



BSI Standards Publication

Cranes - General Design

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

National foreword

This British Standard is the UK implementation of EN 13001-3-1:2012+A2:2018. It supersedes BS EN 13001-3-1:2012+A1:2013, which is withdrawn.

This standard, together with BS EN 13001-1:2004+A1:2009, BS EN 13001-2:2014, BS EN 13001-3-2:2014, BS EN 13001-3-3:2014, BS EN 13001-3-4 and DD CEN/TS 13001-3-5:2010, supersedes BS 2573-1:1983 and BS 2573-2:1980, which will be withdrawn on publication of all parts of the BS EN 13001 series.

Users' attention is drawn to the fact that neither BS 2573-1:1983 nor BS 2573-2:1980 should be used in conjunction with the EN 13001 series as they are not complementary. The BS 2573 series will remain current until all parts of the BS EN 13001 series cited above have been published to ensure that a coherent package of standards remains available in the UK during the transition to European standards.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by A1 A1.

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 secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 89958 4

ICS 53.020.20

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2012.

Amendments/corrigenda issued since publication

Date	Text affected
30 September 2013	Implementation of CEN amendment A1:2013
30 November 2014	National foreword supersession information updated
31 August 2018	Implementation of CEN amendment A2:2018

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

This European Standard was approved by CEN on and includes Amendment 2 approved by CEN on 30 October 2017.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Contents

Page

1	Scope	7
2	Normative references	7
3	Terms ,definitions, symbols and abbreviations.....	9
3.1	Terms and definitions	9
3.2	Symbols and abbreviations	9
4	General.....	12
4.1	Documentation.....	12
4.2	Materials for structural members.....	13
4.2.1	Grades and qualities.....	13
4.2.2	Impact toughness	16
4.3	Bolted connections	18
4.3.1	Bolt materials	18
4.3.2	General.....	18
4.3.3	Shear and bearing connections.....	19
4.3.4	Friction grip type (slip resistant) connections.....	19
4.3.5	Connections loaded in tension	19
4.4	Pinned connections	19
4.5	Welded connections.....	20
4.6	Proof of competence for structural members and connections.....	20
5	Proof of static strength.....	21
5.1	General.....	21
5.2	Limit design stresses and forces.....	21
5.2.1	General.....	21
5.2.2	Limit design stress in structural members.....	21
5.2.3	Limit design forces in bolted connections.....	23
5.2.4	Limit design forces in pinned connections	31
5.2.5	Limit design stresses in welded connections.....	35
5.3	Execution of the proof	38
5.3.1	Proof for structural members.....	38
5.3.2	Proof for bolted connections.....	38
5.3.3	Proof for pinned connections	39
5.3.4	Proof for welded connections.....	40
6	Proof of fatigue strength.....	40
6.1	General.....	40
6.2	Limit design stresses.....	42
6.2.1	Characteristic fatigue strength.....	42
6.2.2	Weld quality	44
6.2.3	Requirements for fatigue testing.....	45
6.3	Stress histories.....	45
6.3.1	General.....	45
6.3.2	Frequency of occurrence of stress cycles	45
6.3.3	Stress history parameter	46
6.3.4	Stress history classes S.....	47
6.4	Execution of the proof	48

6.5	Determination of the limit design stress range	49
6.5.1	Applicable methods	49
6.5.2	Direct use of stress history parameter	49
6.5.3	Use of class S	49
6.5.4	Combined effect of normal and shear stresses	51
7	Proof of static strength of hollow section girder joints	51
8	Proof of elastic stability	52
8.1	General	52
8.2	Lateral buckling of members loaded in compression	52
8.2.1	Critical buckling load	52
8.2.2	Limit compressive design force	54
8.3	Buckling of plate fields subjected to compressive and shear stresses	57
8.3.1	General	57
8.3.2	Limit design stress with respect to longitudinal stress σ_x	59
8.3.3	Limit design stress with respect to transverse stress σ_y	61
8.3.4	Limit design stress with respect to shear stress τ	63
8.4	Execution of the proof	64
8.4.1	Members loaded in compression	64
8.4.2	Plate fields	64
Annex A (informative) Limit design shear force $F_{v,Rd}$ per bolt and per shear plane for multiple shear plane connections		66
Annex B (informative) Preloaded bolts		67
Annex C (normative) Design weld stresses $\sigma_{w,Sd}$ and $\tau_{w,Sd}$		69
C.1	Butt joint	69
C.2	T-joint with fillet or partial penetration weld	70
C.3	Effective distribution length under concentrated load	71
C.4	Other types of welds	72
Annex D (normative) Values of slope constant m and characteristic fatigue strength $\Delta\sigma_c$, $\Delta\tau_c$		73
Annex E (normative) Calculated values of limit design stress ranges $\Delta\sigma_{Rd}$ and $\Delta\sigma_{Rd,1}$		94
Annex F (informative) Evaluation of stress cycles (example)		96
Annex G (informative) Calculation of stiffnesses for connections loaded in tension		98
Annex H (informative) Hollow Sections		101
Annex I (informative) Selection of a suitable set of crane standards for a given application		113
Annex ZA (informative) Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC		114

European foreword

This document (EN 13001-3-1:2012+A2:2018) has been prepared by Technical Committee CEN/TC 147 “Cranes - Safety”, the secretariat of which is held by BSI.

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 July 2018, and conflicting national standards shall be withdrawn at the latest by July 2018.

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

This document includes Amendment 1 approved by CEN on 11 May 2013.

This document includes Amendment 2 approved by CEN on 30 October 2017.

This document supersedes A2 EN 13001-3-1:2012+A1:2013 A2.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1 or A2 A2.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

A1 CEN/TC 147/WG 2 has made a new edition of EN 13001-3-1 to adapt the standard as follows:

- Subclause 4.2.1 is changed in such a way that Table 2 is permanently valid and requirements for other materials are added, and
- editorial changes are done to improve the document. A1

A2 CEN/TC 147/WG 2 has made a new consolidation of EN 13001-3-1 to adapt the standard as follows:

- New steel qualities from EN 10149-2 and stainless steels from EN 10088-2 added to 4.2.1.
- Application of bolt preloading scatter in 5.2.3.3 was modified.
- Table 8 changed to exclude matching material for ultra-high strength steel.
- Fatigue strength specific resistance factors were adjusted in 6.1.
- Requirements for fatigue testing were modified.
- Formula for assessing combined effect of normal and shear stresses was changed in 6.5.4.
- Annex C improved for calculation of fillet welds.

- Characteristic fatigue strengths modified for notch cases D.1.1, D.1.2, D.3.29 and D.3.30.
- Number of minor changes for reasons of editorial and technical accuracy. [A2](#)

This European Standard is one Part of EN 13001, *Cranes — General design*. The other parts are as follows:

- *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.*

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, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This European Standard has been prepared to be a harmonized standard to provide one means for the mechanical design and theoretical verification of cranes to conform $\boxed{A_2}$ to $\langle A_2 \rangle$ the essential health and safety requirements of the Machinery Directive, as amended. This standard also establishes interfaces between the user (purchaser) and the designer, as well as between the designer and the component manufacturer, in order to form a basis for selecting cranes and components.

This European Standard is a type C standard as stated in EN ISO 12100.

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

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 European Standard is to be used together with EN 13001-1 and EN 13001-2 and as such they specify general conditions, requirements and methods to prevent mechanical hazards of cranes by design and theoretical verification.

NOTE Specific requirements for particular types of cranes are given in the appropriate European Standard for the particular crane type.

The following is a list of significant hazardous situations and hazardous events that could result in risks to persons during intended use and reasonably foreseeable misuse. Clauses 4 to 8 of this standard are necessary to reduce or eliminate risks associated with the following hazards:

- 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 European Standard is not applicable to cranes which are manufactured before the date of its publication as EN and serves as reference base for the European Standards for particular crane types (see Annex I).

NOTE EN 13001-3-1 deals only with the limit state method in accordance with EN 13001-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

☐A2☐ deleted reference ☐A2☐

EN 1993-1-8:2005, *Eurocode 3: Design of steel structures — Part 1-8: Design of joints*

EN 10025-2:2004, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 10025-3:2004, *Hot rolled products of structural steels — Part 3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels*

EN 10025-4:2004, *Hot rolled products of structural steels — Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels*

EN 10025-6:2004, *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*

☐A2☐ deleted references ☐A2☐

EN 10088-2:2014, *Stainless steels — Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes*

EN 10149-2:2013, *Hot-rolled flat products made of high yield strength steels for cold forming — Part 2: 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: 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 conditions of hot-rolled steel plates, wide flats and sections — Part 1: General requirements*

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

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

EN 10164:2004, *Steel products with improved deformation properties perpendicular to the surface of the product — Technical delivery conditions*

EN 13001-1, *Cranes — General design — Part 1: General principles and requirements*

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

EN 20273:1991, *Fasteners — Clearance holes for bolts and screws (ISO 273:1979)*

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

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 5817:2014, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2014)*

EN ISO 9013:2002, *Thermal cutting — Classification of thermal cuts — Geometrical product specification and quality tolerances (ISO 9013:2002)*

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

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 ~~Ⓐ~~ *deleted text* ~~Ⓐ~~ apply. For the definitions of loads, Clause 6 of ISO 4306-1:2007 applies.

3.2 Symbols and abbreviations

The symbols and abbreviations used in this Part of the EN 13001 are given in Table 1.

Table 1 — Symbols and abbreviations (1 of 4)

Symbols, 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	throat thickness of fillet welds
a_r	effective weld thickness
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
$\mathbb{A}_1 F_k \mathbb{A}_1$	characteristic value (force)
F_p	preloading force in bolt
F_{Rd}	limit design force
F_e	external 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

Table 1 — Symbols and abbreviations (2 of 4)

Symbols, abbreviations	Description
$F_{t,Rd}$	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
$F_{s,Rd}$	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
$\langle A_1 \rangle f_k \langle A_1 \rangle$	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_y	$\langle A_2 \rangle$ yield stress of material, specified or measured $\langle A_2 \rangle$
f_{yb}	yield stress of bolts
f_{yp}	$\langle A_2 \rangle$ yield stress of pins, specified or measured $\langle A_2 \rangle$
$\langle A_1 \rangle h_d$	distance between weld and contact level of acting load $\langle A_1 \rangle$
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_{τ}	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
M_{Sd}	design bending moment
m	slope constant of $\log \Delta\sigma / \log N$ -curve
N	compressive force (buckling)

Table 1 — Symbols and abbreviations (3 of 4)

Symbols, abbreviations	Description
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
α	cross section parameter (lateral buckling)
α_b	characteristic factor for bearing connection
α_L	load introduction factor (bolted connection)
α_w	characteristic factor for limit weld stress
γ_m	general resistance factor
γ_{mf}	fatigue strength specific resistance factor
γ_p	partial safety factor
γ_R	resulting resistance factor
γ_S	specific resistance factor
γ_{Rb}	resulting resistance factor of bolt
$\gamma_{sbb}, \gamma_{sbs}, \gamma_{sbt}$	specific resistance factors of bolted connections
γ_{Rm}	resulting resistance factor of members
γ_{sm}	specific resistance factor of members
γ_{Rp}	resulting resistance factor of pins
$\gamma_{spm}, \gamma_{sps}, \gamma_{spb}, \gamma_{spt}$	specific resistance factors of pins
γ_{Rs}	resulting resistance factor of slip-resistance connection
γ_{ss}	specific resistance factor of slip-resistance connection
γ_{Rc}	resulting resistance factor for tension on section with holes
γ_{st}	specific resistance factor for tension on section with holes
γ_{Rw}	resulting resistance factor of welding connection
γ_{sw}	specific resistance factor of welding connection
δ_p	elongation from preloading
ϕ_2	dynamic factor
κ	dispersion angle (wheel pressure)
K, K_x, K_y, K_T	reduction factors (buckling)
λ	width of contact area in weld direction

Table 1 — Symbols and abbreviations (4 of 4)

Symbols, abbreviations	Description
$\lambda_x, \lambda_y, \lambda_z$	non-dimensional plate slenderness (buckling)
ψ	edge stress ratio (buckling)
ΔF_b	additional force
$\Delta \delta_t$	additional elongation
μ	slip factor
v	relative total number of stress cycles ~~A₁~~ deleted text ~~A₁~~
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)
σ_e	reference stress (buckling)
σ_b	lower extreme value of stress range
σ_u	upper extreme value of stress range
σ_{Sd}	design stress (normal)
τ_{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,
- 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

European Standards specify materials and specific values. This standard gives a preferred selection.

For structural members, steel according to following European Standards should be used:

- a) Non-alloy structural steels EN 10025-2;
- b) Weldable fine grain structural steels in conditions:
 - 1) normalized (N) EN 10025-3;
 - 2) thermomechanical (M) EN 10025-4;
- c) High yield strength structural steels in the quenched and tempered condition EN 10025-6;
- d) High yield strength steels for cold forming in conditions:
 - 1) thermomechanical (M) EN 10149-2;
 - 2) normalized (N) EN 10149-3.

A2 e) Austenitic stainless steels EN 10088-2.

Where stainless steels are welded, special attention should be given to the welding process and corrosion effects.

Table 2 shows specific values for the nominal value of strength f_u, f_y . 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. For more information see the specific European Standard. **A2**

A1 *deleted text* **A1**

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. To allow the use of nominal dimensions for other steel products than plates, their minus tolerances shall be within those of the relevant European standards for those products.

A1 Grades and qualities other than those mentioned in the above standards and in Table 2 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. **A1**

NOTE Where it is deemed necessary to check for internal defects, classes of EN 10160 should be specified.

Table 2 — Specific values of steels for structural members

Steel	Standard	Thickness t mm	Nominal strength	
			f_y	f_u
			yield	ultimate
			N/mm ²	N/mm ²
S235	EN 10025-2	$t \leq 16$	235	340
		$16 < t \leq 40$	225	
		$40 < t \leq 100$	215	
		$100 < t \leq 150$	195	
S275		$t \leq 16$	275	430
		$16 < t \leq 40$	265	
		$40 < t \leq 63$	255	
		$63 < t \leq 80$	245	
		$80 < t \leq 100$	235	
		$100 < t \leq 150$	225	
S355		$t \leq 16$	355	490
		$16 < t \leq 40$	345	
		$40 < t \leq 63$	335	
		$63 < t \leq 80$	325	
		$80 < t \leq 100$	315	
		$100 < t \leq 150$	295	
S355	EN 10025-3 (N) EN 10025-4 (M)	$t \leq 16$	355	450
		$16 < t \leq 40$	345	
		$40 < t \leq 63$	335	
		$63 < t \leq 80$ (N)	325	
		$80 < t \leq 100$ (N)	315	
		$100 < t \leq 150$ (N)	295	
S420		$t \leq 16$	420	500
		$16 < t \leq 40$	400	
		$40 < t \leq 63$	390	
		$63 < t \leq 80$ (N)	370	
		$80 < t \leq 100$ (N)	360	
		$100 < t \leq 150$ (N)	340	
S460		$t \leq 16$	460	530

Steel	Standard	Thickness t mm	Nominal strength	
			f_y	f_u
			yield	ultimate
			N/mm ²	N/mm ²
				$16 < t \leq 40$
		$40 < t \leq 63$	430	
		$63 < t \leq 80$ (N)	410	
		$80 < t \leq 100$ (N)	400	
S460	EN 10025-6	$3 < t \leq 50$	460	550
		$50 < t \leq 100$	440	
S500		$3 < t \leq 50$	500	590
		$50 < t \leq 100$	480	
S550		$3 < t \leq 50$	550	640
		$50 < t \leq 100$	530	
S620		$3 < t \leq 50$	620	700
		$50 < t \leq 100$	580	
S690		$3 < t \leq 50$	690	770
		$50 < t \leq 100$	650	760
S890		$3 < t \leq 50$	890	940
		$50 < t \leq 100$	830	880
S960		$3 < t \leq 50$	960	980
S315	EN 10149-3 EN 10149-2	all t	315	390
S355			355	430
S420			420	480
S460	EN 10149-2	all t	460	520
S500			500	550
S550			550	600
S600			600	650
S650		$t \leq 8$	650	700
		$t > 8$	630	
S700		$t \leq 8$	700	750
		$t > 8$	680	
S900		all t	900	930
S960			960	980

Steel	Standard	Thickness t mm	Nominal strength	
			f_y	f_u
			yield	ultimate
			N/mm ²	N/mm ²
X2CrNi18-9	EN 10088-2	$t \leq 75$	200 ^a	500 ^b
X5CrNi18-10			210 ^a	520 ^b
X2CrNi19-11			200 ^a	500 ^b
X2CrNiMo17-12-2			220 ^a	520 ^b
X5CrNiMo17-12-2			220 ^a	520 ^b
^a 0,2 % – proof strength for hot rolled plate (P);				
^b Tensile strength for hot rolled plate (P).				



4.2.2 Impact toughness

A2 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 3 gives the impact toughness parameters q_i for various influences. Table 4 gives the required steel quality and impact energy/test temperature in dependence of Σq_i . The direction of loading shall be considered when assessing the impact toughness. Grades and qualities of steel other than mentioned in Table 4 may be used, if an impact energy/temperature is tested in accordance with EN ISO 148-1, specified and meet the requirements given in first two rows of Table 4. **A2**

Table 3 — Impact toughness parameters q_i

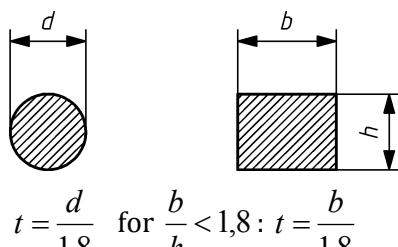
i	Influence	q_i
1	Operating temperature T (°C)	$0 \leq T$
		$-10 \leq T < 0$
		$-20 \leq T < -10$
		$-30 \leq T < -20$
		$-40 \leq T < -30$
		$-50 \leq T < -40$
2	Yield stress f_y (N/mm ²)	$f_y \leq 300$
		$300 < f_y \leq 460$
		$460 < f_y \leq 700$
		$700 < f_y \leq 1000$
		$1\,000 < f_y \leq 1300$
3	Material thickness t (mm) Equivalent thickness t for solid bars:  $t = \frac{d}{1,8} \quad \text{for } \frac{b}{h} < 1,8 : t = \frac{b}{1,8}$	$t \leq 10$
		$10 < t \leq 20$
		$20 < t \leq 40$
		$40 < t \leq 60$
		$60 < t \leq 80$
		$80 < t \leq 100$
		$100 < t \leq 125$
		$125 < t \leq 150$
4	Characteristic value of stress range $\Delta\sigma_c$ (N/mm ²) (see Annex D and Annex H)	$\Delta\sigma_c > 125$
		$80 < \Delta\sigma_c \leq 125$
		$56 < \Delta\sigma_c \leq 80$
		$40 < \Delta\sigma_c \leq 56$
		$30 < \Delta\sigma_c \leq 40$
		$\Delta\sigma_c \leq 30$
5	Utilization of static strength (see 5.3.1)	$\sigma_{Sd} > 0,75 \times f_{Rd\sigma}$
		$0,5 \times f_{Rd\sigma} < \sigma_{Sd}$ and $\sigma_{Sd} \leq 0,75 \times f_{Rd\sigma}$
		$0,25 \times f_{Rd\sigma} < \sigma_{Sd}$ and $\sigma_{Sd} \leq 0,5 \times f_{Rd\sigma}$
		$\sigma_{Sd} \leq 0,25 \times f_{Rd\sigma}$

Table 4 — 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	JR	J0	J2	a
EN 10025-3	N	N	N	NL
EN 10025-4	M	M	M	ML
EN 10025-6	Q	Q	Q	QL
EN 10149-2	MC	MC	MC	a
EN 10149-3	NC	NC	NC	a
EN 10088-2	b	b	b	b
^a May be used if the impact toughness is at least 27 J at -40 °C, tested in accordance with EN ISO 148-1 and specified. ^b All steels of EN 10088-2 listed in Table 2. The impact energy is not explicitly given by EN 10088-2 at these temperatures however the impact energy/ test temperature requirement in the row two is fulfilled.				

4.3 Bolted connections

4.3.1 Bolt materials

For bolted connections bolts of the property classes (bolt grades) 4.6, 5.6, 8.8, 10.9 or 12.9 in accordance with **EN ISO 898-1:2013** shall be used. Table 5 shows nominal values of the strengths to be used in design calculations:

Table 5 — Property classes (bolt grades)

Property class (Bolt grade)	4.6	5.6	8.8	10.9	12.9
f_{yb} (N/mm ²)	240	300	640	900	1 080
f_{ub} (N/mm ²)	400	500	800	1 000	1 200

NOTE The designer should ask the bolt supplier to demonstrate compliance with the requirements regarding the protection against hydrogen brittleness, for the property classes (bolt grades) 10.9 and 12.9. Technical requirements can be found in EN ISO 15330, EN ISO 4042 and ISO 9587.

4.3.2 General

For the purpose of this standard bolted connections are connections between members and/or components utilizing bolts.

In general, bolted connections are tensioned wrench tight.

Where slippage (e.g. caused by vibrations or fluctuations in loading) causes deleterious changes in geometry, bolts shall be tightened to avoid slippage sufficiently or the joint surfaces shall be secured against rotation (e.g. by using multiple bolts).

4.3.3 Shear and bearing connections

For the purpose of this standard 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, when bolts are exposed to load reversal or where slippage may cause deleterious changes in geometry;
- in other cases wider clearances in accordance with EN 20273 may be used;
- special surface treatment of the contact surfaces is not needed.

4.3.4 Friction grip type (slip resistant) connections

For the purpose of this standard friction grip connections are those connections where the loads are transmitted by friction between the joint surfaces, and where:

- high strength bolts of property classes (bolt grades) 8.8, 10.9 or 12.9 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 accordingly;
- in addition to standard holes oversized and slotted holes may be used.

4.3.5 Connections loaded in tension

For the purpose of this standard 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;
- high strength bolts of property classes (bolt grades) 8.8, 10.9 or 12.9 are used and tightened by a controlled method to a specified preloading state.

NOTE Bolts in tension that are not preloaded are treated as structural members.

4.4 Pinned connections

For the purpose of this standard 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 loads with changing directions closer tolerances shall be applied.

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

In order to inhibit local out-of-plane distortion (dishing), consideration shall be given to the stiffness of the connected parts.

4.5 Welded connections

For the purposes of this standard 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, see Annex H).

Quality levels of EN ISO 5817 shall be applied, and appropriate methods of non-destructive testing 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.

Terms for welded joints are as given in EN ISO 17659.

Although the distribution of stresses along the length of the weld may be non-uniform, such distributions can, for the purposes of this standard, be considered uniform in which case the effective weld length shall not exceed 150 times the weld thickness a .

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.

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

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.

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.

NOTE The deformation and vibrational behaviour of structures should be limited considering the intended use of the crane.

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 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 is not considered acceptable within the terms of this standard.

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 and applying the resistances according to 5.2.

This standard 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 standard may 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:

$$\text{Limit design stresses } f_{Rd} = \text{function} (f_k, \gamma_R) \quad \text{or} \quad (2)$$

$$\text{Limit design forces } F_{Rd} = \text{function} (F_k, \gamma_R) \quad (3)$$

where

f_k or F_k are characteristic values (or nominal values)

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

γ_m is the general resistance factor $\gamma_m = 1,1$ (see EN 13001-2)

γ_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 / γ_m in EN 13001-1.

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:

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

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

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

where

f_y is the value of the yield stress of the material σ_{A2}

γ_{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):

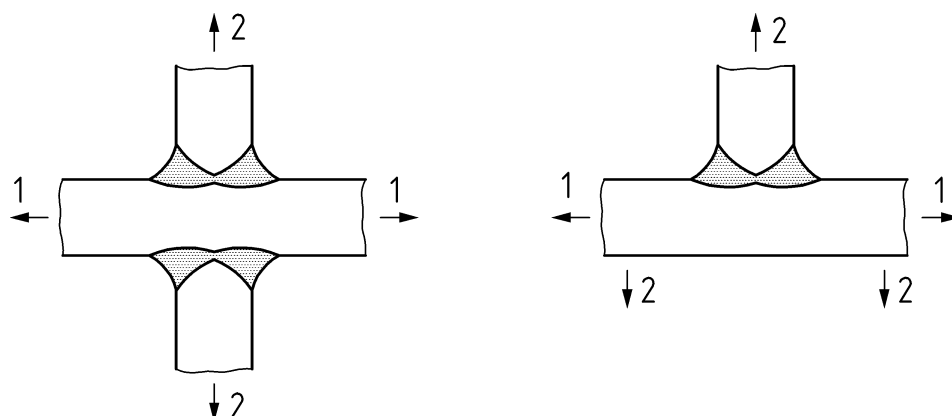
Material shall be suitable for carrying perpendicular loads and be free of lamellar defects.

$\gamma_{sm} = \sigma_{A2} 1,0$ for plate thicknesses less than 15 mm or material in quality classes Z25 or better in accordance with EN 10164:2004 σ_{A2}

$\gamma_{sm} = 1,16$ for material in quality class Z15 in accordance with EN 10164:2004

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

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

**Key**

1 $\overline{A_2}$ deleted text $\overline{A_2}$

1 is the direction of the plane of rolling

2 $\overline{A_2}$ is the direction of stress $\overline{A_2}$

Figure 1 — $\overline{A_2}$ Tensile stress perpendicular to plane of rolling $\overline{A_2}$

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 is 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 5)

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

γ_{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 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 2, Table 5)

d is the shank diameter of the bolt

d_0 is the diameter of the hole

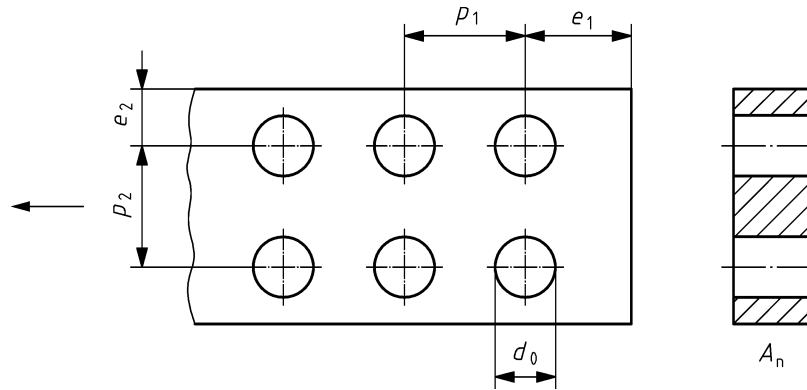
t is the thickness of the connected part in contact with the unthreaded part of the bolt

γ_{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 Equation (7).

Arrow shows the direction of force.

Figure 2 — Illustration for Equation (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)

γ_{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

μ	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 μm to 80 μm 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 $F_{cr} = F_e$ may be used).

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

γ_{ss} is the specific resistance factor for friction grip type connections (see Table 6)

Table 6 — Specific resistance factor γ_{ss} for friction grip connections

Effect of connection slippage	Type of holes			
	Standard holes ^a	Oversized ^b and short-slotted ^c holes	Long-slotted holes ^c	Long-slotted holes ^d
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
^a Holes with clearances in accordance with the medium series of EN 20273:1991. ^b Holes with clearances in accordance with the coarse series of EN 20273:1991. ^c Slotted holes with slots perpendicular to the direction of force. ^d Slotted holes with slots parallel to the direction of force. Short slotted hole: length of hole is smaller than or equal to 1,25 times the diameter of the bolt. Long slotted hole: length of hole is larger than 1,25 times the diameter of the bolt. In order to reduce pressure under bolt or nut appropriate washers shall be used.				

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 5)

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.

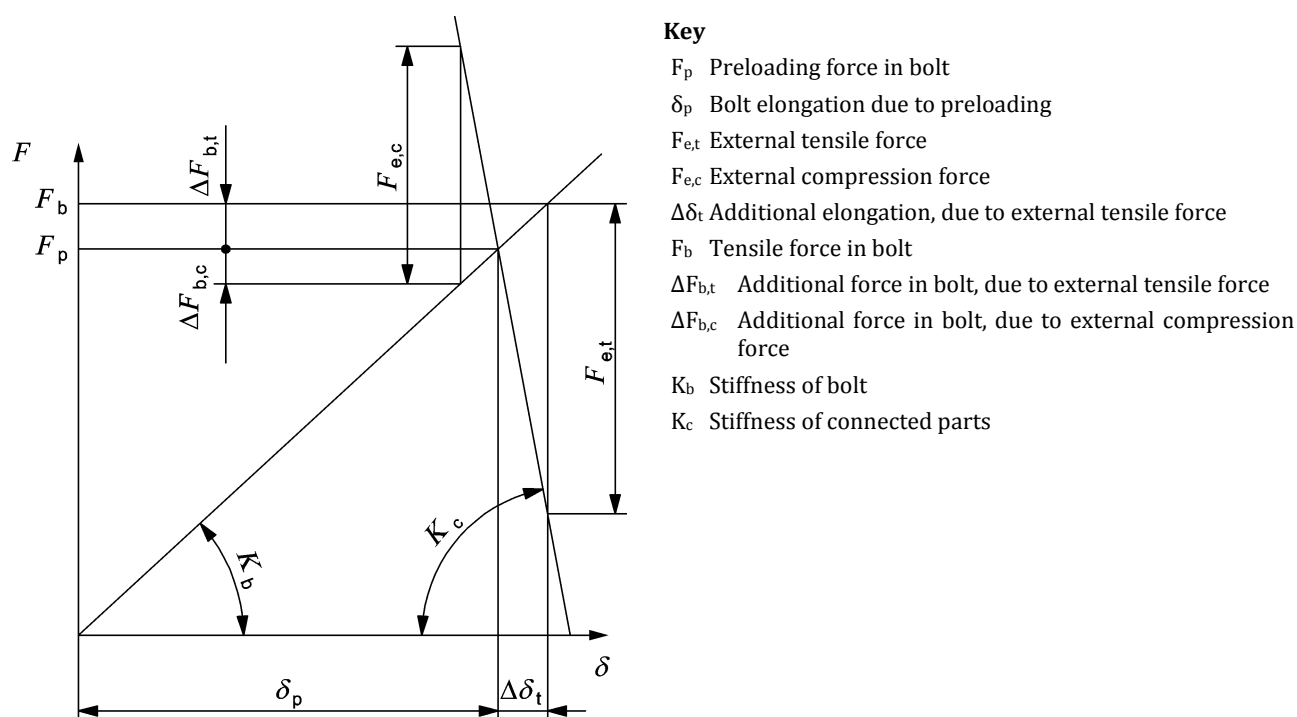
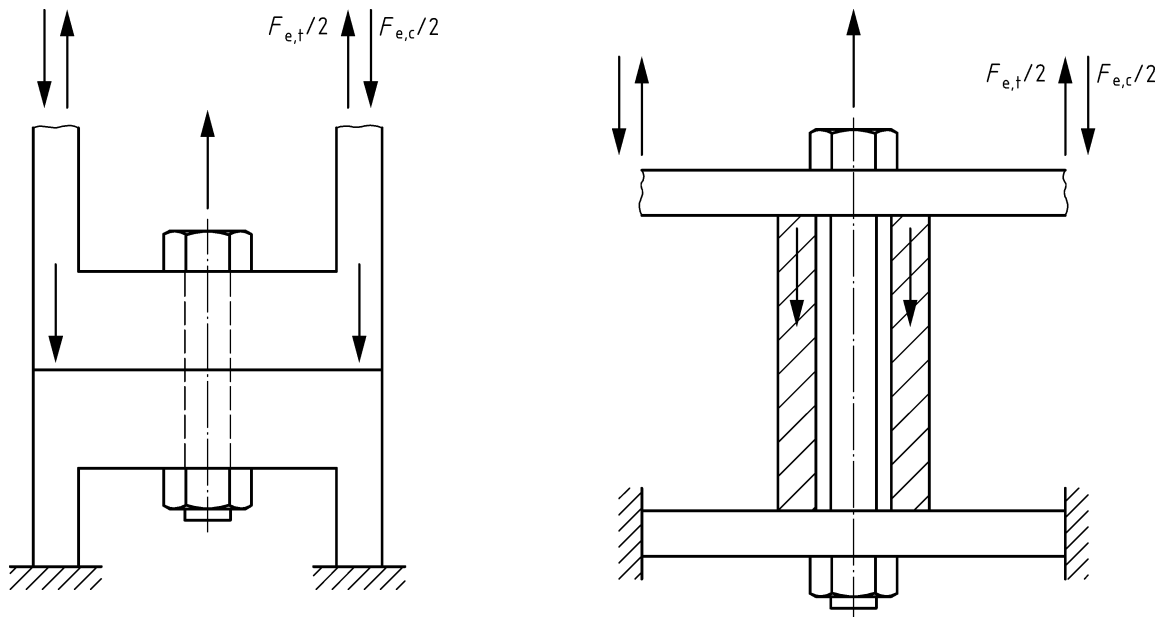


Figure 3 — Force-elongation-diagram



- 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, Equation (10);
- 2) the connection shall not open (gap) under the resulting bolt force from the external force and the minimum design preload, Equation (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 is 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 Equation (12)),
f_{yb}	is the yield stress of the bolt material,
A_s	is the stress area of the threaded part of the bolt,
Φ	is the stiffness ratio factor of the connection, see Annex G,
γ_{sbt}	is the specific resistance factor for connections loaded in tension,
	$\gamma_{sbt} = 0,91$

The limit design tensile force per bolt for the opening criteria of the connection is 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 Equation (13)).

The variation of preload due to scatter is 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,

A_2

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) may 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."

Ⓐ₂

The nominal value of the design preload $F_{p,d}$ value shall not exceed the values given in Table 7. Otherwise, any value for the preload may be chosen for a particular connection.

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

Ⓐ₂

Type of preloading method	Upper limit of nominal value of design preload $F_{p,d}$
Methods, where the bolt is subjected to torque	$0,7 F_y$
Methods, where only direct tension is applied to the bolt 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 $0,9 \cdot F_y$.	$0,85 F_y$

Ⓐ₂

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 is calculated as follows:

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

where

ΔF_b is the additional force in bolt

Φ 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 equation) 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 ΔF_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

$F_{t,Rd}$ 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 is 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

γ_{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 is 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

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

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

where

$$\nu_D = \frac{D_i}{D_o},$$

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

γ_{sps} is the specific resistance factor for shear force in pinned connections

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

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

5.2.4.3 Pins and connected parts, limit design bearing force

The limit design bearing force is 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

$$\alpha_b = \text{Min} \begin{cases} \frac{f_{yp}}{f_y} \\ 1,0 \end{cases}$$

f_y 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

γ_{spb} 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

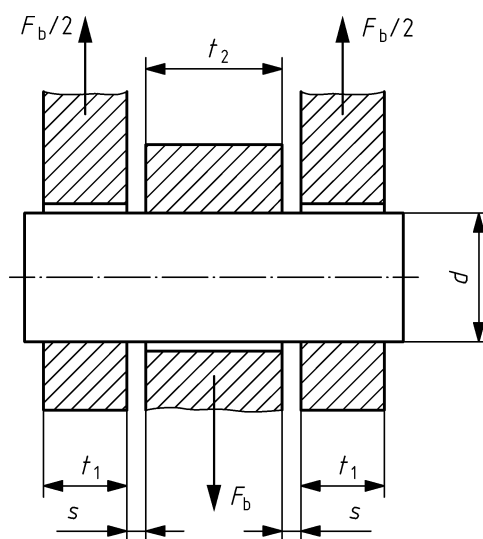


Figure 5 — Pinned connections

NOTE 1 In case of significant movement between the pin and the bearing surface, consideration should be given to choosing a limiting value below the calculated value of the limit bearing force in order to reduce wear.

NOTE 2 In case of reversing load, consideration should be given to the avoidance of excessive play in the connection.

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 is calculated as follows:

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

with

$$A_s = 2 \times s \times t \quad \text{for a symmetric construction as in Figure 6 a) and c),}$$

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

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 $\sqrt{A_2}$ 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 should be proportioned such that c or s are equal or greater than $0,8 \times d$, unless tests or analysis support a different proportioning. $\sqrt{A_2}$

t is the thickness of the member.

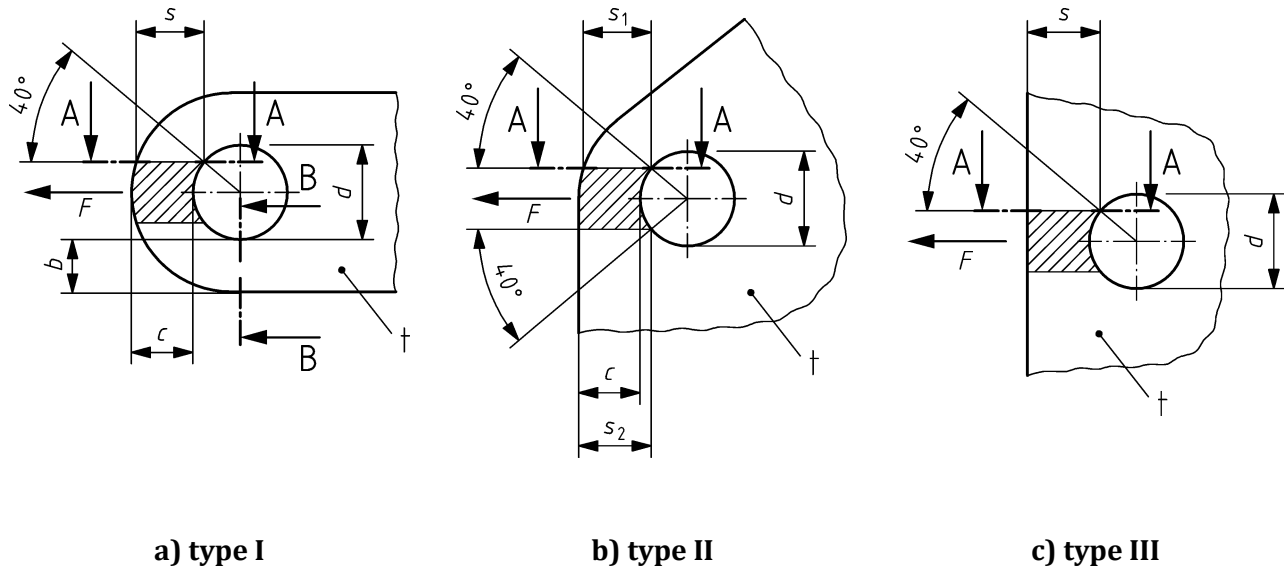


Figure 6 — Connected parts

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) is 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,

γ_{spt} is the specific resistance factor for tension at pinned connections,