimen for both methods:

The hardened cast in concrete connector specimens are stored for minimum 24h in 60°C water before load according method A or B is applied. The load shall be applied constantly comparable to a standard pull-out test during several minutes. After reaching the wanted load, the load is controlled at increasingly longer intervals. Minimum three times a week the load shall be controlled and adjusted.

Method A: Regression with time temperature shift with failure at different load levels

Test conditions: The test is carried out on connectors cast into high-alkaline concrete according to Annex A.2.1. One end of the connector is restraint to cause failure of the connector. The concrete is stored in a tempered water bath. The load is applied and held constant until failure.

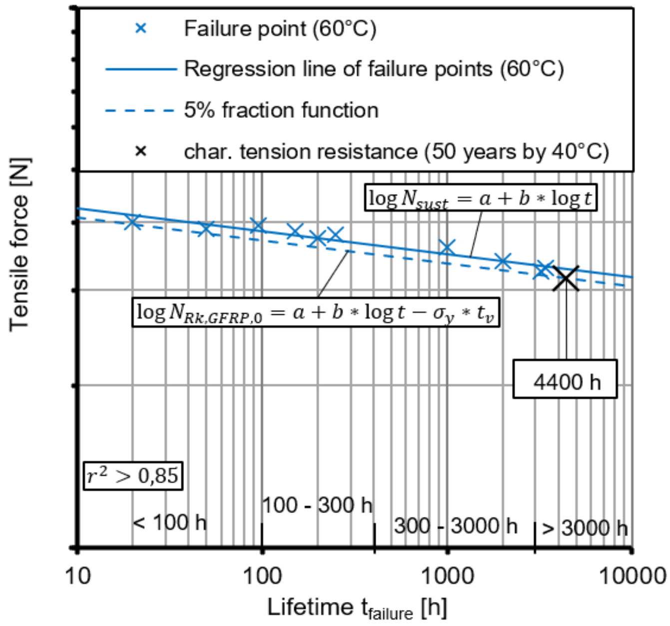
The load is chosen on different levels. The highest load for the expected shortest failure times can be determined through static tests with high loads. Depending on the material 70-90% of the short-term resistance can be chosen for times to failure < 100h. For most GFRP materials 10-25% less load leads to a tenfold time to failure.

An example of a testing rig is shown in Figure 2.2.3.2.1. Report the sustained load level, failure mode and location and time of failure of each test.

EN 705 [9], Method A, describes the assessment method for determination of the average of load for a time of 4400h. There shall be a minimum of n = 10 tests.

< 100 h	2 – 3 specimens
100 h – 300 h	2 – 3 specimens
300 h – 3000 h	2 – 3 specimens
> 3000 h	2 – 3 specimens

If the probability measure r^2 is smaller than 0,85 for n = 10 specimens the number of tests has to be accordingly increased so that the probability measure r^2 according to EN 705 [9] is achieved. Probability measures r^2 between n = 10 and n = 13 may be linear interpolated.



a -	Intersection point of the y-axis
b –	Gradient of regression line
t –	time [h]
σ_y -	Sum of the failure squares parallel to the y-axis divided by the number of tests (n-2)
t_v -	Student's time value for n-2 according to EN 705 [9]
r^2 -	Coefficient of determination of the points of failure to the regression line

Figure 2.2.3.2.2: Example of evaluating characteristic tensile resistance $N_{Rk,GFRP,0}$ for test method A

The characteristic value can be obtained by shifting the regression line.

Experiments are carried out up to a failure time of > 3.000 h at a temperature of 60°C. The degree of regression is to be extrapolated by means of EN 705 [9], Method A, over a period of 438.000 h (50 years). Subsequently, using the methods of the statistics, the 5% fraction is to be formed using the residual standard deviation and the student value.

Method B: Long-term test with one increased load and time temperature shift without failure

Test conditions: The test is carried out on connectors cast into high-alkaline concrete according to Annex A.2.1. One end of the connector is restraint to cause failure of the connector. The concrete is stored in a tempered water bath. The load is applied and held constant until failure.

The load is chosen by increasing the intended characteristic strength by the estimated coefficient of variation of the connector strength.

$$N_{sust,test} = \alpha_3 \cdot N_{Rk,GFRP,ref}\ (1 + cv_F) \quad [kN] \qquad (2.2.3.2.1)$$

$N_{sust,test}$ = sustained tension load for tests [kN]

α_3 = 0,8 [-]
reduction factor for sustained load

$N_{Rk,GFRP,ref}$ reference characteristic resistance of GFRP under tension load according to 2.2.3.1 [kN]

cv_F = coefficient of variation related to loads in test series Table A.1, line N1 [-]

The load is held constant until failure or 3000h. Report the sustained load level $N_{sust,test}$ and time of failure of each test. There shall be a minimum of 10 tests.

If one or more connectors fail or seem to fail during the 3000h, the series shall be performed for a smaller load (by using a smaller factor α_3 in Equation (2.2.3.2.1)) until there are 10 tests without failure.

Assessment:

The basic value of characteristic resistance $N_{Rk,\ GFRP,0}$ is determined according to the following Equation:

$$N_{Rk,\ GFRP,0} = minN_{sust,test} / (1 + cv_F) \quad [kN] \qquad (2.2.3.2.2)$$

$N_{Rk,GFRP,0}$ = Basic value of characteristic resistance of GFRP under tension load [kN]

$minN_{sust,test}$ = minimum sustained tension load of all tests without failure [kN]

cv_F = coefficient of variation related to loads in test series Table A.1, line N1 [-]

If the connector has a circular cross-section and it is demonstrated that the bond stress is independent of diameter in the short-term tests, it is possible to interpolate different diameters between the results of the tests under long-term stress.

The basic value of characteristic resistance $N_{Rk\ GFRP,0}$ of a connector shall be determined by one of the methods A or B.

Both methods deliver despite the testing temperature of 60°C a long-term resistance for 40°C and 50 years. This constant temperature is seen as representative concerning the durability for 50 years of service life in all European regions including the effect of the different daily and yearly surface temperature fluctuations in the range from -20°C to 65°C.

To limit the practical testing time and to ensure the resistance in the range of the practical maximum temperature, the test is made at 60°C with a shorter duration. The time/temperature shifting factor of 100 for shifting from 40 °C to 60°C is safe for a wide range of GFRP materials.

2.2.3.3 GFRP resistance after cyclic shear deformation (test series N3)

Purpose: Determination of the maximum acceptable shear deformation of the connector, without any damage of the connector, and determination of the reduction factor α_1 (N,GFRP).

Required tests: Perform the tests according to Table A.1, line N3, until failure after alternating shear deformation tests (pre-tests)

Pre-test conditions: Perform pushout tests with alternating shear deformation according to the following deformation collective with all 21.100 cycles for each test specimen according to Figure 2.2.3.3.1:

100 cycles with $\frac{7}{7}\, w_{\max}$

2.000 cycles with $\frac{6}{7}\, w_{\max}$

20.000 cycles with $\frac{4}{7}\, w_{\max}$

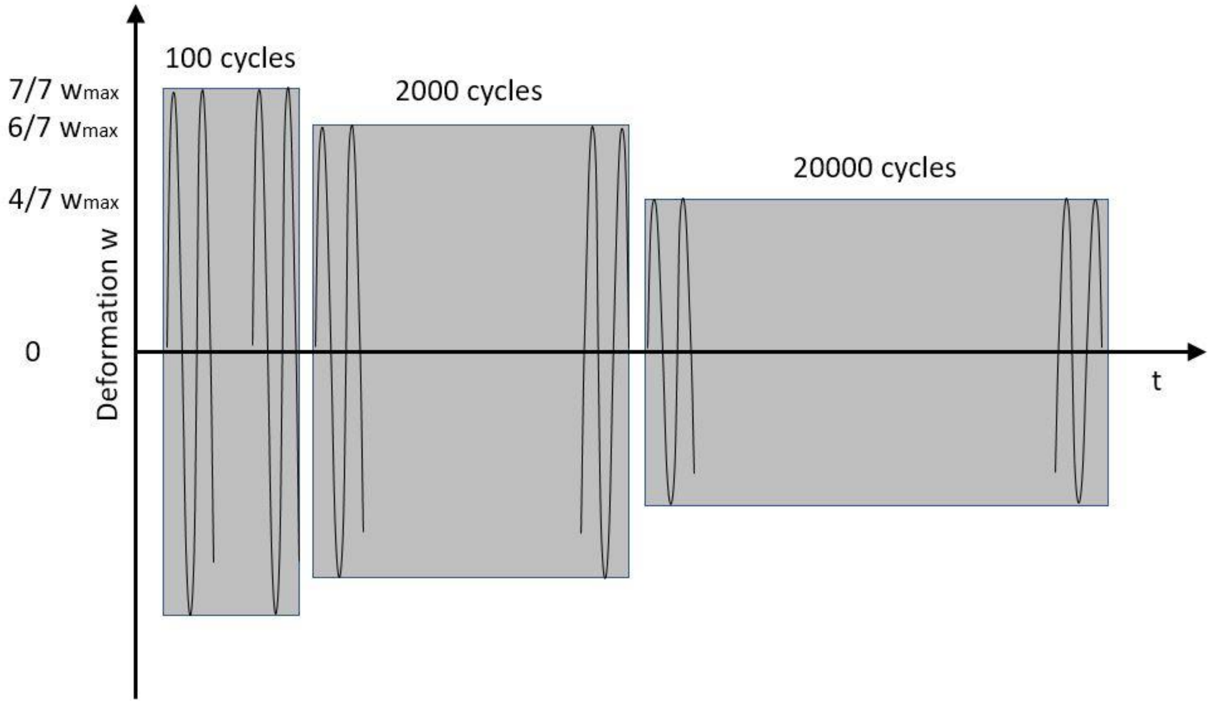


Figure 2.2.3.3.1: Deformation collective for cyclic shear of each test specimen

$$w_{\max} = \pm \alpha_c \cdot e_{\max} \cdot \Delta T \qquad \text{[mm]} \qquad (2.2.3.3.1)$$

$w_{\max}$ = Maximum shear deformation [mm]

α_c = Linear coefficient of thermal expansion of concrete = $10 \cdot 10^{-6}$ [K^{-1}]

$e_{\max}$ = Max. distance between outer connector and fixpoint of the cover layer [mm]

ΔT = Total temperature difference between cover layer and structural layer = 50 [K]

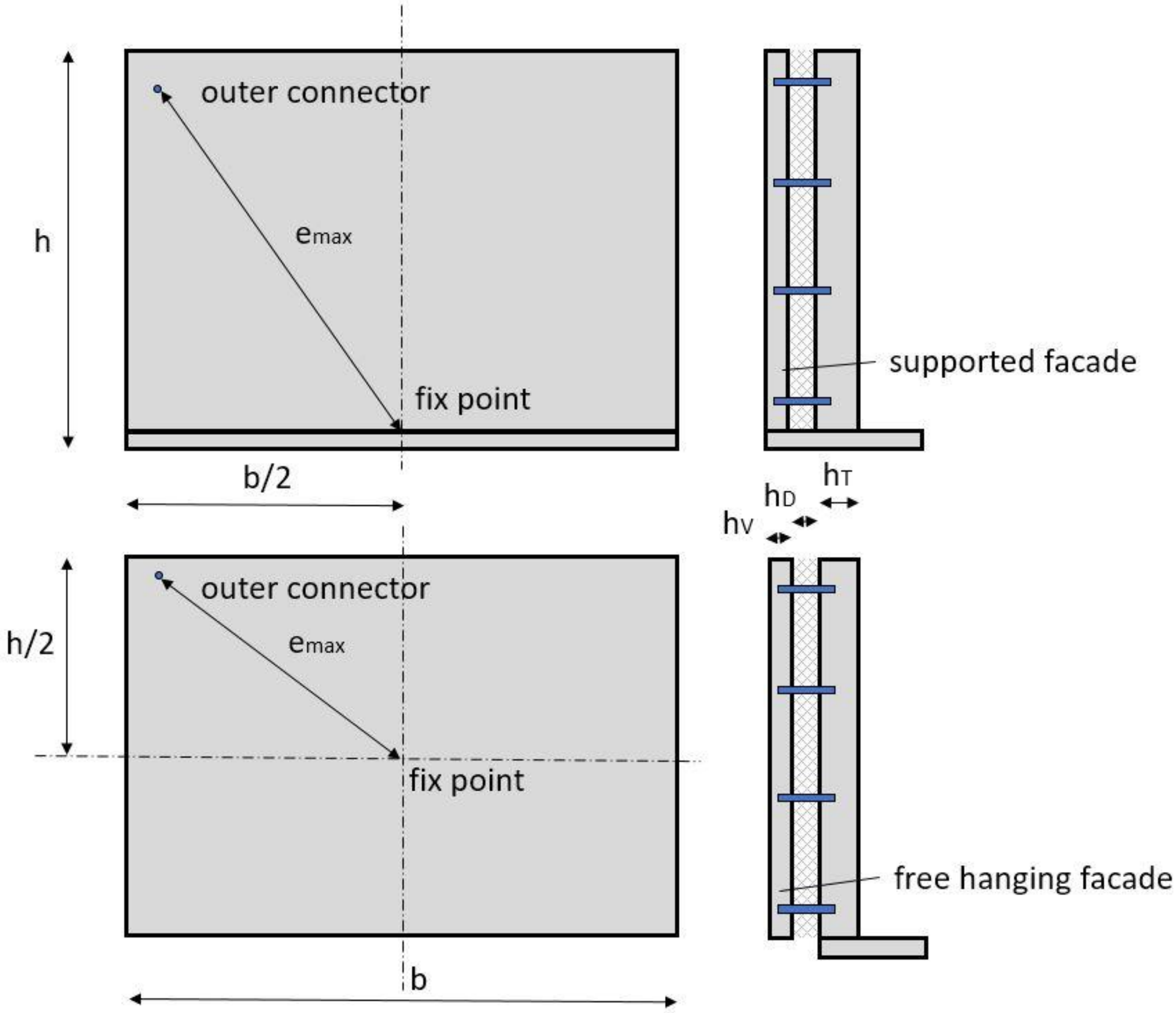
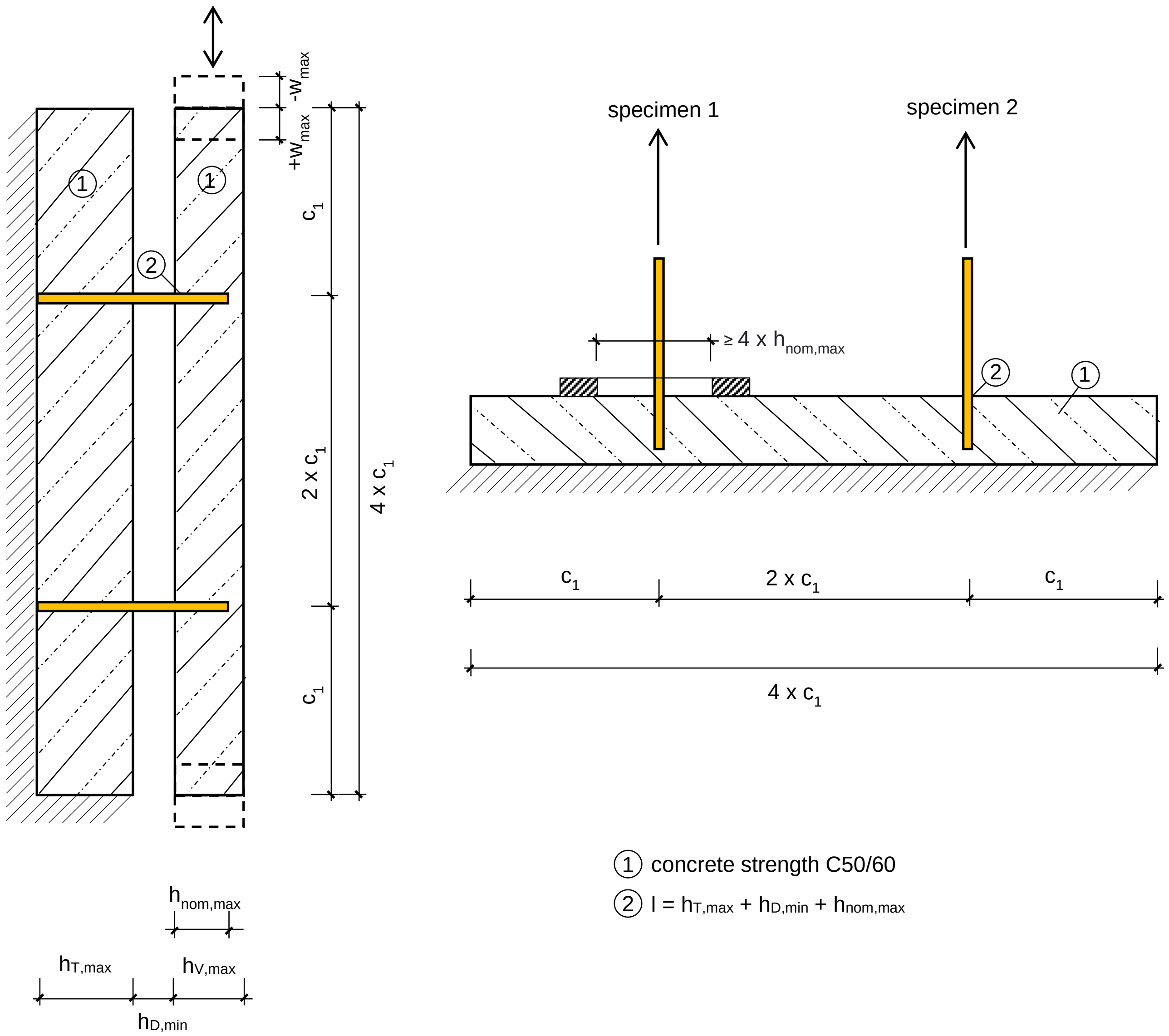


Figure 2.2.3.3.2: Example for maximum distance between outer connector and fixpoint e_{max} for supported and free hanging facade

The connectors are embedded with $h_{nom,max}$ in concrete C50/60 with $h_{T,max}$ and $h_{V,max}$. The tests represent $h_{D,max}$ of the thermal insulation.

After each pushout test the GFRP pin and the adjacent concrete shall be free of cracks and spallings. Else e_{max} will be reduced and the tests according to Table A.1, line N3, are repeated with an appropriate reduced w_{max}.

Test conditions: Perform tension tests of the pre-tested connectors until failure.



a) cyclic shear deformation test b) pull-out test

Figure 2.2.3.3.3: Example for a test setup cyclic shear deformation and for pull-out tests after that cyclic shear

Assessment in case of GFRP failure:

Assessment of failure loads according to Annex B, B.2, and determination of residual resistance $N_{Rk,GFRP,w}$ according to the following Equation:

$$N_{Rk,GFRP,w} = F_{5\%}\ (N3) \qquad (2.2.3.3.2)$$

with: $F_{5\%}$ (N3) = 5%-fractile of the failure loads of test series N3

The factor $\alpha_{N,GFRP,w}$ shall be calculated according to the following Equation:

$$\alpha_{N,GFRP,w} = \frac{N_{Rk,GFRP,w}}{N_{Rk,GFRP,ref}} \quad [-] \qquad (2.2.3.3.3)$$

$N_{Rk,GFRP,w}$ = Residual tension resistance to GFRP failure after cyclic shear deformation [kN]

$N_{Rk,GFRP,ref}$ = Reference tension resistance to GFRP failure according to 2.2.3.1 [kN]

The reduction factor shall be calculated according to the following Equation:

α_1 (N,GFRP) = $min\left(\frac{\alpha_{N,GFRP,w}}{0.9}; 1.0\right)$ [-] (2.2.3.3.4)

<u>Assessment in case of concrete failure (no part of GFRP connector fails)</u>:

The reduction factor α_1 (N,GFRP) = 1,0.

Note: Concrete failure after cyclic shear deformation is assessed in 2.2.4.4.

2.2.3.4 Characteristic resistance to GFRP failure under tension load

The characteristic resistance $N_{Rk,GFRP}$ is determined according to the following Equation and $N_{Rk,GFRP}$ is rounded down to 0,1 kN steps:

$N_{Rk,GFRP}$ = $N_{Rk,GFRP,0} \cdot \alpha_1$ (N,GFRP) [kN] (2.2.3.4.1)

$N_{Rk,GFRP,0}$ = According to 2.2.3.2 [kN]

α_1 (N,GFRP) = According to 2.2.3.3 [-]

2.2.4 Resistance to concrete failure under tension load

2.2.4.1 Concrete cone or pull-out failure in low-strength concrete (test series N4)

<u>Purpose</u>: Determination of the basic value of the characteristic resistance for concrete failure in low-strength concrete

<u>Required tests</u>: Perform the tests according to Table A.1, line N4 until failure.

<u>Test conditions</u>: The tests are carried out on connectors embedded in uncracked concrete with the load applied to the connector (see also A.2.3.1). The thickness of the concrete member is $h_{V,min}$ and the connector is cast into concrete with the minimum overall connector embedment depth. The support of the concrete member does not influence the concrete cone. No thermal insulation is used. Report the failure load, failure mode and, if applicable, the concrete cone diameter of each test.

<u>Assessment:</u> Assessment of failure loads according to Annex B, B.1 and B.2, and determination of the basic value of characteristic resistance $N_{Rk,c,ucr,0}$ (C20/25, uncracked concrete) according to the following Equation:

$N_{Rk,c,ucr,0}$ (C20/25) = $F_{5\%}$ (N4) (2.2.4.1.1)

with: $F_{5\%}$ (N4) = 5%-fractile of the converted failure loads of test series N4

2.2.4.2 Concrete cone or pull-out failure in high-strength concrete (test series N5)

<u>Purpose</u>: Determination of the basic value of the characteristic resistance for concrete failure in high-strength concrete.

<u>Required tests</u>: Perform the tests according to Table A.1, line N5, until failure if resistances considering concrete compression strength are manufacturer's interest.

<u>Test conditions</u>: The tests are carried out on connectors embedded in uncracked concrete with the load applied to the connector. The thickness of the concrete member is $h_{v,min}$ and the connector is cast into concrete with the minimum overall connector embedment depth. The support of the concrete member does not influence the concrete cone. No thermal insulation is used. Report the failure load, failure mode and, if applicable, the concrete cone diameter of each test.

Assessment: Assessment of failure loads according to Annex B, B.1 and B.2, and determination of the basic value of characteristic resistance $N_{Rk,c,ucr,0}$ (C50/60, uncracked concrete) according to the following Equation:

$$N_{Rk,c,ucr,0}\,(C50/60) = F_{5\%}\,(N5) \tag{2.2.4.2.1}$$

with: $F_{5\%}$ (N5) = 5%-fractile of the converted failure loads of test series N5

2.2.4.3 Concrete cone or pull-out failure in cracked concrete (test series N6)

Purpose: Determination of the basic value of the characteristic resistance for concrete failure in low-strength cracked concrete.

Required tests: Perform the tests according to Table A.1, line N6 until failure.

Test conditions: The tests are carried out on connectors embedded in cracked concrete with crack width at least 0,3 mm and with the load applied to the connector according to the section A.2.1, A.2.2, A.2.3.1 and A.2.4.1.

Connectors are placed in the middle of hairline cracks. It shall be verified that the connector is placed over the entire anchoring zone in the crack by suitable methods (e.g., borescope). The thickness of the concrete member is $h_{V,min}$ and the connector is cast into concrete with the minimum overall connector embedment depth. The support of the concrete member does not influence the concrete cone. No thermal insulation is used.

Assessment: Assessment of failure loads according to Annex B, B.1 and B.2, and determination of the basic value of characteristic resistance $N_{Rk,c,cr,0}$ (20/25, cracked concrete) according to the following Equation:

$$N_{Rk,c,cr,0}\,(C20/25)= F_{5\%}\,(N6) \tag{2.2.4.3.1}$$

with: $F_{5\%}$ (N6) = 5%-fractile of the converted failure loads of test series N6

2.2.4.4 Concrete resistance after cyclic shear deformation (test series N7)

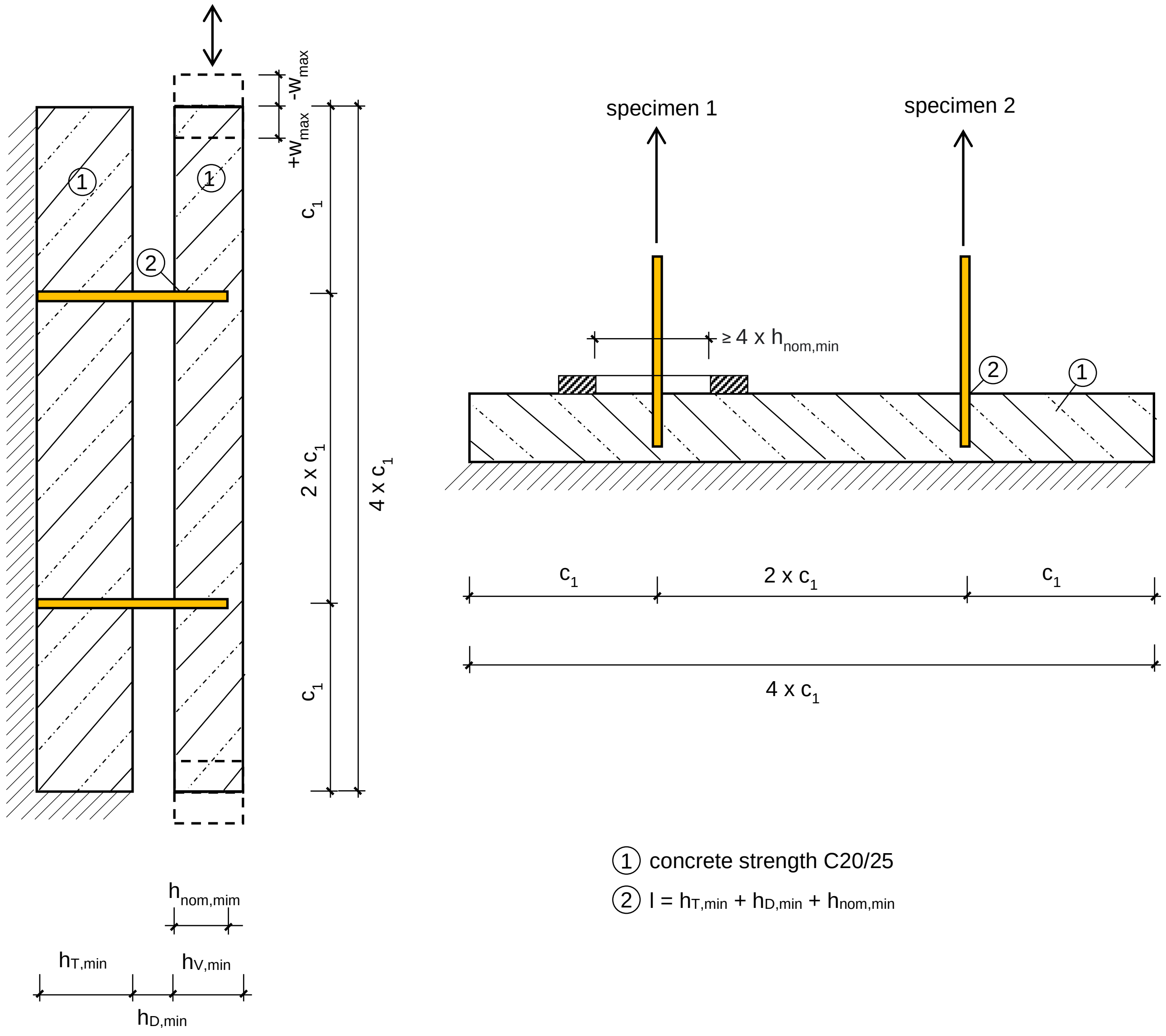
Purpose: Determination of the maximum acceptable shear deformation of the connector, without any damage of the concrete, and of the reduction factor α_1 (N,c).

Required tests: Perform the tests according to Table A.1, line N7, until failure after alternating shear deformation tests (pre-tests) if concrete damage due to high stiffness of the connector may occur.

Pre-test conditions: Perform pushout tests with alternating shear deformation according to section 2.2.3.3. The connectors are embedded with $h_{nom,min}$ in concrete C20/25 with min. h_T and min. h_V. The tests represent $h_{D,min}$ of the thermal insulation. An example of a test setup is shown in Figure 2.2.4.4.1.

After each pushout test the GFRP pin and the adjacent concrete shall be free of cracks and spallings. Else e_{max} will be reduced and tests according to 2.2.3.3 are repeated with an appropriate reduced w_{max}.

Test conditions: Perform tension tests of the pre-tested connectors until failure.



a) cyclic shear deformation test b) pull-out test

Figure 2.2.4.4.1: Example for a test setup cyclic shear deformation and for pull-out tests after that cyclic shear

Assessment: Assessment of failure loads according to Annex B, B.1 and B.2, and determination of residual resistance $N_{Rk,c,w}$ according to the following Equation:

$$N_{Rk,c,w} = F_{5\%}\ (N7) \qquad (2.2.4.4.1)$$

with: $F_{5\%}$ (N7) = 5%-fractile of the converted failure loads of test series N7

$$\alpha_{N,c,w} = \frac{N_{Rk,c,w}}{N_{Rk,c,ref}} \quad [-] \qquad (2.2.4.4.2)$$

$N_{Rk,c,w}$ = Residual tension resistance to concrete failure after cyclic shear deformation [kN]

The $N_{Rk,c,ref}$ = $N_{Rk,ucr,0}$ (basic value of characteristic resistance for concrete failure in low-strength concrete according to 2.2.4.1) [kN]

factor $\alpha_{N,c,w}$ shall be calculated according to the following Equation:

The reduction factor shall be calculated according to the following Equation:

$$\alpha_1 \text{ (N,c)} = \min\left(\frac{\alpha_{N,c,w}}{0.9};1.0\right) \quad [-] \qquad (2.2.4.4.3)$$

2.2.4.5 Concrete failure of connectors after cyclic tension load (test series N8)

Purpose: Determination of the resistance of the connector under repeated loads without any damage of the concrete.

Required tests: Perform the tests according to Table A.1, line N8, until failure after repeated tension load tests (pre-tests) if concrete damage may occur due to high stiffness of the connector.

Pre-test conditions: Perform pull-out tests with 22.100 cycles and repeated tension load. The tension load pulsates between $N_o = 0{,}6 * N_{Rk,c,ucr,0}$ (C20/25) as upper limit and $0{,}03 * N_0$ +-($0{,}02 * N_0$) as lower limit according to the following tension collective:

100	cycles with	$\frac{7}{7} N_o$
2.000	cycles with	$\frac{6}{7} N_o$
20.000	cycles with	$\frac{4}{7} N_o$

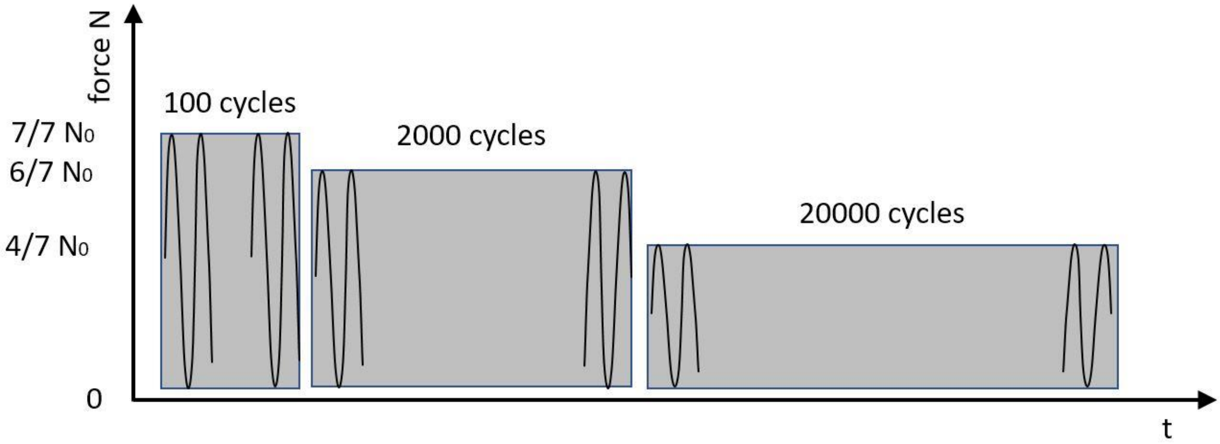
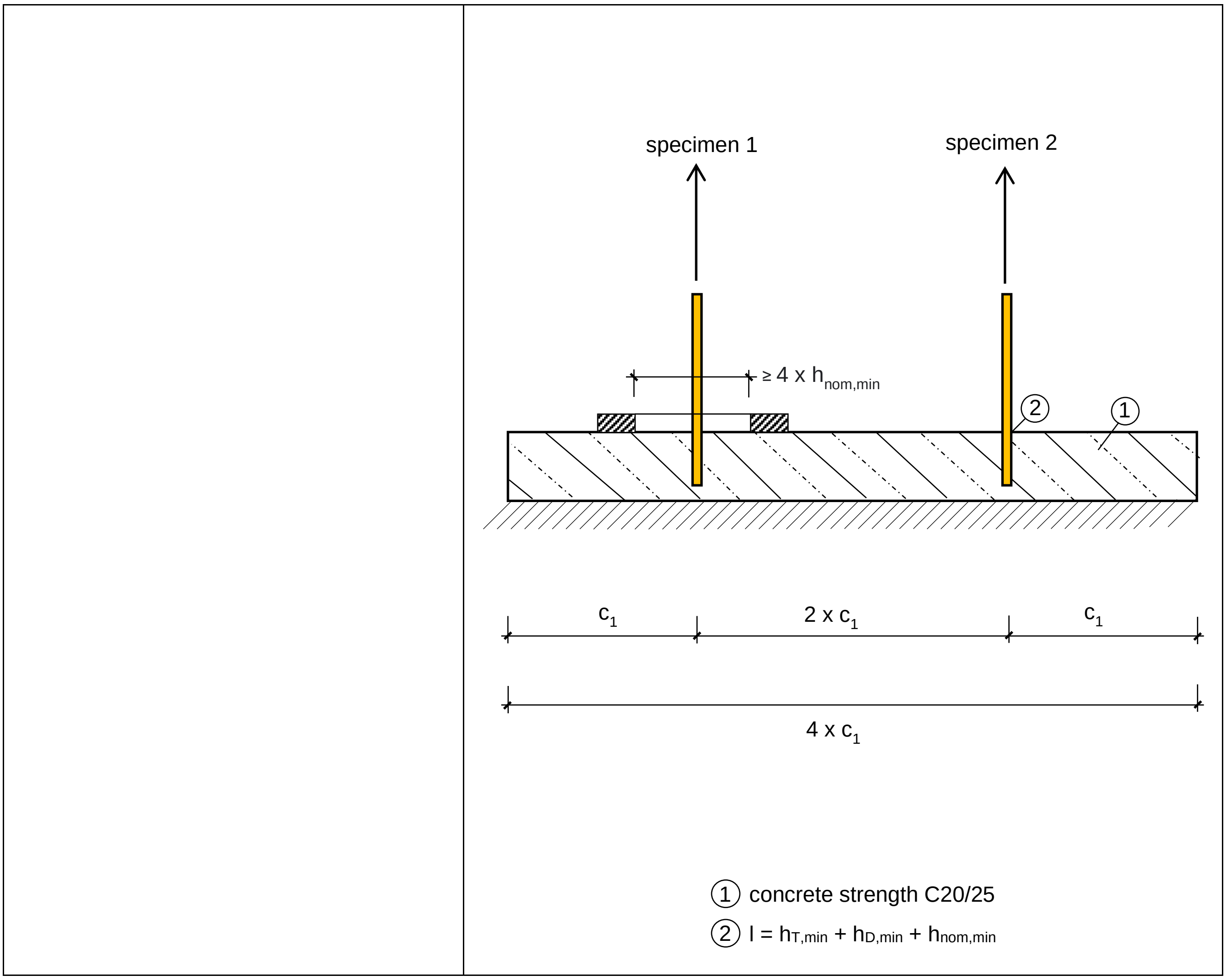


Figure 2.2.4.5.1: Tension collective for cyclic tension of each test specimen

The connectors are embedded with $h_{nom,min}$ in concrete C20/25 with $h_{T,min}$ and $h_{V,min}$. The tests represent $h_{D,min}$ of the thermal insulation.

Test conditions: Perform tension tests of the pre-tested connectors until failure.



a) cyclic tension test

b) pull-out test

Figure 2.2.4.5.2: Example for a test setup for cyclic tension and for push-out tests after that cyclic tension

<u>Assessment:</u> Assessment of failure loads according to Annex B, B.1 and B.2, and determination of residual resistance $N_{Rk,c,N}$ according to the following Equation:

$$N_{Rk,c,N} = F_{5\%}\ (N8) \qquad (2.2.4.5.1)$$

with: $F_{5\%}$ (N8) = 5%-fractile of the converted failure loads of test series N8

The factor $\alpha_{N,c,N}$ shall be calculated according to the following Equation:

$$\alpha_{N,c,N} = \frac{N_{Rk,c,N}}{N_{Rk,c,ref}} \quad [-] \qquad (2.2.4.5.2)$$

$N_{Rk,c,N}$ = Residual tension resistance to concrete failure after cyclic tension load [kN]

$N_{Rk,c,ref}$ = $N_{Rk,ucr,0}$ (basic value of characteristic resistance for concrete failure in low-strength concrete according to 2.2.4.1) [kN]

The reduction factor shall be calculated according to the following Equation:

$$\alpha_2(N,c) = \min\left(\frac{\alpha_{N,c,N}}{0.9};1.0\right) \quad [-] \qquad (2.2.4.5.3)$$

2.2.4.6 Characteristic resistance to concrete failure under tension load

The characteristic resistances $N_{Rk,c}$ are determined according to the following Equations and $N_{Rk,c}$ is rounded down to 0,1 kN steps:

$$N_{Rk,c,ucr}(C20/25) = N_{Rk,c,ucr,0}(C20/25) \cdot \alpha_1(N,c) \cdot \alpha_2(N,c) \quad [kN] \qquad (2.2.4.6.1)$$

$$N_{Rk,c,ucr}(C50/60) = N_{Rk,c,ucr,0}(C50/60) \cdot \alpha_1(N,c) \cdot \alpha_2(N,c) \quad [kN] \qquad (2.2.4.6.2)$$

$$N_{Rk,c,cr}(C20/25) = N_{Rk,c,cr,0}(C20/25) \cdot \alpha_1(N,c) \cdot \alpha_2(N,c) \quad [kN] \qquad (2.2.4.6.3)$$

$N_{Rk,c,ucr,0}(C20/25)$ = According to 2.2.4.1 [kN]

$N_{Rk,c,ucr,0}(C50/60)$ = According to 2.2.4.2 [kN]

$N_{Rk,c,cr,0}(C20/25)$ = According to 2.2.4.3 [kN]

$\alpha_1(N,c)$ = According to 2.2.4.4 [-]

$\alpha_2(N,c)$ = According to 2.2.4.5 [-]

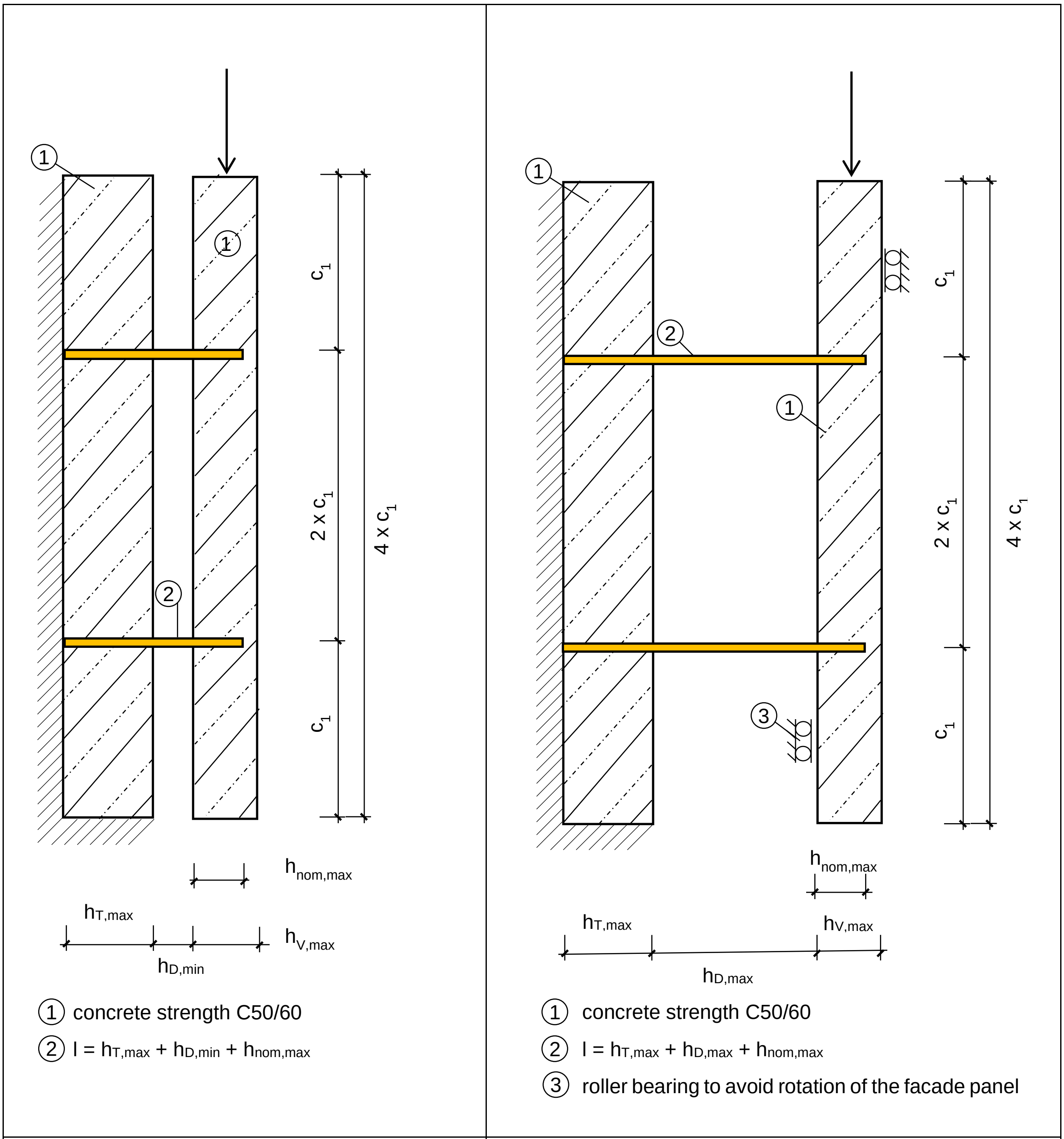
2.2.5 Resistance to GFRP material failure under shear load

2.2.5.1 Bending or interlaminar short-term failure (test series V1)

Purpose: Determination of short-term behaviour for bending or interlaminar shear failure as reference for tests

Required tests: Perform the tests according to Table A.1, line V1a, without thermal insulation (representing lowest stiffness of thermal insulation, e.g., mineral wool) and tests according to Table A.1, line V1b, with a roller bearing (representing highest stiffness of thermal insulation, e.g., glass foam).

Test conditions: Perform pushout tests . The tests are carried out on connectors embedded in uncracked concrete with the load applied to the concrete layers. The thickness of the concrete member is $h_{V,max}$ and the connector is cast into concrete with the maximum overall connector embedment depth. The support of the concrete member does not influence the concrete cone. The tests represent $h_{D,min}$ and $h_{D,max}$ of the thermal insulation. Report the failure load and failure mode.



a) Representing lowest stiffness

b) Representing highest stiffness

Figure 2.2.5.1.1: Example for test setup for monotonic shear simulating limit thermal insulations stiffnesses

Assessment: Assessment of failure loads according to Annex B, B.2, and determination of the characteristic reference resistance according to the following Equation:

$$V_{Rk,GFRP,ref} = \min (F_{5\%} (V1a); F_{5\%} (V1b)) \qquad (2.2.5.1.1)$$

with: $F_{5\%}$ (V1a) = 5%-fractile of the failure loads of test series V1a

$F_{5\%}$ (V1b) = 5%-fractile of the failure loads of test series V1b

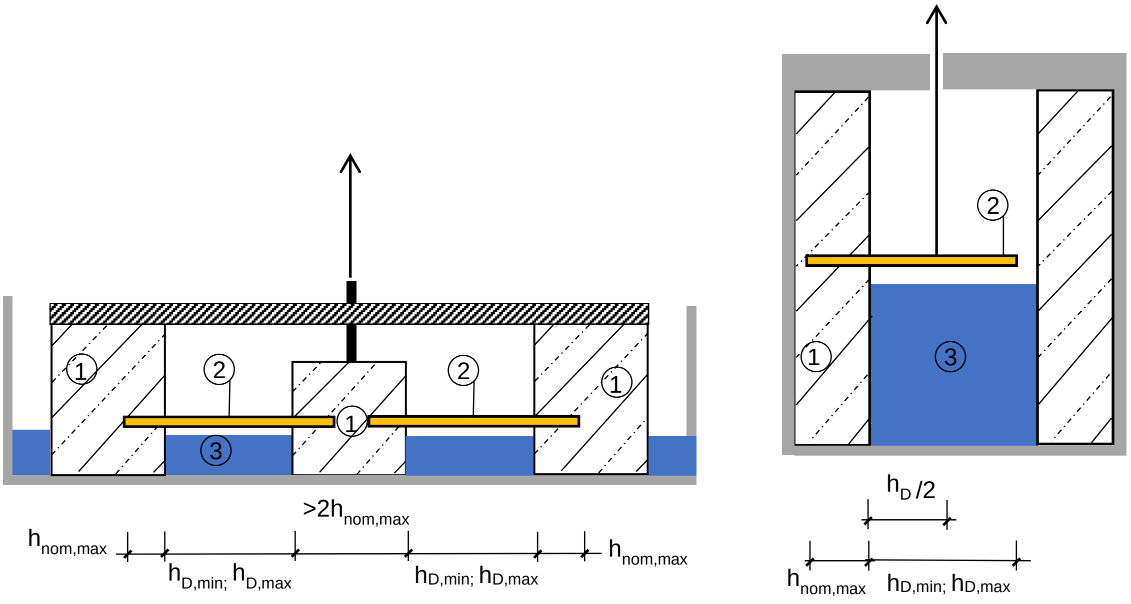
2.2.5.2 Sustained load (test series V2)

Purpose: Determination of the characteristic shear resistance of the connector for permanent loads.

Required tests: Perform the tests according to Table A.1, line V2, 60 °C

There are two different test conditions and evaluation of test results: Method A and B. One of the two methods can be selected.

Method A results in time-to-failure curves (more precise results). Method B is a simplified method without failure (safe side). If an assumption of a reduction factor α_3 for sustained loads for method B (see equation 2.2.3.2.1) is not possible, method A shall be used.



① concrete strength C50/60

② GFRP connector

③ tempered water bath

① concrete strength C50/60

② $l = h_{nom,max} + h_D$

③ tempered water bath

a) double push-out

b) single push-out

Figure 2.2.5.2.1: Examples for test setups for test under sustained shear load

<u>Preconditioning and loading of test specimen for both methods</u>:

The hardened cast in concrete connector specimens shall be stored for minimum 24h in 60°C water before load according to method A or B is applied. The load shall be applied constantly comparable to a standard pull-out test during several minutes. After reaching the wanted load, the load is controlled at increasingly longer intervals. Minimum three times a week the load shall be controlled and adjusted.

<u>Method A: Regression with time temperature shift with failure at different load levels</u>

<u>Test conditions</u>: The test is carried out on connectors cast into high-alkaline concrete according to Annex A.2.1. The ends of the connector are supported sufficiently restraint to cause failure of the connector. The concrete is stored in a tempered water bath. The load is applied and held constant until failure.

The load is chosen on different levels. The highest load for the expected shortest failure times can be determined through static tests with high loads. Depending on the material 70-90% of the short-term resistance can be chosen for times to failure < 100h. For most GFRP materials 10-25% less load leads to a tenfold time to failure.

An example of a testing rig is shown in Figure 2.2.5.2.1. The tests represent $h_{D,min}$ and $h_{D,max}$ of the thermal insulation. Report the failure sustained load level, failure mode and time of failure of each test.

EN 705 [9], Method A, describes the evaluation method for determination of the average of load for a time of 4400h. There shall be a minimum of n = 10 tests.

< 100 h	2 – 3 specimens
100 h – 300 h	2 – 3 specimens
300 h – 3000 h	2 – 3 specimens
> 3000 h	2 – 3 specimens

If the probability measure r^2 is smaller than 0.85 n= 10 specimens, the number of tests shall be accordingly increased so that the probability measure r^2 according to EN 705 [9] is achieved. Probability measures r^2 between n = 10 and n = 13 may be linear interpolated. An example of evaluating characteristic tensile resistance $N_{Rk,GFRP,0}$ for test method A is given in Figure 2.2.3.2.2. Evaluating $V_{Rk,GFRP,0}$ shall be done analogously.

Figure 2.2.5.2.1: Example for a shear test setup

The characteristic value can be obtained by shifting the regression line.

Experiments are carried out up to a failure time of > 3.000 h at a temperature of 60°C. The degree of regression is to be extrapolated by means of EN 705 [9], Method A, over a period of 438.000 h (50 years). Subsequently, using the methods of the statistics, the 5% fraction is to be formed using the residual standard deviation and the student value.

<u>Method B: Long-term test with one increased load and time temperature shift without failure</u>

<u>Test conditions</u>: The test is carried out on connectors cast into high-alkaline concrete according to Annex A.2.1. The ends of the connector are supported sufficiently restraint to cause failure of the connector. The concrete is stored in a tempered water bath. An example of a testing rig is shown in Figure 2.2.5.2.1.

The load is chosen by increasing the intended characteristic strength by the estimated coefficient of variation of the connector strength.

$$V_{sust,test} = \alpha_4 \cdot V_{Rk,GFRP,ref} \; (1 + cv_F) \quad [kN] \tag{2.2.5.2.1}$$

$V_{sust,test}$ = sustained tension load for tests [kN]

α_4 = reduction factor for sustained load $V_{sust,test} < V_{Rk,GFRP,ref}\ (1 + cv_F)$, chosen by the manufacturer and considered for characteristic resistance (as min$V_{sust,test}$ in Equation (2.2.5.2.2)), if no reduction factor is chosen by the manufacturer a factor of 0,8 is recommended [-]

$V_{Rk,GFRP,ref}$ = reference characteristic resistance of GFRP under tension load according to 2.2.5.1 [kN]

cv_F = coefficient of variation related to loads in test series Table A.1, test series V1a or V1b (related to test series with min $F_{5\%}$ for $V_{Rk,GFRP,ref}$ – see also 2.2.5.1) [-]

The load is held constant until failure. Report the sustained load level $V_{sust,test}$ failure mode and time of failure of each test. There shall be a minimum of 10 tests.

If one or more connectors fail during the 3000h, the series shall be repeated for a smaller load (by using a smaller factor α_3 in Equation (2.2.3.2.1) until there are 10 tests without failure.

If concrete failure occurs the embedment depth shall be increased.

Assessment: The basic value of characteristic resistance $V_{Rk,GFRP,0}$ is determined according to the following Equation:

$$V_{Rk,GFRP,0} = \min V_{sust,test} / (1 + cv_F) \quad [\text{kN}] \qquad (2.2.5.2.2)$$

$V_{Rk,GFRP,0}$ Basic value of characteristic resistance of GFRP under shear load [kN]

$\min V_{sust,test}$ = minimum sustained shear load of all tests without failure [kN]

cv_F = coefficient of variation related to loads in test series Table A.1, line V1a or V1b (related to test series with min $F_{5\%}$ for $V_{Rk,GFRP,ref}$ – see also 2.2.5.1) [-]

The basic value of characteristic resistance $V_{Rk,GFRP,0}$ of a connector shall be determined by one of the methods A or B. Both methods deliver despite the testing temperature of 60°C a long-term resistance for 40°C and 50 years.

This constant temperature is seen as representative concerning the durability for 50 years of service life in all European regions including the effect of the different daily and yearly surface temperature fluctuations in the range from -20°C to 65°C.

To limit the practical testing time and to ensure the resistance in the range of the practical maximum temperature, the test is made at 60°C with a shorter duration. The time/temperature shifting factor of 100 for shifting from 40 °C to 60°C is safe for a wide range of GFRP materials.

The tests represent $h_{D,min}$ and $h_{D,max}$ of the thermal insulation.

2.2.5.3 GFRP resistance after cyclic shear deformation (test series V3)

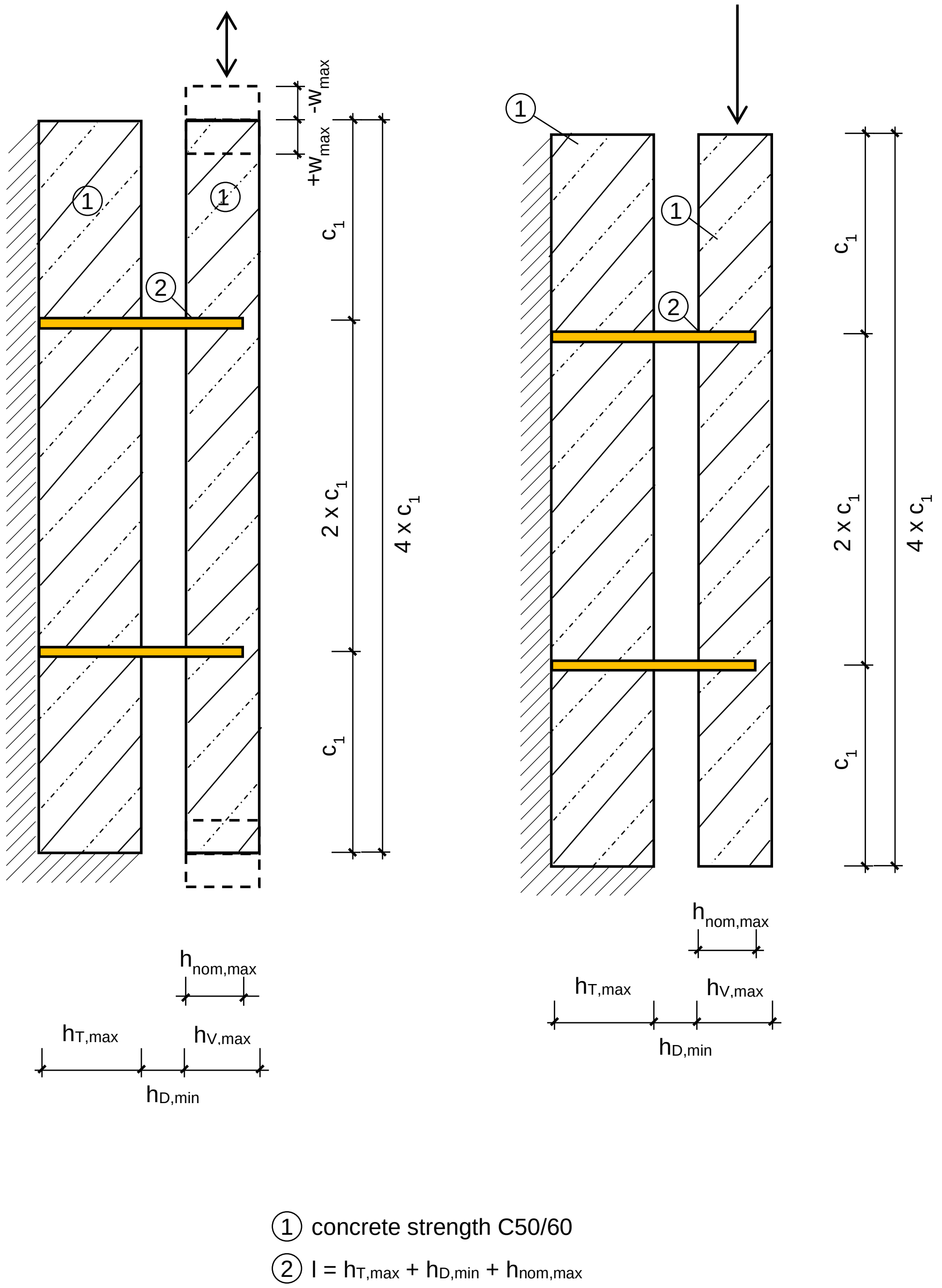
Purpose: Determination of the maximum acceptable shear deformation of the connector, without any damage of the connector, and determination of the reduction factor α_1 (V,GFRP).

Required tests: Perform the tests according to Table A.1, line V3, until failure after alternating shear deformation tests (pre-tests)

Pre-test conditions: Perform pushout tests with alternating shear deformation according to section 2.2.3.3.

After each pushout test the GFRP pin and the adjacent concrete shall be free of cracks and spallings. Else e_{max} will be reduced and pre-tests are repeated with an appropriate reduced w_{max}.

Test conditions: Perform shear tests of the pre-tested connectors until failure.



a) cyclic shear deformation test b) shear test

Figure 2.2.5.3.1: Example for a test setup cyclic shear deformation and for shear tests after that cyclic shear

Assessment: Assessment of failure loads according to Annex B, B.2, and determination of residual resistance $V_{Rk,GFRP,w}$ according to the following Equation:

$$V_{Rk,GFRP,w} = F_{5\%}\,(V3) \qquad (2.2.5.3.1)$$

with: $F_{5\%}$ (V3) = 5%-fractile of the failure loads of test series V3

The factor $\alpha_{V,GFRP,w}$ shall be calculated according to the following Equation:

$\alpha_{V,GFRP,w}$ = $\frac{V_{Rk,GFRP,w}}{V_{Rk,GFRP,ref}}$ [-] (2.2.5.3.2)

$V_{Rk,GFRP,w}$ = Residual shear resistance to GFRP failure after cyclic shear deformation [kN]

$V_{Rk,GFRP,ref}$ = Reference shear resistance to GFRP failure according to 2.2.5.1 [kN]

The reduction factor shall be calculated according to the following Equation:

α_1 (V,GFRP) = $min\left(\frac{\alpha_{V,GFRP,w}}{0.9}; 1.0\right)$ [-] (2.2.5.3.3)

2.2.5.4 Characteristic resistance to GFRP failure under shear load

The characteristic resistance $V_{Rk,GFRP}$ is determined according to the following Equation and $V_{Rk,GFRP}$ is rounded down to 0,1 kN steps:

$V_{Rk,GFRP}$ = $V_{Rk,GFRP,0} \cdot \alpha_1$ (V,GFRP) [kN] (2.2.5.4.1)

$V_{Rk,GFRP,0}$ = According to 2.2.5.2 [kN]

α_1 (V,GFRP) = According to 2.2.5.3 [-]

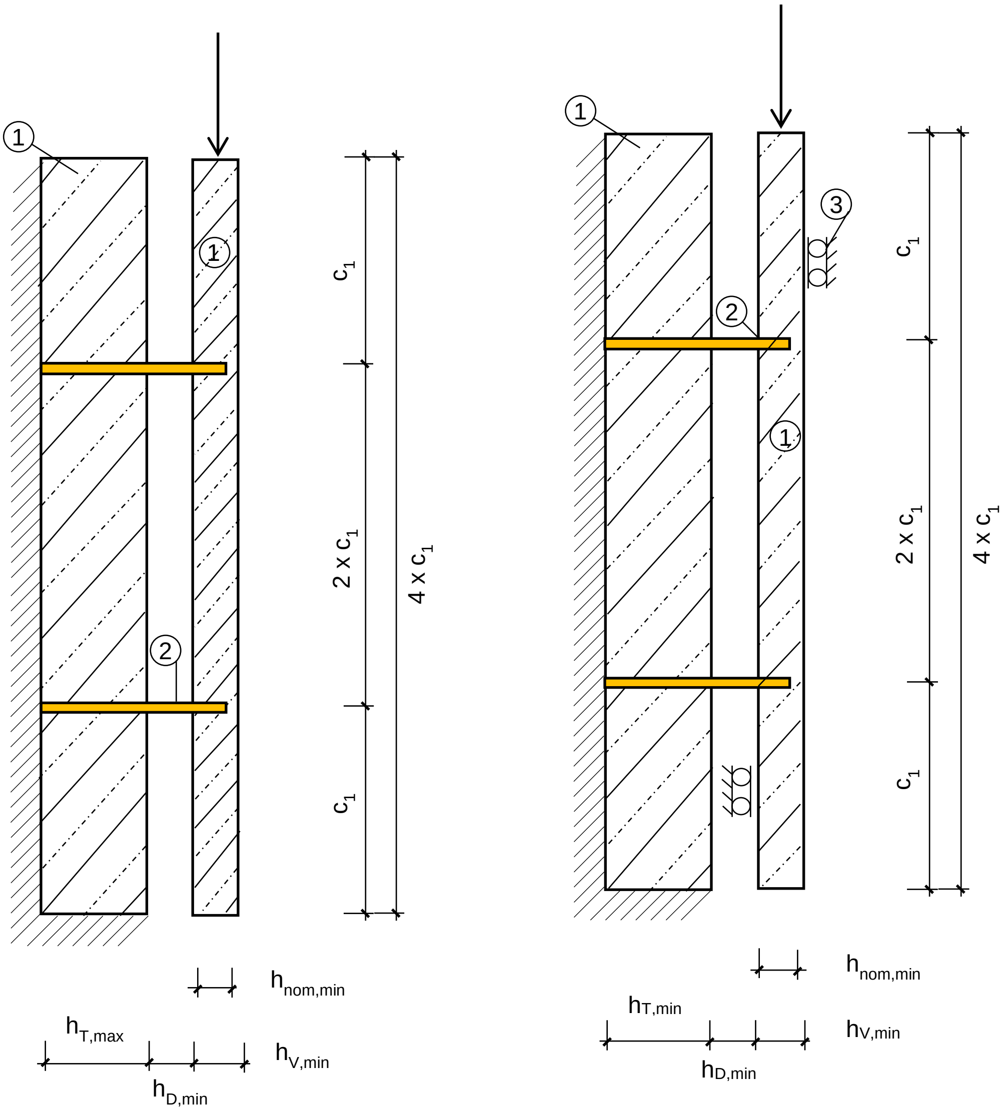
2.2.6 Resistance to concrete failure under shear load

2.2.6.1 Pry-out failure (test series V4)

Purpose: Determination of the basic value of the characteristic resistance for pry-out failure

Required tests: Perform the tests according to Table A.1, line V4a, without thermal insulation (representing lowest stiffness of thermal insulation, e.g., mineral wool) and tests according to Table A.1, line V4b, with a roller bearing (representing highest stiffness of thermal insulation, e.g., glass foam).

Test conditions: Perform pushout tests or half pushout tests. The tests are carried out on connectors embedded in uncracked concrete with the load applied to the concrete layers. The thickness of the concrete member is $h_{V,min}$ and the connector is cast into concrete with the minimum overall connector embedment depth. The support of the concrete member does not influence the concrete cone. The tests represent $h_{D,min}$ of the thermal insulation. Report the failure load and failure mode.



③ roller bearing to avoid rotation of the facade panel

① concrete strength C50/60

② l = $h_{T,max} + h_{D,min} + h_{nom,max}$

a) Representing lowest stiffness b) Representing highest stiffness

Figure 2.2.6.1.1: Example for a test setup for monotonic shear simulating limit thermal insulations

<u>Assessment:</u> Assessment of failure loads according to Annex B, B.1 and B.2, and determination of the basic value of the characteristic resistance $V_{Rk,c}$ (C20/25) according to the following Equation:

$$V_{Rk,c,0,} = \min (F_{5\%} (V4a); F_{5\%} (V4b)) \qquad (2.2.6.1.1)$$

with: $F_{5\%}$ (V4a) = 5%-fractile of the converted failure loads of test series V4a

$F_{5\%}$ (V4b) = 5%-fractile of the converted failure loads of test series V4b

2.2.6.2 Pryout failure of connectors after cyclic shear deformation (test series V5)

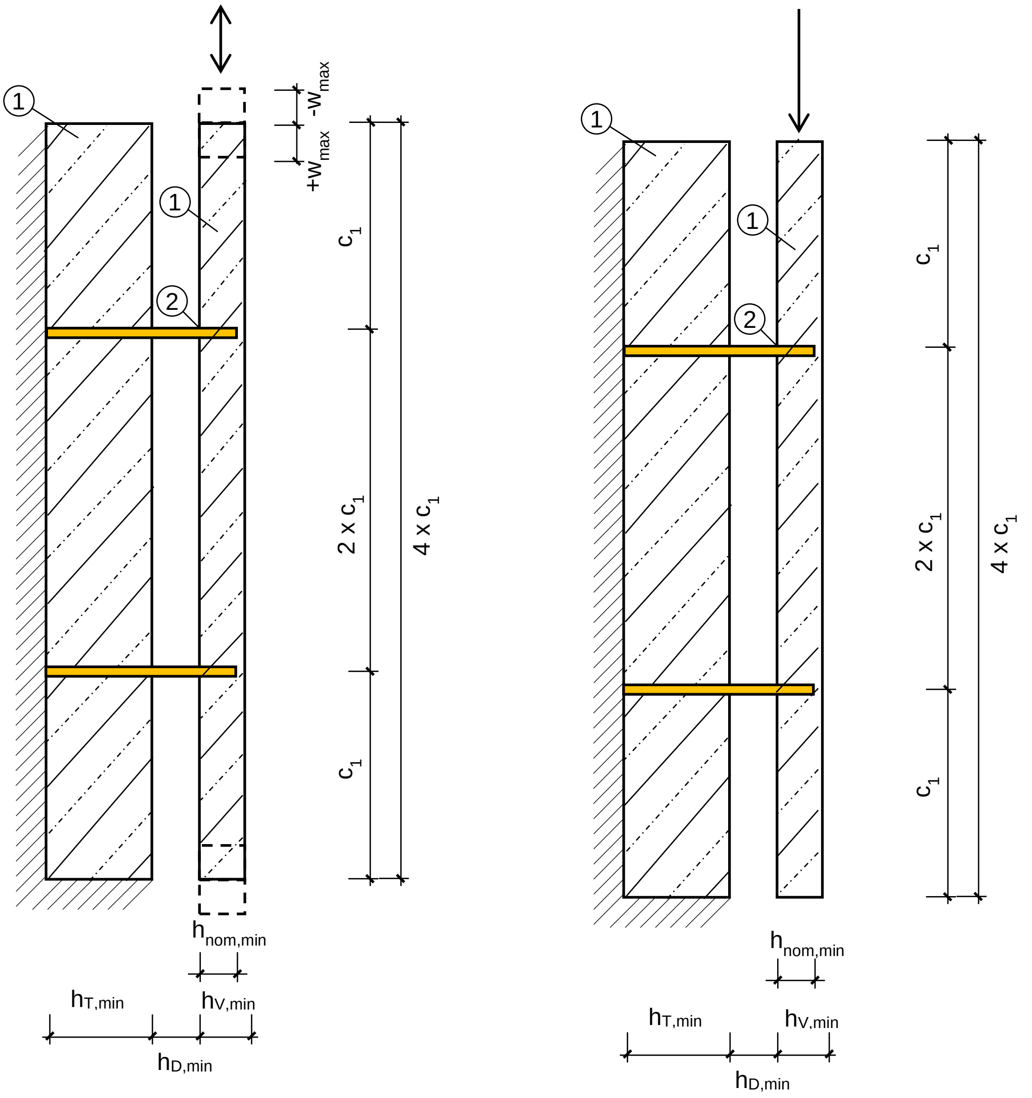
<u>Purpose</u>: Determination of the maximum acceptable shear deformation of the connector without any damage of the concrete.

<u>Required tests</u>: Perform the tests according to Table A.1, line V5, until failure after alternating shear deformation tests (pre-tests) if concrete damage may occur due to high stiffness of the connector.

Pre-test conditions: Perform pushout tests with alternating shear deformation according section 2.2.3.3.

After each pushout test the GFRP pin and the adjacent concrete shall be free of cracks and spallings. Else e_{max} will be reduced and tests according to 2.2.3.3 are repeated with an appropriate reduced w_{max}.

Test conditions: Perform shear tests of the pre-tested connectors until failure.



① Concrete strength C20/25

② $l = h_{T,min} + h_{D,min} + h_{nom,min}$

a) cyclic shear deformation test b) shear test

Figure 2.2.6.2.1: Example for a test setup cyclic shear deformation and for shear tests after that cyclic shear

Assessment: Assessment of failure loads according to Annex B, B.1 and B.2, and determination of residual resistance $V_{Rk,c,w}$ according to the following Equation:

$$V_{Rk,c,w} = F_{5\%}\,(V5) \qquad (2.2.6.2.1)$$

with: $F_{5\%}$ (V5) = 5%-fractile of the converted failure loads of test series V5

The factor $\alpha_{V,c,w}$ shall be calculated according to the following Equation:

$$\alpha_{V,c,w} = \frac{V_{Rk,c,w}}{V_{Rk,c,ref}} \quad [-] \qquad (2.2.6.2.2)$$

$V_{Rk,c,w}$ = Residual shear resistance to concrete failure after cyclic shear deformation [kN]

$V_{Rk,c,ref}$ = $V_{Rk,c,0}$ (basic value of characteristic resistance for concrete failure according to 2.2.6.1) [kN]

The reduction factor shall be calculated according to the following Equation:

$$\alpha_1\ (V,c) = \min\left(\frac{\alpha_{V,c,w}}{0{,}9};1{,}0\right) \quad [-] \qquad (2.2.6.2.3)$$

2.2.6.3 Characteristic resistance to concrete failure under shear load

The characteristic resistances $N_{Rk,c}$ are determined according to the following Equation and $N_{Rk,c}$ is rounded down to 0,1 kN steps:

$$V_{Rk,c} = V_{Rk,c,0} \cdot \alpha_1\ (V,c) \quad [kN] \qquad (2.2.6.3.1)$$

$V_{Rk,c,0}$ = According to 2.2.6.1 [kN]

$\alpha_1\ (V,c)$ = According to 2.2.6.2 [-]

2.2.7 Maximum acceptable shear deformation

The maximum shear deformation of the connector without damage, w_{max} shall be given in the ETA. The smaller value w_{max} assessed according to section 2.2.3.3, 2.2.4.4, 2.2.5.3 and 2.2.6.2 is decisive.

2.2.8 Edge distances and spacing

The minimum edge distance is determined by the following Equation:

$$c_{min} = \max\ ((0{,}5\ d_{failure\ cone});(1{,}5\ h_{nom})) \qquad (2.2.8.1)$$

with: $d_{failure\ cone}$: maximum value of diameter of failure cones in test series C2, N4 to N7, V4 to V5

h_{nom}: overall embedment depth of the connector

According to current experience the minimum spacing is: $s_{min} = 2\ c_{min}$

2.2.9 Modulus of elasticity

The tensile modulus of elasticity E_N of connector made of GFRP shall be determined according to EN ISO 527-4 [6] in principle at 23 °C. Only deviation to EN 527-4 [6]: The final product is used as specimen.

The bending modulus of elasticity E_M of the connector made of GFRP shall be determined according to ISO 3597-2 [7].

2.2.10 Geometric parameters

The parameters A, I_y, I_z are calculated based on the geometry of the connector(s) as available to a TAB.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System 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 97/463/EC.

The system is 2+.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the glass fibre-reinforced plastic (GFRP) connectors for use in sandwich and element walls made of concrete in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1 (control plan).

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]					
Raw material					
1	Material and material properties of pin	Certificates	control plan	3	Each manu-facturing batch
End product					
2	Fibre content	EN ISO 1172 [1]	control plan	3	Each manufacturing batch
3	Cure ratio	According to control plan, e.g., CSA-S807-10		1	
4	Mechanical properties (tensile strength, tensile modulus and ultimate strain at 20 °C	According to EN ISO 527-4 [6]		3	
5	Density, void content, meter weight	EN ISO 1183-1 [2]		3	After each 5,000 meter of the connector resp. per 15,000 connectors resp. once per production week
6	Determination of the functional measurements (diameter or width and height, reductions of cross section, e.g., rib or dovetail for bond or undercut) of the connectors	Gauge		3	
7	Modulus of elasticity and bending strength	4-point bending test according to EN 3597-2 [7]		3	
8	Interlaminar shear strength	EN ISO 14130 [10] at 20°C or Direct shear test on 5-10 mm thick slices of connector		3	

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 glass fibre-reinforced plastic (GFRP) connector for use in sandwich and element walls made of concrete 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	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the connector. In particular it shall be checked if all tasks given in Table 3.2.1 were performed. [1)	see control plan	Laid down in control plan	-	1
2	The manufacturer of the connector shall demonstrate that the manufacturing plant is capable of performing the pultrusion process with a steady distribution of glass fibres over the cross-section due to tests according Table 3.2.1, line 7 (4-point bending test of FPC).	see control plan	Laid down in control plan	-	1
Continuous surveillance, assessment and evaluation of factory production control					
3	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan. In particular it shall be checked if all tasks given in Table 3.2.1 were performed. 1)	-	Laid down in control plan	-	1/year

1) If the product criteria in Table 3.2.1 are observed, it is not necessary to monitor specific stages of production.

4 REFERENCE DOCUMENTS

[1] EN ISO 1172:1998 Textile-glass-reinforced plastics - Prepregs, moulding compounds and laminates - Determination of the textile-glass and mineral-filler content; calcination methods

[2] EN ISO 1183-1:2019 Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pyknometer method and titration method

[3] EN 1992-4:2018 Eurocode 2: Design of concrete structures - Part 4: Design of fastenings for use in concrete

[4] EN 206:2013+A2:2021 Concrete. Specification, performance, production and conformity

[5] EN 197-1:2011 Cement - Part 1: Composition, specifications and conformity criteria for common cements

[6] EN ISO 527-4:2021 Plastics – Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites;

[7] ISO 3597-2:2003-10 Textile glass; rovings; determination of mechanical properties on rods; part 2: determination of flexural strength;

[8] EN 13791:2019 Assessment of in-situ compressive strength in structures and precast concrete components

[9] EN 705:1994 Plastics piping systems - Glass-reinforced thermosetting plastics (GRP) pipes and fittings - Methods for regression analyses and their use

[10] EN ISO 14130:1997 Fibre reinforced plastic composites - Determination of apparent interlaminar shear strength by short beam-method

[11] EAD 330389-00-0601:2017 Point connector made of reinforced polymer for sandwich walls

[12] EN 1992-1-1:2004+AC:2010 Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings

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

[11] CSA S807-10:2010-03-01 Specification for fibre-reinforced polymers

[12] Owen, D. Handbook of Statistical Tables, Addison/Wesley Publishing Company Inc., 1962

ANNEX A DETAILS OF TESTS

A.1 Test program

Table A.1 Required tests under static or quasi-static actions (compression, tension and shear)

N°	Tests according to the following sections	Concrete	h_{nom} [mm]	h_T / h_V [mm]	h_D [mm]	Number of tests	Remarks
	2.2.1 GFRP failure under compression load						
C1	Buckling	—[5]	—	—	max.	≥ 5	restraint at the ends of the connector
	2.2.2 Concrete failure under compression load						
C2	Punching	C20/25	max.	min.	—	≥ 5	min. concrete cover in direction of load
	2.2.3 GFRP failure under tension load						
N1	2.2.3.1 Short time behaviour	—	—	—	—	≥ 5	reference tests
N2	2.2.3.2 Failure under sustained load	C50/60	min.[7]	min.[7]	—	≥ 10	60°C, in alkaline environment
N3	2.2.3.3 Failure after cyclic shear deformation	C50/60	max.	max.	[6]	≥ 5	shear deformation
	2.2.4 Concrete failure under tension load						
N4	2.2.4.1 Concrete cone or pull-out failure, low-strength concrete	C20/25	min.	min.	—	≥ 5	unconfined tests
N5	2.2.4.2 Concrete cone or pull-out failure, high-strength concrete	C50/60	min.	min.	—	≥ 5[1]	unconfined tests
N6	2.2.4.3 Concrete cone or pull-out failure, cracked concrete	C20/25	min.	min.	—	≥ 5[4]	unconfined tests, w = 0,3 mm
N7	2.2.4.4 Concrete cone or pull-out failure, low-strength concrete after cvclic shear deformation	C20/25	min	min.	min.	≥ 5[2]	shear deformation
N8	2.2.4.5 Concrete cone or pull-out failure, low-strength concrete after cyclic tension load	C20/25	min	min.	—	≥ 5	longitudinal deformation with 0.6 x N_{Rk}
	2.2.5 GFRP failure under shear load						
V1a	2.2.5.1 Bending or interlaminar shear failure[3]	C50/60	max.	max.	min. max.	≥ 5	no thermal insulation
V1b						≥ 5	with roller bearing
V2	2.2.5.2 Failure under sustained load[3]	C50/60	max.	max.	min. max.	≥ 10	60°C, in alkaline environment
V3	2.2.5.3 Interlaminar shear failure after cyclic shear deformation	C50/60	max.	max.	min.	≥ 5	shear deformation
	2.2.6 Concrete failure under shear load						
V4a	2.2.6.1 Pry-out failure	C20/25	min.	min.	min.	≥ 5[2]	no thermal insulation
V4b						≥ 5[2]	with roller bearing
V5	2.2.6.2 Pry-out failure after cyclic shear deformation	C20/25	min.	min.	min.	≥ 5[2]	shear deformation

[1] May be omitted if resistance in high-strength concrete is evaluated by tests according to line N4

[2] May be omitted if connector $I_y \leq 2.000$ mm^4 and E ≤ 10.000 N/mm²: $V_{Rk\ GFRP}$, according lines V1 to V3 is decisive

[3] Testing according to line V1a, V1b and V2 with $h_{D,min.}$ and $h_{D,max.}$ to generate failure modes: bending and interlaminar shear

[4] May be omitted if geometry of connector shows sufficient undercut compared to crack width

[5] Test can be done cast-in, if GFRP failure is generated

[6] Maximum ratio w_{max}/h_D are tested

[7] If concrete failure expected, h_{nom} and h_T / h_V should be increased such, that GFRP failure occurs

A.2 Test details

The characteristic resistances are determined by tests within the context of this EAD.

A.2.1 Test members

The concrete test member shall be manufactured in accordance with EN 206 [4].

].The connector performance is only valid for the range of tested concrete.

Aggregates shall be of natural occurrence (i.e., non-artificial) and with a grading curve falling within the boundaries given in Figure A.2.1.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m^3 (see EN 206 [4]).

The boundaries reported in Figure A.2.1.1 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.

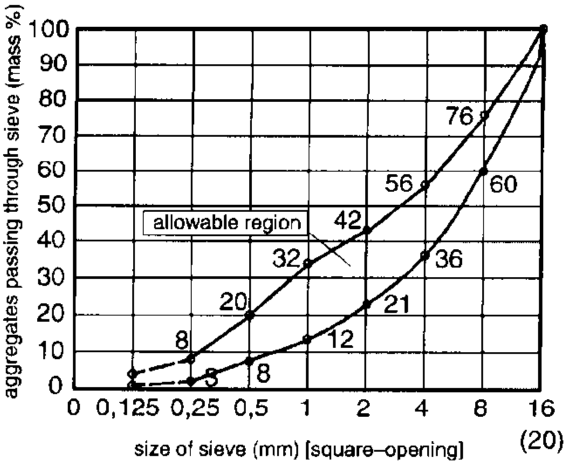


Figure A.2.1.1 Admissible region for the grading curve

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 [5])

The water/cement ratio shall not exceed 0,75 and the cement content shall be at least 240 kg/m^3.

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

For the tests carried out in low-strength concrete (strength class C20/25) and high-strength concrete (strength class C50/60) the following mean compressive strengths at the time of testing connectors shall be obtained for the two classes:

C20/25 f_c = 20-30 MPa (cylinder: diameter 150 mm, height 300 mm)
f_{cube} = 25-35 MPa (cube:150 x 150 x 150 mm)
C50/60 f_c = 50-60 MPa (cylinder: diameter 150 mm, height 300 mm)
f_{cube} = 60-70 MPa (cube:150 x 150 x 150 mm)

It is recommended to measure the concrete compressive strength 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

$$f_c = \frac{1}{1{,}25} f_{cube} \tag{A.2.1.1}$$

C50/60 $$f_c = \frac{1}{1{,}20} f_{cube} \qquad \text{(A.2.1.2)}$$

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

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \qquad \text{(A.2.1.3)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \qquad \text{(A.2.1.4)}$$

$f_{cube} = f_{core100}$ (according to EN 13791 [8], section 7.1) (A.2.1.5)

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 connectors 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 connector 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.

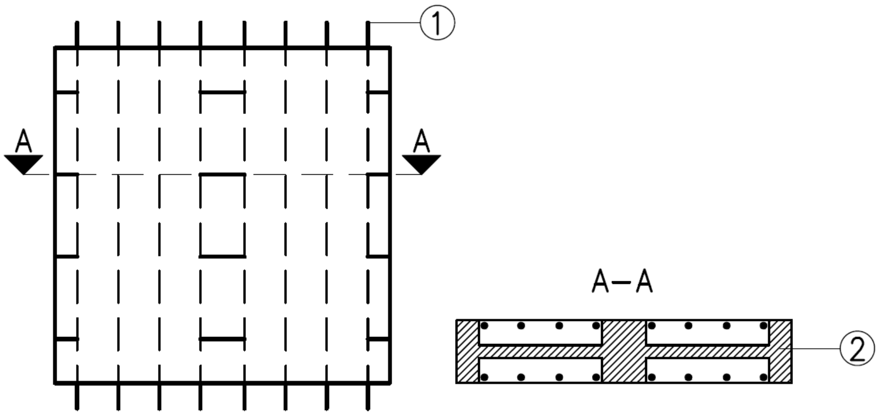
The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

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 (A.2.1.5).

Generally, the tests in uncracked concrete are 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 connectors 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°.

For test in cracked concrete the test members have unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. The thickness of the test member shall be $h \geq 2\, h_{nom}$ 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 A.2.1.2.

In the test with variable crack width the reinforcement ratio (top and bottom reinforcement) shall be $\mu = A_s / (b \cdot h) \sim 0{,}01$ and the spacing of the bars ≤ 250 mm.



1 reinforcement

2 crack inducers

Figure A.2.1.2: Example of a test member for connectors tested in cracked concrete

For tests with sustained load test members are made of high-alkaline concrete with a ph of more than 13. This is achieved by using a CEM I cement (portland cement) with a Na2O equivalent of 1%.

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 connectors the concrete shall be at least 21 days old.

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

A.2.2 Connector/ installation of connectors

The relevant dimensions (e.g., minimal cross section of the connector) and material properties (e.g., tensile strength of the connector and concrete compression strength) shall be measured analogue to section A.2.5.

Connectors shall be installed in the test member in accordance with the manufacturer´s product installation instructions (MPII).

A.2.3 Test equipment

Test equipment and test procedure especially for tension and shear tests shall be according to the following:

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.

During all tests, the load shall be applied to the connector by a fixture, a rope or another concrete layer representing the conditions found in practice.

All tests shall be performed deformation controlled and statically loaded.

A.2.3.1 Tension tests

Tension tests for concrete failure according to Table A.1, Lines N3, N4, N5, N6, N7 and N8, shall be conducted as unconfined tests according to this section.

An example for an unconfined test setup is shown in Figure A.2.3.1.1.

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 connector shall be at least 2 h_{nom}.

In tests on single connectors 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 connector. To achieve this, hinges shall be incorporated between the loading device and the connector. An example of a tension test rig is illustrated in Figure A.2.3.1.1.

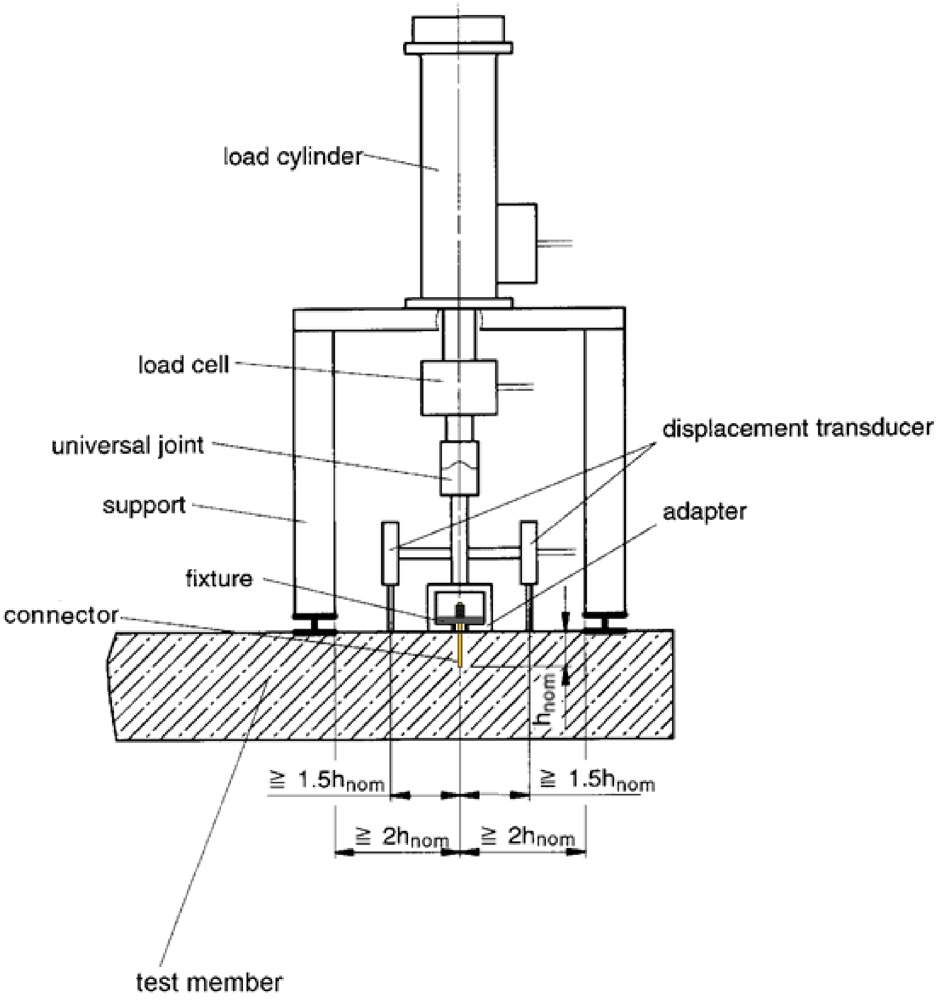


Figure A.2.3.1.1 Example of a tension test rig for unconfined tests

A.2.3.2 Shear tests

Shear tests for concrete failure according to Table A.1, Lines V3, V4 and V5, shall be conducted as unconfined tests according to this section.

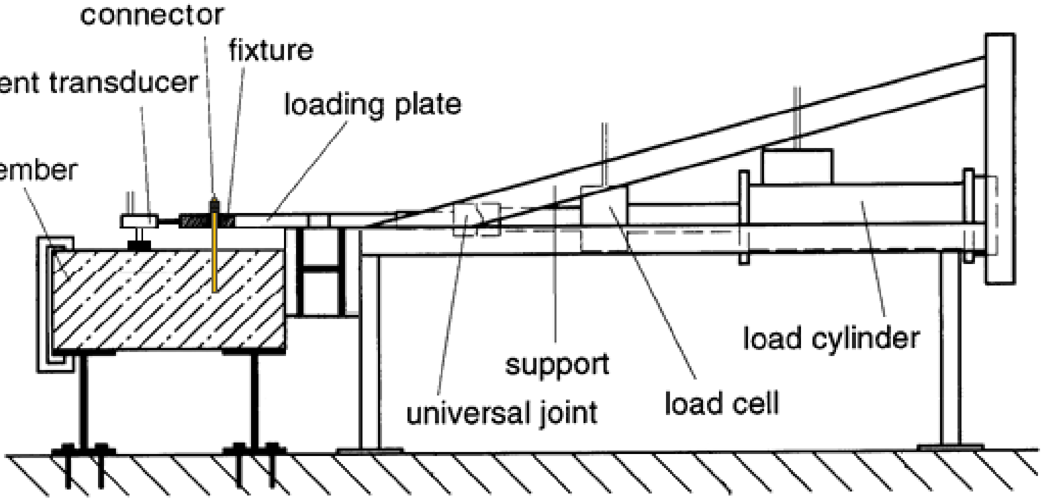
For unconfined tests the test rigs shall allow the formation of an unrestricted rupture cone. For this reason, the distance between the support reaction and a connector shall be at least 2 c_1 (shear test at the edge with load applied towards the edge, with c_1 = edge distance in load direction) as shown in Figure A.2.3.2.1. Only in shear tests without edge influence where GFRP failure is expected this distance may be less than 2 c_1.

In shear tests the load shall be applied parallel to the concrete surface.

If the connector is requested to be assessed for different embedment depths for a specific diameter, the most unfavourable condition shall be tested. If the most unfavourable condition cannot be determined all embedment depths have to be tested.

An example of a shear test rig is illustrated in Figure A.2.3.2.1. As there is a lever arm between the applied load and the support reaction, the test member is stressed by a torsion moment. This shall be taken up by additional reaction forces placed sufficiently far away from the connector.

Side view:



Top view:

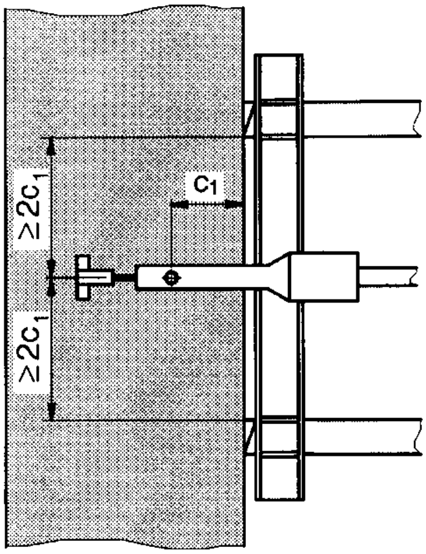


Figure A.2.3.2.1 Example of a shear test rig

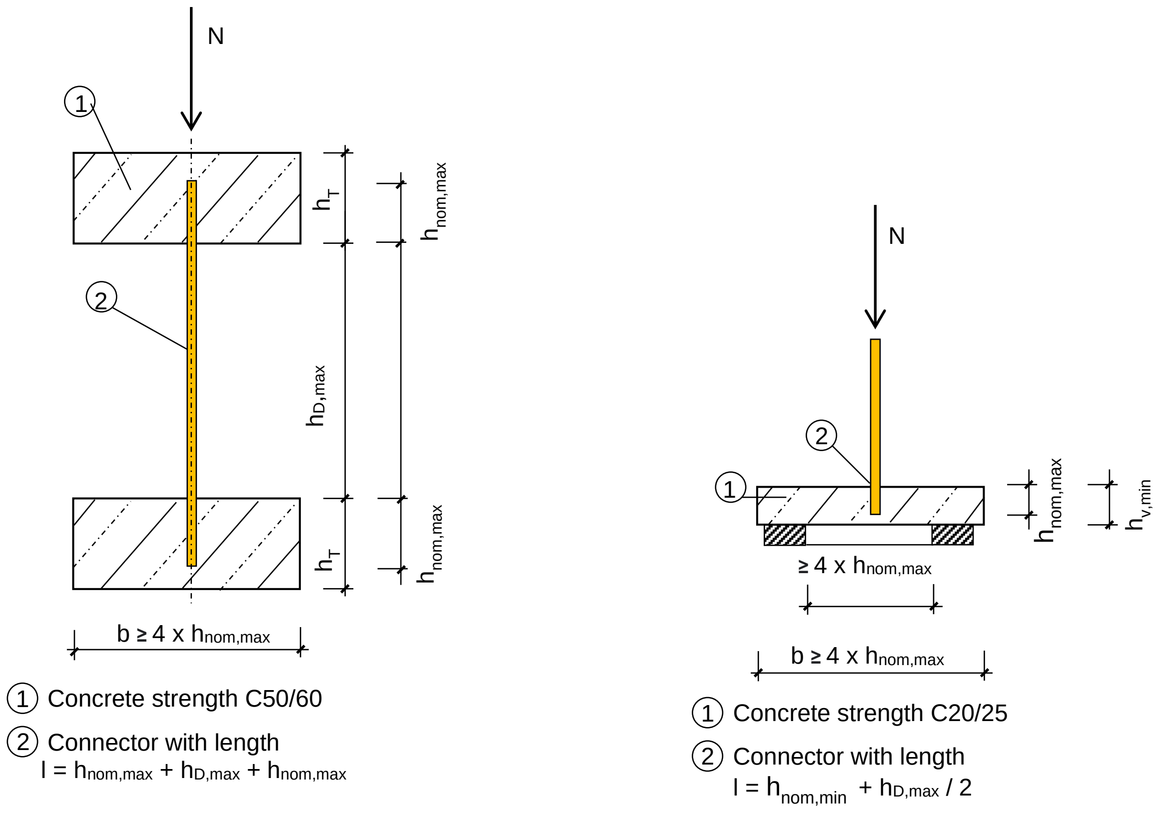
A.2.3.3 Compression tests

Compression tests for concrete failure according to Table A.1, Line C2, shall be conducted as unconfined tests according to this section.

An example for an unconfined test setup is shown in Figure A.2.3.3.1.

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 connector shall be at least 2 h_{nom} .

During compression tests the load shall be applied concentrically to the connector. An example of a compression test rig is illustrated in Figure A.2.3.3.1.



a) for buckling (test series C1)

b) for punching (test series C2)

Figure A.2.3.3.1 Example of a compression test rig

A.2.4 Test procedure

For each individual test the peak load shall be determined, the failure mode shall be given and the load-displacement relationship shall be recorded continuously, if not noted otherwise with a specific test series. A test report according to section A.2.5 shall be done for every individual test.

A.2.4.1 Tension tests

For tension tests after installation, the connector is connected to the test rig and loaded to failure. The displacements of the connector relative to the concrete surface shall be measured by use of either one displacement transducer on the head of the connector or by use of at least two displacement transducers on either side at a distance of ≥ 1,5 h_{nom} from the connector; 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 connector at a distance of approximately 1,0 h_{nom} and at least on the face of the test member in which the connectors are installed.

The tension tests in cracked concrete are undertaken in unidirectional cracks. The required crack width Δw is 0.3 mm. Δw is the difference between the crack width when loading the connector and the crack width at connector installation. After installation of the connector the crack is widened to the required crack width while the connector 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 connector is 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 connector 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.

Report the failure load, failure mode and, if applicable, the concrete cone diameter of each test.

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

A.2.4.2 Shear tests

After installation, the connector is connected to the test and is then loaded to failure. The displacements of the connector relative to the concrete shall be measured in the direction of the load application, e.g., by use of a displacement transducer fixed behind the connector (seen from the direction of load application) on the concrete (see Figure A.2.3.3.1).

A.2.4.3 Compression tests

For compression tests after installation, the connector will be compressed to failure through a compression die on concreted connectors. The displacements of the connector relative to the concrete surface shall be measured by use of either one displacement transducer on the head of the connector, by use of at least two displacement transducers on either side or through displacement measuring of the test machine; the mean value of the transducer readings shall be recorded in the latter case.

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.

Report the failure load and failure mode of each test.

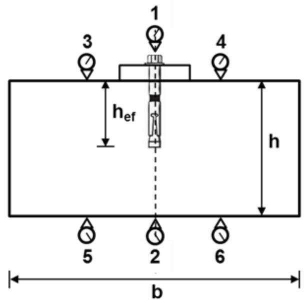
The data shall be collected with a frequency of 3 Hz – 5 Hz.

A.2.5 Test protocol

Since only relevant parameter shall be followed for each test series this table is meant as a check list. The test report shall include at least the appropriate information for the particular test series.

1. Description test specimen	
Connector type	Manufacturer, trade name, dimensions, material
status of specimen	serial product / prototype
production lot / batch	
Material and material properties of pin	Certificates
Fibre content according to EN ISO 1172 [1]	
Cure ratio according to CSA-S807-10 [11]	
Density, void content, meter weight according to EN ISO 1183-1 [2]	
Diameter or width and height, reductions of cross section, e.g., rib or dovetail for bond or undercut) of the connectors	
Modulus of elasticity and bending strength (4-point bending test according to EN 3597-2 [7])	

Interlaminar shear strength according to EN ISO 14130 [10] at 20°C or Direct shear test on 5-10 mm thick slices of connector	
2. Test member	
element type / drawing no.	sketch according to "examples cross section" and "example for test member with bond breaking pipes"
dimensions	(length / width / height)
concrete mix	e.g., cement, aggregate type and content, w/c-ratio
curing conditions	
age of concrete member at time of testing	
type and grade of reinforcement	
longitudinal reinforcement quantity	
longitudinal reinforcement size	
pre-debonding length	
type of bond breaker sheets	e.g., wood/ plastic/ metal/ none
reinforcement spacing	e.g., 254 mm horizontal, 50 mm from edges
distribution of reinforcement over depth of member	e.g., two rows, 100 mm from top and bottom
reinforcement is distributed double symmetrically	
3. Setting/ Installation information	
ratio member thickness / h_{nom}	e.g., 2,2
place of connector installation	formwork side
type/ diameter of support	confined / unconfined d = 450 mm
spacing between rebar and connector	200 mm
Connector placed in hairline crack	yes / no
overall embedment depth h_{nom}	
thickness of fixture (t_{fix}) [mm]	
clearance hole d_f [mm]	
position of the connector over load transfer zone in the crack	sketch
verification method of connector position in crack	e.g., borescope (sketch of crack formation over load transfer zone)
4. Test parameter	
crack opening mechanism	Describe how the crack width in the area of the load transfer zone is ensured
loading/ unloading rates [sec.]	e.g., 2,5 / 2,5
nominal sustained load	e.g., 10 kN
min. sustained load	10,1 kN
max. sustained load	10,9 kN
mean sustained load	10,3 kN
no. of replicates tested simultaneously	e.g., one
measuring of connector displacement	e.g., continuously / at the connector
amount / type of crack width measurement	e.g., 4 / capacitive sensor

position of the crack width sensors	sketch with distances e.g.: 
determination of crack width at connector	e.g., (linear interpolation)
measuring uncertainty for crack width transducers	e.g., ±0,005 mm.
minimal frequency during the test	
maximal frequency during the test	
5. Test results	
Load at failure	
Load at loss of adhesion	
Displacement at failure	
Displacement at 50% of failure load	
Diagram with load displacement curve	
Failure mode (If initial failure is not clear, a combination of failure modes may be reported.)	- (cc) concrete cone failure – give diameter and depth of concrete cone - (sp) splitting – test condition for tests in uncracked concrete in case when a first crack of the concrete is observed - (po) pull-out – pull-out failure may be combined with a shallow concrete breakout - (g) connector failure – define position of the connector rupture over length of the connector - (pr) pry-out – concrete breakout opposite to the load direction (may occur for shallow embedment) - (be) bond – element failure
Diagram with displacement over time of testing (long-term tests only)	

ANNEX B GENERAL ASSESSMENT METHODS

B.1 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to Equation (B.1.1) to (B.1.2) depending on the failure mode.

Concrete failure $$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}}\right)^{0,5} \quad \text{with } \frac{f_c}{f_{c,t}} \leq 1{,}0 \qquad \text{(B.1.1)}$$

Pull-out failure $$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}}\right)^{1} \quad \text{with } \frac{f_c}{f_{c,t}} \leq 1{,}0 \qquad \text{(B.1.2)}$$

B.2 Establishing 5 % fractile

The 5 %-fractile of the ultimate loads measured in a test series is to be calculated according to statistical procedures for a confidence level of 90 %. If a precise verification does not take place, a normal distribution and an unknown standard deviation of the population shall be assumed.

$$F_{5\%} = F_{u,m} \, (1 - k_s \cdot cv_F) \qquad \text{(B.2.1)}$$

$F_{u,m}$ = mean value of failure loads of a test series

In case of concrete failure or pull-out failure: mean value of converted failure loads of a test series (Conversion according to B.1)

k_s = tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90%, in general derived from a Gaussian distribution for which the population standard deviation is unknown, values for specific sample sizes n may be taken from statistical handbooks (e.g., [12]).

e.g.: n = 5 tests: k_s = 3,40

n = 10 tests: k_s = 2,57

cv_F = coefficient of variation related to loads in test series

Note: The confidence level of 90% is defined for characteristic resistance of fasteners in EN 1992-4 [3] and is therefore used for the assessment in this EAD.