

EUROPEAN ASSESSMENT DOCUMENT

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LATTICE GIRDERS FOR THE INCREASE OF PUNCHING SHEAR RESISTANCE OF FLAT SLABS OR FOOTINGS AND GROUND SLABS

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1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers lattice girders for the increase of punching shear resistance of flat slabs or footings and ground slabs made of weldable reinforcing steel bars with material properties according to EN 1992-1-1¹, Annex C, hereafter referred to as lattice girders. The lattice girders covered by this EAD comply with the following descriptions:

- lattice girders with defined shape (an example is given in Figure 1.1);
- lattice girders with longitudinal chords with nominal diameter $d_{ch} \geq 10$ mm;
- lattice girders with inclined bars (diagonals) of nominal diameter $d_D \geq 9$ mm;
- lattice girders with a defined overlapping of the inclined diagonals over the chords;
- lattice girders with a defined inclination of the diagonals;
- lattice girders with defined shear resistance of the welded knots.

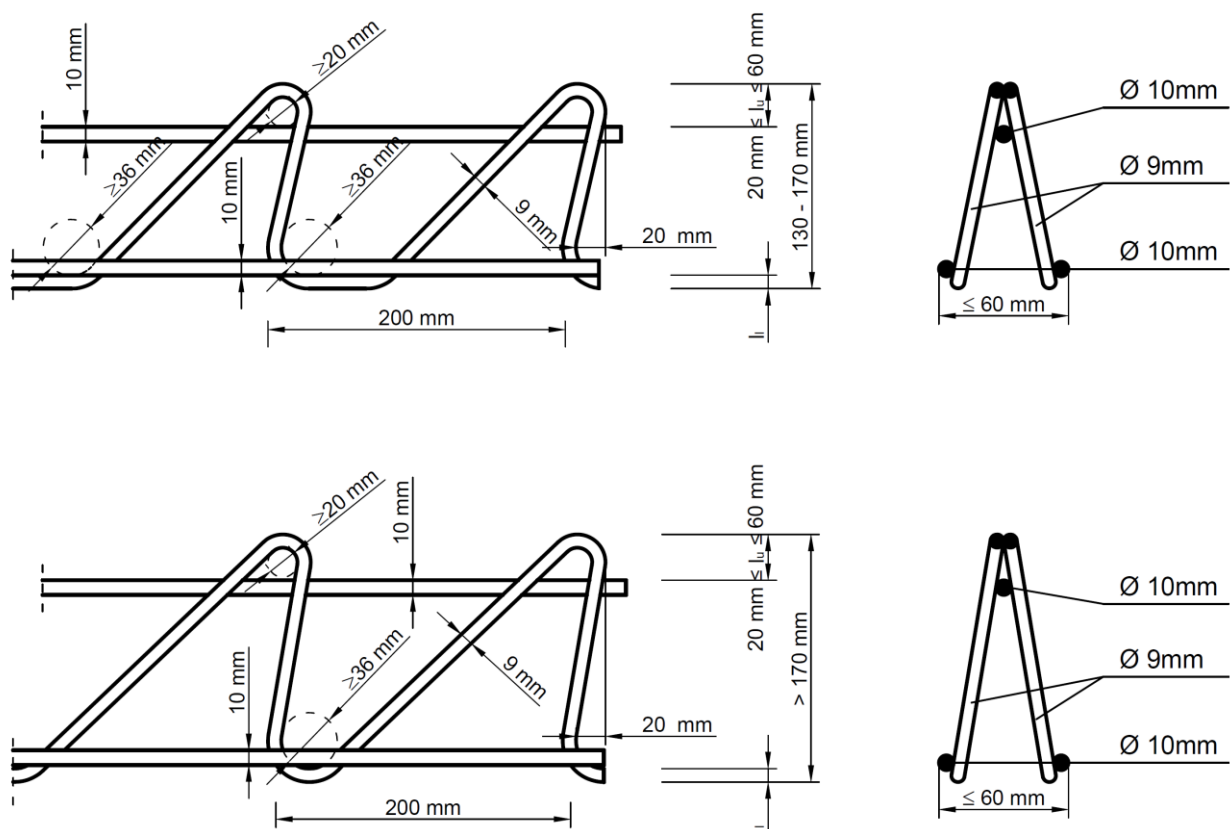


Figure 1.1: Example of a lattice girder used as punching shear reinforcement

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

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

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

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

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 EAD.

1.2 Information on the intended use of the construction product

1.2.1 Intended use

The lattice girders are intended to be used as punching shear reinforcement elements for the increase of the punching shear resistance of flat slabs or footings and ground slabs under static, quasi-static and fatigue loading.

The lattice girders are located adjacent to columns or high concentrated loads.

This EAD covers the following specifications of the intended use:

- flat slabs or footings and ground slabs made of reinforced normal weight concrete of strength class C20/25 to C50/60 according to EN 206;
- flat slabs or footings and ground slabs with a height $h \geq 180$ mm;
- lattice girders positioned such that the diagonal bars which are bend in loops protrude into the upper layer of the flexural reinforcement layer;
- lattice girders positioned such that the concrete cover complies with the provisions according to EN 1992-1-1;
- lattice girders positioned such that the minimum and maximum distances between the lattice girders and between the elements and a column or area of high concentrated load complies with the provisions according to Annex A.

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 product for the intended use of 50 years when installed in the works (provided that the product is subject to appropriate installation). 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 works².

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.

² 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.

1.3 Specific terms used in this EAD (if necessary in addition to the definitions in CPR, Art 2)

1.3.1 Abbreviations

Indices

| | |
|-----|---|
| R | resistance |
| V | shear force |
| Ch | chord |
| D | diagonal (inclined bar) of the lattice girder |
| C | area C around the column |
| c | concrete |
| fo | footing or ground slab |
| k | characteristic value |
| max | maximum |
| min | minimum |
| pu | punching shear |
| re | reinforcement |
| s | steel |
| sl | flat slab |
| msl | monolithic flat slab |
| csl | composite flat slab |
| y | yield |
| d | effective depth as defined in EN 1992-1-1 |

Mechanical characteristics

| | |
|------------|---|
| $V_{Rd,c}$ | punching shear resistance without shear reinforcement |
| f_{ck} | characteristic compressive cylinder strength (150 mm diameter by 300 mm cylinder) |
| f_{yk} | characteristic value of yield stress of a bar |

Concrete, reinforcement and lattice girders

| | |
|---------------|---|
| a | distance from column face to control perimeter |
| u_0 | column perimeter |
| d_{Ch} | nominal diameter of the chord of the lattice girder |
| d_D | nominal diameter of the diagonal (inclined bar) of the lattice girder |
| s | distance between the axis's of lattice girders |
| s_C | distance between the axis's of lattice girders in area C |
| β | coefficient taking into account the effects of load eccentricity |
| β_{red} | reduced coefficient taking into account the effects of load eccentricity |
| d | effective depth |
| u_1 | perimeter of the critical section at a distance of $2.0 \cdot d$ from the column face |
| l_s | distance between column face and outermost effective bar of the reinforcement |

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of the product is assessed in relation to the essential characteristics.

Table 2.1 Essential characteristic 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 | Increasing factor for punching shear of monolithic slabs | 2.2.1 | $k_{pu,msl}$ [-] |
| 2 | Increasing factor for punching shear of composite slabs | 2.2.2 | $k_{pu,csi}$ [-] |
| 3 | Increasing factor for punching shear of slabs with alternative arrangement | 2.2.3 | $k_{pu,asi}$ [-] |
| 4 | Increasing factor for punching shear of foundation and ground floors | 2.2.4 | $k_{pu,fo}$ [-] |
| 5 | Increasing factor for maximum interface shear resistance | 2.2.5 | $k_{max,i}$ [-] |
| 6 | Mechanical characteristics for fatigue loading | 2.2.6 | $\Delta\sigma_{Rsk,n=2\cdot 10^6}$ [MPa] or $\Delta\sigma_{Rsk,0,n}$ [MPa] |
| Basic Works Requirement 2: Safety in case of fire | | | |
| 7 | 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.

2.2.1 Increasing factor for punching shear resistance of monolithic flat slabs

The characteristic increasing factor is determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the method given in Table 2.2.

These factors are applicable for calculation of the punching shear resistance of concrete monolithic slabs according to TR 058 equation (2.19).

Table 2.2 Determination of punching shear resistance of monolithic slabs

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|---|---|----------------------------|---------------------------|
| 1 | characteristic increasing factor for punching shear resistance of monolithic flat slabs | ≥ 6 full scale tests ¹⁾ | Annex D.1 | $k_{pu,msl}$ [-] |

¹⁾ concrete members (monolithic or composite slabs) with lattice girders

2.2.2 Increasing factor for punching shear resistance of composite flat slabs

The characteristic increasing factor is determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the method given in Table 2.3.

These factors are applicable for calculation of the punching shear resistance of composite concrete slabs according to TR 058 equation (2.19).

Table 2.3 Determination of punching shear resistance of composite slabs

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|--|---|----------------------------|---------------------------|
| 1 | characteristic increasing factor for punching shear resistance of composite flat slabs | ≥ 3 full scale tests ¹⁾ | Annex D.2 | $k_{pu,csf}$ [-] |

¹⁾ tests with composite slabs

2.2.3 Increasing factor for punching shear resistance of slabs with alternative arrangement

The characteristic increasing factor is determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the method given in Table 2.4.

These factors are applicable for calculation of the punching shear resistance of slabs according to TR 058 equation (2.19).

Table 2.4 Determination of punching shear resistance with alternative arrangement

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|---|---|----------------------------|---------------------------|
| 1 | characteristic increasing factor for punching shear resistance of flat slabs with alternative arrangement | ≥ 3 full scale tests ¹⁾ | Annex D.3 | $k_{pu,asl}$ [-] |

¹⁾ no tests are required if a deviating arrangement is not applicable

2.2.4 Increasing factor for punching shear resistance of footings and ground slabs

The characteristic increasing factor can be taken as $k_{pu,fo} = 1.5$ without testing.

A higher characteristic increasing factor can be determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the method given in Table 2.4.

This factor is applicable for calculation of the punching shear resistance of slabs according to TR 058 equation (2.22).

Table 2.5 Determination of punching shear resistance of footings and ground slabs

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|--|---------------------------|----------------------------|---------------------------|
| 1 | characteristic increasing factor for punching shear resistance of ground floors and foundation | ≥ 3 full scale tests | Annex D.4 | $k_{pu,fo}$ [-] |

2.2.5 Increasing factor for maximum interface shear resistance in composite slabs

The characteristic maximum increasing factor is determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the method given in Table 2.6.

These factors are applicable for calculation of the interface shear resistance of composite slabs according to TR 058 equation (5.1).

Table 2.6 Determination maximum interface shear resistance

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|---|---|----------------------------|---------------------------|
| 1 | characteristic increasing factor for maximum interface shear resistance of composite flat slabs | ≥ 3 full scale tests ¹⁾ | Annex D.5 | $k_{max,i}$ [-] |

¹⁾ concrete composite slabs with lattice girders

2.2.6 Mechanical characteristic for fatigue loading

The mechanical characteristic for fatigue loading is determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed and evaluated according to the methods given in Table 2.7.

For the determination of the characteristic fatigue resistances of lattice girders, one of the characteristics outlined in Table 2.7, No 1 to 2 can be chosen by the manufacturer: line 1 in case of $n = 2 \cdot 10^6$ load cycles, line 2 in case of determining a “S-n-Curve”

Table 2.7 Determination of mechanical characteristics for fatigue loading

| No | characteristic | number of samples | test method and evaluation | expression of performance |
|----|---|--|----------------------------|---|
| 1 | characteristic fatigue strength for $n = 2 \cdot 10^6$ load cycles | ≥ 3 diagonal-upper chord ¹⁾ ≥ 3 diagonal-lower chord ²⁾ | Annex C.1 | $\Delta\sigma_{Rsk,n=2 \cdot 10^6}$ [MPa] |
| 2 | characteristic fatigue strength for $n=1$ to $n=\infty$ load cycles | ≥ 20 | Annex C.2 | $\Delta\sigma_{Rsk,0,n}$ [MPa] |

¹⁾ diagonal connected with an upper chord

²⁾ diagonal connected with a lower chord

2.2.7 Reaction to fire

The product is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the EC Decision 96/603/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.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

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

For the products covered by this EAD the applicable European legal act is Decision 97/597/EC.
The system is 1+.

3.2 Tasks of the manufacturer

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

Table 3.1 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 | raw material – material properties | Annex B.1 | ¹⁾ | all | each delivery |
| 2 | lattice girders – mechanical properties | Annex B.2 | ¹⁾ | ≥ 3 | each cast (at least each 50to, at least once a production week) |
| 3 | lattice girders – ribbed area | Annex B.3 | ¹⁾ | ≥ 3 | each cast (at least each 50to, at least once a production week) |
| 4 | lattice girders – geometry | Annex B.4 | ¹⁾ | ≥ 1 | each production dimension (at least each 50to, at least once a production week) |
| 5 | lattice girders – welded strength | Annex B.5 | ¹⁾ | 5 | each production dimension (at least each 50to, at least once a production week) |
| 6 | lattice girders – strength of the loop of the diagonal | Annex B.6 | ¹⁾ | 3 | each cast (at least each 50to, at least once a production week) |

¹⁾ according to the manufacturer's technical file

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 of the product are laid down in Table 3.2.

Table 3.2 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 product. | Verification of the complete FPC | - | - | When starting the production or a new production line |
| Continuous surveillance, assessment and evaluation of factory production control | | | | | |
| 2 | Ascertain that the system of factory production control and the specified automated manufacturing process are maintained | Verification of the controls on the raw materials, on the process and on the product as indicated in Table 3.1 | - | - | 1 per year |
| Audit-testing of samples taken by the notified product certification body at the manufacturing plant or at the manufacturer's storage facilities | | | | | |
| 3 | lattice girders – geometrical characteristics | Annex B.4 | 1) | one | 1 per year |
| 4 | lattice girders – mechanical properties | Annex B.2 | 1) | 3 tests each bar | |
| 5 | lattice girders – ribbed area | Annex B.3 | 1) | 3 tests each bar | |
| 6 | lattice girders – strength of the loop of the diagonal | Annex B.6 | 1) | 3 tests each bar | |
| 7 | lattice girders – welded strength | Annex B.5 | 1) | 3 each knot ²⁾ | |
| 8 | Characteristic steel fatigue resistance | Annex B.7 | 1) | 3 | per year |

¹⁾ according to the manufacturer's technical file

²⁾ knot at the upper and lower chord

4 REFERENCE DOCUMENTS

| | |
|---|---|
| EN 1990:2002 + A1:2005 + A1:2005/AC:2010 | Eurocode: Basis of structural design |
| EN 1992-1-1:2004 + AC:2010 | Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings |
| EN 206:2013+A1:2016 | Concrete - Specification, performance, production and conformity |
| EN ISO 15630-1:2019 | Steel for the reinforcement and prestressing of concrete – Test methods – Part 1: Reinforcing bars, wire rod and wire |
| EN 10204:2004 | Metallic products - Types of inspection documents |
| ISO 16269-6:2014-01 | Statistical interpretation of data – Part 6: Determination of statistical tolerance intervals |

ANNEX A SPECIFICATION ON THE INTENDED USE

A.1 Positioning of the punching shear reinforcement elements

A.1.1 Specifications for Flat slabs

The positioning of the punching shear reinforcement elements is given by maximum distances of the elements to the column and to each other. It is distinguished between elements which run in the direction of the column (radial placed) and parallel to the column face (tangential placed) and it is distinguished between area C and area D.

The area with a radial distance from the face of the column of $\leq 1.125d$ is called area C.

The area with a radial distance from the face of the column of $> 1.125d$ is called area D.

The maximum distance of the adjacent element to the column is $0.35d$. In case of radial arranged elements this distance is measured from the countable place of the adjacent bar to the column face. In case of tangential arranged elements this distance is measured from the axis of the lattice girder to the column face (compare Figure A.1).

The maximum distance between the axis of the reinforcement elements is shown in Figure A.1.

Maximum axis distance for tangential placed elements in area C: 0.5d

Maximum axis distance for tangential placed elements in area D in the axis of the column perpendicular to the direction of the parallel reinforcement elements: 0.75d

Maximum axis distance in area C:

$$\beta \cdot V_{Ed} = k_{pu,msl(csl)} \cdot V_{Rd,c} : \quad \text{0.75d}$$

$$\beta \cdot V_{Ed} \leq 1.8 \cdot V_{Rd,c} : \quad \text{1.25d}$$

Linear interpolation between the maximum distance for $1.8 \cdot V_{Rd,c}$ and for $k_{pu,msl(csl)} \cdot V_{Rd,c}$ is possible.

Maximum axis distance in area D: 2.5d

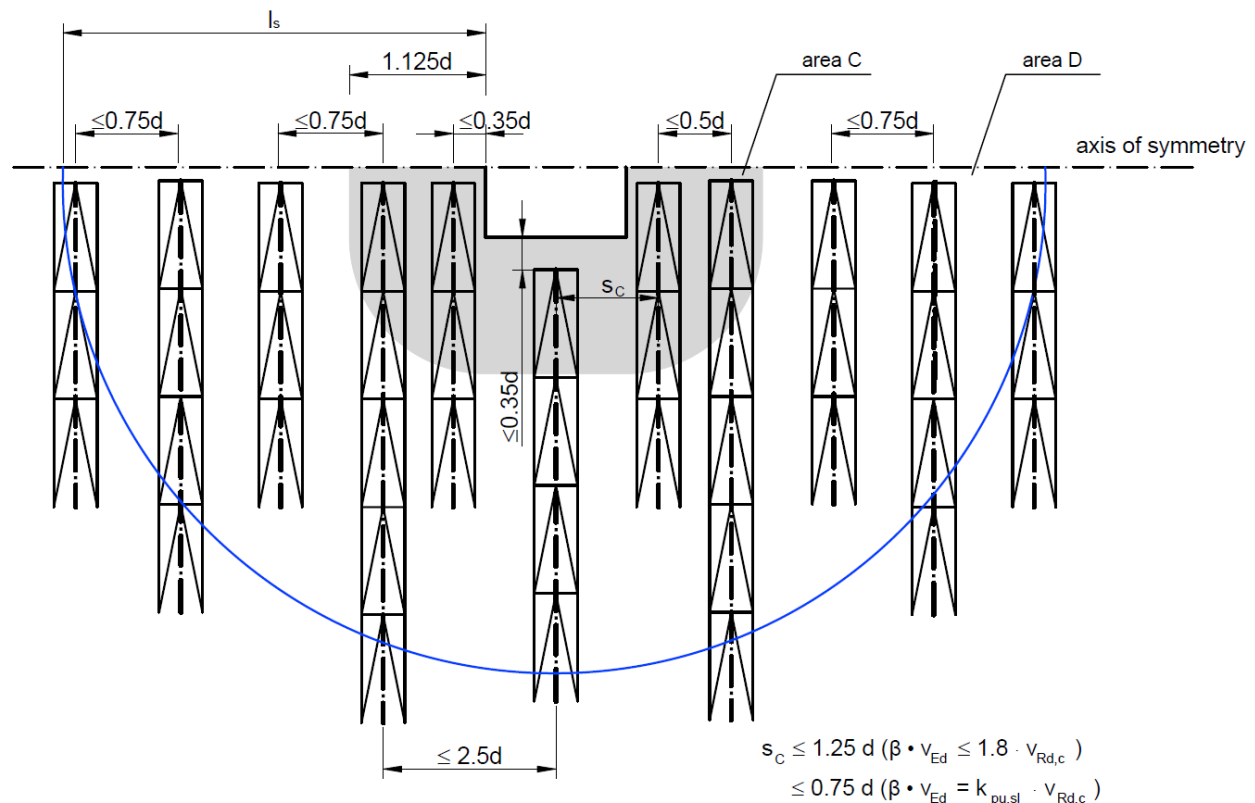


Figure A1: Maximum distances of lattice girders as punching shear reinforcement in flat slabs

In addition to the arrangement according to Figure A.1 an alternative arrangement according to Figure A.2 can be given in an EAD.

The maximum distance between the axis of the reinforcement elements for the alternative arrangement is shown in Figure A.2.

Maximum axis distance to the direction of the parallel reinforcement elements:

$$\beta \cdot v_{Ed} = k_{pu,asl} \cdot v_{Rd,c} : \quad 0.75d$$

$$\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c} : \quad 1.25d$$

Linear interpolation between the maximum distance for $1.8 \cdot v_{Rd,c}$ and for $k_{pu,asl} \cdot v_{Rd,c}$ is possible.

Maximum axis distance in area D: 40 cm

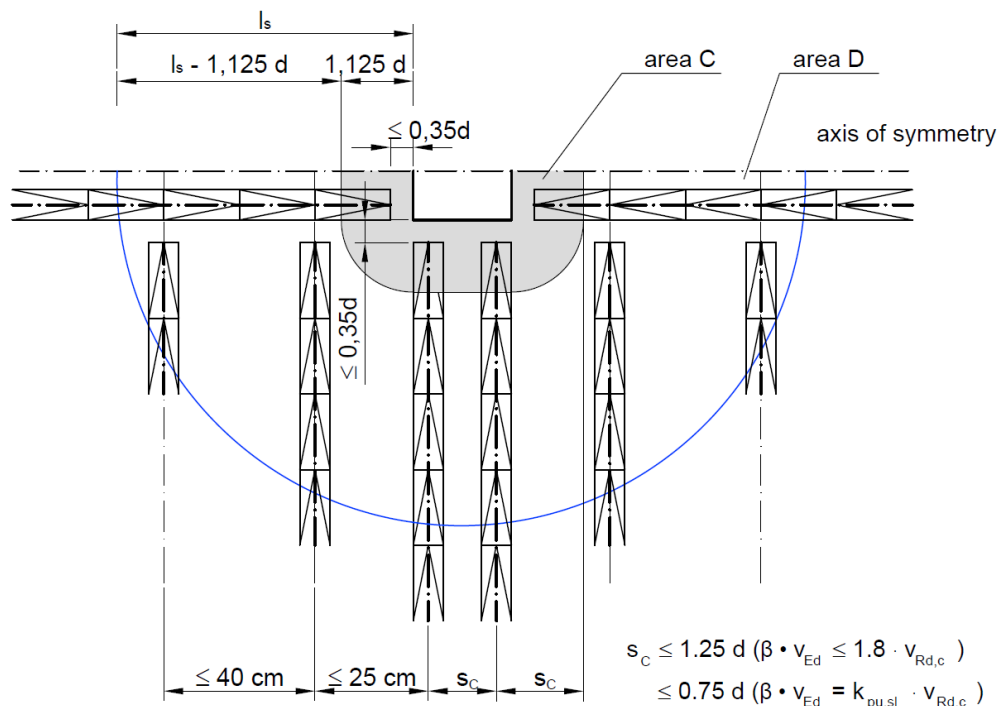


Figure A.2: Alternative arrangement of the shear reinforcement elements in a flat slab

A.1.2 Footings and ground slabs:

The positioning of the shear reinforcement elements is given by maximum distances of the elements to the column and to each other. It is distinguished between elements which run in the direction of the column (radial placed) and parallel to the column face (tangential placed) and it is distinguished between area C and area D.

The area with a radial distance from the face of the column of $\leq 1.125d$ is called area C.

The area with a radial distance from the face of the column of $> 1.125d$ is called area D.

The countable bars of the lattice shear reinforcement in area C must be placed between $0.3d$ and $0.8d$.

The maximum axis distances of the shear reinforcement elements in area C is $0.5d$.

The maximum axis distances of the shear reinforcement elements in area D is $0.75d$.

ANNEX B ASSESSMENT FOR THE VERIFICATION OF CONSTANCY OF PERFORMANCE – DETAILS FOR AVCP

B.1 Raw Material – Material Properties

The raw materials shall be checked before acceptance. Check of raw materials shall include control of the inspection documents presented by the supplier of the raw materials. The properties of the raw material shall comply with the values specified by the manufacturer.

The raw materials shall be supplied with the following documents:

Wire rod: Material properties to be proven by a specific test report 3.1 according to EN 10204.

B.2 Lattice girders – Mechanical Properties

The characteristic yield strength f_{yk} shall be determined by tests as 5%-fractile of the test results f_y .

The characteristic tensile strength f_{tk} shall be determined by tests as 5%-fractile of the test results f_t .

The characteristic strain at maximum force ε_{uk} shall be determined by tests as 5%-fractile of the test results ε_u .

The characteristic ratio of tensile strength/yield strength $(f_t/f_y)_k$ shall be determined by tests as 5%-fractile of the ratio f_t/f_y .

All tests shall be performed according to EN ISO 15630-1.

B.3 Lattice girders – Ribbed Area

The relative ribbed area should be measured accordingly to EN ISO 15630-1.

B.4 Lattice girders - geometry

The following geometry according to Table B.1 must be measured.

Table B.1 Control plan for the geometry

| No | Subject | dimension | Test or control method | Criteria, if any | remark |
|----|--|-----------|------------------------|------------------|--------|
| 1 | Height h_{LG} | mm | gauge | 1) | - |
| 2 | Distance between welding points d_{wp} | mm | gauge | 1) | - |
| 3 | Overlapping over upper chord l_{uc} | mm | gauge | 1) | - |
| 4 | Overlapping over lower chord l_{lc} | mm | gauge | 1) | - |
| 5 | Protruding of upper chord p_{uc} | mm | Gauge | 1) | - |
| 6 | Overbending of bar o | mm | gauge | 1) | - |

¹⁾ according to manufacturer's technical file

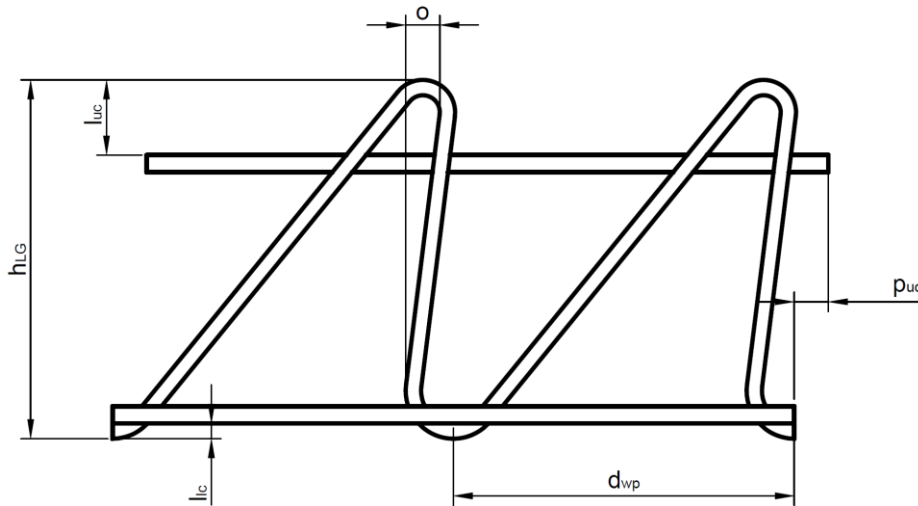


Figure B1: Filigran Punching shear reinforcement - Measurements

B.5 Lattice girders – welded strength

The shear resistance of the welded knot should be tested according to figure B.2 or B.3.

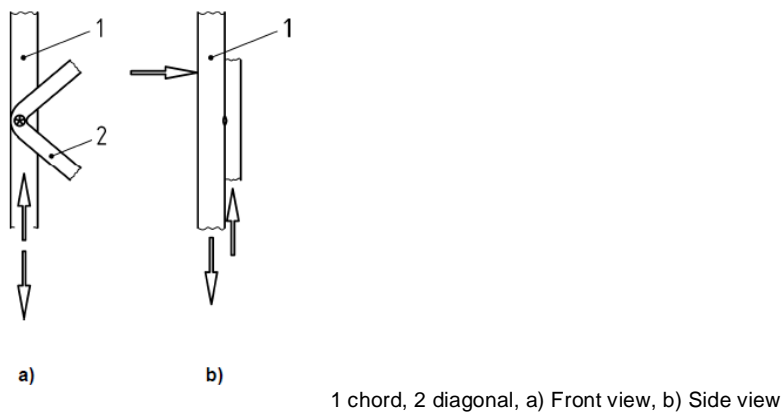


Figure B.2: Shear test according to procedure 1

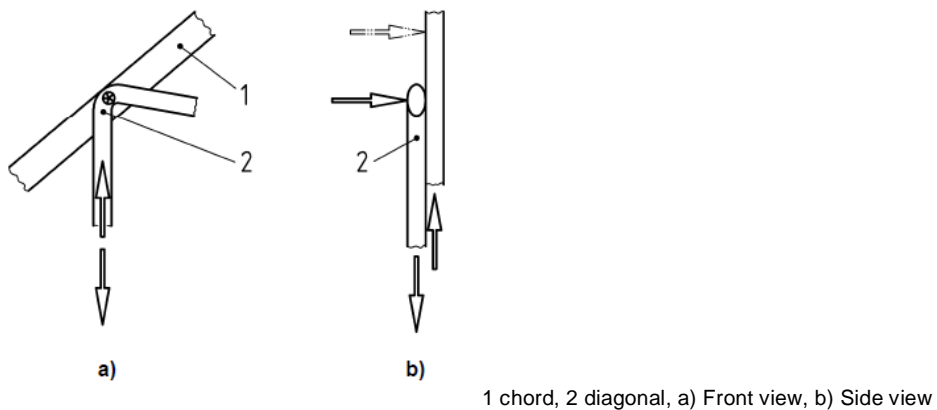


Figure B.3: Shear test according to procedure 2

B.6 Strength of the bended loops

From the de-coiled rebar which is to be bent and welded to the diagonal in a lattice girder for the increase of punching resistance a section with the overall length of 0.8 m is to be cut off.

This 0.8m-piece is to be bent to a loop with a bending mandrel with the diameter as in the product diameter, with the legs of the loop in a parallel position. In a tensile machine, the tensile test where the loop is fixed at one end on the mandrel, and clamped at the other end with the grips of the tensile machine, the loop is to be tested until fracture (s. Figure B.4).

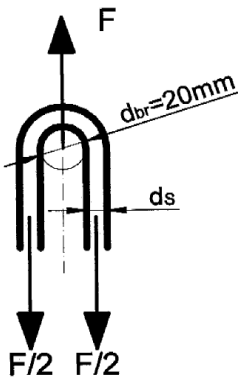


Figure B.4: Tensile test for loops with a bending-diameter smaller than $4 \cdot \varnothing$

The result of this test shall be related to the nominal Area of the tested coiled rebar and the yield strength shall not be less than the nominal R_e of that bar.

It is not necessary in this context to determine the deformations of the test specimen.

B.7 Fatigue tests – audit testing

Criteria for $\Delta\sigma_{Rsk, n=2 \cdot 10^6}$:

Load-cycle tests with a upper level of $\sigma_{up} = 0.6 f_{yk, nom}$, a stress level of $\Delta\sigma_{Rsk, n=2 \cdot 10^6} / 0.78$ and at least $n = 2 \cdot 10^6$ load cycles shall be performed. The test setup shall correspond to C.3.

The constancy of performance is verified if the number of cycles exceeds $n = 2 \cdot 10^6$.

Criteria for $\Delta\sigma_{Rsk, 0, n}$:

Load-cycle tests under different load levels shall be performed. The test setup shall correspond to C.3.

The load levels are determined as follows:

$$\text{test a: } \Delta S_a \approx \left(S_k - \frac{1}{3} (S_k - \Delta S_{D, k}) \right)$$

$$\text{test b: } \Delta S_b \approx \left(S_k - \frac{2}{3} (S_k - \Delta S_{D, k}) \right)$$

$$\text{test c: } \Delta S_c = \Delta S_{D, k}$$

The constancy of performance is verified if the number of cycles of the first two specimens exceeds the number of cycles for the corresponding characteristic resistance. The number of cycles of the third specimen shall reach the limit number of cycles n_{lim} and pass the run-out test on the level of the first test (test a).

ANNEX C DETAILS OF TESTS AND EVALUATION OF THE TEST RESULTS FOR DETERMINATION OF MECHANICAL CHARACTERISTIC FOR FATIGUE LOADING

C.1 Determination of the characteristic fatigue resistance for $n = 2 \cdot 10^6$ load cycles

Load-cycle tests acc. to C.3 shall be performed with a upper level of $\sigma_{up} = 0.6 f_{yk,nom}$, a certain stress range of $\Delta\sigma_s = k_1$ [MPa] and at least $N = 2 \cdot 10^6$ load cycles.

All steel qualities/properties specified by the manufacturer shall be tested.

The value k_1 may be specified by the manufacturer. The minimum stress range in the tests should be $\Delta\sigma_s = k_1 = 60$ MPa based on the nominal cross section of the wire. The recommended value is 90 MPa.

If in 6 tests (3 upper chord connection and 3 lower chord connection) no failure occurs up to $N = 2 \cdot 10^6$ load cycles the characteristic stress range $\Delta\sigma_{Rsk}$ shall be determined as follows:

$$\Delta\sigma_{Rsk,n=2 \cdot 10^6} = 0.78 \cdot k_1 \text{ [MPa]}$$

If a failure occurs before reaching $N = 2 \cdot 10^6$ load cycles the test series shall be repeated with a smaller value k_1 [MPa]. In this case only the test series (upper chord connection or lower chord connection) with the lowest load cycles up to failure must be repeated.

If in 3 further tests on a reduced stress level no failure occurs the stress range $\Delta\sigma_{Rsk,n=2 \cdot 10^6}$ shall be determined as shown before.

C.2 Determination of the characteristic fatigue resistance as a function of the number of load cycles.

C.2.1 General

Required tests: For the determination of the characteristic fatigue resistance function $\Delta\sigma_{Rsk,n}$ tests on at least 20 samples shall be performed. All steel qualities/properties specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Figure C.7. The sample shall be loaded with a sinusoidal load process according to Figure C.8. Additional information on the testing and loading requirements is included in C.3.

The number of cycles to failure n for each range of strength $\Delta\sigma$ shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

Tests which are stopped without failure (first load level) and re-loaded with a higher stress range (second load level) may be included in the final evaluation. Only results on the first load level can be used for evaluation. The results on the second load level are used only to detect damage on the tests previously stopped.

The characteristic fatigue resistance function is determined by statistical evaluation according to C.2.6 based on the 5%-quantiles with a confidence level of 75% or on the 10%-quantiles with a confidence level of 90%.

$$\Delta\sigma_{Rsk,n} = \Delta S_k$$

where:

ΔS_k according to Equation (C.11), characteristic value of fatigue resistance after n load cycles

The characteristic resistance S_k as determined in static tension tests in accordance with C.2.2 shall be taken as the characteristic fatigue resistance for $n = 1$ cycles.

The test reports shall include all the relevant information regarding the fatigue resistance function. The following information shall be at least provided:

- Equations of the average and characteristic fatigue resistance functions
- Four calculated values for the control of the characteristic fatigue resistance function

- Diagram according to Figure C.1 showing cyclic test results, average and characteristic fatigue resistance functions and four calculated control values
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

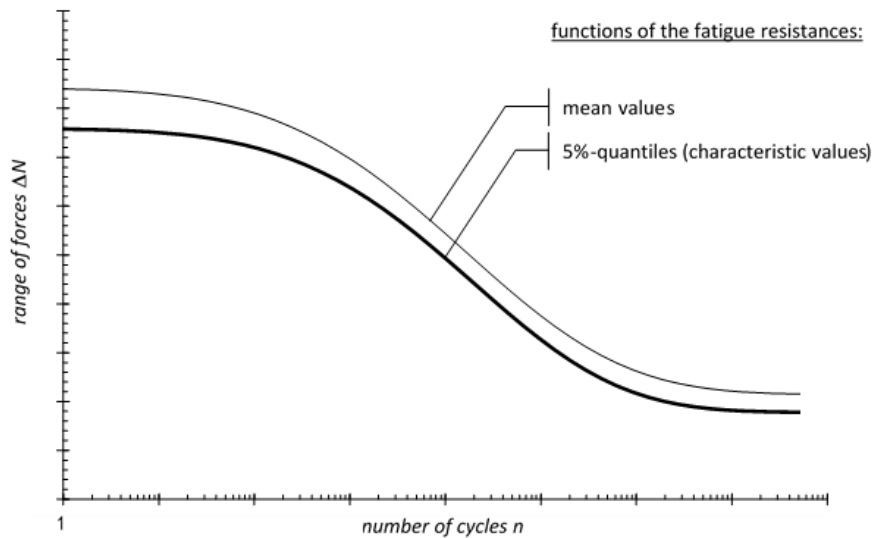


Figure C.1: Example of the characteristic fatigue resistance function (S-n-Curve)

The force-controlled periodic loading with sinusoidal course is used as the most disadvantageous case (practical application) of the test specimen.

The repeated loads consist of a constant lower stress level and an upper stress level both under tension and are applied on the specimen until fatigue failure or a limit number of cycles is reached.

Test specimen reaching the limit number of cycles without failure, are to be tested again at a higher stress level (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.

The test method provides an average function and a quantile function of the fatigue resistance from one ($n = 1$) to infinite number of cycles ($n \Rightarrow \infty$).

C.2.2 Determination of the characteristic static resistance

For the determination of the characteristic static resistance S_k at least three tests ($n \geq 3$) are required.

For the determination of the static and fatigue resistances testing shall be done on the identical product regarding batch, geometry, material etc. It is sufficient to test only connections of the diagonals with the upper chord or the lower chord respectively.

The characteristic value S_k is equivalent to the 5%-quantiles with a confidence level of 75% or on the 10%-quantiles with a confidence level of 90% and unknown standard deviation by using the normal distribution.

The value is determined as follows:

$$S_k = \bar{S} - k_{n,p,1-\alpha} \cdot \hat{s} \quad (C.1)$$

where

$k_{n,p,1-\alpha}$ statistic factors according to ISO 16269-6

$$\hat{s} = \sqrt{\frac{\sum_{i=1}^n (\bar{S} - S_i)^2}{n-1}}, \text{ standard deviation} \quad (C.2)$$

C.2.3 Planning of the fatigue cyclic load levels

To choose the connection to be tested three fatigue tests of each connection should be tested and the connection with the lowest load cycle should be chosen for the fatigue test series described in the following.

The stress range ΔS_i is the difference between upper and lower level for every load level i :

$$\Delta S_i = S_{upi} - S_{lo} \tag{C.3}$$

The lower level of the sinusoidal course S_{lo} is equal for all fatigue cyclic load levels and should be kept to a minimum.

Results from testing with only one cycle, i.e. under quasi-static loading, already exist (see Section C2.2). These results will be included later in the evaluation. The first attempt under fatigue cyclic loading with constant load range is carried out on a level close to the elastic limit of the specimen/system made of steel.

After the first attempt, the expected fatigue limit resistance ΔS_D shall be estimated by existing experiences. The estimated value ΔS_D^{\approx} may be the expected mean value of the fatigue limit resistance.

Note: As an orientation guide for the estimated value the following range for welded reinforcement may be used subject to the static mean resistance \bar{S} .

$$\Delta S_D^{\approx} \approx (0.20; \dots; 0.50) \cdot \bar{S}$$

Thus, attempts two and three may be planned by setting the load ranges between the first load level and the estimated fatigue limit resistance.

The fourth attempt is carried out on the estimated fatigue limit resistance level, which may be amended on the basis of the first three test results. The first evaluation to determine the average function and the 5%-quantile (10%-quantile) is conducted after the fourth attempt, without distinction between failed and run-out specimens.

Afterward a second test sequence starts with an attempt whose level is lying between the first and second attempt. The load levels of attempt six and seven are arranged between the second and third respectively third and fourth attempt. Attempt eight has a load level above the average value of fatigue limit resistance determined after seven test results. The ninth attempt falls below the average value of fatigue limit resistance but already on the basis of eight evaluated test results.

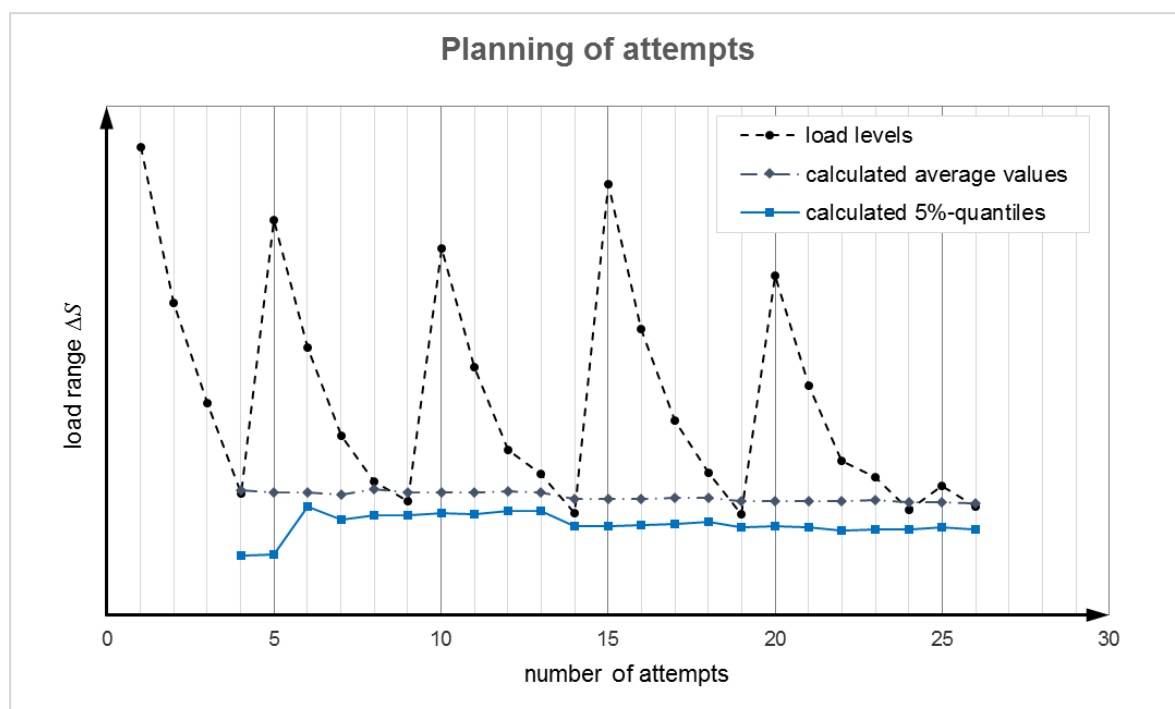


Figure C.2: Planning of attempts – average values and 5%-quantiles apply to the fatigue limit resistance (example)

The further course of experimental design is detailed shown in Figure C.2. The analysis is carried out after each attempt and shall include all fatigue cyclic tests inclusive run-out tests on their first (lower) load level. Run-out test results on their second (higher) load level are not included in the evaluation. A new test sequence always starts with the fifth, tenth, 15th and 20th attempt on high stress level. As a rule, testing may be stopped after at least 20 attempts because calculated results have stabilized. The stabilization of fatigue limit resistance is shown in Figure C.2.

During the testing at least three „real“ run-out specimens shall be identified. Failure of specimens between run-outs is permitted.

C.2.4 Determination of the limit number of cycles and load level for run-out test

The limit number of cycles n_{lim} is allocated to the interval $5 \cdot 10^6 \leq n_{lim} \leq 8 \cdot 10^6$ for carbon steel.

Specimen reaching $n \geq n_{lim}$ without failure are to be tested again with the stress range ΔS_{RT} until failure occurs. A possible damage of the specimen, despite reaching the limit number of cycles, may be located by applying this so called run-out test. The specimen is considered as a „real“ run-out specimen on the first load level, if the number of cycles on the second load level exceed the 5%-quantile (10%-quantile) function. If the run-out test is not passed, then the specimen was damaged during the first load level and is not considered as a „real“ run-out specimen.

Only results of run-out tests performed on their first load level shall be included in the determination of the average (Section C.2.5) and characteristic resistance functions (Section C.2.6). Results of run out tests performed on their second load level are required only to verify that damage to the specimens was not occurring during the tests at a lower load level.

This second test is to be set on the lower limit of the upper third of the finite fatigue life area (see Figure C.3) and is calculated as follows:

$$\Delta S_{RT} \approx \bar{S} - (\bar{S} - \Delta \bar{S}_D) / 3 \tag{C.4}$$

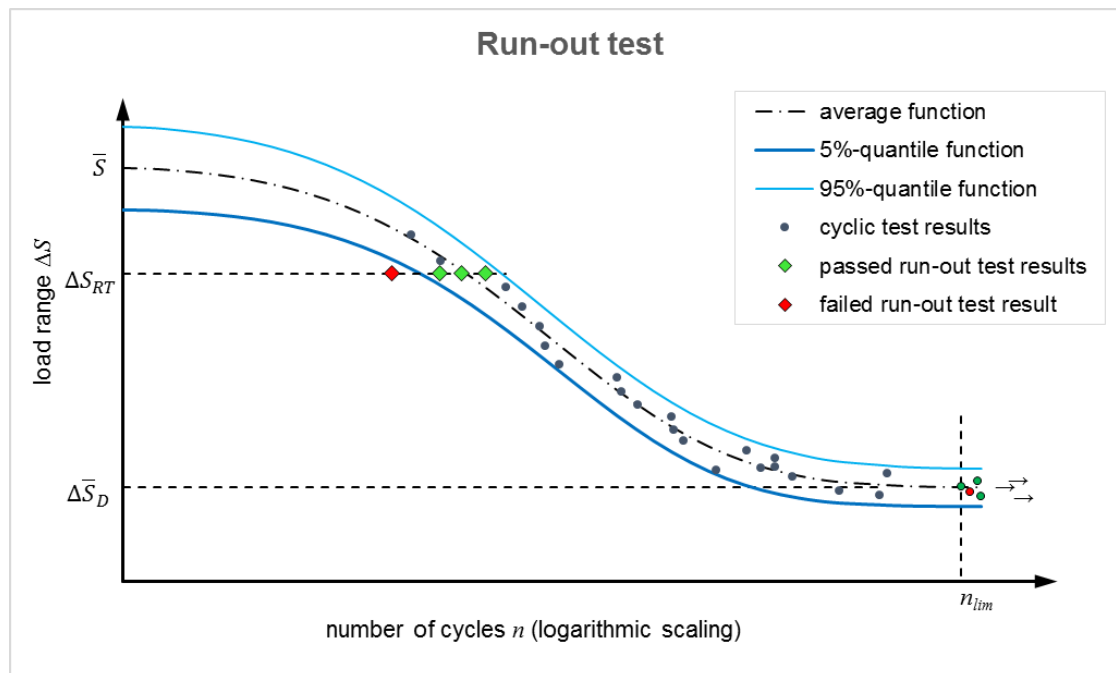


Figure C.3: Load level for run-out test

C.2.5 Determination of the average function

If test results with different load ranges and number of cycles are available, then the results are described by the Equation (C.5) according to the principles of the least squares method. The free parameters a_m , b_m and $\Delta\bar{S}_D$ are adjusted by using a regression analysis to find the minimum of least squares from the difference between load ranges. This function corresponds to the average of the fatigue resistance (see Figure C.4).

$$\Delta\bar{S} = \Delta\bar{S}_D + (\bar{S} - S_{lo} - \Delta\bar{S}_D) \cdot a_m (\lg n)^{b_m} \tag{C.5}$$

where

a_m, b_m positive dimensionless numbers for the average function, where $a_m < 1.0$

n number of cycles

$\Delta\bar{S}$ mean load range of fatigue resistance

$\Delta\bar{S}_D$ mean load range of fatigue limit resistance

\bar{S} mean static resistance determined in preliminary static tests

S_{lo} lower limit of fatigue cyclic loads

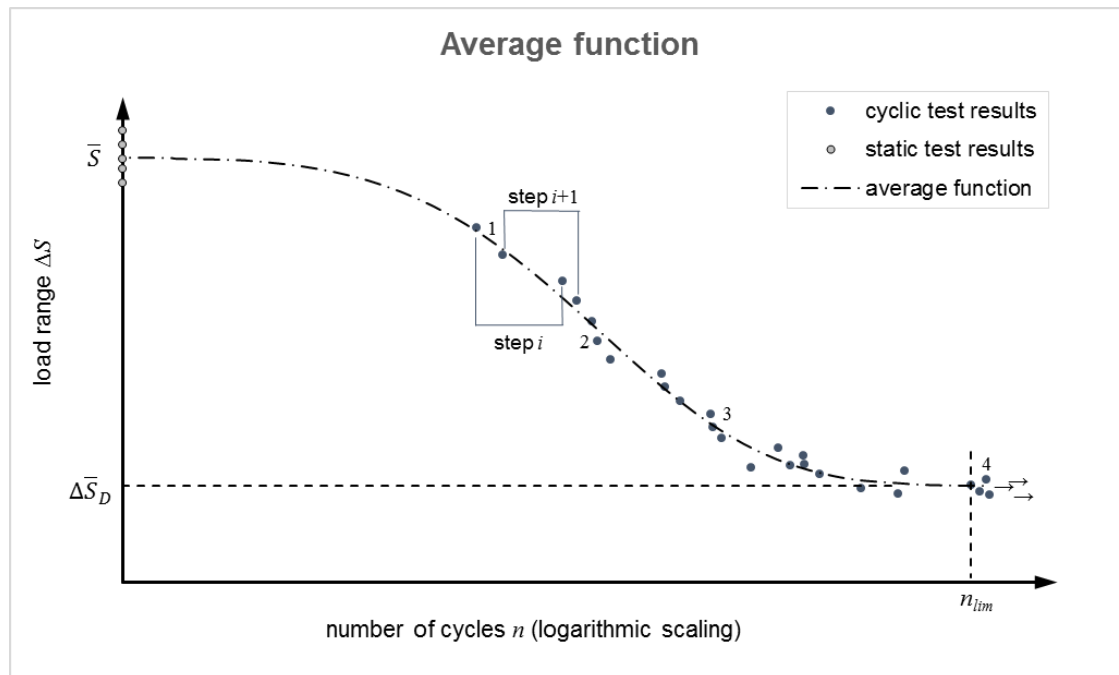


Figure C.4: Tests results and average function of fatigue resistance

C.2.6 Determination of the characteristic fatigue resistance

For the statistical evaluation three juxtaposed results are considered, independently of the COV.

Due to the average function a calculated mean value for each number of cycles is available, thus the deviation between test result load range and average function may be determined. This gives the standard deviation, which is valid for these three values. In the next step $i + 1$ the following pair of values with next higher number of cycles is taken into account and the pair of values with smallest number of cycles of step i is disregarded (see Figure C.4). This gives also the standard deviation, which is valid for these three values. Consequently the variance is obtained along the S/n-curve and thus also the 5%-quantile.

The 5%-quantiles are determined according to the following sequence:

1. For n_i cross sections corresponding mean load ranges and residuals are calculated:

$\Delta\bar{S}_i$ mean load range in the cross section for every step i according to Equation (C.5)

where

n_i number of cycles in the cross section for every step i

$$\Delta\Delta S_i = \Delta S_i - \Delta\bar{S}_i, i = 1, \dots, h \quad (\text{C.6})$$

where

h total number of available fatigue cyclic test results

2. Estimation of the average variance and average standard deviation for each three results:

$$\hat{s}_j^2 = \frac{((\Delta\Delta S_i)^2 + (\Delta\Delta S_{i+1})^2 + (\Delta\Delta S_{i+2})^2) \cdot h}{3 \cdot (h-2)}, j = 1, \dots, h-2 \quad (\text{C.7})$$

$$\hat{s}_j = \sqrt{\hat{s}_j^2} \quad (\text{C.8})$$

3. The mean load ranges in cross sections \hat{n}_j are calculated as follows:

$\Delta\bar{S}_j$ mean load range in the cross section for every step j according to Equation (C.5)

where

$$\hat{n}_j = 10^{((\lg n_i + \lg n_{i+1} + \lg n_{i+2})/3)} \quad (\text{C.9})$$

4. The 5%-quantile in cross section \hat{n}_j is calculated on a level of confidence of 90% by using the normal distribution:

$$\Delta\hat{S}_{j,5\%} = \Delta\bar{S}_j - k_{h,p,1-\alpha} \cdot \hat{s}_j, j = 1, \dots, h-2 \quad (\text{C.10})$$

The course of the 5%-quantiles is calculated using Equation (C.11) according to the principles of the least squares method (ref. Eq. (C.5)). An example of the 5%-quantile function is shown in Figure A.5.

$$\Delta S_k = \Delta S_{D,k} + (S_k - S_{lo} - \Delta S_{D,k}) \cdot a_5^{(\lg n)^{b_5}} \quad (\text{C.11})$$

where

a_5, b_5 positive dimensionless numbers for the 5%-quantile function are readjusted

n number of cycles

ΔS_k characteristic load range value of fatigue resistance

$\Delta S_{D,k}$ characteristic load range value of fatigue limit resistance

S_k characteristic static resistance determined in preliminary static tests

S_{lo} lower limit of fatigue cyclic loads

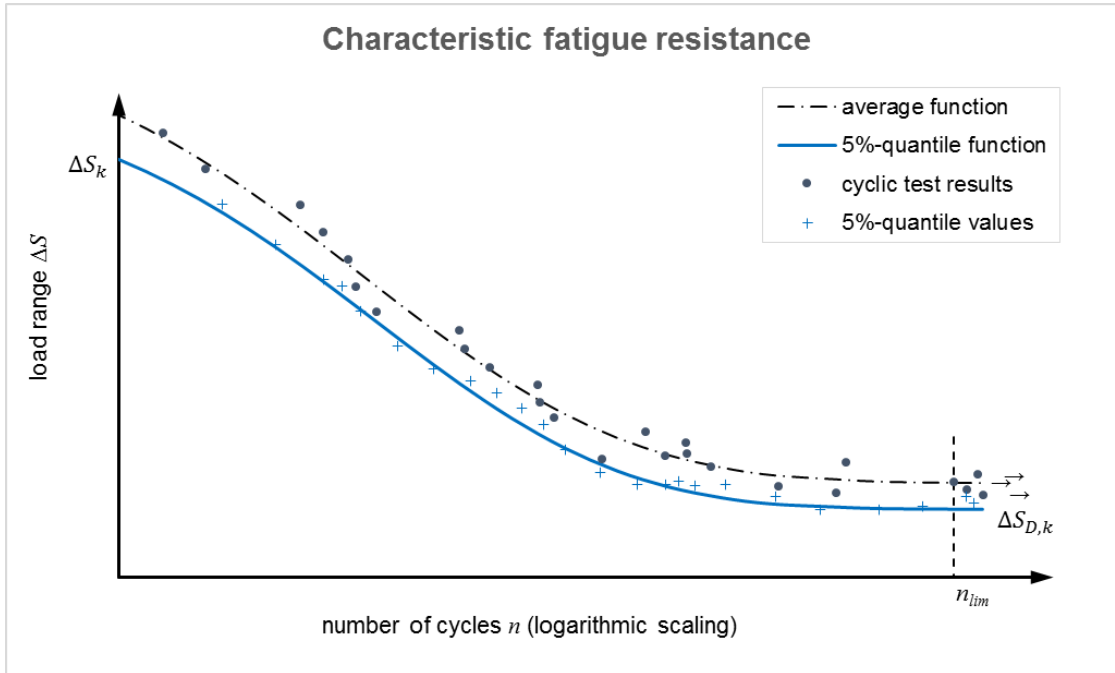


Figure C.5: Tests results, average function and 5%-quantile after regression analysis

The characteristic fatigue strength $\Delta\sigma_{Rsk,0,n}$ is equal to ΔS_k according to equation (C11).

C.2.7 Control of the characteristic fatigue resistance

On one hand, to check the characteristic fatigue resistance 5%-quantiles are determined at three cross sections along the number of cycles-axis (see Figure C.6):

Area A – all fatigue cyclic test results (h):

$$\Delta\hat{S}_{A,5\%} = \Delta\bar{S}_A - k_{h,p,1-\alpha} \cdot \hat{s}_A \tag{C.12}$$

where

$$\Delta\bar{S}_A \quad \text{mean load range of area A according to Equation (C.5)}$$

$$\text{where } \hat{n}_A = 10^{((\sum_{i=1}^h \lg n_i)/h)} \tag{C.13}$$

$$\hat{s}_A = \sqrt{\frac{\sum_{i=1}^h (\Delta\Delta S_i)^2}{h - 2}} \tag{C.14}$$

Area B – first half quantity of the fatigue cyclic test results ($0.5h$):

$$\Delta\hat{S}_{B,5\%} = \Delta\bar{S}_B - k_{h,p,1-\alpha} \cdot \hat{s}_B \tag{C.15}$$

where

$$\Delta\bar{S}_B \quad \text{mean load range of area B according to Equation (C.5)}$$

$$\text{where } \hat{n}_B = 10^{((\sum_{i=1}^{0.5h} \lg n_i)/0.5h)} \tag{C.16}$$

$$\hat{s}_B = \sqrt{\frac{(\sum_{i=1}^{0.5h} (\Delta\Delta S_i)^2) \cdot h}{0.5h \cdot (h - 2)}} \tag{C.17}$$

Note: if h is an odd number, then round down $0.5h$ to a whole number

Area C – second half quantity of the fatigue cyclic test results (0.5h):

$$\Delta\hat{S}_{C,5\%} = \Delta\bar{S}_C - k_{h,p,1-\alpha} \cdot \hat{s}_C \tag{C.18}$$

where

$\Delta\bar{S}_C$ mean load range of area C according to Equation (C.5)

where $\dot{n}_C = 10^{((\sum_{i=1}^{0.5h} \lg n_i)/0.5h)}$ (C.19)

$$\hat{s}_C = \sqrt{\frac{(\sum_{i=1}^{0.5h} (\Delta\Delta S_i)^2) \cdot h}{0.5h \cdot (h - 2)}} \tag{C.20}$$

Note: if h is an odd number, then round up 0.5h to a whole number

Furthermore, the control of the fatigue limit resistance is carried out using the reduction factor η_A , which results from the ratio of 5%-quantile to the mean load range in the centroid \dot{n}_A :

$$\eta_A = \Delta\hat{S}_{A,5\%} / \Delta\bar{S}_A \tag{C.21}$$

Using this factor the mean load range of the fatigue limit resistance is reduced as follows:

$$\eta_A \cdot \Delta\bar{S}_D \tag{C.22}$$

If these four calculated values lie above the characteristic fatigue resistance or at the same level, the control is passed. Otherwise the characteristic fatigue resistance shall be reduced to a level such that all the four calculated values lie above or coincide with the calculated function. All the information required to control and verify the characteristic fatigue resistance shall be reported in the test and evaluation reports accompanying the assessment of the test results.

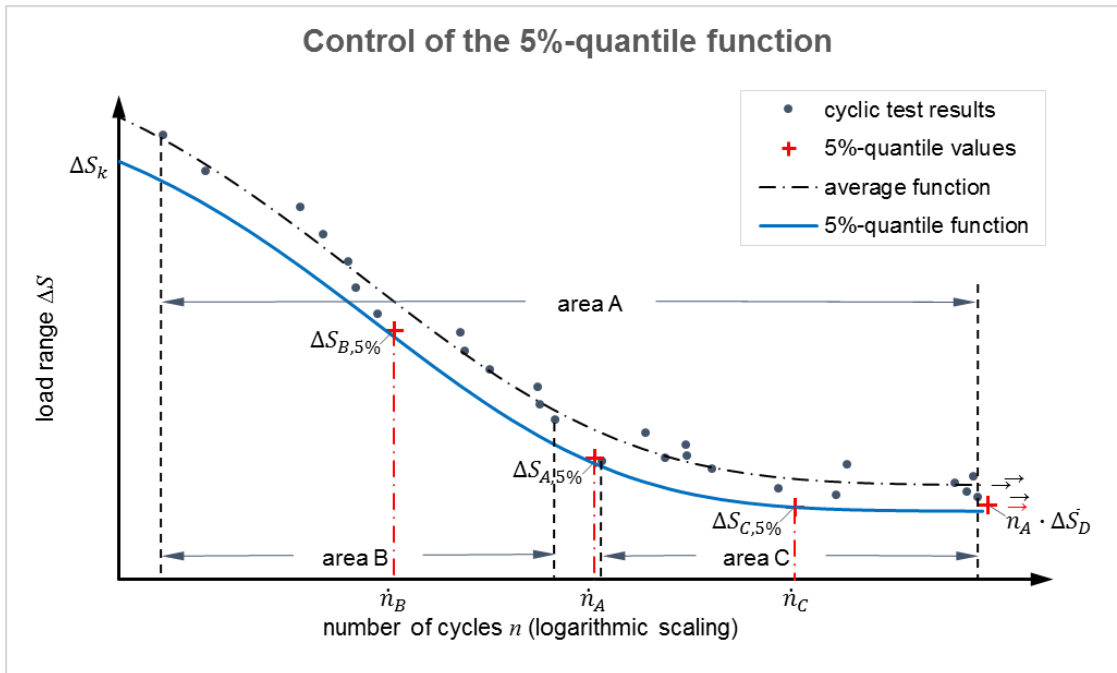


Figure C.6: Control of the characteristic fatigue resistance

C.2.8 Method to determine the characteristic fatigue resistance as a trilinear function

On the basis of the evaluation according to the interactive method a trilinear function of the fatigue resistance can be evaluated.

C.3 Requirements on test setup

Testing shall be performed on samples manufactured with the same material batch and production lot. Before testing, it shall be checked whether the products, used for testing are within the manufacturer's specifications keeping the tolerances. All measured values shall be included in the test reports.

The tests shall be carried out on a single element installed in concrete class C20/25. An example for the load application is given in Figure C.7.

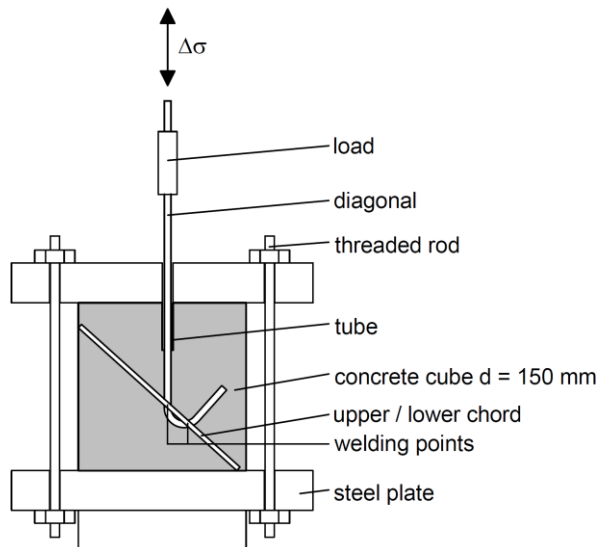


Figure C.7: Tests of the diagonal-chord-connection under fatigue load

The fastener shall be loaded with a sinusoidal load process according Figure C.8.

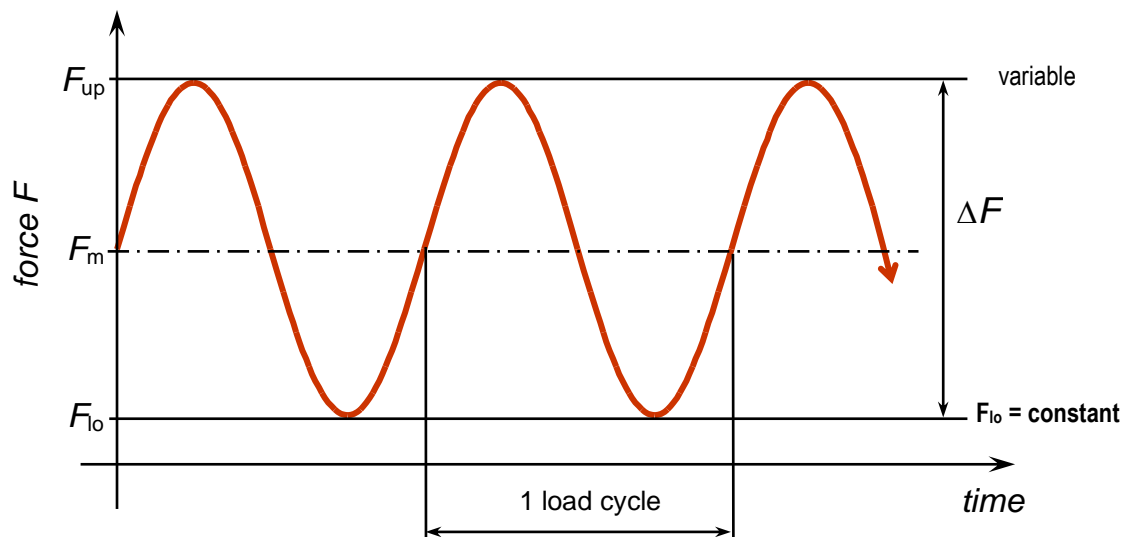


Figure C.8: Example of fatigue cyclic loading protocol

All elements with all steel qualities/properties and coatings specified by the manufacturer shall be tested. The pulsating load has to be controlled in accordance with Figure C.8.

The maximum testing frequency shall not be higher than 20 Hz.

ANNEX D REQUIREMENTS FOR THE LOAD BEARING TEST ON SLABS FOR DETERMINATION OF THE INCREASING FACTOR FOR PUNCHING SHEAR RESISTANCE

D.1 Punching Shear resistance of monolithic slabs

The annex D describes the test procedure and evaluation to determine the increasing factors according to chapter 2.2 of this EAD. This Annex D.1 gives the requirements for an application in monolithic flat slabs with an arrangement of the reinforcement according to Figure A.1.

Table D.1 gives the minimum numbers of test to determine the increasing factor $k_{pu,sl}$ for flat slabs. To determine the maximum shear resistance the tests series according to line 1 to 5 in table D.1 shall be performed. The arrangement of the reinforcement elements should be chosen accordingly to avoid steel failure. This can lead to a smaller distance of the reinforcement element than the maximum distance given by Figure A.1 belonging to the maximum shear resistance.

With an additional test (line 6 in table D.1) the concept of the steel design should be proved.

Table D.1 - Large scale tests for flat slabs

| No | failure mode | test parameters ¹⁾ | number of tests |
|----|----------------------------------|--|-----------------|
| 1 | punching failure at maximum load | $h = \min; f_{ck} = \min$ | ≥ 1 |
| 2 | punching failure at maximum load | $h = \min; f_{ck} = \max$ | ≥ 1 |
| 3 | punching failure at maximum load | $h = \max; f_{ck} = \min$ | ≥ 1 |
| 4 | punching failure at maximum load | $h = \max; f_{ck} = \text{mean to max}$ | ≥ 1 |
| 5 | punching failure at maximum load | $h = \text{mean}; f_{ck} = \text{min to mean}$ | ≥ 1 |
| 6 | steel failure | $h = \text{mean}; f_{ck} = \text{mean to max}$ | ≥ 1 |

¹⁾ $h_{\min} = 180 \text{ mm}$, $h_{\max} = \text{about maximum thickness applied for the ETA}$, $f_{ck,\min} = 20 \text{ MPa}$, $f_{ck,\max} = 50 \text{ MPa}$

It should be at least one test conducted with yield strength of the flexural reinforcement with $f_{yk} \geq 500 \text{ MPa}$, if a flexural reinforcement with a strength higher than $f_{yk} = 500 \text{ MPa}$ should be incorporated, so as not to limit the scope of EN 1992-1-1.

The test set up and the test procedure shall comply with the requirements according to Annex D.6.

The punching shear tests shall be performed with different effective depths, with different concrete strengths, different column diameters and different reinforcement ratios.

All parameters should be chosen carefully so as to allow extrapolating the influence of these parameters where necessary, especially in such cases where direct test results cannot be obtained due to technical limitations (i.e. slab thickness).

Although special cases may be identified and treated specifically, test specimens should generally represent the severe end of the range of situations covered by TR 058. They shall not embody favourable features not accounted for in the TR 058.

Large scale tests shall be performed according to Table D.1 (line 1 to 5) to determine the maximum increasing factor $k_{pu,msl}$. Monolithic slabs should be used. However, test made with composite slabs made of precast slabs and in situ topping can be taken into account to determine the increasing factor also for monolithic slabs. If the concrete strength of the precast part is not higher than the in situ concrete strength plus 10 MPa ($f_{c,precast} \leq f_{c,insitu} + 10 \text{ MPa}$) the strength of the in situ concrete shall be taken into consideration for the test evaluation. If the strength of the precast part is more than 10 MPa higher, the strength of the precast part should be taken into account.

The results of punching tests shall be used to verify that the punching resistance achieved by tests are compatible with the punching resistance calculated according to TR 058.

Test results, where bending failure occurs, shall not be considered.

The calculation methods described in TR 058 for determining the punching resistance comprises the scaling factor which is assumed and confirmed by EN 1992-1-1.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing according to equation (D.1).

$$k_{pu,i} = \frac{v_{test}}{v_{Rd,c}} \quad (D.1)$$

$k_{pu,i}$ increasing factor for a single test

v_{test} punching shear resistance reached in the test

$v_{Rd,c}$ estimated shear resistance according to TR 058, equation (2.12)

For calculation of $v_{Rd,c}$ the characteristic compressive cylinder strength f_{ck} shall be determined as follows:

$f_{ck} = f_{cm} - 4$ [MPa] with f_{cm} = measured value of concrete cylinder compressive strength in the test.

The results of the individual test series shall be evaluated together to determine the increasing factor $k_{pu,msl}$ for monolithic slabs. The characteristic increasing factor for punching resistance of monolithic slabs $k_{pu,msl}$ shall be determined as 5%-fractile of the ratio $v_{test}/v_{Rd,c}$.

The 5 %-fractile shall be determined in accordance with annex D of EN 1990 using a known standard deviation and a confidence level of 75 %.

D.2 Punching shear resistance of composite flat slabs

For determination of the increasing factor $k_{pu,csl}$, at least 3 of the test series according to line 1 to 5 in table D.1 shall be carried out with composite slabs. The minimum, medium and maximum slab thickness as well as the minimum and the maximum concrete strength shall be covered by tests.

The test set up and the test procedure shall comply with the requirements according to Annex D.6.

The tests specimen shall be made of about 5 cm thick precast elements and in situ concrete. Butt joints between the precast slabs shall be between 3 cm and 4 cm. The joint between the precast slab and the column edge shall be between 4 cm and 0 cm (an overlap of precast slab and column of a maximum of 1 cm is tolerable).

The results of the individual test series shall be evaluated together to determine the increasing factor $k_{pu,csl}$ for composite slabs. The characteristic increasing factor for punching resistance of composite slabs $k_{pu,csl}$ shall be determined as 5%-fractile of the ratio $v_{test}/v_{Rd,c}$.

The 5 %-fractile shall be determined in accordance with annex D of EN 1990 using a known standard deviation and a confidence level of 75 %.

If it can be shown that the results with composite slabs are in the same range as tests with monolithic slabs, these tests can also be evaluated together as one group of tests.

D.3 Punching shear resistance for an alternative shear reinforcement arrangement

For determination of the increasing factor $k_{pu,asl}$, at least 3 of the test series according to line 1 to 5 in table D.1 shall be carried out with an alternative arrangement according to figure A.2. The minimum, medium and maximum slab thickness as well as the minimum and the maximum concrete strength shall be covered by tests.

The test set up and the test procedure shall comply with the requirements according to Annex D.6.

The results of the individual test series shall be evaluated together to determine the increasing factor $k_{pu,asl}$ for slabs with modified arrangement of lattice girders. The characteristic increasing factor for punching resistance $k_{pu,asl}$ shall be determined as 5%-fractile of the ratio $v_{test}/v_{Rd,c}$.

The 5 %-fractile shall be determined in accordance with annex D of EN 1990 using a known standard deviation and a confidence level of 75 %.

If it can be shown that the results with modified arrangement are in the same range as tests with other slabs, the tests can also be evaluated together as one group of tests.

D.4 Punching resistance of footings and ground slabs

If a higher increasing factor for footing and ground slabs than $k_{pu,fo} = 1.5$ shall be given in the ETA of the lattice punching shear reinforcement, tests according to table D.2 are necessary.

Large scale tests shall be performed according to Table D.2.

The test specimen is loaded at least by 16 identical loads to achieve an approximately uniform pressure.

Table D.2 - Large scale tests for footings and ground slabs

| No | failure mode | test parameters | number of tests |
|----|----------------------------------|---|-----------------|
| 1 | punching failure at maximum load | d about maximum slab thickness ¹⁾ $f_{ck} = 20$ to 30 MPa | ≥ 3 |

¹⁾ maximum thickness given in the ETA

The shear span – depth ratio of the footings should vary between $a_x/d=1.25$ and 2.00. a_x is the distance from the face of the column to the line of contra flexure for the bending moments in radial direction.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing according to equation (D.2).

$$k_{pu,i} = \frac{v_{test}}{v_{Rd,c}} \quad (D.2)$$

$k_{pu,i}$ increasing factor for a single test

v_{test} punching shear resistance reached in the test

$v_{Rd,c}$ estimated shear resistance according to TR 058, equation (2.18)

For calculation of $v_{Rd,c}$ the characteristic compressive cylinder strength f_{ck} shall be determined as follows:

$f_{ck} = f_{cm} - 4$ [MPa] with f_{cm} = measured value of concrete cylinder compressive strength in the test.

The results of the individual test series shall be evaluated together to determine the increasing factor $k_{pu,fo}$ for footings and ground slabs. The characteristic increasing factor $k_{pu,fo}$ for punching shear shall be determined as 5%-fractile of the ratio $v_{test}/v_{Rd,c}$.

The 5 %-fractile shall be determined in accordance with annex D of EN 1990 using a known standard deviation and a confidence level of 75 %.

D.5 Maximum resistance of the interface in case of composite slabs

At least 3 punching shear tests with composite slabs within the range of table D.1 must be carried out to determine the $k_{max,i}$ according to equation (5.1) of TR 058, chapter 5. The increasing factor for maximum interface resistance for each single test is given by equation (D.3).

$$k_{max,i} = \frac{v_{Edi,test}}{0.5 \cdot v \cdot f_{ck}} \quad (D.3)$$

$k_{max,i}$ increasing factor for maximum interface resistance for a single test

$v_{Edi,test}$ interface shear resistance reached in the test

with

$$v_{di,test} = V_{test} / (u_{1.5d} \cdot z)$$

v factor for the roughness of the interface

for a smooth surface with a roughness $R_T < 1.5$ mm measured with the sand patch method a value of $v = 0.2$ is recommended

for a rough surface with a roughness $R_T \geq 1.5$ mm measured with the sand patch method a value of $v = 0.5$ is recommended

The characteristic compressive cylinder strength f_{ck} in equation (D.3) shall be determined as $f_{ck} = f_{cm} - 4$ [MPa] with f_{cm} = measured value of concrete cylinder compressive strength in the test (f_{cm} should be taken as the minimum of the precast and in situ strength).

The increasing factor k_{max} in the ETA can be taken as the minimum of $k_{max,i}$ of at least 3 tests.

D.6 Requirements on test setup

Test specimen for the punching shear tests to determine the maximum shear strength shall be designed to exhibit punching shear failure inside the critical perimeter. (Other failure modes should not be taken into account when assessing the maximum load bearing capacity.)

In order to simulate realistically the conditions on the construction site, test specimens shall be full scale test. Effective depth of the slab and column diameter shall be chosen appropriately to cover unfavourable effects of bending over the column head.

Concrete strength and flexural reinforcement ratio shall be chosen appropriately to allow the assessment of the full range of concrete strength classes. This may follow from an evaluation of tests where the influence of concrete strength on the load bearing capacity is evident.

All relevant properties shall be documented by proper measuring methods, including appropriate measuring devices. These shall allow for the evaluation of the following:

- Moment distribution at ultimate load;
- Crack development in dependence of the loading history (first crack, crack propagation, maximum crack at design load level);
- Residual load bearing capacity (if any) after failure, determined by re-loading;
- Concrete strain and splitting (if any);
- Effects of the boundary conditions (load distribution, membrane effects (if any));
- Vertical displacements of the ends of the slab should be measured allowing to define the “rotation capacity” and to assess the ductility of failure;
- Strains of the flexural reinforcement;
- Material properties of the concrete and the reinforcement steel.

The types of specimens most commonly used in punching tests of flat slabs are illustrated in figure D.1. In such specimens, the clear distances between loads and supports should be as long as the distance between the peak of the negative bending moment and the beginning of the positive bending moment for typical slabs. Any reduction of this distance reduces the local strains of the concrete and the flexural reinforcement near the column. Clear distances of $3 \cdot d$ to $5 \cdot d$ should be suitable for reinforced concrete slabs. Test with slender slabs can be taken into consideration on the safe side.

The slab should not extend significantly beyond the outer loads or reactions. Large extensions which are favourable for the development of a compressive membrane action shall be avoided.

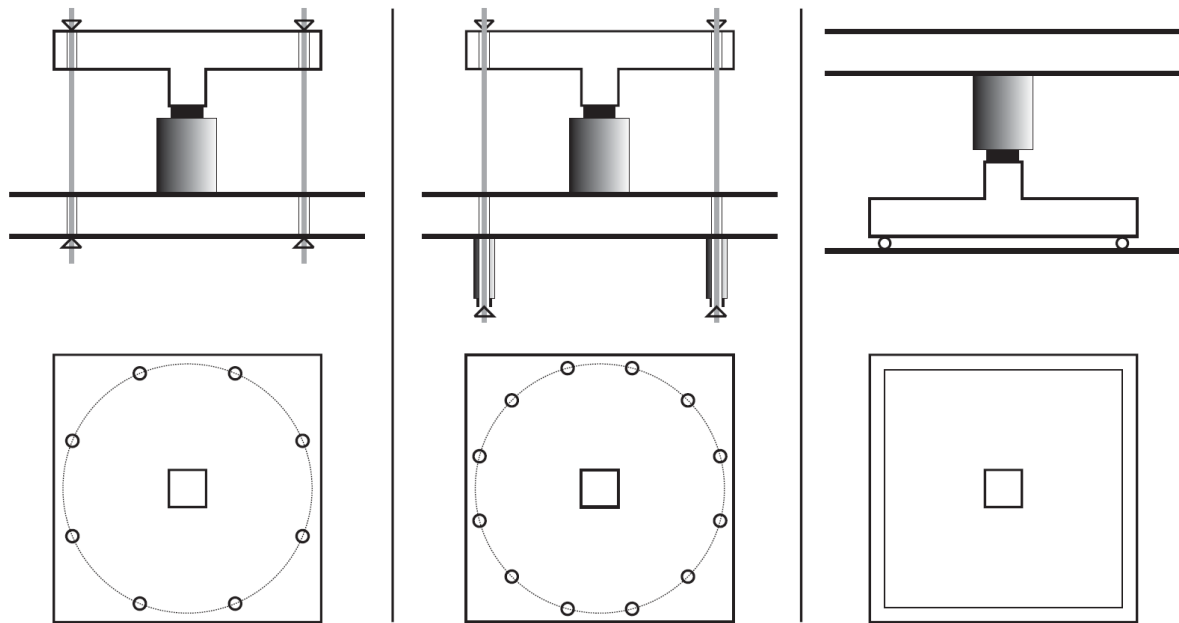


Figure D.1: different test setups for flat slabs

The anchorages of the shear reinforcement should have normal cover. Anchorage above the level of the flexural reinforcement, or very close to the surface of the compression zone is more favourable than normal practice.

The system of loads or supports near the slab edge should allow freedom of outward movement to avoid that friction and compressive membrane action increase the failure load (friction increases the failure load by up to 15% and compressive membrane action increases the failure load by up to 25%). Therefore, tests where friction and compressive membrane action are not avoided are unsuitable for determining maximum punching load resistance in the context of this EAD. The test set up in the middle of figure D.1 ensures due to the arrangement of the supports a uniform load distribution and prevents increasing of the failure load due to friction or compressive membrane action and shall be the test set up chosen to determine the maximum load bearing capacity.

The proposed test setup for footings is shown in figure D.2. The test specimen is loaded at least by 16 identical loads to achieve approximately a uniform pressure. To avoid a membrane action in the specimen, the load application points allow freedom of radial and tangential movement, otherwise the failure load has to be reduced by the amount of friction and membrane forces. For punching tests on footings, a minimum value of the effective depth with $d \geq 500$ mm or the maximum thickness which is applied for an ETA is assumed.

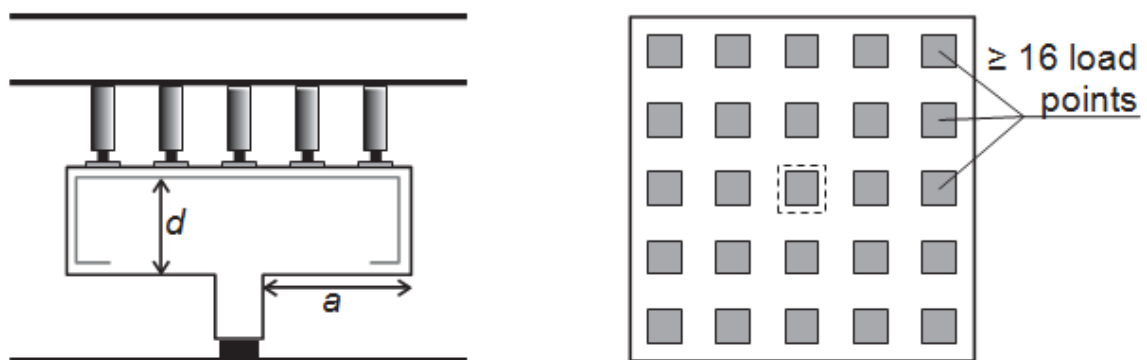


Figure D.2: test setup for footings