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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 22 December 2024.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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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of an identical text or by endorsement, at the latest by August 2025, and conflicting national standards shall be withdrawn at the latest by August 2025.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

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/

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

Table 1 — Symbols and abbreviations

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_r	throat thickness of fillet welds
b	width of plate
c	edge stress ratio factor (buckling)
$D_{\mathrm{o}}, D_{\mathrm{i}}$	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
$F_{\mathrm{e,t}}$	external tensile force on bolted connection
$F_{\mathrm{b,\,Rd}}$	limit design bearing force
$F_{\mathrm{b,\,Sd}}$; $F_{\mathrm{bi,\,Sd}}$	design bearing force
$F_{\mathrm{cs,\,Rd}}$	limit design tensile force
$F_{\mathrm{p,\,d}}$	design preloading force
F_{cr}	reduction in compression force due to external tension
$F_{\mathrm{t,\,Rd}}$	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
$F_{\mathrm{vp,\,Rd}}$	limit design shear force per pin and shear plane
$F_{vp,\,Sd}$	design shear force per pin and shear plane

Symbols, abbreviations	Description
$F_{s,Rd}$	limit design slip force per bolt and shear plane
$F_{\mathrm{vs,\,Rd}}$	limit design shear force of the connected part
$\mathrm{F_{vd,\,Sd}}$	design force in the connected part
$F_{\mathrm{vt,\,Rd}}$	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
$f_{\mathrm{w,\,Rd}}$	limit design weld stress
$f_{\mathrm{w,\,Rd,1}}$	limit design weld stress with respect to the weld material
$f_{\mathrm{w,\,Rd,2}}$	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
$k_{\sigma x}, k_{\sigma y}, k_\tau$	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, abbreviations	Description
M_{Sd}	design bending moment
m	slope constant of log Δσ/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
α	cross section parameter (lateral buckling)
α_b	characteristic factor for bearing connection
α_L	load introduction factor (bolted connection)
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
γ_{sbb}, γ_{sbs}, γ_{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
γ_{spm}, γ_{sps}, γ_{spb}, γ_{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

Symbols, abbreviations	Description
γ_{sw}	specific resistance factor of welding connection
δ_{p}	elongation from preloading
ϕ_2	dynamic factor
κ	dispersion angle (wheel pressure)
κ, κ_x, κ_y, κ_τ	reduction factors (buckling)
λ	width of contact area in weld direction
λ_x, λ_y, λ_τ	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
v_{D}	ratio of diameters
$\Delta\sigma_{\text{c}}$	characteristic value of stress range (normal stress)
$\Delta\tau_{\text{c}}$	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)
$\sigma_{\text{w, Sd}}$	design weld stress (normal)
$\tau_{\text{w, Sd}}$	design weld stress (shear)
$\Delta\sigma_{\text{Rd}}$	limit design stress range (normal)
$\Delta\sigma_{\text{Rd,1}}$	limit design stress range for k* = 1
$\Delta\tau_{\text{Rd}}$	limit design stress range (shear)
$\Delta\sigma_{\text{Sd}}$	design stress range (normal)
$\Delta\tau_{\text{Sd}}$	design stress range (shear)

4 General

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.

4.2.1 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.

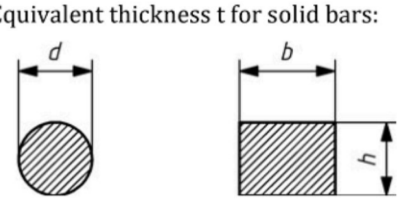
Specific values for the nominal value of strength f_u, f_y are given in Annex M (normative). For limit design stresses f_{Rd}, see 5.2. The values given are applicable for temperatures up to 100 °C for stainless steels and up to 150 °C for all other steels.

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 Σq_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)	$0 \leq T$	0
		$-10 \leq T < 0$	1
		$-20 \leq T < -10$	2
		$-30 \leq T < -20$	3
		$-40 \leq T < -30$	4
		$-50 \leq T < -40$	6
2	Yield stress f_y (N/mm²)	$f_y \leq 300$	0
		$300 < f_y \leq 460$	1
		$460 < f_y \leq 700$	2
		$700 < f_y \leq 1\,000$	3
		$1\,000 < f_y \leq 1\,300$	4
3	Material thickness t (mm) Equivalent thickness t for solid bars:  $t = \frac{d}{1,8}$ for $\frac{b}{h} < 1,8 : t = \frac{b}{1,8}$	$t \leq 10$	0
		$10 < t \leq 20$	1
		$20 < t \leq 40$	2
		$40 < t \leq 60$	3
		$60 < t \leq 80$	4
		$80 < t \leq 100$	5
		$100 < t \leq 125$	6
		$125 < t \leq 150$	7

i	**Influence**		q_i
4	Characteristic value of stress range $\Delta\sigma_c$ (N/mm²) (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
		$0{,}5 \times f_{Rd\sigma} < \sigma_{sd}$ and $\sigma_{sd} \leq 0{,}75 \times f_{Rd\sigma}$	−1
		$0{,}25 \times f_{Rd\sigma} < \sigma_{sd}$ and $\sigma_{sd} \leq 0{,}5 \times f_{Rd\sigma}$	−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]

[a] 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.

[b] 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.

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 (Bolt grade)	4.6	5.6	8.8		10.9	12.9
			d ≤ 16 mm	d > 16 mm		
f_{yb} (N/mm^2)	240	300	640	660	940	1100
f_{ub} (N/mm^2)	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) / Test temperature	Percentage elongation A5 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.

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.

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.

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 :

$$S_d \leq R_d \tag{1}$$

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

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.

5.2.1 General

The limit design stresses and forces shall be calculated from:

Limit design stresses f_{Rd} = function (f_k, γ_R) or

Limit design forces F_{Rd} = function (F_k, γ_R) (2)

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 [44]);
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 [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:

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

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

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

where

f_y is the value of the yield stress of the material

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):

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

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

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

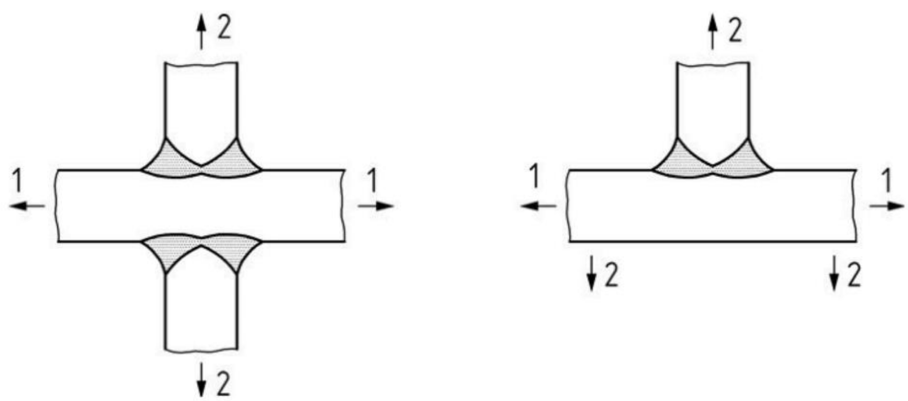
Material shall be suitable for carrying perpendicular loads and be free of lamellar defects.

$\gamma_{sm} = 1{,}0$ 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:

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

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

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;

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 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:

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

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

with the requirement

$$e_1 \geq 1,5 \times d_0 \tag{7}$$

and with the following recommendations for the plate

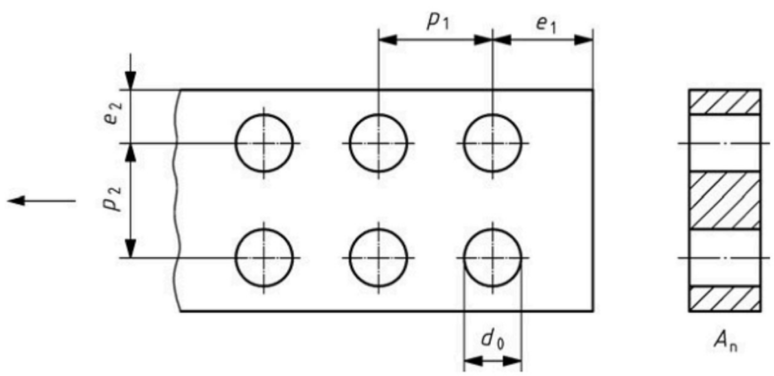
$e_2 \geq 1,5 \times d_0$

$p_1 \geq 3,0 \times d_0$

$p_2 \geq 3,0 \times d_0$

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;
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 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:

$$F_{cs,Rd} = \frac{f_y \times A_n}{\gamma Rc} \tag{8}$$

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:

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

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 $F_{cr} = F_{e,t}$ 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

	Type of holes			
Effect of connection slippage	**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
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.				

[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.

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);

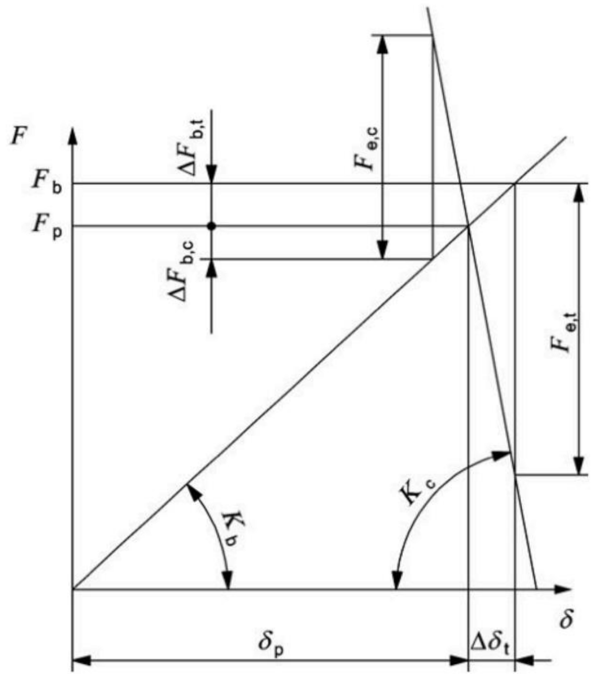
A_s is the stress area of the bolt (Table B.2).

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).

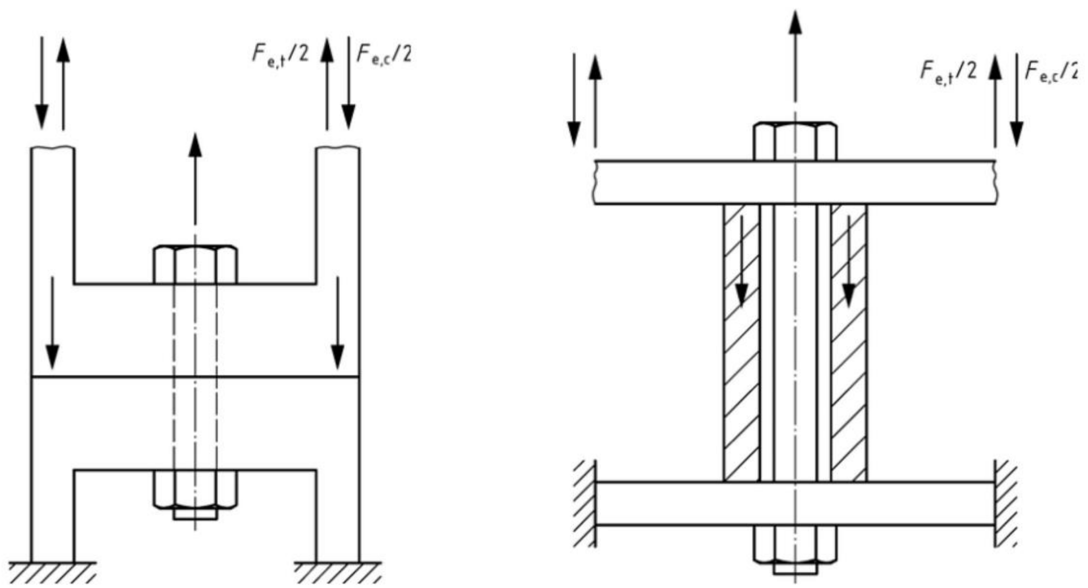
Proof of competence calculations of a preloaded connection shall take into account the stiffness of the bolt and the connected parts, see Figure 3. In addition to that, the effect of different load paths of the external compression force, depending upon the joint construction, shall be taken into account,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



Key

F_p	Preloading force in bolt
δ_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:

$$F_{t_1,Rd} = \frac{F_y / \gamma_{Rb} - F_{p,\max}}{\Phi} \tag{10}$$

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;

$F_{\mathrm{p,max}}$ 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;

Φ is the stiffness ratio factor of the connection, see informative Annex G (informative);

γ_{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:

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

where

$F_{\mathrm{p,min}}$ 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:

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

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

where

$F_{\mathrm{p,d}}$ is the nominal value of the design preload;

$F_{\mathrm{p,max}}$ is the maximum value of the preload;

$F_{\mathrm{p,min}}$ 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 $F_{\mathrm{p,min}}$ 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 $F_{\mathrm{p,d}}$ 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 $F_{p,d}$
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

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:

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

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 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 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:

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

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:

$$M_{Rd} = \frac{W_{\text{el}} \times f_{\text{yp}}}{\gamma_{\text{Rp}}} \tag{16}$$

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 shall be calculated from:

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

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

where

u is the shape factor

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

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

where $v_D = \frac{D_i}{D_0}$

D_i is the inner diameter of pin

D_0 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

$\gamma_{sps} = 1{,}0$ 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:

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

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

where

$$a_{\mathrm{b}} = \mathrm{Min}\begin{cases} \dfrac{f_{\mathrm{yp}}}{f_{\mathrm{y}}} \\ 1{,}0 \end{cases}$$

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

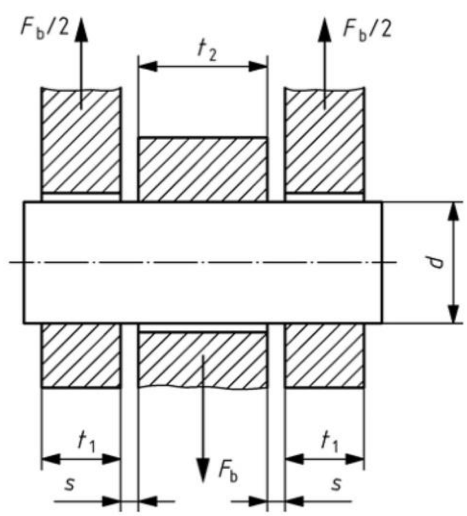


Figure 5 — Pinned connections

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:

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

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)

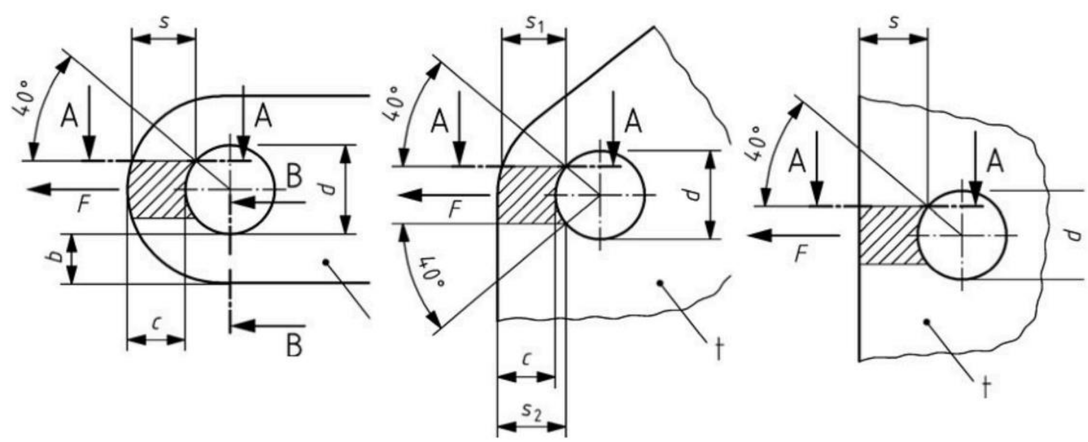
where

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.



a) type I **b) type II** **c) type III**

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:

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

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;
- 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≤ c/b ≤2 and 0,5 ≤ b/d ≤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.

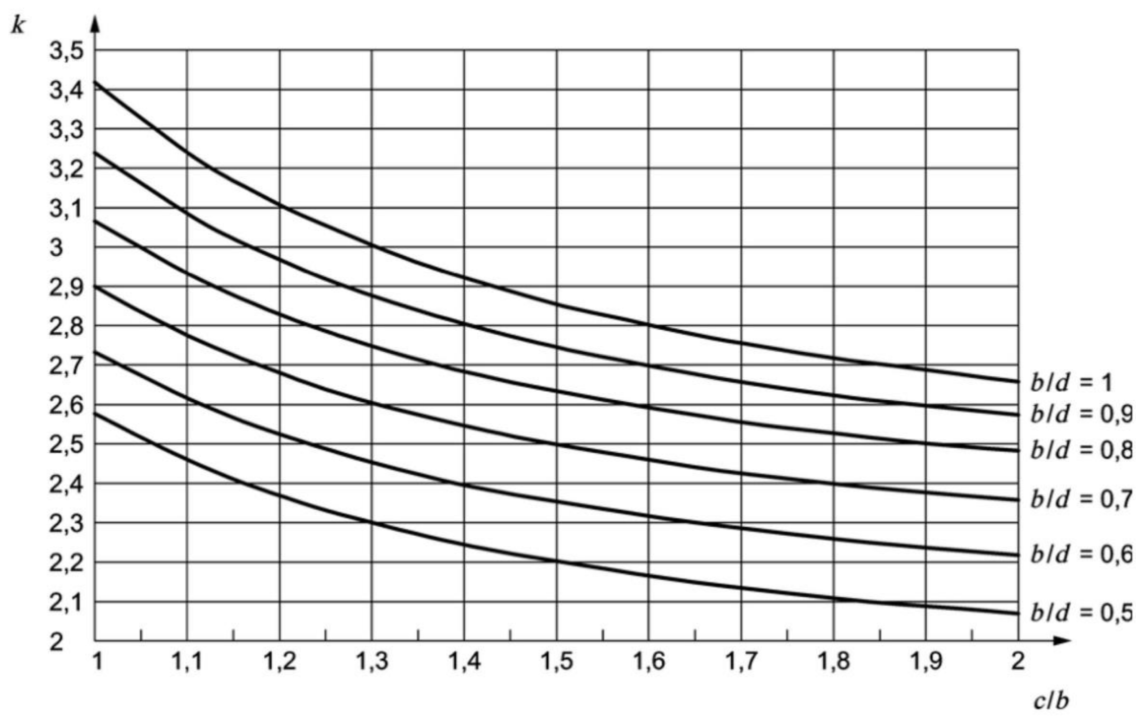


Figure 7 — Stress concentration factors for a specific type of pinned connection

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:

$$f_{w,Rd,1} = \frac{f_{yw}}{\gamma_m} \tag{21}$$

$$f_{w,Rd,2} = \frac{f_y}{\gamma_m} \tag{22}$$

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);
- γ_m is the general resistance factor.

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

5.3.1 Proof for structural members

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

$$\sigma_{Sd} \le f_{Rd\sigma} \text{ and } \tau_{Sd} \le f_{Rd\tau} \tag{23}$$

where

- σ_{Sd}, τ_{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:

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

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:

$$F_{Sd} \leq F_{Rd} \tag{25}$$

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:

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

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;

$F_{vt,Rd}$ is the limit design tensile force of the connected part in accordance with 5.2.4.5.

As a conservative assumption in the absence of a more detailed analysis the following formula shall be used:

$$M_{Sd} = \frac{F_b}{8} \times \left(2 \times t_1 + t_2 + 4 \times s\right) \tag{27}$$

where

F_b, t_1, t_2 and s are as shown in Figure 5.

5.3.4 Proof for welded connections

5.3.4.1 General

The design resistance of a weld shall be determined using either the general method given in 5.3.4.2 or a simplified method given in 5.3.4.3.

The proof of the connected members, in accordance with 5.3.1 is always required in addition to the proof of the weld, in accordance with this 5.3.4. In case of connected members from different materials, the proof shall be made for each member separately.

For full penetration butt welds, the proof of static strength of the weld is not necessary, in case of matching weld material.

5.3.4.2 General method

The design stresses shall be calculated in accordance with Annex C (normative).

For the weld to be designed, it shall be proven that:

$$\sqrt{\sigma_\perp^2 + 3 \times \left(\tau_\perp^2 + \tau_{||}^2\right)} \leq f_{w,Rd,1} \text{ and } \sigma_\perp \leq f_{w,Rd,2} \tag{28}$$

where

$\sigma_\perp$ is the normal stress perpendicular to the throat;

$\tau_\perp$ is the shear stress (in the plane of the throat) perpendicular to the axis of the weld;

$\tau_{||}$ is the shear stress (in the plane of the throat) parallel to the axis of the weld;

$f_{w,Rd,1}$ is the limit design weld stress with respect to the weld material;

$f_{w,Rd,2}$ is the limit design weld stress with respect to the material of the connected members.

5.3.4.3 Simplified method

Alternatively, to 5.3.4.2, with a conservative method considering that the weld is loaded only by shear stress, it shall be proven that:

$$\frac{F \times \sqrt{3}}{s_r \times l_r} \leq f_{w,Rd,1} \tag{29}$$

where

F is the force transferred by the weld, whatever the direction;

s_r is the effective throat thickness, see normative Annex C;

l_r is the effective length of the weld, see normative Annex C.

6 Proof of fatigue strength

A proof of fatigue strength is intended to prevent risk of failure due to formation and propagation of critical cracks in structural members or connections under cyclic loading.

In general, the proof shall be executed by applying the load combinations A in accordance with EN 13001-2:2021, setting all partial safety factors $\gamma_p = 1$, and applying the limit design stresses according to 6.2. In some applications a load from load combinations B (occasional loads) can occur frequently enough to require inclusion in the fatigue assessment. The stresses from these occasional loads shall be handled in the same way as those from the regular loads.

The fatigue assessment of the detail under consideration shall be made using one of these methods:

— the nominal stress method, see 6.2.3;

— the geometric stress (hot spot) method, see 6.2.4;

— the effective notch method, see 6.2.5.

The nominal stress method considers stresses in the base material adjacent to a potential crack location, calculated in accordance with the theory of elasticity, but not including any stress concentrations, as the stress concentrations are instead included in the notch cases on the resistance side. The geometric stress method considers local stress concentration effects due to the geometry in the vicinity of a weld by including this in the calculated stress. The effective notch method in addition also includes the effect of the weld geometry itself in the calculated stress. The geometric stress method or the effective notch method requires a finite element modelling.

NOTE For further information, see [11], [25], [26] and [27].

As alternative to the characteristic fatigue strengths given in 6.2.4 or in Annexes D (normative), Annex H (normative) and Annex I (normative), the characteristic fatigue strength shall be established by fatigue testing in accordance with 6.2.6 or taken from other recognized sources that adhere to the same principle as described in this clause.

For the execution of the proof of fatigue strength, the cumulative damages caused by variable stress cycles shall be calculated. In this document, the Palmgren-Miner's rule of linear cumulative damage is reflected by use of the stress history parameters (see 6.3).

Mean-stress influence (see [44]) in structures in as-welded condition (without stress relieving) can be considered but is negligible. Therefore, the stress history parameter s is considered to be independent of the mean-stress and the fatigue strength is based on the stress range only.

The fatigue strength specific resistance factor γ_{mf} (given in Table 8) is applied to take into account the uncertainty of fatigue strength values and the possible consequences of fatigue damage. The factor can be specified individually for each detail.

Table 8 — Fatigue strength specific resistance factor γ_{mf}

Accessibility for inspection	Fail-safe detail	Non-fail-safe detail	
		without hazards for persons [b]	with hazards for persons
Detail accessible without disassembly	1,0	1,05	1,15
Detail accessible by disassembly	1,05	1,10	1,20
Non-accessible detail	N/A [a]	1,15	1,25

Fail-safe structural details are those where fatigue cracks do not lead to global failure of the crane or dropping of the load.

Cranes working in protected areas with no access to persons are considered to be without hazards to persons.

Disassembly means that components shall be taken apart or dismounted.

A detail is considered to be accessible without disassembly also in cases, where a crack is initiated inside of a closed structure but accessible for detection from outside.

[a] Non-accessible details shall not be considered to be fail-safe.

[b] If a risk coefficient $\gamma_n \geq 1,2$ is applied, this column may be applied to any non-fail-safe detail.

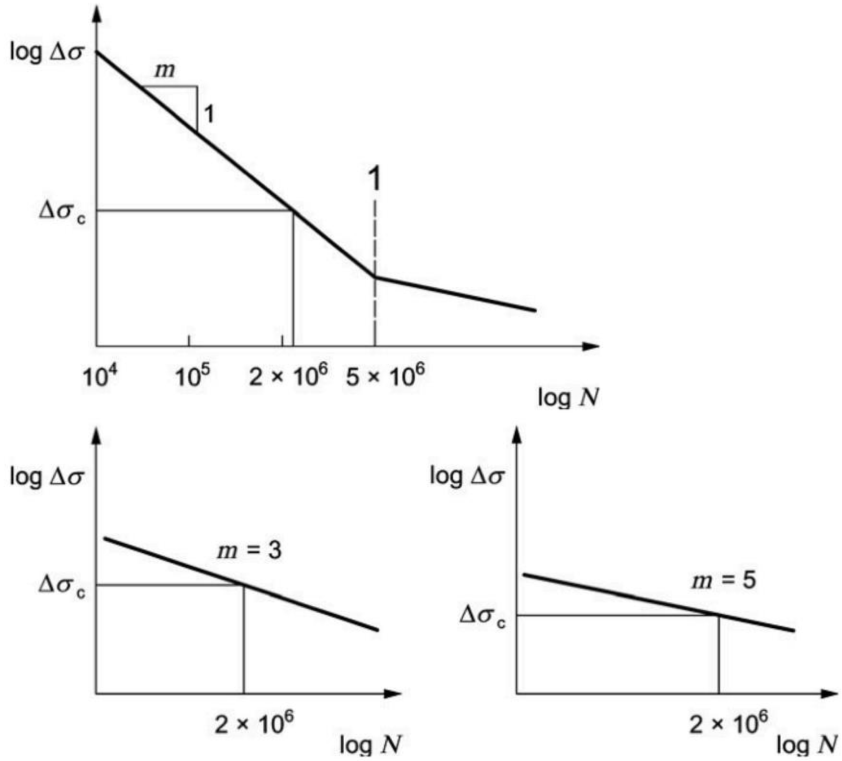
Pinned connections are considered in the proof of fatigue strength as structural members. Any additional notch effect (e.g. welds, holes) in the vicinity of the hole shall be taken into account, e.g. by using the stress concentration factor *k* given in 5.2.4.5.

6.2.1 Characteristic fatigue strength

The limit design stress of a constructional detail is characterized by the value of $\Delta\sigma_c$, the characteristic fatigue strength. $\Delta\sigma_c$ represents the fatigue strength at 2×10^6 cycles under constant stress range loading and with a probability of survival equal to $P_s = 97,7\%$ (mean value minus two standard deviations obtained by normal distribution and single sided test), see Figure 8.

a)

b)



Key

a) principle

b) simplification using one value for m (see [44])

1 Constant stress range fatigue limit

m is the slope constant of the fatigue strength curve. The curves have slopes of $-1/m$ in the log/log representation.

This document is based on the use of stress history parameter s_m which requires the use of the one slope simplification of the $\log \Delta\sigma - \log N$ curve as shown in Figure 8b). Other methods are indicated in the bibliography.

Figure 8 — Illustration of $\Delta\sigma$ -N curve and $\Delta\sigma_c$

6.2.2 Weld quality

$\Delta\sigma_c$-values in Annex D (normative) and Annex H (normative) depend on the quality level of the weld. Quality levels B, C, D shall be in accordance with EN ISO 5817:2023. In Annex H (normative) level C is assumed. Lower quality than level D shall not be used. Additionally, where high fatigue resistance is needed, quality levels C and B shall meet the requirements for C63 and B90 respectively in Table B.1 of EN ISO 5817:2023.

Where post treatment [31], e.g. TIG dressing, peening or grinding, of the potential crack initialization zone of a welded joint is used to increase the fatigue strength, welds of quality level C for design purposes may be upgraded to quality level B for any joint configuration.

For the purposes of this document, an additional quality level B* can be used. The requirements in addition to those of level B given hereafter specify quality level B*.

Additional requirements for quality level B*:

For butt joints:

— full penetration without initial (start and stop) points;

— both surfaces machined or flush ground down to plate surface with grinding in stress direction, or alternatively, the weld toe post-treated by grinding, remelting by TIG [31], plasma welding or by needle peening so that any undercut and slag inclusions are removed;

— linear misalignment of the joining plates less than 5 % of the greater thickness of the two plates;

— sum of lengths of root concavities and shrinkage grooves of weld less than 5 % of the total length of the weld;

— 100 % NDT: VT together with UT or RT and with MT or PT in accordance with EN ISO 17635:2016.

For parallel and lap joints (e.g. with fillet welds):

— weld toe angle of the weld to the plate surface shall exceed 155°;

— the weld toe post-treated by grinding, remelting by TIG, plasma welding or by needle peening;

— 100 % NDT: VT together with MT or PT in accordance with EN ISO 17635:2016.

All other joints:

— full penetration;

— weld toe angle of the weld to the plate surface shall exceed 155°;

— the weld toe post-treated by grinding, remelting by TIG, plasma welding or by needle peening;

— 100 % NDT: VT together with MT or PT in accordance with EN ISO 17635:2016;

— linear misalignment less than 10 % of the greater thickness of the two plates.

6.2.3 Nominal stress method

In the Annex E (normative) the values of $\Delta\sigma_c$ are arranged in a sequence of notch classes (NC) and with the constant ratio of 1,125 between contiguous classes.

For shear stresses $\Delta\sigma_c$ is replaced by $\Delta\tau_c$.

The values of characteristic fatigue strength $\Delta\sigma_c$ or $\Delta\tau_c$ and the related slope constants m of the $\log\Delta\sigma - \log N$ -curve are given in Annex D (normative) and Annex H (normative) for:

Table D.1: Basic material of structural members;

Table D.2: Elements of non-welded connections;

Table D.3: Welded members;

Table H.1: Values of slope constant m of the $\log\Delta\sigma - \log N$ -curve and limit design stress range $\Delta\sigma_c$ for connections and joints of hollow section girders;

Table H.2: Values of slope constant m of the $\log\Delta\sigma - \log N$ -curve and limit design stress range $\Delta\sigma_c$ for lattice type connections of hollow section girders.

The given values apply for the specified basic conditions. For deviating conditions as specified in Annex D (normative), a notch class (NC) shall be selected one or more notch classes above (+1 NC, +2 NC, ...) to increase the resistance or below (-1 NC, -2 NC, ...) the basic notch class to decrease the resistance according to Annex D (normative). The effects of several deviating conditions shall be added up.

6.2.4 Geometric stress method

The geometric stress (hot spot) method can be used to assess the fatigue strength with respect to stresses normal to the weld toe and for potential cracks originating from the weld toe. Where this method is used, characteristic fatigue strengths for different notch cases shall be taken from Table I.1 of Annex I (normative). The Wöhler slope $m = 3$ shall be used for all notch cases.

6.2.5 Effective notch method

The effective notch method can be used to assess the fatigue strength with respect to stresses normal to the weld and for potential cracks originating both from the root and the weld toe. The effective notch radius and characteristic fatigue strength shall be in accordance with Table I.3. The Wöhler slope shall be $m = 3$ for all cases. See [25] for selection of notch radius.

6.2.6 Requirements for fatigue testing for the nominal stress method

Details not given or deviating from those in Annex D (normative) and Annex H (normative) or considering mean stress influence may be assigned $\Delta\sigma_c$ and m by tests.

Requirements for such tests are:

— test specimen representing the constructional detail in actual size (1:1), e.g. material thickness, geometry, weld and loading;

— test specimen produced under workshop conditions;

— the stress cycles shall be completely in the tensile range;

— at least 7 tests per stress range level.

Requirements for determination of m and $\Delta\sigma_c$ are:

— $\Delta\sigma_c$ shall be determined from numbers of cycles based on mean value of $\log(N)$ minus two standard deviations of $\log(N)$ in a log–log presentation;

— at least one stress range level that results in a mean number of stress cycles to failure between 1×10^4 and 1×10^5 cycles shall be used;

— at least one stress range level that results in a mean number of stress cycles to failure over 5×10^5 cycles shall be used.

When applying an alternative method using one stress level for the determination of $\Delta\sigma_c$, the following shall apply:

— m shall be set to $m = 3$;

— a stress range level that results in a mean number of stress cycles to failure of less than 1×10^5 cycles shall be used.

6.3.1 General

The stress history is a numerical presentation of all stress variations that are significant for fatigue. Using the established rules of metal fatigue, the large number of variable magnitude stress cycles are condensed to one or two parameters. Stress histories shall be determined either through stress calculations or measurements, in both cases simulating the specified crane use.

Stress histories shall be represented in terms of maximum stress amplitudes and frequencies of occurrence of stress amplitudes. The methods and formulae described hereafter are shown for normal stresses, but apply also to shear stresses.

6.3.2 Frequency of occurrence of stress cycles

For the proof of fatigue strength, stress histories are expressed as single-parameter representations of frequencies of occurrence of stress ranges by using methods such as the hysteresis counting method (Rainflow or Reservoir method).

Each of the stress ranges shall be described by its upper and lower extreme value.

$$\Delta\sigma = \sigma_u - \sigma_b \tag{30}$$

where

σ_u is the upper extreme value of a stress range;

σ_b is the lower extreme value of a stress range;

$\Delta\sigma$ is the stress range

6.3.3 Stress history parameter

Stress history parameter s_m shall be calculated as follows, based on a one-parameter presentation of stress histories during the design life of the crane:

$$s_m = v \times k_m \tag{31}$$

where

$$k_{\mathrm{m}} = \sum_i \left[\frac{\Delta\sigma_i}{\Delta\hat{\sigma}}\right]^m \times \frac{n_i}{N_{\mathrm{t}}} \tag{32}$$

$$v = \frac{N_t}{N_{ref}} \tag{33}$$

where

v is the relative total number of occurrences of stress ranges;

k_m is the stress spectrum factor dependant on m;

$\Delta\sigma_i$ is the stress range i ;

$\Delta\hat{\sigma}$ the maximum stress range;

n_i is the number of occurrences of stress range i ;

$N_t = \sum_i n_i$ is the total number of occurrences of stress ranges during the design life of the crane;

$N_{ref} = 2 \times 10^6$ is the reference number of cycles;

m is the slope constant of the $\log \Delta\sigma - \log N$ -curve of the component under consideration.

Stress history parameter s_m has specific values for different points in a structural component. These values are related to crane duty and decisively depend on:

— the number of working cycles;

— the net load spectrum;

— crane configuration;

— the effect of the crane motions on stress variations (traverse, slewing, luffing, etc).

For thermally stress relieved or non-welded structural members the compressive portion of the stress range may be reduced to 60 %.

Stress histories characterized by the same value of s_m are assumed to be equivalent in respect to the damage in similar materials, details or components.

Proof of competence for fatigue may be omitted for structural members in cases, where the value of the stress history parameter is lower than 0,001 and the yield stress is 500 N/mm^2 or lower.

Where the design stress always is purely compressive in a uniaxial stress state, and hence crack propagation cannot occur, a proof of fatigue strength is not required for compressive stresses, however the stresses in the shear plane shall be taken into account.

NOTE An example for the determination of stress histories by simulation is given in an Annex F (informative).

6.3.4 Stress history classes *S*

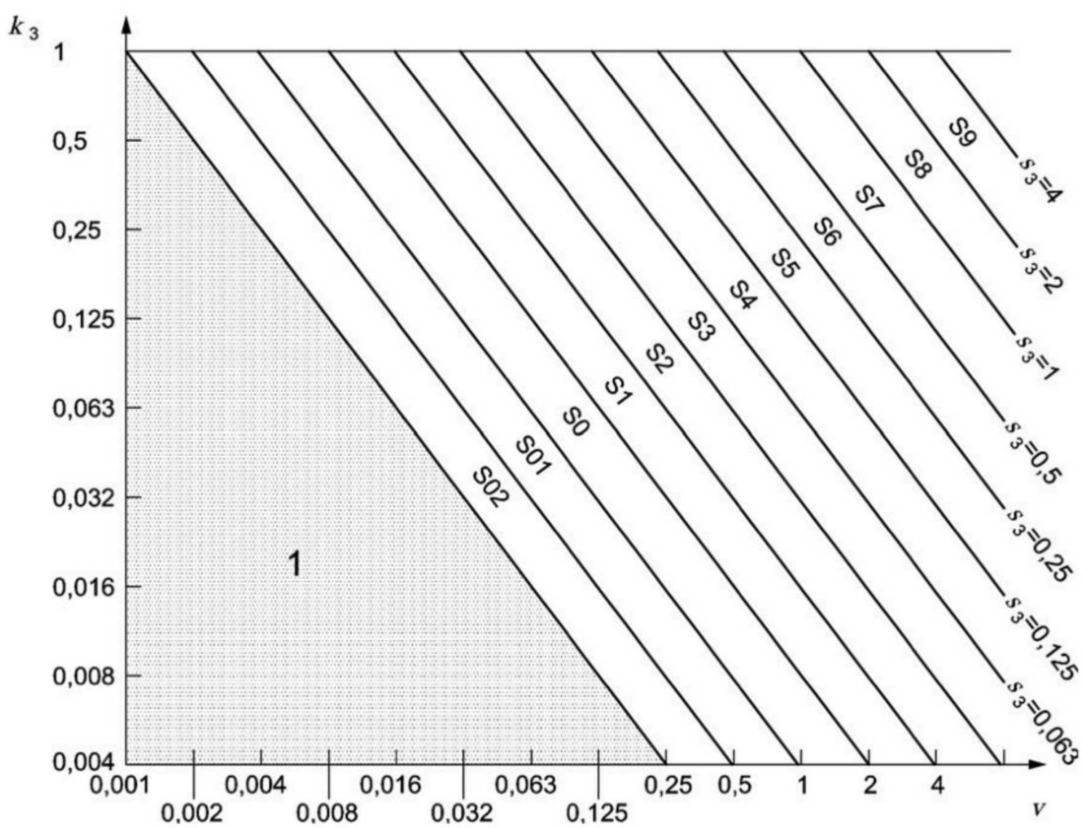
Members of crane structures can be arranged into classes *S* of the stress history parameter s_m. The classification is based upon $m = 3$ and is specified in Table 9 and illustrated in the Figure 9.

Where a class *S* is referred to in the proof of fatigue strength of a member, the value of stress history parameter s_3 shall be taken in accordance with the Table 10.

Where a single stress history class *S* is used for the calculation of the whole structure, the most severe class occurring within the structure shall be used.

Table 9 — Classes *S* of stress history parameter s_3

Class	Stress history parameter s_3
*S*02	$0,001 < s_3 \leq 0,002$
*S*01	$0,002 < s_3 \leq 0,004$
*S*0	$0,004 < s_3 \leq 0,008$
*S*1	$0,008 < s_3 \leq 0,016$
*S*2	$0,016 < s_3 \leq 0,032$
*S*3	$0,032 < s_3 \leq 0,063$
*S*4	$0,063 < s_3 \leq 0,125$
*S*5	$0,125 < s_3 \leq 0,250$
*S*6	$0,250 < s_3 \leq 0,500$
*S*7	$0,500 < s_3 \leq 1,000$
*S*8	$1,000 < s_3 \leq 2,000$
*S*9	$2,000 < s_3 \leq 4,000$



Key

1 fatigue assessment might not be required

k_3 is the stress spectrum factor based on m = 3

ν is the relative total number of occurrences of stress range

Figure 9 — Illustration of the classification of stress history parameter s for m = 3

The diagonal lines for the class limits represent the k_3 to v relationship for s_m = constant in a log/log scale diagram.

For the detail under consideration it shall be proven that:

$$\Delta\sigma_{Sd} \leq \Delta\sigma_{Rd} \tag{34}$$

$$\Delta\sigma_{Sd} = \max\sigma - \min\sigma \tag{35}$$

where

$\Delta\sigma_{Sd}$	is the maximum range of design stresses, the same value that is used for $\Delta\hat{\sigma}$ in 6.3.3;
$\max\sigma$, $\min\sigma$	are the extreme values of design stresses (compression stresses with negative sign);
$\Delta\sigma_{Rd}$	is the limit design stress range.

Shear stresses τ are treated similarly.

For each stress component σ_x, σ_y and τ the proof shall be executed separately (where *x,y* indicate the orthogonal directions of stresses), In case of non welded details, if the normal and shear stresses induced by the same loading event vary simultaneously, or if the plane of the maximum principal stress does not change in the course of a loading event, the maximum principal stress range may be used instead.

6.5.1 Applicable methods

The limit design stress ranges $\Delta\sigma_{Rd}$ for the detail under consideration shall be determined either by direct use of stress history parameter s_m or by simplified method based on the use of class S.

6.5.2 Direct use of stress history parameter

The limit design stress range shall be calculated from:

$$\Delta\sigma_{Rd} = \frac{\Delta\sigma_c}{\gamma_{mf} \times \sqrt[m]{s_m}} \tag{36}$$

where

Δo_{Rd}	is the limit design stress range;
$\Delta\sigma_c$	is the characteristic fatigue strength (see Annex D (normative) and Annex H (normative));
m	is the slope constant of the $\log\Delta\sigma - \log N$ curve (see Annex D (normative) and Annex H (normative));
γ_{mf}	is the fatigue strength specific resistance factor (see Table 8);
s_m	is the stress history parameter.

6.5.3 Use of class *S*

6.5.3.1 Slope constant *m*

When the detail under consideration is related to a class *S* according to 6.3, the simplified determination of the limit design stress range is dependent on the (negative inverse) slope constant m of the $\log \Delta\sigma - \log N$ -curve.

6.5.3.2 Slope constant *m* = 3

Values of stress history parameter s_3 corresponding to individual stress history classes S shall be selected according to Table 10.

Table 10 — Values of s_3 for stress history classes S

Class	*S02*	*S01*	*S0*	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*
s_3	0,002	0,004	0,008	0,016	0,032	0,063	0,125	0,25	0,5	1,0	2,0	4,0
NOTE Values of stress history parameter s_3 shown above are the upper limit values of ranges shown in Table 9.												

The limit design stress range shall be calculated from:

$$\Delta\sigma_{Rd} = \frac{\Delta\sigma_c}{\gamma_{mf} \times \sqrt[3]{s_3}} \tag{37}$$

where

$\Delta\sigma_{Rd}$ is the limit design stress range;

$\Delta\sigma_c$ is the characteristic fatigue strength of details with $m = 3$ (see Annex D);

s_3 is the classified stress history parameter (see Table 10);

γ_{mf} is the fatigue strength specific resistance factor (see Table 8).

6.5.3.3 Slope constant *m* ≠ 3

If the slope constant m of the $\log \Delta\sigma - \log N$ curve is not equal to 3, the limit design stress range is dependent on the class *S* and the stress spectrum factor k_m.

The limit design stress range $\Delta\sigma_{Rd}$ shall be calculated from:

$$\Delta\sigma_{Rd} = \Delta\sigma_{Rd,1} \times k^* \tag{38}$$

$$\Delta\sigma_{Rd,1} = \frac{\Delta\sigma_c}{\gamma_{mf} \times \sqrt[m]{s_3}} \tag{39}$$

$$k^* = \sqrt[m]{\frac{k_3}{k_m}} \geq 1 \tag{40}$$

where

$\Delta\sigma_{Rd}$	is the limit design stress range;
$\Delta\sigma_{Rd,1}$	is the limit design stress range for $k^* = 1$;
k^*	is the specific spectrum ratio factor;
$\Delta\sigma_c$ and m	are the characteristic values of stress range and the respective inverse slope of the $\log \Delta\sigma - \log N$ -curve (see Annex D (normative) and Annex H (normative));
s_3	is the classified stress history parameter (see Table 10);
γ_{mf}	is the fatigue strength specific resistance factor (see Table 8);
k_3	is the stress spectrum factor based on $m = 3$;
k_m	is the stress spectrum factor based on m of the detail under consideration;
k_3 and k_m	shall be based on the same stress spectrum that is derived either from calculation or simulation.

6.5.3.4 Simplified method for slope constants $m \neq 3$

$k^* = 1$ covers the most unfavourable stress spectra for cases with $m > 3$ and $s_m < 1$ and $\Delta\sigma_{Rd,1}$ shall then be used as limit design stress range. Alternatively, the value of k^* shall be calculated from k_3 and k_m taken from stress spectra obtained from tests.

6.5.4 Combined effect of normal and shear stresses

In addition to the separate proofs for σ and τ (see 6.4), the combined fatigue effect of concurrent normal and shear stresses in a detail shall be taken into account by:

$$\left(\frac{\Delta\sigma_{\mathrm{Sd}}}{\Delta\sigma_{\mathrm{Rd}}}\right)^2 + \left(\frac{\Delta\tau_{\mathrm{Sd}}}{\Delta\tau_{\mathrm{Rd}}}\right)^2 \leq 1,0 \qquad (41)$$

where

$\Delta\sigma_{\mathrm{Sd}}$, $\Delta\tau_{\mathrm{Sd}}$	are the calculated maximum ranges of design stresses;
$\Delta\sigma_{\mathrm{Rd}}$, $\Delta\tau_{\mathrm{Rd}}$	are the limit design stress ranges, see Formula (37);
σ	indicates the normal stress;
τ	indicates the respective shear stress.

The proof shall be done separately for the two normal stresses acting in orthogonal directions.

7 Proof of static strength of hollow section girder joints

The proof shall be executed in accordance with Clause 7 of EN 1993-1-8:2024.

8 Proof of elastic stability

The proof of elastic stability is made to prove that ideally straight structural members or components will not lose their stability due to lateral deformation caused solely by compressive forces or compressive stresses. Deformations due to compressive forces or compressive stresses in combination with externally applied bending moments, or in combination with bending moments caused by initial geometric imperfections, shall be assessed by the theory of second order as part of the proof of static strength. This chapter covers global buckling of members under compression, lateral-torsional buckling of beams, and local buckling of plate fields subjected to compressive stresses.

NOTE Other phenomena of elastic instability not dealt with in 8.2 and 8.3 exist and might occur, e.g. buckling of cylindrical shells.

Further information can be found in the Bibliography.

8.2.1 Critical buckling load

The critical buckling load N_{k} is the smallest bifurcation load according to elastic theory. For members with constant cross section, N_{k} is given in Table 11 for a selection of boundary conditions, also known as Euler's buckling cases.

Table 11 — Critical buckling load N_k for Euler's buckling cases

Euler case no	1	2	3	4	5
Boundary conditions					
N_k	$\frac{\pi^2 \times E \times I}{4 \times L^2}$	$\frac{\pi^2 \times E \times I}{L^2}$	$\frac{2,05 \times \pi^2 \times E \times I}{L^2}$	$\frac{4 \times \pi^2 \times E \times I}{L^2}$	$\frac{\pi^2 \times E \times I}{L^2}$

Key

E is the modulus of elasticity;

I is the moment of inertia of the member in the plane of the figure;

L is the length of the member.

For other boundary conditions or for members consisting of several parts i, with different cross sections, N_k can be found in the bibliography or can be computed from the differential equation, or system of differential equations, of the elastic deflection curve in its deformed state, which has the general solution:

$$y = A_i \times \cos\left(k_i \times x\right) + B_i \times \sin\left(k_i \times x\right) + C_i \times x + D_i, \quad k_i = \sqrt{\frac{N}{E \times I_i}} \tag{42}$$

where

x	is the longitudinal coordinate;
y	is the lateral coordinate in the weakest direction of the member;
E	is the modulus of elasticity;
I_i	is the moment of inertia of part i in the weakest direction of the member;
N	is the compressive force;
A_i, B_i, C_i, D_i	are constants to be found by applying the boundary conditions.

The critical buckling load N_k shall be the smallest positive value N that satisfies Formula (42), or system of Formula (42), when solved with the boundary conditions applied.

8.2.2 Limit compressive design force

The limit compressive design force N_{Rd} for the member or its considered part shall be computed from the critical buckling load N_k by:

$$N_{Rd} = \frac{\kappa \times f_y \times A}{\gamma_m} \tag{43}$$

where

κ	is a reduction factor;
f_y	is the yield stress;
A	is the cross section area of the member.

The reduction factor κ shall be computed from the slenderness λ, which is given by:

$$\lambda = \sqrt{\frac{f_y \times A}{N_k}} \tag{44}$$

where

N_k is the critical buckling load according to 8.2.1.

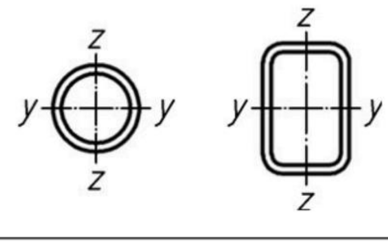
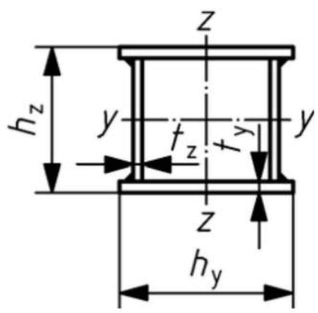
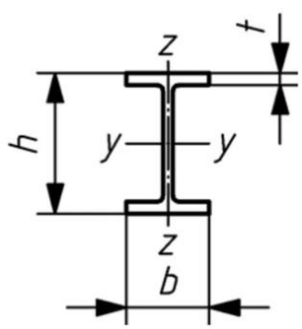
Depending on the value of λ and the cross section parameter α, the reduction factor κ shall be calculated from:

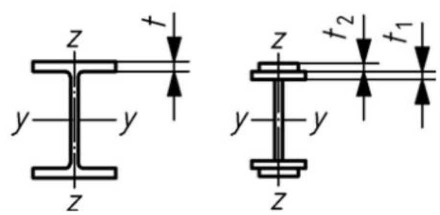
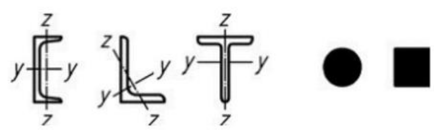
$$\lambda \le 0,2: \quad K = 1,0$$

$$0,2 < \lambda \qquad K = \frac{1}{\xi + \sqrt{\xi^2 - \lambda^2}} \qquad \xi = 0,5 \times \left[1 + \alpha \times \left(\lambda - 0,2\right) + \lambda^2\right] \tag{45}$$

Depending of the type of cross section, the parameter α shall be taken from Table 12.

Table 12 — Parameter α and acceptable bow imperfections for various cross sections

	Type of cross section		**Buckling about axis**	$f_y < 460 \frac{N}{mm^2}$		$f_y \geq 460 \frac{N}{mm^2}$	
				α	δ_1	α	δ_1
1	Hollow sections 	Hot rolled	$y-y$ $z-z$	0,21	$L/300$	0,13	$L/300$
		Cold formed	$y-y$ $z-z$	0,34	$L/250$	0,34	$L/250$
2	Welded box sections 	Thick welds (a > t_y/2) and $h_y / t_y < 30$ $h_z / t_z < 30$	$y-y$ $z-z$	0,49	$L/200$	0,49	$L/200$
		Otherwise	$y-y$ $z-z$	0,34	$L/250$	0,34	$L/250$
3	Rolled sections 	$h / b > 1,2$ $t \leq 40$mm	$y-y$ $z-z$	0,21 0,34	$L/300$ $L/250$	0,13 0,13	$L/350$ $L/350$
		$h / b > 1,2$ 40mm $< t \leq$ 80mm $h / b > 1,2$ $t \leq$ 80mm	$y-y$ $z-z$	0,34 0,49	$L/250$ $L/200$	0,21 0,21	$L/300$ $L/300$
		$t > 80mm$	$y-y$ $z-z$	0,76	$L/150$	0,49	$L/200$

	Type of cross section		Buckling about axis	$f_y < 460 \frac{N}{mm^2}$		$f_y \geq 460 \frac{N}{mm^2}$	
				α	δ_1	α	δ_1
4	Welded I sections 	$t_i \leq 40mm$	$y-y$ $z-z$	0,34 0,49	$L/250$ $L/200$	0,34 0,49	$L/250$ $L/200$
		$t_i > 40mm$	$y-y$ $z-z$	0,49 0,76	$L/200$ $L/150$	0,49 0,76	$L/200$ $L/150$
5	Channels, L, T and solid sections 		$y-y$ $z-z$	0,49	$L/200$	0,49	$L/200$

δ_1 is the maximum allowable amplitude of initial bow imperfection measured over the total length of the member (i.e. equivalent geometric imperfection that covers the effects of residual stresses and real geometrical imperfections).

L is the length of the member.

In case of a member with varying cross section, the formulae in 8.2.2 shall be applied to all parts of the member. The smallest resulting value of N_{Rd} shall be used, and in addition it shall be conform to the following:

$$N_{Rd} \leq \frac{N_k}{1{,}2 \times \gamma_m} \tag{46}$$

8.3.1 General

Plate fields are unstiffened plates that are supported only along their edges or plate panels between stiffeners.

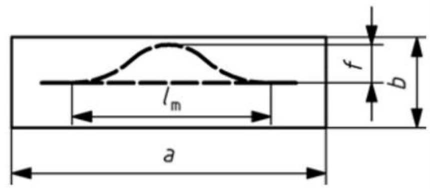
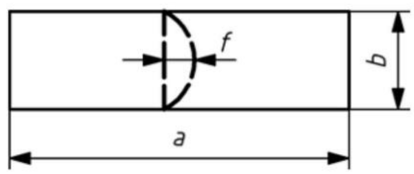
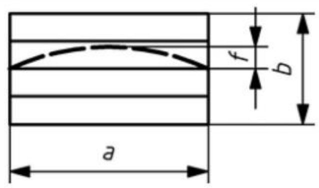
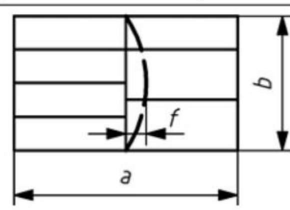
The limit design stresses provided by this clause do not consider post buckling behaviour. The following conditions shall be fulfilled:

— geometric imperfections of the plate shall be less than the maximum values shown in Table 13,

— stiffeners shall be designed with stiffness and strength that allow the required buckling resistance of the plate to be developed (i.e. buckling strength of stiffeners is greater than that of the plate field),

— the plate field shall be supported along its edges as shown in Table 13.

Table 13 — Maximum allowable imperfection f for plates and stiffeners

Item	Type of stiffness		Illustration	Allowable imperfection f
1	Unstiffened plates	General		$f = \dfrac{l_m}{250}$ $l_m = a$, where $a \le 2b$ $l_m = 2b$ where $a > 2b$
2		Subject to transverse compression		$f = \dfrac{l_m}{250}$ $l_m = b$, where $b \le 2a$ $l_m = 2a$, where $b > 2a$
3	Longitudinal stiffeners in plates with longitudinal stiffening			$f = \dfrac{a}{400}$
4	Transverse stiffeners in plates with longitudinal and transverse stiffening			$f = \dfrac{a}{400}$ $f = \dfrac{b}{400}$

f shall be measured in the perpendicular plane.

l_m is the gauge length.

Figure 10 shows a plate field with dimensions a and b (side ratio α = a/b). It is subjected to longitudinal stress varying between σ_x (maximum compressive stress) and $\psi \times \sigma_x$ along its end edges, coexistent shear stress τ and with coexistent transverse stress σ_y,(e.g. from wheel load, see C.4) applied on one side only.

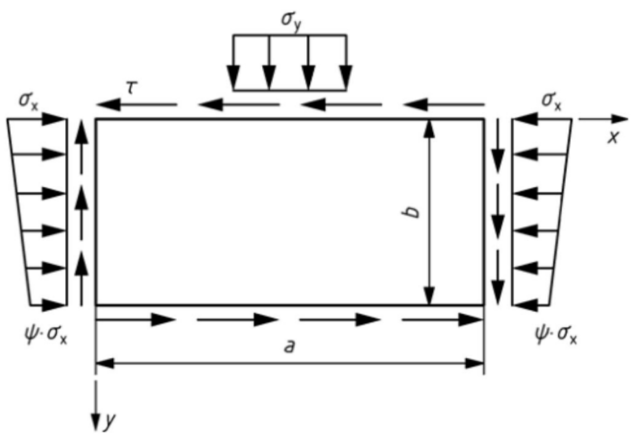


Figure 10 — Stresses applied to plate field

8.3.2 Limit design stress with respect to longitudinal stress σ_x

The limit design compressive stress $f_{b,Rd,x}$ shall be calculated from:

$$f_{b,Rd,x} = \frac{\kappa_x \times f_y}{\gamma_m} \tag{47}$$

where

κ_x is a reduction factor according to Formula (48);

f_y is the yield stress of the plate material.

The reduction factor κ_x shall be calculated from:

$$\begin{aligned} &\kappa_x = 1{,}05 && \text{for} && \lambda_x \le 0{,}635 \\ &\kappa_x = 1{,}474 - 0{,}677 \times \lambda_x && \text{for} && 0{,}635 < \lambda_x < 1{,}26 \\ &\kappa_x = \frac{1}{\lambda_x^2} && \text{for} && \lambda_x \ge 1{,}26 \end{aligned} \tag{48}$$

where

λ_x is a non-dimensional plate slenderness according to Formula (49);

The non-dimensional plate slenderness λ_x shall be calculated from:

$$\lambda_x = \sqrt{\frac{f_y}{k_{\sigma x} \times \sigma_e}} \tag{49}$$

where

σ_e is a reference stress according to Formula (50);

$k_{\sigma x}$ is a buckling factor given in Table 14.

The reference stress σ_e shall be calculated from:

$$\sigma_e = \frac{\pi^2 \times E}{12 \times \left(1 - \nu^2\right)} \times \left(\frac{t}{b}\right)^2 \tag{50}$$

where

E is the modulus of elasticity of the plate;

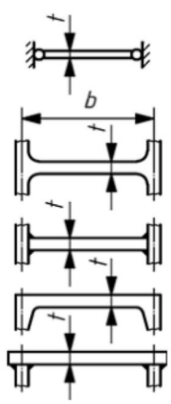
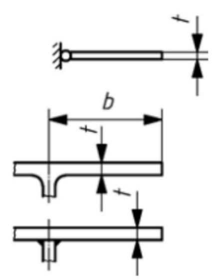
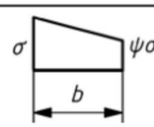
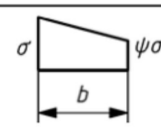
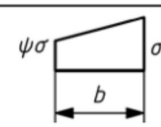
ν is the Poisson's ratio of the plate ($\nu = 0{,}3$ for steel);

t is the plate thickness;

b is the width of the plate field.

The buckling factor $k_{\sigma x}$ depends on the edge stress ratio ψ, the side ratio α and the edge support conditions of the plate field. Table 14 gives values for the buckling factor $k_{\sigma x}$ for plate fields supported along both transverse and longitudinal edges (Case 1) and plate fields supported along both transverse edges but only along one longitudinal edge (Case 2).

Table 14 — Buckling factor $k_{\sigma x}$

<table>
<tr><th></th><th></th><th>Case 1</th><th colspan="2">Case 2</th></tr>
<tr><td>1</td><td>Type of support</td><td>Supported along all four edges
</td><td colspan="2">Supported along both loaded (end) edges and along only one longitudinal edge.
</td></tr>
<tr><td>2</td><td>Stress distribution</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>$\psi = 1$</td><td>4</td><td colspan="2">0,43</td></tr>
<tr><td>4</td><td>$1 > \psi > 0$</td><td>$\frac{8{,}2}{\psi + 1{,}05}$</td><td>$\frac{0{,}578}{\psi + 0{,}34}$</td><td>$0{,}57 - 0{,}21\psi + 0{,}07\psi^2$</td></tr>
<tr><td>5</td><td>$\psi = 0$</td><td>7,81</td><td>1,70</td><td>0,57</td></tr>
<tr><td>6</td><td>$0 > \psi > -1$</td><td>$7{,}81 - 6{,}29\psi + 9{,}78\psi^2$</td><td>$1{,}70 - 5\psi + 17{,}1\psi^2$</td><td>$0{,}57 - 0{,}21\psi + 0{,}07\psi^2$</td></tr>
<tr><td>7</td><td>$\psi = -1$</td><td>23,9</td><td>23,8</td><td>0,85</td></tr>
<tr><td>8</td><td>$\psi < -1$</td><td>$5{,}98 \times (1-\psi)^2$</td><td>23,8</td><td>$0{,}57 - 0{,}21\psi + 0{,}07\psi^2$</td></tr>
</table>

For Case 1, the values and formulae for buckling factors $k_{\sigma x}$ given in Table 14 for plate fields supported along all four edges can give overly conservative results for plate fields (see Figure 10 for α) with $\alpha < 1{,}0$ for rows 3 to 6 and $\alpha < 0{,}66$ for row 7. For Case 2, the results can be overly conservative for plate fields with $\alpha < 2{,}0$. Further information regarding alternative values for short plate fields can be found in additional references, see Bibliography.

8.3.3 Limit design stress with respect to transverse stress σ_y

The limit design transversal normal stress shall be calculated from:

$$f_{b,\mathrm{Rd},y} = \frac{\kappa_y \times f_y}{\gamma_m} \tag{51}$$

κ_y is a reduction factor according to Formula (52);

f_y is the minimum yield stress of the plate material.

The reduction factor κ_y shall be calculated from:

$$\begin{aligned} \kappa_y &= 1{,}05 && \text{for} && \lambda_y \le 0{,}635 \\ \kappa_y &= 1{,}474 - 0{,}677 \times \lambda_y && \text{for} && 0{,}635 < \lambda_y < 1{,}26 \\ \kappa_y &= \frac{1}{\lambda_y^2} && \text{for} && \lambda_y \ge 1{,}26 \end{aligned} \tag{52}$$

The non-dimensional plate slenderness λ_y shall be calculated from:

$$\lambda_y = \sqrt{\frac{f_y}{k_{\sigma y} \times \sigma_e \times \frac{a}{c}}} \tag{53}$$

where

σ_e is a reference stress according to Formula (50);

$k_{\sigma y}$ is a buckling factor determined using Figure 11;

a is the plate field length;

c is the width over which the transverse load is distributed ($c = 0$ corresponds to a theoretical point load in Figure 11, see C.3).

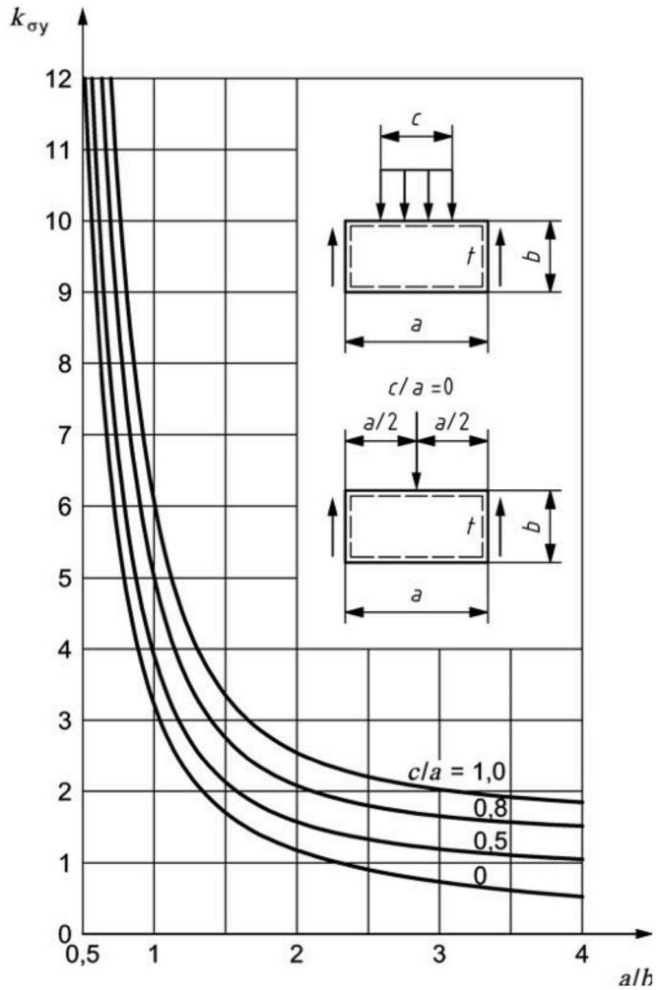


Figure 11 — Buckling factor $k_{\sigma y}$

8.3.4 Limit design stress with respect to shear stress τ

The limit design buckling shear stress shall be calculated from:

$$f_{b,\mathrm{Rd},\tau} = \frac{\kappa_\tau \times f_y}{\sqrt{3} \times \gamma_m} \tag{54}$$

where

κ_τ is a reduction factor that shall be calculated from:

$$\kappa_\tau = \frac{0,84}{\lambda_\tau} \text{ for } \lambda_\tau \geq 0,84 \tag{55}$$

$$\kappa_\tau = 1 \text{ for } \lambda_\tau < 0,84$$

where

$$\lambda_{\tau} = \sqrt{\frac{f_y}{k_{\tau} \times \sigma_e \times \sqrt{3}}} \tag{56}$$

f_{yk} is the minimum yield strength of the plate material;

σ_e is a reference stress according to Formula (50);

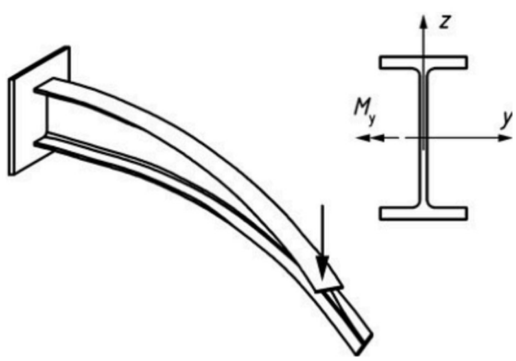
k_{τ} is a buckling factor calculated (for a plate field supported along all four edges) using formulae given in Table 15.

Table 15 — Buckling factor k_{τ}

α	k_{τ}
α > 1	$k_{\tau} = 5{,}34 + \frac{4}{\alpha^2}$
α ≤ 1	$k_{\tau} = 4 + \frac{5{,}34}{\alpha^2}$

8.4.1 General

Lateral-torsional buckling instability occurs in beams bent about their major axis y and is characterized by the beam undergoing a combination of large displacements in lateral direction y and torsion about its longitudinal axis x in addition to a primary flexural deflection in its major bending plane x-z; see Figure 12.



Key

y is the principal axis for larger moment of inertia

z is the principal axis for smaller moment of inertia.

M_y is the bending moment around axis for larger moment of inertia

Figure 12 — Simply supported beam

The instability affects mostly beams of open sections. However, their susceptibility to the instability can be suppressed by a provision of restraints e.g. at ends of beams or to their compression flange. Beams with certain types of other cross-sections, such as hollow sections (rolled or fabricated circular tubes, rectangular or square box sections) are not susceptible to lateral-torsional buckling.

8.4.2 Limit design moment for lateral-torsional buckling

The limit design resistance moment for lateral-torsional buckling $M_{Rd,LT}$ of a laterally unrestrained beam shall be calculated from:

$$M_{Rd,LT} = \frac{\chi_{LT} \times W_y \times f_y}{\gamma_m} \tag{57}$$

where

W_y is the section modulus about y-axis of beam cross-section;

χ_{LT} is the reduction factor for lateral-torsional buckling (see 8.4.3);

f_y is the minimum value of the yield stress of the beam material;

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

8.4.3 Reduction factor for lateral-torsional buckling – General case

For beam members with open sections (rolled or equivalent welded sections – the latter being welded sections of similar size and proportions to standard rolled sections), the value of χ_{LT}, the reduction factor for lateral-torsional buckling shall be calculated from:

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \overline{\lambda_{LT}}^2}} \tag{58}$$

where

$$\Phi_{LT} = 0,5 \times \left(1 + \alpha_{LT} \times \left(\overline{\lambda_{LT}} - 0,2\right) + \overline{\lambda_{LT}}^2\right) \tag{59}$$

Φ_{LT} is a variable required in the calculation of the reduction factor for lateral-torsional stability $\chi_{LT\alpha}$;

α_{LT} is an imperfection factor, see Table 16 below for recommended values.

A non-dimensional slenderness factor $\bar{\lambda}_{LT}$ shall be calculated from the formula below:

$$\overline{\lambda_{LT}} = \sqrt{\frac{W_y \times f_y}{M_{cr}}} \tag{60}$$

where

W_y is the section modulus about y-axis of beam cross-section;

f_y is the minimum value of the yield stress of the beam material;

M_{cr} is the elastic critical moment for lateral-torsional buckling, (see 8.4.4).

Table 16 — Recommended values for imperfection factors for lateral-torsional buckling

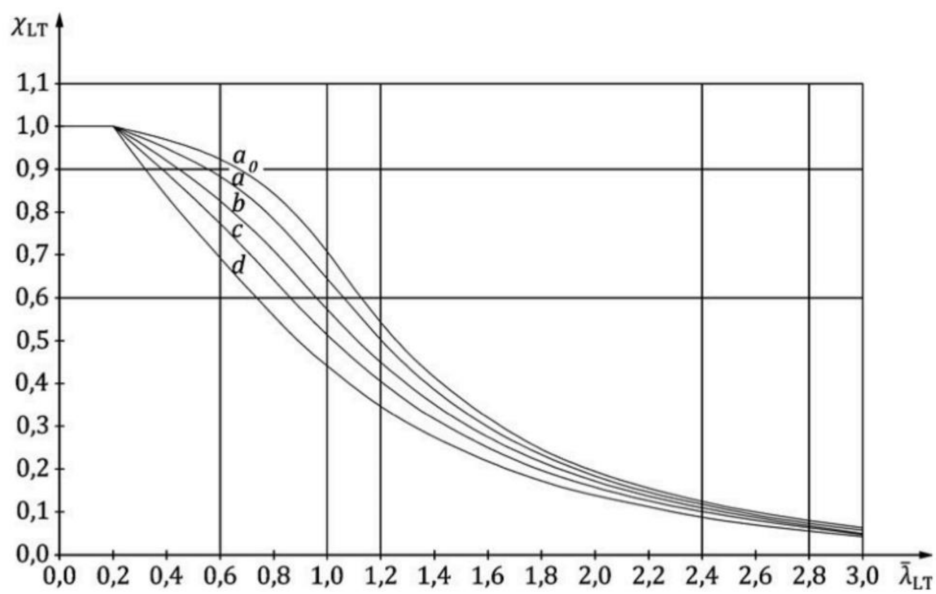
Buckling curve	**a_0**	**a**	**b**	**c**	**d**
Imperfection factor α_{LT}	0,13	0,21	0,34	0,49	0,76

Recommendations for the selection of buckling curves are given in Table 17 below, for I-sections of height h and width b.

Table 17 — Recommended values for lateral-torsional buckling curves according to 8.4.3

Cross-section	**Limits**	**Buckling curve**
Rolled I-sections	$h/b \leq 2$ $h/b > 2$	**a** **b**
Welded I-sections	$h/b \leq 2$ $h/b > 2$	**c** **d**
Other cross-sections	-	**d**

As an alternative to calculating its values from the Formulae (58) to (60), the reduction factor X_{LT} may be obtained from Figure 13, below for the non-dimensional slenderness $\bar{\lambda}_{LT}$ and buckling curve.



Key

χ_{LT}	is the reduction factor
$\bar{\lambda}_{LT}$	is the non-dimensional slenderness factors
a_0, a, b, c, d	see Table 16

Figure 13 — Reduction factor χ_{LT}

A check of lateral-torsional buckling may be omitted for cases with non-dimensional slenderness factors $\bar{\lambda}_{LT} \leq \lambda_{LT,0} = 0,2$.

8.4.4 Critical buckling moment in lateral-torsional buckling

Elastic critical moment M_{cr} is specified as the maximum value of bending moment a beam, free from any type of imperfections, can support without lateral-torsional instability occurring. It plays a fundamental role in the lateral-torsional buckling of beams.

In general, the value of the elastic critical moment M_{cr}^{E} depends upon:

— loading of the beam and its support conditions;

— length between the supports of beam (L);

— lateral bending stiffness of the beam ($E \cdot I_z$);

— torsional stiffness of the beam ($G \cdot I_T$);

— warping stiffness of the beam ($E \cdot I_w$).

For a simple case of a simply supported beam having a double symmetric cross-section, with lateral displacements and rotation around the longitudinal axis (twist rotations) prevented at supports, but with warping and rotations about cross-section axes (y and z) possible and subjected to a uniform bending moment M_y ("standard case", see Figure 14 below), the elastic critical moment M_{cr}^{E} shall be calculated from the formula below:

$$M_{cr}^{E} = \frac{\pi}{L} \times \sqrt{G \times I_T \times E \times I_z \times \left(1 + \frac{\pi^2 \times E \times I_w}{L^2 \times G \times I_T}\right)} \tag{61}$$

where

L is the length between the supports of the beam;

I_z is the second moment of inertia about the major axis of the beam (z-axis);

I_T is the torsional moment of inertia (St Venant type torsion) of the beam;

I_w is the warping constant of the beam;

E is the modulus of elasticity of beam material;

G is the shear modulus of beam material.

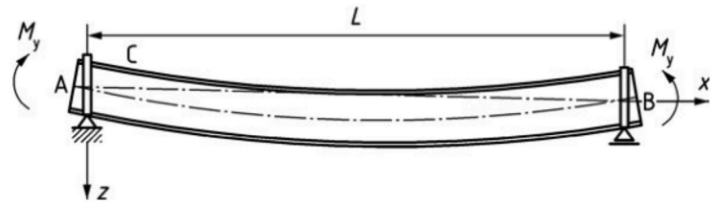


Figure 14 — Simply supported beam

NOTE For other cases of loading, end conditions and restraints, a more general formula for the critical moment is given in Annex J (informative).

Closed form analytical solutions for calculations of elastic critical moments for lateral-torsional buckling are available only for a limited number of cases the case above being one and the simplest one. In general, calculations of critical buckling moments and associated section properties (allowing for warping) by means of traditional methods tend to be complicated and laborious. However, computer software, bespoke or general and Finite Element Analysis packages provide alternatives for these.

8.5.1 Members loaded in compression

For the member under consideration, it shall be proven that:

$$N_{Sd} \leq N_{Rd} \tag{62}$$

where

N_{Sd} is the design value of the compressive force;

N_{Rd} is the limit design compressive force according to 8.2.2.

8.5.2 Plate fields

8.5.2.1 Plate fields subjected to longitudinal or transverse compressive stress

For the plate field under consideration, it shall be proven that:

$$\left|\sigma_{\mathrm{Sd},x}\right| \leq f_{b,Rd,x} \quad \text{and} \quad \left|\sigma_{\mathrm{Sd},y}\right| \leq f_{b,Rd,y} \tag{63}$$

where

$\sigma_{\mathrm{Sd,x}}$, $\sigma_{\mathrm{Sd,y}}$ are the design values of the compressive stresses σ_x or σ_y;

$f_{\mathrm{b,Rd,x}}$, $f_{\mathrm{b,Rd,y}}$ are the limit design compressive stresses in accordance with 8.3.2 and 8.3.3.

8.5.2.2 Plate fields subjected to shear stress

For the plate field under consideration, it shall be proven that:

$$\tau_{Sd} \leq f_{b,Rd,\tau} \tag{64}$$

where

τ_{Sd} is the design value of the shear stress;

$f_{b,Rd,\tau}$ is the limit design shear stress in accordance with 8.3.4.

8.5.2.3 Plate fields subjected to coexistent normal and shear stresses

For the plate field subjected to coexistent normal (longitudinal and/or transverse) and shear stresses, apart from a separate proof carried out for each stress component in accordance with 8.5.2.1 and 8.5.2.2, it shall be additionally proven that:

$$\left(\frac{\left|\sigma_{Sd,x}\right|}{f_{b,Rd,x}}\right)^{e_1}+\left(\frac{\left|\sigma_{Sd,y}\right|}{f_{b,Rd,y}}\right)^{e_2}-V\times\left(\frac{\left|\sigma_{Sd,x}\times\sigma_{Sd,y}\right|}{f_{b,Rd,x}\times f_{b,Rd,y}}\right)+\left(\frac{\left|\tau_{Sd}\right|}{f_{b,Rd,\tau}}\right)^{e_3}\leq 1 \tag{65}$$

where

$$e_1 = 1+\kappa_x^4 \tag{66}$$

$$e_2 = 1+\kappa_y^4 \tag{67}$$

$$e_3 = 1+\kappa_x\times\kappa_y\times\kappa_\tau^2 \tag{68}$$

and with κ_x calculated in accordance with 8.3.2, κ_y in accordance with 8.3.3 and κ_τ in accordance with 8.3.4.

$$V = \left(\kappa_x\times\kappa_y\right)^6 \quad \text{for } \sigma_{Sd,x}\times\sigma_{Sd,y}\geq 0 \tag{69}$$

$$V = -1 \quad \text{for } \sigma_{Sd,x}\times\sigma_{Sd,y}< 0$$

8.5.3 Lateral-torsional stability of beams

For the beam under consideration. It shall be proven that:

$$M_{Sd,LT} < M_{Rd,LT} \tag{70}$$

where

$M_{Sd,LT}$ is the design bending moment for lateral-torsional buckling, determined for the relevant loads, load combinations and partial safety factors, in accordance with EN 13001-2:2021;

$M_{Rd,LT}$ is the limit design value of bending moment for lateral-torsional buckling (see 8.4.2).

Annex A
(informative)

Limit design shear force F per bolt and per shear plane for multiple shear plane connections

Table A.1 and Table A.2 give limit design shear forces in relation to the shank diameter and the bolt material for a selection of bolt grades in accordance with EN ISO 898-1:2013.

Table A.1 — Limit design shear force $F_{v,Rd}$ per fitted bolt and per shear plane for multiple shear plane connections

Fitted bolt	Shank diameter [mm]	$F_{v,Rd}$ [kN] Fitted bolt material for γ_{Rb} = 1,1				
		4.6	**5.6**	**8.8**	**10.9**	**12.9**
M12	13	16,7	20,9	44,6	65,5	76,6
M16	17	28,6	35,7	76,2	112,0	131,0
M20	21	43,5	54,4	120,0	170,9	200,0
M22	23	52,2	65,3	143,9	205,0	239,9
M24	25	61,8	77,3	170,0	242,2	283,4
M27	28	77,6	97,0	213,3	303,8	355,5
M30	31	95,1	118,8	261,5	372,4	435,8

Table A.2 — Limit design shear force $F_{v,Rd}$ in the shank per standard bolt and per shear plane for multiple shear plane connections

Bolt	Shank diameter [mm]	$F_{v,Rd}$ [kN] Bolt material for γ_{Rb} = 1,1				
		4.6	**5.6**	**8.8**	**10.9**	**12.9**
M12	12	14,2	17,8	37,9	55,7	65,2
M16	16	25,3	31,6	67,5	99,1	116,0
M20	20	39,5	49,4	108,8	154,9	181,3
M22	22	47,8	59,8	131,6	187,5	219,4
M24	24	56,9	71,2	156,7	223,1	261,1
M27	27	72,1	90,1	198,3	282,4	330,5
M30	30	89,0	111,3	244,8	348,7	408,1

Annex B
(informative)

Preloaded bolts

B.1 General

Tightening torques and limit design slip forces are given in Tables B.1 and B.2 for a selection of bolt grades in accordance with EN ISO 898-1:2013. Bolt sizes in Tables B.1 and B.2 refer to standard series of ISO metric thread and pitch in accordance with [7].

B.2 Tightening torques

The tightening torque $T_{\mathrm{p,d}}$ to achieve the design preload level $F_{p,d}$ can be calculated with any of both Formulae (B.1) and (B.2) below, based on the formula of [28] and [29].

General tightening torques calculated with the total friction coefficient μ_{tot}:

$$T_{p,d} = F_{p,d} \times \left(\frac{P}{2 \cdot \pi} + \mu_{tot} \times \left(0{,}577 \times d_2 + 0{,}5 \times D_b \right) \right) \tag{B.1}$$

with $D_b = \dfrac{D_o + d_h}{2}$

where

- $F_{p,d}$ is the design preloading force;
- P is the pitch of the thread;
- μ_{tot} is the total friction coefficient (i.e. considering friction both in the thread and between bearing surfaces, see [29]);
- d_2 is the basic pitch diameter of thread;
- D_b diameter of bearing surface under nut or bolt head for friction (theoretical or measured);
- D_o is the outer diameter of bearing surface, d_w min or d_k min;
- d_h is the clearance hole diameter of washer or bearing part (nominal value).

Table B.1 — Tightening torques $T_{p,d}$ in order to achieve the design preload level for $F_{p,d} = 0,7 \times F_y$

Bolt size	Bolt grade 8.8		Bolt grade 10.9		Bolt grade 12.9	
	Total friction coefficient		Total friction coefficient		Total friction coefficient	
	$\mu_{tot} = 0,08$	$\mu_{tot} = 0,14$	$\mu_{tot} = 0,08$	$\mu_{tot} = 0,14$	$\mu_{tot} = 0,08$	$\mu_{tot} = 0,14$
M12	52,2	83,5	76,7	123	90	143
M14	83,1	133	122	196	143	229
M16	126	204	185	300	217	351
M18	183	294	261	419	305	490
M20	254	412	362	586	424	686
M22	344	560	490	797	573	941
M24	438	708	623	1008	729	1179
M27	635	1036	905	1476	1059	1727
M30	868	1411	1236	2010	1447	2352
M33	1162	1900	1655	2706	1937	3166
M36	1502	2448	2139	3487	2503	4081
Hex bolt dimensions are in accordance with either ISO 4014 or ISO 4017. F_y is the bolt yield force, see 5.2.3.3.						

Specific tightening torques for HR and HV bolts in accordance with [32] should be calculates using a k-factor as follows:

$$T_{p,d} = k \times F_{p,d} \times d \tag{B.2}$$

where

k is the k-factor, see [32], provided by the bolt manufacturer or determined by test;

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

d is the nominal bolt diameter.

B.3 Limit design slip force $F_{S,Rd}$

Table B.2 — Limit design slip force $F_{S,Rd}$ per bolt and per friction interface using a design preloading force $F_{p,d} = 0{,}7 \times f_{yb} \times A_s$

Bolt	Stress area A_S mm^2	Design preloading force $F_{p,d}$ in kN Bolt material			Limit design slip force $F_{s,Rd}$ in kN γ_m = 1,1 and γ_{ss} = 1,14 Bolt material											
					8.8 Friction factor:				10.9 Friction factor:				12.9 Friction factor:			
		8.8	**10.9**	**12.9**	**0,50**	**0,40**	**0,30**	**0,20**	**0,50**	**0,40**	**0,30**	**0,20**	**0,50**	**0,40**	**0,30**	**0,20**
M12	84,3	37,8	55,4	64,9	15,1	12,0	9,0	6,0	22,1	17,7	13,3	8,8	25,9	20,7	15,5	10,3
M14	115	51,7	76,0	88,9	20,6	16,5	12,4	8,2	30,3	24,2	18,2	12,1	35,4	28,4	21,3	14,2
M16	157	70,2	103	121	28,0	22,4	16,8	11,2	41,1	32,9	24,7	16,4	48,1	38,5	28,9	19,2
M18	192	88,9	127	148	35,5	28,4	21,3	14,2	50,5	40,4	30,3	20,2	59,1	47,3	35,5	23,6
M20	245	113	161	188	45,1	36,1	27,1	18,0	64,2	51,4	38,5	25,7	75,2	60,1	45,1	30,1
M22	303	140	200	234	55,9	44,7	33,5	22,4	79,6	63,7	47,8	31,8	93,1	74,5	55,9	37,3
M24	353	163	232	271	64,9	51,9	39,0	26,0	92,5	74,0	55,5	37,0	108	86,6	64,9	43,3
M27	459	212	302	354	84,6	67,7	50,8	33,9	121	96,4	72,3	48,2	141	113	84,6	56,4
M30	561	259	369	432	103	82,6	62,0	41,3	147	118	88,2	58,8	172	138	103	68,8
M33	694	320	456	534	128	102	76,7	51,1	182	146	109	72,8	213	170	128	85,2
M36	817	377	537	629	150	120	90,3	60,2	214	171	129	85,7	251	201	150	100

Annex C
(normative)

Design weld stresses

C.1 General method

In this method, the forces transmitted by a weld are successively:

— distributed into both components which directions are parallel and normal to the longitudinal axis of the weld,

— and for each of these components, it may result in shear and normal stresses in the throat section.

This applies to all types of weld.

For the welds under consideration, the total effective throat area A_w shall be determined by:

$$A_w = \sum s_r \times l_r \tag{C.1}$$

where

s_r is the effective throat thickness including penetration in accordance with EN ISO 17659:2004 ($s_r = s_1 + s_2$ for double sided partial penetration welds);

l_r is the effective weld length, in general given by:

$$l_r = l_w - 2 \times s_r \text{ (for continuous welds)} \tag{C.2}$$

unless measures are taken to ensure that the whole weld length is effective, in which case $l_r = l_w$

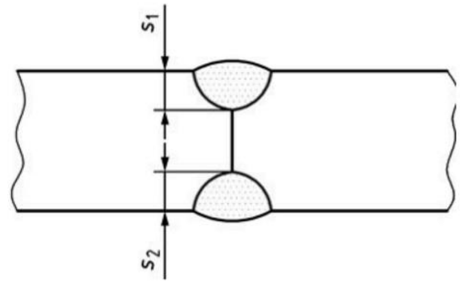
with

l_w is the weld length (see Figure C.2).

Figure C.1 provides some examples of effective throat thickness, for different kinds of welds and joints.

Partial penetration welded from both sides

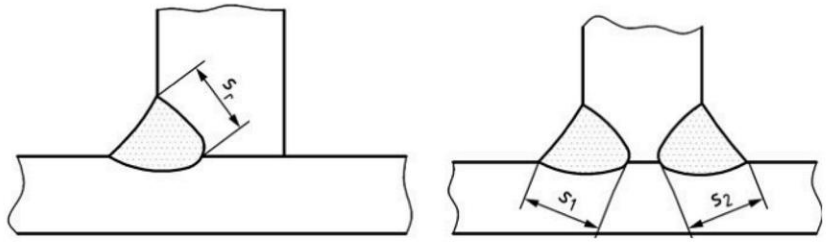
- Butt joint or corner joint



$s_r = s_1+s_2$

Partial penetration weld

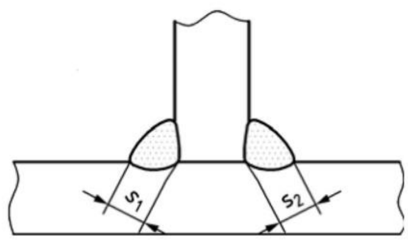
- T joint



$s_r = s_1+s_2$

Fillet weld

- T joint



$s_r = s_1+s_2$

Fillet weld

- Lap joint

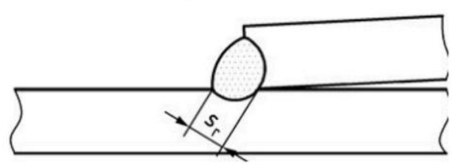
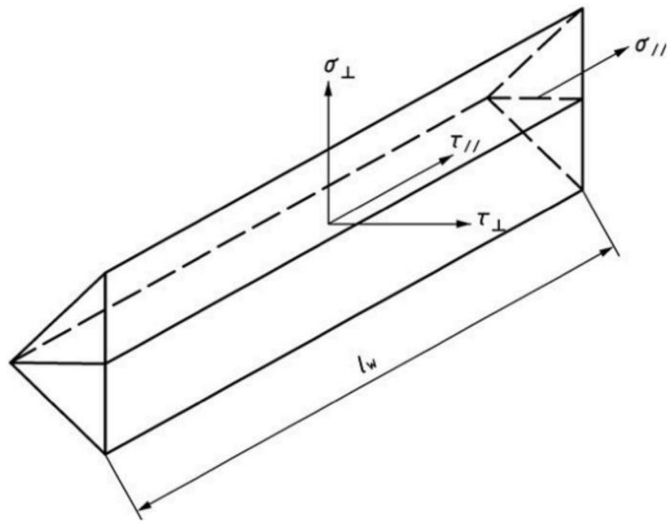


Figure C.1 — Examples of effective throat thickness

A uniform distribution of stress is assumed in the throat section of the weld, leading to the normal stresses and shear stresses shown in Figure C.2.



Key

- $\sigma_{\perp}$ is the normal stress perpendicular to the throat
- $\sigma_{/\!/}$ is the normal stress parallel to the axis of the weld
- $\tau_{\perp}$ is the shear stress (in the plane of the throat) perpendicular to the axis of the weld
- $\tau_{/\!/}$ is the shear stress (in the plane of the throat) parallel to the axis of the weld

Figure C.2 — Stresses in the throat of a fillet weld

The welds joining parts of built-up members, e.g. flange-to-web connections, may be designed without regard to normal stress parallel $\sigma_{/\!/}$ to the axis of the weld, provided either the welds are proportioned to accommodate the shear forces developed between those parts, or the welds cross-section is negligible compared to the entire built-up member cross-section.

C.2 Simple examples

For the case of butt joint submitted to a force perpendicular to the weld presented in the Figure C.3, the distribution of stress leads to the following formula and results:

$$\sigma \perp = \frac{F_{\sigma}}{A_w} = \frac{F_{\sigma}}{s_r \cdot l_r}, F_{\tau} = 0, \tau_{/\!/} = \sigma_{/\!/} = 0 \tag{C.3}$$

NOTE Single sided partial penetration butt welds with transverse loads are not covered by this document.

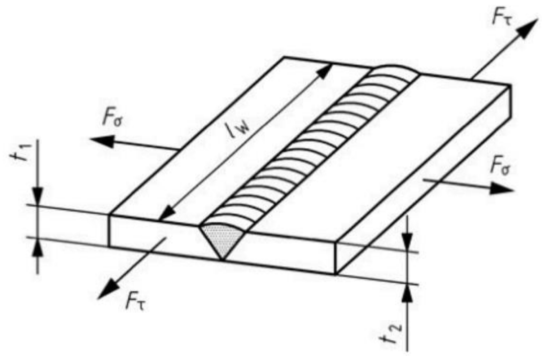


Figure C.3 — Butt joint

For the case of a T joint submitted to a force along the axis presented in the Figure C.4, the distribution of stress leads to the following formula and results:

$$\sigma \perp = \tau \perp = \frac{F}{\sqrt{2} \times A_w} = \frac{F}{\sqrt{2} \times s_r \times l_w} \tag{C.4}$$

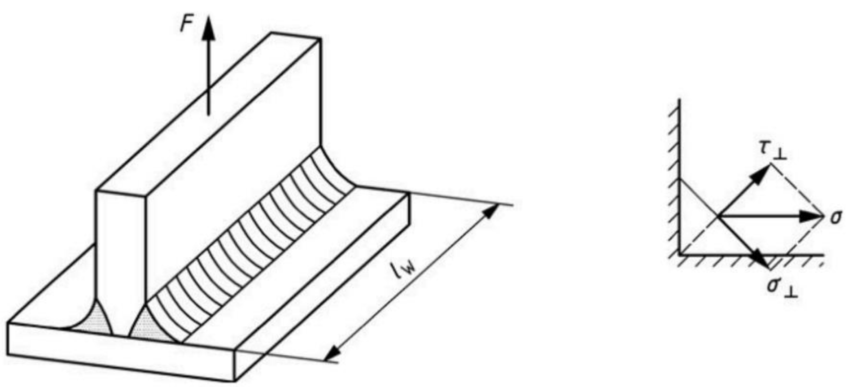


Figure C.4 — Fillet weld and distribution of stresses

C.3 Reduction factor for long welds

Although the distribution of stresses along the length of the weld might be non-uniform, such distributions can, for the purposes of this document, generally be considered to be uniform with the following restrictions:

— For long lap and T joints which are shear stressed, the design resistance of the fillet welds shall be reduced to take into account the evolution of stress since a minimum value at their middle to a maximum one at their extremities,

— This reduction can be obtained by multiplying the design resistance by a reduction factor β_{lw}.

For this kind of joints longer than 150 times the effective throat thickness s_r, the reduction factor β_{lw} multiplying the total effective throat area A_w shall be calculated by the following formula:

$$\beta_{lw} = 1{,}2 - \frac{0{,}2 \times l_r}{150 \times s_r} \geq 0{,}6 \tag{C.5}$$

where

l_r is the effective length of the weld.

This provision concerning the reduction factor β_{lw} does not apply when the stress distribution along the weld corresponds to the stress distribution in the adjacent base metal, as, for example, in the case of a weld connecting the flange and the web of a plate girder.

C.4 Effective distribution length under concentrated load

For simplification, the normal design stresses in the weld and parent material under concentrated load, from e.g. a wheel as shown in Figure C.5, shall be calculated using the effective distribution length as follows:

$$l_r = 2 \times h_d \times \tan K + \lambda \tag{C.6}$$

where

l_r is the effective distribution length;

h_d is the distance between the section under consideration and contact level of acting load;

λ is the length of the contact area.

For wheels λ shall be set to: $\lambda = 0{,}2 \times r$ with $\lambda_{\max} = 50mm$

where

r is the radius of wheel;

κ is the dispersion angle. κ shall be set to $\kappa \leq 45^\circ$.

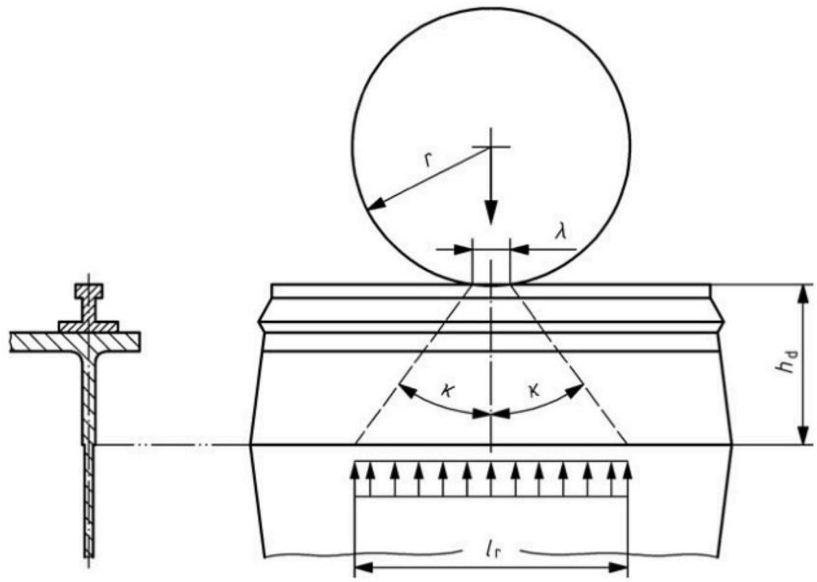


Figure C.5 — Concentrated load

Alternatively, the more advanced method given in EN 1993-6:2007, Table 5.1 [45] with l_r taken as l_{eff}, may be applied.

The values for $\Delta\sigma_c$ and $\Delta\tau_c$ in Annex D (normative) are based on the calculation presented herein.

C.5 Other types of welds

The design stresses, $\sigma_{W,Sd}$ and $\tau_{W,Sd}$ for other types of welds (e.g. circular welds) shall be calculated from the stress components as specified in C.1 to C.3.

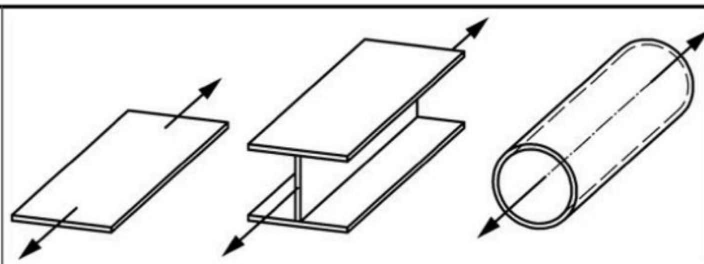
Annex D
(normative)

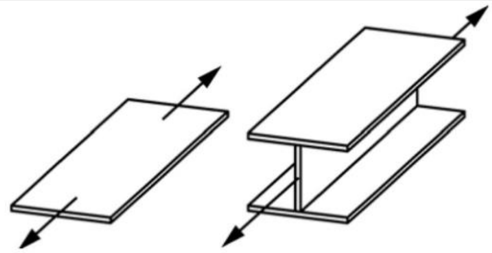
Values of slope constant m and characteristic fatigue strength $\Delta\sigma$, $\Delta\tau$

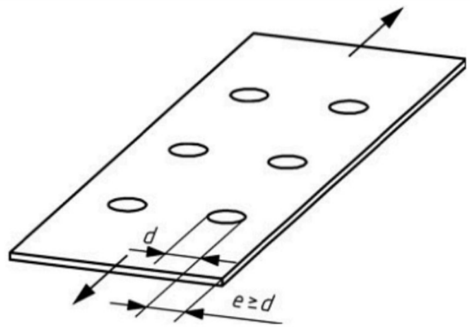
Where low strength steel is used, the fatigue strength for basic material as shown in Table D.1 can be governing even in the presence of other details such as those shown in Tables D.2 and D.3. This can be not only due to the effect of different values of $\Delta\sigma_c$ but also due to the different values of the slope constant m.

Notch classes (NC) refer to Annex E (normative) (see 6.2.3).

Table D.1 — Basic material of structural members

Detail No.	Constructional detail					Requirements
1.1	m = 5	 Plates, flat bars, rolled profiles under normal stresses				General requirements: — Rolled surfaces — No geometrical notch effects (e.g. cut outs)
	$\Delta\sigma_c$ MPa					
		– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or D3 – Edges machined or no free edges		– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or C3 – Edges rolled or machined or no free edges – Any burrs and flashes removed from rolled edges		Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A1 or C1 (repair welding allowed)
	Plate surface roughness	Rz ≤ 20 µm	20 < Rz ≤ 40 µm	40 < Rz ≤ 60 µm	60 < Rz ≤ 100 µm	—
	$180 \le f_y \le 220$	**180**	**160**	**160**	**140**	**140**
	$220 < f_y \le 320$	**200**	**180**	**180**	**160**	
	$320 < f_y \le 500$	**225**	**200**	**200**	**180**	
	$500 < f_y \le 650$	**250**	**225**	**225**	**200**	
	$650 < f_y \le 900$	**280**	**250**	**225**	**200**	
	$900 < f_y$	**315**	**280**	**225**	**200**	

<table>
<tr><th>Detail No.</th><th colspan="5">Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="11">1.2</td><td>m = 5</td><td colspan="4">
Edges in plates, flat bars, rolled profiles under normal stresses</td><td>General requirements:
– Rolled surfaces
– Thermal cut edges
– No geometrical notch effects (e.g. cutouts)</td></tr>
<tr><td colspan="6">$\Delta\sigma_c$ MPa</td></tr>
<tr><td></td><td colspan="2">– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or D3
– Mill scale removed before cutting
– Machine controlled cutting</td><td colspan="2">– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or C3
– Machine controlled cutting</td><td>Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A1 or C1 (repair welding allowed)</td></tr>
<tr><td>Edge quality in accordance with Table 5 of EN ISO 9013:2017</td><td>Range 1</td><td>Range 2</td><td colspan="2">Range 3</td><td>Range 4</td></tr>
<tr><td>Plate surface roughness</td><td>Rz ≤ 20 µm</td><td>20 < Rz ≤ 40 µm</td><td>40 < Rz ≤ 60 µm</td><td>60 < Rz ≤ 100 µm</td><td>—</td></tr>
<tr><td>$180 \le f_y \le 220$</td><td>160</td><td>160</td><td>160</td><td>140</td><td rowspan="6">140</td></tr>
<tr><td>$220 < f_y \le 320$</td><td>180</td><td>180</td><td>180</td><td>160</td></tr>
<tr><td>$320 < f_y \le 500$</td><td>200</td><td>180</td><td>180</td><td>160</td></tr>
<tr><td>$500 < f_y \le 650$</td><td>225</td><td>200</td><td>200</td><td>180</td></tr>
<tr><td>$650 < f_y \le 900$</td><td>250</td><td>225</td><td>200</td><td>180</td></tr>
<tr><td>$900 < f_y$</td><td>280</td><td>250</td><td>200</td><td>180</td></tr>
</table>

<table>
<tr><th>Detail No.</th><th>$\Delta\sigma_c$
MPa</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="7">1.3</td><td>m = 5</td><td>

Hole edges in a plate under normal stresses</td><td>General requirements:
— Nominal stress calculated for the net cross-section
— Holes not flame cut,
— Bolts may be present as long as these are stressed to no more than 20 % of their strength in shear/ bearing connections or to no more than 100 % of their strength in slip-resistant connections</td></tr>
<tr><td>80</td><td>Independent of f_y</td><td>— Holes may be punched</td></tr>
<tr><td>100</td><td>$180 < f_y \leq 220$</td><td rowspan="5">— Holes machines or thermal cut to a quality in accordance with Table 5 Range 3 of EN ISO 9013:2017
— Holes not punched
— Burr on hole edges removed
— Rolled surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or C3
— Plate surface roughness $Rz \leq 100 \mu m$</td></tr>
<tr><td>112</td><td>$220 < f_y \leq 320$</td></tr>
<tr><td>125</td><td>$320 < f_y \leq 500$</td></tr>
<tr><td>140</td><td>$500 < f_y \leq 650$</td></tr>
<tr><td>160</td><td>$650 < f_y$</td></tr>
</table>

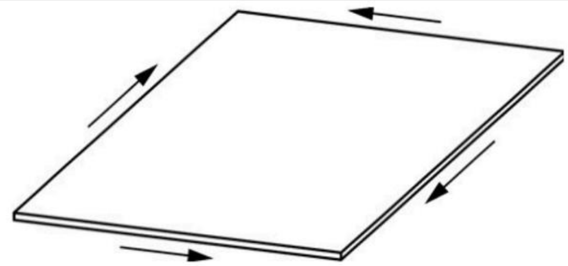
<table>
<tr><th>Detail No.</th><th colspan="4">Constructional detail</th><th colspan="2">Requirements</th></tr>
<tr><td rowspan="11">1.4</td><td>m = 5</td><td colspan="3">
Plates, flat bars, rolled profiles under shear stress</td><td colspan="2">General requirements:
– Rolled surfaces
– No geometrical notch effects (e.g. cutouts)
– Surface roughness value before surface treatment such as shot blasting</td></tr>
<tr><td colspan="6">$\Delta\tau_c$ MPa</td></tr>
<tr><td rowspan="2"></td><td colspan="2">– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or D3</td><td colspan="2">– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A3 or C3
– Any burrs and flashes removed from rolled edges</td><td>– Surface condition in accordance with EN 10163-1:2004, EN 10163-2:2004 and EN 10163-3:2004, classes A1 or C1 (repair welding allowed)</td></tr>
<tr><td colspan="2">– Edges machined or no free edges</td><td colspan="2">– Edges rolled or machined or no free edges</td><td>—</td></tr>
<tr><td>Plate surface roughness</td><td>Rz ≤ 20 µm</td><td>20 < Rz ≤ 40 µm</td><td>40 < Rz ≤ 60 µm</td><td>60 < Rz ≤ 100 µm</td><td>—</td></tr>
<tr><td>$180 \leq f_y \leq 220$</td><td>112</td><td>100</td><td>100</td><td>90</td><td rowspan="6">90</td></tr>
<tr><td>$220 < f_y \leq 320$</td><td>125</td><td>112</td><td>112</td><td>100</td></tr>
<tr><td>$320 < f_y \leq 500$</td><td>140</td><td>125</td><td>125</td><td>112</td></tr>
<tr><td>$500 < f_y \leq 650$</td><td>160</td><td>140</td><td>140</td><td>125</td></tr>
<tr><td>$650 < f_y \leq 900$</td><td>180</td><td>160</td><td>140</td><td>125</td></tr>
<tr><td>$900 < f_y$</td><td>200</td><td>180</td><td>140</td><td>125</td></tr>
</table>

Table D.2 — Elements of non-welded connections

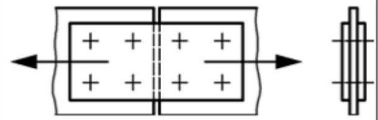
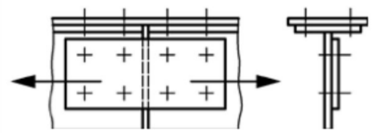
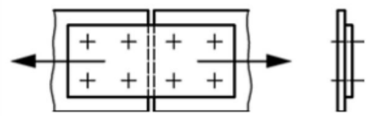
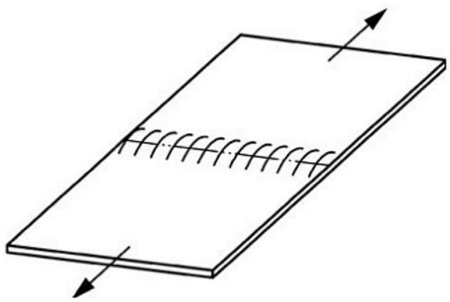
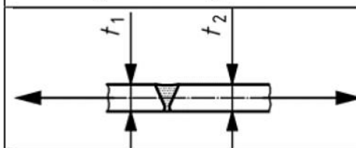
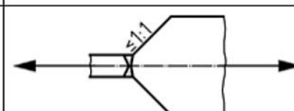
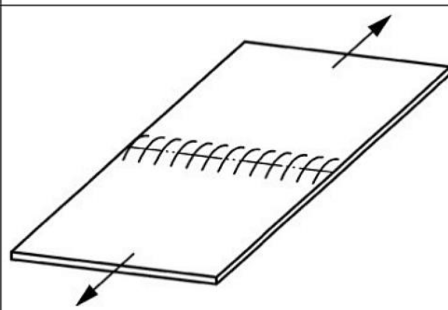
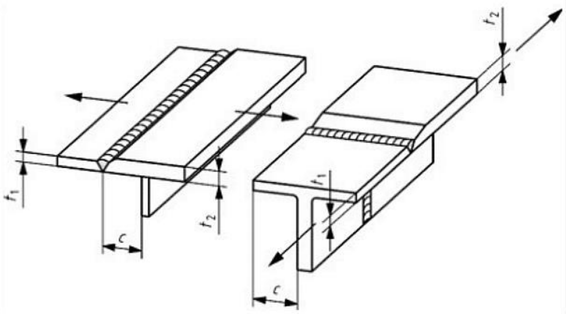
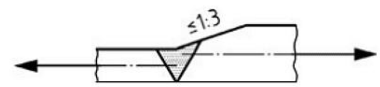
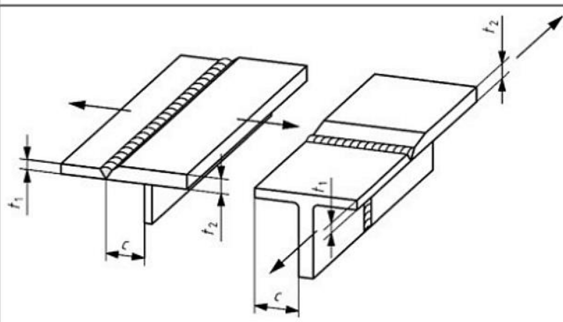
Detail No.	$\Delta\sigma_c$ MPa	Constructional **detail**		**Requirements**
2.1	m = 5	Double shear		— The proof of fatigue strength is not required for bolts of friction grip type bolted connections — Nominal stress calculated for the net cross-section
		Supported single-shear (example)		
		Single-shear		
		Perforated parts in slip-resistant bolted connections under normal stresses		
	160	$f_y \le 275$		
	180	$275 < f_y$		
2.2	m = 5	Perforated parts in shear/bearing connections under normal stresses double-shear and supported single-shear		— Nominal stress calculated for the net cross-section
	180	Normal stress		
2.3	m = 5	Perforated parts in shear/bearing connections under normal stresses single-shear joints, not supported		— Nominal stress calculated for the net cross-section
	125	Normal stress		
2.4	m = 5	Fit bolts in double-shear or supported single-shear joints		— Uniform distribution of stresses is assumed
	125	Shear stress ($\Delta\tau_c$)		
	355	Bearing stress ($\Delta\sigma_c$)		
2.5	m = 5	Fit bolts in single-shear joints, not supported		— Uniform distribution of stresses is assumed
	100	Shear stress ($\Delta\tau_c$)		
	250	Bearing stress ($\Delta\sigma_c$)		
2.6	m = 3	Threaded bolts loaded in tension (bolt grade 8.8 or better)		— $\Delta\sigma$ calculated for the stress-area of the bolt, using ΔF_b (see 5.2.3.3)
	50	Machined thread		
	63	Rolled thread above M30		
	71	Rolled thread for M30 or smaller		

Table D.3 — Welded members

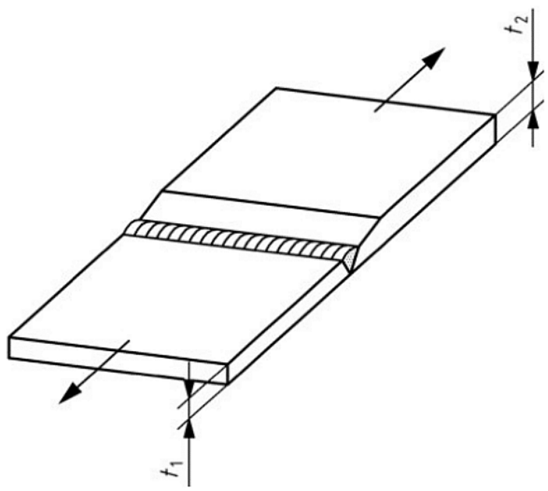
<table>
<tr><th>Detail No.</th><th>$\Delta\sigma_c$
MPa</th><th>Constructional detail</th><th colspan="2">Requirements</th></tr>
<tr><td rowspan="8">3.1</td><td rowspan="5">m = 3</td><td rowspan="5">
Symmetric butt joint, normal stress across the weld</td><td colspan="2">Basic conditions:
— symmetric plate arrangement
— fully penetrated weld
— Components with usual residual stresses
— Angular misalignment < 1°</td></tr>
<tr><td></td><td>$t_1 = t_2$</td></tr>
<tr><td>or</td><td></td></tr>
<tr><td></td><td>slope < 1:3</td></tr>
<tr><td colspan="2">Special conditions:
— Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC</td></tr>
<tr><td>140</td><td>Butt weld, quality level B*</td><td></td><td>−2 NC</td></tr>
<tr><td>125</td><td>Butt weld, quality level B</td><td></td><td>−4 NC</td></tr>
<tr><td>112</td><td>Butt weld, quality level C</td><td></td><td>- 4 NC</td></tr>
<tr><td>3.2</td><td>m = 3</td><td>
Symmetric butt joint, normal stress across the weld</td><td colspan="2">— Components with usual residual stresses
— Angular misalignment < 1°
Special conditions:
Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC</td></tr>
<tr><td></td><td>80</td><td>Butt weld on remaining backing, quality level C</td><td colspan="2"></td></tr>
</table>

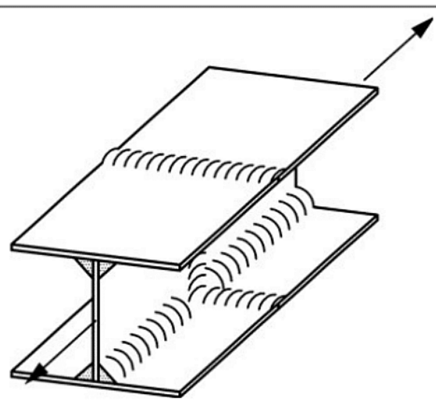
<table>
<tr><th>Detail No.</th><th>$\Delta\sigma_c$
MPa</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="4">3.3</td><td>m = 3</td><td>

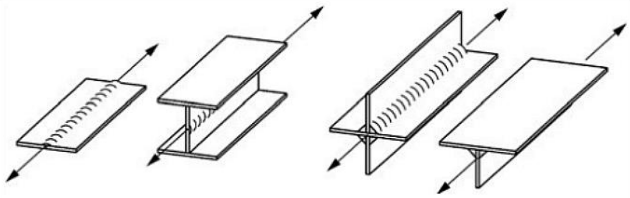
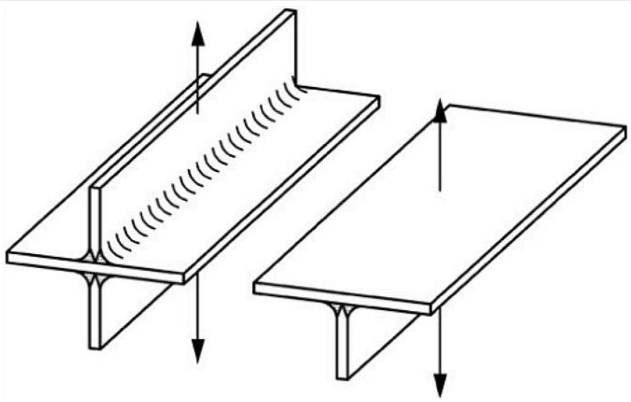
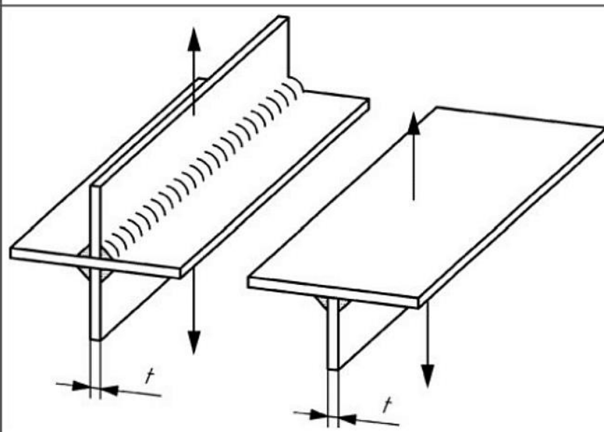
Unsymmetrical supported butt joint, normal stress across the butt weld</td><td>Basic conditions:
— fully penetrated weld
— Supported parallel to butt weld:
$c < 2 \cdot t_2 + 10$mm
— Supported vertical to butt weld:
$c < 12 \cdot t_2$
Components with usual residual stresses


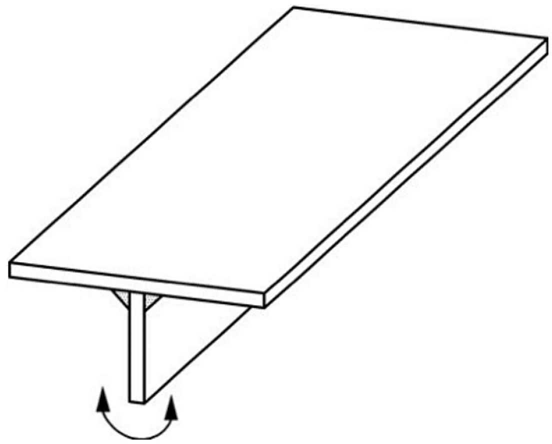
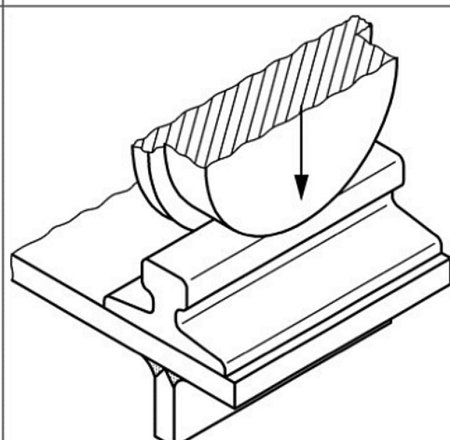
slope ≤ 1:3
$t_2 - t_1 \leq 4$ mm<hr>Special conditions:
— Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC
— Influence of slope and thickness t_2-t_1:<hr>thickness $(t_2 - t_1)$mm</td></tr>
<tr><td>125</td><td>Butt weld, quality level B*</td><td rowspan="3"><table><tr><th>slope</th><th>≤ 4</th><th>≤ 10</th><th>≤ 50</th><th>> 50</th></tr><tr><td>≤ 1:3</td><td>-</td><td>−1NC</td><td>−1NC</td><td>−2NC</td></tr><tr><td>≤ 1:2</td><td>−1NC</td><td>−1NC</td><td>−2NC</td><td>−2NC</td></tr><tr><td>≤ 1:1</td><td>−1NC</td><td>−2NC</td><td>−2NC</td><td>−3NC</td></tr><tr><td>> 1:1</td><td>−2NC</td><td>−2NC</td><td>−3NC</td><td>−3NC</td></tr></table></td></tr>
<tr><td>112</td><td>Butt weld, quality level B</td></tr>
<tr><td>100</td><td>Butt weld, quality level C</td></tr>
<tr><td rowspan="2">3.4</td><td>m = 3</td><td>

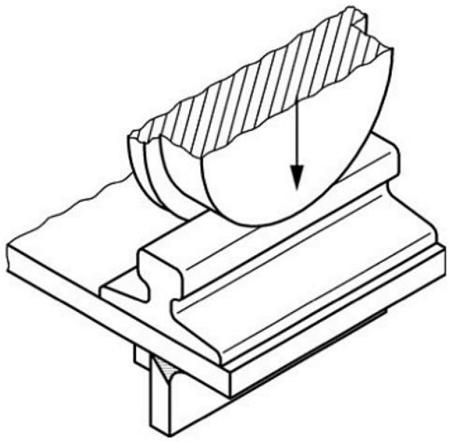
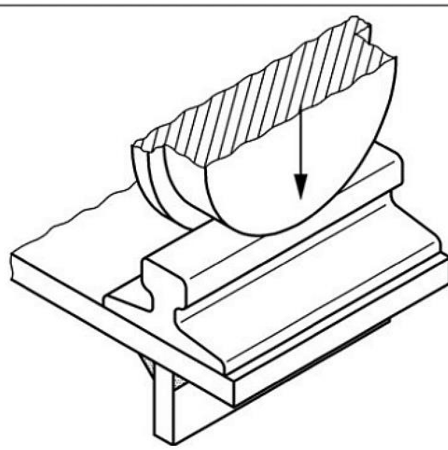
Unsymmetrical supported butt joint, normal stress across the butt weld</td><td>Basic conditions:
— fully penetrated weld
— supported parallel to butt weld:
$c < 2 \cdot t_2 + 10$mm
— supported vertical to butt weld:
$c < 12 \cdot t_2$
— components with usual residual stresses
— $t_2 - t_1 \leq 10$ mm
Special conditions:
— components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC
— $t_2 - t_1 > 10$ mm −1 NC</td></tr>
<tr><td>80</td><td>Butt weld on remaining backing, quality level C</td><td></td></tr>
</table>

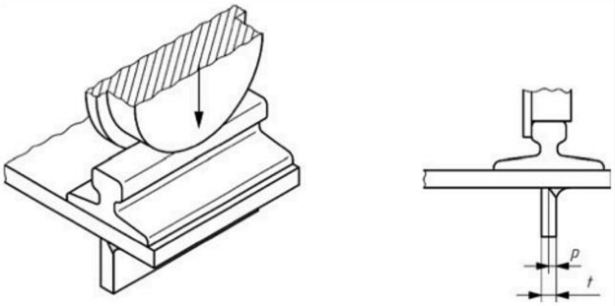
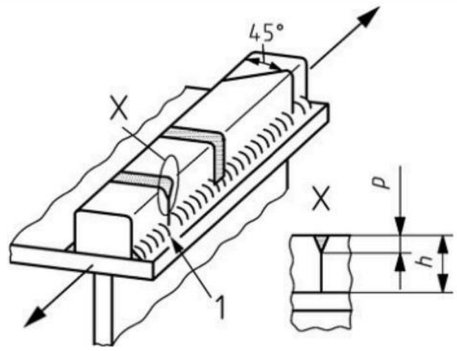
<table>
<tr><th>Detail No.</th><th>$\Delta\sigma_c$
MPa</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="4">3.5</td><td>m = 3</td><td>
Unsymmetrical unsupported butt joint, stress across the butt weld</td><td rowspan="4">Basic conditions:
— fully penetrated weld
— components with usual residual stresses
— slope ≤ 1:1in weld or base material:

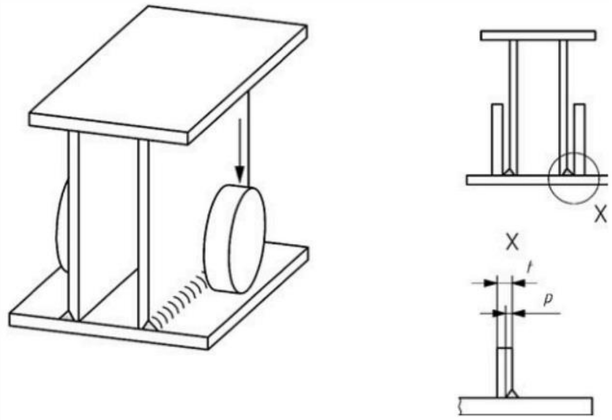
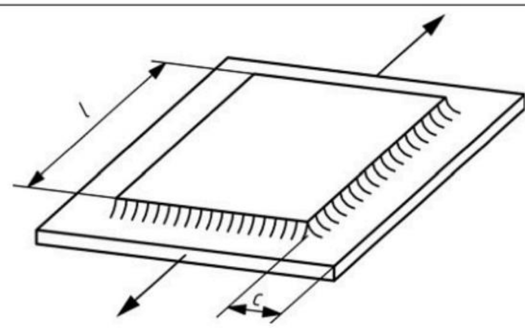

— $t_1/t_2 > 0{,}84$
Special conditions:
— components with considerable residual stresses (e.g. joint of components with restraint of shrinkage)
 −1 NC
 −2 NC
— $0{,}84 \geq t_1/t_2 > 0{,}74$ −1 NC
— $0{,}74 \geq t_1/t_2 > 0{,}63$ −2 NC
— $0{,}63 \geq t_1/t_2 > 0{,}50$ −3 NC
— $0{,}50 \geq t_1/t_2 > 0{,}40$ −4 NC</td></tr>
<tr><td>100</td><td>Butt weld, quality level B*</td></tr>
<tr><td>90</td><td>Butt weld, quality level B</td></tr>
<tr><td>80</td><td>Butt weld quality level C</td></tr>
<tr><td rowspan="4">3.6</td><td>m = 3</td><td>
Butt joint with crossing welds, stress across the butt weld</td><td rowspan="4">Basic conditions:
— components with usual residual stresses</td></tr>
<tr><td>125</td><td>Butt weld, quality level B*</td></tr>
<tr><td>100</td><td>Butt weld, quality level B</td></tr>
<tr><td>90</td><td>Butt weld, quality level C</td></tr>
</table>

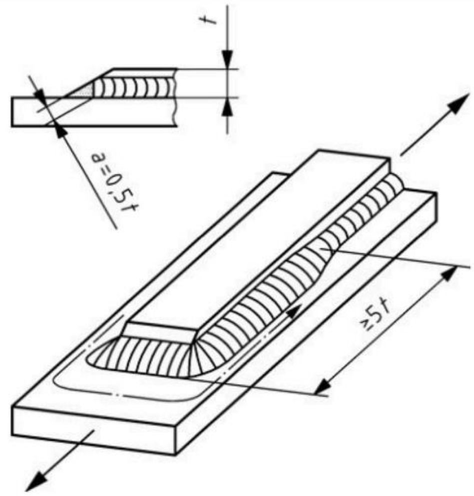
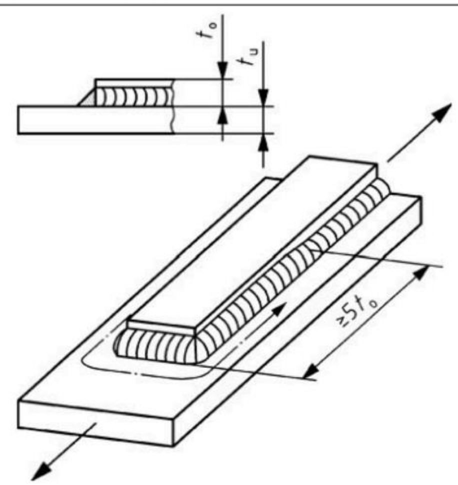
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.7	m = 3	 Normal stress in weld direction	Special conditions: — no irregularities from start-stop-points in quality level C + 1 NC — welding with restraint of shrinkage - 1 NC
	180	Continuous weld, quality level B	
	140	Continuous weld, quality level C	
	80	Intermittent weld, quality level C	
3.8	m = 3	 Cross or T-Joint, groove weld, normal stress across the weld	Basic conditions: — continuous weld — full penetration weld Special conditions: — automatic welding, no initial points + 1 NC — welding with restraint of shrinkage - 1 NC
	112	K-weld, quality level B*	
	100	K-weld, quality level B	
	80	K-weld, quality level C	
	71	V-weld with backing, quality level C	
3.9	m = 3	 Cross or T-Joint, symmetric double fillet weld	Basic conditions: — continuous weld Special conditions: — automatic welding, no initial points + 1 NC — welding with restraint of shrinkage - 1 NC
	45	Stress in weld throat	$\sigma_w = F / (s_r \times l_r)$ see Annex C (normative) for definition of s_r and l_r.
	71	Quality level B	Stress in the loaded plate at weld toe
	63	Quality level C	

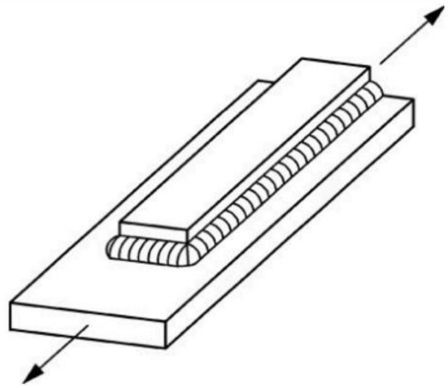
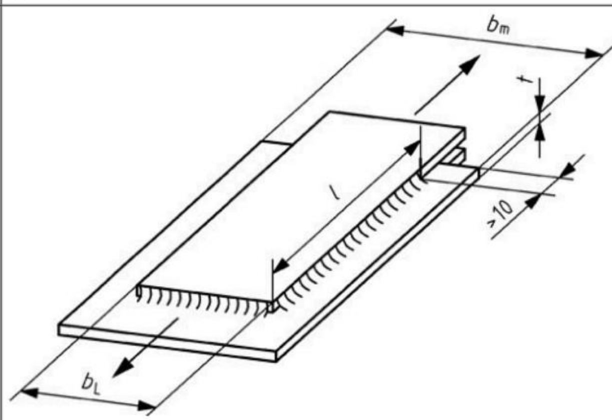
Detail No.	$\Delta\sigma_c$ MPa	**Constructional detail**	**Requirements**
3.10	m = 3	 T-Joint, stresses from bending	
	45	Stress in weld throat	Stress calculated with the applied bending moment and weld joint geometry taken into account, with the plate thickness taken as the lever arm
	80	Stresses in plate at weld toe, Quality level B	
	71	Stresses in plate at weld toe, Quality level C	
3.11	m = 3	 Full penetration weld (double sided) with transverse compressive load (e.g. wheel), stress calculated in the web plate	
	112	Quality level B	
	100	Quality level C	

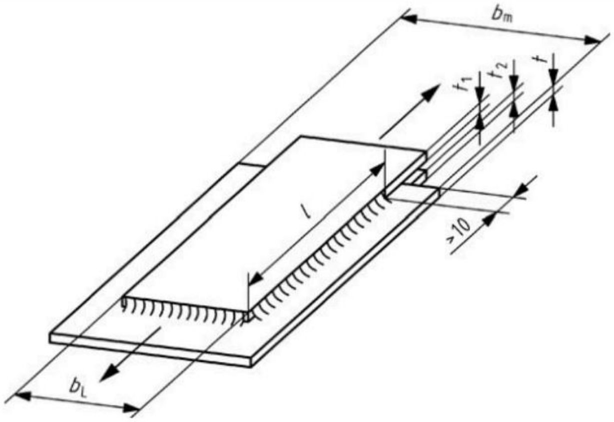
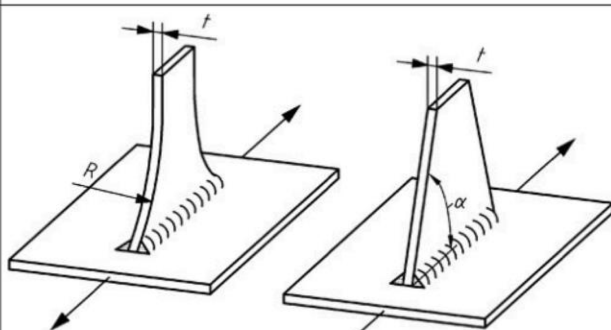
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.12	m = 3	 Full penetration weld (with backing) with transverse compressive load (e.g. wheel), stress calculated in the web plate	
	90	Quality level B	
	80	Quality level C	
3.13	m = 3	 Double fillet weld with transverse compressive load, (e.g. wheel), stress calculated in the web plate	Web thickness t: $0{,}5 \cdot t \leq s_1 \leq 0{,}7 \cdot t$ with s_1 according to Annex C (normative)
	71	Quality level B, C	

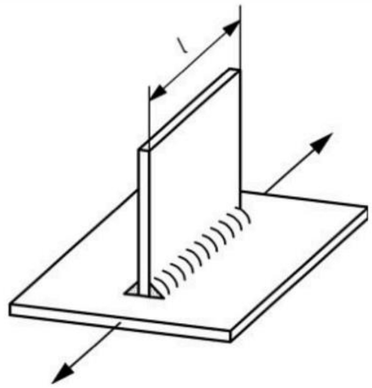
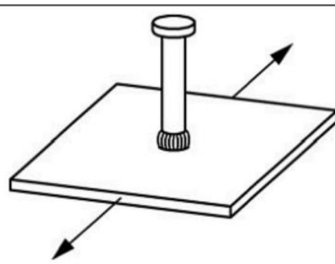
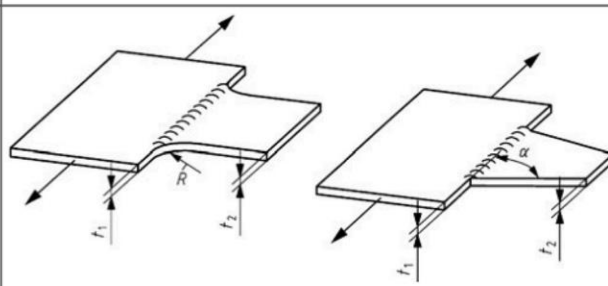
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.14	m = 3	 Partial penetration weld with transverse compressive load (e.g. wheel), stress calculated in the web plate	$0{,}5 \cdot t \leq s_1 \leq 0{,}7 \cdot t$ with s_1 according to Annex C (normative) $p \geq 1$mm for $t \leq 6$mm $p \geq \frac{t}{4}$ for $t > 6$mm
	71	Quality level B, C	
3.15	m = 3	 Plate with a rail welded on it, rail joints without butt weld or with partial penetration butt weld, design stress is that calculated in the plate.	Basic conditions: — all welds quality level C or better Special conditions: — continuous welds (1) over the joint on both sides of the rail with at least a length of 3 times h +1 NC
	45	rail joint cut perpendicular or at any other angle, e.g. 45°, p = 0,	
	56	single weld on top of the rail, h > p ≥ 0,3 × h	
	71	welds on top and on the two sides of the rail, h > p ≥ 0,2 × h	

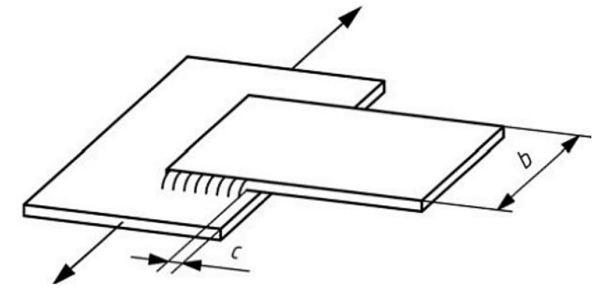
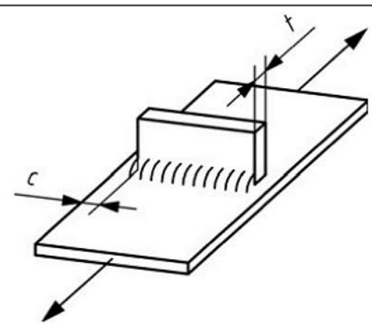
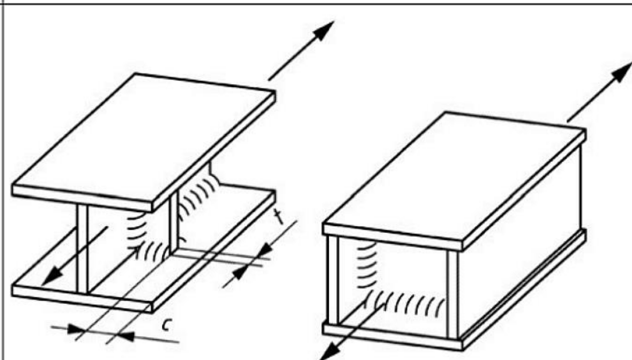
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.16	m = 3	 Partial penetration weld with transverse load (e.g. underslung crab), weld assessed from stress calculated in the web plate. Fatigue of the lower flange is not covered by this case.	Basic conditions: — quality level C — s_1 according to Annex C (normative) Special condition: — fillet weld with penetration and quality level B +1 NC
	63	p ≥ 1mm for $t \leq 6$mm ; $p \geq t/4$ for $t > 6$mm; $0,5 \times t \leq s_1 \leq 0,7 \times t$	
	56	p ≥ 1 mm for t > 6 mm; $0,6 \times t \leq s_1 \leq 0,7 \times t$	
	50	Fillet weld without penetration; $0,6 \times t \leq s_1 \leq 0,7 \times t$	
	40	Fillet weld without penetration; $0,5 \times t \leq s_1 < 0,6 \times t$	
3.17	m = 3	 Continuous component with a welded cover plate	Basic conditions: — quality level C — continuous weld — distance c between the weld toe and rim of continuous component greater than 10 mm Special conditions: — quality level B* +2 NC — quality level B +1 NC — quality level D - 1 NC — $c < 10$ mm - 1 NC
	80	$l \leq 50$ mm	
	71	50 mm < $l \leq 100$ mm	
	63	$l > 100$ mm	

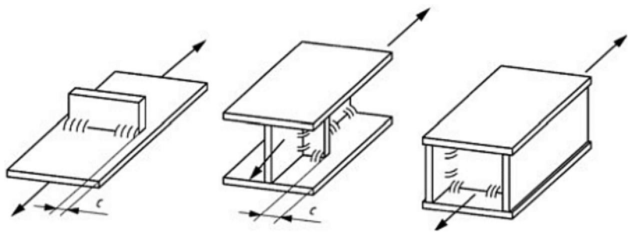
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.18	m = 3	 Continuous component with load carrying flange plate, stress in continuous component at end of connection	Basic conditions: continuous fillet or groove weld
	112	Flange plate with end chamfer ≤ 1:3; edge weld and end of flank weld in weld quality level B*	
	100	Flange plate with end chamfer ≤ 1:2; edge weld and end of flank weld in weld quality level B*	
3.19	m = 3	 Continuous component with load carrying flange plate, stress in continuous component at end of connection	Basic conditions: — continuous fillet or groove weld — $t_o \leq 1{,}5\, t_u$
	80	Edge weld and end of flank weld in weld quality level B*	

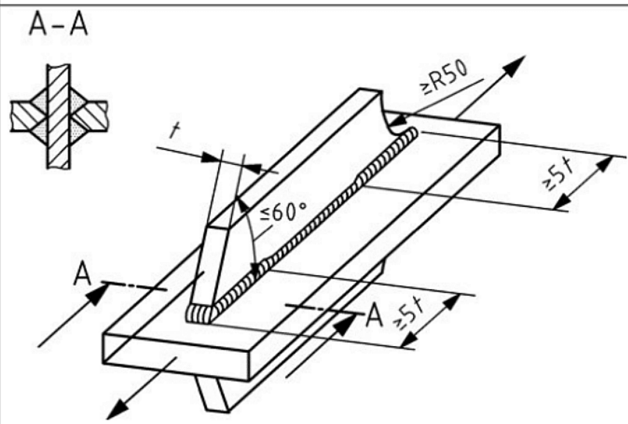
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.20	m = 3	 Continuous component with load carrying flange plate, stress in continuous component at end of connection	Basic conditions: — continuous fillet or groove weld
	63	Quality level B	
	56	Quality level C	
3.21	m = 3	 Overlapped welded joint, main plate	Basic conditions: — stressed area to be calculated from: $A_s = t \times l_r$ $l_r = \min\left(b_m, b_L + l\right)$ see also detail 3.32
	80	Quality level B*	
	71	Quality level B	
	63	Quality level C	

Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.22	m = 3	 Overlapped welded joint, lap plates	Basic conditions: — stressed area to be calculated from: $A_s = b_L \times (t_1 + t_2)$
	50		
3.23	m = 3	 Continuous component with longitudinally mounted parts, Parts rounded or chamfered	Basic conditions: — $R \geq 50$ mm; $\alpha \leq 60°$ — groove weld or all round fillet weld
	90	Quality level B*	$R \geq 150$ mm or $\alpha \leq 45°$
	80	Quality level B	
	71	Quality level C	

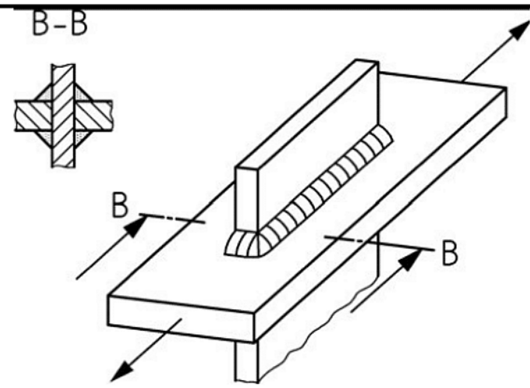
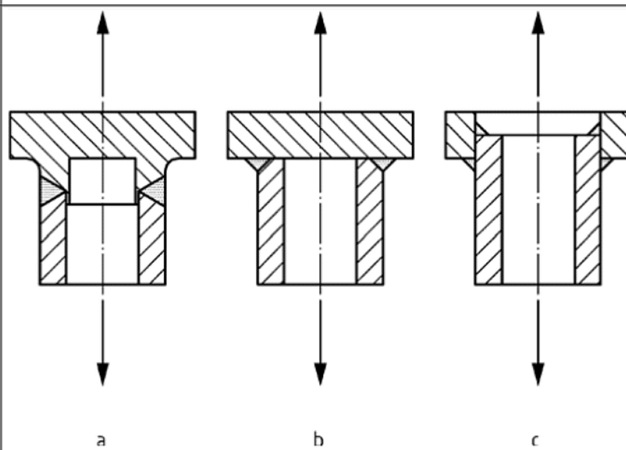
Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.24	m = 3	 Continuous component with parts ending perpendicularly	Basic conditions: — all round fillet weld — quality level B, C Special conditions: — single fillet weld −1 NC — weld quality level D −1 NC
	80	$l \leq 50$ mm	
	71	50 mm < $l \leq 100$ mm	
	63	100 mm < $l \leq 300$ mm	
	56	$l > 300$ mm	
3.25	m = 3	 Continuous component with round attachment (stud, bolt, tube, etc.)	Basic conditions: — all round fillet weld — diameter ≤ 50mm — for diameter > 50mm apply detail 3.17 with length l = diameter Special conditions: — quality level B* +2 NC — quality level B +1 NC
	80	Quality level C	
3.26	m = 3	 Continuous component with longitudinally mounted parts, welded to edge	Basic conditions: — $R \geq 50$ mm; $\alpha \leq 60°$ — groove weld or all round fillet weld Special conditions: — R < 50 mm or α > 60° - 2 NC
	90	Quality level B*	$R \geq 150$ mm or $\alpha \leq 45°$
	80	Quality level B	
	71	Quality level C	

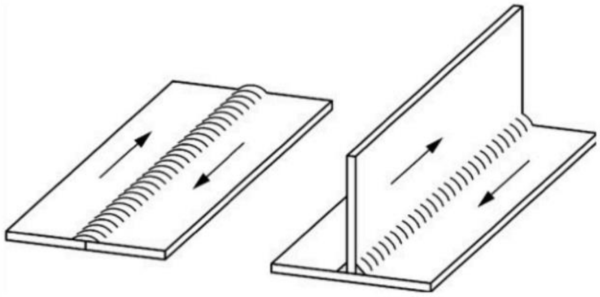
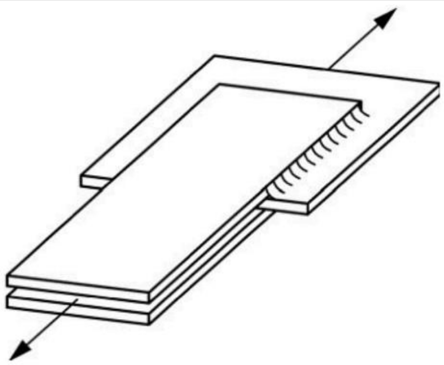
Detail No.	$\Delta\sigma_c$ MPa	**Constructional detail**	**Requirements**
3.27	m = 3	 Continuous component with overlapping parts	Basic conditions — $c \geq 10$ mm — quality level C Special conditions: — $b \leq 50$ mm and quality level B +1 NC — quality level D −1 NC — $c < 10$ mm −1 NC
	80	$b \leq 50$ mm	
	71	50 mm < $b \leq 100$ mm	
	63	$b > 100$ mm	
3.28	m = 3	 Continuous component to which parts are welded transversally	Basic conditions: — plate thickness $t \leq 12$ mm — $c \geq 10$ mm — quality level D not allowed for K-weld Special conditions: — plate thickness $t > 12$ mm (Double fillet welds only) −1 NC — $c < 10$ mm −1 NC — K-weld instead of double fillet weld +1 NC — quality level D instead of C −1 NC
	112	Double fillet weld, quality level B*	
	100	Double fillet weld, quality level B	
	90	Double fillet weld, quality level C	
	80	Single fillet weld, quality level B, C	
	80	Partial penetration V-weld on remaining backing, quality level B, C	
3.29	m = 3	 Continuous component to which stiffeners are welded transversally	Basic conditions: — plate thickness $t \leq 12$ mm — $c \geq 10$ mm Special conditions: — plate thickness $t > 12$ mm (double fillets only) −1 NC — $c < 10$ mm −1 NC — K-weld instead of double fillet weld +1 NC — quality level D instead of C −1 NC

<table>
<tr><th>Detail No.</th><th>$\Delta\sigma_c$
MPa</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="5">3.29</td><td>112</td><td>Double fillet weld, quality level B*</td><td rowspan="5">... continued</td></tr>
<tr><td>100</td><td>Double fillet weld, quality level B</td></tr>
<tr><td>90</td><td>Double fillet weld, quality level C</td></tr>
<tr><td>80</td><td>Single fillet weld, quality level B, C</td></tr>
<tr><td>80</td><td>Partial penetration V-weld on remaining backing, quality level B, C</td></tr>
<tr><td rowspan="3">3.30</td><td>m = 3</td><td>

Continuous component to which transverse parts or stiffeners are welded intermittently, one-sided or double sided weld</td><td>Basic conditions:
— $c \geq 10$ mm
Special conditions:
— $c < 10$ mm −1 NC</td></tr>
<tr><td>80</td><td>Quality level C</td><td rowspan="2">Basic conditions:
— $c \geq 10$ mm
Special conditions:
— $c < 10$ mm −1 NC</td></tr>
<tr><td>63</td><td>Quality level D</td></tr>
<tr><td rowspan="2">3.31</td><td>m = 3</td><td>

Continuous component with longitudinally mounted parts, parts through hole</td><td rowspan="2">Basic conditions:
— $R \geq 50$ mm, angle ≤ 60°
Special conditions:
— $R \geq 100$ mm, angle ≤ 45° +1 NC
— end welds in the zone of at least 5 t fully penetrated +2 NC</td></tr>
<tr><td>80</td><td>Parts rounded or chamfered</td></tr>
</table>

Detail No.	$\Delta\sigma_c$ MPa	Constructional detail	Requirements
3.32	m = 3	 Continuous component with longitudinally mounted parts, parts through hole	
	56	Parts ending perpendicularly	
3.33	m = 3	 Tubes under axial and bending loads, normal stresses calculated in the tube	Basic conditions: — quality level C — groove weld fully penetrated — fillet weld thickness s_r > 0,7 tube thickness, see Annex C (normative) — flange thickness greater than two times tube thickness (for middle figure) Special conditions: — quality B +1 NC — quality B* +2 NC
	80	Butt weld, cylindrical tube (case a)	
	63	Groove weld, cylindrical tube (case b)	
	56	Groove weld, rectangular tube (case b)	
	45	Double fillet weld, cylindrical tube (case c)	
	40	Double fillet weld, rectangular tube (case c)	

Detail No.	$\Delta\tau_c$ MPa	Constructional detail	Requirements
3.34	m = 5	 Continuous groove weld, single or double fillet weld under uniform shear flow	Basic conditions: — quality level C — components with usual residual stresses Special conditions: — components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC — no initial points +1 NC
	112	With full penetration	
	90	Partial penetration	
3.35	m = 5	 Weld in lap joint, shear with stress concentration	Basic conditions: — load is assumed to be transferred by longitudinal welds only
	71	Quality level B	
	63	Quality level C	

Annex E
(normative)

Sequence of notch classes (NC)

Table E.1 specifies the sequence of notch classes (NC) with associated $\Delta\sigma_c$ values. Each value represents the characteristic fatigue strength of a notch class (NC) for basic conditions. +1 NC is one line above, −1 NC is one line below.

Table E.1 — Sequence of notch classes (NC)

NC, $\Delta\sigma_c$ MPa
355
315
280
250
225
200
180
160
140
125
112
100
90
80
71
63
56
50
45
40
36
32
28
25

Annex F
(informative)

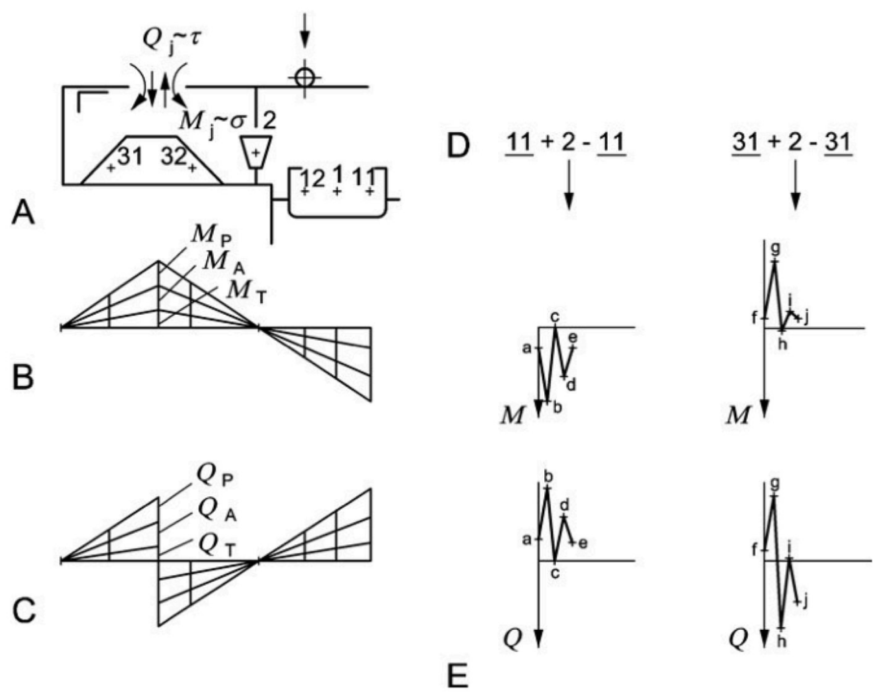
Evaluation of stress cycles (example)

The stress histories at a selected point of the structure depend on the loads, their direction and position during the use of the crane, as well as on the crane configuration.

The total number of working cycles of a crane during its useful life can be divided into several typical tasks with the numbers of working cycles corresponding to them.

A task can be characterized by specific combinations of crane configuration and sequence of intended movements.

Before the sequence of stress peaks occurring during the performance of any task can be evaluated, the corresponding series of loadings has to be determined first, i.e. the magnitude, position and direction of all loads.



Key

A	System
B	Influence lines for bending at selected point *j*
C	Influence lines for shear at selected point *j*
D	Sequences of movements
E	Extreme values of bending M and shear Q (ϕ_2= 1) during sequences of movements
Q_P, Q_A Q_T and M_P, M_A, M_T	(T for trolley, P for payload, A for lifting attachment)

Figure F.1 — Example of load and moment variations due to load movements for tasks on a ship unloader

The unloader handles bulk material from ship to hopper or stockpile, the ranges of points to be served are given by the arrangement of the ship (points 12, 1 and 11), hopper (point 2) and stockpile (points 31 and 32).

Figure F.1 shows the different sequences of movements of an unloader for two tasks considered, moving load from ship (point 11) to hopper (point 2) and moving load from stockpile (point 31) to hopper (point 2).

In the encoded description of each task, the point labels are:

— linked by the sign "+" for working movements (with load) and "-" for dead movements (without load);

— underlined when the grab (load lifting attachment) is grounded.

The influence lines (representing the influences of loading and its position) for bending moment Mj and shear force Qj at the selected point j are shown for different loads (T for trolley, P for payload, A for lifting attachment, i.e. grab).

The description of salient points of the bending moment and shear load variations can be found in Table F.1.

Table F.1 — Description of salient points in bending moment and shear load variations

Point	Trolley position	Grab position	Acting loads
a	11	Grounded	T
b	11	Lifted	T,A,P
c	2	Lifted	T,A,P and T,A when load dropped
d	11	Lifted	T,A
e	11	Grounded	T
f	31	Grounded	T
g	31	Lifted	T,A,P
h	2	Lifted	T,A,P and T,A when load dropped
i	31	Lifted	T,A
j	31	Grounded	T

The sequences of stresses arising from the bending moment M_j ($\sigma(t)$ = global bending stress) and the shear force Q_j ($\tau_{(t)}$ = global shear stress) can be determined directly from the influence lines.

Stress cycles can be identified from the resulting sequences of stress peaks using one of the established stress cycle counting methods, such as the Rainflow counting method or the Reservoir method.

The complete stress history is obtained by summating the individual stress histories taken from the sequences of movements of all different tasks.

Annex G
(informative)

Calculation of stiffnesses for connections loaded in tension

The determination of stiffnesses of elements for the calculation of bolt joints in tension presented in this annex applies in the ideal cases shown in Figure G.1 assuming no more than 5 contact surfaces in practical joints. Adjacent bolts and/or the way of introduction of external forces into the system have great influence on the additional bolt force and should be considered in actual design.

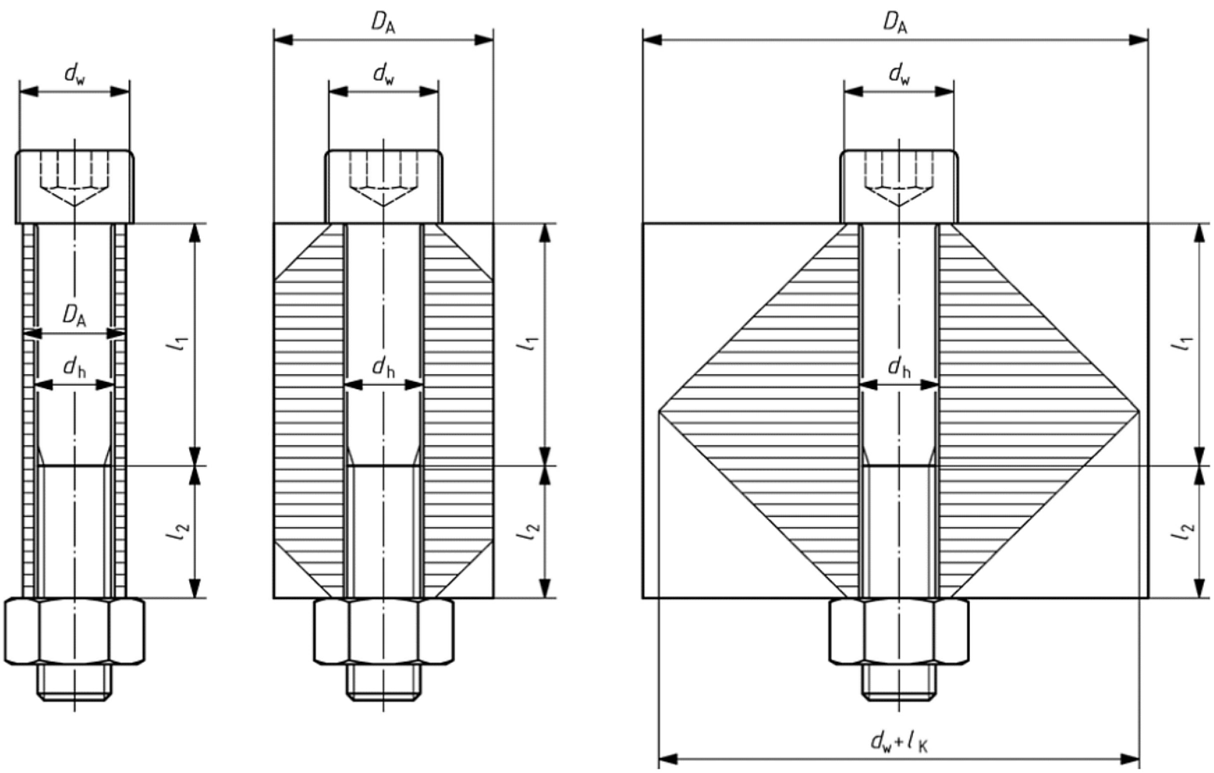


Figure G.1 — Types of connections loaded in tension

The stiffnesses for connections in tension can be calculated as follows:

The stiffness K_c of the connected parts can be calculated from:

$$K_C = \frac{E}{l_K} \times A_{eq} \tag{G.1}$$

where

- E is the modulus of elasticity;
- l_K is the effective clamped length (including all clamped components);

  with $l_K = l_1 + l_2$
- A_{eq} is the equivalent area for calculation.

The calculation of A_{eq} is in dependence of D_A (see Figure G.1):

For $D_A < d_w$:

$$A_{eq} = \frac{\pi}{4} \times \left(D_A^2 - d_h^2 \right) \tag{G.2}$$

For $d_w \leq D_A \leq d_w + l_K$:

$$A_{eq} = \frac{\pi}{4} \times \left(d_w^2 - d_h^2 \right) + \frac{\pi}{8} \times \mathrm{d}_w \times \left(D_A - d_w \right) \times \left[\left(\sqrt[3]{\frac{l_K \times d_w}{D_A^2}} + 1 \right)^2 - 1 \right] \tag{G.3}$$

For $d_w + l_K < D_A$:

$$A_{eq} = \frac{\pi}{4} \times \left(d_w^2 - d_h^2 \right) + \frac{\pi}{8} \times l_K \times d_w \times \left[\left(\sqrt[3]{\frac{l_K \times d_w}{\left(l_K + \mathrm{d}_w \right)^2}} + 1 \right)^2 - 1 \right] \tag{G.4}$$

where

- D_A is the diameter of the available cylinder of clamped material or spacing of adjacent bolts, whichever is smaller;
- d_w is the diameter of the contact area under the bolt head;
- A_{eq} is the equivalent area for calculation;
- d_h is the diameter of the hole;
- l_K is the effective clamped length.

The stiffness of the bolt can be calculated from

$$\frac{1}{K_b} = \frac{1}{E} \times \left(\frac{4 \times \left(l_1 + 2 \times 0,4 \times d \right)}{\pi \times d^2} + \frac{l_2 + 0,5 \times d}{A_r} \right) \tag{G.5}$$

where

- K_b is the stiffness of bolt;
- E is the modulus of elasticity;
- l_1 is the effective length for tension without thread;
- l_2 is the effective length for tension with thread;
- d is the shank diameter;
- A_r is the root area of the bolt (stress area A_S may be used instead of A_r, see values in Table B.2).

According to the shape of the connected parts, the external load is introduced to the bolt near its end (Figure G.2, case a)), between the bolt end and the connection plane (case b)) or close to the connection plane (case c)). This is considered in calculation of the stiffness ratio factor as follows:

$$\phi = \alpha_L \times \frac{K_b}{K_b + K_c} \qquad \text{(G.6)}$$

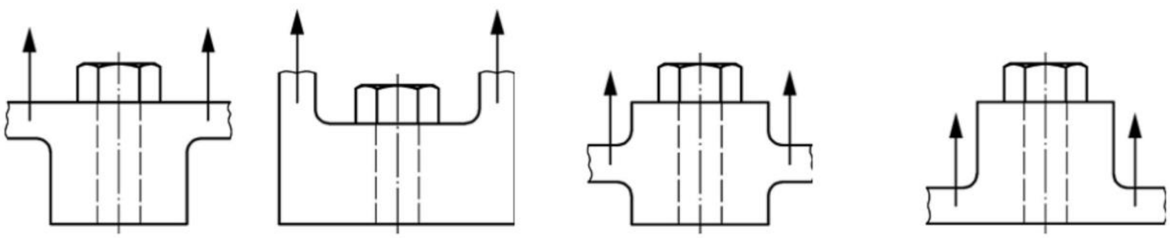
where

Φ is the stiffness ratio factor;

K_b is the stiffness of bolt;

K_c is the stiffness of connected parts;

α_L is the load introduction factor, see Figure G.2.



a) $\alpha_L = 0{,}9 \ldots 1$ b) $\alpha_L = 0{,}6$ c) $\alpha_L = 0{,}3$

Figure G.2 — Values for the load introduction factor α_L as a function of the connection shape

Case a) is typical for bolted connections in cranes. More precise values can be found in the literature. In cases where load introduction cannot be reliably specified, a conservative assumption $\alpha_L = 1$ should be used. In cases where the stiffness ratio factor Φ is determined by finite element analysis of the complete joint, the load introduction factor α_L will become an in-built part of the analysis and the value $\alpha_L = 1$ shall be used with Formula (G.6).

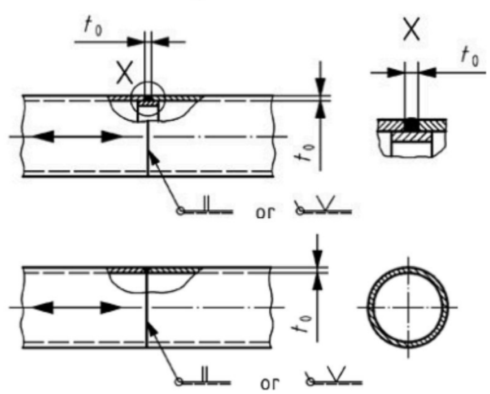
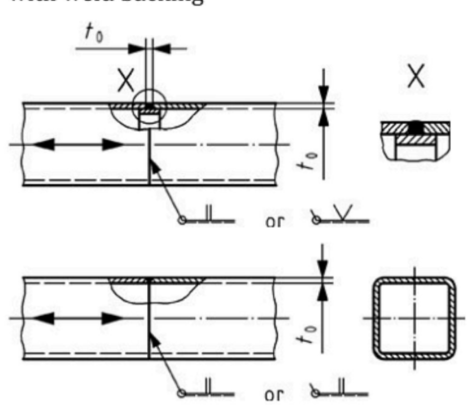
Annex H
(normative)

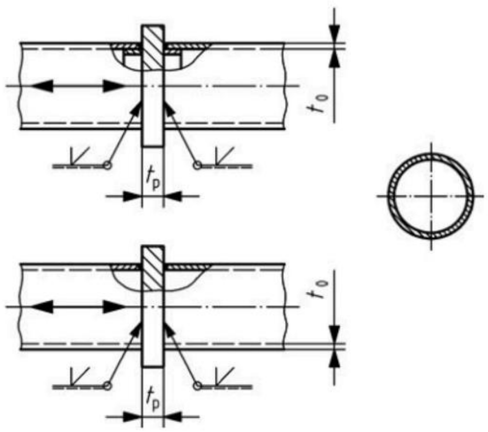
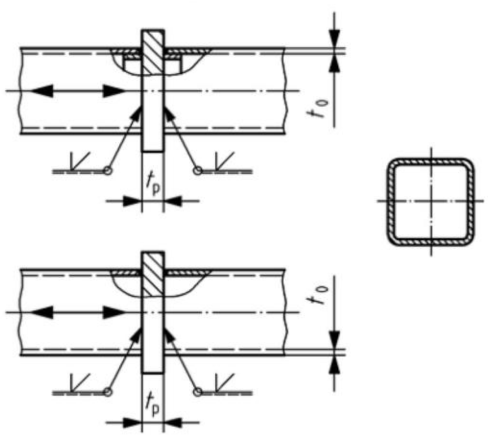
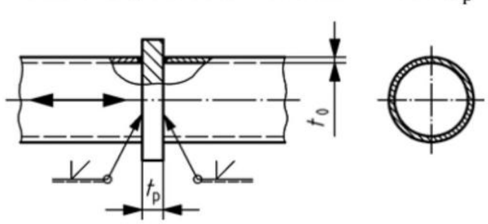
Hollow sections

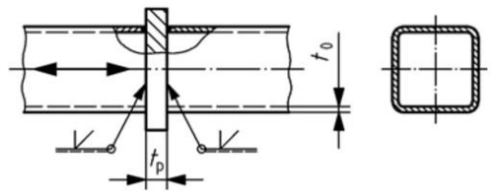
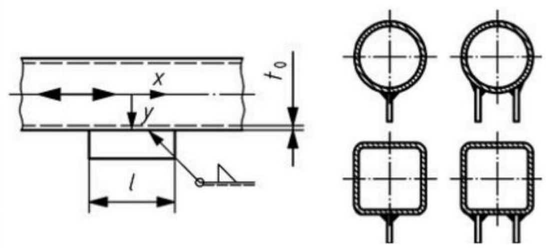
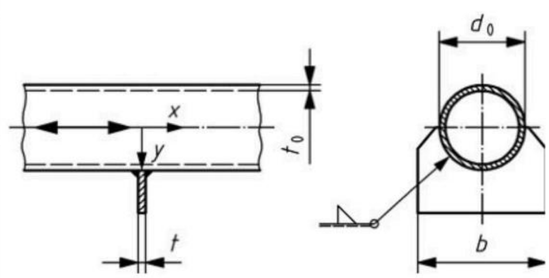
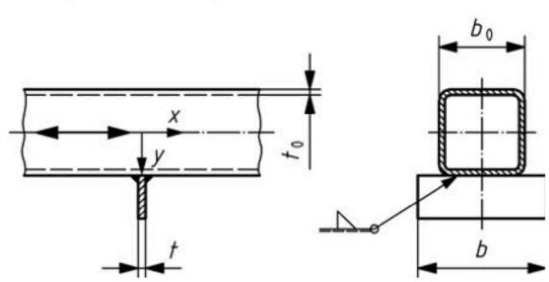
Quality level C is assumed for all welds in the details below.

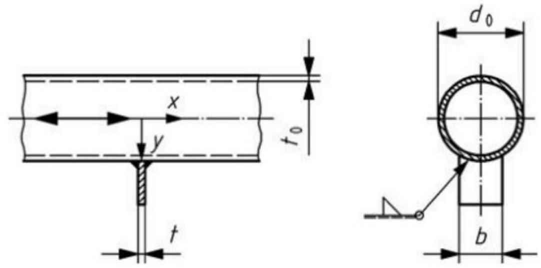
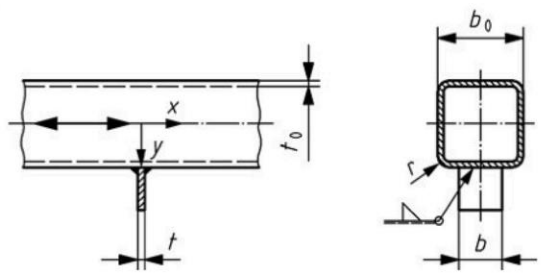
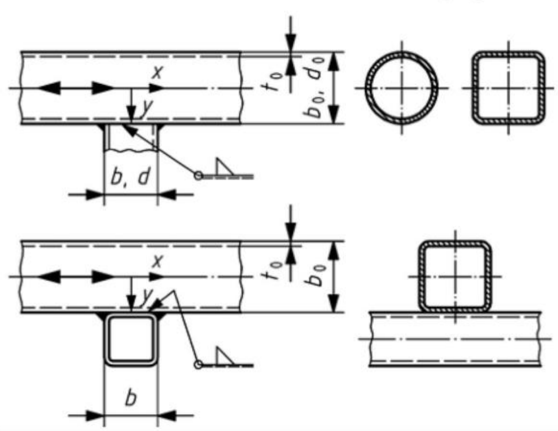
For site welding the given values of $\Delta\sigma_c$ should be multiplied by the factor 0,9.

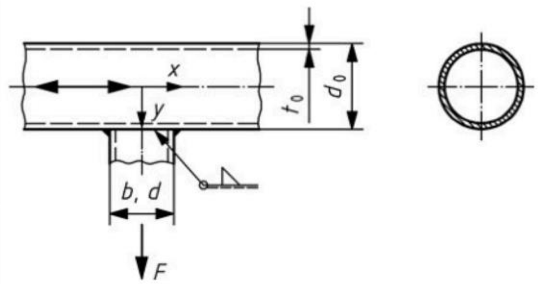
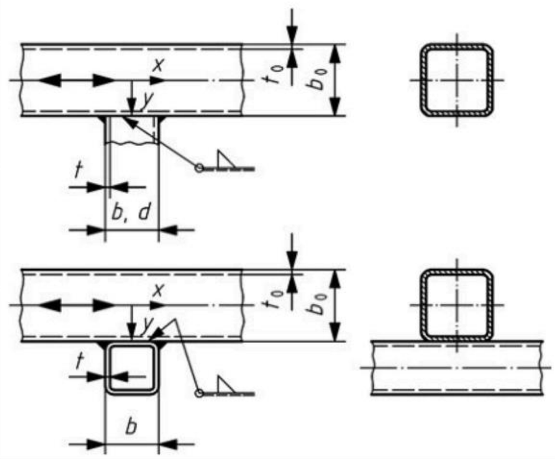
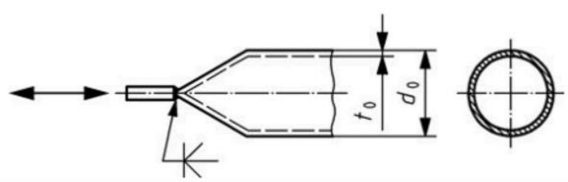
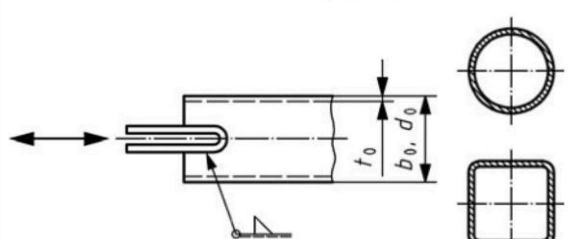
Table H.1 — Values of characteristic fatigue strength $\Delta\sigma_c$, $\Delta\tau_c$ with slope constant m = 5

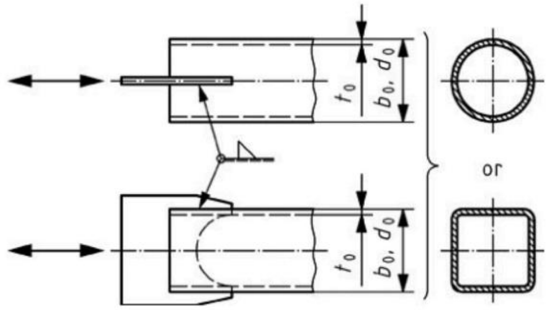
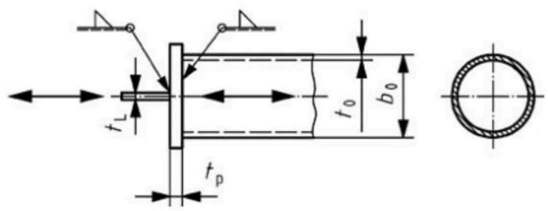
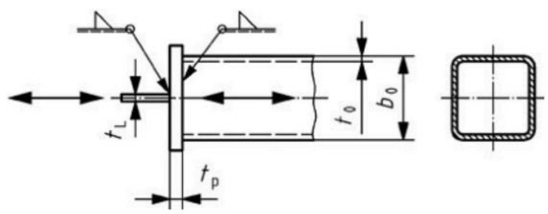
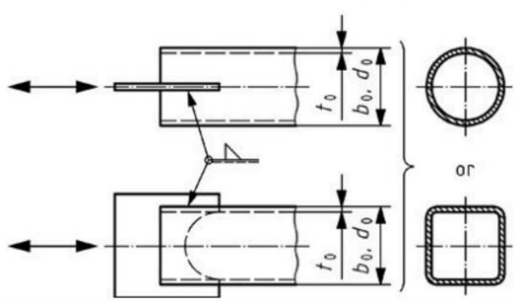
No.	**$\Delta\sigma_c$, $\Delta\tau_c$ N/mm²**	**Dimensions** mm	**Constructional detail**	**Requirements**
1	90	$2 < t_0 \leq 25$	Butt joint with I- or V-weld with weld backing  without backing weld	The admissible mismatch of the sections due to a change of the plate thickness is $\leq t_0/3$, but not more than max. 2 mm. In case of a higher mismatch, especially for a transverse plate butt of rectangular hollow section girders of different dimensions, $\Delta\sigma_c$ is reduced to 80 % of the given values.
	90	$8 < t_0 \leq 25$		
	71	$2 < t_0 \leq 8$		
2	80	$2 < t_0 \leq 25$	Butt joint with I- or V-weld with weld backing  without weld backing	Requirements analogous to No. 1
	80	$8 < t_0 \leq 25$		
	63	$2 < t_0 \leq 8$		

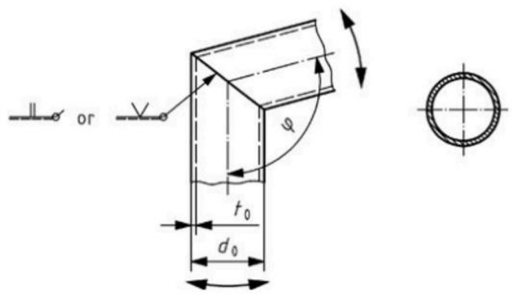
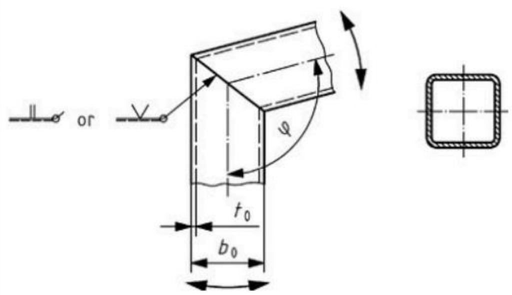
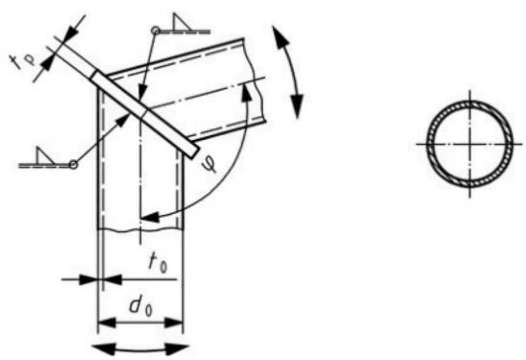
No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
3	63	$2 < t_0 \leq 25$	Transverse plate butt with semi V-welds ($t_p \geq 2\ t_o$) with weld backing  without weld backing	Requirements analogous to No. 1
	63	$8 < t_0 \leq 25$		
	56	$2 < t_0 \leq 8$		
4	56	$2 < t_0 \leq 25$	Transverse plate butt with semi V-welds ($t_p \geq 2\ t_o$) with weld backing  without weld backing	Requirements analogous to No. 1
	56	$8 < t_0 \leq 25$		
	50	$2 < t_0 \leq 8$		
5	45	$2 < t_0 \leq 8$	Transverse plate butt with semi V-welds ($t_p \geq 2\ t_o$) 	Requirements analogous to No. 1

No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
6	40	$2 < t_0 \leq 8$	Transverse plate butt with semi V-welds ($t_p \geq 2\ t_o$) 	Weld thickness = t_0
7	80	$l \leq 50$	Longitudinally welded outer fin not bearing transverse loading in y-direction ($2 < t_0 \leq 25$) 	Fillet weld thickness a: for $2 < t_0 \leq 3$ $a = 2$ for $3 \leq t_0 \leq 25$ $a = 0{,}7 \cdot t_0$
	71	$50 < l \leq 100$		
	56	$l > 100$		
8	100	$t \leq 6$	Transversally welded outer fin with projection, not bearing transverse loading in y-direction ($2 < t_o \leq 25$), ($b > b_0$) 	Fillet weld thickness a: for $2 < t_0 \leq 3$ $a = 2$ for $3 \leq t_0 \leq 25$ $a \leq 0{,}7 \cdot t_0$, but not more than $a = 10$
	90	$6 < t \leq 12$		
	80	$12 < t \leq 25$		
9	80	$t \leq 6$	Transversally welded outer fin with projection, not bearing transverse loading in y-direction ($2 < t_0 \leq 25$), ($b > b_0$) 	Fillet weld thickness a: for $2 < t_0 \leq 3$ $a = 2$ for $3 \leq t_0 \leq 25$ $a \leq 0{,}7 \cdot t_0$, but not more than $a = 10$
	71	$6 < t \leq 12$		
	63	$12 < t \leq 25$		

No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
10	80	$t \le 6$	Transversally welded outer fin without projection, not bearing transverse loading in y-direction ($2 < t_0 \le 25$), ($b \le 0{,}8\ d_0$) 	Fillet weld thickness a: for $2 < t_0 \le 3$ $a = 2$ for $3 \le t_0 \le 25$ $a \le 0{,}7 \cdot t_0$, but not more than $a = 10$
	71	$6 < t \le 12$		
	63	$12 < t \le 25$		
11	100	$t \le 6$	Transversally welded outer fin without projections, not bearing transverse loading in y-direction ($2 < t_0 \le 25$), ($b \le 0{,}8\ b_0$) 	Fillet weld thickness a: for $2 < t_0 \le 3$ $a = 2$ for $3 \le t_0 \le 25$ $a \le 0{,}7 \cdot t_0$, but not more than $a = 10$
	90	$6 < t \le 12$		
	80	$12 < t \le 25$		
12	63	$2 < t_0 \le 8$	Welded-on hollow section girder, not bearing transverse loading in y-direction ($b,d \le b_0,d_0$) 	Fillet weld thickness $a = t_0$

No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
13	10	$t_0/t = 1$ $(b,d)/d_0 = 0{,}6$	Welded-on hollow section girder, bearing transverse loading F in y-direction ($b,d \leq d_0$), ($2 < t_0 \leq 8$) 	Fillet weld thickness $a = t_0$
	36	$t_0/t = 1$ $(b,d)/d_0 = 1$		
	16	$t_0/t \geq 1$ $(b,d)/d_0 = 0{,}6$		
	50	$t_0/t \geq 1$ $(b,d)/d_0 = 0{,}6$		
14	6	$t_0/t = 1$ $(b,d)/b_0 = 0{,}6$	Welded-on hollow section girder, bearing transverse loading in y-direction ($b,d \leq b_0$), ($2 < t_0 \leq 8$) 	Fillet weld thickness $a = t_0$
	32	$t_0/t = 1$ $(b,d)/b_0 = 1$		
	12,5	$t_0/t \geq 1$ $(b,d)/b_0 = 0{,}6$		
	40	$t_0/t \geq 1$ $(b,d)/b_0 = 0{,}6$		
15	80	$2 < t_0 \leq 8$	Single butt strap at chamfered end of tube ($d_0/t_0 < 25$) 	Pinched end of tube $a = 2 \cdot t_0$
16	80	$2 < t_0 \leq 8$	Welded double butt strap ($(b_0,d_0)/t_0 < 25$) 	Hot-bended strap, rounded slot milled at end of tube Fillet weld thickness a = t_0

No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
17	71	$2 < t_0 \leq 8$	Inserted dovetail strap ($(b_0,d_0)/t_0 < 25$) 	Fillet weld thickness $a = t_0$
18	56	$2 < t_0 \leq 8$	End face strap ($d_0/t_0 < 25$), ($t_P \geq 2{,}5\ t_0$) 	Fillet weld thickness for the hollow section girder: $a = t_0$ for the strap: $a = 0{,}7 \cdot t_L$
19	45	$2 < t_0 \leq 8$	End face strap ($b_0/t_0 < 25$), ($t_P \geq 2{,}5\ t_0$) 	Fillet weld thickness for the hollow section girder: $a = t_0$ for the strap: $a = 0{,}7 \cdot t_L$
20	45	$2 < t_0 \leq 8$	Inserted rectangular strap [$(b_0,d_0)/t_0 < 25$] 	Fillet weld thickness $a = t_0$

No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
21	56	$8 < t_0 \leq 25$	Mitre joint with I- or V-weld without weld backing, stressed by bending ($d_0/t_0 < 25$), ($\varphi \geq 90°$) 	Requirements analogous to No. 1
	50	$2 < t_0 \leq 8$		
22	50	$8 < t_0 \leq 25$	Mitre joint with I- or V- weld without weld backing, stressed by bending ($b_0/t_0 < 25$), ($\varphi \geq 90°$) 	Requirements analogous to No. 1
	45	$2 < t_0 \leq 8$		
23	50	Weld thickness a: $2 < a \leq 8$	Mitre joint with transverse plate and fillet welds, stressed by bending ($d_0/t_0 < 25$), ($\varphi \geq 90°$), ($t_P \geq 2{,}5$ t_0) 	Requirements analogous to No. 1
	45	Weld thickness a: $8 < a \leq 14$		

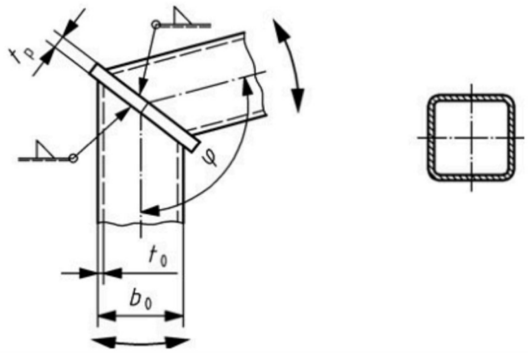
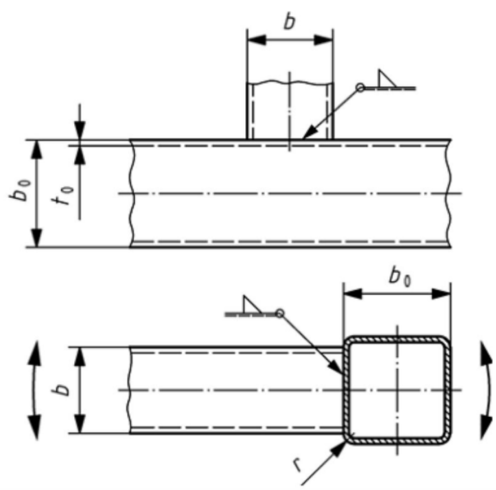
No.	$\Delta\sigma_c$, $\Delta\tau_c$ N/mm^2	Dimensions mm	Constructional detail	Requirements
24	45	Weld thickness a: $2 < a \leq 8$	Mitre joint with transverse plate and fillet welds, stressed by bending ($b_0/t_0 < 25$), ($\varphi \geq 90°$), ($t_P \geq 2{,}5\ t_0$) 	Requirements analogous to No. 1
	40	Weld thickness a: $8 < a \leq 14$		
25	45	Weld thickness a: $2 < a \leq 8$	Joint of column and transverse girder with fillet welds, stressed by bending ($b_0/t_0 < 25$), ($b_0 \leq b + 3\ r$) 	Fillet weld thickness $a = t_0$ where t_0 is the existing minimum plate thickness
	40	Weld thickness a: $8 < a \leq 14$		

Table H.2 — Values of characteristic fatigue strength $\Delta\sigma_c$ with slope constant m = 5 for lattice type connections

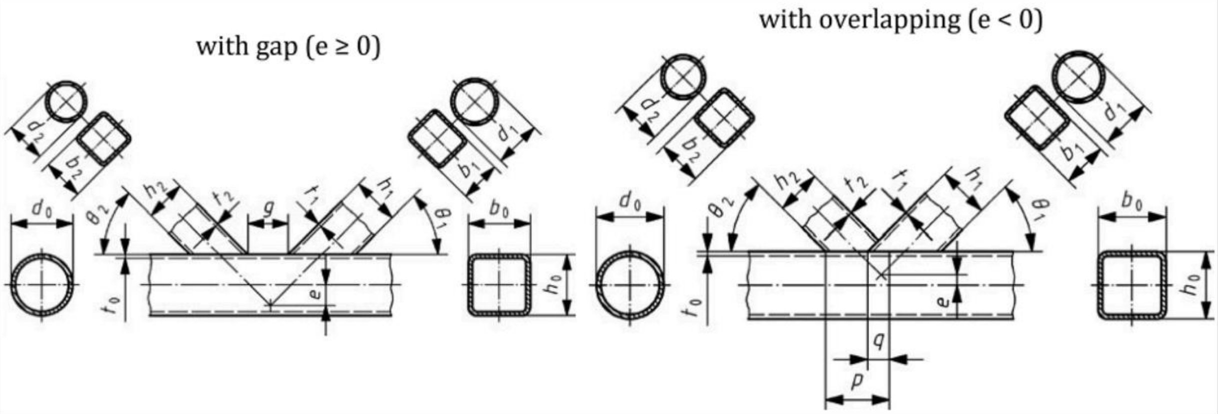
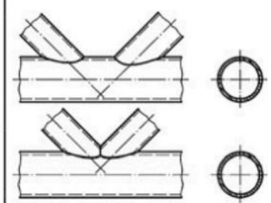
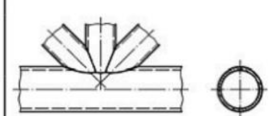
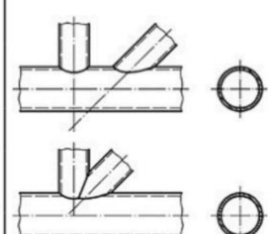
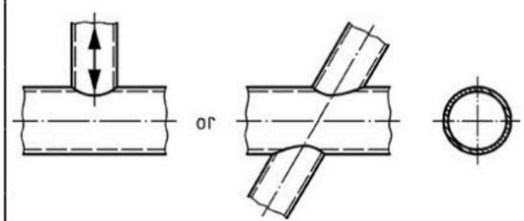
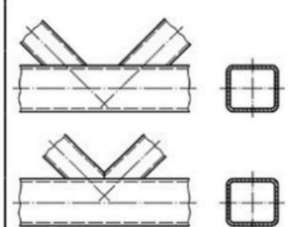
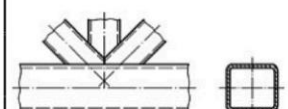
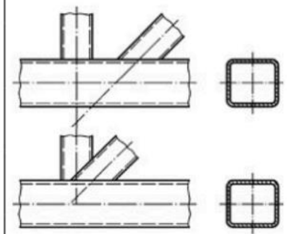
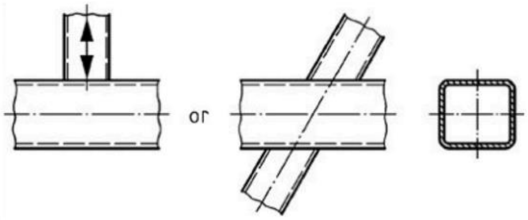
Basic symbols for all items

Basic requirements for all items
a) Bending in individual members should be included in the calculated nominal stress
b) $b_0, d_0 \leq 120mm$. For $b_0, d_0 > 120mm$, the given values of $\Delta\sigma_c$ should be multiplied by the factor f_a
c) $f_a = \sqrt[4]{120 / (b_0, d_0)}$
d) $t_0 \leq 12{,}5mm$
e) Weld thickness a = min t
f) Incline of the diagonal members: $35° \leq \Theta_i \leq 50°$
g) $(b_0, d_0) / t_0 < 25$; $t_0 / t_i \geq 1$; $0{,}6 \leq (b_i, \mathrm{d}_i) / (b_0, d_0) \leq 1$
h) Eccentricity 1) in the plane of the lattice work: $-0{,}5 \leq \mathrm{e} / (h_0, d_0) \leq 0{,}25$ 2) perpendicular to the plane of the lattice work: $\leq 0{,}02 \cdot (b_0, d_0)$
i) Welding under shop conditions. For site welding the given values of $\Delta\sigma_c$ should be multiplied by the factor 0,9.

Table H.2 *(continued)*

<table>
<tr><th>No.</th><th>$\Delta\sigma_c$ (N/mm²)
Intermediate values by straight-line interpolation</th><th>Requirements</th></tr>
<tr><td>1</td><td>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$d_i / d_0 = 0,6$</td><td>36</td><td>80</td></tr>
<tr><td>$d_i / d_0 = 1$</td><td>45</td><td>90</td></tr>
</table>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$d_i / d_0 = 0,6$</td><td>50</td><td>80</td></tr>
<tr><td>$d_i / d_0 = 1$</td><td>56</td><td>90</td></tr>
</table>
</td><td>K-gusset with direct strut joint
a) with gap:

$g \leq 0,3 \cdot d_0$
$g \leq (2/3) \cdot d_i$
$0,3 \leq q / p \leq 1$
b) with overlapping</td></tr>
<tr><td>2</td><td>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$d_i / d_0 = 0,6$</td><td>36</td><td>71</td></tr>
<tr><td>$d_i / d_0 = 1$</td><td>45</td><td>80</td></tr>
</table>
</td><td>K-T-gusset with direct strut joint

$0,3 \leq q / p \leq 1$</td></tr>
<tr><td>3</td><td>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$d_i / d_0 = 0,6$</td><td>18</td><td>56</td></tr>
<tr><td>$d_i / d_0 = 1$</td><td>25</td><td>63</td></tr>
</table>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$d_i / d_0 = 0,6$</td><td>45</td><td>80</td></tr>
<tr><td>$d_i / d_0 = 1$</td><td>50</td><td>90</td></tr>
</table>
</td><td>N-gusset with direct strut joint
a) with gap:

$g \leq 0,3 \cdot d_0$
$g \leq (2/3) \cdot d_i$
$0,3 \leq q / p \leq 1$
b) with overlapping</td></tr>
</table>

<table>
<tr><th>No.</th><th>$\Delta\sigma_c$ (N/mm²)
Intermediate values by straight-line interpolation</th><th>Requirements</th></tr>
<tr><td>4</td><td><table><tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr><tr><td>$d_i / d_0 = 0,6$</td><td>10</td><td>16</td></tr><tr><td>$d_i / d_0 = 1$</td><td>36</td><td>50</td></tr></table></td><td>T- and X-gusset with direct strut joint
$60° \leq \Theta_i \leq 90°$


Bending of boom member should be considered</td></tr>
<tr><td>5</td><td><table><tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr><tr><td>$b_i / b_0 = 0,6$</td><td>32</td><td>63</td></tr><tr><td>$b_i / b_0 = 1$</td><td>36</td><td>71</td></tr></table></td><td>K-gusset with direct strut joint
a) with gap:
$g \leq 0,3 \cdot b_0$
$g \leq (2 / 3) \cdot b_i$

$0,3 \leq q / p \leq 1$
b) with overlapping</td></tr>
<tr><td>6</td><td><table><tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr><tr><td>$b_i / b_0 = 0,6$</td><td>32</td><td>56</td></tr><tr><td>$b_i / b_0 = 1$</td><td>36</td><td>63</td></tr></table></td><td>K-T-gusset with direct strut joint

$0,3 \leq q / p \leq 1$</td></tr>
</table>

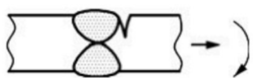
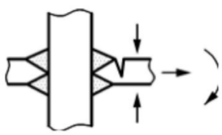
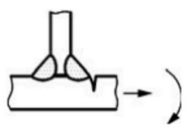
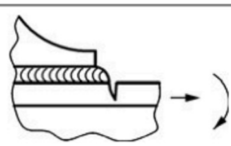
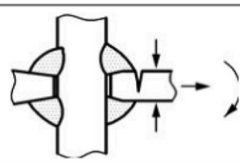
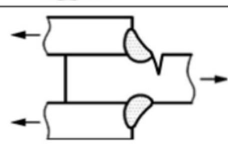
<table>
<tr><th>No.</th><th>$\Delta\sigma_c$ (N/mm²)
Intermediate values by straight-line interpolation</th><th>Requirements</th></tr>
<tr><td>7</td><td>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$b_i / b_0 = 0,6$</td><td>29</td><td>50</td></tr>
<tr><td>$b_i / b_0 = 1$</td><td>36</td><td>56</td></tr>
</table>
</td><td>N-gusset with direct strut joint
a) with gap:
$g \leq 0,3 \cdot b_0$
$g \leq (2 / 3) \cdot b_i$

$0,3 \leq q / p \leq 1$
b) with overlapping</td></tr>
<tr><td>8</td><td>
<table>
<tr><th></th><th>$t_0 / t_i = 1$</th><th>$t_0 / t_i \geq 2$</th></tr>
<tr><td>$b_i / b_0 = 0,6$</td><td>6</td><td>12,5</td></tr>
<tr><td>$b_i / b_0 = 1$</td><td>32</td><td>40</td></tr>
</table>
</td><td>T- and X-gusset with direct strut joint
$60° \leq \Theta_i \leq 90°$


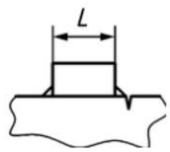
Bending of boom member should be considered</td></tr>
</table>

Annex I
(normative)

Characteristic fatigue strengths for the geometric stress method and the effective notch method

Table I.1 — Characteristic fatigue strengths $\Delta\sigma_c$ for different notch cases for the geometric stress method

Case	Structural detail	Description	Requirements	$\Delta\sigma_c$ (MPa)
1		Butt weld	As welded, quality C	100
			As welded, quality B	112
2		Cruciform or T-joint with full penetration K-butt welds	K-butt welds, as welded	100
3		Non-load-carrying fillet welds	Transverse non-load carrying attachment, not thicker than main plate, as welded	100
4		Bracket ends, ends of longitudinal stiffeners	Fillet welds welded around or not, as welded	100
5		Cover plate ends and similar joints	Fillet weld, as welded	100
6		Cruciform joints with load-carrying fillet welds	Fillet welds, as welded	90
7		Lap joint with load carrying fillet welds	Fillet welds, as welded	90

Case	Structural detail	Description	Requirements	$\Delta\sigma_c$ (MPa)
8		Long attachment welded all around with fillet or full penetration weld	L ≤ 100mm, as welded	100
			L > 100mm, as welded	90
The nominally non- or partially load-carrying fillet welds shown under cases 3 and 5 may actually be load-carrying in certain cases, e.g. for very large attachments or if the bending of the base plate is restrained. In these cases, load-carrying fillet welds shall be assumed with notch classes given under case 6 or 7. This also applies to case 4 without soft bracket end. A further reduction by one notch class shall be applied to fillet welds having throat thicknesses of less than one third of the thickness of the base plate.				

TIG treatment [31] of the weld toe can be used to increase its fatigue strength, in which case the modified characteristic fatigue strengths is given in Table I.2.

Table I.2 — Characteristic fatigue strengths $\Delta\sigma_c$ for TIG treated welds using the geometric stress method

Weld type	Load-carrying fillet welds	Butt welds and non-load-carrying fillet welds
$\Delta\sigma_c$ (MPa)	112	125

Table I.3 — Characteristic fatigue strengths $\Delta\sigma_c$ for the effective notch method

Notch radius (mm)	0,05	0,3	1,0
Weld toe: $\Delta\sigma_c$ (MPa)	500	300	225
Weld root: $\Delta\sigma_c$ (MPa)	630	340	225

Annex J
(informative)

General formula for elastic critical moment in lateral-torsional buckling of a simple beam

Formula (61) provides a solution for elastic critical moment M_{cr} of the simplest case of a simply supported simple beam subjected to equal end moments.

A general formula providing a solution for an elastic critical moment M_{cr} of simple beams, with other cases of end restraints and loadings (shown in tables below) is shown below:

$$M_{cr} = C_1 \times \frac{\pi^2 \times E \times I_z}{(k \times L)^2 \times g} \cdot \left(\sqrt{\left(\frac{k}{k_w}\right)^2 \times \frac{I_w}{I_z} + \frac{(k \times L)^2 \times G \times I_T}{\pi^2 \times E \times I_z} + (C_2 \times z_g)^2} - C_2 \times z_g \right) \quad \text{(J.1)}$$

where

C_1 is the equivalent uniform moment factor providing an allowance for an influence of actual bending moment distribution compared to uniform bending moment distribution (C_1 = 1, the most severe scenario). For values see Table J.1 and Table J.2;

$g = \sqrt{1 - \frac{I_z}{I_y}}$ allows for in-plane curvature prior to buckling (conservatively it may be taken as unity);

k is an effective length parameter, defaults to 1 – see Table J.3 for examples;

k_w is a warping restraint parameter; it should be taken as unity when no warping restraint is provided and conservatively, when the degree of warping restraint is uncertain;

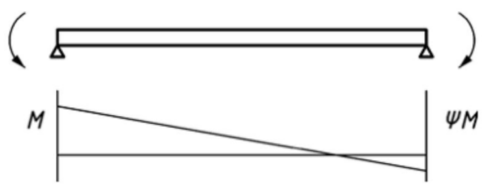
z_g is the distance between the level of application of the loading and the shear centre; z_g is positive for destabilizing loads applied above the shear centre;

C_2 is a parameter associated with the load level relative to shear centre and is dependent on the shape of the bending moment diagram;

NOTE With variables L, Iz, IT, Iw, E, G as specified above and the corresponding values of constants kz, C1 and C2 as specified in the two tables below.

Table J.1 — Values of the equivalent uniform moment factor C_1 as a function of end moment parameter ψ (see Figure J.1)

ψ	C_1	$1/\sqrt{C_1}$
1,00	1,00	1,00
0,75	1,17	0,92
0,50	1,36	0,86
0,25	1,56	0,80
0,00	1,77	0,75
−0,25	2,00	0,71
−0,50	2,24	0,67
−0,75	2,49	0,63
−1,00	2,76	0,60



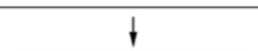
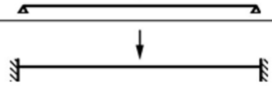
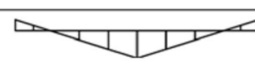
Key

M is the largest end moment

ψ is the end moment parameter

Figure J.1 — Bending moment distribution

Table J.2 — Values for factors C_1 and C_2 as function of beam end restraints and with $z_g = 0$

Loading and Supporting conditions	Bending Moment Diagram	C_1	C_2
		1,13	0,45
		2,60	1,55
		1,35	0,63
		1,69	1,64

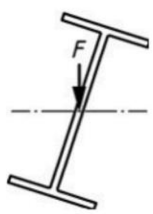
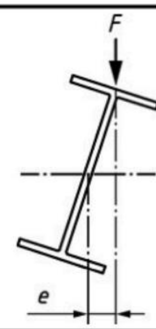
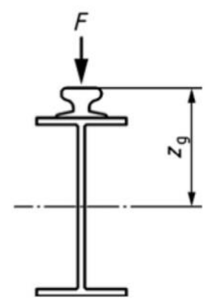
NOTE The values C1 and C2 have been calculated with the conservative assumption of κ = 0.

Table J.3 — Values of k parameter as a function of beam support restraints

Case	Conditions of restraint at supports	k
1	Both flanges fully restrained against rotation	0,7
2	Both flanges partially restrained against rotation	0,8
3	Both flanges free to rotate	1,0
4	Compression flange fully restrained against rotation	0,75
5	Compression flange partially restrained against rotation	0,85

Parameter C_2 takes into account of the effect of loading position relative to shear centre of the beam cross section, see Table J.4. Loads applied above the shear centre are de-stabilizing, resulting in elastic critical moment M_{cr} being reduced, whilst loads below the shear centre are stabilizing, resulting in elastic critical moment M_{cr} being increased.

Table J.4 — Load application level with reference to shear centre

			
Loading at:	a) Shear centre	b) Top flange	c) Above top flange

A non-dimensional parameter $\eta = 2 \times z_g / h_f$ is used to describe this effect. There are three limit cases for a simply supported beam with a uniformly distributed load.

a) Load applied at shear centre $\eta = 0$

b) Load applied at top flange level $\eta = 1$

c) Load applied above top flange $\eta = -1$

With elastic critical moment M_{cr} for case a) denoted as $M_{cr,\eta=0}$, elastic critical moment M_{cr} for cases b) and c) can be calculated from the formula below:

$$\frac{M_{cr}}{M_{cr,\eta=0}} = \frac{\sqrt{1+\frac{1}{\kappa}+\left(C_2 \times \eta\right)^2} - C_2 \times \eta}{\sqrt{1+\frac{1}{\kappa}}} \tag{J.2}$$

where

$$\kappa = \frac{\pi^2 \times E \times I_w}{G \times I_T} \tag{J.3}$$

Annex K
(informative)

Selection of a suitable set of crane standards for a given application

When a product standard in the following list suits the application, use that product standard directly	
EN 13000	Cranes — Mobile cranes
EN 14439	Cranes — Tower cranes
EN 14985	Cranes — Slewing jib cranes
EN 15011	Cranes — Bridge and gantry cranes
EN 13852-1	Cranes — Offshore cranes — Part 1: General purpose offshore cranes
EN 13852-2	Cranes — Offshore cranes — Part 2: Floating cranes
EN 14492-1	Cranes — Power driven winches and hoists — Part 1: Power driven winches
EN 14492-2	Cranes — Power driven winches and hoists — Part 2: Power driven hoists
EN 12999	Cranes — Loader cranes
EN 13157	Cranes — Safety — Hand powered cranes
EN 13155	Cranes — Non-fixed load lifting attachments
EN 14238	Cranes — Manually controlled load manipulating devices
EN 15056	Cranes — Requirements for container handling spreaders
EN 16851	Cranes — Light crane systems
EN 17076	Tower cranes — Anti-collision systems - Safety requirements
When a suitable product standard does not exist, use the following generic standards:	
EN 13001-1	Cranes — General design — Part 1: General principles and requirements
EN 13001-2	Crane safety — General design — Part 2: Load actions
EN 13001-3-1	Cranes — General Design — Part 3–1: Limit States and proof of competence of steel structure
EN 13001-3-2	Cranes — General design — Part 3–2: Limit states and proof of competence of wire ropes in reeving systems
EN 13001-3-3	Cranes — General design — Part 3–3: Limit states and proof of competence of wheel / rail contacts
EN 13001-3-4	Cranes — General design — Part 3–4: Limit states and proof of competence of machinery — Bearings
EN 13001-3-5	Cranes — General design — Part 3–5: Limit states and proof of competence of forged hooks and cast hooks
EN 13001-3-6	Cranes — General design — Part 3–6: Limit states and proof of competence of machinery — Hydraulic cylinders
EN 13135	Cranes — Requirements for equipment
EN 13557	Cranes — Controls and control stations
EN 12077-2	Cranes safety — Requirements for health and safety — Part 2: Limiting and indicating devices
EN 13586	Cranes — Access
EN 14502-1	Cranes — Equipment for the lifting of persons — Part 1: Suspended baskets
EN 14502-2	Cranes — Equipment for the lifting of persons — Part 2: Elevating control stations
EN 12644-1	Cranes — Information for use and testing — Part 1: Instructions
EN 12644-2	Cranes — Information for use and testing — Part 2: Marking

Annex L
(informative)

List of hazards

Table L.1 is provided in this Annex, showing the significant, hazardous situations, hazardous events according CEN GUIDE 414:2017 and their relation to the Essential Requirements of the Machinery Directive 2006/42/EC and the risk reduction relevant requirement clause(s) of this document.

As a starting point, Annex ZA (informative) and the entry of the reference in the OJEU should be checked to ensure that the standard's presumption of conformity does not exclude any essential health and safety requirements.

Table L.1 — List of hazards

Group	**Significant hazard in accordance with EN ISO 12100:2010,** Table B.1	**Directive 2006/42/EC, Annex I**	**Relevant clause(s) in this document**
General, for many machines relevant			
1	**Mechanical hazards**		
1.1	Due to machine parts or workpieces, e.g. — by potential energy (falling objects, height from the ground, gravity) — by kinetic energy (acceleration, deceleration, moving/rotating elements) — by mechanical strength (break-up)	1.3.2 Risk of break-up during operation	4, 5, 6, 7, 8
Supplementary, due to lifting operations			
22	**Mechanical hazards caused by load falls, collisions, machine tipping**		
22.9	Insufficient mechanical strength of parts	4.1.2.3 Mechanical strength	4, 5, 6, 7, 8

Annex M
(normative)

Specific values of steels for structural members

Table M.1 — Specific values of steels for structural members

Steel	Standard	Thickness t mm	Nominal strength f_y yield N/mm²	Nominal strength f_u ultimate N/mm²
S235	EN 10025-2:2019	$t \leq 16$	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 10025-3:2019 (N) EN 10025-4:2019+ A1:2022 (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
		$16 < t \leq 40$	440	
		$40 < t \leq 63$	430	
		$63 < t \leq 80$ (N)	410	
		$80 < t \leq 100$ (N)	400	

Steel	Standard	Thickness t mm	Nominal strength f_y yield N/mm²	Nominal strength f_u ultimate N/mm²
S460	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	460	550
S460	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	440	550
S500	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	500	590
S500	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	480	590
S550	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	550	640
S550	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	530	640
S620	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	620	700
S620	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	580	700
S690	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	690	770
S690	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	650	760
S890	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	890	940
S890	EN 10025-6:2019+A1:2022	$50 < t \leq 100$	830	880
S960	EN 10025-6:2019+A1:2022	$3 < t \leq 50$	960	980
S315	EN 10149-2:2013 EN 10149-3:2013	all t	315	390
S355	EN 10149-2:2013 EN 10149-3:2013	all t	355	430
S420	EN 10149-2:2013 EN 10149-3:2013	all t	420	480
S460	EN 10149-2:2013	all t	460	520
S500	EN 10149-2:2013	all t	500	550
S550	EN 10149-2:2013	all t	550	600
S600	EN 10149-2:2013	all t	600	650
S650	EN 10149-2:2013	$t \leq 8$	650	700
S650	EN 10149-2:2013	$t > 8$	630	700
S700	EN 10149-2:2013	$t \leq 8$	700	750
S700	EN 10149-2:2013	$t > 8$	680	750
S900	EN 10149-2:2013	all t	900	930
S960	EN 10149-2:2013	all t	960	980
X2CrNi18–9	EN 10088-2:2024 EN 10088-3:2023	$t \leq 75$	200 [a]	500 [b]
X5CrNi18–10	EN 10088-2:2024 EN 10088-3:2023	$t \leq 75$	210 [a]	520 [b]
X2CrNi19–11	EN 10088-2:2024 EN 10088-3:2023	$t \leq 75$	200 [a]	500 [b]
X2CrNiMo17–12–2	EN 10088-2:2024 EN 10088-3:2023	$t \leq 75$	220 [a]	520 [b]
X5CrNiMo17–12–2	EN 10088-2:2024 EN 10088-3:2023	$t \leq 75$	220 [a]	520 [b]

[a] 0,2 % – proof strength for hot rolled plate (P);

[b] Tensile strength for hot rolled plate (P).

Annex ZA
(informative)

Relationship between this European Standard and the essential requirements of Directive 2006/42/EC aimed to be covered

This European Standard has been prepared under a Commission's standardization request "M/396 Mandate to CEN and CENELEC for Standardisation in the field of machinery" to provide one voluntary means of conforming to essential requirements of Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast).

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding essential requirements of that Directive, and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Annex I of Directive 2006/42/EC

The relevant Essential Requirements of Directive 2006/42/EC	Clause(s)/sub-clause(s) of this EN	Remarks/Notes
1.3.2	4.1, 4.2, 4.3, 4.4, 4.5, 4,6, 5.1, 5.2, 5.3, 6.1, 6.2.2, 6.2.3, 6.2.4, 6.2.5, 6.2.6, 6.3, 6.4, 6.5.1, 6.5.2, 6.5.3.2, 6.5.3.3, 6.5.3.4, 6.5.4, 7, 8.1, 8.2, 8.3, 8.4.2, 8.4.3, 8.4.4, 8.5	
4.1.2.3	4.1, 4.2, 4.3, 4.4, 4.5, 4,6, 5.1, 5.2, 5.3, 6.1, 6.2.2, 6.2.3, 6.2.4, 6.2.5, 6.2.6, 6.3, 6.4, 6.5.1, 6.5.2, 6.5.3.2, 6.5.3.3, 6.5.3.4, 6.5.4, 7, 8.1, 8.2, 8.3, 8.4.2, 8.4.3, 8.4.4, 8.5	

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) falling within the scope of this standard.

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