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Cranes — Proof of competence of steel structures

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

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 20332 was prepared by Technical Committee ISO/TC 96, *Cranes*, Subcommittee SC 10, *Design principles and requirements*.

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 may give specific proof-of-competence requirements for particular crane types.

Proofs of competence, 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, 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. The allowable stress method is a permitted alternative to the limit state method as set forth in this International Standard.

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

NOTE Proof of competence for elastic stability is to be covered by another International Standard.

2 Normative references

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

ISO 148-1:2006, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

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

ISO 286-2:1988, *ISO system of limits and fits — Part 2: Tables of standard tolerance grades and limit deviations for holes and shafts,* corrected by ISO 286-2:1988/Cor 1:2006

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

ISO 898-1:—[1], *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 4301-1:1986, *Cranes and lifting appliances — Classification — Part 1: General*

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

1) To be published. (Revision of ISO 898-1:1999)

ISO 5817:2003, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections,* corrected by ISO 5817:2003/Cor 1:2006

ISO 8686 (all parts), *Cranes — Design principles for loads and load combinations — Part 1: General*

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

ISO 12100-1:2003, *Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology*

ISO 12100-2:2003, *Safety of machinery — Basic concepts, general principles for design — Part 2: Technical principles*

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

3 Terms, definitions, symbols and abbreviations

For the purposes of this document, the terms and definitions given in ISO 12100-1, ISO 12100-2, ISO 17659 and ISO 4306-1:2007, Clause 6, and the following terms, definitions, symbols and abbreviations (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

Symbols	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
b_c	Geometric dimension
b_{eff}	Effective dimension for calculation
b_l	Geometric dimension
C	Total number of working cycles
c	Geometric dimension

Table 1 (*continued*)

Symbols	Description
D_A	Diameter of the sheet
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_o	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
$F_{p, d}$	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
$F_{t, Rd}$	Limit design tensile force 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_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

Table 1 (*continued*)

Symbols	Description
$f_{w, Rd}$	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
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
k^*	Specific spectrum ratio factor
l_k	Effective length for tension
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 for the stress cycle described by $\sigma_{a,i}$ and $\sigma_{m,j}$
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_{ij}	Number of stress cycles of class ij
$n_{ij}^{(r)}$	Number of stress cycles of class ij occurring each time task r is carried out
$\hat{n}$	Total number of stress cycles
P_s	Probability of survival
p_1, p_2	Distances between bolt centres
Q	Mass of the maximum hoist load
q	Impact toughness parameter
R	Constant stress ratio selected for one-parameter classification of stress cycles
R_d	Design resistance

Table 1 (*continued*)

Symbols	Description
r	Radius of wheel
S	Class of stress history parameter, s
S_d	Design stresses or forces
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_r	Relative number of working cycles for each task r
α_w	Characteristic factor for limit weld stress
α_1, α_2	Angles between the horizontal line and the line of N = constant in the σ_a–σ_m plane
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_{Rw}	Total resistance factor of welding 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
γ_{sw}	Specific resistance factor of welding connection
$\Delta\delta$	Additional elongation

Table 1 (*continued*)

Symbols	Description
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
ν	Relative total number of stress cycles (normalized)
ν_D	Ratio of diameters
σ	Indicate the respective stress
$\Delta\sigma$	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_m	Constant mean stress selected for one-parameter classification of stress cycles
$\sigma_{m,j}$	Mean stress of range, j, resulting from rainflow or reservoir method
$\Delta\sigma_{Rd}$	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)
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

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 shall include

- design assumptions including calculation models,
- applicable loads and load combinations,
- material properties,
- weld quality classes in accordance with ISO 5817, and
- properties of connecting elements.

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 as amended [1];
- ISO 6930-1 [7];
- ISO 4950 [3];
- ISO 4951-1, ISO 4951-2 and ISO 4951-3 [4], [5], [6].

Where other steels are used, the specific values of strengths f_u and f_y have to be known. The mechanical properties and the chemical composition shall be specified according to ISO 404. When used in welded structures, the weldability shall be demonstrated.

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

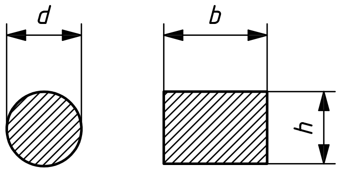
i	Influence		q_i
1	Temperature T (°C) of operating environment	$0 \leqslant T$	0
		$-20 \leqslant T < 0$	1
		$-40 \leqslant T < -20$	2
		$-50 \leqslant T < -40$	4
2	Yield stress f_y (N/mm²)	$f_y \leqslant 300$	0
		$300 < f_y \leqslant 460$	1
		$460 < f_y \leqslant 700$	2
		$700 < f_y \leqslant 1\,000$	3
		$1\,000 < f_y$	4
3	Material thickness t (mm)	$t \leqslant 10$	0
	Equivalent thickness t for solid bars:	$10 < t \leqslant 20$	1
		$20 < t \leqslant 50$	2
		$50 < t \leqslant 100$	3
	$t = \frac{d}{1{,}8}$ for $\frac{b}{h} < 1{,}8$: $t = \frac{b}{1{,}8}$	$t > 100$	4
4	Stress concentration and notch class $\Delta\sigma_c$ (N/mm²) (see Annex D)	$\Delta\sigma_c > 125$	0
		$80 < \Delta\sigma_c \leqslant 125$	1
		$56 < \Delta\sigma_c \leqslant 80$	2
		$\Delta\sigma_c \leqslant 56$	3
NOTE	For environmental temperatures below –50°C, special measures are required.		

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

	$\sum q_i \leqslant 3$	$4 \leqslant \sum q_i \leqslant 6$	$7 \leqslant \sum q_i \leqslant 9$	$\sum q_i \geqslant 10$
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) ISO 898-1:—, 4.6, 5.6, 8.8, 10.9 or 12.9, 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;

— other 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 286-2:1988, tolerances h13 and H11, or closer, when bolts are exposed to load reversal or where slippage may cause deleterious changes in geometry;

— in other cases, wider clearances according to 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) ISO 898-1:—, 8.8, 10.9 or 12.9 shall be used;

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

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

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

4.5.5 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) ISO 898-1:—, 8.8, 10.9 or 12.9 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 according to ISO 286-2:1988, 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.

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, for steels of yield stress less than 400 N/mm^2, ISO 5817:2003, quality level C is acceptable in connections requiring a static proof of competence.

ISO 5817:2003, 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 may be non-uniform, such distributions can, in most cases, be considered uniform. 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.

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:

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

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 according to Clause 5;

— proof of fatigue strength according to Clause 6, except for crane parts with values of the stress history parameter, s, below 0,001 (see 6.3.3).

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 and fracture of structural members or connections. Dynamic factors given in the applicable parts of ISO 8686 are used to produce static-equivalent loads to simulate dynamic effects.

NOTE Proof of elastic instability is not dealt with in this International Standard.

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 below.

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 for the proof given in this International Standard could yield inordinately conservative results.

5.2 Limit design stresses and forces

5.2.1 General

The limit design stresses shall be calculated from:

$$f_{Rd} = f(f_k, \gamma_R) \tag{2}$$

Limit design forces shall be calculated from:

$$F_{Rd} = f(F_k, \gamma_R) \tag{3}$$

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:

$\gamma_m = 1{,}1$

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

NOTE f_{Rd} and F_{Rd} are equivalent to $\frac{R}{\gamma_m}$ in ISO 8686-1:1989, 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:

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

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

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

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

$\gamma_{sm} = 1{,}0$ for stresses in the plane of rolling;

$\gamma_{sm} = 1{,}0$ for compressive and shear stresses;

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

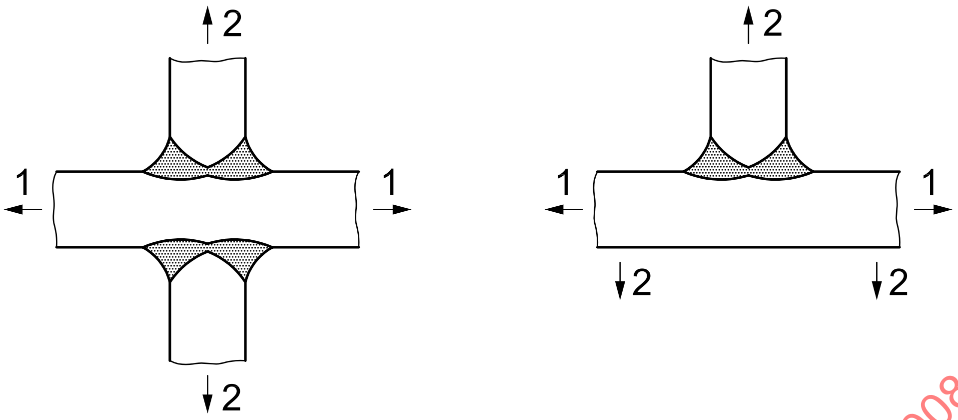
$\gamma_{sm} = 1{,}0$ for plate thicknesses less than 15 mm or material with reduction in area of more than 20 %;

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

$\gamma_{sm} = 1{,}50$ 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.

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:

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

$\gamma_{sb} = 1{,}2$ 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 may be calculated from:

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

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

where

$$\alpha = \mathrm{Min}\begin{cases} \dfrac{e_1}{3 \times d_o} \\ \dfrac{f_{ub}}{f_u} \\ 1{,}0 \end{cases} \tag{10}$$

With the following requirements for the plate:

$e_1 \geqslant 2{,}0 \times d_o$

$e_2 \geqslant 1{,}5 \times d_o$

$p_1 \geqslant 3{,}0 \times d_o$

$p_2 \geqslant 3{,}0 \times d_o$

where

f_{ub} is the ultimate strength (nominal value) of the bolt;

f_u is the ultimate strength (nominal value) of the material of the connected parts;

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

d is the shank diameter of the bolt;

d_o is the diameter of the hole;

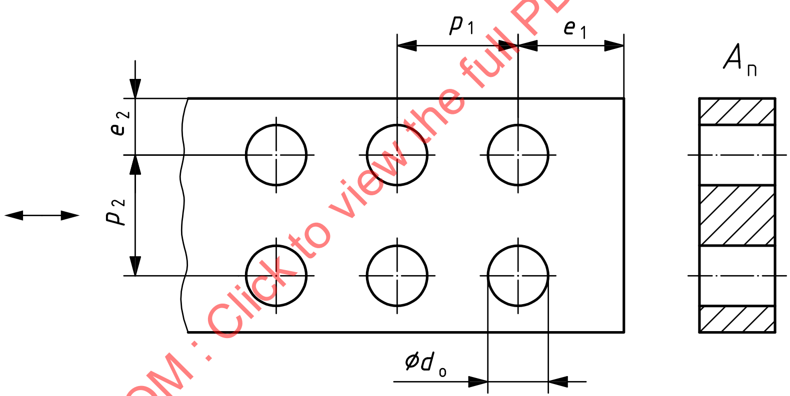
t is the thicknesses of the connected part in contact with the unthreaded part of the bolt;

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

$\gamma_{sb} = 0{,}7$ for multiple shear plane connections;

$\gamma_{sb} = 0{,}9$ for single shear plane connections;

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



NOTE See also Equation (11).

Figure 2 — Illustration of Equation (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 is calculated from:

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

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:

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

5.2.3.2 Friction grip type connections

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

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

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

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

where

μ is the friction coefficient:

- $\mu = 0{,}50$ for surfaces blasted metallic bright with steel grit or sand, no unevenness;
- $\mu = 0{,}50$ for surfaces blasted with steel grit or sand and aluminized;
- $\mu = 0{,}50$ for surfaces blasted with steel grit or sand and metallized with a product based on zinc;
- $\mu = 0{,}40$ for surfaces blasted with steel grit or sand and alkali-zinc-silicate coating of 50 µm to 80 µm thickness;
- $\mu = 0{,}40$ for surfaces hot-dip galvanized and lightly blasted;
- $\mu = 0{,}30$ for surfaces cleaned metallic bright with wire brush or scarfing;
- $\mu = 0{,}25$ for surfaces cleaned and treated with etch primer;
- $\mu = 0{,}20$ for surfaces cleaned of loose rust, oil and dirt (minimum requirement);

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

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

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

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.

[a] Holes with clearances according to the medium series of ISO 273:1979.

[b] Holes with clearances according to the coarse series of ISO 273:1979.

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

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

See Annex B for limit design slip forces using, for example, a specific resistance factor for friction grip of $\gamma_{ss} = 1{,}14$ and a design preloading force of

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

where

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

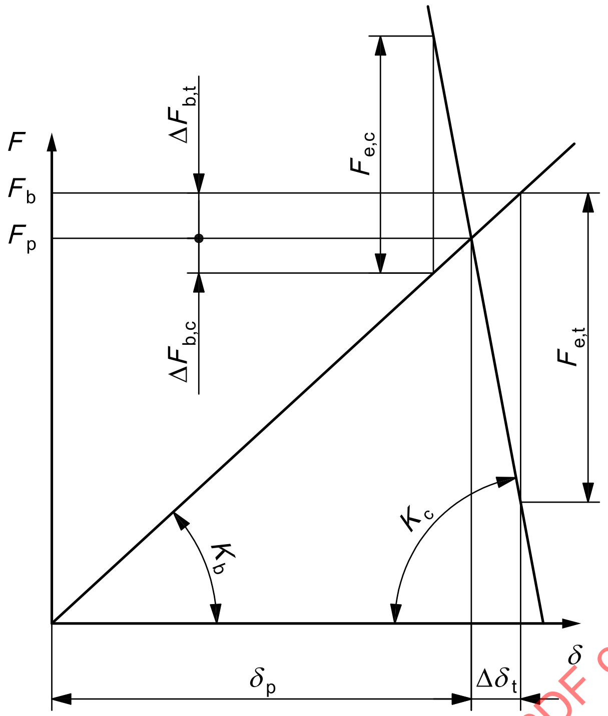
A_S is the stress area of the bolt.

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

δ_p bolt elongation due to preloading

$F_{e,t}$ external tensile force

$F_{e,c}$ external compression force

$\Delta_{\delta t}$ additional elongation, due to external tensile force

F_b tensile force in bolt

$\Delta F_{b,t}$ additional force in bolt, due to external tensile force

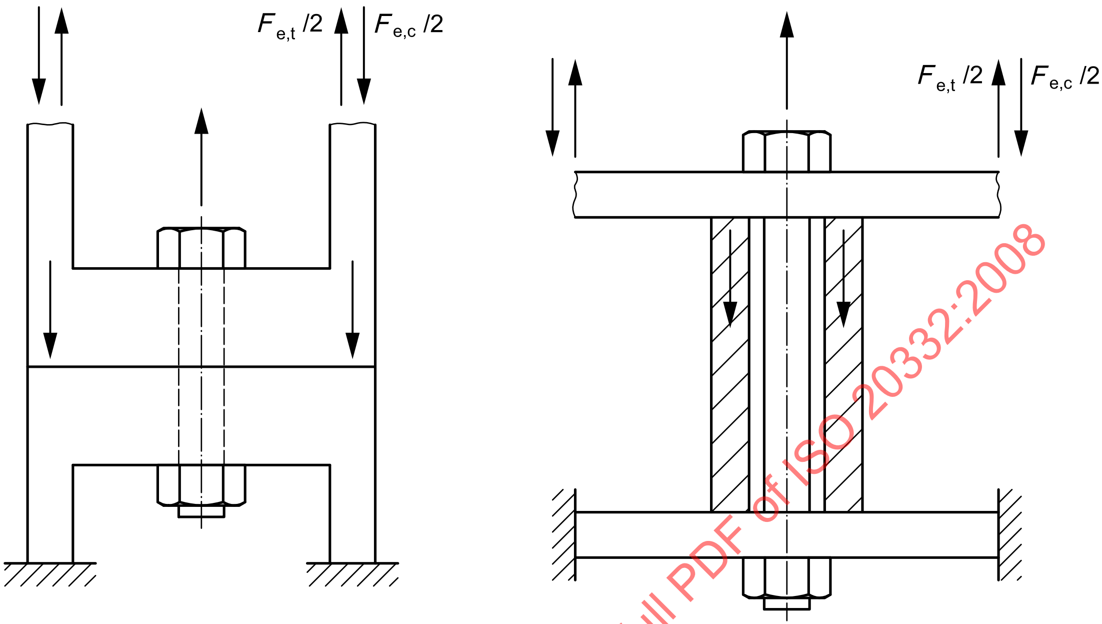
$\Delta F_{b,c}$ additional force in bolt, due to external compression force

slope K_b stiffness of the bolt

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 Equation (13);

b) the connection under the external force and under the minimum design preload shall not open (gap), see Equation (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:

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

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,

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:

$\gamma_{sb} = 0,91$

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:

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

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:

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

and

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

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;

$\pm s$ 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.

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

Table 6 — Maximum nominal preload levels according to 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 equation) in cases where it does not interfere with the compression zone under the bolt, 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 according to 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:

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

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:

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

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:

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

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:

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

$\gamma_{sp} = 1{,}3$ 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. $t_1 + t_2$ or t_3, as shown in Figure 5;

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

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

$\gamma_{sp} = 0{,}9$ 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 plastic deformation.

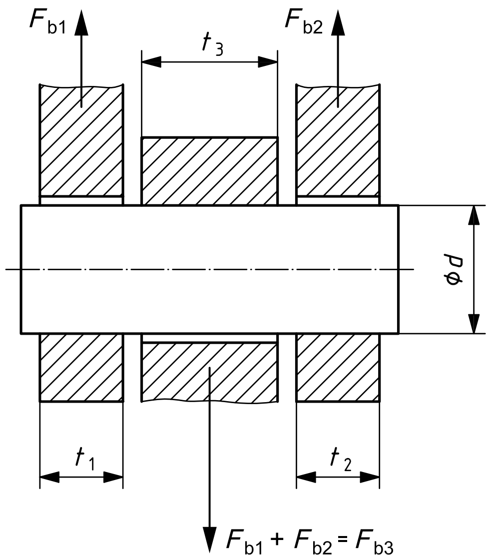


Figure 5 — Pinned connections

5.2.4.4 Connected parts, limit design force with respect to shear

The limit design force is calculated from:

$$F_{v,Rd} = \frac{2 \times t \times (c + d_o / 2) \times f_y}{\gamma_m \times \sqrt{3}} \tag{22}$$

where

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

b,c,t are the geometric dimensions according to Figure 6, with $c \geqslant b$;

d_o is the hole diameter.

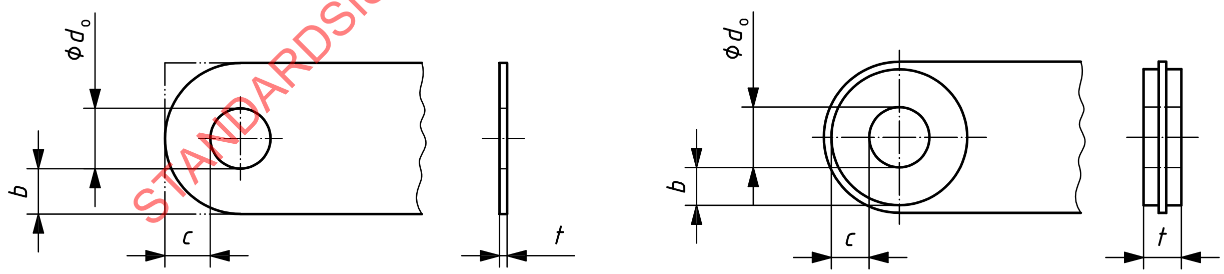


Figure 6 — Connected parts

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

The limit design force for the most unfavourable direction in the plane of the part is calculated from:

$$F_{\text{v,Rd}} = \frac{2 \times t \times b_{\text{eff}} \times f_{\text{y}}}{\gamma_{\text{Rp}}} \quad (23)$$

where

$$b_{\text{eff}} = \text{Min} \begin{cases} 2 \times t + 16 \text{ mm} \\ b \end{cases}$$

t, b are as illustrated in Figure 6;

f_{y} is the yield stress (minimum value) of the material of the connected parts;

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

where

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

$\gamma_{\text{sp}} = 1{,}0$ for unidirectional loads;

$\gamma_{\text{sp}} = 1{,}2$ for reversing or direction changing loads.

5.2.5 Limit design stresses in welded connections

The limit design weld stress, $f_{\text{w,Rd}}$, 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 equation number given in Table 7, the limit design weld stress, $f_{\text{w,Rd}}$, shall be calculated using either Equation (24) or (25):

$$f_{\text{w,Rd}} = \frac{\alpha_{\text{w}} \times f_{\text{yk}}}{\gamma_{\text{m}}} \quad (24)$$

$$f_{\text{w,Rd}} = \frac{\alpha_{\text{w}} \times f_{\text{uw}}}{\gamma_{\text{m}}} \quad (25)$$

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.

Table 7 — Factor α_W for limit weld stress

Direction of stress	Type of weld	Type of stress	Equation number	α_W	
				$f_{yk} < 960$ (N/mm²)	$f_{yk} \geqslant 960$ (N/mm²)
Stress normal to the weld direction	Full penetration weld, matching weld material	Tension	24	1,0	0,93
		Compression	24	1,0	0,93
	Full penetration weld, undermatching weld material	Tension	25	0,80	0,80
		Compression	25	0,80	0,80
	Partial penetration weld, matching weld material	Tension or compression	24	0,70	0,65
	Partial penetration weld, undermatching weld material	Tension or compression	25	0,56	0,56
	All welds, matching weld material	Shear	24	0,70	0,65
	All welds, undermatching weld material	Shear	25	0,54	0,54
Stress parallel to the weld direction	All welds	Tension and compression	24	1,0	0,93
	All welds, matching weld material	Shear	24	0,60	0,55
	Full penetration welds, undermatching weld material	Shear	25	0,50	0,50
	Partial penetration weld, undermatching weld material	Shear	25	0,50	0,50

The values of α_W are valid for welds in ISO 5817:2003, quality classes B and C.

In case of different f_{yk} of the connected members, the proof shall be made for both members separately.

Undermatching weld material: weld material with strength properties less than those of the welded parts.

Filet welds and partial-penetration groove 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.

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:

$$\sigma_{Sd} \leqslant f_{Rd\sigma} \text{ and } \tau_{Sd} \leqslant f_{Rd\tau} \tag{26}$$

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 according to 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:

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

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

$$F_{Sd} \leqslant F_{Rd} \qquad (28)$$

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 according to 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;
- $F_{t,Rd}$ limit design tensile force.

5.3.3 Proof for pinned connections

For pins, it shall be proven that:

$$\begin{aligned} M_{Sd} &\leqslant M_{Rd} \\ F_{v,Sd} &\leqslant F_{v,Rd} \\ F_{bi,Sd} &\leqslant F_{b,Rd} \end{aligned} \qquad (29)$$

where

M_{Sd} is the design value of the bending moment in the pin;

M_{Rd} is the limit design bending moment according to 5.2.4.1;

$F_{v,Sd}$ is the design value of the shear force in the pin;

$F_{v,Rd}$ is the limit design shear force according to 5.2.4.2;

$F_{bi,Sd}$ is the most unfavourable design value of the bearing force in the joining plate, i, of the pinned connection;

$F_{b,Rd}$ is the limit design bearing force according to 5.2.4.3.

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

$$M_{Sd} = \frac{l}{4} \times F_{b3} \tag{30}$$

where

l is the distance between F_{b1} and F_{b2} ;

F_{b3} is the sum of F_{b1} and F_{b2} (see Figure 5).

5.3.4 Proof for welded connections

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

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

where

$\tau_{w,Sd}$, $\sigma_{w,Sd}$ are the design weld stresses (see Annex C);

$f_{w,Rd}$ is the corresponding limit design weld stress according to 5.2.5.

For plane states of stresses in welded connections, it shall additionally be proven that:

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

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. This International Standard does not use other methods such as the hot spot stress method.

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, 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 special investigation (see 6.5).

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}

γ_{mf}			
Accessibility	**Fail-safe components**	**Non-fail-safe components**	
		without hazards for persons	**with hazards for persons**
Accessible joint detail	1,0	1,15	1,25
Joint detail with poor accessibility	1,15	1,25	1,35
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

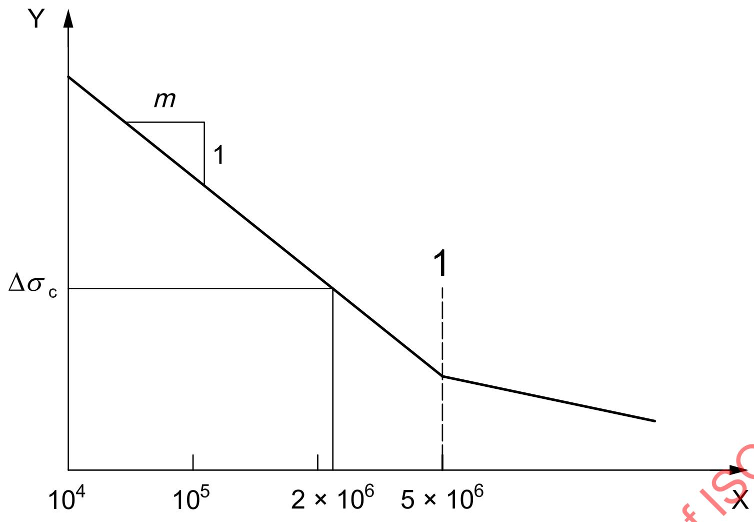
The limit design stress of a constructional detail is characterized by the value the characteristic fatigue strength, $\Delta\sigma_c$, which represents the fatigue strength at 2×10^6 cycles under constant stress range loading and with a probability of survival equal to $P_s = 97{,}7\ \%$ (mean value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

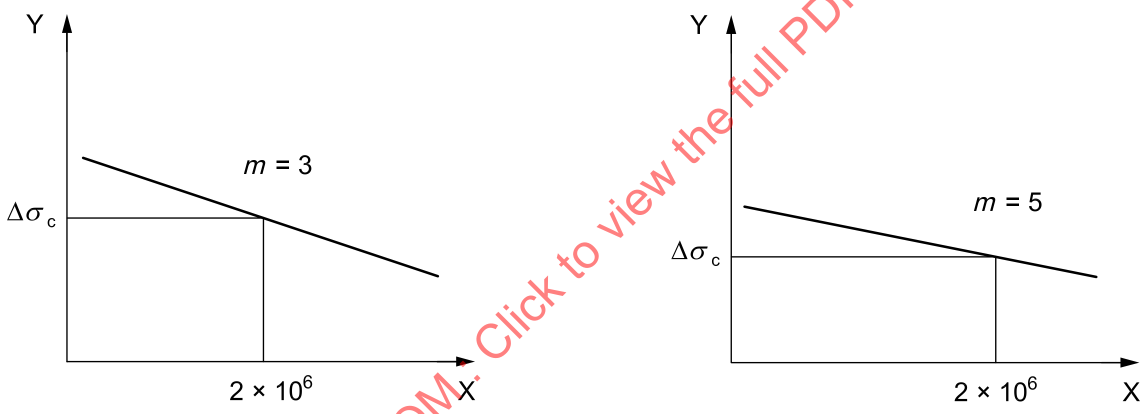
For shear stresses, $\Delta\sigma_c$ is replaced by $\Delta\tau_c$.

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.

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, + 2NC, ...) the basic notch class to increase the resistance, or below (– 1 NC, – 2 NC, ...) the basic notch class to decrease the resistance according to 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

X log N

Y log $\Delta\sigma$

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

Figure 7 — Illustration of $\Delta\sigma - N$ curve and $\Delta\sigma_c$

6.2.2 Weld quality

6.2.2.1 General

The $\Delta\sigma_c$ values presented in Annex D depend on the quality level of the weld. Quality classes shall be in accordance with ISO 5817:2003, 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:

— 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 in Annex D or consideration of mean stress influence require specific investigation into $\Delta\sigma_c$ and m. Requirements are as follows:

— the test specimen shall be in actual size (1:1);

— 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 $\Delta\sigma_{\text{c}}$ 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 of less than 2×10^4 cycles shall be used;

— at least one stress range level that results in a mean number of stress cycles to failure between $1{,}5 \times 10^6$ 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) according to 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) according to 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 either

a) frequencies of occurrence of stress amplitudes and mean stresses, or

b) densities of stress amplitudes and mean stresses and the total number of stress cycles.

In the following subclauses, only a) is dealt with.

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:

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

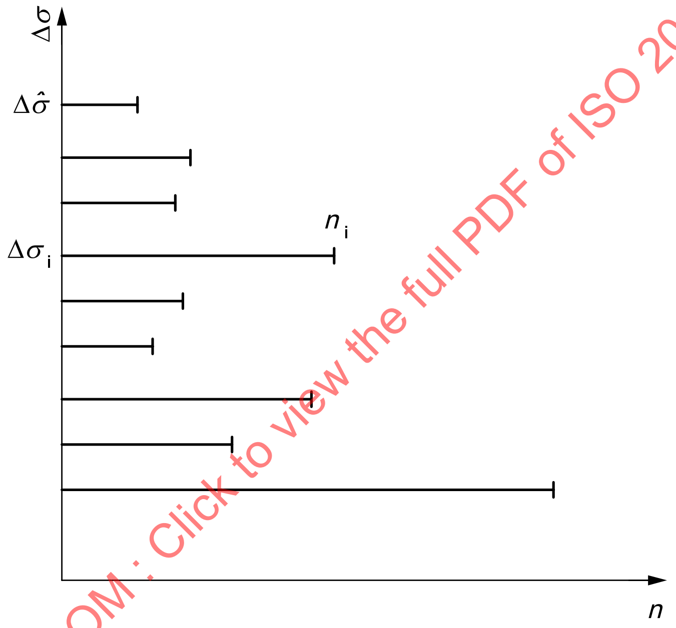
where

σ_u is the upper extreme value of a stress range;

σ_b is the lower extreme value of a stress range;

$\Delta\sigma$ is the stress range.

Figure 8 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 8 — 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 useful life of the crane:

$$s_m = \nu \times k_m \quad (34)$$

where

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

$$\nu = \frac{N_t}{N_{ref}} \quad (36)$$

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 (see Figure 8);
$\Delta\hat{\sigma}$	the maximum stress range (see Figure 8);
n_i	is the number of occurrences of stress range i (see Figure 8);
$N_t = \sum_i n_i$	is the total number of occurrences of stress ranges during the useful 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.

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 9 as s_3.

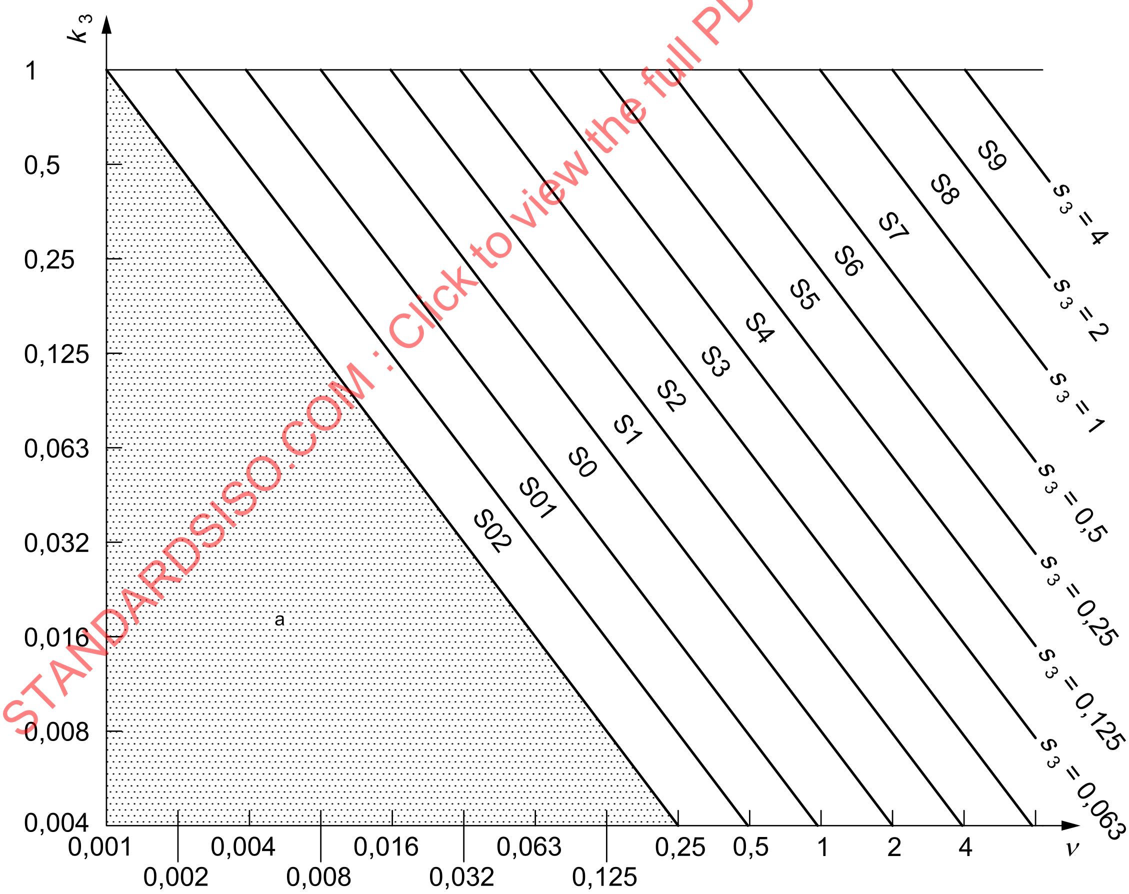
A given stress history falls into the specific S class, independent of the slope constant, m, of the relevant $\log\sigma - \log N$ curve. The diagonal lines for the class limits represent the k_m to ν relationship for $s = \text{constant}$ in a log/log scale diagram.

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 lower than 0,001 do not require a proof of competence for fatigue.

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

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



[a] Fatigue assessment not required.

Figure 9 — 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),

— the net load spectrum and Q class (see ISO 4301-1), 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 according to Table 10.

Table 10 — S classes determined from A classes

A class according to ISO 4301-1	**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 4301-1:1986, class A8, could be applicable.	

6.4 Execution of the proof

For the detail under consideration it shall be proven that:

$$\Delta\sigma_{Sd} \leqslant \Delta\sigma_{Rd} \tag{37}$$

$$\Delta\sigma_{Sd} = \max\sigma - \min\sigma \tag{38}$$

where

$\Delta\sigma_{Sd}$ is the calculated maximum range of design stresses;

$\max\sigma$, $\min\sigma$ are the extreme values of design stresses resulting from load combinations, A, according to 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 Equation (35) and used for the determination of the stress history parameter, s_m, values of $\max\sigma$ and $\min\sigma$ 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:

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

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 according to 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 according to 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:

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

where

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

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

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

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

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

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 $\Delta\sigma_{Rd}$ shall then be calculated from:

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

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

$$k^* = \sqrt[m]{\frac{k_3}{k_m}} \geqslant 1 \qquad (43)$$

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 $\gamma_{mf} = 1{,}25$ 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, $\Delta\sigma_{Rd,1}$ calculated from Equation (42) may be used as limit design stress range. The value of k^* may 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:

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

where

$\Delta\sigma_{Sd}$, $\Delta\tau_{Sd}$ 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.

Annex A
(informative)

Limit design shear force, $F_{v,Rd}$, in shank per bolt and per shear plane for multiple shear plane connections

See Table A.1.

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

Bolt	Shank diameter mm	$F_{v,Rd}$ kN				
		Bolt material for $\gamma_{Rb} = 1,1$				
		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

See Tables B.1 and B.2.

Table B.1 — Tightening torques (in newton metres) 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	300
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

NOTE A friction coefficient of μ = 0,14 is assumed for the tightening torque calculations.

Table B.2 — Limit design slip force, $F_{s,Rd}$, per bolt and per friction interface using a design preloading force, $F_{p,d} = 0{,}7 \times f_{yb} \times A_s$, and a specific resistance factor for friction grip, $\gamma_{ss} = 1{,}14$

Bolt	Stress area A_s mm²	Design preloading force $F_{p,d}$ kN			Limit design slip force $F_{s,Rd}$ kN											
		Bolt material			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	12,1	9,1	6,0	21,2	17,0	12,7	8,5	25,5	20,4	15,3	10,2
M16	157,0	70,3	98,9	119,0	28,1	22,5	16,9	11,2	39,6	31,6	23,7	15,8	47,6	38,1	28,6	19,0
M20	245,0	110,0	154,0	185,0	44,0	35,2	26,4	17,6	61,6	49,3	37,0	24,6	74,0	59,2	44,4	29,6
M22	303,0	136,0	191,0	229,0	54,4	43,5	32,6	21,8	76,4	61,1	45,8	30,6	91,6	73,3	55,0	36,6
M24	353,0	158,0	222,0	267,0	63,2	50,6	37,9	25,3	88,8	71,0	53,3	35,5	107,0	85,4	64,1	42,7
M27	459,0	206,0	289,0	347,0	82,4	65,9	49,4	33,0	116,0	92,5	69,4	46,2	139,0	111,0	83,3	55,5
M30	561,0	251,0	353,0	424,0	100,0	80,3	60,2	40,2	141,0	113,0	84,7	56,5	170,0	136,0	102,0	67,8
M36	817,0	366,0	515,0	618,0	146,0	117,0	87,8	58,6	206,0	165,0	124,0	82,4	247,0	198,0	148,0	98,9

Annex C
(normative)

Design weld stress, $\sigma_{w,Sd}$ 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:

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

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 weld thickness;

l_r is the effective weld length.

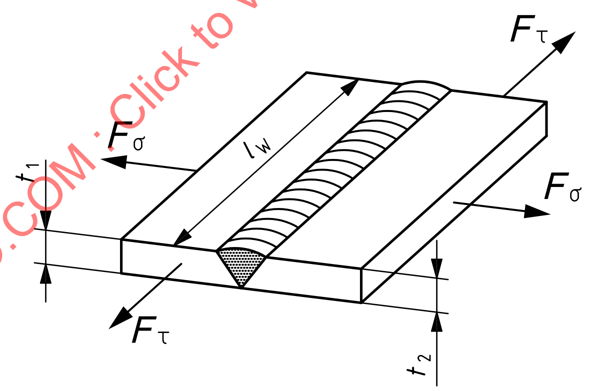


Figure C.1 — Butt weld

The effective weld 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.

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 weld 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:

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

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 weld thicknesses (see Figure C.2):

$$a_{ri} = a_i$$

l_{ri} are the effective weld lengths.

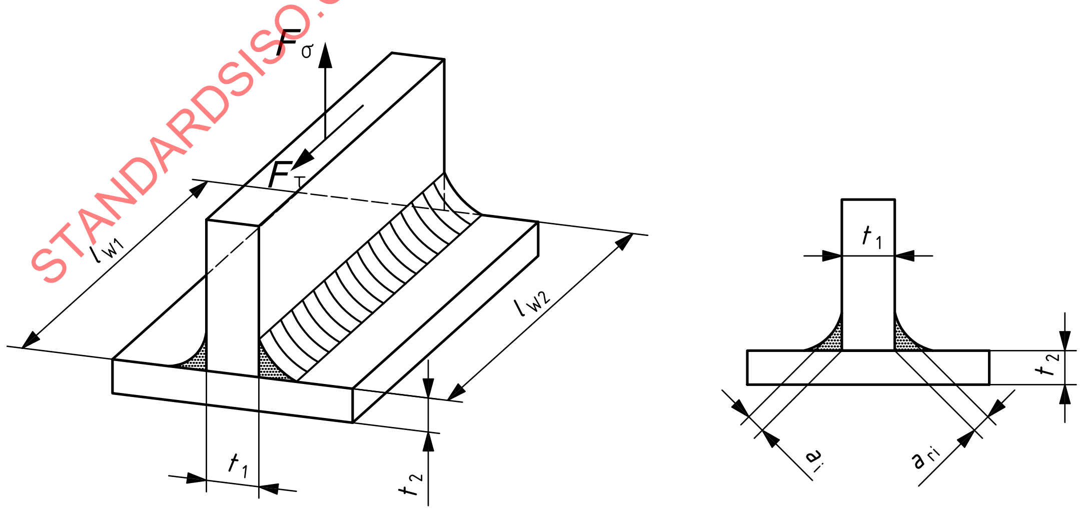


Figure C.2 — Joint dimensions

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

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.

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:

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

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 weld thicknesses (see Figure C.3);

$a_{ri} = a_i + a_{hi}$

l_{ri} are the effective weld lengths.

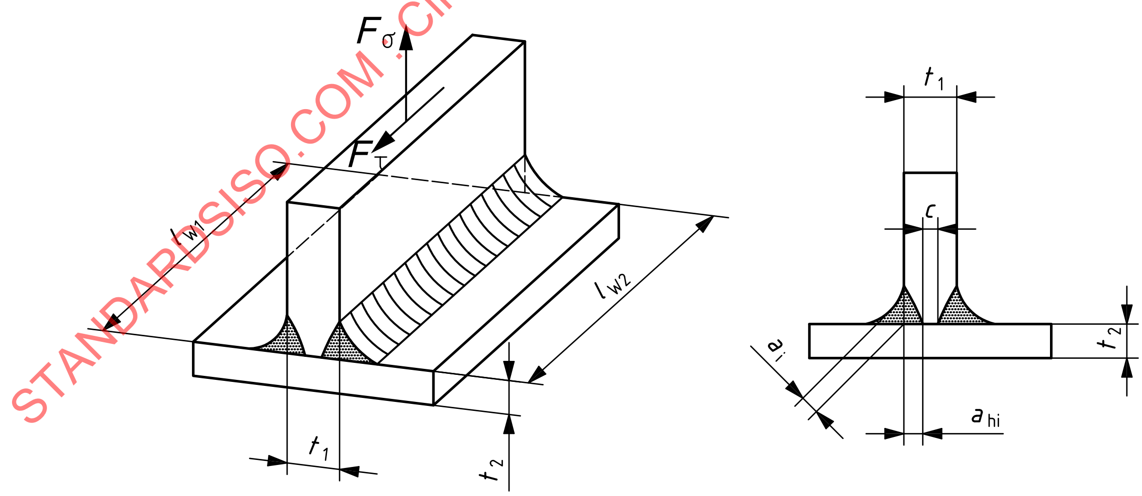


Figure C.3 — Joint dimensions

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

For the effective weld lengths see C.1.

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

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

where

l_r is the effective distribution length;

h_d is the distance between weld and contact area of acting load;

λ is the width of contact area in weld direction — 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;

2κ is the dispersion angle: κ shall be set to $\kappa \leqslant 45°$.

See Figure C.4.

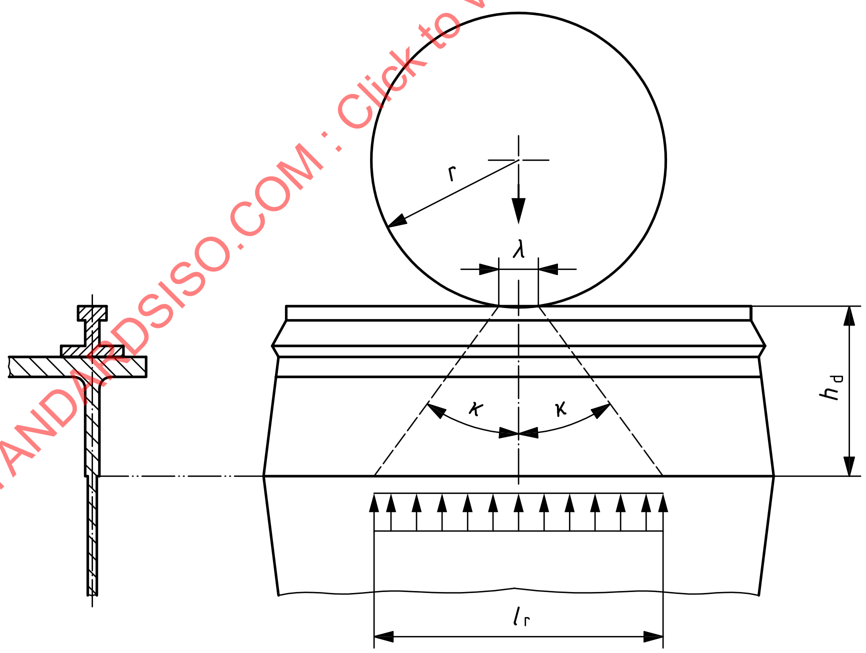


Figure C.4 — Concentrated load

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, $\Delta\sigma_c$, $\Delta\tau_c$

See Tables D.1 to D.3.

NOTE Notch classes (NC) refer to the first column of Annex E (see also 6.2.1).

Table D.1 — Basic material of structural members

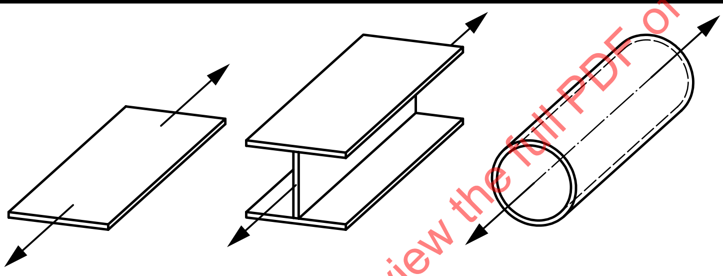
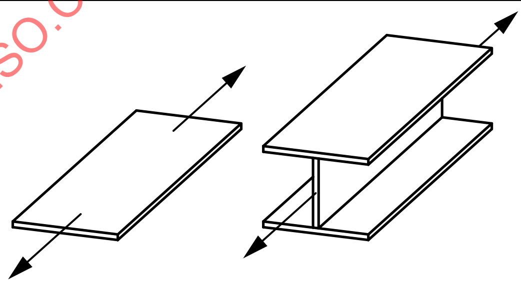
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	Constructional detail	Requirement(s)
1.1	m = 5	 Plates, flat bars, rolled profiles under normal stresses	— Rolled surfaces and edges — Good surface condition — No thermal cutting, — No notches or geometrical notch effects (e.g. cutouts)
	225	$f_y \leqslant 275$	
	250	$275 < f_y \leqslant 355$	
	280	$355 < f_y$	
1.2	m = 5	 Plates, flat bars, rolled profiles under normal stresses	— Flame cut edges, quality according to ISO 9013:2002, Table 5, Range 3 — No geometrical notch effects (e.g. cutouts)
	180	$f_y \leqslant 275$	
	200	$275 < f_y$	

Table D.1 (*continued*)

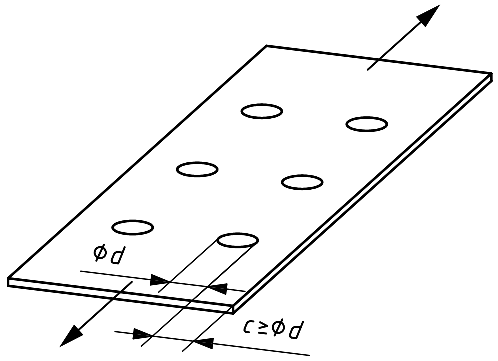
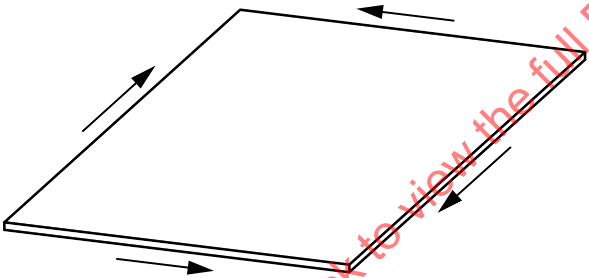
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	**Constructional detail**	**Requirement(s)**
1.3	m = 5	 Holes in a plate under normal stresses	— Nominal stress calculated for the net cross-section — Holes not flame cut — Bolts may be present, when these are stressed up to 20 % of their strength in shear/bearing connections or up to 100 % of their strength in slip-resistant connections
	180	$f_y \leqslant 275$	
	200	$275 < f_y$	
1.4	m = 5	 Plates, flat bars, rolled profiles under shear stress	
	140	$f_y \leqslant 275$	
	160	$275 < f_y \leqslant 355$	
	180	$355 < f_y$	

Table D.2 — Elements of non-welded connections

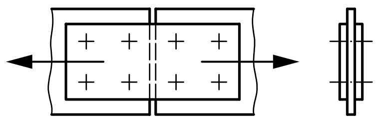
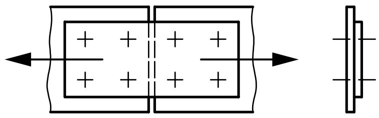
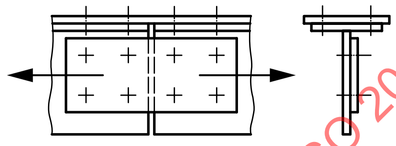
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail		Requirement(s)
2.1	m = 5	Double shear		— Proof of fatigue strength not required for bolts of friction grip type bolted connections — Nominal stress calculated for the net cross-section
		Supported single-shear (example)		
		Single-shear		
		Perforated parts in slip-resistant bolted connections under normal stresses		
	160	$f_y \leqslant 275$		
	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	Fitted 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	Fitted 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		
NOTE	Pinned connections are considered in the proof of fatigue strength as structural members.			

Table D.3 — Welded members

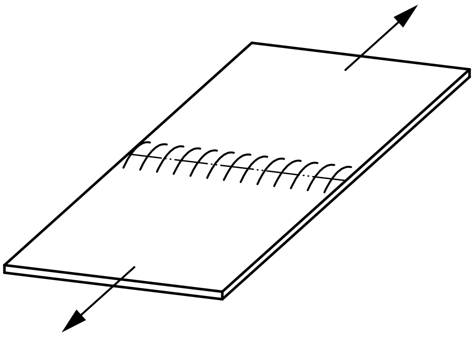
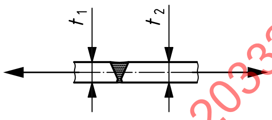
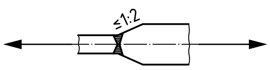
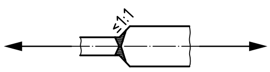
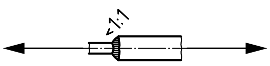
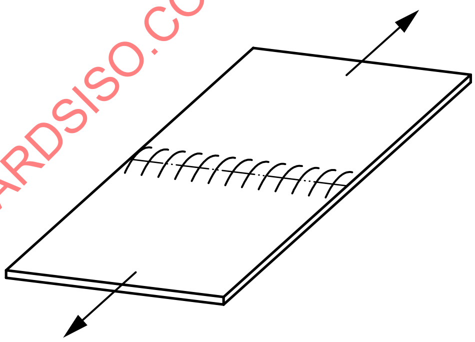
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	Constructional detail	Requirement(s)	
3.1	m = 3	 Symmetric butt joint, normal stress across the weld	Basic conditions: — symmetric plate arrangement — fully penetrated weld — components with usual residual stresses — angular misalignment < 1°	
				$t_1 = t_2$
			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
3.2	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° Special conditions: — Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC	
	80	Butt weld on remaining backing, quality level C		

Table D.3 (*continued*)

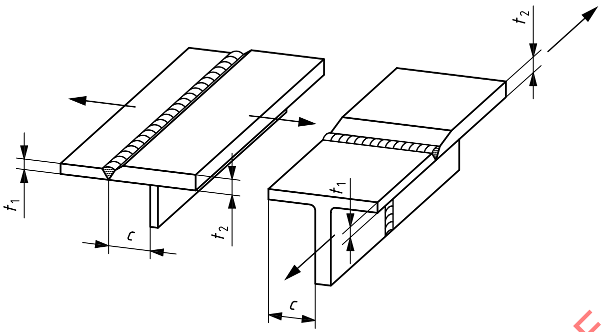
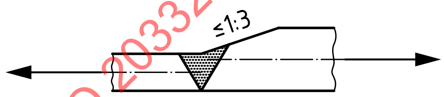
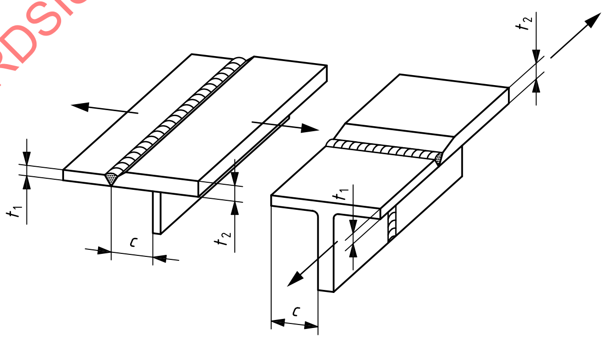
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.3	m = 3	 Unsymmetrical supported butt joint, normal stress across the butt weld	Basic conditions: — fully penetrated weld — Supported parallel to butt weld: $e < 2\ t_2 + 10$ mm — Supported vertical to butt weld: $e < 12\ t_2$ Components with usual residual stresses  slope ⩽ 1:3 $t_2 - t_1 \leqslant 4$ mm Special conditions: — Components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) −1 NC — Influence of slope and thickness $t_2 - t_1$:
	125	Butt weld, quality level B*	thickness $t_2 - t_1$ slope / ⩽4 / ⩽ 10 / ⩽ 50 / > 50 ⩽1:3 / — / −1NC / −1NC / −2NC
	112	Butt weld, quality level B	⩽1:2 / −1NC / −1NC / −2NC / −2NC
	100	Butt weld, quality level C	⩽1:1 / −1NC / −2NC / −2NC / −3NC >1:1 / −2NC / −2NC / −3NC / −3NC
3.4	m = 3	 Unsymmetrical supported butt joint, normal stress across the butt weld	Basic conditions: — fully penetrated weld — supported parallel to butt weld: $e < 2\ t_2 + 10$ mm — supported vertical to butt weld: $e < 12\ t_2$ — components with usual residual stresses — $t_2 - t_1 \leqslant 10$ 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*)

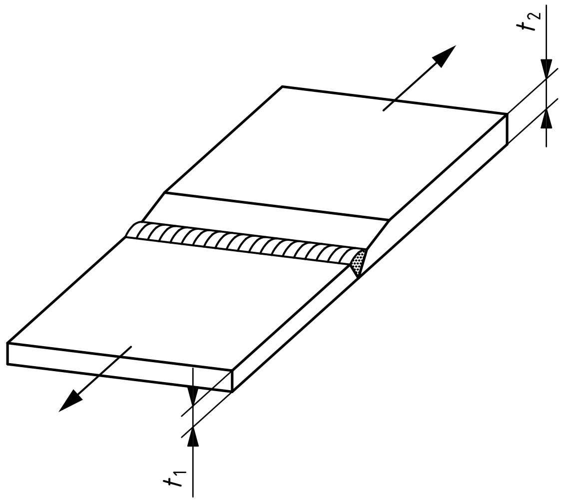
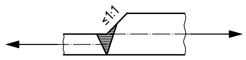
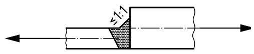
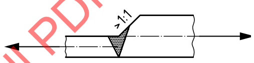
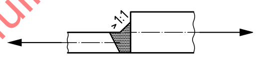
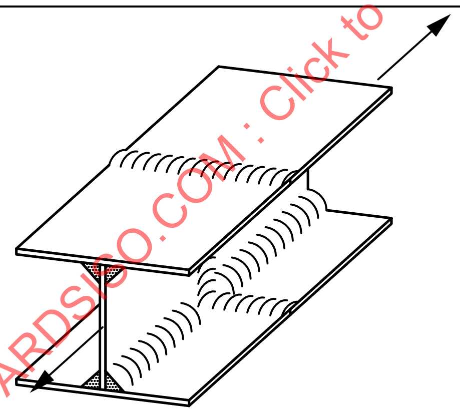
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.5	m = 3	 Unsymmetrical unsupported butt joint, stress across the butt weld	Basic conditions: — fully penetrated weld — components with usual residual stresses  slope ⩽ 1:1  slope in weld or base material $t_1/t_2 > 0,84$ Special conditions: — components with considerable residual stresses (e.g. joint of components with restraint of shrinkage) –1 NC   –2 NC
	100	Butt weld, quality level B*	— $t_1/t_2 > 0,74$ –1 NC
	90	Butt weld, quality level B	— $t_1/t_2 > 0,63$ –2 NC
	80	Butt weld quality level C	— $t_1/t_2 > 0,50$ –3 NC
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	

Table D.3 (*continued*)

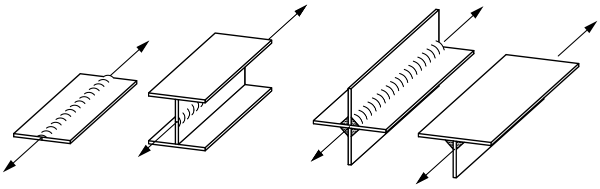
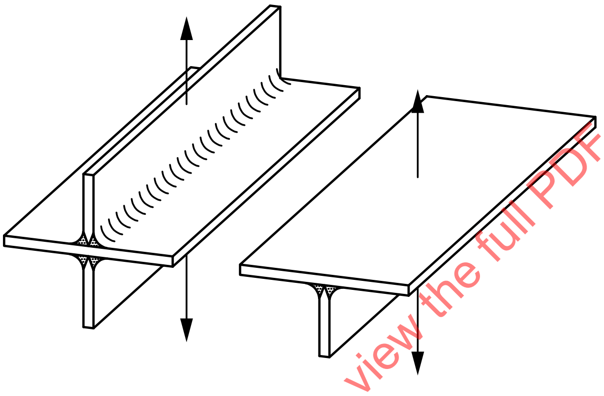
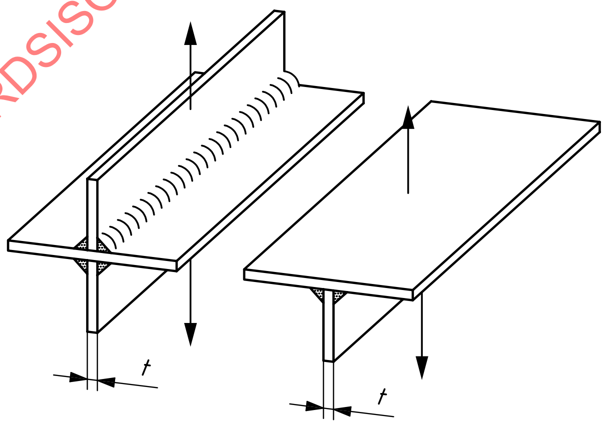
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.7	m = 3	 Normal stress in weld direction	Special conditions: — no irregularities from start-stop-points in quality level C +1 NC — welding with restraint of shrinkage −1 NC
	180	Continuous weld, quality level B	
	140	Continuous weld, quality level C	
	80	Intermittent weld, quality level C	
3.8	m = 3	 Cross or T-Joint, groove weld, normal stress across the weld	Basic conditions: — continuous weld Special conditions: — 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 full penetration and backing, quality level C	
3.9	m = 3	 Cross or T-Joint, symmetric double fillet weld	Basic conditions: — continuous weld Special conditions: — welding with restraint of shrinkage −1 NC
	45	Stress in weld throat	$\sigma_w = F/(2 \times a_r \times l)$ see Annex C
	71	Quality level B	Stress in the loaded plate at weld toe
	63	Quality level C	

Table D.3 (*continued*)

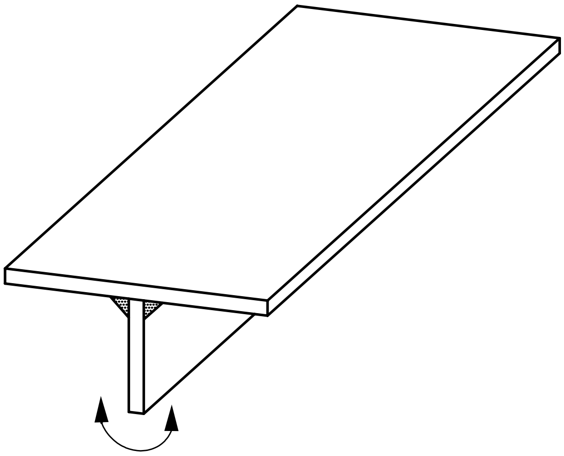
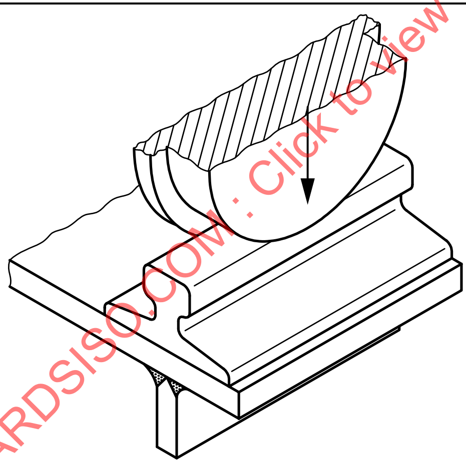
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.10	m = 3	 T-joint, stresses from bending	
	45	Stress in weld throat	Stress calculated with the applied bending moment and weld joint geometry taken into account
	80	Stresses in plate at weld toe, Quality level B	
	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)	
	112	Quality level B	
	100	Quality level C	

Table D.3 (*continued*)

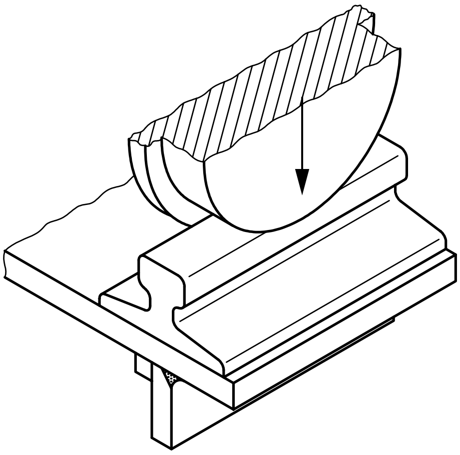
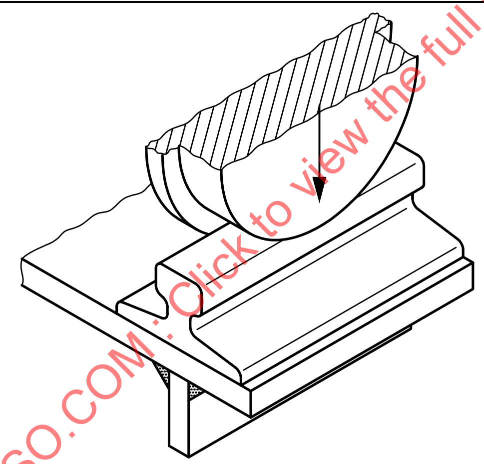
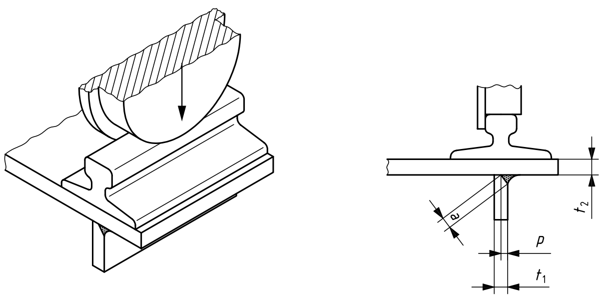
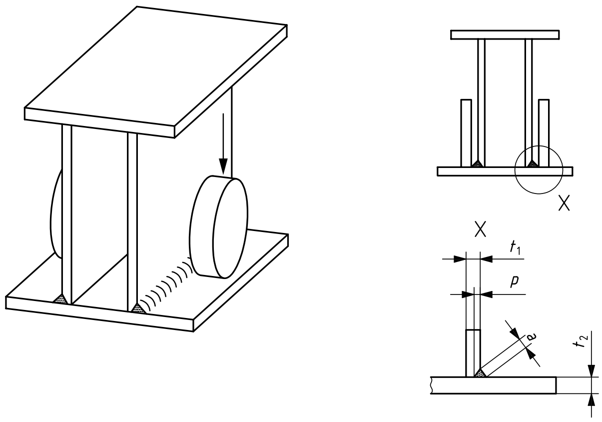
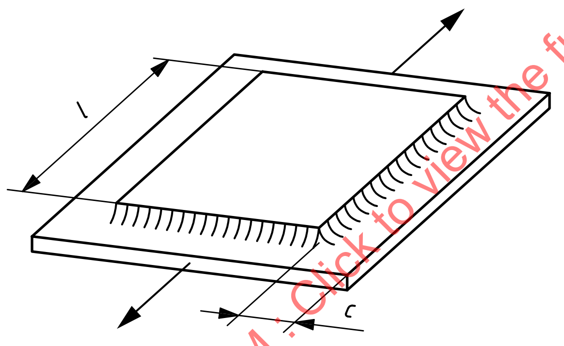
Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.12	$m = 3$	 Full penetration weld (with backing) with transverse compressive load (e.g. wheel)	
	80	Quality level C	
3.13	$m = 3$	 Double fillet weld with transverse compressive load, (e.g. wheel), stress calculated in the plate	Weld throat $a \geqslant 0{,}7 \times t$
	63	Quality level C	
3.14	$m = 3$	 Partial penetration weld with transverse compressive load (e.g. wheel), stress calculated in the plate	$0{,}5 \times t \leqslant a \leqslant 0{,}7 \times t$ with a according to Annex C $p = 1$ mm for $t \leqslant 6$ mm $p \geqslant t/4$ for $t > 6$ mm
	71	Quality level C	

Table D.3 (*continued*)

Detail no.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm^2	Constructional detail	Requirement(s)
3.15	$m = 3$	 Partial penetration weld with transverse load (e.g. underslung crab), stress calculated in the plate	$0,5 \times t \leqslant a \leqslant 0,7 \times t$ with a according to Annex C $p = 1$ mm for $t \leqslant 6$ mm $p \geqslant t/4$ for $t > 6$ mm
	63	Quality level C	
3.16	$m = 3$	 Continuous component with a welded cover plate	Basic conditions: — quality level C — continuous weld — distance c between the weld toe and rim of continuous component greater than 10 mm Special conditions: — quality level B* +2 NC — quality level B +1 NC — quality level D –1 NC — $c < 10$ mm –1 NC
	80	$l \leqslant 50$ mm	
	71	50 mm $< l \leqslant 100$ mm	
	63	$l > 100$ mm	

