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Cranes — Proof of competence of steel structures

Appareils de levage à charge suspendue — Vérification d'aptitude des charpentes en acier

Reference number
ISO 20332:2016(E)

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html

The committee responsible for this document is ISO/TC 96, *Cranes*, Subcommittee SC 10, *Design principles and requirements*.

This second edition cancels and replaces the first edition (ISO 20332:2008), which has been technically revised.

Cranes — Proof of competence of steel structures

1 Scope

This International Standard sets forth general conditions, requirements, methods, and parameter values for performing proof-of-competence determinations of the steel structures of cranes based upon the limit state method. It is intended to be used together with the loads and load combinations of the applicable parts of ISO 8686.

This International Standard is general and covers cranes of all types. Other International Standards can give specific proof-of-competence requirements for particular crane types.

Proof-of-competence determinations, by theoretical calculations and/or testing, are intended to prevent hazards related to the performance of the structure by establishing the limits of strength, e.g. yield, ultimate, fatigue, and brittle fracture.

According to ISO 8686-1 there are two general approaches to proof-of-competence calculations: the *limit state* method, employing partial safety factors, and the *allowable stress* method, employing a global safety factor. Though it does not preclude the validity of allowable stress methodology, ISO 20332 deals only with the limit state method.

Proof-of-competence calculations for components of accessories (e.g. handrails, stairs, walkways, cabins) are not covered by this International Standard. However, the influence of such attachments on the main structure needs to be considered.

2 Normative references

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

ISO 148-1:2009, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 273:1979, *Fasteners — Clearance holes for bolts and screws*

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*. Corrected by ISO 286-2:2010/Cor 1:2013.

ISO 404:1992, *Steel and steel products — General technical delivery requirements*

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 4042:1999, *Fasteners — Electroplated coatings*

ISO 4301-1:2016, *Cranes and lifting appliances — Classification — Part 1: General*

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

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

ISO 7452:2013, *Hot-rolled steel plates — Tolerances on dimensions and shape*

ISO 7788:1985, *Steel — Surface finish of hot-rolled plates and wide flats — Delivery requirements*

ISO 8686-1:2012, *Cranes — Design principles for loads and load combinations — Part 1: General*

ISO 8686-2, *Cranes — Design principles for loads and load combinations — Part 2: Mobile cranes*

ISO 8686-3, *Cranes — Design principles for loads and load combinations— Part 3: Tower cranes*

ISO 8686-4, *Cranes — Design principles for loads and load combinations— Part 4: Jib cranes*

ISO 8686-5, *Cranes — Design principles for loads and load combinations— Part 5: Overhead travelling and portal bridge cranes*

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

ISO 9587:2007, *Metallic and other inorganic coatings — Pretreatments of iron or steel to reduce the risk of hydrogen embrittlement*

ISO 12100, *Safety of machinery — Basic concepts, general principles for design — Risk assessment and risk reduction*

ISO 15330:1999, *Fasteners — Preloading test for the detection of hydrogen embrittlement — Parallel bearing surface method*

ISO 17659:2002, *Welding — Multilingual terms for welded joints with illustrations*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 12100, ISO 17659, ISO 4306-1:2007, Clause 6, and the following terms, definitions, symbols and abbreviated terms (see Table 1) apply.

3.1
grade of steel
marking that defines the strength of steel, usually defining yield stress, f_y, sometimes also ultimate strength, f_u

3.2
quality of steel
marking that defines the impact toughness and test temperature of steel

Table 1 — Main symbols and abbreviations used in this International Standard

Symbol	Description
A	Cross-section
A_{eq}	Equivalent area for calculation
A_n	Net cross-sectional area at bolt or pin holes
A_r	Minor area of the bolt
A_S	Stress area of the bolt
a	Geometric dimension
a_{hi}	Geometric dimension for weld penetration
a_r	Effective weld thickness
b	Geometric dimension
c	Geometric dimension
D_A	Diameter of available cylinder of clamped material
D_i	Inner diameter of hollow pin
D_o	Outer diameter of hollow pin
d	Diameter (shank of bolt, pin)
d_h	Diameter of the hole
d_w	Diameter of the contact area of the bolt head
d_0	Diameter of the hole
E	Modulus of elasticity
e_1, e_2	Edge distances
F	Force
F_b	Tensile force in bolt
$F_{b,Rd}$	Limit design bearing force
$F_{b,Sd}$, $F_{bi,Sd}$	Design bearing force
ΔF_b	Additional force
F_{cr}	Reduction in the compression force due to external tension
$F_{cs,Rd}$	Limit design tensile force
F_d	Limit force
$F_{e,t}$	External force (on bolted connection)
F_k	Characteristic value (force)
F_p	Preloading force in bolt

Table 1 (*continued*)

Symbols	Description
$F_{p,d}$	Design preloading force
F_{Rd}	Limit design force
F_{Sd}	Design force of the element
$F_{s,Rd}$	Limit design slip force per bolt and friction interface
$F_{t1,Rd}$, $F_{t2,Rd}$	Limit design tensile forces per bolt
$F_{t,Sd}$	External tensile force per bolt
$F_{v,Rd}$	Limit design shear force per bolt/pin and shear plane
$F_{v,Sd}$	Design shear force per bolt/pin and shear plane
$F_{\sigma,\tau}$	Acting normal/shear force
f	Out-of-plane imperfection of plate field
$f_{b,Rd,x}$	Limit design compressive longitudinal stress
$f_{b,Rd,y}$	Limit design compressive transverse stress
$f_{b,Rd,\tau}$	Limit design buckling shear stress
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_{uw}	Ultimate strength of the weld
$f_{w, Rd}$	Limit design weld stress
f_y	Yield stress of material or 0,2 % offset yield strength
f_{yb}	Yield stress of bolts
f_{yk}	Yield stress (minimum value) of base material or member
f_{yp}	Yield stress of pins
h	Thickness of workpiece
h_d	Distance between weld and contact area of acting load
I	Moment of inertia
K_b	Stiffness (slope) of bolt
K_c	Stiffness (slope) of flanges
k_m	Stress spectrum factor based on m of the detail under consideration

Table 1 (*continued*)

Symbols	Description
k^*	Specific spectrum ratio factor
$k_{\sigma x}$, k_{τ}	Buckling factors for plate fields
L	Length of compressed member
l_k	Effective clamped length
l_m	Gauge length for imperfection of plate field
l_r	Effective weld length
l_w	Weld length
l_1	Effective length for tension without threat
l_2	Effective length for tension with threat
M_{Rd}	Limit design bending moment
M_{Sd}	Design bending moment
m	(Negative inverse) slope constant of log σ/log N curve
N	Number of stress cycles to failure by fatigue
N_c	Compressive force
N_k	Critical buckling load of compressed member
N_{Rd}	Limit design compressive force
N_{Sd}	Design compressive force
N_{ref}	Number of cycles at the reference point
N_t	Total number of occurrences
NC	Notch class
NDT	Non-destructive testing
n_i	Number of stress cycles with stress amplitude of range i
n	Number of equally loaded bolts
P_s	Probability of survival
p_1, p_2	Distances between bolt centres
Q	Shear force
q_i	Impact toughness parameter
R_d	Design resistance
r	Radius of wheel
S	Class of stress history parameter, s
S_d	Design stresses or forces

Table 1 (*continued*)

Symbols	Description
s_m	Stress history parameter
T	Temperature
TIG	Tungsten inert gas
t	Thickness
U	Class of working cycles
u	Shape factor
v	Diameter ratio
W_{el}	Elastic section modulus
α	Characteristic factor for bearing connection
α_w	Characteristic factor for limit weld stress
γ_{mf}	Fatigue strength specific resistance factor
γ_m	General resistance factor
γ_p	Partial safety factor
γ_R	Total resistance factor
γ_{Rb}	Total resistance factor of bolt
γ_{Rc}	Total resistance factor for tension on sections with holes
γ_{Rm}	Total resistance factor of members
γ_{Rp}	Total resistance factor of pins
γ_{Rs}	Total resistance factor of slip-resistance connection
γ_s	Specific resistance factor
γ_{sb}	Specific resistance factor of bolt
γ_{sm}	Specific resistance factor of members
γ_{sp}	Specific resistance factor of pins
γ_{ss}	Specific resistance factor of slip-resistance connection
γ_{st}	Specific resistance factor for tension on sections with holes
$\Delta\delta_t$	Additional elongation
δ_p	Elongation from preloading
Θ_i	Incline of diagonal members
κ	Dispersion angle
λ	Width of contact area in weld direction
μ	Slip factor

Table 1 (*continued*)

Symbols	Description
ν	Relative total number of stress cycles (normalized)
ν_D	Ratio of diameters
σ	Indicate the respective stress
Δ_σ	Stress range
$\Delta\sigma_i$	Stress range *i*
$\Delta\hat{\sigma}$	Maximum stress range
σ_b	Lower extreme value of stress cycle
$\Delta\sigma_c$	Characteristic fatigue strength (normal stress)
σ_e	Reference stress for plate buckling
σ_m	Constant mean stress selected for one-parameter classification of stress cycles
$\Delta\sigma_{Rd}$	Limit design stress range (normal)
$\Delta\sigma_{Rd,1}$	Limit design stress range for $k^* = 1$
σ_{Sd}	Design stress (normal)
$\Delta\sigma_{Sd}$	Design stress range (normal)
$\sigma_{Sd,x}$	Design compressive longitudinal stress
$\sigma_{Sd,y}$	Design compressive transverse stress
σ_u	Upper extreme value of stress cycle
$\sigma_{w, Sd}$	Design weld stress (normal)
σ_x, σ_y	Normal stress component in direction *x*, *y*
$\hat{\sigma}_a$	Maximum stress amplitude
min σ, max σ	Extreme values of stresses
τ	Shear stress
$\Delta\tau_c$	Characteristic fatigue strength (shear stress)
τ_{Sd}	Design stress (shear)
$\Delta\tau_{Sd}$	Design stress range (shear)
$\Delta\tau_{Rd}$	Limit design stress range (shear)
$\tau_{w, Sd}$	Design weld stress (shear)
ϕ_i	Dynamic factor
Ψ	Stress ratio across plate fields

4 General

4.1 General principles

Proof-of-competence calculations shall be done for components, members, and details exposed to loading or repetitive loading cycles that could cause failure, cracking, or distortion interfering with crane functions.

NOTE See ISO 8686 for further information applicable to the various types of crane. Not all calculations are applicable for every crane type.

4.2 Documentation

The documentation of the proof-of-competence calculations shall include the following:

— design assumptions including calculation models;

— applicable loads and load combinations;

— material properties;

— weld quality classes in accordance with ISO 5817;

— properties of connecting elements;

— relevant limit states;

— results of the proof-of-competence calculations and tests when applicable.

4.3 Alternative methods

The competence may be verified by experimental methods in addition to or in coordination with the calculations. The magnitude and distribution of loads during tests shall correspond to the design loads and load combinations for the relevant limit states.

Alternatively, advanced and recognized theoretical or experimental methods generally may be used, provided that they conform to the principles of this International Standard.

4.4 Materials of structural members

It is recommended that steels in accordance with the following International Standards be used:

— ISO 630;

— ISO 6930-1;

— ISO 4950-1;

— ISO 4951-1, ISO 4951-2, and ISO 4951-3.

Where other steels are used, the specific values of strengths f_u and f_y shall be specified. The mechanical properties and the chemical composition shall be specified in accordance with ISO 404. Furthermore, the following conditions shall be fulfilled:

— the design value of f_y shall be 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 shall be specified and, if intended for welding, weldability demonstrated;

— if the material is intended for cold forming, the pertinent parameters shall be specified.

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 ISO 7452:2013. Otherwise, the actual minimum value of plate thickness shall be used.

When verifying the grade and quality of the steel (see referenced International Standards) used for tensile members, the sum of impact toughness parameters, q_i, shall be taken into account. Table 2 gives q_i for various influences. The required impact energy/test temperatures in dependence of $\sum q_i$ are shown in Table 3 and shall be specified by the steel manufacturer on the basis of ISO 148-1.

Table 2 — Impact toughness parameters, q_i

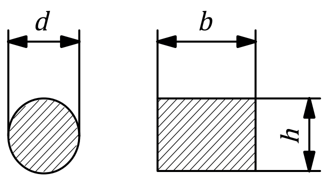
i	**Influence**		q_i
1	Operating temperature T (°C)	$0 \le T$	0
		$-10 \le T < 0$	1
		$-20 \le T < -10$	2
		$-30 \le T < -20$	3
		$-40 \le T < -30$	4
		$-50 \le T < -40$	6
2	Yield stress f_y (N/mm^2)	$f_y \le 300$	0
		$300 < f_y \le 460$	1
		$460 < f_y \le 700$	2
		$700 < f_y \le 1\,000$	3
		$1\,000 < f_y \le 1\,300$	4
3	Material thickness t (mm) Equivalent thickness t for solid bars:  $t = \frac{d}{1,8}$ for $\frac{b}{h} < 1,8:\ t = \frac{b}{1,8}$	$t \le 10$	0
		$10 < t \le 20$	1
		$20 < t \le 40$	2
		$40 < t \le 60$	3
		$60 < t \le 80$	4
		$80 < t \le 100$	5
		$100 < t \le 125$	6
		$125 < t \le 150$	7
4	Characteristic value of stress range $\Delta\sigma_c$ (N/mm^2) (see Annex D)	$\Delta\sigma_c > 125$	0
		$80 < \Delta\sigma_c \le 125$	1
		$56 < \Delta\sigma_c \le 80$	2
		$40 < \Delta\sigma_c \le 56$	3
		$30 < \Delta\sigma_c \le 40$	4
		$\Delta\sigma_c \le 30$	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 $\sigma_{Sd} \le 0,75 \times f_{Rd\sigma}$	−1
		$0,25 \times f_{Rd\sigma} < \sigma_{Sd}$ and $\sigma_{Sd} \le 0,5 \times f_{Rd\sigma}$	−2
		$\sigma_{Sd} \le 0,25 \times f_{Rd\sigma}$	−3

Table 3 — Impact toughness requirement for $\sum q_i$

	$\sum q_i \le 5$	$6 \le \sum q_i \le 8$	$9 \le \sum q_i \le 11$	$12 \le \sum q_i \le 14$
Impact energy/ test temperature requirement	27 J/ + 20°C	27 J/0 °C	27 J/ −20 °C	27 J/ −40 °C

4.5 Bolted connections

4.5.1 Bolt materials

For bolted connections, bolts of the property classes (bolt grades) in accordance with ISO 898-1:2013 given in Table 4 shall be used. Table 4 shows nominal values of the strengths.

Table 4 — Property classes (bolt grades)

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

Where necessary, the designer should ask the bolt provider to demonstrate compliance with the requirements for protection against hydrogen brittleness relative to the property classes (bolt grades) 10.9 and 12.9. Technical requirements can be found in ISO 15330, ISO 4042, and ISO 9587.

4.5.2 General

For the purposes of this International Standard, bolted connections are connections between members and/or components utilizing bolts where the following applies:

— bolts shall be tightened sufficiently to compress the joint surfaces together when subjected to vibrations, reversals or fluctuations in loading, or where slippage can cause deleterious changes in geometry;

— in general, bolted connections can be made wrench tight;

— the joint surfaces shall be secured against rotation (e.g. by using multiple bolts).

4.5.3 Shear and bearing connections

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

— the clearance between the bolt and the hole shall conform to ISO 286-2:2010, tolerances h13 and H11, or closer, when bolts are exposed to load reversal or where slippage can cause deleterious changes in geometry;

— in other cases, wider clearances in accordance with ISO 273 may be used,

— only the unthreaded part of the shank shall be considered in the bearing calculations;

— special surface treatment of the contact surfaces is not required.

4.5.4 Friction grip type (slip resistant) connections

For the purposes of this International Standard, friction grip connections are those connections where the loads are transmitted by friction between the joint surfaces and where the following applies:

— high strength bolts of property classes (bolt grades) 8.8, 10.9 or 12.9 according to ISO 898-1:2013 shall be used;

— bolts shall be tightened by a controlled method to a specified preloading state;

— the surface condition of the contact surfaces shall be specified and taken into account accordingly;

— in addition to standard holes, oversized and slotted holes may be used.

4.5.5 Connections loaded in tension

For the purposes of this International Standard, connections loaded in tension are those connections where the loads act in the direction of the bolt axis and cause axial stresses in the bolts and where the following applies:

— preloaded joints shall comprise high strength bolts of property classes (bolt grades) 8.8, 10.9 or 12.9 according to ISO 898-1:2013 tightened by a controlled method to a specified preloading state;

— the additional bolt tension that can be induced by leverage action (prying) due to joint geometry shall be considered;

— evaluation of bolt fatigue shall consider variations in bolt tension affected by the structural features of the joint, e.g. stiffness of the connected parts and prying action.

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

4.6 Pinned connections

For the purposes of this International Standard, pinned connections are connections that do not constrain rotation between the 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 ISO 286-2:2010, tolerances h13 and H13, or closer. In case of loads with changing directions, closer tolerances shall be applied.

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

When pinned connections are intended to permit rotation under load, the retaining means shall restrict the axial displacement of the pin.

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

4.7 Welded connections

For the purposes of this International Standard, welded connections are joints between members and/or components that utilize fusion welding processes and where the joined parts are 3 mm or larger in thickness.

Terms for welded connections are as given in ISO 17659.

The quality levels of ISO 5817 are applicable and appropriate methods of non-destructive testing shall be used to verify compliance with quality level requirements.

In general, ISO 5817:2014, quality level C, is acceptable in connections requiring a static proof of competence.

ISO 5817:2014, 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.

Although the distribution of stresses along the length of the weld can be non-uniform, such distributions can, in most cases, be considered uniform, in which case the effective weld length shall not exceed 150 times the weld thickness a. However, other stress distributions may be assumed provided they satisfy the basic requirements of equilibrium and continuity and that they adequately relate to the actual deformation characteristics of the joint.

Residual stresses and stresses not participating in the transfer of forces need not 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.

4.8 Proof-of-competence for structural members and connections

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

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

The design stresses or forces, S_d, shall be determined by applying the relevant loads, load combinations, and partial safety factors from the applicable parts of ISO 8686.

In the following clauses, the design resistances, R_d, are represented by 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 elastic stability in accordance with Clause 7.

5 Proof of static strength

5.1 General

Proof of static strength by calculation is intended to prevent excessive deformation due to yielding of the material, sliding of friction-grip connections, elastic instability (see Clause 7), and fracture of structural members or connections. Dynamic factors given in the applicable parts of ISO 8686 or in product standards implementing ISO 8686-1 shall be used to produce static-equivalent loads to simulate dynamic effects.

The use of the theory of plasticity for calculation of ultimate load bearing capacity is not considered acceptable within the terms of this International Standard.

The proof shall be carried out for structural members and connections while taking into account the most unfavourable effects under load combinations A, B, or C from the applicable parts of ISO 8686 and comparing them with the design resistances given in 5.2.

This International Standard considers only nominal stresses, i.e. those calculated using traditional elastic strength of materials theory; localized stress concentration effects are excluded. When alternative methods of stress calculation are used such as finite element analysis, using those stresses directly for the proof given in this International Standard could yield inordinately conservative results as the given limit states are intended to be used in conjunction with nominal stresses.

5.2 Limit design stresses and forces

5.2.1 General

The limit design stresses shall be calculated from

$$f_{\mathrm{Rd}} = f(f_{\mathrm{k}}, \gamma_{\mathrm{R}}) \tag{2}$$

Limit design forces shall be calculated from

$$F_{\mathrm{Rd}} = f(F_{\mathrm{k}}, \gamma_{\mathrm{R}}) \tag{3}$$

where

f_k, F_k are characteristic (or nominal) values;

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

γ_m is the general resistance factor: $\gamma_m = 1{,}1$;

This constant value replaces all those from the applicable parts of ISO 8686.

γ_s is the specific resistance factor applicable to specific structural components as given in the subclauses below.

f_{Rd} and F_{Rd} are equivalent to R/γ_m in ISO 8686-1:2012, Figure A.2.

5.2.2 Limit design stress in structural members

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

$$f_{\mathrm{Rd}\sigma} = \frac{f_{\mathrm{yk}}}{\gamma_{\mathrm{Rm}}} \text{ for normal stresses} \tag{4}$$

$$f_{\mathrm{Rd}\tau} = \frac{f_{\mathrm{yk}}}{\gamma_{\mathrm{Rm}}\sqrt{3}} \text{ for shear stresses} \tag{5}$$

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

where

f_{yk} is the minimum value of the yield stress of the material;

γ_{sm} is the specific resistance factor for material:

— for non-rolled material: $\gamma_{sm} = 0{,}95$;

— for rolled material (e.g. plates and profiles):

γ_{sm} = 0,95 for stresses in the plane of rolling;

γ_{sm} = 0,95 for compressive and shear stresses;

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

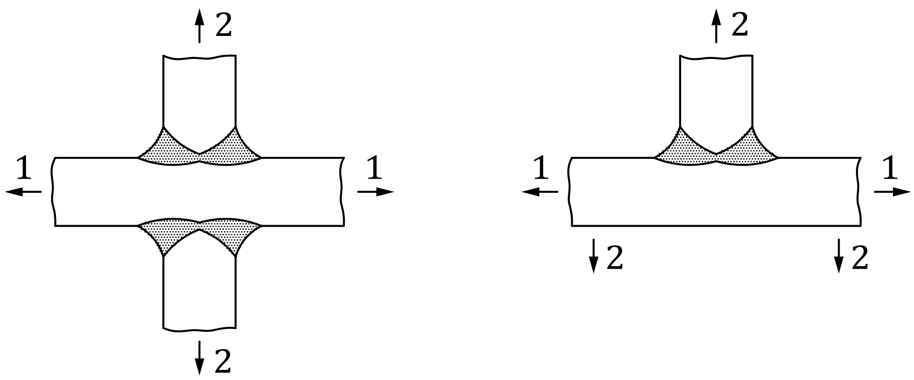
γ_{sm} = 1,0 for plate thicknesses less than 15 mm or material with reduction in area of more than 20 %;

γ_{sm} = 1,16 for material with reduction in area of 20 % to 10 %;

γ_{sm} = 1,50 for material with reduction in area of less than 10 %.

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

NOTE Reduction in area is the difference, expressed as a percentage of the initial area between the initial cross-sectional area of a tensile test specimen and the minimum cross-sectional area measured after complete separation.



Key

1 direction of the plane of rolling

2 direction of stress/load

Figure 1 — Tensile load 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 the following.

When threads are not within the shear plane

$$F_{v,Rd} = \frac{f_{yb} \times A}{\gamma_{Rb} \times \sqrt{3}} \tag{6}$$

When threads are within a shear plane

$$F_{v,Rd} = \frac{f_{yb} \times A_S}{\gamma_{Rb} \times \sqrt{3}} \tag{7}$$

Or, for simplification

$$F_{v,Rd} = 0,75 \times \frac{f_{yb} \times A}{\gamma_{Rb} \times \sqrt{3}} \tag{8}$$

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

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;

A_S is the stress area of the bolt (see ISO 898-1);

γ_{sb} is the specific resistance factor for bolted connections:

γ_{sb} = 1,0 for multiple shear plane connections;

γ_{sb} = 1,3 for single shear plane connections.

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

5.2.3.1.3 Bearing on bolts and connected parts

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

$$F_{b,Rd} = \frac{f_y \times d \times t}{\gamma_{Rb}} \tag{9}$$

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

where

f_y is the lowest yield stress of the materials in the joint;

d is the shank diameter of the bolt;

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

γ_{sb} is the specific resistance factor for bolted connections:

γ_{sb} = 0,7 for multiple shear plane connections;

γ_{sb} = 0,9 for single shear plane connections.

With the following requirements for the plate:

$$e_1 \geq 1{,}5 \times d_0 \tag{10}$$

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

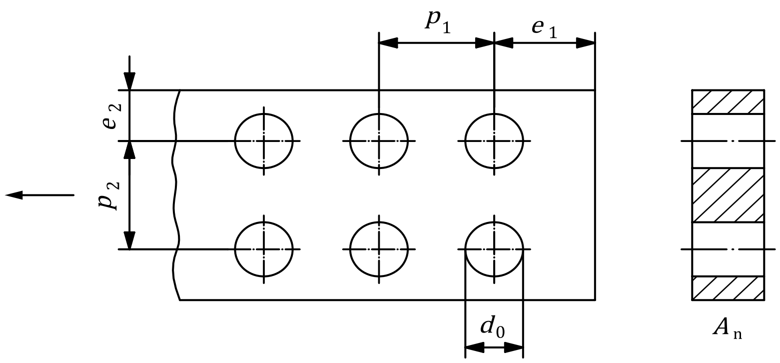
$$p_1 \geq 3{,}0 \times d_0$$

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

where

p_1, p_2, e_1, e_2 are distances (see Figure 2);

d_0 is the diameter of the hole.



NOTE See also Formula (11).

Figure 2 — Illustration of Formula (10)

5.2.3.1.4 Tension in connected parts

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

$$F_{cs,Rd} = \frac{f_y \times A_n}{\gamma_{Rc}} \tag{11}$$

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

where

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

γ_{st} is the specific resistance factor for tension on sections with holes:

γ_{st} = 1,2.

5.2.3.2 Friction grip type connections

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

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

$$F_{s,Rd} = \frac{\mu \times (F_{p,d} - F_{cr})}{\gamma_{Rs}} \quad (12)$$

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

where

μ is the friction coefficient:

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

μ = 0,50 for surfaces blasted with steel grit or sand and aluminized;

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

μ = 0,40 for surfaces blasted with steel grit or sand and alkali-zinc-silicate coating of 50 µm to 80 µm thickness;

μ = 0,40 for surfaces hot-dip galvanized and lightly blasted;

μ = 0,30 for surfaces cleaned metallic bright with wire brush or scarfing;

μ = 0,25 for surfaces cleaned and treated with etch primer;

μ = 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 (as a conservative assumption that does not require the calculation of a stiffness ratio, see 5.2.3.3, $F_{cr} = F_e$ can be used);

γ_{ss} is the specific resistance factor for friction grip type connections (see Table 5).

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

Table 5 — Specific resistance factor, γ_{ss}, for friction grip connections

Effect of connection slippage	Type of hole			
	Standard[a]	Oversized[b] and short-slotted[c]	Long-slotted[c]	Long-slotted[d]
Hazard created	1,14	1,34	1,63	2,00
No hazard created	1,00	1,14	1,41	1,63

[a] Holes with clearances in accordance with the medium series of ISO 273.

[b] Holes with clearances in accordance with the coarse series of ISO 273.

[c] Slotted holes with slots perpendicular to the direction of force.

[d] Slotted holes with slots parallel to the direction of force.

Short-slotted holes: the length of the hole is smaller than or equal to 1,25 times the diameter of the bolt.

Long-slotted holes: the length of the hole is larger than 1,25 times the diameter of the coarse series of the bolt. In order to reduce pressure under the bolt or nut, appropriate washers shall be used.

See Annex B for limit design slip forces using, for example, a specific resistance factor for friction grip of γ_{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 (see Table 4);

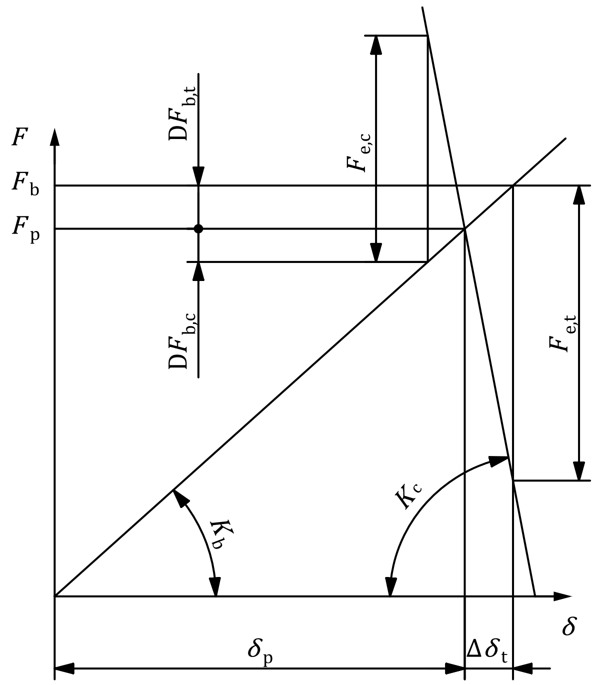
A_S is the stress area of the bolt.

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 following 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).

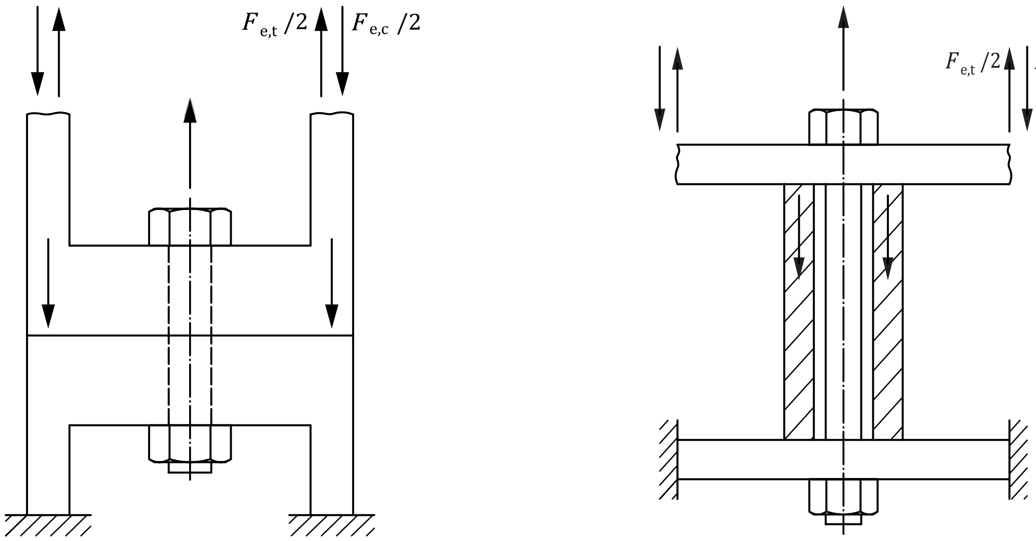


Key

F_p	preloading force in bolt	F_b	tensile force in bolt
δ_p	bolt elongation due to preloading	$\Delta F_{b,t}$	additional force in bolt due to external tensile force
$F_{e,t}$	external tensile force	$\Delta F_{b,c}$	additional force in bolt due to external compression force
$F_{e,c}$	external compression force	slope K_b	stiffness of bolt
$\Delta\delta_t$	additional elongation due to external tensile force	slope K_c	stiffness of connected parts

Figure 3 — Force-elongation diagram

Additionally, the load path of the external compression force based upon the joint construction shall be taken into account (see Figure 4).



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

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

Figure 4 — Load path alternatives for the external compression force

Two separate design limits are to be considered for the external tensile bolt force.

a) The resulting bolt force under the external force and under the maximum design preload shall not exceed the bolt yield load [see Formula (13)].

b) The connection under the external force and under the minimum design preload shall not open (gap) [see Formula (14)].

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

The limit design tensile force per bolt for the bolt yield criteria is calculated from

$$F_{t1,Rd} = \frac{F_y / \gamma_{Rb} - F_{p,max}}{\Phi} \tag{13}$$

with

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

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

where

F_y is the bolt yield force;

$F_{p,max}$ is the maximum value of the design preload [see Formula (15)];

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 also Annex G);

γ_{sb} is the specific resistance factor for connections loaded in tension: γ_{sb} = 0,91.

A load introduction factor, α_L, may be taken into account when calculating factor Φ (see Annex G).

The limit design tensile force per bolt for the opening criteria of the connection is calculated from

$$F_{t2,Rd} = \frac{F_{p,min}}{\gamma_{Rb} \times \left(1 - \Phi\right)} \tag{14}$$

where $F_{p,min}$ is the minimum value of the design preload.

The scatter of preload is taken into account by the maximum and minimum values of the design preload as follows.

$$F_{p,max} = \left(1 + s\right) \times F_{pn} \tag{15}$$

and

$$F_{p,min} = \left(1 - s\right) \times F_{pn} \tag{16}$$

where

F_{pn} is the nominal, target value of the applied preload;

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

$F_{p,min}$ is the minimum value of the design preload;

s is the preload scatter:

s = 0,23 where controlled tightening, rotation angle, or tightening torque is measured;

s = 0,09 where controlled tightening, force in bolt, or elongation is measured.

When several identical and equally loaded bolts are used in a connection, the scatter used for computing $F_{p,min}$ in Formula (16) may be taken as

$$s = 0{,}23 \big/ \sqrt{n}\,,\ s \geq 0{,}10$$

where controlled tightening, rotation angle, or tightening torque is measured, and

$$s = 0{,}09 \big/ \sqrt{n}\,,\ s \geq 0{,}05$$

where controlled tightening, force in bolt, or elongation is measured,

where n is the number of identical and equally loaded bolts.

The nominal preload, $F_{p,n}$, value shall be limited to that given in Table 6. Otherwise, any value for the preload may be chosen for a particular connection.

Table 6 — Maximum nominal preload levels in accordance with method of preloading

Types of preloading method	Maximum nominal preload level
Methods where torque is applied to the bolt	0,7 F_y
Methods where only direct tension is applied to the bolt	0,9 F_y

See Annex B 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 the bolt is calculated as follows.

$$\Delta F_b = \Phi \times \left(F_{e,t} + F_{e,c}\right) \tag{17}$$

where

ΔF_b is the additional force in the bolt;

Φ is the stiffness ratio factor;

$F_{e,t}$ is the external tensile force;

$F_{e,c}$ is the external compression force.

The external compression force, $F_{e,c}$, shall be omitted (i.e. set to zero in the formula) in cases where it does not interfere with the compression zone under the bolt as illustrated in Figure 4 a).

The additional force in the 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.

$$\left(\frac{F_{t,Sd}}{F_{t,Rd}}\right)^2 + \left(\frac{F_{v,Sd}}{F_{v,Rd}}\right)^2 \leq 1 \tag{18}$$

where

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

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

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

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

5.2.4 Limit design forces in pinned connections

5.2.4.1 Pins, limit design bending moment

The limit design bending moment is calculated from

$$M_{\mathrm{Rd}} = \frac{W_{\mathrm{el}} \times f_{\mathrm{yp}}}{\gamma_{\mathrm{Rp}}} \tag{19}$$

with $\gamma_{\mathrm{Rp}} = \gamma_{\mathrm{m}} \times \gamma_{\mathrm{sp}}$

where

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

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

γ_{sp} is the specific resistance factor for pinned connections bending moment: $\gamma_{\mathrm{sp}} = 1{,}0$

5.2.4.2 Pins, limit design shear force

The limit design shear force per shear plane for pins is calculated from

$$F_{\mathrm{v,Rd}} = \frac{1}{u} \times \frac{A \times f_{\mathrm{yp}}}{\sqrt{3} \times \gamma_{\mathrm{Rp}}} \tag{20}$$

with $\gamma_{\mathrm{Rp}} = \gamma_{\mathrm{m}} \times \gamma_{\mathrm{sp}}$

where

u is the shape factor:

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

$u = \frac{4}{3} \times \frac{1 + \nu_{\mathrm{D}} + \nu_{\mathrm{D}}^2}{1 + \nu_{\mathrm{D}}^2}$ for hollow pins:

where $\nu_{\mathrm{D}} = \frac{D_{\mathrm{i}}}{D_{\mathrm{o}}}$

D_{i} is the inner diameter of pin;

D_{o} is the outer diameter of pin;

A is the cross-sectional area of the pin;

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

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

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

5.2.4.3 Pins and connected parts, limit design bearing force

The limit design bearing force is calculated from

$$F_{b,Rd} = \frac{\alpha \times d \times t \times f_y}{\gamma_{Rp}} \tag{21}$$

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

where

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

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

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

d is the diameter of the pin;

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

γ_{sp} is the specific resistance factor for the bearing force in pinned connections:

γ_{sp} = 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;

γ_{sp} = 0,9 for single shear plane connections or when connected parts in multiple shear plane connections are not held firmly together.

In case of significant movement between the pin and the bearing surface, consideration should be given to reducing the limit bearing force in order to reduce wear.

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

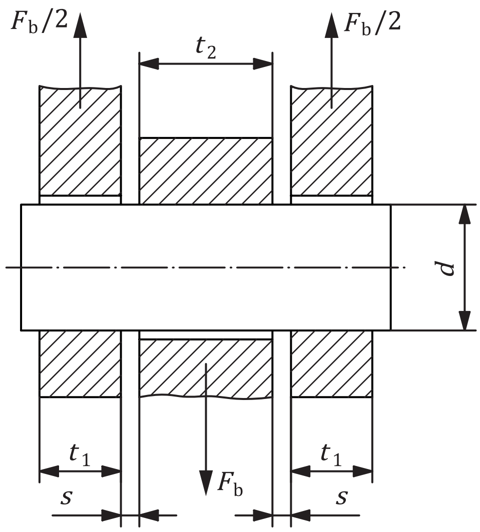


Figure 5 — Pinned connections

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 force is calculated from

$$F_{\mathrm{vs,Rd}} = \frac{A_{\mathrm{s}} \times f_{\mathrm{y}}}{\gamma_{\mathrm{m}} \cdot \sqrt{3}} \tag{22}$$

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)].

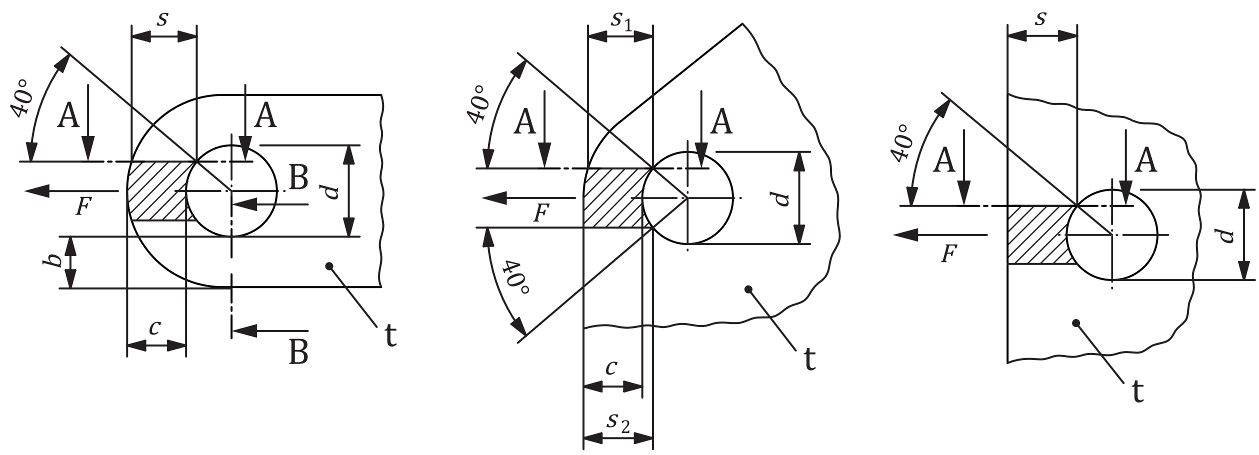
where

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

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° rule as indicated;

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) is determined as follows.

$$F_{\text{vt,Rd}} = \frac{2 \times b \times t \times f_{\text{y}}}{k \times \gamma_{\text{m}} \times \gamma_{\text{spt}}} \tag{23}$$

with

$$\gamma_{\text{spt}} = \frac{0{,}95}{\sqrt{k}} \times \frac{1{,}38 \times f_{\text{y}}}{f_{\text{u}}}$$

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* may be taken from Figure 7. The clearance between the hole and the pin are assumed to conform ISO 286-2:2010, tolerances H11/h11 or closer. In case of a larger clearance, higher values of *k* shall be used.

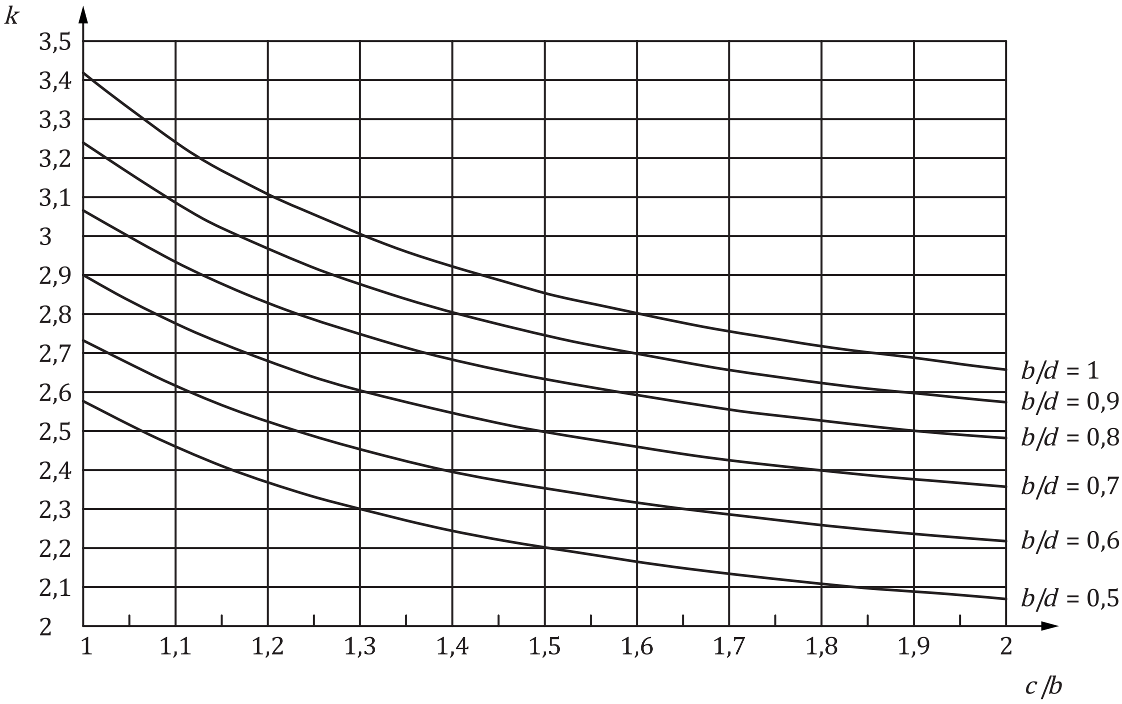


Figure 7 — Stress concentration factors for a specific type of pinned connection

NOTE Tensile loads or tensile parts of reversing loads only need to be considered within this clause. However, reversing load situations may require additional considerations where this may 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,

— the type of the weld,

— the type of stress evaluated in accordance with Annex C, and

— the weld quality.

Depending on the formula number given in Table 7, the limit design weld stress, $f_{w,Rd}$, shall be calculated using either Formula (24) or Formula (25).

$$f_{w,Rd} = \frac{\alpha_w \times f_{yk}}{\gamma_m} \quad (24)$$

$$f_{w,Rd} = \frac{\alpha_w \times f_{uw}}{\gamma_m} \quad (25)$$

where

α_w is a factor given in Table 7 that depends on the type of weld, the type of stress, and the material;

f_{yk} is the minimum value of the yield strength of the connected member under consideration;

f_{uw} is the ultimate strength of the weld material (all weld metal).

The welds joining component parts of built-up members such as flange-to-web connections may be designed without regard to the tensile or compressive stress in those parts that are parallel to the axis of the weld provided the welds are proportioned to accommodate the shear forces developed between those parts.

Table 7 — Factor α_w for limit weld stress

Type of weld material	Direction of stress	Type of weld	Type of stress	Formula number	α_w		
					$f_y \leq 420$ N/mm^2	$f_y > 420$ $f_y < 930$ N/mm^2	$f_y \geq 930$ N/mm^2
Matching (f_y refers to the welded members)	Stress normal to the weld direction	Full penetration weld	Tension or compression	24	1,0		0,93
		Partial penetration weld[a]	Tension or compression	24	0,90		0,85
	Stress parallel to the weld direction	All welds	Shear	24	0,60		0,55
Under-matching (f_y refers to the weld material)	Stress normal to the weld direction	Full penetration weld	Tension or compression	25	0,80	0,85	0,90
		Partial penetration weld[a]	Tension or compression	25	0,70	0,75	0,80
	Stress parallel to the weld direction	All welds	Shear	25	0,45	0,50	0,50

[a] An asymmetric weld is not recommended. However, if used, connected members shall be supported so as to avoid the effect of load eccentricity on the weld.

The values of α_w are valid for welds in quality level C or better in accordance with ISO 5817:2014.

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 5.3.4. In case of connected members from different materials, the proof shall be made for each member separately.

For the definition of full penetration and partial penetration weld, see ISO 17659.

Matching weld material: Weld material with ultimate strength equal or better than those of the connected members.

Undermatching weld material: Weld material with ultimate strength less than those of connected members.

5.3 Execution of the proof

5.3.1 Proof for structural members

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

$$\sigma_{Sd} \leq f_{Rd\sigma} \text{ and } \tau_{Sd} \leq f_{Rd\tau} \quad (26)$$

where

σ_{Sd}, τ_{Sd} are the design stresses — the von Mises equivalent stress σ 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 — where von Mises is used, $f_{Rd\sigma}$ is the limit design stress.

For plane states of stresses when von Mises stresses are not used, it shall additionally be proven that

$$\left(\frac{\sigma_{Sd,x}}{f_{Rd\sigma,x}}\right)^2 + \left(\frac{\sigma_{Sd,y}}{f_{Rd\sigma,y}}\right)^2 - \frac{\sigma_{Sd,x} \times \sigma_{Sd,y}}{f_{Rd\sigma,x} \times f_{Rd\sigma,y}} + \left(\frac{\tau_{Sd}}{f_{Rd\tau}}\right)^2 \leq 1 \quad (27)$$

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 and for the most unfavourably loaded element of a connection, it shall be proven that

$$F_{Sd} \leq F_{Rd} \quad (28)$$

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.

Care should be taken in apportioning the total load into individual components of the connection.

5.3.3 Proof for pinned connections

For pins and connected parts, it shall be proven that

$$
\begin{aligned}
&M_{\mathrm{Sd}} \le M_{\mathrm{Rd}} \\
&F_{\mathrm{vp,Sd}} \le F_{\mathrm{vp,Rd}} \\
&F_{\mathrm{bi,Sd}} \le F_{\mathrm{b,Rd}} \\
&F_{\mathrm{vd,Sd}} \le F_{\mathrm{vs,Rd}} \\
&F_{\mathrm{vd,Sd}} \le F_{\mathrm{vt,Rd}}
\end{aligned}
\tag{29}
$$

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;
$F_{\mathrm{vp,Sd}}$	is the design value of the shear force in the pin;
$F_{\mathrm{vp,Rd}}$	is the limit design shear force in accordance with 5.2.4.2;
$F_{\mathrm{bi,Sd}}$	is the most unfavourable design value of the bearing force in the joining plate, *i*, of the pinned connection;
$F_{\mathrm{b,Rd}}$	is the limit design bearing force in accordance with 5.2.4.3;
$F_{\mathrm{vd,Sd}}$	is the design force in the connected part;
$F_{\mathrm{vs,Rd}}$	is the limit design shear force in the connected part in accordance with 5.2.4.4;
$F_{\mathrm{vt,Rd}}$	is the limit design tensile force of the connected part in accordance with 5.2.4.5.

In multi-pin connections, care should be taken in apportioning the total load into individual components of the connection.

As a conservative assumption in the absence of a more detailed analysis, Formula (30) may be used.

$$
M_{\mathrm{Sd}} = \frac{F_{\mathrm{b}}}{8} \times \left(2 \times t_1 + t_2 + 4 \times s\right) \tag{30}
$$

where F_{b}, t_1, t_2 and s are as shown in Figure 5.

5.3.4 Proof for welded connections

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

$$
\sigma_{\mathrm{w,Sd}} \text{ and } \tau_{\mathrm{w,Sd}} \le f_{\mathrm{w,Rd}} \tag{31}
$$

where

$\tau_{\mathrm{w,Sd}}$, $\sigma_{\mathrm{w,Sd}}$	are the design weld stresses (see Annex C);
$f_{\mathrm{w,Rd}}$	is the corresponding limit design weld stress in accordance with 5.2.5.

For plane states of stresses (with orthogonal stress components $\tau_{\mathrm{w,Sd}}$, $\sigma_{\mathrm{w,Sd,x}}$, $\sigma_{\mathrm{w,Sd,y}}$) in welded connections, it shall additionally be proven that

$$
\left(\frac{\sigma_{\mathrm{w,Sd,x}}}{f_{\mathrm{w,Rd,x}}}\right)^2 + \left(\frac{\sigma_{\mathrm{w,Sd,y}}}{f_{\mathrm{w,Rd,y}}}\right)^2 - \frac{\sigma_{\mathrm{w,Sd,x}} \times \sigma_{\mathrm{w,Sd,y}}}{f_{\mathrm{w,Rd,x}} \times f_{\mathrm{w,Rd,y}}} + \left(\frac{\tau_{\mathrm{w,Sd}}}{f_{\mathrm{w,Rd}}}\right)^2 \le 1,0 \tag{32}
$$

where *x*, *y* indicate the orthogonal directions of stress components.

6 Proof of fatigue strength

6.1 General

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

The stresses are calculated in accordance with the nominal stress concept. This International Standard deals only with the nominal stress method (see the Bibliography for alternative methods). A nominal stress is a stress in the base material adjacent to a potential crack location calculated in accordance with simple elastic strength of materials theory, excluding local stress concentration effects. The constructional details given in Annex D contain the influences illustrated in the figures and thus, the characteristic fatigue strength values include the effects of

— local stress concentrations due to the shape of the joint and the weld geometry,

— size and shape of acceptable discontinuities,

— the stress direction,

— residual stresses,

— metallurgical conditions, and

— in some cases, the welding process and post-weld improvement procedures.

The effect of geometric stress concentrations other than those listed above (global stress concentrations) shall be included with the nominal stress by means of relevant stress concentration factors.

NOTE This International Standard does not use other methods such as the hot spot stress method (see Reference [8]).

For the execution of the proof of fatigue strength, the cumulative damages caused by variable stress cycles shall be calculated. In this International Standard, Palmgren-Miner's rule of cumulative damage is reflected by use of the stress history parameter, s_m (see 6.3.3). Values for this parameter can be determined by simulation, testing, or using S classes. Thus, the service conditions and their effect on the stressing of the structure are taken into account.

Mean-stress influence in structures in as-welded condition (without stress relieving) can be considered (see 6.3), but is negligible. Therefore, the stress history parameter, s_m, is independent of the mean stress and the fatigue strength is based on the stress range only.

In non-welded details or stress-relieved welded details, the effective stress range to be used in the fatigue assessment may be determined by adding the tensile portion of the stress range and 60 % of the compressive portion of the stress range or by fatigue testing (see 6.2.2.2).

The fatigue strength specific resistance factor, γ_{mf}, given in Table 8 is used to account for the uncertainty of fatigue strength values and the possible consequences of fatigue damage.

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

Accessibility	γ_{mf}		
	Fail-safe components	Non-fail-safe components	
		without hazards for persons	with hazards for persons
Accessible joint detail	1,0	1,10	1,20
Joint detail with poor accessibility	1,05	1,15	1,25
Fail-safe structural components are those with reduced consequences of failure such that the local failure of one component does not result in failure of the structure or falling of loads. *Non-fail-safe* structural components are those where local failure of one component leads rapidly to failure of the structure or falling of loads.			

6.2 Limit design stresses

6.2.1 Characteristic fatigue strength

The limit design stress of a constructional detail is characterized by the value of the characteristic fatigue strength, $\Delta\sigma_c$, which 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, Annex D, and Annex E).

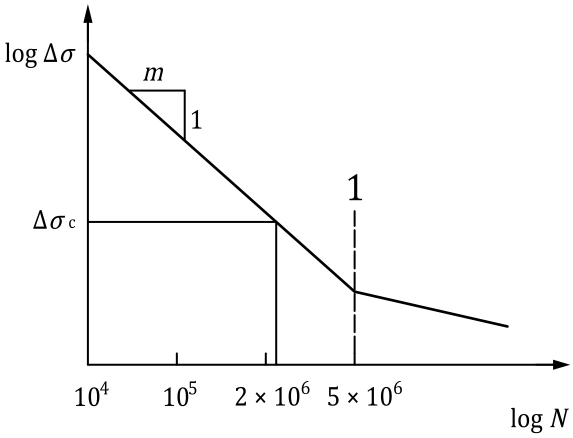
In the first column of the tables presented in Annex E, the values of $\Delta\sigma_c$ are arranged in a sequence of notch classes (NC) and with the constant ratio of 1,125 between the classes.

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

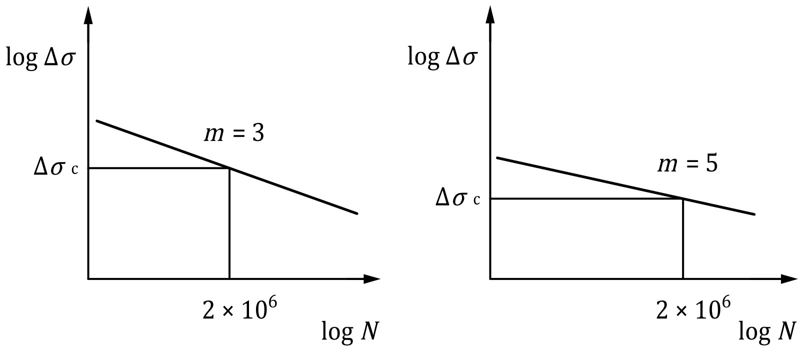
The values of characteristic fatigue strength, $\Delta\sigma_c$ or $\Delta\tau_c$, and the related slope constants, m, of the $\Delta\sigma - N$ curve are given in the tables of Annex D for basic material of structural members, elements of non-welded connections, and welded members.

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 should be taken into account.

The given values apply for the defined basic conditions. For deviating conditions, an appropriate NC shall be selected one or more notch classes above (+1 NC, +2 NC, ...) the basic notch class to increase the resistance or below (−1 NC, −2 NC, ...) the basic notch class to decrease the resistance in accordance with Annex D. The effects of several deviating conditions shall be summed up.



a) Principle



b) Simplification

Key

1 constant stress range fatigue limit

m slope constant of fatigue strength curve

The curves have slopes of $-1/m$ in the log/log representation.

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

6.2.2 Weld quality

6.2.2.1 General

The $\Delta\sigma$ values presented in Annex D depend on the quality level of the weld. Quality classes shall be in accordance with ISO 5817:2014, classes B, C and D. Use of quality levels lower than class D is not allowed.

For the purposes of this International Standard, an additional quality level B* may be used on condition that the requirements given in 6.2.2.2, additional to those of level B, are fulfilled.

6.2.2.2 Additional requirements for quality level B*

For the purposes of this International Standard, 100 % NDT (non-destructive testing) is the inspection of the whole length of the weld with an appropriate method that shall ensure that the following specified quality requirements are met.

For butt welds:

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

— both surfaces machined or flush ground down to plate surface grinding in stress direction;

— the weld toe post-treated by grinding, remelting by TIG, plasma welding, or by needle peening so that any undercut and slag inclusions are removed;

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

— sum of lengths of concavities of weld less than 5 % of the total length of the weld;

— 100 % NDT.

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

— transition angle of the weld to the plate surface shall not exceed 25°;

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

— 100 % NDT.

All other joints:

— full penetration;

— transition angle of the weld to the plate surface shall not exceed 25°;

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

— 100 % NDT;

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

If TIG dressing is used as a post treatment of the potential crack initialization zone of a welded joint in order to increase the fatigue strength, welds of quality class C for design purposes may be upgraded to quality class B for any joint configuration.

6.2.3 Requirements for fatigue testing

Details not given or deviating from those in Annex D or consideration of mean stress influence requires specific investigation into $\Delta\sigma_c$ and m. Requirements for such tests are as follows:

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

— the test specimen shall be produced under workshop conditions;

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

— there shall be at least seven tests per stress range level.

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

— $\Delta\sigma_c$ shall be determined from numbers of cycles based on mean value minus two standard deviations 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 5×10^4 cycles shall be used;

— at least one stress range level that results in a mean number of stress cycles to failure between $1{,}0 \times 10^6$ and $2{,}5 \times 10^6$ cycles shall be used.

A simplified method for the determination of m and $\Delta\sigma_c$ may be used:

— 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 Stress histories

6.3.1 Determination of stress histories

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.

For the proof of fatigue strength of mechanical or structural components of a crane selected for the proof calculation, the stress histories arising from the specified service conditions shall be determined.

Stress histories may be determined by tests or estimated from elasto-kinetic or rigid body-kinetic simulations.

In general, the proof of fatigue strength shall be executed by applying the load combinations A (regular loads) in accordance with the applicable parts of ISO 8686, multiplied by the dynamic factor, ϕ_i, setting all partial safety factors, $\gamma_P = 1$, and the resistances (i.e. limit design stresses) in accordance with 6.2. In some applications, a load from load combinations B (occasional loads) can occur often enough to require inclusion of that load combination in the fatigue assessment. The stress histories from these occasional loads may be estimated in the same way as those from the regular loads.

Those stress histories which are not proportional (such as in the top chord of a girder from the beam's theory and the local effects from the wheel loads or the stresses from bending and torsion shear in a gear shaft) may be determined independently. The fatigue assessment of the combined effect of such histories, interaction, is based on the action of the independent ones.

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.

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

6.3.2 Frequency of occurrence of stress cycles

For this 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) with the influence of mean stress neglected.

Each of the stress ranges is sufficiently described by its upper and lower extreme value.

$$\Delta\sigma = \sigma_u - \sigma_b \tag{33}$$

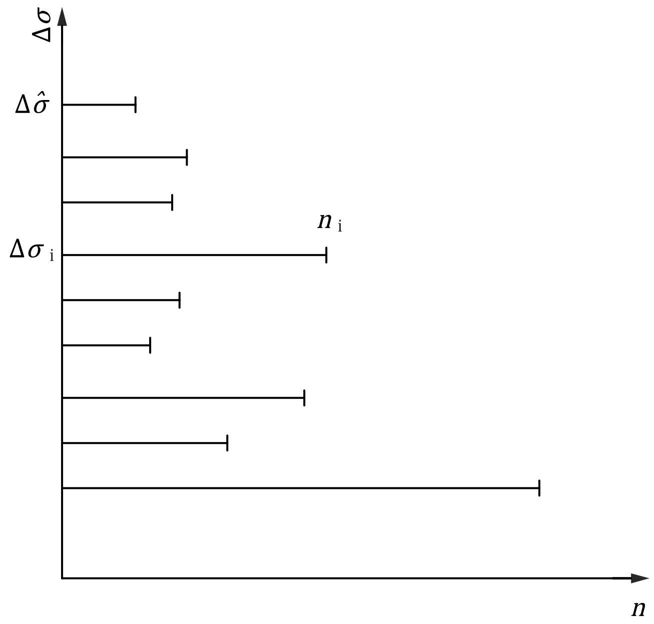
where

σ_u is the upper extreme value of a stress range;

σ_b is the lower extreme value of a stress range;

Δ_σ is the stress range.

Figure 9 illustrates a resulting one parameter representation.



Key

$\Delta\sigma_i$ stress range *i*

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

n_i number of stress cycles within stress range *i*

Figure 9 — One-parameter representation of stress histories (frequencies of occurrence of stress ranges)

6.3.3 Stress history parameter

The stress history parameter, s_m, is calculated as follows based on a one-parameter presentation of stress histories during the design life of the crane.

$$s_m = \nu \times k_m \tag{34}$$

$$k_m = \sum_i \left[\frac{\Delta\sigma_i}{\Delta\hat{\sigma}} \right]^m \times \frac{n_i}{N_t} \tag{35}$$

$$\nu = \frac{N_t}{N_{ref}} \tag{36}$$

where

ν	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 (see Figure 9);
$\Delta\hat{\sigma}$	is the maximum stress range (see Figure 9);
n_i	is the number of occurrences of stress range i (see Figure 9);
$N_t = \sum_i n_i$	is the total number of occurrences of stress ranges during the design life of the crane;
$N_{ref} = 2 \times 10^6$	is the number of cycles at the reference point;
m	is the slope constant of the $\log\Delta\sigma/\log N$ curve of the component under consideration.

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

A given stress history falls into the specific S class independent of the slope constant, m, of the relevant $\log\sigma/\log N$ curve. The diagonal lines for the class limits represent the k_m to ν relationship for s_m = constant in a log/log scale diagram.

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

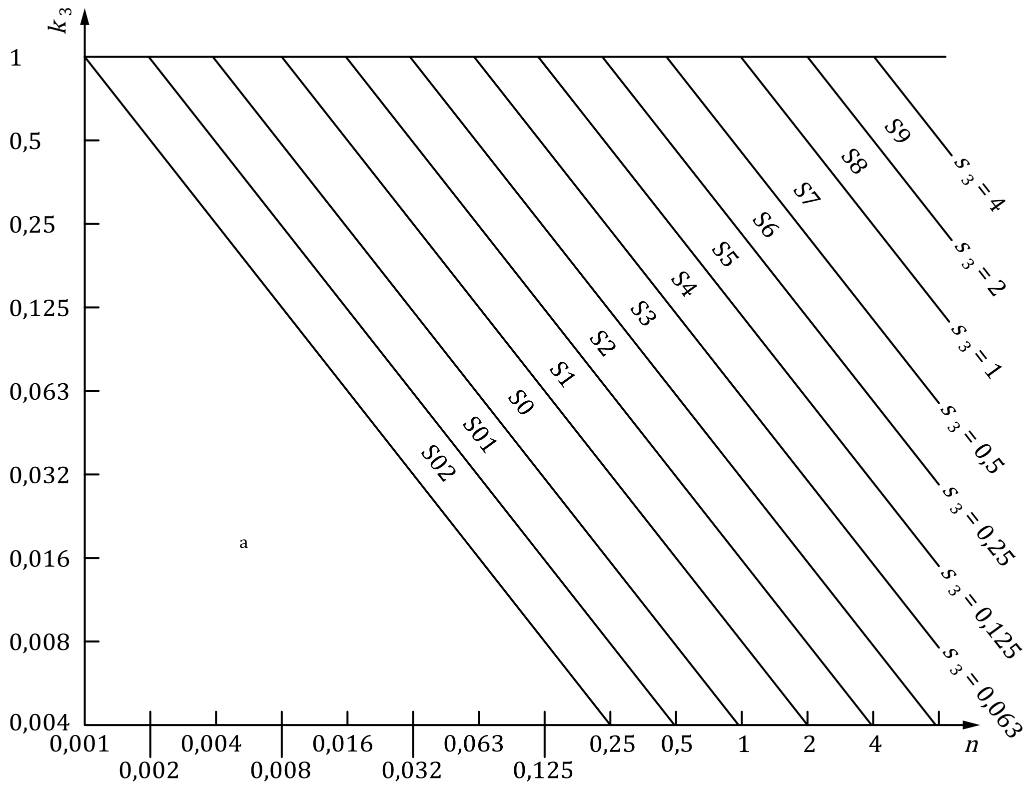
Crane parts with a value of s_m lower than 0,001 do not require a proof-of-competence for fatigue.

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 have to be taken into account.

The classification of stress histories by S classes of the stress history parameters, s_m, is based on $m = 3$, given in Table 9 and illustrated in Figure 10 as s_3.

Table 9 — S classes of stress history parameter (s_3)

S class	Stress history parameter value
S02	$0,001 < s_3 \leq 0,002$
S01	$0,002 < s_3 \leq 0,004$
S0	$0,004 < s_3 \leq 0,008$
S1	$0,008 < s_3 \leq 0,016$
S2	$0,016 < s_3 \leq 0,032$
S3	$0,032 < s_3 \leq 0,063$
S4	$0,063 < s_3 \leq 0,125$
S5	$0,125 < s_3 \leq 0,250$
S6	$0,250 < s_3 \leq 0,500$
S7	$0,500 < s_3 \leq 1,000$
S8	$1,000 < s_3 \leq 2,000$
S9	$2,000 < s_3 \leq 4,000$



[a] Fatigue assessment not required.

Figure 10 — Illustration of classification of stress history parameter for $m = 3$

6.3.4 Determination of stress history class, S

6.3.4.1 General

For members of crane structures, the S class of the stress history parameter may be taken from Table 9 when the value of the stress history parameter is known, obtained by calculation, or measurement.

The stress history class may also be selected directly based on experience with technical justification. The corresponding value of stress history parameter, s_3, is given by Table 11. The S class of the stress history parameter is related to crane duty and decisively depends on

— the number of working cycles and the U class (see ISO 4301-1:2016),

— the net load spectrum and Q class (see ISO 4301-1:2016), and

— the crane configuration and the effect of the crane motions (traverse, slewing, luffing, etc.).

If a single stress history class is used to characterize the whole structure, the most severe class applicable within the structure shall be used.

6.3.4.2 Special case

In a special case where the stress variations in a structural member depend upon the hoist load variations only without load effect variations, for example, due to dead weight of moving parts of the crane (i.e. the number of relevant stress cycles is equal to the number of load cycles and the stress ranges are directly proportional to the hoist load variations), the S class for a such member may be determined in accordance with Table 10.

Table 10 — S classes determined from A classes

A class in accordance with ISO 4301-1:2016	**S class**
A1	S01
A2	S0
A3	S1
A4	S2
A5	S3
A6	S4
A7	S5
A8	S6
Higher stress history classes (S7 to S9) not covered by ISO 4301-1:2016, class A8, could be applicable.	

6.4 Execution of the proof

For the detail under consideration, it shall be proven that

$$\Delta\sigma_{Sd} \leq \Delta\sigma_{Rd} \quad (37)$$

$$\Delta\sigma_{Sd} = \max\sigma - \min\sigma \quad (38)$$

where

$\Delta\sigma_{Sd}$	is the calculated maximum range of design stresses;
max σ, min σ	are the extreme values of design stresses in accordance with the applicable parts of ISO 8686 by applying $\gamma_p = 1$ (compression stresses with negative sign);
$\Delta\sigma_{Rd}$	is the limit design stress range.

For the design weld stress, see Annex C. For thermally stress-relieved or non-welded structural members, the compressive portion of the stress range may be reduced to 60 %. When the stress spectrum factor, k_m, is obtained by calculation from Formula (35) and used for the determination of the stress history parameter, s_m, values of max σ and min σ shall be based on the same loading assumptions — including dynamic factors, accelerations, and combinations — as those used in the determination of the maximum 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 stress components.

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 significantly in the course of a loading event, only the maximum principal stress range may be used.

6.5 Determination of the limit design stress range

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 the stress history parameter, s_m, or simplified by the use of an S class.

6.5.2 Direct use of stress history parameter

The limit design stress range shall be calculated from

$$\Delta\sigma_{Rd} = \frac{\Delta\sigma_c}{\gamma_{mf} \times \sqrt[m]{s_m}} \quad (39)$$

where

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

When s_m is obtained on the basis of $m = 3$, the limit design stress range may be calculated using the method given in 6.5.3.2.

6.5.3 Use of S classes

6.5.3.1 Slope constant, m

When the detail under consideration is related to an S class in accordance with 6.3, the simplified determination of the limit design stress range is dependent on the slope constant, m, of the $\log\sigma - \log N$ curve.

6.5.3.2 Slope constant, $m = 3$

Values of the stress history parameter, s_3, corresponding to individual stress history classes, S, are selected in accordance with Table 11.

Table 11 — Values of s_3 for stress history classes, S

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 Stress history parameter values presented here are the upper limit values of the ranges given in Table 9.												

The limit design stress range shall be calculated from

$$\Delta\sigma_{\mathrm{Rd}} = \frac{\Delta\sigma_{\mathrm{c}}}{\gamma_{\mathrm{mf}} \times \sqrt[3]{s_3}} \tag{40}$$

where

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

$\Delta\sigma_{\mathrm{c}}$ is the characteristic fatigue strength of details, with $m = 3$ (see Annex D);

s_3 is the classified stress history parameter (see Table 11);

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

For the most severe $\gamma_{\mathrm{mf}} = 1,25$, Annex E gives the values of $\Delta\sigma_{\mathrm{Rd}}$ depending on the S class and $\Delta\sigma_{\mathrm{c}}$.

6.5.3.3 Slope constant $m \neq 3$

If the slope constant, m, of the $\log\sigma - \log N$ curve is not equal to 3, the limit design stress range is dependent on the S class and the stress spectrum factor, k_m (see 6.3.3).

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

$$\Delta\sigma_{\mathrm{Rd}} = \Delta\sigma_{\mathrm{Rd,1}} \times k^* \tag{41}$$

$$\Delta\sigma_{\mathrm{Rd,1}} = \frac{\Delta\sigma_{\mathrm{c}}}{\gamma_{\mathrm{mf}} \times \sqrt[m]{s_3}} \tag{42}$$

$$k^* = \sqrt[m]{\frac{k_3}{k_{\mathrm{m}}}} \geq 1 \tag{43}$$

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;
$\Delta\sigma_c$, m	are the characteristic fatigue strength and the respective slope constant of the $\log\sigma/\log N$ curve (see Annex D);
s_3	is the classified stress history parameter for $m = 3$ (see Table 11);
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.

For the most severe $\gamma_{mf} = 1{,}25$ and $m = 5$, Annex E gives the values of $\Delta\sigma_{Rd,1}$ depending on the S class and $\Delta\sigma_c$.

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

As $k^* = 1$ covers the most unfavourable stress spectra for cases with $m > 3$ and $s_m < 1$, $\Delta\sigma_{Rd,1}$ calculated from Formula (42) may be used as limit design stress range. The value of k^* may also be calculated for k_3 and k_m from the stress spectrum estimated by experience.

6.5.4 Independent concurrent normal and/or shear stresses

In addition to the separate proof for σ and τ (see 6.4), the action of independently varying ranges of normal and shear stresses shall be considered by

$$\left(\frac{\gamma_{mf} \times \Delta\sigma_{Sd,x}}{\Delta\sigma_{c,x}}\right)^{m_x} \times s_{m,x} + \left(\frac{\gamma_{mf} \times \Delta\sigma_{Sd,y}}{\Delta\sigma_{c,y}}\right)^{m_y} \times s_{m,y} + \left(\frac{\gamma_{mf} \times \Delta\tau_{Sd}}{\Delta\tau_c}\right)^{m_\tau} \times s_{m\tau} \leq 1{,}0 \qquad (44)$$

where

$\Delta\sigma_{Sd}$, $\Delta\tau_{Rd}$	are the calculated maximum ranges of design stresses;
$\Delta\sigma_c$, $\Delta\tau_c$	are the characteristic fatigue strengths;
γ_{mf}	is the fatigue strength specific resistance factor (see Table 8);
s_m	is the stress history parameter;
m	is the slope constant of $\log\sigma - \log N$ curve;
x, y	indicates the orthogonal directions of normal stresses;
τ	indicates the respective shear stress.

7 Proof of elastic stability

7.1 General

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 and local buckling of plate fields subjected to compressive stresses.

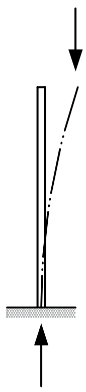
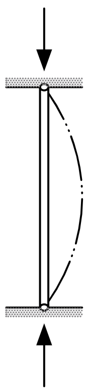
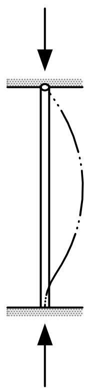
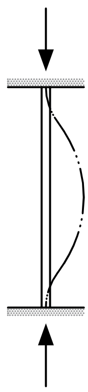
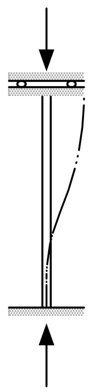
NOTE Other phenomena of elastic instability exist and might occur, e.g. in cylindrical shells or in open sections. Further information can be found in the Bibliography.

7.2 Lateral buckling of members loaded in compression

7.2.1 Critical buckling load

The critical buckling load N_k is the smallest bifurcation load in accordance with elastic theory. For members with constant cross section, N_k is given in Table 12 for a selection of boundary conditions also known as Euler's buckling cases.

Table 12 — Critical buckling load N_k for Euler's buckling cases

Euler case no.	1	2	3	4	5
Boundary conditions					
N_k	$\frac{\pi^2 \times E \times I_i}{4 \times L^2}$	$\frac{\pi^2 \times E \times I_i}{L^2}$	$\frac{2{,}05 \times \pi^2 \times E \times I_i}{L^2}$	$\frac{4 \times \pi^2 \times E \times I_i}{L^2}$	$\frac{\pi^2 \times E \times I_i}{L^2}$
E is the modulus of elasticity I_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 may be computed from the differential formula or system of differential formulae of the elastic deflection curve in its deformed state which has the general solution

$$y = A_i \times \cos(k_i \times x) + B_i \times \sin(k_i \times x) + C_i \times x + D_i, \quad k_i = \sqrt{\frac{N_c}{E \times I_i}} \tag{45}$$

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_c	is the compressive force;
A_i, B_i, C_i, D_i	are constants to be found by applying appropriate boundary conditions.

The critical buckling load, N_k, is found as the smallest positive value N that satisfies Formula (45), or the system of Formula (45), when solved with the appropriate boundary conditions applied.

7.2.2 Limit compressive design force

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

$$N_{Rd} = \frac{\kappa \times f_y \times A}{\gamma_m} \tag{46}$$

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 is computed from the slenderness λ which is given by

$$\lambda = \sqrt{\frac{f_y \times A}{N_k}} \tag{47}$$

where

N_k is the critical buckling load in accordance with 7.2.1.

Depending on the value of λ and the cross section parameter α, the reduction factor κ is given by

$\lambda \leq 0{,}2$: $\quad \kappa = 1{,}0$

$$0{,}2 < \lambda: \quad \kappa = \frac{1}{\xi + \sqrt{\xi^2 - \lambda^2}} \qquad \xi = 0{,}5 \times \left[1 + \alpha \times (\lambda - 0{,}2) + \lambda^2\right] \tag{48}$$

Depending of the type of cross section, the parameter α is given in Table 13.

Table 13 — Parameter α and acceptable bow imperfections for various cross sections

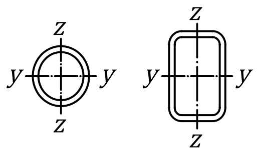
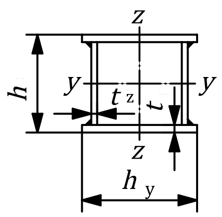
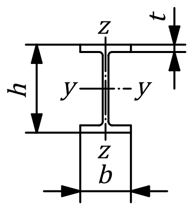
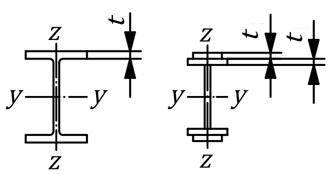
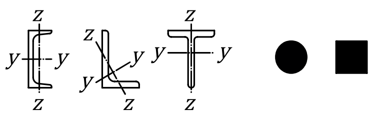
	Type of cross section		Buckling about axis	$f_y < 460 \frac{N}{mm^2}$		$f_y \geq 460 \frac{N}{mm^2}$	
				α	δ_I	α	δ_I
1	Hollow sections 	Hot rolled	$y-y$ $z-z$	0,21	$L/300$	0,13	$L/350$
		Cold formed	$y-y$ $z-z$	0,34	$L/250$	0,34	$L/250$
2	Welded box sections 	Thick welds ($a > t_y/2$) and $h_y/t_y < 30$ $h_z/t_z < 30$	$y-y$ $z-z$	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	$L/350$ $L/350$
		$h/b > 1,2$; 40 mm $< t \leq 80$ mm $h/b \leq 1,2$; $t \leq 80$ mm	$y-y$ $z-z$	0,34 0,49	$L/250$ $L/200$	0,21 0,21	$L/300$ $L/300$
		$t > 80$ mm	$y-y$ $z-z$	0,76	$L/150$	0.49	$L/200$
4	Welded I sections 	$t_i \leq 40$ mm	$y-y$ $z-z$	0,34 0,49	$L/250$ $L/200$	0,34 0,49	$L/250$ $L/200$
		$t_i > 40$ mm	$y-y$ $z-z$	0,49 0,76	$L/200$ $L/150$	0,49 0,76	$L/200$ $L/150$

Table 13 (*continued*)

	Type of cross section		Buckling about axis	$f_y < 460 \frac{\text{N}}{\text{mm}^2}$		$f_y \geq 460 \frac{\text{N}}{\text{mm}^2}$	
				α	δ_I	α	δ_I
5	Channels, L, T, and solid sections 		$y-y$ $z-z$	0,49	$L/200$	0,49	$L/200$

δ_I is the maximum allowable amplitude of initial bow imperfection measured over the total length of the member.
L is the length of the member.

In case of a member with varying cross section, the formulae in 7.2.2 shall be applied to all parts of the member. The smallest resulting value of N_{Rd} shall be used and in addition, it shall conform to the following:

$$N_{Rd} \leq \frac{N_k}{1,2 \times \gamma_m} \tag{49}$$

7.3 Buckling of plate fields subjected to compressive and shear stresses

7.3.1 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 ensure that no buckling of plates takes place, i.e. post buckling behaviour is not utilized. The Bibliography gives information on literature about methods using post buckling behaviour. When using those methods, the effects of post buckling, e.g. on fatigue, shall be taken into account.

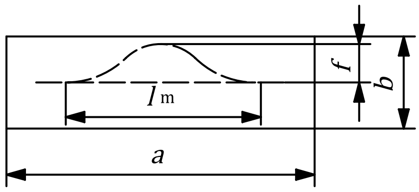
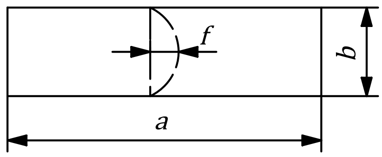
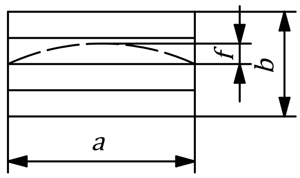
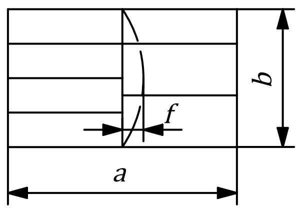
It is assumed that

— geometric imperfections of the plate are less than the maximum values shown in Table 14,

— stiffeners are designed with sufficient stiffness and strength to 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), and

— the plate field is supported along its edges as shown in Table 15.

Table 14 — Maximum allowable imperfection *f* for plates and stiffeners

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

f shall be measured in the perpendicular plane.

l_m is the gauge length.

Figure 11 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.

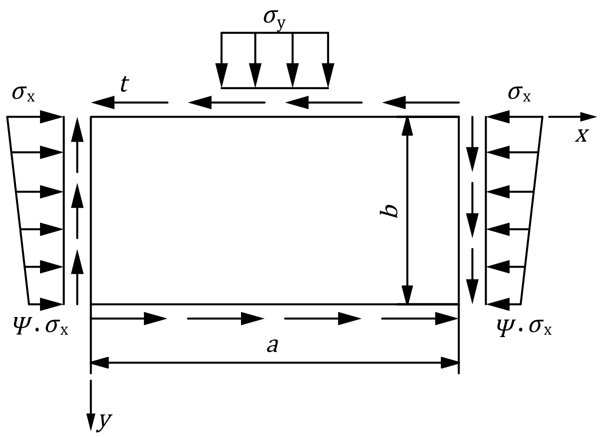


Figure 11 — Stresses applied to plate field

7.3.2 Limit design stress with respect to longitudinal stress σ_x

The limit design compressive stress $f_{b,Rd,x}$ is calculated from

$$f_{b,Rd,x} = \frac{\kappa_x \times f_y}{\gamma_m} \tag{50}$$

where

κ_x is a reduction factor in accordance with Formula (51);

f_y is the yield stress of the plate material.

The reduction factor κ_x is given by

$$\begin{aligned} \kappa_x &= 1 && \text{for} \quad \lambda_x \le 0,7 \\ \kappa_x &= 1,474 - 0,677 \times \lambda_x && \text{for} \quad 0,7 < \lambda_x < 1,291 \\ \kappa_x &= \frac{1}{\lambda_x^{\,2}} && \text{for} \quad \lambda_x \ge 1,291 \end{aligned} \tag{51}$$

where

λ_x is a non-dimensional plate slenderness in accordance with Formula (52).

The non-dimensional plate slenderness λ_x is given by

$$\lambda_x = \sqrt{\frac{f_y}{k_{\sigma x} \times \sigma_e}} \tag{52}$$

where

σ_e is a reference stress in accordance with Formula (53);

$k_{\sigma x}$ is a buckling factor given in Table 15.

The reference stress σ_e is given by

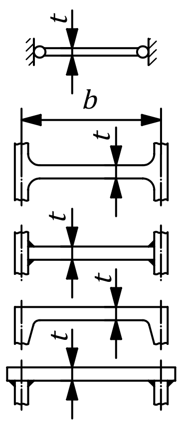
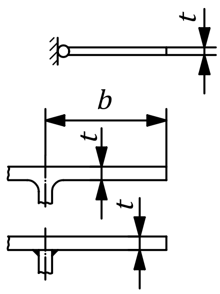
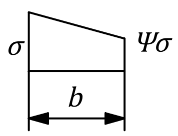
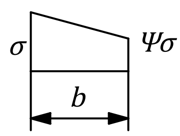
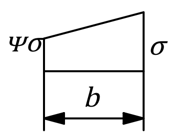
$$\sigma_e = \frac{\pi^2 \times E}{12 \times (1 - \nu^2)} \times \left(\frac{t}{b}\right)^2 \tag{53}$$

where

- E is the modulus of elasticity of the plate;
- ν is the Poisson's ratio of the plate (ν = 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 15 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 15 — Buckling factor, $k_{\sigma x}$

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

NOTE For Case 1, the values and formulae for buckling factors, $k_{\sigma x}$, given in Table 15 for plate fields supported along all four edges can give overly conservative results for plate fields (see Figure 11 for α) with $\alpha < 1{,}0$ for row 3 to row 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 the Bibliography).

7.3.3 Limit design stress with respect to transverse stress σ_y

Where the transverse stresses are due to a moving load, e.g. travelling wheel load on a bridge girder, the use of methods utilizing post buckling mentioned in 7.3.1 is not allowed.

The limit design transversal normal stress shall be calculated from

$$f_{\mathrm{b,Rd,y}} = \frac{\kappa_y \cdot f_y}{\gamma_m} \tag{54}$$

where

κ_y is a reduction factor in accordance with Formula (55);

f_y is the minimum yield stress of the plate material.

The reduction factor κ_y is given by

$$\begin{aligned} \kappa_y &= 1 && \text{for} \quad \lambda_y \le 0{,}7 \\ \kappa_y &= 1{,}474 - 0{,}677 \times \lambda_y && \text{for} \quad 0{,}7 < \lambda_y < 1{,}291 \\ \kappa_y &= \frac{1}{\lambda_y^2} && \text{for} \quad \lambda_y \ge 1{,}291 \end{aligned} \tag{55}$$

The non-dimensional plate slenderness λ_y is given by

$$\lambda_y = \sqrt{\frac{f_y}{k_{\sigma y} \times \sigma_e \times \dfrac{a}{c}}} \tag{56}$$

where

σ_e is a reference stress in accordance with Formula (53);

$k_{\sigma y}$ is a buckling factor determined using Figure 12;

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 12 (see C.4)].

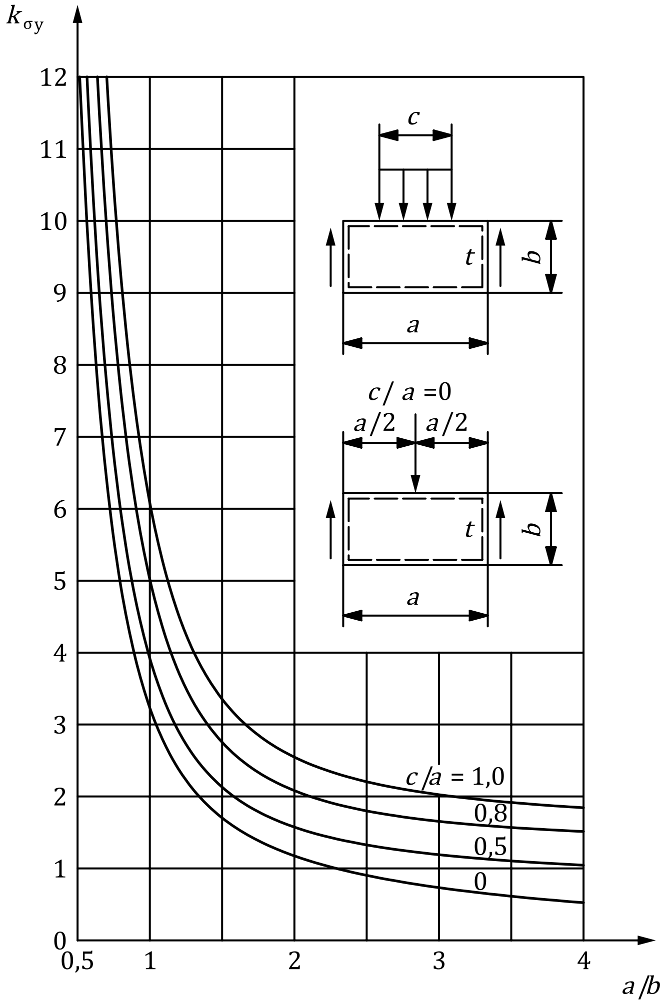


Figure 12—Buckling factor $k_{\sigma y}$

7.3.4 Limit design stress with respect to shear stress τ

The limit design buckling shear stress is calculated from

$$f_{\mathrm{b,Rd,\tau}} = \frac{\kappa_\tau \cdot f_\mathrm{y}}{\sqrt{3} \cdot \gamma_\mathrm{m}} \tag{57}$$

where

κ_τ is a reduction factor given by

$$\kappa_\tau = \frac{0{,}84}{\lambda_\tau} \quad \text{for } \lambda_\tau \geq 0{,}84 \tag{58}$$

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

$$\lambda_\tau = \sqrt{\frac{f_y}{k_\tau \cdot \sigma_e \cdot \sqrt{3}}} \quad (59)$$

where

f_y is the minimum yield strength of the plate material;

σ_e is a reference stress in accordance with Formula (53);

k_τ is a buckling factor calculated (for a plate field supported along all four edges) using formulas given in Table 16.

Table 16 — Buckling factor k_τ

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

7.4 Execution of the proof

7.4.1 Members loaded in compression

For the member under consideration, it shall be proven that

$$N_{Sd} \leq N_{Rd} \quad (60)$$

where

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

N_{Rd} is the limit design compressive force in accordance with 7.2.2.

7.4.2 Plate fields

7.4.2.1 Plate fields subjected to longitudinal or transverse compressive stress

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

$$\left|\sigma_{Sd,x}\right| \leq f_{b,Rd,x} \text{ and } \left|\sigma_{Sd,y}\right| \leq f_{b,Rd,y} \quad (61)$$

where

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

$f_{b,Rd,x}$, $f_{b,Rd,y}$ are the limit design compressive stresses in accordance with 7.3.2 and 7.3.3.

7.4.2.2 Plate fields subjected to shear stress

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

$$\tau_{Sd} \leq f_{b,Rd,\tau} \tag{62}$$

where

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

$f_{b,Rd,\tau}$ is the limit design shear stress in accordance with 7.3.4.

7.4.2.3 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 7.4.2.1 and 7.4.2.2, it shall be additionally proven that

$$\left(\frac{\left|\sigma_{\mathrm{Sd,x}}\right|}{f_{\mathrm{b,Rd,x}}}\right)^{e_1} + \left(\frac{\left|\sigma_{\mathrm{Sd,y}}\right|}{f_{\mathrm{b,Rd,y}}}\right)^{e_2} - V \times \left(\frac{\left|\sigma_{\mathrm{Sd,x}} \times \sigma_{\mathrm{Sd,y}}\right|}{f_{\mathrm{b,Rd,x}} \times f_{\mathrm{b,Rd,y}}}\right) + \left(\frac{\left|\tau_{\mathrm{Sd}}\right|}{f_{\mathrm{b,Rd,\tau}}}\right)^{e_3} \leq 1 \tag{63}$$

where

$$e_1 = 1 + \kappa_{\mathrm{x}}^4 \tag{64}$$

$$e_2 = 1 + \kappa_{\mathrm{y}}^4 \tag{65}$$

$$e_3 = 1 + \kappa_{\mathrm{x}} \times \kappa_{\mathrm{y}} \times \kappa_{\tau}^2 \tag{66}$$

and with κ_x calculated in accordance with 7.3.2, κ_y in accordance with 7.3.3, and κ_τ in accordance with 7.3.4.

$$V = (\kappa_x \times \kappa_y)^6 \quad \text{for } \sigma_{Sd,x} \times \sigma_{Sd,y} \geq 0 \tag{67}$$

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

Annex A
(informative)

Limit design shear force, $F_{v,Rd}$, in shank 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 and are independent of the detailed design of the bolt

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

Bolt	Shank diameter mm	$F_{v,Rd}$ kN Fit 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	62,8	75,4
M16	17	28,6	35,7	76,2	107,2	128,6
M20	21	43,5	54,4	116,2	163,2	196,1
M22	23	52,2	65,3	139,4	196,0	235,2
M24	25	61,8	77,3	164,9	231,9	278,3
M27	28	77,6	97,0	206,9	291,0	349,2
M30	31	95,1	111,8	253,6	356,6	428,0

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 Standard 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	53,4	64,1
M16	16	25,3	31,6	67,5	94,9	113,9
M20	20	39,5	49,4	105,5	148,4	178,0
M22	22	47,8	59,8	127,6	179,5	215,4
M24	24	56,9	71,2	151,9	213,6	256,4
M27	27	72,1	90,1	192,3	270,4	324,5
M30	30	89,0	111,3	237,4	333,9	400,6

Annex B
(informative)

Preloaded bolts

Bolt sizes in Table B.1 and Table B.2 refer to standard series of ISO metric thread and pitch in accordance with ISO 262, *ISO general purpose metric screw threads — Selected sizes for screws, bolts and nuts*.

Table B.1 — Tightening torques (Nm) for achieving the maximum allowable preload level, $0{,}7 \times F_y$

Bolt size	Bolt material		
	8.8	**10.9**	**12.9**
M12	86	122	145
M14	136	190	230
M16	210	300	360
M18	290	410	495
M20	410	590	710
M22	560	790	950
M24	710	1 000	1 200
M27	1 040	1 460	1 750
M30	1 410	2 000	2 400
M33	1 910	2 700	3 250
M36	2 460	3 500	4 200
A friction coefficient, $\mu = 0{,}14$, is assumed in the calculations of the preceding tightening torques. For other values of the friction coefficient, the tightening torques should be adjusted accordingly.			

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 $\gamma_m = 1{,}1$ and $\gamma_{ss} = 1{,}14$ Bolt material											
					8.8 Slip factor				10.9 Slip factor				12.9 Slip 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	53,1	63,7	15,1	12,0	9,0	6,0	21,2	16,9	12,7	8,5	25,4	20,3	15,2	10,2
M14	115	51,5	72,5	86,9	20,5	16,4	12,3	8,2	28,9	23,1	17,3	11,6	34,7	27,7	20,8	13,9
M16	157	70,3	98,9	119	28,0	22,4	16,8	11,2	39,4	31,6	23,7	15,8	47,3	37,9	28,4	18,9
M18	192	86,0	121	145	34,3	27,4	20,6	13,7	48,2	38,6	28,9	19,3	57,9	46,3	34,7	23,2
M20	245	110	154	185	43,8	35,0	26,3	17,5	61,5	49,2	36,9	24,6	73,9	59,1	44,3	29,5
M22	303	136	191	229	54,1	43,3	32,5	21,6	76,1	60,9	45,7	30,4	91,3	73,1	54,8	36,5
M24	353	158	222	267	63,1	50,4	37,8	25,2	88,7	70,9	53,2	35,5	106	85,1	63,8	42,6
M27	459	206	289	347	82,0	65,6	49,2	32,8	115	92,2	69,2	46,1	138	111	83,0	55,3
M30	561	251	353	424	100	80,2	60,1	40,1	141	113	84,6	56,4	169	135	101	67,6
M33	694	311	437	525	124	99,2	74,4	49,6	174	139	105	69,7	209	167	126	83,7
M36	817	366	515	618	146	117	87,6	58,4	205	164	123	82,1	246	197	148	98,5

Annex C
(normative)

Design weld stresses, $\sigma_{w,Sd}$ and $\tau_{w,Sd}$

C.1 Butt joint

Normal weld design stress, $\sigma_{w,Sd}$, and shear weld design stress, $\tau_{w,Sd}$, are calculated from

$$\sigma_{w,Sd} = \frac{F_\sigma}{a_r \times l_r}, \ \tau_{w,Sd} = \frac{F_\tau}{a_r \times l_r} \qquad \text{(C.1)}$$

where

F_σ is the acting normal force (see Figure C.1);

F_τ is the acting shear force (see Figure C.1);

a_r is the effective throat thickness;

l_r is the effective weld length.

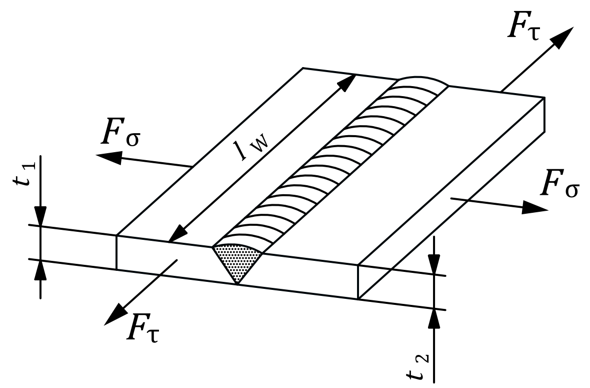


Figure C.1 — Butt weld

The effective throat thickness, a_r, is calculated from

$a_r = \min(t_1, t_2)$ for full penetration welds;

$a_r = 2 \times a_i$ for double-sided symmetrical partial penetration welds, where a_i is the thickness of either weld throat.

NOTE Single-sided partial penetration butt welds are not covered by this International Standard.

In general, the effective weld length, l_r, is given by $l_r = l_W - 2 \times a_r$ (for continuous welds), unless measures are taken to ensure that the whole weld length is effective, in which case

$l_r = l_w$

where

l_w is the weld length (see Figure C.1);

a_r is the effective throat thickness;

t_1, t_2 are the thicknesses of the plates.

C.2 Fillet weld

Normal weld design stress, $\sigma_{w,Sd}$, and shear weld design stress, $\tau_{w,Sd}$, are calculated from

$$\sigma_{w,Sd} = \frac{F_\sigma}{a_{r1} \times l_{r1} + a_{r2} \times l_{r2}}, \quad \tau_{w,Sd} = \frac{F_\tau}{a_{r1} \times l_{r1} + a_{r2} \times l_{r2}} \tag{C.2}$$

where

F_σ is the acting normal force (see Figure C.2);

F_τ is the acting shear force (see Figure C.2);

a_{ri} are the effective throat thicknesses (see Figure C.2) with $a_{ri} = a_i$;

l_{ri} are the effective weld lengths.

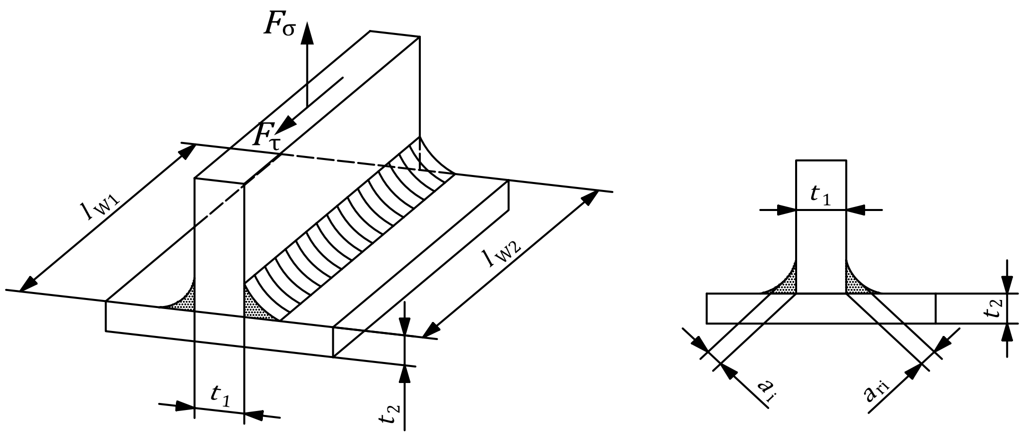


Figure C.2 — Joint dimensions

The effective throat thickness, a_r, is limited to $a_r \leq 0{,}7 \times \min(t_1, t_2)$.

For the effective weld lengths, see C.1.

Single-sided welds may be used loaded with forces as shown in Figure C.2.

For single-sided welds, $\sigma_{w,Sd}$ and $\tau_{w,Sd}$ are calculated in an analogous manner using the relevant weld parameters.

NOTE In the proof of competence, the effect of the in-plane shear component due to F_σ coexistent with $\sigma_{W,Sd}$ is taken into account implicitly.

C.3 T-joint with full and partial penetration

Normal weld design stress, $\sigma_{w,Sd}$, and shear weld design stress, $\tau_{w,Sd}$, are calculated from

$$\sigma_{w,Sd} = \frac{F_\sigma}{a_{r1} \times l_{r1} + a_{r2} \times l_{r2}}, \ \tau_{w,Sd} = \frac{F_\tau}{a_{r1} \times l_{r1} + a_{r2} \times l_{r2}} \tag{C.3}$$

where

- F_σ is the acting normal force (see Figure C.3);
- F_τ is the acting shear force (see Figure C.3);
- a_{ri} are the effective throat thicknesses (see Figure C.3) with $a_{ri} = a_i + a_{hi}$;
- l_{ri} are the effective weld lengths.

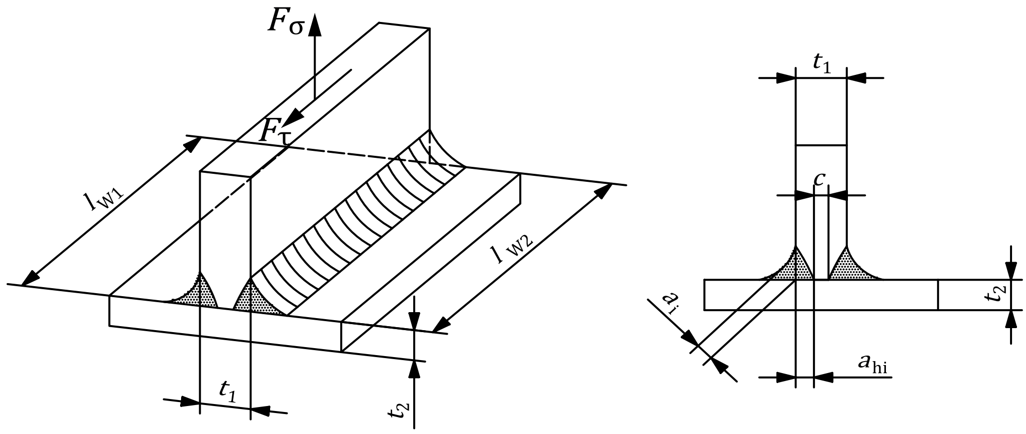


Figure C.3 — Joint dimensions

The effective weld thickness a_r is limited to $a_r \leq 0,7 \cdot \min(t_1, t_2)$.

For the effective weld lengths, see C.1.

Single-sided welds may be used loaded with forces as shown in Figure C.3.

For single-sided welds, $\sigma_{w,Sd}$ and $\tau_{w,Sd}$ are calculated in an analogous manner using the relevant weld parameters.

C.4 Effective distribution length under concentrated load

For simplification, the normal weld design stress, $\sigma_{w,Sd}$, and shear weld design stress, $\tau_{w,Sd}$, may be calculated using the effective distribution length under concentrated load (see Figure C.4).

$$l_r = 2 \times h_d \tan \kappa + \lambda \tag{C.4}$$

where

- l_r is the effective distribution length;

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

λ is the length of the contact area;

For wheels, λ may be set to

$\lambda = 0{,}2 \times r$, with $\lambda_{max} = 50$ mm

where

r is the radius of the wheel;

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

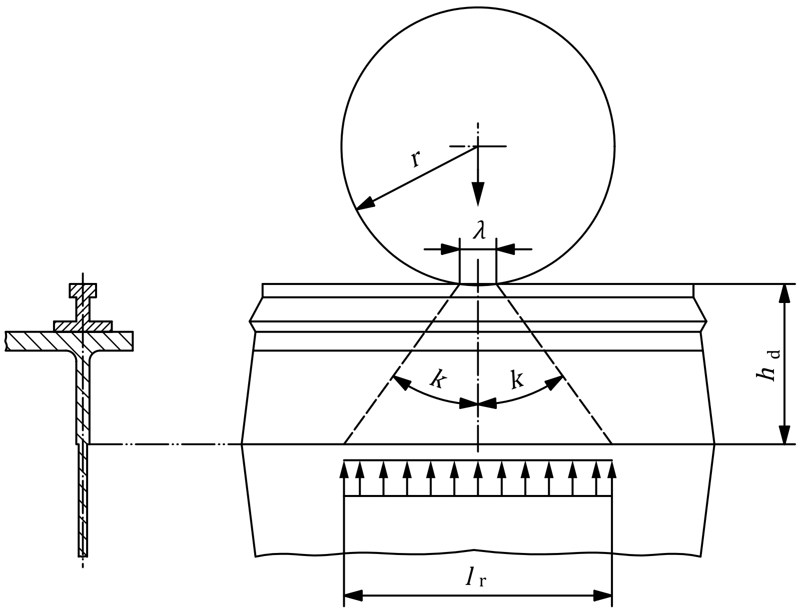


Figure C.4 — Concentrated load

Other calculations for the determination of the design stresses may be used; however, the values for $\Delta\sigma_c$ and $\Delta\tau_c$ presented in Annex D are based on the presented calculation herein.

Annex D
(normative)

Values of slope constant, *m*, and characteristic fatigue strength, $\Delta\sigma_c$, $\Delta\tau_c$

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 Table D.2 and Table 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 the first column of Annex E (see 6.2.1).

Table D.1 — Basic material of structural members

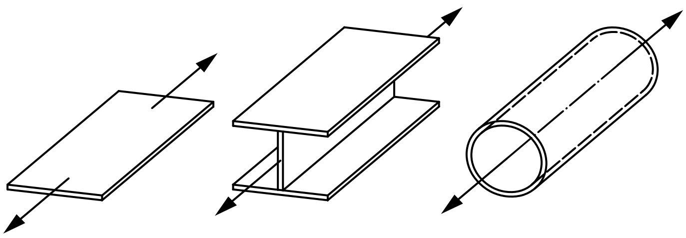
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
1.1	$m = 5$	 Plates, flat bars, rolled profiles under normal stresses	General requirements: — Rolled surfaces — No geometrical notch effects (e.g. cut outs) — Surface roughness values before surface treatment such as shot blasting
	140	Independent of f_y	— Surface condition in accordance with ISO 7788:1985, Table 1 — Repair welding allowed
	140	$180 \leq f_y \leq 220$	— Surface condition in accordance with ISO 7788:1985, Table 1 — No repair welding — Surface roughness Rz ≤ 100 µm — Edges rolled or machined or no free edges — Surface roughness Rz ≤ 60 µm +1 NC
	160	$220 < f_y \leq 320$	
	180	$320 < f_y \leq 500$	
	200	$500 < f_y$	

Table D.1 (*continued*)

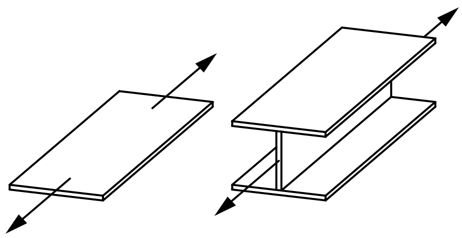
<table>
<tr><th>Detail no.</th><th>$\Delta\sigma_c$
$\Delta\tau_c$
N/mm^2^</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="6"></td><td>**180**</td><td>$180 \leq f_y \leq 220$</td><td rowspan="6">— Surface condition in accordance with ISO 7788:1985, Table 1
— No repair welding
— Surface roughness Rz ≤ 20 μm
— Edges rolled or machined or no free edges</td></tr>
<tr><td>**200**</td><td>$220 < f_y \leq 320$</td></tr>
<tr><td>**225**</td><td>$320 < f_y \leq 500$</td></tr>
<tr><td>**250**</td><td>$500 < f_y \leq 650$</td></tr>
<tr><td>**280**</td><td>$650 < f_y \leq 900$</td></tr>
<tr><td>**315**</td><td>$900 < f_y$</td></tr>
<tr><td rowspan="5">1.2</td><td>$m = 5$</td><td>
Plates, flat bars, rolled profiles under normal stresses</td><td>General requirements:
— Rolled surfaces
— Thermal cut edges
— No geometrical notch effects (e.g. cutouts)
— Surface roughness values before surface treatment such as shot blasting</td></tr>
<tr><td>**140**</td><td>Independent of f_y</td><td>— Surface condition in accordance with ISO 7788:1985, Table 1
— Repair welding allowed
— Edge quality in accordance with ISO 9013:2002, Table 5, Range 3</td></tr>
<tr><td>**140**</td><td>$180 \leq f_y \leq 220$</td><td rowspan="3">— Surface condition in accordance with ISO 7788:1985, Table 1
— Edge quality in accordance with of ISO 9013:2002, Table 5, Range 3
— No repair welding
— Surface roughness Rz ≤ 100 μm
— Machine controlled cutting
— Plate surface roughness Rz ≤ 60 μm and edge quality in accordance with ISO 9013:2002+1 NC, Table 5, Range 2</td></tr>
<tr><td>**160**</td><td>$220 < f_y \leq 500$</td></tr>
<tr><td>**180**</td><td>$500 < f_y$</td></tr>
</table>

Table D.1 (*continued*)

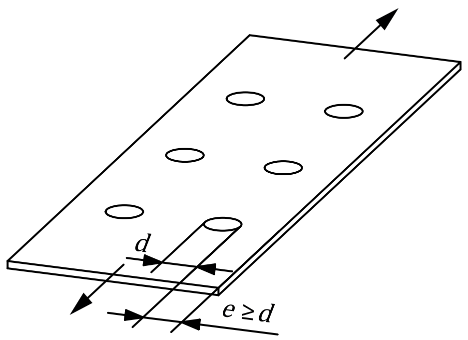
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
	160	$180 \le f_y \le 220$	— Surface condition in accordance with ISO 7788:1985, Table 1 — Edge quality in accordance with ISO 9013:2002, Table 5, Range 1 — No repair welding — Plate surface roughness Rz ≤ 20 µm — Mill scale removed before cutting — Machine controlled cutting
	180	$220 < f_y \le 320$	
	200	$320 < f_y \le 500$	
	225	$500 < f_y \le 650$	
	250	$650 < f_y \le 900$	
	280	$900 < f_y$	
1.3	$m = 5$	 Hole edges in a plate under normal stresses	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
	80	Independent of f_y	— Holes may be punched
	100	$180 < f_y \le 220$	— Holes machined or thermal cut to a quality in accordance with ISO 9013:2002, Table 5, Range 3 — Holes not punched — Burr on hole edges removed — Rolled surface condition in accordance with ISO 7788:1985, Table 1 — No repair welding — Plate surface roughness Rz ≤ 100 µm
	112	$220 < f_y \le 320$	
	125	$320 < f_y \le 500$	
	140	$500 < f_y \le 650$	
	160	$650 < f_y$	

Table D.1 (*continued*)

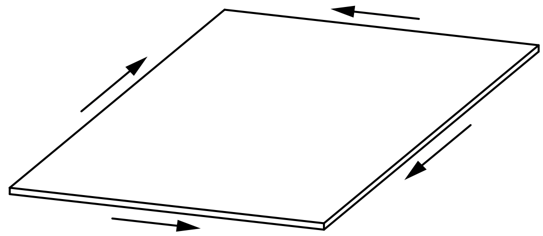
<table>
<tr><th>Detail no.</th><th>$\Delta\sigma_c$
$\Delta\tau_c$
N/mm^2</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="12">1.4</td><td>$m = 5$</td><td>
Plates, flat bars, rolled profiles under normal stresses</td><td>General requirements:
— Rolled surfaces
— No geometrical notch effects (e.g. cut outs)
— Surface roughness values before surface treatment such as shot blasting</td></tr>
<tr><td>90</td><td>Independent of f_y</td><td>— Surface condition in accordance with ISO 7788:1985, Table 1
— Repair welding allowed.</td></tr>
<tr><td>90</td><td>$180 \le f_y \le 220$</td><td rowspan="4">— Surface condition in accordance with ISO 7788:1985, Table 1
— No repair welding
— Surface roughness Rz ≤ 100 µm
— Edges rolled or machined or no free edges
— Any burrs and flashes removed from rolled edges
— Surface roughness Rz ≤ 60 µm +1 NC</td></tr>
<tr><td>100</td><td>$220 < f_y \le 320$</td></tr>
<tr><td>112</td><td>$320 < f_y \le 500$</td></tr>
<tr><td>125</td><td>$500 < f_y$</td></tr>
<tr><td>112</td><td>$180 \le f_y \le 220$</td><td rowspan="6">— Surface condition in accordance with ISO 7788:1985, Table 1
— No repair welding
— Surface roughness Rz ≤ 20 µm
— Edges machined or no free edges</td></tr>
<tr><td>125</td><td>$220 < f_y \le 320$</td></tr>
<tr><td>140</td><td>$320 < f_y \le 500$</td></tr>
<tr><td>160</td><td>$500 < f_y \le 650$</td></tr>
<tr><td>180</td><td>$650 < fy \le 900$</td></tr>
<tr><td>200</td><td>$900 < fy$</td></tr>
</table>

Table D.2 — Elements of non-welded connections

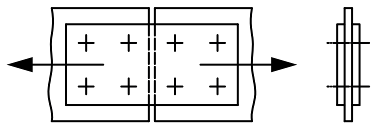
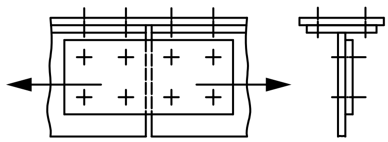
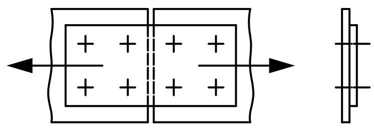
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	Constructional detail		Requirements
2.1	m = 5	Double shear		— The proof of fatigue strength is not required for bolts of friction grip type bolted connections — Nominal stress calculated for the net cross-section
		Supported single-shear (example)		
		Single-shear		
		Perforated parts in slip-resistant bolted connections under normal stresses		
	160	$f_y \leq 275$		
	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

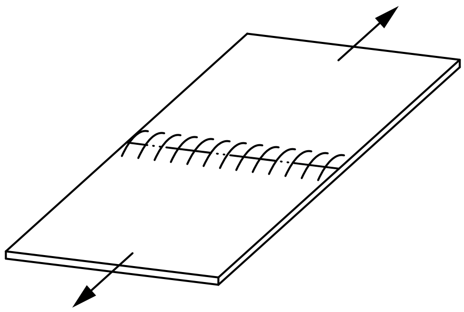
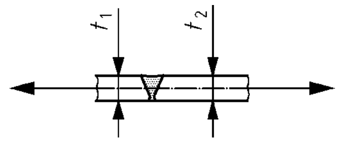
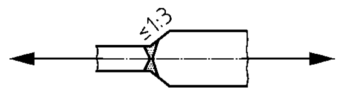
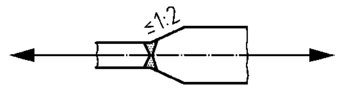
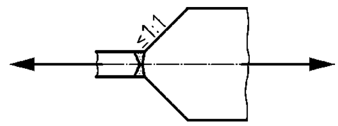
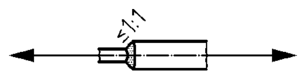
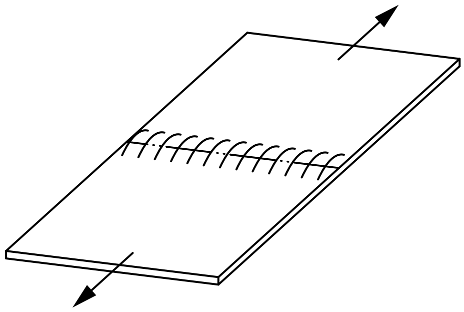
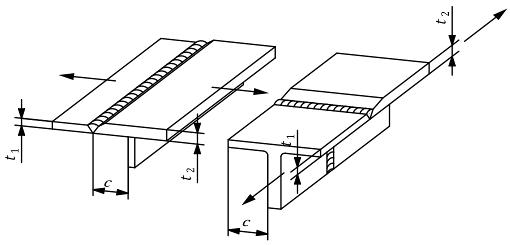
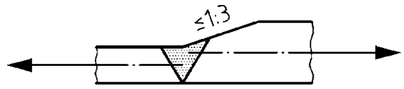
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.1	$m = 3$	 Symmetric butt joint, normal stress across the weld	Basic conditions: — Symmetric plate arrangement — Fully penetrated weld — Components with usual residual stresses — Angular misalignment < 1°  $t_1 = t_2$ or  slope < 1:3 Special conditions: — Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC
	140	Butt weld, quality level B*	 −2 NC
	125	Butt weld, quality level B	 −4 NC
	112	Butt weld, quality level C	 −4 NC

Table D.3 (*continued*)

<table>
<tr><th>Detail no.</th><th>$\Delta\sigma_c$
$\Delta\tau_c$
N/mm²</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="2">3.2</td><td>$m = 3$</td><td>
Symmetric butt joint, normal stress across the weld</td><td>Basic conditions:
— Symmetric plate arrangement
— Fully penetrated weld
— 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>80</td><td>Butt weld on remaining backing, quality level C</td><td></td></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 rowspan="4">Basic conditions:
— Fully penetrated weld
— Supported parallel to butt weld: $c < 2\, t_2 + 10$ mm
— Supported vertical to butt weld: $c < 12\, t_2$
Components with usual residual stresses:


slope ≤ 1:3
$t_2 - t_1 \le 4$ mm
Special conditions:
— Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC
— Influence of slope and thickness $t_2 - t_1$:

thickness ($t_2 - t_1$) mm
<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>125</td><td>Butt weld, quality level B*</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>
</table>

Table D.3 (*continued*)

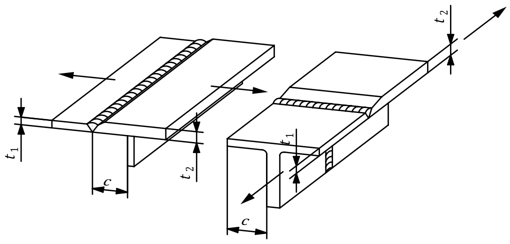
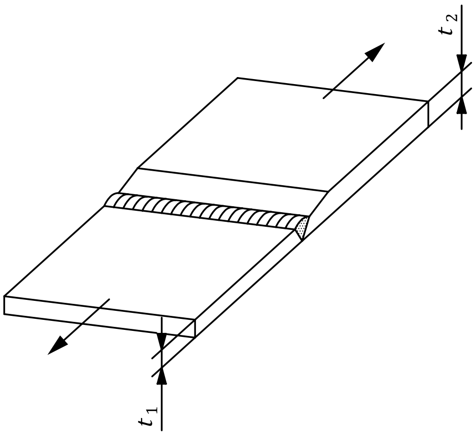
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	**Constructional detail**	**Requirements**
3.4	$m = 3$	 Unsymmetrical supported butt joint, normal stress across the butt weld	Basic conditions: — Fully penetrated weld — Supported parallel to butt weld: $c < 2t_2 + 10$ mm — Supported vertical to butt weld: $c < 12t_2$ — 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
	80	Butt weld on remaining backing, quality level C	

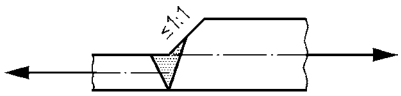
Table D.3 (*continued*)

<table>
<tr><th>Detail no.</th><th>$\Delta\sigma_c$
$\Delta\tau_c$
N/mm²</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="4">3.5</td><td>$m = 3$</td><td>


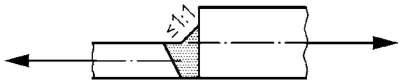
Unsymmetrical unsupported butt joint, stress across the butt weld</td><td>Basic conditions:

— Fully penetrated weld

— Components with usual residual stresses



slope ≤ 1:1

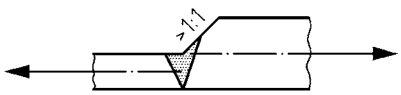


slope in weld or base material

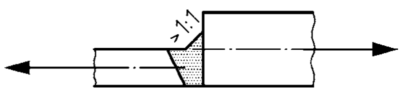
$t_1/t_2 > 0,84$

Special conditions:

— Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage)



−1 NC



−2 NC</td></tr>
<tr><td>**100**</td><td>Butt weld, quality level B*</td><td>— $0,84 \geq t_1/t_2 > 0,74$ −1 NC</td></tr>
<tr><td>**90**</td><td>Butt weld, quality level B</td><td>— $0,74 \geq t_1/t_2 > 0,63$ −2 NC</td></tr>
<tr><td>**80**</td><td>Butt weld quality level C</td><td>— $0,63 \geq t_1/t_2 > 0,50$ −3 NC
— $0,50 \geq t_1/t_2 > 0,40$ −4 NC</td></tr>
</table>

Table D.3 (*continued*)

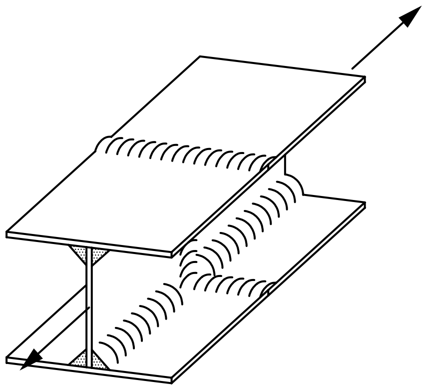
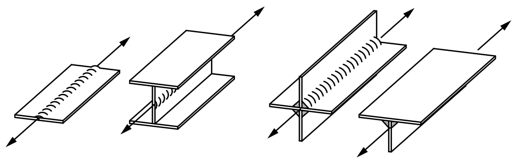
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.6	m = 3	 Butt joint with crossing welds, stress across the butt weld	Basic conditions: — Components with usual residual stresses
	125	Butt weld, quality level B*	
	100	Butt weld, quality level B	
	90	Butt weld, quality level C	
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	

Table D.3 (*continued*)

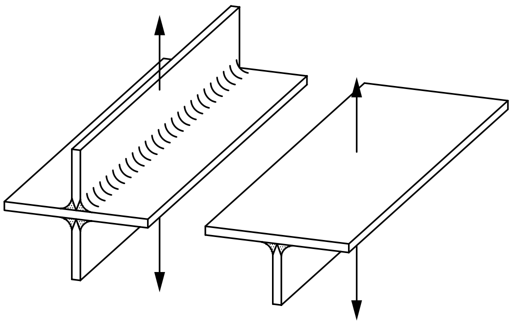
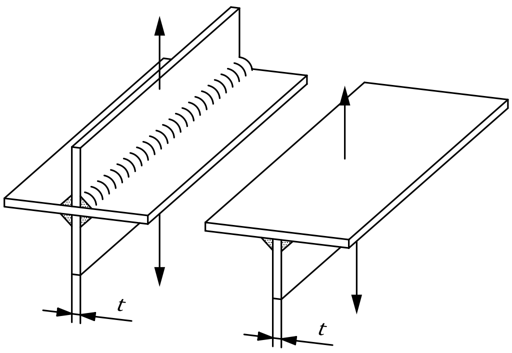
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.8	$m = 3$	 Cross or T-Joint, groove weld, normal stress across the weld	Basic conditions: — Continuous weld — Full penetration weld Special conditions: — Automatic welding, no initial points +1 NC — Welding with restraint 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	$\sigma_w = F/(2 \times a \times l)$ (see Annex C)
	71	Quality level B	Stress in the loaded plate at weld toe
	63	Quality level C	

Table D.3 (*continued*)

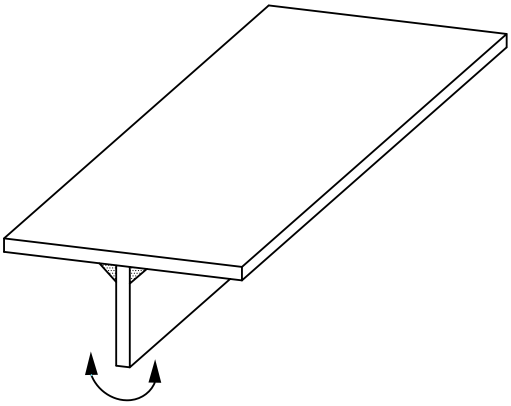
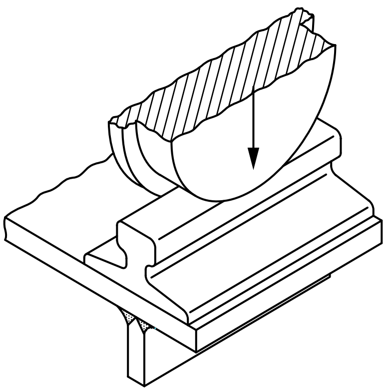
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
3.10	*m* = 3	 T-Joint, stresses from bending	
	45	Stress in weld throat	Stress calculated with the applied bending moment and weld joint geometry taken into account
	80	Stresses in plate at weld toe, Quality 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	

Table D.3 (*continued*)

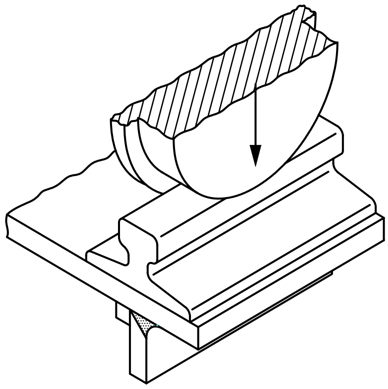
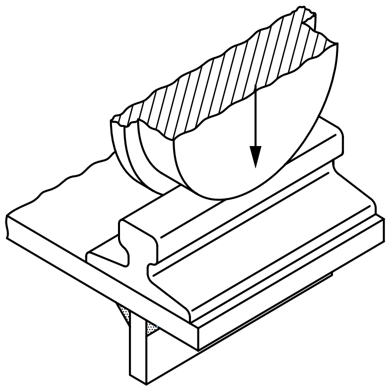
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.12	$m = 3$	 Full penetration weld (with backing) with transverse compressive load (e.g. wheel), stress calculated in the web plate	
	90	Quality level B	
	80	Quality level C	
3.13	$m = 3$	 Double fillet weld with transverse compressive load, (e.g. wheel), stress calculated in the web plate	Web thickness t: $0{,}5 \cdot t \leq a \leq 0{,}7 \cdot t$ with a in accordance with Annex C
	71	Quality level B, C	

Table D.3 (*continued*)

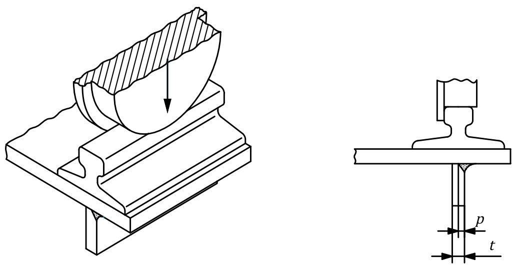
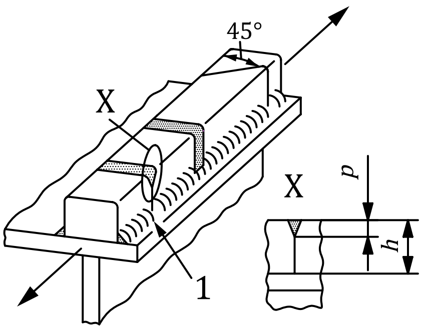
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
3.14	$m = 3$	 Partial penetration weld with transverse compressive load (e.g. wheel), stress calculated in the web plate	$0{,}5 \cdot t \le a \le 0{,}7 \cdot t$ with a in accordance with Annex C $p \ge 1$ mm for $t \le 6$ mm $p \ge \frac{t}{4}$ for $t > 6$ mm
	71	Quality level B, C	
3.15	$m = 3$	 Plate with 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 three 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, $h > p \ge 0{,}3 \times h$	
	71	Welds on top and on the two sides of the rail, $h > p \ge 0{,}2 \times h$	

Table D.3 (*continued*)

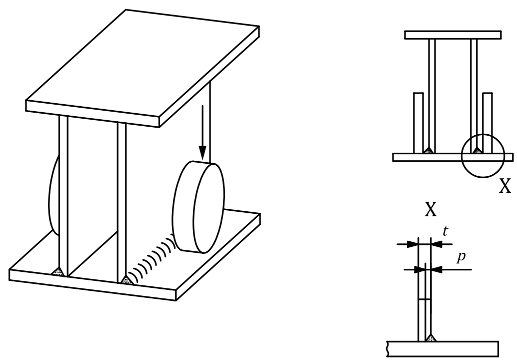
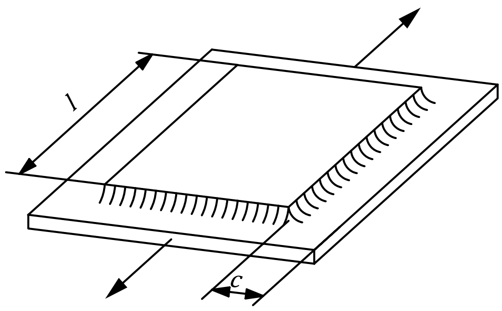
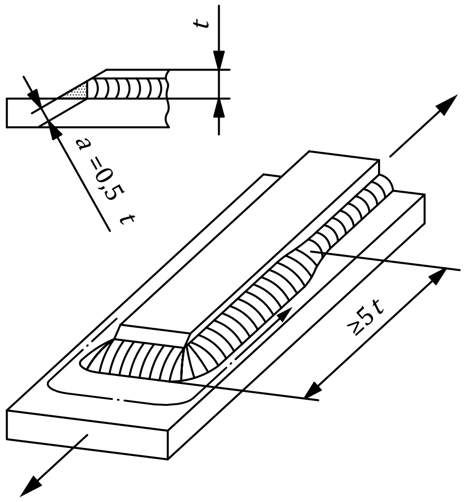
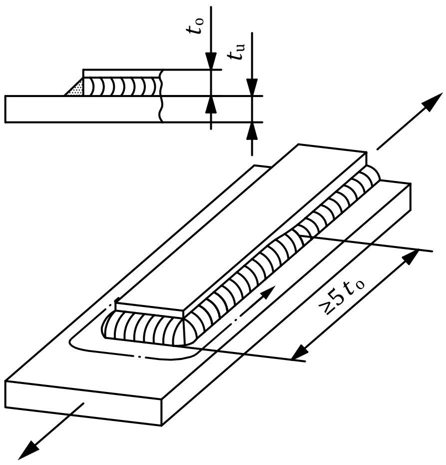
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
3.16	$m = 3$	 Partial penetration weld with transverse load (e.g. underslung crab), stress calculated in the web plate	Basic conditions: — Quality level C — *a* and *p* in accordance with Clause C.3 Special conditions: — Fillet weld with penetration and quality level B +1 NC
	63	$p \geq 1$ mm for $t \leq 6$ mm; $p \geq \frac{t}{4}$ for $t > 6$ mm; $0{,}5 \times t \leq a \leq 0{,}7 \times t$	
	56	$p \geq 1$ mm for $t > 6$ mm; $0{,}6 \times t \leq a \leq 0{,}7 \times t$	
	50	Fillet weld without penetration; $0{,}6 \times t \leq a \leq 0{,}7 \times t$	
	40	Fillet weld without penetration; $0{,}5 \times t \leq a \leq 0{,}6 \times t$	
3.17	$m = 3$	 Continuous component with welded cover plate	Basic conditions: — Quality level C — Continuous weld — Distance, *c*, between 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	

Table D.3 (*continued*)

<table>
<tr><th>Detail no.</th><th>$\Delta\sigma_c$
$\Delta\tau_c$
N/mm²</th><th>Constructional detail</th><th>Requirements</th></tr>
<tr><td rowspan="3">3.18</td><td>m = 3</td><td>

Continuous component with load carrying flange plate, stress in continuous component at end of connection</td><td rowspan="3">Basic conditions:
— Continuous fillet or groove weld</td></tr>
<tr><td>112</td><td>Flange plate with end chamfer ≤ 1:3; edge weld and end of flank weld in weld quality level B*</td></tr>
<tr><td>100</td><td>Flange plate with end chamfer ≤ 1:2; edge weld and end of flank weld in weld quality level B*</td></tr>
<tr><td rowspan="2">3.19</td><td>m = 3</td><td>

Continuous component with load carrying flange plate, stress in continuous component at end of connection</td><td rowspan="2">Basic conditions:
— Continuous fillet or groove weld
— $t_o \leq 1,5t_u$</td></tr>
<tr><td>80</td><td>Edge weld and end of flank weld in weld quality level B*</td></tr>
</table>

Table D.3 (*continued*)

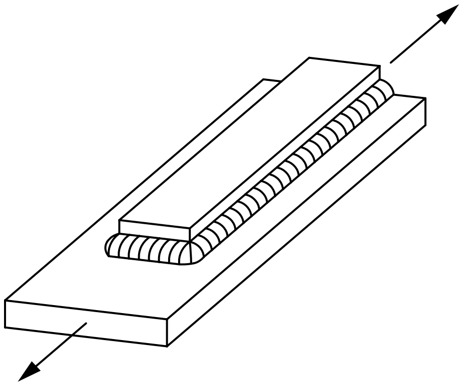
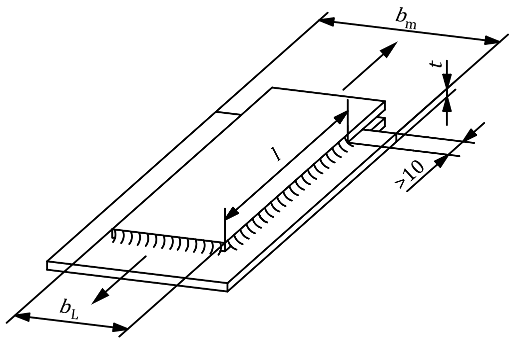
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	**Constructional detail**	**Requirements**
3.20	$m = 3$	 Continuous component with load carrying flange plate, stress in continuous component at end of connection	Basic conditions: — Continuous fillet or groove weld
	63	Quality level B	
	56	Quality level C	
3.21	$m = 3$	 Overlapped welded joint, main plate	Basic conditions — Stressed area to be calculated from $A_s = t \times l_r$ $l_r = \min(b_m, b_L + l)$ (See also detail 3.32)
	80	Quality level B*	
	71	Quality level B	
	63	Quality level C	

Table D.3 (*continued*)

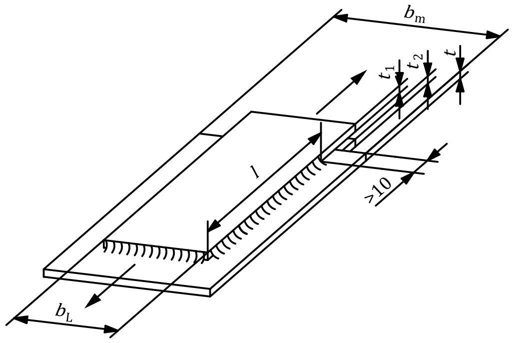
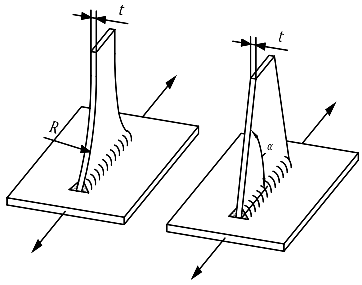
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
3.22	m = 3	 Overlapped welded joint, lap plates	Basic conditions: — Stressed area to be calculated from $A_s = b_L \times (t_1 + t_2)$
	50		
3.23	m = 3	 Continuous component with longitudinally mounted parts, 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	

Table D.3 (*continued*)

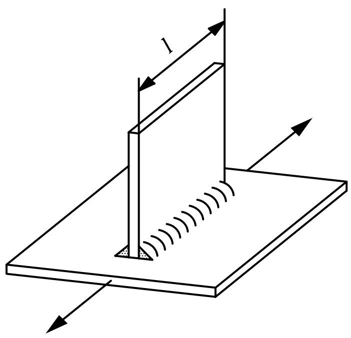
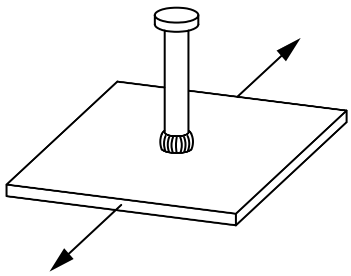
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.24	m = 3	 Continuous component with parts ending perpendicularly	Basic conditions: — All round fillet weld — Quality level B, C Special conditions: — Single fillet weld −1 NC — Weld quality level D −1 NC
	80	$l \leq 50$ 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
	80	Quality level C or better	

Table D.3 (*continued*)

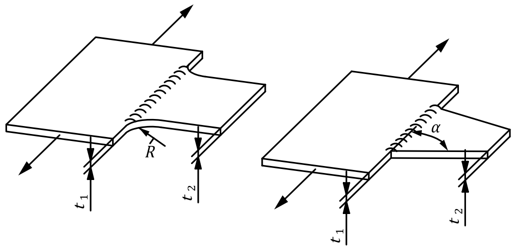
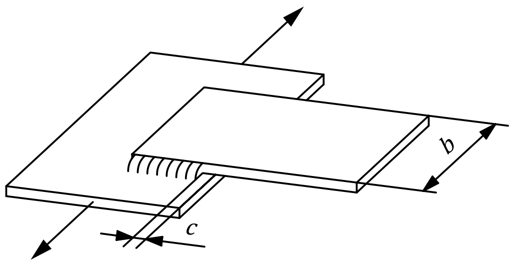
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.26	m = 3	 Continuous component with longitudinally mounted parts, welded to edge	Basic conditions: — $R \geq 50$ mm; $\alpha \leq 60°$ — Groove weld or allround fillet weld Special conditions: — $R < 50$ mm or $\alpha > 60°$ − 2 NC
	90	Quality level B*	$R \geq 150$ mm or $\alpha \leq 45°$
	80	Quality level B	
	71	Quality level C	
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	

Table D.3 (*continued*)

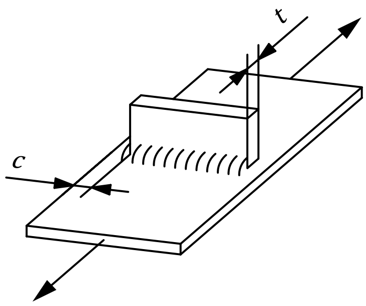
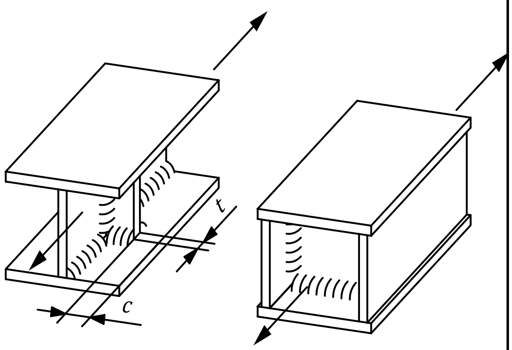
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirements
3.28	$m = 3$	 Continuous component to which parts are welded transversally	Basic conditions: — Plate thickness $t \leq 12$ mm — $c \geq 10$ mm — Quality level D not allowed for K-weld Special conditions: — Plate thickness $t > 12$ 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	
	71	Single fillet weld, quality level B, C	
	71	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
	112	Double fillet weld, quality level B*	
	100	Double fillet weld, quality level B	
	90	Double fillet weld, quality level C	
	71	Single fillet weld, quality level B, C	
	71	Partial penetration V-weld on remaining backing, quality level B, C	

Table D.3 (*continued*)

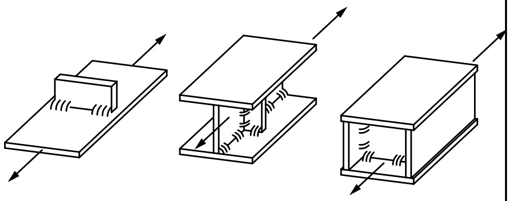
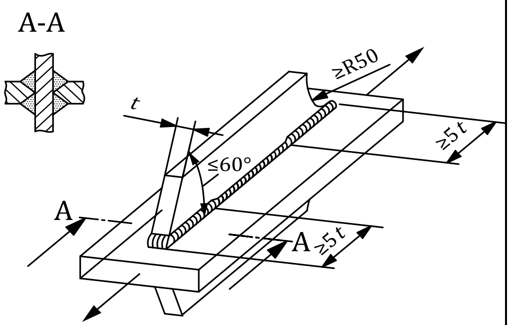
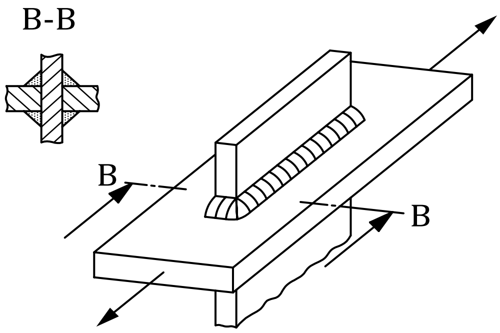
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
3.30	m = 3	 Continuous component to which transverse parts or stiffeners are welded intermittently	
	63	Quality level C	
	50	Quality level D	
3.31	m = 3	 Continuous component with longitudinally mounted parts, parts through hole	Basic conditions: — $R \geq 50$ mm, $\alpha \leq 60°$ Special conditions: — $R \geq 100$ mm, $\alpha \leq 45°$ + 1 NC — End welds in the zone of at least 5t fully penetrated +2 NC
	80	Parts rounded or chamfered	
3.32	m = 3	 Continuous component with longitudinally mounted parts, parts through hole	
	56	Parts ending perpendicularly	

Table D.3 (*continued*)

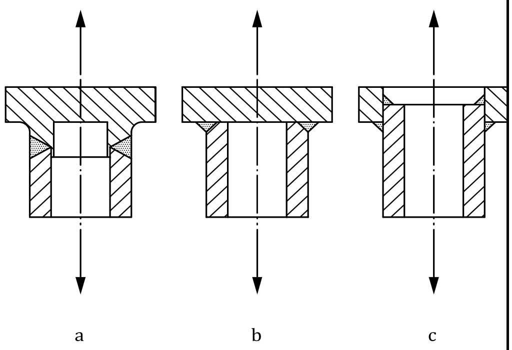
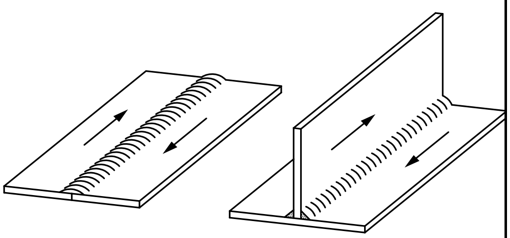
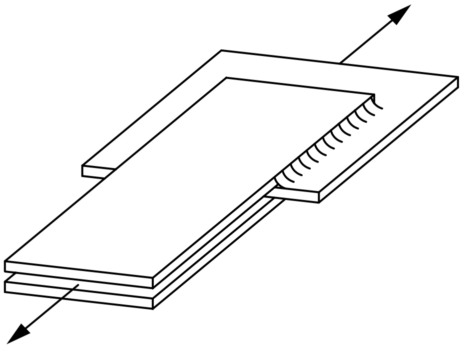
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	**Constructional detail**	**Requirements**
3.33	m = 3	 Tubes under axial and bending loads, normal stresses calculated in the tube	Basic conditions: — Quality level C — Groove weld fully penetrated — Fillet weld thickness a > 0,7 tube thickness — Flange 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)	
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	

Table D.3 (*continued*)

Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	**Constructional detail**	**Requirements**
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)

Calculated values of limit design stress range, $\Delta\sigma_{Rd}$ and $\Delta\sigma_{Rd,1}$

See Table E.1 and Table E.2.

A row represents a notch class (NC) for basic conditions: +1 NC is one line above; −1 NC is one line below.

Table E.1 — Details with m = 3 and γ_{mf} = 1,25

NC, $\Delta\sigma_c$ N/mm^2	$\Delta\sigma_{Rd}$ **as a function of notch class stress values and classes S** N/mm^2											
	S02	**S01**	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
355	2254,1	1789,1	1420,0	1127,1	894,5	713,7	568,0	450,8	357,8	284,0	225,4	178,9
315	2000,1	1587,5	1260,0	1000,1	793,8	633,3	504,0	400,0	317,5	252,0	200,0	158,8
280	1777,9	1411,1	1120,0	888,9	705,6	562,9	448,0	355,6	282,2	224,0	177,8	141,1
250	1587,4	1259,9	1000,0	793,7	630,0	502,6	400,0	317,5	252,0	200,0	158,7	126,0
225	1428,7	1133,9	900,0	714,3	567,0	452,4	360,0	285,7	226,8	180,0	142,9	113,4
200	1269,9	1007,9	800,0	635,0	504,0	402,1	320,0	254,0	201,6	160,0	127,0	100,8
180	1142,9	907,1	720,0	571,5	453,6	361,9	288,0	228,6	181,4	144,0	114,3	90,7
160	1015,9	806,3	640,0	508,0	403,2	321,7	256,0	203,2	161,3	128,0	101,6	80,6
140	888,9	705,6	560,0	444,5	352,8	281,5	224,0	177,8	141,1	112,0	88,9	70,6
125	793,7	630,0	500,0	396,9	315,0	251,3	200,0	158,7	126,0	100,0	79,4	63,0
112	711,2	564,4	448,0	355,6	282,2	225,2	179,2	142,2	112,9	89,6	71,1	56,4
100	635,0	504,0	400,0	317,5	252,0	201,1	160,0	127,0	100,8	80,0	63,5	50,4
90	571,5	453,6	360,0	285,7	226,8	180,9	144,0	114,3	90,7	72,0	57,1	45,4
80	508,0	403,2	320,0	254,0	201,6	160,8	128,0	101,6	80,6	64,0	50,8	40,3
71	450,8	357,8	284,0	225,4	178,9	142,7	113,6	90,2	71,6	56,8	45,1	35,8
63	400,0	317,5	252,0	200,0	158,8	126,7	100,8	80,0	63,5	50,4	40,0	31,8
56	355,6	282,2	224,0	177,8	141,1	112,6	89,6	71,1	56,4	44,8	35,6	28,2
50	317,5	252,0	200,0	158,7	126,0	100,5	80,0	63,5	50,4	40,0	31,7	25,2
45	285,7	226,8	180,0	142,9	113,4	90,5	72,0	57,1	45,4	36,0	28,6	22,7
40	254,0	201,6	160,0	127,0	100,8	80,4	64,0	50,8	40,3	32,0	25,4	20,2
36	228,6	181,4	144,0	114,3	90,7	72,4	57,6	45,7	36,3	28,8	22,9	18,1
32	203,2	161,3	128,0	101,6	80,6	64,3	51,2	40,6	32,3	25,6	20,3	16,1
28	177,8	141,1	112,0	88,9	70,6	56,3	44,8	35,6	28,2	22,4	17,8	14,1
25	158,7	126,0	100,0	79,4	63,0	50,3	40,0	31,7	25,2	20,0	15,9	12,6

Table E.2 — Details with m=5 and γ_{mf} = 1,25

NC, $\Delta\sigma_c$ N/mm^2	$\Delta\sigma_{Rd,1}$ **as a function of notch class stress values and classes S** N/mm^2											
	S02	**S01**	**S0**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
355	984,3	856,9	745,9	649,4	565,3	493,7	430,5	374,7	326,2	284,0	247,2	215,2
315	873,4	760,3	661,9	576,2	501,6	438,1	382,0	332,5	289,5	252,0	219,4	191,0
280	776,3	675,8	588,3	512,2	445,9	389,4	339,5	295,6	257,3	224,0	195,0	169,8
250	693,1	603,4	525,3	457,3	398,1	347,7	303,1	263,9	229,7	200,0	174,1	151,6
225	623,8	543,1	472,8	411,6	358,3	312,9	272,8	237,5	206,8	180,0	156,7	136,4
200	554,5	482,7	420,2	365,8	318,5	278,1	242,5	211,1	183,8	160,0	139,3	121,3
180	499,1	434,5	378,2	329,3	286,6	250,3	218,3	190,0	165,4	144,0	125,4	109,1
160	443,6	386,2	336,2	292,7	254,8	222,5	194,0	168,9	147,0	128,0	111,4	97,0
140	388,2	337,9	294,2	256,1	222,9	194,7	169,8	147,8	128,7	112,0	97,5	84,9
125	346,6	301,7	262,7	228,7	199,1	173,8	151,6	132,0	114,9	100,0	87,1	75,8
112	310,5	270,3	235,3	204,9	178,4	155,8	135,8	118,2	102,9	89,6	78,0	67,9
100	277,3	241,4	210,1	182,9	159,2	139,1	121,3	105,6	91,9	80,0	69,6	60,6
90	249,5	217,2	189,1	164,6	143,3	125,2	109,1	95,0	82,7	72,0	62,7	54,6
80	221,8	193,1	168,1	146,3	127,4	111,3	97,0	84,4	73,5	64,0	55,7	48,5
71	196,9	171,4	149,2	129,9	113,1	98,7	86,1	74,9	65,2	56,8	49,4	43,0
63	174,7	152,1	132,4	115,2	100,3	87,6	76,4	66,5	57,9	50,4	43,9	38,2
56	155,3	135,2	117,7	102,4	89,2	77,9	67,9	59,1	51,5	44,8	39,0	34,0
50	138,6	120,7	105,1	91,5	79,6	69,5	60,6	52,8	45,9	40,0	34,8	30,3
45	124,8	108,6	94,6	82,3	71,7	62,6	54,6	47,5	41,4	36,0	31,3	27,3
40	110,9	96,5	84,0	73,2	63,7	55,6	48,5	42,2	36,8	32,0	27,9	24,3
36	99,8	86,9	75,6	65,9	57,3	50,1	43,7	38,0	33,1	28,8	25,1	21,8
32	88,7	77,2	67,2	58,5	51,0	44,5	38,8	33,8	29,4	25,6	22,3	19,4
28	77,6	67,6	58,8	51,2	44,6	38,9	34,0	29,6	25,7	22,4	19,5	17,0
25	69,3	60,3	52,5	45,7	39,8	34,8	30,3	26,4	23,0	20,0	17,4	15,2

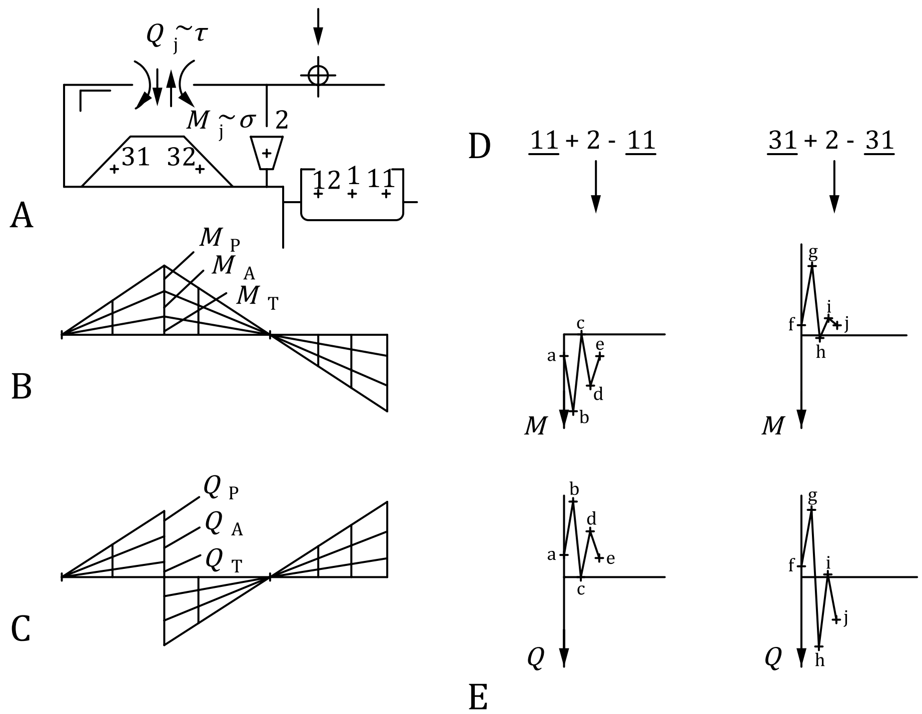
Annex F
(informative)

Evaluation of stress cycles — Example

The stress histories at a selected point of the structure depend on the loads, their direction, and their 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 design life can be divided into several typical tasks with the numbers of working cycles corresponding to them. A task can be characterized by a specific combination of crane configuration and sequence of intended movements.

For evaluating the sequence of stress peaks occurring during the performance of any task, the corresponding series of loadings has to be determined, i.e. the magnitude, position, and direction of all loads. 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).



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* ($\phi_2 = 1$) 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

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

— 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 the bending moment, M_j, and the shear force, Q_j, at the selected point, j, are shown for different loads (subscripts 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 M_j ($\sigma(t)$ = global bending stress) and Q_j ($\tau(t)$ = global shear stress) can be directly determined from the influence lines.

From those resulting sequences of stress peaks, the stress cycles can be identified by either the rainflow counting or the reservoir method.

The complete stress history is made by summation of all the individual stress histories taken from the sequences of movements of the 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 five 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.

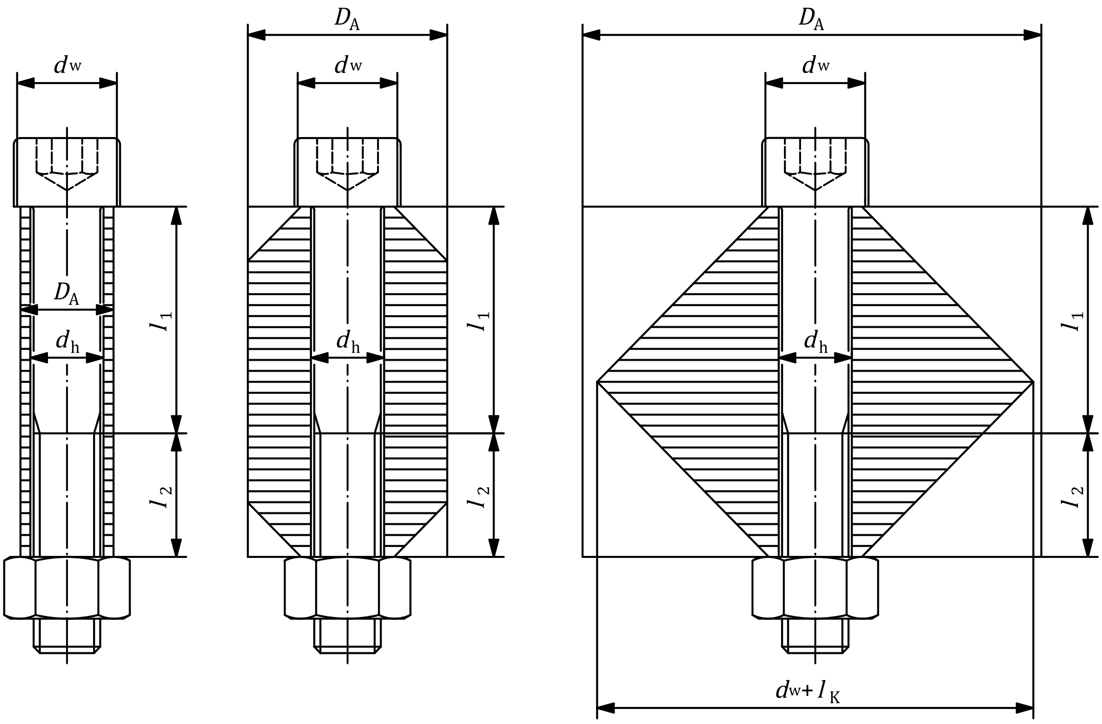


Figure G.1 — Types of connections loaded in tension

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

The stiffness K_c of the connected parts is calculated from

$$K_c = \frac{E}{l_k} \times A_{eq} \tag{G.1}$$

where

- K_c is the stiffness of flanges or compressed parts;
- E is the modulus of elasticity;
- l_k is the effective clamped length (including all clamped components): $_k = l_1 + l_2$;
- A_{eq} is the equivalent area for calculation.

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

For $D_A < d_w$:

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

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

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

For $d_w + l_K < D_A$

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

where

D_A is the diameter of the available cylinder of clamped material;

d_w is the diameter of the contact area of 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 is calculated from

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

where

K_b is the stiffness of the bolt or compressed parts;

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, can be used instead of A_r (see values in Table B.2)].

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

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

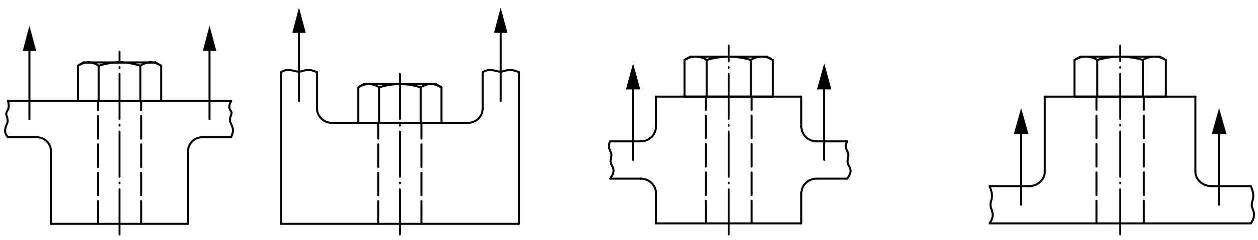
where

Φ is the stiffness ratio factor;

K_b is the stiffness of the bolt;

K_c is the stiffness of connected parts;

α_L is the load introduction factor (see Figure G.2).



a) α_L = 0,9 ...1 **b)** α_L = 0,6 **c)** α_L = 0,3

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

The case illustrated by Figure G.2 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, α_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 α_L = 1 shall be used with Formula (G.6).

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