



**BSI Standards Publication**

## **Cranes — General design**

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Part 3-1: Limit states and proof competence of steel structure

## National foreword

This British Standard is the UK implementation of EN 13001-3-1:2025. It supersedes BS EN 13001-3-1:2012+A2:2018, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MHE/3/1, Crane design.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

## Cranes - General design - Part 3-1: Limit states and proof competence of steel structure

Appareils de levage à charge suspendue - Conception  
générale - Partie 3-1 : Etats limites et vérification  
d'aptitude des charpentes en acier

Krane - Konstruktion allgemein - Teil 3-1:  
Grenzzustände und Sicherheitsnachweis von  
Stahltragwerken

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## European foreword

This document (EN 13001-3-1:2025) has been prepared by Technical Committee CEN/TC 147 “Cranes - Safety”, the secretariat of which is held by SFS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2025, and conflicting national standards shall be withdrawn at the latest by August 2025.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13001-3-1:2012+A2:2018.

This document has been prepared under a standardization request addressed to CEN by the European Commission. The Standing Committee of the EFTA States subsequently approves these requests for its Member States.

For the relationship with EU Legislation, see informative Annex ZA, which is an integral part of this document.

CEN/TC 147 WG 2 has reviewed EN 13001-3-1:2012+A2:2018 to adapt the document to technical progress. The main changes are:

- design values for standardized steels (4.2.1) were moved to a new Annex M (normative);
- design values for bolt materials were changed (Table 4);
- limit design values for welded connection were changed (5.2.5);
- static proof of welded connections was changed (5.3.4 and Annex C (normative));
- proof of fatigue strength was revised to include additional modern methods (6.1);
- fatigue strength specific resistance factors were modified (Table 8);
- the geometric stress (Hot Spot) method was added (6.2.4 and Annex I (normative));
- the effective notch method was added (6.2.5 and Annex I (normative));
- lateral-torsional stability of beams was added (8.4 and 8.5.3 and Annex J (informative));
- recommended tightening torques for preloaded bolts were modified (Annex B (informative));
- characteristic fatigue strengths for plates in shear were modified (Table D.1);
- Annex L (informative) with a list of hazards was inserted;
- Annex ZA (informative) was significantly revised.

This document is one part of the EN 13001 series of standards. The other parts are:

- *Part 1: General principles and requirements;*
- *Part 2: Load actions;*
- *Part 3-2: Limit states and proof of competence of wire ropes in reeving systems;*
- *Part 3-3: Limit states and proof of competence of wheel/rail contacts;*
- *Part 3-4: Limit states and proof of competence of machinery;*
- *Part 3-5: Limit states and proof of competence of forged hooks and cast hooks;*
- *Part 3-6: Limit states and proof of competence of hydraulic cylinders.*

An overview of European Standards for cranes is provided in Annex K (informative).

Any feedback and questions on this document should be directed to the users' national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

## Introduction

This document has been prepared to be a harmonized standard to provide one means for the mechanical design and theoretical verification of cranes to conform to the essential health and safety requirements of the Machinery Directive, as amended.

This document is a type-C standard as stated in EN ISO 12100:2010.

This document is of relevance, in particular, for the following stakeholder groups representing the market players with regard to machinery safety:

- machine manufacturers (small, medium and large enterprises);
- health and safety bodies (regulators, accident prevention organizations, market surveillance, etc.).

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

- machine users/employers (small, medium and large enterprises);
- machine users/employees (e.g. trade unions, organizations for people with special needs);
- service providers, e.g. for maintenance (small, medium and large enterprises);
- consumers (in case of machinery intended for use by consumers).

The above-mentioned stakeholder groups have been given the possibility to participate in the drafting process of this document.

The machinery concerned and the extent to which hazards, hazardous situations or hazardous events are covered are indicated in the scope of this document.

When provisions of this type-C standard are different from those which are stated in type-A or B standards, the provisions of this type-C standard take precedence over the provisions of the other standards, for machines that have been designed and built according to the provisions of this type-C standard.

## 1 Scope

This document specifies limit states, requirements and methods to prevent mechanical hazards in steel structures of cranes by design and theoretical proof of competence.

The significant hazardous situations and hazardous events that could result in risks to persons during intended use are identified in an informative Annex L (informative). Clauses 4 to 8 of this document provide requirements and methods to reduce or eliminate these risks:

- a) exceeding the limits of strength (yield, ultimate, fatigue);
- b) exceeding temperature limits of material or components;
- c) elastic instability of the crane or its parts (buckling, bulging).

This document does not apply to cranes which are designed before the date of its publication as EN.

NOTE This document deals only with the limit state method in accordance with reference [44].

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1993-1-8:2024, *Eurocode 3 — Design of steel structures — Part 1-8: Joints*

EN 10025-2:2019, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 10025-3:2019, *Hot rolled products of structural steels — Part 3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels*

EN 10025-4:2019+A1:2022, *Hot rolled products of structural steels — Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels*

EN 10025-6:2019+A1:2022, *Hot rolled products of structural steels — Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition*

EN 10029:2010, *Hot-rolled steel plates 3 mm thick or above — Tolerances on dimensions and shape*

EN 10088-2:2024, *Stainless steels — Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resistant steels for general purposes*

EN 10088-3:2023, *Stainless steels — Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resistant steels for general purposes*

EN 10149-2:2013, *Hot rolled flat products made of high yield strength steels for cold forming — Part 2: Technical delivery conditions for thermomechanically rolled steels*

EN 10149-3:2013, *Hot rolled flat products made of high yield strength steels for cold forming — Part 3: Technical delivery conditions for normalized or normalized rolled steels*

EN 10160:1999, *Ultrasonic testing of steel flat product of thickness equal or greater than 6 mm (reflection method)*

EN 10163-1:2004, *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections — Part 1: General requirements*

EN 10163-2:2004, *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections — Part 2: Plate and wide flats*

EN 10163-3:2004, *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections — Part 3: Sections*

EN 10164:2018, *Steel products with improved deformation properties perpendicular to the surface of the product — Technical delivery conditions*

EN 13001-2:2021, *Crane safety — General design — Part 2: Load actions*

EN ISO 148-1:2016, *Metallic materials — Charpy pendulum impact test — Part 1: Test method (ISO 148-1:2016)*

EN ISO 286-2:2010, *Geometrical product specifications (GPS) — ISO code system for tolerances on linear sizes — Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts (ISO 286-2:2010)*

EN ISO 898-1:2013, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread (ISO 898-1:2013)*

EN ISO 5817:2023, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2023)*

EN ISO 6892-1:2019, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature (ISO 6892-1:2019)*

EN ISO 9013:2017, *Thermal cutting — Classification of thermal cuts — Geometrical product specification and quality tolerances (ISO 9013:2017)*

EN ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction (ISO 12100:2010)*

EN ISO 17635:2016, *Non-destructive testing of welds — General rules for metallic materials (ISO 17635:2016)*

EN ISO 17659:2004, *Welding — Multilingual terms for welded joints with illustrations (ISO 17659:2002)*

ISO 4306-1:2007, *Cranes — Vocabulary — Part 1: General*

### 3 Terms, definitions, symbols and abbreviations

#### 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100:2010 apply. For the definitions of loads, Clause 6 of ISO 4306-1:2007 applies.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp/>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.2 Symbols and abbreviations

The symbols and abbreviations used in this document are given in Table 1.

**Table 1 — Symbols and abbreviations**

| Symbols,<br>abbreviations | Description                                             |
|---------------------------|---------------------------------------------------------|
| $A$                       | cross section                                           |
| $A_n$                     | net cross section                                       |
| $A_S$                     | stress area of a bolt                                   |
| $A_S$                     | shear area of the tear-out section (pinned connections) |
| $a$                       | length of plate in buckling                             |
| $a_r$                     | throat thickness of fillet welds                        |
| $b$                       | width of plate                                          |
| $c$                       | edge stress ratio factor (buckling)                     |
| $D_o, D_i$                | outer, inner diameter of hollow pin                     |
| $d$                       | diameter (shank of bolt, pin)                           |
| $d_o$                     | diameter of hole                                        |
| $E$                       | modulus of elasticity                                   |
| $F_b$                     | tensile force in bolt                                   |
| $F_d$                     | limit force                                             |
| $F_k$                     | characteristic value (force)                            |
| $F_p$                     | preloading force in bolt                                |
| $F_{Rd}$                  | limit design force                                      |
| $F_{e,t}$                 | external tensile force on bolted connection             |
| $F_{b, Rd}$               | limit design bearing force                              |
| $F_{b, Sd}, F_{bi, Sd}$   | design bearing force                                    |
| $F_{cs, Rd}$              | limit design tensile force                              |
| $F_{p, d}$                | design preloading force                                 |
| $F_{cr}$                  | reduction in compression force due to external tension  |
| $F_{t, Rd}$               | limit design tensile force in bolt                      |
| $F_{t, Sd}$               | external tensile force per bolt                         |
| $F_{v, Sd}$               | design shear force per bolt and shear plane             |
| $F_{vp, Rd}$              | limit design shear force per pin and shear plane        |
| $F_{vp, Sd}$              | design shear force per pin and shear plane              |

| Symbols,<br>abbreviations  | Description                                                                    |
|----------------------------|--------------------------------------------------------------------------------|
| $F_{s,Rd}$                 | limit design slip force per bolt and shear plane                               |
| $F_{vs,Rd}$                | limit design shear force of the connected part                                 |
| $F_{vd,Sd}$                | design force in the connected part                                             |
| $F_{vt,Rd}$                | limit design tensile force of the connected part                               |
| $F_{\sigma,\tau}$          | acting normal/shear force                                                      |
| $f$                        | maximum imperfection                                                           |
| $f_d$                      | limit stress                                                                   |
| $f_k$                      | characteristic value (stress)                                                  |
| $f_{Rd}$                   | limit design stress                                                            |
| $f_u$                      | ultimate strength of material                                                  |
| $f_{ub}$                   | ultimate strength of bolts                                                     |
| $f_{w,Rd}$                 | limit design weld stress                                                       |
| $f_{w,Rd,1}$               | limit design weld stress with respect to the weld material                     |
| $f_{w,Rd,2}$               | limit design weld stress with respect to the material of the connected members |
| $f_y$                      | yield stress of material, specified or measured                                |
| $f_{yb}$                   | yield stress of bolts                                                          |
| $f_{yp}$                   | yield stress of pins, specified or measured                                    |
| $h_d$                      | distance between weld and contact level of acting load                         |
| $I, I_i$                   | moments of inertia of members                                                  |
| $k$                        | stress concentration factor (pinned connections)                               |
| $K_b$                      | stiffness of bolt                                                              |
| $K_c$                      | stiffness of connected parts                                                   |
| $k^*$                      | specific spectrum ratio factor                                                 |
| $k_m$                      | stress spectrum factor based on m of the detail under consideration            |
| $k_3$                      | stress spectrum factor based on m = 3                                          |
| $k_{ox}, k_{oy}, k_{\tau}$ | buckling factors                                                               |
| $L$                        | element length (buckling)                                                      |
| $l_m$                      | gauge length                                                                   |
| $l_r$                      | relevant weld length                                                           |
| $l_w$                      | weld length                                                                    |
| $M_{Rd}$                   | limit design bending moment                                                    |

| Symbols,<br>abbreviations                                | Description                                                   |
|----------------------------------------------------------|---------------------------------------------------------------|
| $M_{Sd}$                                                 | design bending moment                                         |
| $m$                                                      | slope constant of $\log \Delta\sigma / \log N$ -curve         |
| $N$                                                      | compressive force (buckling)                                  |
| $NC$                                                     | notch class                                                   |
| $N_k$                                                    | critical buckling load                                        |
| $N_{ref}$                                                | reference number of cycles                                    |
| $\min \sigma, \max \sigma$                               | extreme values of stresses                                    |
| $P_S$                                                    | probability of survival                                       |
| $p$                                                      | penetration of weld                                           |
| $Q$                                                      | shear (evaluation of stress cycles)                           |
| $q_i$                                                    | impact toughness parameter                                    |
| $s_r$                                                    | effective throat thickness                                    |
| $\alpha$                                                 | cross section parameter (lateral buckling)                    |
| $\alpha_b$                                               | characteristic factor for bearing connection                  |
| $\alpha_L$                                               | load introduction factor (bolted connection)                  |
| $\gamma_m$                                               | general resistance factor                                     |
| $\gamma_{mf}$                                            | fatigue strength specific resistance factor                   |
| $\gamma_p$                                               | partial safety factor                                         |
| $\gamma_R$                                               | resulting resistance factor                                   |
| $\gamma_S$                                               | specific resistance factor                                    |
| $\gamma_{Rb}$                                            | resulting resistance factor of bolt                           |
| $\gamma_{sbb}, \gamma_{sbs}, \gamma_{sbt}$               | specific resistance factors of bolted connections             |
| $\gamma_{Rm}$                                            | resulting resistance factor of members                        |
| $\gamma_{sm}$                                            | specific resistance factor of members                         |
| $\gamma_{Rp}$                                            | resulting resistance factor of pins                           |
| $\gamma_{spm}, \gamma_{sps}, \gamma_{spb}, \gamma_{spt}$ | specific resistance factors of pins                           |
| $\gamma_{Rs}$                                            | resulting resistance factor of slip-resistance connection     |
| $\gamma_{ss}$                                            | specific resistance factor of slip-resistance connection      |
| $\gamma_{Rc}$                                            | resulting resistance factor for tension on section with holes |
| $\gamma_{st}$                                            | specific resistance factor for tension on section with holes  |
| $\gamma_{Rw}$                                            | resulting resistance factor of welding connection             |

| Symbols,<br>abbreviations                 | Description                                          |
|-------------------------------------------|------------------------------------------------------|
| $\gamma_{sw}$                             | specific resistance factor of welding connection     |
| $\delta_p$                                | elongation from preloading                           |
| $\phi_2$                                  | dynamic factor                                       |
| $\kappa$                                  | dispersion angle (wheel pressure)                    |
| $\kappa, \kappa_x, \kappa_y, \kappa_\tau$ | reduction factors (buckling)                         |
| $\lambda$                                 | width of contact area in weld direction              |
| $\lambda_x, \lambda_y, \lambda_\tau$      | non-dimensional plate slenderness (buckling)         |
| $\psi$                                    | edge stress ratio (buckling)                         |
| $\Delta F_b$                              | additional force                                     |
| $\Delta \delta_t$                         | additional elongation                                |
| $\mu$                                     | slip factor                                          |
| $v$                                       | relative total number of stress cycles               |
| $v_D$                                     | ratio of diameters                                   |
| $\Delta \sigma_c$                         | characteristic value of stress range (normal stress) |
| $\Delta \tau_c$                           | characteristic value of stress range (shear stress)  |
| $\sigma_e$                                | reference stress (buckling)                          |
| $\sigma_b$                                | lower extreme value of stress range                  |
| $\sigma_u$                                | upper extreme value of stress range                  |
| $\sigma_{Sd}$                             | design stress (normal)                               |
| $\tau_{Sd}$                               | design stress (shear)                                |
| $\sigma_{w, Sd}$                          | design weld stress (normal)                          |
| $\tau_{w, Sd}$                            | design weld stress (shear)                           |
| $\Delta \sigma_{Rd}$                      | limit design stress range (normal)                   |
| $\Delta \sigma_{Rd,1}$                    | limit design stress range for $k^* = 1$              |
| $\Delta \tau_{Rd}$                        | limit design stress range (shear)                    |
| $\Delta \sigma_{Sd}$                      | design stress range (normal)                         |
| $\Delta \tau_{Sd}$                        | design stress range (shear)                          |

## 4 General

### 4.1 Documentation

The documentation of the proof of competence shall include:

- design assumptions including calculation models,
- applicable loads and load combinations,
- material grades and qualities,
- weld quality levels, in accordance with EN ISO 5817:2023,
- materials of connecting elements,
- relevant limit states,
- results of the proof of competence calculation and tests when applicable.

### 4.2 Materials for structural members

#### 4.2.1 Grades and qualities

For structural members, steels in accordance with the following European Standards shall be used:

- a) Non-alloy structural steels EN 10025-2:2019;
- b) Weldable fine grain structural steels in conditions:
  - 1) normalized (N) EN 10025-3:2019;
  - 2) thermomechanical (M) EN 10025-4:2019+A1:2022;
- c) High yield strength structural steels in the quenched and tempered condition EN 10025-6:2019+A1:2022;
- d) High yield strength steels for cold forming in conditions:
  - 1) thermomechanical (M) EN 10149-2:2013;
  - 2) normalized (N) EN 10149-3:2013.
- e) Austenitic stainless steels EN 10088-2:2024 and EN 10088-3:2023.

Alternatively, grades and qualities other than those mentioned in the above standards may be used, if the mechanical properties and the chemical composition are specified in a manner corresponding to relevant European Standard, and the following conditions are fulfilled:

- the design value of  $f_y$  is limited to  $f_u/1,05$  for materials with  $f_u/f_y < 1,05$ ;
- the percentage elongation at fracture  $A \geq 7\%$  on a gauge length  $L_0 = 5,65 \times \sqrt{S_0}$  (where  $S_0$  is the original cross-sectional area);
- the weldability or non-weldability of the material is specified and, if intended for welding, weldability is demonstrated;
- if the material is intended for cold forming, the pertinent parameters are specified.

Where stainless steels are welded, special attention shall be given to the welding process and corrosion effects. Only austenitic stainless steels are covered by this document.

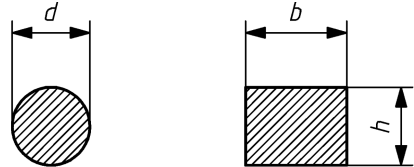
Specific values for the nominal value of strength  $f_u, f_y$  are given in Annex M (normative). For limit design stresses  $f_{Rd}$ , see 5.2. The values given are applicable for temperatures up to 100 °C for stainless steels and up to 150 °C for all other steels.

To allow the use of nominal values of plate thicknesses in the proof calculations, the minus tolerance of the plate shall be equal or better than that of class A of EN 10029:2010. Otherwise, the actual minimum value of plate thickness shall be used. Nominal dimensions for other steel products than plates may be used, provided those products comply with their standardized minus tolerances.

#### 4.2.2 Impact toughness

When selecting grade and quality of the steel for tensile members, the sum of impact toughness parameters  $q_i$  shall be taken into account. Table 2 gives the impact toughness parameters  $q_i$  for various influences. Table 3 gives the required steel quality and the required Charpy V impact energy/test temperature in accordance with EN ISO 148-1:2016 and in dependence of  $\Sigma q_i$ . The direction of loading shall be considered when assessing the impact toughness. Grades and qualities of steel other than mentioned in Table 3 may be used, if an impact energy/temperature is tested in accordance with EN ISO 148-1:2016, specified and meet the requirements given in first two rows of Table 3.

**Table 2 — Impact toughness parameters  $q_i$**

| $i$ | Influence                                                                                                                                                                                                                             | $q_i$                      |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| 1   | Operating temperature $T$ (°C)                                                                                                                                                                                                        | $0 \leq T$                 |
|     |                                                                                                                                                                                                                                       | $-10 \leq T < 0$           |
|     |                                                                                                                                                                                                                                       | $-20 \leq T < -10$         |
|     |                                                                                                                                                                                                                                       | $-30 \leq T < -20$         |
|     |                                                                                                                                                                                                                                       | $-40 \leq T < -30$         |
|     |                                                                                                                                                                                                                                       | $-50 \leq T < -40$         |
| 2   | Yield stress $f_y$ (N/mm <sup>2</sup> )                                                                                                                                                                                               | $f_y \leq 300$             |
|     |                                                                                                                                                                                                                                       | $300 < f_y \leq 460$       |
|     |                                                                                                                                                                                                                                       | $460 < f_y \leq 700$       |
|     |                                                                                                                                                                                                                                       | $700 < f_y \leq 1\,000$    |
|     |                                                                                                                                                                                                                                       | $1\,000 < f_y \leq 1\,300$ |
| 3   | Material thickness $t$ (mm)<br>Equivalent thickness $t$ for solid bars:<br> $t = \frac{d}{1,8} \text{ for } \frac{b}{h} < 1,8 : t = \frac{b}{1,8}$ | $t \leq 10$                |
|     |                                                                                                                                                                                                                                       | $10 < t \leq 20$           |
|     |                                                                                                                                                                                                                                       | $20 < t \leq 40$           |
|     |                                                                                                                                                                                                                                       | $40 < t \leq 60$           |
|     |                                                                                                                                                                                                                                       | $60 < t \leq 80$           |
|     |                                                                                                                                                                                                                                       | $80 < t \leq 100$          |
|     |                                                                                                                                                                                                                                       | $100 < t \leq 125$         |
|     |                                                                                                                                                                                                                                       | $125 < t \leq 150$         |

| <i>i</i> | Influence                                                                                                                |                                                                                               | <i>q<sub>i</sub></i> |
|----------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|----------------------|
| 4        | Characteristic value of stress range $\Delta\sigma_c$ (N/mm <sup>2</sup> ) (see normative Annex D and normative Annex H) | $\Delta\sigma_c > 125$                                                                        | 0                    |
|          |                                                                                                                          | $80 < \Delta\sigma_c \leq 125$                                                                | 1                    |
|          |                                                                                                                          | $56 < \Delta\sigma_c \leq 80$                                                                 | 2                    |
|          |                                                                                                                          | $40 < \Delta\sigma_c \leq 56$                                                                 | 3                    |
|          |                                                                                                                          | $30 < \Delta\sigma_c \leq 40$                                                                 | 4                    |
|          |                                                                                                                          | $\Delta\sigma_c \leq 30$                                                                      | 5                    |
| 5        | Utilization of static strength (see 5.3.1)                                                                               | $\sigma_{sd} > 0,75 \times f_{Rd\sigma}$                                                      | 0                    |
|          |                                                                                                                          | $0,5 \times f_{Rd\sigma} < \sigma_{sd}$<br>and<br>$\sigma_{sd} \leq 0,75 \times f_{Rd\sigma}$ | -1                   |
|          |                                                                                                                          | $0,25 \times f_{Rd\sigma} < \sigma_{sd}$<br>and<br>$\sigma_{sd} \leq 0,5 \times f_{Rd\sigma}$ | -2                   |
|          |                                                                                                                          | $\sigma_{sd} \leq 0,25 \times f_{Rd\sigma}$                                                   | -3                   |

Table 3 — Impact toughness requirement and corresponding steel quality for  $\sum q_i$ 

| Impact energy/ test temperature requirement                                                                                                                                                                                                                                                                                                                                 | $\sum q_i \leq 5$ | $6 \leq \sum q_i \leq 8$ | $9 \leq \sum q_i \leq 11$ | $12 \leq \sum q_i \leq 14$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|--------------------------|---------------------------|----------------------------|
|                                                                                                                                                                                                                                                                                                                                                                             | 27 J / +20 °C     | 27 J / 0 °C              | 27 J / -20 °C             | 27 J / -40 °C              |
| Grades and qualities which meet the impact energy/test temperature requirement                                                                                                                                                                                                                                                                                              |                   |                          |                           |                            |
| EN 10025-2:2019                                                                                                                                                                                                                                                                                                                                                             | JR                | J0                       | J2                        | a                          |
| EN 10025-3:2019                                                                                                                                                                                                                                                                                                                                                             | N                 | N                        | N                         | NL                         |
| EN 10025-4:2019+A1:2022                                                                                                                                                                                                                                                                                                                                                     | M                 | M                        | M                         | ML                         |
| EN 10025-6:2019+A1:2022                                                                                                                                                                                                                                                                                                                                                     | Q                 | Q                        | Q                         | QL                         |
| EN 10149-2:2013                                                                                                                                                                                                                                                                                                                                                             | MC                | MC                       | MC                        | a                          |
| EN 10149-3:2013                                                                                                                                                                                                                                                                                                                                                             | NC                | NC                       | NC                        | a                          |
| EN 10088-2:2024                                                                                                                                                                                                                                                                                                                                                             | b                 | b                        | b                         | b                          |
| EN 10088-3:2023                                                                                                                                                                                                                                                                                                                                                             | b                 | b                        | b                         | b                          |
| <p><sup>a</sup> May be used if the impact toughness is at least 27 J at -40 °C, tested in accordance with EN ISO 148-1:2016 and specified.</p> <p><sup>b</sup> All steels of EN 10088-2:2024 and EN 10088-3:2023. The impact energy is not explicitly given at these temperatures, however the impact energy/ test temperature requirement in the row two is fulfilled.</p> |                   |                          |                           |                            |

## 4.3 Bolted connections

### 4.3.1 Bolt materials

For bolted connections, bolts of the property classes (bolt grades) in accordance with EN ISO 898-1:2013 or EN ISO 3506-1:2020 shall be used. Table 4 shows specific strength values for a selection of bolt grades from EN ISO 898-1:2013.

**Table 4 — Specific strength values for a selection of bolt grades**

| Property class<br>(Bolt grade) | 4.6 | 5.6 | 8.8       |           | 10.9 | 12.9 |
|--------------------------------|-----|-----|-----------|-----------|------|------|
|                                |     |     | d ≤ 16 mm | d > 16 mm |      |      |
| $f_{yb}$ (N/mm <sup>2</sup> )  | 240 | 300 | 640       | 660       | 940  | 1100 |
| $f_{ub}$ (N/mm <sup>2</sup> )  | 400 | 500 | 800       | 830       | 1040 | 1220 |

For the property classes (bolt grades) 10.9 and 12.9 the compliance regarding the protection against hydrogen brittleness shall be demonstrated.

In addition, for bolt grade 12.9 the characteristics tested in accordance with EN ISO 898-1:2013 and given in Table 5 shall apply to load carrying bolts.

**Table 5 — Bolt grade 12.9 characteristics**

| Bolt grade | Impact energy (single minimum) /<br>Test temperature | Percentage elongation A5<br>according to EN ISO 6892-1:2019 |
|------------|------------------------------------------------------|-------------------------------------------------------------|
| 12.9       | 25 J / -20 °C                                        | ≥ 10 %                                                      |

NOTE Technical requirements are given in EN ISO 15330:1999, EN ISO 4042:2022 and ISO 9587:2007.

### 4.3.2 General

For the purposes of this document, bolted connections are connections between members and/or components utilizing bolts.

In general, bolted connections are tensioned wrench tight. A controlled bolt tightening method is a method, where the tightening force in the bolt is measured during tightening, either directly or indirectly through tightening torque, rotation angle or bolt elongation.

Where slippage (e.g. caused by vibrations or fluctuations in loading) causes deleterious changes in geometry, bolts shall be tightened to avoid slippage or the connected members shall be secured against relative displacement by form closed locking means.

### 4.3.3 Shear and bearing connections

For the purposes of this document, shear and bearing connections are those connections where the loads act perpendicular to the bolt axis and cause shear and bearing stresses in the bolts and bearing stresses in the connected parts, and where:

- clearance between bolt and hole shall conform to EN ISO 286-2:2010, tolerances h13 and H11 or closer, where bolts are exposed to load reversal or where slippage can cause deleterious changes in geometry;
- in other cases, wider clearances in accordance with EN 20273:1991 [46] may be used;
- special surface treatment of the contact surfaces is not needed.

#### 4.3.4 Friction grip type (slip resistant) connections

For the purposes of this document, friction grip connections are those connections where the loads are transmitted by friction between the joint surfaces. The following requirements apply:

- bolts of property classes (bolt grades) 8.8, 10.9, 12.9, A2-80, A4-80 or A4-100 shall be used;
- bolts shall be tightened by a controlled method to a specified preloading state;
- the surface condition of the contact surfaces shall be specified and taken into account in accordance with 5.2.3.2;
- washers compatible in strength and size with the bolts and compatible with the hole shape shall be used;
- plastic deformation resulting in loss of pretension and stripping of internal threads shall be prevented;
- friction grip connections where the connected parts are made of stainless steel shall not be used unless their performance in a particular application is qualified by testing.

#### 4.3.5 Connections loaded in tension

For the purposes of this document, connections loaded in tension are those connections where the loads act in the direction of the bolt axis and cause axial stresses in the bolts. The following requirements apply:

- bolts of property classes (bolt grades) 8.8, 10.9 or 12.9 shall be used and tightened by a controlled method to a specified preloading state;
- washers compatible in strength and size with the bolts shall be used;
- plastic deformation resulting in loss of pretension and stripping of internal threads shall be prevented.

Axially loaded bolts that are not preloaded shall be designed as structural members.

#### 4.4 Pinned connections

For the purposes of this document, pinned connections are connections that do not constrain rotation between connected parts. Only round pins are considered.

The requirements herein apply to pinned connections designed to carry loads, i.e. they do not apply to connections made only as a convenient means of attachment.

Clearance between pin and hole shall be in accordance with EN ISO 286-2:2010, tolerances h13 and H13 or closer. In case of forces with varying directions, closer tolerances shall be applied.

The material used for pinned connections shall comply with the requirements in 4.2.1 and 4.2.2.

All pins shall be furnished with retaining means to prevent the pins from becoming displaced from the hole.

## 4.5 Welded connections

For the purposes of this document, welded connections are joints between members and/or components which utilize fusion welding processes, and where connected parts are 3 mm or larger in thickness except for hollow sections.

Quality levels of EN ISO 5817:2023 shall be applied, and methods of non-destructive testing, compatible with quality requirement and welding method, shall be used to verify compliance with quality level requirements.

In general, load carrying welds shall be at least of quality level C. Quality level D may be applied only in joints where local failure of the weld will not result in failure of the structure or falling of loads.

Residual stresses and stresses not transferring forces across the weld need not to be considered in the design of welds subjected to static actions. This applies specifically to the normal stress parallel to the axis of the weld which is accommodated by the base material.

When the static tensile strength of a butt joint is tested, the test may be carried out with weld reinforcement not removed.

Attention shall be paid to the dimensions of intermittent fillet welds (guidelines can be found in EN 1993-1-8:2024).

Single sided fillet welds are not recommended for carrying loads perpendicular to the weld. However, if used connected members shall be supported so as to avoid the effect of load eccentricity on the weld.

## 4.6 Proof of competence for structural members and connections

The object of the proof of competence is to demonstrate that the design stresses or forces  $S_d$  do not exceed the design resistances  $R_d$  :

$$S_d \leq R_d \quad (1)$$

The design stresses or forces  $S_d$  shall be determined by applying the relevant loads, load combinations and partial safety factors in accordance with EN 13001-2:2021.

In the following clauses, the design resistances  $R_d$  are represented as limit stresses  $f_d$  or limit forces  $F_d$  .

The following proofs for structural members and connections shall be demonstrated:

- proof of static strength in accordance with Clause 5;
- proof of fatigue strength in accordance with Clause 6;
- proof of strength of hollow section girder joints in accordance with Clause 7;
- proof of elastic stability in accordance with Clause 8.

## 5 Proof of static strength

### 5.1 General

A proof of static strength by calculation is intended to prevent excessive deformations due to yielding of the material, sliding of friction-grip connections, elastic instability (see Clause 8) and fracture of structural members or connections. Dynamic factors given in EN 13001-2:2021 are used to produce equivalent static loads to simulate dynamic effects.

The use of the theory of plasticity for calculation of ultimate load bearing capacity shall not be used within the terms of this document.

The proof shall be carried out for structural members and connections whilst taking into account the most unfavourable load effects from the load combinations A, B or C in accordance with EN 13001-2:2021 and applying the resistances according to 5.2.

This document is based on nominal stresses, i.e. stresses calculated using traditional elastic strength of materials theory which in general neglect localized stress non-uniformities. When more accurate alternative methods of stress calculation are used, such as finite element analysis, using those stresses for the proof given in this document can yield inordinately conservative results.

### 5.2 Limit design stresses and forces

#### 5.2.1 General

The limit design stresses and forces shall be calculated from:

Limit design stresses  $f_{Rd} = \text{function} (f_k, \gamma_R)$  or

Limit design forces  $F_{Rd} = \text{function} (F_k, \gamma_R)$  (2)

where

$f_k$  or  $F_k$  are characteristic values (or nominal values);

$\gamma_R$  is the total resistance factor  $\gamma_R = \gamma_m \times \gamma_s$ ;

$\gamma_m$  is the general resistance factor  $\gamma_m = 1,1$  (see [44]);

$\gamma_s$  is the specific resistance factor applicable to specific structural components as given in the clauses below.

NOTE  $f_{Rd}$  and  $F_{Rd}$  are equivalent to  $R / \gamma_m$  in [44].

#### 5.2.2 Limit design stress in structural members

The limit design stress  $f_{Rd}$ , used for the design of structural members, shall be calculated from:

$$f_{Rd\sigma} = \frac{f_y}{\gamma_{Rm}} \quad \text{for normal stresses} \quad (3)$$

$$f_{Rd\tau} = \frac{f_y}{\gamma_{Rm} \times \sqrt{3}} \quad \text{for shear stresses} \quad (4)$$

with  $\gamma_{Rm} = \gamma_m \times \gamma_{sm}$

where

$f_y$  is the value of the yield stress of the material

$\gamma_{sm}$  is the specific resistance factor for material as follows:

For non-rolled material:

$$\gamma_{sm} = 0,95$$

For rolled materials (e.g. plates and profiles):

$$\gamma_{sm} = 0,95 \quad \text{for stresses in the plane of rolling}$$

$$\gamma_{sm} = 0,95 \quad \text{for compressive and shear stresses}$$

For tensile stresses perpendicular to the plane of rolling (see Figure 1):

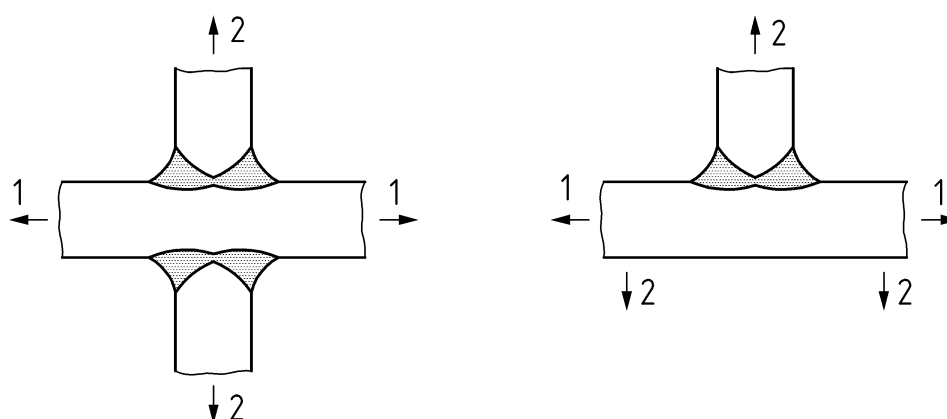
Material shall be suitable for carrying perpendicular loads and be free of lamellar defects.

$\gamma_{sm} = 1,0$  for plate thicknesses less than 15 mm or material in quality classes Z25 or better in accordance with EN 10164:2018

$\gamma_{sm} = 1,16$  for material in quality class Z15 in accordance with EN 10164:2018

$\gamma_{sm} = 1,34$  for materials without quality classification in accordance with EN 10164:2018, but conforming to classes S2 and E3 of EN 10160:1999

$\gamma_{sm} = 1,50$  without quality classification of through-thickness property.



#### Key

- 1 is the direction of the plane of rolling
- 2 is the direction of stress

**Figure 1 — Tensile stress perpendicular to plane of rolling**

### 5.2.3 Limit design forces in bolted connections

#### 5.2.3.1 Shear and bearing connections

##### 5.2.3.1.1 General

The resistance of a connection shall be taken as the least value of the limit forces of the individual connection elements.

In addition to the bearing capacity of the connection elements other limit conditions at the most stressed sections shall be verified using the resistance factor of the base material.

Only the unthreaded part of the shank shall be considered effective in the bearing calculations.

##### 5.2.3.1.2 Bolt shear

The limit design shear force  $F_{v,Rd}$  per bolt and for each shear plane shall be calculated from:

$$F_{v,Rd} = \frac{f_{yb} \times A}{\gamma_{Rb} \times \sqrt{3}} \quad (5)$$

with  $\gamma_{Rb} = \gamma_m \times \gamma_{sbs}$

where

$f_{yb}$  is the yield stress (nominal value) of the bolt material (see Table 4);

$A$  is the cross-sectional area of the bolt shank at the shear plane;

$\gamma_{sbs}$  is the specific resistance factor for bolted connections:

$\gamma_{sbs} = 1,0$  for multiple shear plane connections;

$\gamma_{sbs} = 1,3$  for single shear plane connections.

See informative Annex A for limit design shear forces of selected bolt sizes.

##### 5.2.3.1.3 Bearing on bolts and connected parts

The limit design bearing force  $F_{b,Rd}$  per bolt shall be calculated from:

$$F_{b,Rd} = \frac{f_y \times d \times t}{\gamma_{Rb}} \quad (6)$$

with  $\gamma_{Rb} = \gamma_m \times \gamma_{sbb}$

with the requirement

$$e_1 \geq 1,5 \times d_0 \quad (7)$$

and with the following recommendations for the plate

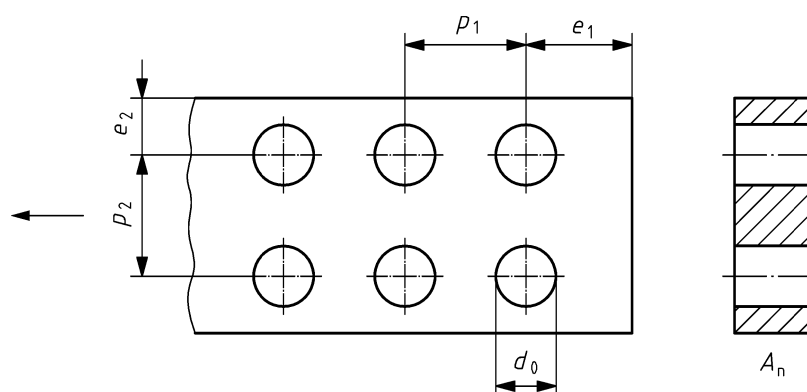
$$e_2 \geq 1,5 \times d_0$$

$$p_1 \geq 3,0 \times d_0$$

$$p_2 \geq 3,0 \times d_0$$

where

- $f_y$  is the minimum value of yield stresses of the basic materials and bolt (Table 4);
- $d$  is the shank diameter of the bolt;
- $d_0$  is the diameter of the hole;
- $t$  is the thickness of the connected part in contact with the unthreaded part of the bolt;
- $\gamma_{sbb}$  is the specific resistance factor for bolt connections
- $\gamma_{sbb} = 0,7$  for multiple shear plane connections
- $\gamma_{sbb} = 0,9$  for single shear plane connections;
- $p_1, p_2, e_1, e_2$  are distances (see Figure 2).



#### Key

$p_1, p_2, e_1, e_2$  are distances used in Formula (7).

Arrow shows the direction of force.

**Figure 2 — Illustration for Formula (7)**

#### 5.2.3.1.4 Tension in connected parts

The limit design tensile force per connected member with respect to yielding,  $F_{cs,Rd}$ , on the net cross-section shall be calculated from:

$$F_{cs,Rd} = \frac{f_y \times A_n}{\gamma_{Rc}} \quad (8)$$

with

$$\gamma_{Rc} = \gamma_m \times \gamma_{st}$$

where

$A_n$  is the net cross-sectional area at bolt holes or pin holes (see Figure 2);

$\gamma_{st}$  is the specific resistance factor for tension on sections with holes;

$$\gamma_{st} = 1,2$$

### 5.2.3.2 Friction grip type connections

The resistance of a connection shall be determined by summing the limit forces of the individual connecting elements.

For friction grip type connections, the limit design slip force  $F_{s,Rd}$  per bolt and per friction interface shall be calculated from:

$$F_{s,Rd} = \frac{\mu \times (F_{p,d} - F_{cr})}{\gamma_{Rs}} \quad (9)$$

with  $\gamma_{Rs} = \gamma_m \times \gamma_{ss}$

where

$\mu$  is the friction coefficient;

$\mu = 0,50$  for surfaces blasted metallic bright with steel grit or sand, no unevenness;

$\mu = 0,50$  for surfaces blasted with steel grit or sand and aluminized;

$\mu = 0,50$  for surfaces blasted with steel grit or sand and metallized with a product based on zinc;

$\mu = 0,40$  for surfaces blasted with steel grit or sand and alkali-zinc-silicate coating of 50  $\mu\text{m}$  to 80  $\mu\text{m}$  thickness;

$\mu = 0,40$  for surfaces hot dip galvanized and lightly blasted;

$\mu = 0,30$  for surfaces cleaned metallic bright by wire brushing;

$\mu = 0,25$  for surfaces cleaned and treated with etch primer;

$\mu = 0,20$  for surfaces cleaned of loose rust, oil and dirt (minimum requirement);

$F_{p,d}$  is the design preloading force;

$F_{cr}$  is the reduction in the compression force due to external tension on connection (for simplification  $F_{cr} = F_{e,t}$  may be used).

The applied preloading force shall be greater than or equal to the design preloading force.

$\gamma_{ss}$  is the specific resistance factor for friction grip type connections (see Table 6).

**Table 6 — Specific resistance factor  $\gamma_{ss}$  for friction grip connections**

| Effect of connection slippage                                                                                                                                                                                                                                                                                                                         | Type of holes               |                                                             |                                 |                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-------------------------------------------------------------|---------------------------------|---------------------------------|
|                                                                                                                                                                                                                                                                                                                                                       | Standard holes <sup>a</sup> | Oversized <sup>b</sup> and short-slotted <sup>c</sup> holes | Long-slotted holes <sup>c</sup> | Long-slotted holes <sup>d</sup> |
| a hazard is created                                                                                                                                                                                                                                                                                                                                   | 1,14                        | 1,34                                                        | 1,63                            | 2,00                            |
| a hazard is not created                                                                                                                                                                                                                                                                                                                               | 1,00                        | 1,14                                                        | 1,41                            | 1,63                            |
| Short slotted hole: length of hole is smaller than or equal to 1,25 times the diameter of the bolt.<br>Long slotted hole: length of hole is larger than 1,25 times the diameter of the bolt.                                                                                                                                                          |                             |                                                             |                                 |                                 |
| <sup>a</sup> Holes with clearances in accordance with the medium series of EN 20273:1991.<br><sup>b</sup> Holes with clearances in accordance with the coarse series of EN 20273:1991.<br><sup>c</sup> Slotted holes with slots perpendicular to the direction of force.<br><sup>d</sup> Slotted holes with slots parallel to the direction of force. |                             |                                                             |                                 |                                 |

Table B.2 gives limit design slip forces using the specific resistance factor value  $\gamma_{ss} = 1,14$  and a design preloading force of:

$$F_{p,d} = 0,7 \times f_{yb} \times A_s$$

where

$f_{yb}$  is the yield stress (nominal value) of the bolt material (Table 4);

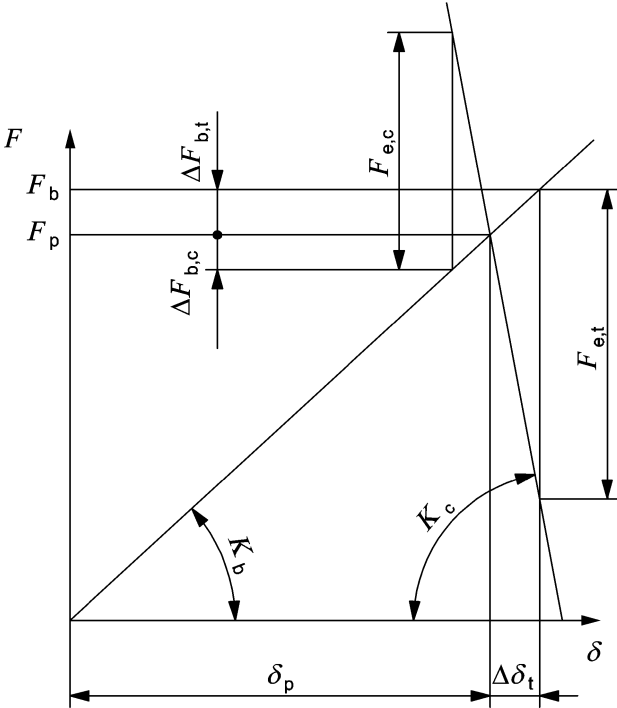
$A_s$  is the stress area of the bolt (Table B.2).

### 5.2.3.3 Connections loaded in tension

This subclause specifies the limit state for a bolt in the connection. The connected parts and their welds shall be calculated with the general rules for structural members, where the preload in the bolt is considered as one loading component.

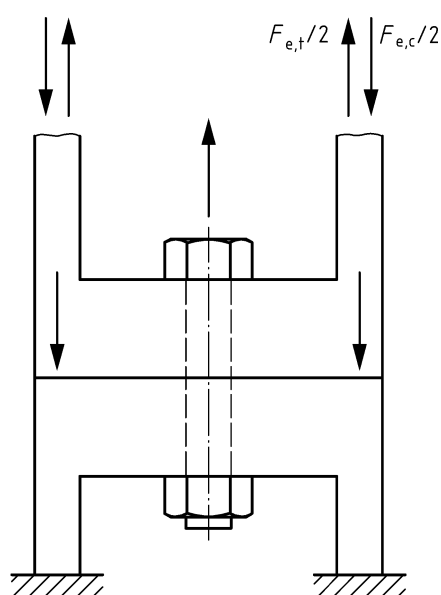
The proof calculation shall be done for the bolt under maximum external force in a connection, with due consideration to the force distribution in a multi-bolt connection and the prying effects (i.e. leverage).

Proof of competence calculations of a preloaded connection shall take into account the stiffness of the bolt and the connected parts, see Figure 3. In addition to that, the effect of different load paths of the external compression force, depending upon the joint construction, shall be taken into account, see Figure 4.

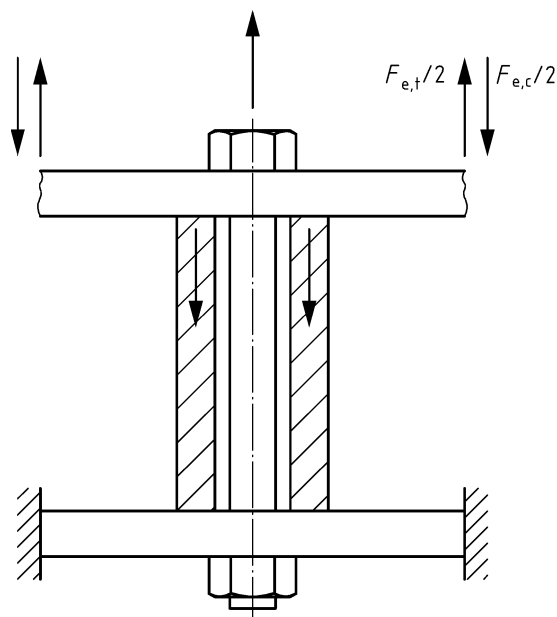


|                  |                                                             |
|------------------|-------------------------------------------------------------|
| <b>Key</b>       |                                                             |
| $F_p$            | Preloading force in bolt                                    |
| $\delta_p$       | Bolt elongation due to preloading                           |
| $F_{e,t}$        | External tensile force                                      |
| $F_{e,c}$        | External compression force                                  |
| $\Delta\delta_t$ | Additional elongation, due to external tensile force        |
| $F_b$            | Tensile force in bolt                                       |
| $\Delta F_{b,t}$ | Additional force in bolt, due to external tensile force     |
| $\Delta F_{b,c}$ | Additional force in bolt, due to external compression force |
| $K_b$            | Stiffness of bolt                                           |
| $K_c$            | Stiffness of connected parts                                |

Figure 3 — Force-elongation-diagram



a) External compression force does not interfere with the compression zone under the bolt



b) External compression force is transferred through the compression zone under the bolt

For simplicity, a symmetric loading with the bolt in the middle is assumed in the figure.

**Figure 4 — Load path alternatives for the external compression force**

Two separate design limits shall be considered for the external tensile bolt force:

- 1) the resulting bolt force from the external force and the maximum design preload shall not exceed the bolt limit design tensile force, Formula (10);
- 2) the connection shall not open (gap) under the resulting bolt force from the external force and the minimum design preload, Formula (11).

For connections loaded in tension it shall be proven that the external tensile design force in the bolt  $F_{e,t}$  does not exceed either of the two limit design forces  $F_{t1,Rd}$  or  $F_{t2,Rd}$ , see also 5.3.2.

The limit design tensile force per bolt for the bolt yield criteria shall be calculated from:

$$F_{t1,Rd} = \frac{F_y / \gamma_{Rb} - F_{p,max}}{\Phi} \quad (10)$$

with

$$\Phi = \frac{K_b}{K_b + K_c}$$

and

$$\gamma_{Rb} = \gamma_m \times \gamma_{sbt} \text{ and } F_y = f_{yb} \times A_s$$

where

$F_y$  is the bolt yield force;

- $F_{p,max}$  is the maximum value of the preload (see Formula (12));
- $f_{yb}$  is the yield stress of the bolt material;
- $A_s$  is the stress area of the threaded part of the bolt;
- $\Phi$  is the stiffness ratio factor of the connection, see informative Annex G (informative);
- $\gamma_{sbt}$  is the specific resistance factor for connections loaded in tension;
- $\gamma_{sbt} = 0,95$

The limit design tensile force per bolt for the opening criteria of the connection shall be calculated from:

$$F_{t2,Rd} = \frac{F_{p,min}}{\gamma_{Rb} \cdot (1 - \Phi)} \quad (11)$$

where

$F_{p,min}$  is the minimum value of the preload (see Formula (13)).

The variation of preload due to scatter shall be taken into account by the maximum and minimum values of the preload as follows:

$$F_{p,max} = (1 + s) \times F_{p,d} \text{ and} \quad (12)$$

$$F_{p,min} = (1 - s) \times F_{p,d} \quad (13)$$

where

- $F_{p,d}$  is the nominal value of the design preload;
- $F_{p,max}$  is the maximum value of the preload;
- $F_{p,min}$  is the minimum value of the preload;
- $s$  is the preload scatter;
- $s = 0,23$  controlled tightening, tightening torque is measured
- $s = 0,18$  controlled tightening, rotation angle is measured
- $s = 0,09$  controlled tightening, force in bolt or elongation is measured.

When several identical and equally loaded bolts are used in a connection, the scatter used for computing  $F_{p,min}$  in Formula (13) shall be taken as:

- $s = 0,23 / \sqrt{n}, s \geq 0,10$  where controlled tightening, tightening torque is measured;
- $s = 0,18 / \sqrt{n}, s \geq 0,10$  where controlled tightening, rotation angle is measured;
- $s = 0,09 / \sqrt{n}, s \geq 0,05$  where controlled tightening, force in bolt or elongation is measured;
- and where

$n$  is the number of identical bolts, identically pre-loaded and equally loaded in the proof of competence under consideration.

The nominal value of the design preload  $F_{p,d}$  value shall not exceed the values given in Table 7.

**Table 7 — Upper limits of preload levels according to method of preloading**

| Type of preloading method                                                                                                                                                                                                                                                                                             | Upper limit of nominal value of design preload<br>$F_{p,d}$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| Methods, where the bolt is subjected to torque                                                                                                                                                                                                                                                                        | $0,7 F_y$                                                   |
| Methods, where only direct tension is applied to the bolt<br>For direct tensioning method, the nominal preload equal to $0,85 \cdot F_y$ is the remaining preload achieved after a possible loss of the applied preload during the tensioning operation, with an initially applied preload equal to $0,9 \cdot F_y$ . | $0,85 F_y$                                                  |

See Table B.1 for information on tightening torques.

For the calculation of the additional force in bolt, the load path of the external compression force shall be considered, see Figure 4. In a general format, the additional force in bolt shall be calculated as follows:

$$\Delta F_b = \phi \times (F_{e,t} + F_{e,c}) \quad (14)$$

where

$\Delta F_b$  is the additional force in bolt;

$\phi$  is the stiffness ratio factor;

$F_{e,t}$  is the external tensile force (acting on the connection);

$F_{e,c}$  is the external compression force (acting on the connection). This shall be omitted (i.e.  $F_{e,c}$  is set to zero in the formula) in cases, where the external compression force does not interfere with the compression zone under the bolt, case a) in Figure 4.

The additional force in bolt  $\Delta F_b$  shall be used in the proof of fatigue strength of the bolt in accordance with Clause 6.

#### 5.2.3.4 Bearing type connections loaded in combined shear and tension

When bolts in a bearing type connection are subjected to both tensile and shear forces, the applied forces shall be limited as follows:

$$\left( \frac{F_{t,Sd}}{F_{t,Rd}} \right)^2 + \left( \frac{F_{v,Sd}}{F_{v,Rd}} \right)^2 \leq 1 \quad (15)$$

where

$F_{t,Sd}$  is the external tensile force per bolt;

$F_{t1,Rd}$  is the limit tensile force per bolt (see 5.2.3.3);

$F_{v,Sd}$  is the design shear force per bolt per shear plane;

$F_{v,Rd}$  is the limit shear force per bolt per shear plane (see 5.2.3.1.2).

## 5.2.4 Limit design forces in pinned connections

### 5.2.4.1 Pins, limit design bending moment

The limit design bending moment shall be calculated from:

$$M_{Rd} = \frac{W_{el} \times f_{yp}}{\gamma_{Rp}} \quad (16)$$

with  $\gamma_{Rp} = \gamma_m \times \gamma_{spm}$

where

$W_{el}$  is the elastic section modulus of the pin;

$f_{yp}$  is the yield stress (minimum value) of the pin material;

$\gamma_{spm}$  is the specific resistance factor for pinned connections bending moment  $\gamma_{spm} = 1,0$ .

### 5.2.4.2 Pins, limit design shear force

The limit design shear force per shear plane for pins shall be calculated from:

$$F_{vp,Rd} = \frac{1}{u} \times \frac{A \times f_{yp}}{\sqrt{3} \times \gamma_{Rp}} \quad (17)$$

with  $\gamma_{Rp} = \gamma_m \times \gamma_{sps}$

where

$u$  is the shape factor

$$u = \frac{4}{3} \text{ for solid pins}$$

$$u = \frac{4}{3} \times \frac{1 + v_D + v_D^2}{1 + v_D^2} \text{ for hollow pins}$$

$$\text{where } v_D = \frac{D_i}{D_o}$$

$D_i$  is the inner diameter of pin

$D_o$  is the outer diameter of pin;

$A$  is the cross-sectional area of the pin

$\gamma_{sps}$  is the specific resistance factor for shear force in pinned connections

$\gamma_{sps} = 1,0$  for multiple shear plane connections (see Figure 5)

$\gamma_{sps} = 1,3$  for single shear plane connections.

#### 5.2.4.3 Pins and connected parts, limit design bearing force

The limit design bearing force shall be calculated from:

$$F_{b,Rd} = \frac{\alpha_b \times d \times t \times f_y}{\gamma_{Rp}} \quad (18)$$

with  $\gamma_{Rp} = \gamma_m \times \gamma_{spb}$

where

$$a_b = \text{Min} \left\{ \begin{array}{l} \frac{f_{yp}}{f_y} \\ 1,0 \end{array} \right.$$

$f_v$  is the yield stress (minimum value) of the material of the connected parts;

$f_{yp}$  is the yield stress (minimum value) of the pin material;

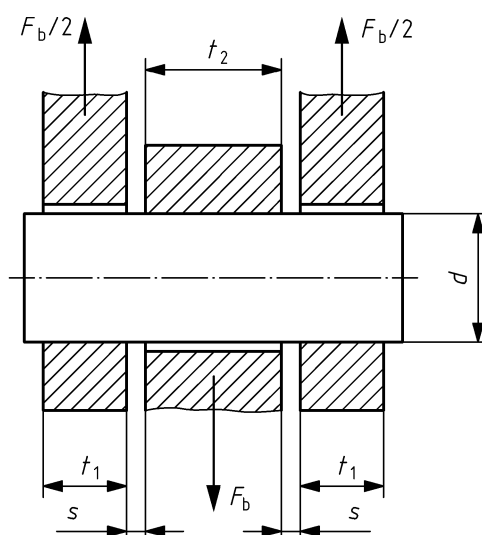
$d$  is the diameter of the pin;

$t$  is the lesser value of the thicknesses of the connected parts, i.e.  $2 \times t_1$  or  $t_2$  in Figure 5;

$\gamma_{snb}$  is the specific resistance factor for the bearing force in pinned connections:

$\gamma_{spb} = 0,6$  when connected parts in multiple shear plane connections are held firmly together by retaining means such as external nuts on the pin ends

$\gamma_{spb} = 0,9$  for single shear plane connections or when connected parts in multiple shear plane connections are not held firmly together



### Figure 5 — Pinned connections

#### 5.2.4.4 Connected parts, limit design force with respect to shear

The limit design force in a failure mode, where a piece of material is torn out, shall be based upon shear stress in a critical section. In general, a uniform shear stress distribution throughout the section is assumed.

The limit design shear force shall be calculated as follows:

$$F_{vs,Rd} = \frac{A_s \times f_y}{\gamma_m \cdot \sqrt{3}} \quad (19)$$

with

$A_s = 2 \times s \times t$  for a symmetric construction as in Figure 6 a) and c);

$A_s = (s_1 + s_2) \times t$  for a construction as in Figure 6 b) (both  $s_1$  and  $s_2$  shall be greater than  $c$ )

where

$f_y$  is the yield stress of the material of the structural member in question;

$A_s$  is the shear area of the tear-out section;

$s, s_1, s_2$  are shear lengths of the tear-out section. For constructions in accordance with Figure 6 the tear-out section is A-A and shear lengths are determined through a 40 degree rule as indicated. The connection shall be proportioned such that  $c$  or  $s$  are equal or greater than  $0,8 \times d$ , unless tests or analysis support a different proportioning;

$t$  is the thickness of the member.

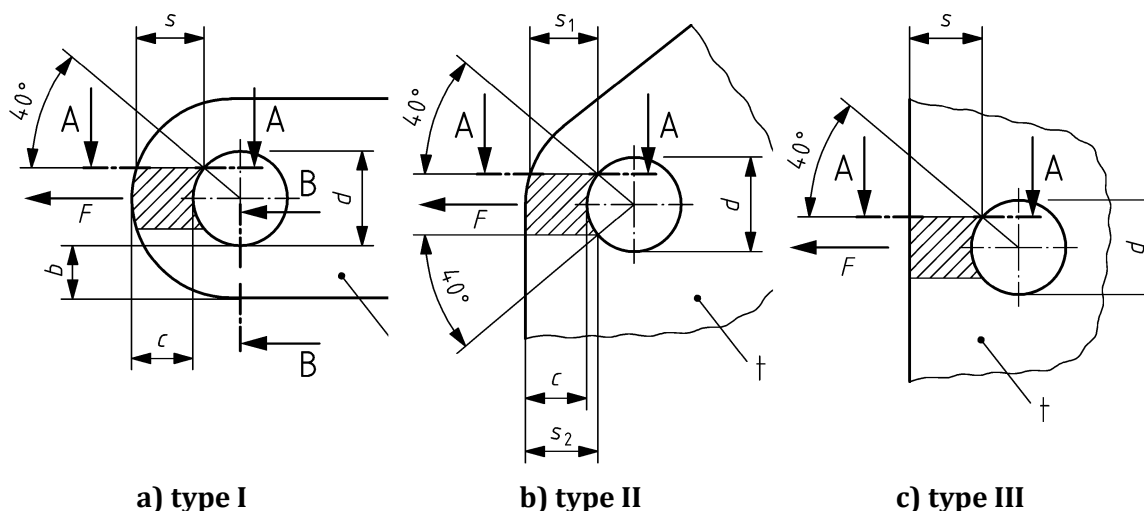


Figure 6 — Connected parts

#### 5.2.4.5 Connected parts, limit design force with respect to tensile stress

Design shall be based upon the maximum tensile stress at inner surface of the pin hole. Stress concentration due to geometry of the pin hole shall be considered.

The limit design force for the construction in accordance with Figure 6 a) shall be determined as follows:

$$F_{vt,Rd} = \frac{2 \times b \times t \times f_y}{k \times \gamma_m \times \gamma_{spt}} \quad (20)$$

with

$$\gamma_{spt} = \frac{0,95}{\sqrt{k}} \times \frac{1,38 \times f_y}{f_u}$$

where

- $f_y$  is the yield stress of the material of the structural member in question;
- $f_u$  is the ultimate strength of the material of the structural member in question;
- $\gamma_{spt}$  is the specific resistance factor for tension at pinned connections;
- $k$  is the stress concentration factor, i.e. ratio between the maximum stress and the average stress in the section. For a construction with the geometric proportions as  $1 \leq c/b \leq 2$  and  $0,5 \leq b/d \leq 1$  (see Figure 6a)), the stress concentration factor  $k$  is given in Figure 7. The clearance between the hole and the pin are assumed to conform EN ISO 286-2:2010, tolerances H11/h11 or closer. In case of a larger clearance, higher values of  $k$  shall be used.

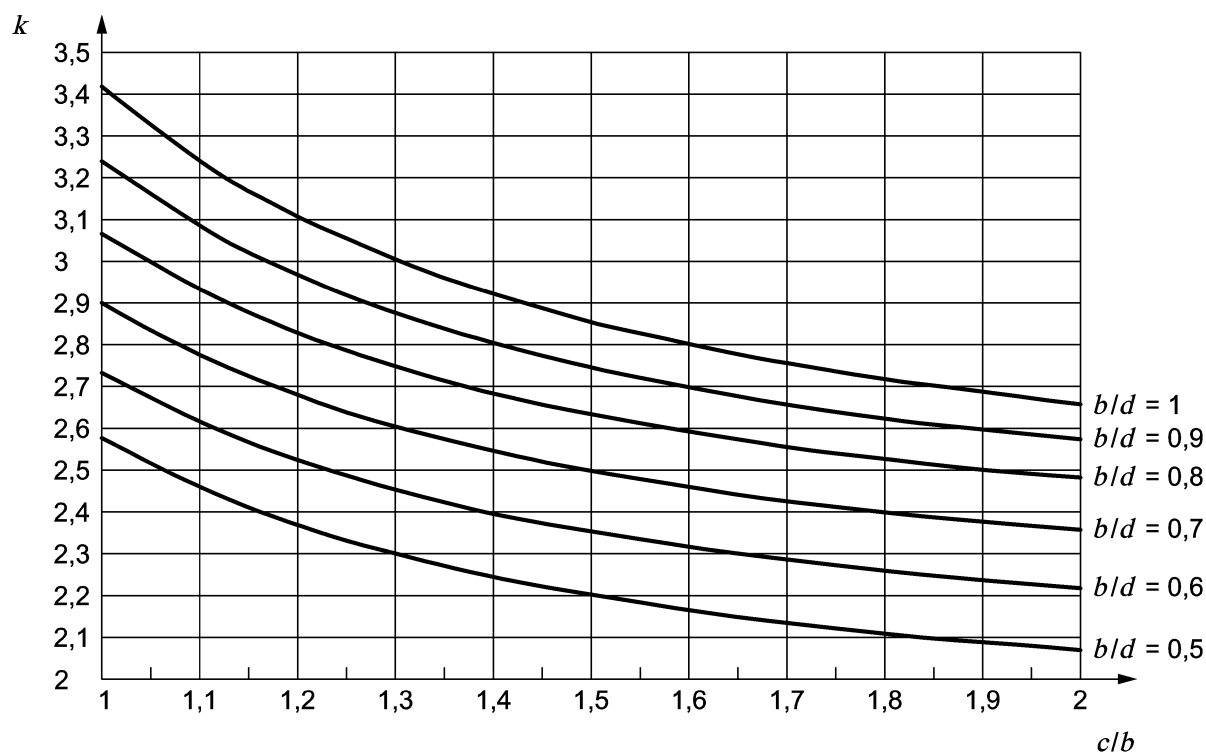


Figure 7 — Stress concentration factors for a specific type of pinned connection

Only tensile loads or tensile parts of reversing loads shall be considered within this clause. However, reversing load situations shall be given additional considerations as this can result in excessive play or impair functionality of the connection (see 5.2.4.3).

### 5.2.5 Limit design stresses in welded connections

The limit design weld stress  $f_{w,Rd}$  used for the design of a welded connection depends on the base material to be welded and the weld material used.

These two limit design weld stresses shall be considered:

$$f_{w,Rd,1} = \frac{f_{yw}}{\gamma_m} \quad (21)$$

$$f_{w,Rd,2} = \frac{f_y}{\gamma_m} \quad (22)$$

where

- $f_y$  is the minimum value of the yield strength of the connected members under consideration;
- $f_{yw}$  is the yield strength of the weld material (property of filler metal);
- $\gamma_m$  is the general resistance factor.

NOTE Yield strengths of weld materials can be found in references [33] to [43].

## 5.3 Execution of the proof

### 5.3.1 Proof for structural members

For the structural member to be designed it shall be proven that:

$$\sigma_{Sd} \leq f_{Rd\sigma} \text{ and } \tau_{Sd} \leq f_{Rd\tau} \quad (23)$$

where

- $\sigma_{Sd}, \tau_{Sd}$  are the design stresses. The von Mises equivalent stress may be used as the design stress instead;
- $f_{Rd\sigma}, f_{Rd\tau}$  are the corresponding limit design stresses in accordance with 5.2.2. In case von Mises is used,  $f_{Rd\sigma}$  is the limit design stress.

In case of plane states of stresses when von Mises stresses are not used it shall additionally be proven that:

$$\left( \frac{\sigma_{Sd,x}}{f_{Rd\sigma,x}} \right)^2 + \left( \frac{\sigma_{Sd,y}}{f_{Rd\sigma,y}} \right)^2 - \frac{\sigma_{Sd,x} \times \sigma_{Sd,y}}{f_{Rd\sigma,x} \times f_{Rd\sigma,y}} + \left( \frac{\tau_{Sd}}{f_{Rd\tau}} \right)^2 \leq 1 \quad (24)$$

where

- $x, y$  indicate the orthogonal directions of stress components.

Spatial states of stresses may be reduced to the most unfavourable plane state of stress.

### 5.3.2 Proof for bolted connections

For each mode of failure of a connection it shall be proven for the most highly loaded member that:

$$F_{Sd} \leq F_{Rd} \quad (25)$$

where

- $F_{Sd}$  is the design force of the element, depending on the type of connection, e.g.
  - $F_{e,t}$  for connections loaded in tension (see 5.2.3.3);
- $F_{Rd}$  is the limit design force in accordance with 5.2.3, depending on the type of the connection, i.e.
  - $F_{v,Rd}$  limit design shear force
  - $F_{b,Rd}$  limit design bearing force
  - $F_{s,Rd}$  limit design slip force
  - $F_{cs,Rd}$  limit design tensile force per connected member
  - $F_{t1,Rd}$ ,  $F_{t2,Rd}$  limit design tensile forces.

### 5.3.3 Proof for pinned connections

For pins and connected parts, it shall be proven that:

$$\begin{aligned} M_{Sd} &\leq M_{Rd} \\ F_{vp,Sd} &\leq F_{vp,Rd} \\ F_{bi,Sd} &\leq F_{b,Rd} \\ F_{vd,Sd} &\leq F_{vs,Rd} \\ F_{vd,Sd} &\leq F_{vt,Rd} \end{aligned} \quad (26)$$

where

- $M_{Sd}$  is the design value of the bending moment in the pin;
- $M_{Rd}$  is the limit design bending moment in accordance with 5.2.4.1;
- $F_{vp,Sd}$  is the design value of the shear force in the pin;
- $F_{vp,Rd}$  is the limit design shear force in accordance with 5.2.4.2;
- $F_{bi,Sd}$  is the most unfavourable design value of the bearing force in the joining plate  $i$  of the pin connection;
- $F_{b,Rd}$  is the limit design bearing force in accordance with 5.2.4.3;
- $F_{vd,Sd}$  is the design force in the connected part;
- $F_{vs,Rd}$  is the limit design shear force in the connected part in accordance with 5.2.4.4;