10. Determination of technical data for fastening design

The determination of technical data is based on the following tests:

• Application limits

• Tensile tests to determine pull-out and pull-over strength

• Shear tests to determine bearing capacity of the attached material and the base material.

These tests are described in more detail in the sections "Steel and other metal base material" and "Concrete base material".

10.1 Fastenings to steel

Failure loads in tension and in shear are normally distributed and the variation coefficient is <20%. The test data for each test condition are evaluated for the average and characteristic values. The characteristic value is based on the 5% fractile for a 75% probability.

The application range of the fastener is determined by application limit test where fasteners are set on steel plates of thickness ranging from the minimum recommended thickness $t_{II,min}$ to full steel (≥ 20 mm) and varied plate strength.

The application limit is reached when 1 shear off failure with 30 fasteners tested occurs, or if a detrimental effect on the load values (resistance) occurs, or if a detrimental effect on the load values (resistance) occurs.

Due to the small scatter in failure loads fastenings in steel can thus be designed as single points, although good engineering practice should be kept in mind. System redundancy must be always ensured.

10.2 Profile sheet fastenings

In addition to general fastenings to steel, specific data applies to profile sheet fastenings:

Cyclic loading

Profile sheet fastenings are subjected to repeated loading to simulate wind effects. Cyclic pull-through tests are additional optional tests where the failure load at 5,000 cycles is determined.

The design value of the pull-through resistance for repeated wind loads is the design value of the static pull-through resistance multiplied by a reduction factor of α_{cycl}.

- If cyclic tests are carried out:

  $\alpha_{cycl} = 1.5 \, (N_{Rk,cycl.} / N_{Rk,sta}) \leq 1$

  (The factor 1.5 takes the different safety levels for fatigue and predominately static design into account)
- If no cyclic tests are carried out:

  $\alpha_{cycl} = 0.5$

Sheet bearing capacity

Profile sheet fastenings may be subjected to shear stresses from building movements or thermal dilatation of the sheets. Tests are undertaken to prove the suitability of the fastenings to support the deformations imposed.

For this, shear tests are carried out using a substrate of the minimum and maximum thickness and 2 layers of profile sheet of the thickness specified.

The fastening is considered suitable if an elongation of 2 mm is achieved without the sheet coming loose or showing an excessive reduction in pull-out load capacity. In this case, no consideration of forces of constraint is required since sufficient ductility is provided by the fastening due to hole elongation.

Standardization

The pull-over strength of profiled sheet fastenings is given with reference to core sheet thickness. Ultimate load data is standardized to the minimum sheet thickness and strength as specified by the relevant sheet standard. The correction applied is as follows:

$$F_{u'} = F_u \times \frac{t_{min}}{t_{act}} \times \frac{f_{u,min}}{f_{u,act}}$$

10.3 Fastenings to concrete (standard DX / GX)

The failure loads in tension and shear show a large scatter with a variation coefficient of up to 60%. For specific applications, fastener driving failures may be detected and the fasteners replaced (e.g. threaded studs). For others, however, detection may not be possible (e.g. when fastening wooden battens) and this must be taken into consideration.

The design resistance is therefore determined for:
• failure loads without considering fastener driving failures
• failure loads considering a 20% rate of fastener driving failure
Evaluation of technical data and design according to the single point design approach based on fractiles and a safety factor is not feasible for such systems. The characteristic value would become zero at a variation coefficient of about 50%.
The evaluation of the data and the determination of the design resistance is therefore based on a multiple fastening, i.e. a redundant design, in which the failure probability not of a single, but of a number of fasteners supporting a structure is calculated. By this system, load may be transferred between the fasteners, if slip or failure or moreof one of the fasteners occurs.
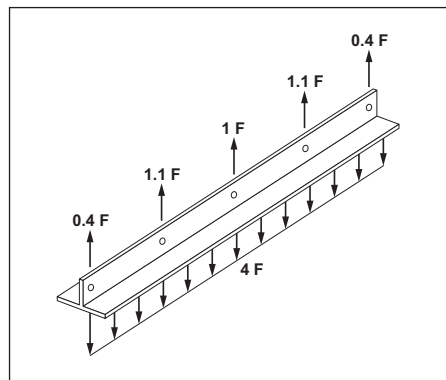
Test data
The test data for the fastener is consolidated to form a master pullout load distribution.
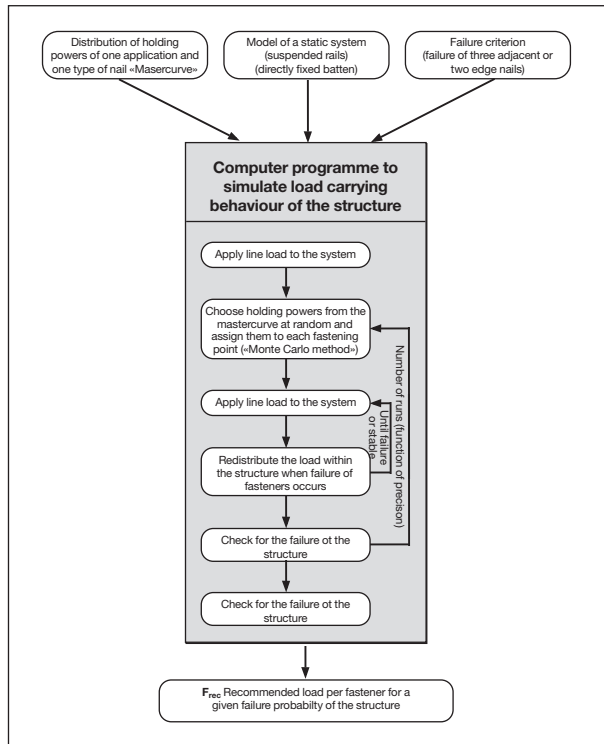
Static system

Two static systems are examined
• A suspended beam allowing unrestrained flexure of the beam
• A beam directly attached to the surface, which shows restrained flexure

Calculation method

The calculation method used is the Monte Carlo method, by which holding values taken stochastically from the master distribution are attributed to the individual fasteners of the system and the system is checked to determine whether the imposed line load can be supported. By performing a large number of such simulations, statistical information on the failure probability of a system under a given line load is obtained.

| Distribution of holding powers of one application and one type of nail «Masercurve» | Model of a static system (suspended rails) (directly fixed batten) | Failure criterion (failure of three adjacent or two edge nails) |

Computer programme to simulate load carrying behaviour of the structure

Apply line load to the system

Choose holding powers from the mastercurve at random and assign them to each fastening point («Monte Carlo method»)

Apply line load to the system

Redistribute the load within the structure when failure of fasteners occurs

Check for the failure ot the structure

Check for the failure ot the structure

Number of runs (function of precison)
Until failure or stable

F_{rec} Recommended load per fastener for a given failure probabilty of the structure

Design parameters

The design is based on the following parameters:
- Failure probability: 1×10^{-6}
- Number of fasteners: 5
- Line load uniformly distributed
- Failure criterion: 2 edge or 3 central fastenings

The result is expressed in **recommended load per fastening.**

Effect on a fastening design

The overall condition for a fastening design in practice is that redundancy of the complete system has to be ensured. The effect of the Monte Carlo approach on a design is illustrated with two examples below.

Static system

Example:

Fastening of a plumbing with five ceiling hangers.
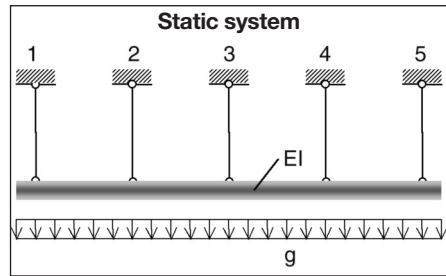
1. Due to the stiffness (EI) of the plumbing a redistribution of the dead load (g) to the remaining hangers is given in case of two neighbouring hangers failing.
   ➢ Fixing of each hanger with one nail is sufficient.

2. The plumbing is not stiff enough to redistribute the dead load to the neighbouring hangers in case of one fastener failing.
   ➢ Each hanger has to be fastened with five nails.

10.4 DX fastenings to concrete (DX-Kwik)

Failure loads in tension and shear are log-normally distributed and the variation coefficient is <20 %. The test data is evaluated to yield the 5 % fractile based on a 90% probability. The recommended working loads are obtained by applying a global safety factor of 3 for tension and shear.

The determination of technical data for cracked concrete (tensile zone) is based on tensile tests. Shear tests in cracked and uncracked concrete give similar results and are therefore not performed.

Failure loads in cracked concrete show a higher variation coefficient. Test data is also evaluated to yield the 5% fractile. The recommended load for the tensile zone is taken as the smaller of the following values:

• $N_{rec} = N_{Rk}/\gamma_{GLOB}$ γ_{GLOB} = 3.0 for 0.2 mm crack width
• $N_{rec} = N_{Rk}/\gamma_{GLOB}$ γ_{GLOB} = 1.5 for 0.4 mm crack width.

The application range of the fastener is determined by application limit test where fastenings are made on concrete of varying strength and age according to the application conditions specified (pre-drilling and setting). The attachment height is kept at the lower end of the range specified. The application limit is reached, if the failure rate exceeds 3% or the pull-out values strongly deviate from a lognormal distribution. The sample size is 30 per condition.

10.5 Fastener design in the USA and Canada

Testing of powder-actuated fasteners is carried out according to the ICC-ES AC 70 acceptance criteria and ASTM E 1190 standard test method. The test procedure covers tensile and shear testing in steel, concrete and masonry.

The determination of the allowable (recommended) load is shown below. The recommended working load is derived from the test data by taking the average failure load or the calculated characteristic load divided by a global safety factor.

Three different options have to be distinguished:

COV ≥ 15%		COV < 15%
based on characteristic load N = 30 tests	based on lowest ultimate load N = 10 tests	based on mean ultimate load N = 10 tests
$F_{rec} = \dfrac{F_{u,m} - 2s}{\nu} = F_{u,m}\dfrac{1 - 2COV}{\nu}$	$F_{rec} = \dfrac{minF_u}{\nu}$	$F_{rec} = \dfrac{F_{u,m}}{\nu}$

with a safety factor of $\nu = 3.5$	with a safety factor of $\nu = 5$

where:

F_{rec}	= allowable (recommended) load
COV	= $s/F_{u,m}$ = coefficient of variation in a test series
s	= standard deviation in a test series
$F_{u,m}$	= average ultimate load in test series