



BSI Standards Publication

Railway applications — Bolting of rail vehicles and components

National foreword

This British Standard is the UK implementation of EN 17976:2024.

The UK participation in its preparation was entrusted to Technical Committee RAE/3/-/11, Railway Applications - Structural requirements and Welding.

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

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Published by BSI Standards Limited 2024

ISBN 978 0 539 20976 1

ICS 21.060.10; 21.060.20

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2024.

Amendments/corrigenda issued since publication

Date	Text affected

English Version

Railway applications - Bolting of rail vehicles and components

Applications ferroviaires - Boulonnage des véhicules et des composants ferroviaires

Bahnanwendungen - Verschrauben von Schienenfahrzeugen und -fahrzeugteilen

This European Standard was approved by CEN on 30 September 2024.

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European foreword

This document (EN 17976:2024) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by June 2025, and conflicting national standards shall be withdrawn at the latest by June 2025.

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

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Introduction

Screwed and bolted joints are often used to assemble safety-critical components on rail vehicles. This document sets out key considerations for design and assembly of such joints, based on an assessment of their criticality.

The application of this document results in an appropriate safety level for bolted joints in railway applications considering design, assembling and service phase.

This document gives guidance on the selection and design of bolted joints for rail vehicles in mechanical and electrical applications.

The function of a bolted joint is to connect two or more parts in a sufficient and safe manner over the intended service life under the conditions of the railway environment. The mechanical bolted joint is designed to transmit forces between the connected components without failure, separation or relative movement. The electrical bolted joint is designed to ensure current transmission between electrical conductors safely and without separation or relative movement. For this purpose, the parts are held together by the preload of the bolt.

This document describes the safety categories of bolted joints and gives an overview of the resulting requirements linked to these safety categories.

It specifies standards for the design and verification of bolted joints. Design includes aspects such as joint dimensions, layout, securing of bolted joints and corrosion protection.

It is intended to support the designer in the basic selection of bolted joints for familiarisation with the necessary systematics and terms.

Tightening of bolted joints is a special process in the railway industry in accordance with ISO 22163. Therefore, the conformity of the resulting product cannot be readily determined without destructive analysis prior to use but the influence parameters affecting the process can be controlled. This document provides guidance to control these parameters.

Furthermore, this document specifies requirements for assembly, quality and maintenance.

1 Scope

This document specifies the requirements for designing, strength assessment, assembly and servicing of mechanical and electrical bolted joints made from metallic components and bolts.

This document is not intended for rivets, lock bolts, self-tapping screws, wood screws, thread-rolling screws, thread-forming and chipboards.

This document is applicable to all rail vehicles.

2 Normative references

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

EN 50343, *Railway applications — Rolling stock — Rules for installation of cabling*

EN 15865, *Adhesives — Determination of torque strength of anaerobic adhesives on threaded fasteners (ISO 10964)*

EN ISO 3506-1, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs with specified grades and property classes (ISO 3506-1)*

EN ISO 3506-2, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 2: Nuts with specified grades and property classes (ISO 3506-2)*

EN ISO 4014, *Fasteners — Hexagon head bolts — Product grades A and B (ISO 4014)*

EN ISO 4017, *Fasteners — Hexagon head screws — Product grades A and B (ISO 4017)*

EN ISO 10683, *Fasteners — Non-electrolytically applied zinc flake coating systems (ISO 10683)*

EN ISO 4762, *Hexagon socket head cap screws (ISO 4762)*

EN ISO 10664, *Hexalobular internal driving feature for bolts and screws (ISO 10664)*

ISO 261, *ISO general purpose metric screw threads — General plan*

EN 17149-1:2024, *Railway applications — Strength assessment of rail vehicle structures — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions, symbols and abbreviations given in EN 17149-1:2024 and the following terms and definitions apply.

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

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

3.1

bolt

fastener with a partially threaded shaft

Note 1 to entry: In this document, when only the term bolt is used, it refers to a bolt or a screw.

3.2

screw

fastener with a fully threaded shaft

3.3

bolted joint

assembly of two or more components held together by the preload of a bolt or screw

Note 1 to entry: The bolted joint contains the clamped components, the bolt or screw, nut and washers. In this document the term bolted joint includes the screwed joint.

3.4

screwed joint

bolted joint with an internally threaded component

Note 1 to entry: The bolt or screw is inserted into a tapped component. A nut is not used. A screwed joint contains the clamped components, the bolt or screw and washers.

3.5

fastener

connective element used in a bolted joint

EXAMPLE Screws, bolts, nuts and washers are considered fasteners.

3.6

separation

full loss of contact in the interface between clamped components

Note 1 to entry: The surface pressure between two clamped components falls to zero due to external loads pulling these parts apart.

3.7

permanent plastic deformation

plastification which infringes the functionality and durability of the bolt

3.8

load factor

ratio of additional bolt load to external load

Note 1 to entry: The load factor is determined using the resilience of the bolt and clamped components.

3.9

loosening

effect which results in loss of preload

3.10

slackening

loss of preload due to embedding, creep or exceeding surface pressure limits

3.11

embedding

flattening of joint surfaces, within the thread, under the head or the nut or the interface surfaces

3.12**creep**

time-dependent plastic deformation under load which leads to the loss of preload in bolted joints

Note 1 to entry: In metallic materials, this usually occurs at elevated temperatures (at least 30 % to 40 % of the melting temperature in Kelvin).

3.13**self-acting loosening by rotation**

loss of preload due to relative rotational movement between the nut and bolt or screw and threaded part, often associated with external shear loads overcoming the joint friction

3.14**fatigue load**

repetitive load or combination of loads

[SOURCE: EN 17149-1:2024, 3.1.14]

3.15**exceptional load**

infrequent load which represents the extreme loads or combination of loads for the relevant operation conditions

[SOURCE: EN 17149-1:2024, 3.1.10]

3.16**exceptional design load**

design load derived from an exceptional load

[SOURCE: EN 17149-1:2024, 3.1.12]

3.17**ultimate load**

extreme load that the structure withstands without rupture or collapse

[SOURCE: EN 17149-1:2024, 3.1.11]

3.18**ultimate design load**

design load derived from an ultimate load

[SOURCE: EN 17149-1:2024, 3.1.13]

3.19**failure**

loss of function of the bolted joint

Note 1 to entry: Function is e. g. structural strength or current transfer. Depending on design and function this can be an unacceptable loss of preload or total loss of joint.

3.20**slip-resistant**

property that prevents relative transverse or radial movement between the clamped components

3.21

tightening factor

ratio between maximum and minimum assembly preload of a bolted joint due to the scatter of the tightening process and scatter of friction coefficients

Note 1 to entry: Reduction of preload due to embedding is not taken into account.

3.22

tightening process

sequence of actions to tighten a bolted joint including all influence parameters

Note 1 to entry: The tightening process does not include the assembly of the bolted joint.

3.23

mechanical connection

bolted joint transferring loads between two or more components

3.24

electrical connection

bolted joint connecting two or more components to transfer current

3.25

severity level

severity of the consequences in case of failure of a bolted joint

3.26

safety class

resistance of a design against the feared consequences in case of failure of the bolt

3.27

safety category

classification defining the consequences of failure of the single bolted joint with respect to the effects on persons, facilities and the environment

[SOURCE: EN 15085-1:2007+A1:2013, 3.17, modified – “classification” has been added, “welded joint” has been substituted by “bolted joint”]

3.28

load-transmitting equipment

component or assembly which transfers loads during operation

Note 1 to entry: Examples for equipment loads are traction, braking and damper loads.

3.29

protective earthing

current-carrying electrical connection only in the event of a fault

3.30

TN-C

neutral conductor and protective earthing conductor combined in one unique line inside whole system

3.31

PEN-conductor

conductor combining the functions of both a protective earthing conductor and a neutral conductor

3.32**equipotential bonding system**

provision of electrical connections between conductive parts intended to achieve equipotentiality

3.33**control parameter**

parameter by which the tightening process is terminated

3.34**monitoring parameter**

measured parameter used for supervision purposes

3.35**directly measured parameter**

measured variable without additional physical transformation

Note 1 to entry: The control/monitoring variable is measured using a traceable calibratable sensor integrated into the fastening tool or fastening system and which supplies measurement signals independently of the fastening process.

3.36**indirectly measured parameter**

control or control variable that is not directly measured

Note 1 to entry: e. g., current or pressure shutdown without measurement until the spindle stops.

3.37**manually actuated fastening tool**

fastening tool which is unpowered

Note 1 to entry: An example of a manually actuated fastening tool is a manual torque wrench.

3.38**hand-held tightening system**

motor-driven tightening system, in which the operator supports the reaction torque

Note 1 to entry: Permanent confirmation is achieved through tactile feedback to the user.

3.39**hand-guided tightening system**

motor-driven tightening system, in which the operator does not support the reaction torque

Note 1 to entry: This definition also includes fully automatic robotic systems.

3.40**performance class**

classified scatter of control parameter

3.41**torque wrench**

handheld indicating or setting torque tool

Note 1 to entry: A tool is considered hand-held in accordance with EN ISO 6789 (series) type I and type II.

3.42
quality process

measures to ensure that the assembly result meets the requirements

3.43
statistical tolerance interval

interval determined from a random sample in such a way that one has a specified level of confidence that the interval covers at least a specified proportion of the sampled population

Note 1 to entry: The confidence level in this context is the long-run proportion of intervals generated in this manner that will include at least the specified proportion of the sampled population.

[SOURCE: ISO 3534-1:2006, 1.26, modified: Added Note 1 to entry]

3.44
statistical tolerance limit

statistic representing an end point of a statistical tolerance interval

Note 1 to entry: Statistical tolerance intervals may be either one-sided (with one of its limits fixed at the natural boundary of the random variable), in which case they have either an upper or a lower statistical tolerance limit, or two-sided, in which case they have both.

4 Symbols and abbreviations

Table 1 lists the symbols and abbreviations used in this document.

Table 1 — Symbols and abbreviations

Symbol	Unit	Designation
A	mm ²	effective area of contact
c	mm	size of chamfer
CP	-	performance class
Cbs	-	Abbreviation for “carbodies”
D	mm	diameter
d	mm	nominal diameter of a thread which corresponds to ISO 261
d ₀	mm	outside diameter of the plane head bearing
d _h	mm	diameter of a through hole
d _k	mm	drill sizes for metric threads
E	mm	thread run-out
e ₁ , e ₂	mm	recommended edge distance
F	N	load (force)
F _{ax}	N	axial load
F _M	N	assembly preload when mounting/tightening
F _{sh}	N	shear load

Symbol	Unit	Designation
F_{Vmin}	N	minimum preload
f	-	the degree of freedom is defined as $f = m \cdot (n - 1)$
HV	-	Vickers hardness
K	-	factor used to determine the lower or upper limit of the statistical tolerance interval
$k_C(n; p; 1 - \alpha)$	-	factor used to determine x_L or x_U when the values of μ and σ are unknown for one-sided statistical tolerance interval. The suffix C is chosen because this k-factor is tabulated in ISO 16269-6:2014, Annex C.
$k_D(n; m; p; 1 - \alpha)$	-	factor used to determine x_{Li} and x_{Ui} ($i = 1, 2, \dots, m; m \geq 2$) when the values of the means μ_i and the value of the common σ are unknown for the m two-sided statistical tolerance intervals. The suffix D is chosen because this k-factor is tabulated in ISO 16269-6:2014, Annex D.
l_{tol}	mm	tolerance in length of clamped components and fasteners
M	-	number of samples in the population
m_{eff}	mm	effective length of engagement
m_{tot}	mm	total engagement length
N	-	number of observations in a sample
P	mm	thread pitch
p	N/mm ²	contact pressure
p_1, p_2	mm	spacing distance
p_{t1}, p_{t2}	%	minimum proportion of the population asserted to be lying in the statistical tolerance interval
R_{eH}	N/mm ²	upper yield point
R_m	N/mm ²	tensile strength
$R_{m,max}$	N/mm ²	maximum tensile strength
$R_{p0,2}$	N/mm ²	yield strength
S	-	estimated standard deviation of a sample: positive square root of the mean squared standard deviation from the mean of a sample.
s_i	-	sample standard deviation of i th sample
s_p	-	pooled sample standard deviation of m samples with n observations each
s_c	-	torque scatter
T	Nm	tightening torque
T_A	Nm	nominal tightening torque

Symbol	Unit	Designation
t	mm	sheet thickness or height of a geometric section (e.g. minimum depth (t) of counterbore)
u_p	-	p-fractile of the standardized normal distribution
$u(x_i)$	-	the uncertainty of the single input parameters is $u(x_i)$
$u(y)$	-	the uncertainties of the single input parameters $u(x_i)$ lead to a total uncertainty $u(y)$ of the output parameter $y = f(x_i)$ depending on the input parameters x_i The relation between $u(x_i)$ and the total uncertainty $u(y)$ can be expressed by the law of propagation of uncertainty
v	-	normally distributed variable
$f(v)$	-	density function of a normally distributed variable (Gaussian bell curve)
V_1, V_2	mm	minimum thread protrusion
X_i	-	the input quantities with $i = 1, \dots, m$, where m is the number of input quantities
x_i	-	input parameter
x_L	-	lower limit of the statistical tolerance interval for single population, one-side tolerance interval or two-side tolerance interval
x_U	-	upper limit of the statistical tolerance interval for single population, one-side tolerance interval or two-side tolerance interval
x_j	-	jth observed value
x_{ij}	-	jth observed value ($j = 1, 2, \dots, n$) of ith sample ($i = 1, 2, \dots, m$)
$x_{\max}$	-	maximum value of the observed values: $x_{\max} = \max \{x_1, x_2, \dots, x_n\}$
$x_{\min}$	-	minimum value of the observed values: $x_{\min} = \min \{x_1, x_2, \dots, x_n\}$
$\bar{x}$	-	sample mean: sum of all the data in a sample divided by the number of observations
Y	-	Y is a function of quantities x_i : $y = f(x_1, \dots, x_m)$ it can be expressed as $Y = y \pm u(y)$ with
y	-	output parameter $y = f(x_i)$
α_A	-	tightening factor
$1 - \alpha$	-	confidence level: probability associated with an interval of statistical tolerance
γ_L	-	partial factor for loads
μ	-	mean: sum of all the data in a population divided by the number of observations

Symbol	Unit	Designation
μ_b	-	friction coefficient under bolt head or nut
μ_i	-	population mean of the i th population ($i = 1, 2, \dots, m$)
μ_{int}	-	friction coefficient in the interface
μ_{th}	-	friction coefficient in the thread
μ_{tot}	-	value of the total joint friction combining the thread friction and under bolt head or nut friction coefficients
$\mu_{\text{tot,max,lub}}$	-	maximum value of the scatter of the total friction coefficient in lubricated joints
$\mu_{\text{tot,max,unlub}}$	-	maximum value of the scatter of the total friction coefficient in unlubricated joints
$\mu_{\text{tot,min,lub}}$	-	minimum value of the scatter of the total friction coefficient in lubricated joints
$\mu_{\text{tot,min,unlub}}$	-	minimum value of the scatter of the total friction coefficient in unlubricated joints
σ	-	positive square root of the mean squared standard deviation from the mean from a population
σ_a	N/mm ²	fatigue limit as stress amplitude
σ_{eq}	N/mm ²	equivalent stress in the bolt considering axial stress and torsional stress due to torque tightening
$\Delta\sigma$	N/mm ²	fatigue limit as stress range
τ	N/mm ²	shear stress
τ_{BM}	N/mm ²	shear strength of the internal thread material
τ_{M}	N/mm ²	shear resulting from tightening torque
ν	-	utilization factor of the yield point stress during tightening
Indices		
M		mounting state
max		maximum
min		minimum

5 Personnel competency

All persons involved with the subject of bolting and tightening technology shall be suitably qualified in order to control the human factors associated with the special process of bolt tightening.

The qualification should cover the following contents and can be adapted to the role of the persons in the specific bolting process (e.g. design, purchasing, production planning, assembly, quality). It should include a basic explanation of a bolted joint including preload and clamping of the connected parts:

- Bolt materials: recognition and consequences of using an unsuitable bolt material (property class, hardness);
- Bolt coating and lubrication: consequences of too high and too low friction;
- Application of the tightening torque: position of personnel when tightening, continuous torque application;
- Tightening tools. Differences between tool types (e.g. pneumatic wrench, hand tools, electric tools);
- Safety categories with explanation of failure consequences and special requirements for mounting of bolted joints of safety category H and safety category M;
- embedding and influence of paint, dirt, foreign materials, machining chips, surface roughness to preload of a bolted joint;
- Quality of thread and its recognition.

NOTE An example of qualification is given in VDI 2637-1.

6 Safety category

6.1 Safety category of mechanical and electrical connections

The safety category specifies the consequences of failure of a bolted joint with respect to its effect on persons, facilities and the environment.

Three safety categories are specified as follows:

- High = H:
Failure of the bolted joint leads to consequential events with personal injuries and fatalities, breakdown of the overall function or severe damage to the environment;
- Medium = M:
Failure of the bolted joint leads to an impairment of the overall function or can lead to consequential events with personal injuries or can lead to limited damage to the environment;
- Low = L:
Failure of the bolted joint does not lead to any direct impairment of the overall function. Consequential events with personal injuries or environmental damage are unlikely.

A safety category shall be allocated to each bolted joint. The classification can be derived from an FMEA (e.g. according to EN IEC 60812) or basing on experience.

NOTE Annex A gives hints for classification of bolted joints and as extension Annex D gives hints for classification of bolted joints for special vehicles.

Depending on the safety category different measures shall be taken to ensure the functionality of the joint.

If standards give other recommendations for the application of the safety category these standards may be applied. In case of different classification, the more conservative should be used or an FMEA should be performed.

6.2 Requirements depending on safety category

6.2.1 Mechanical connections

Table 2 summarizes the requirements of mechanical connections depending on safety category.

Table 2 — Requirements of mechanical connections

Safety category	High	Medium	Low	Subclause
Design requirements	Consideration of common design rules for bolted joints			7.1
Design documents	Detailed and unique designation of elements to use (e.g. material, surface treatment, lubrication, relevant installation parameters)			7.6
Securing method	See 7.5			7.5
Corrosion protection	See 7.4			7.4
Strength proof	Mandatory ^a		Not mandatory	7.2
Documentation of strength proof	Mandatory	Mandatory	Not mandatory	7.2
Information for assembly in technical documents	Mandatory	Mandatory	Not mandatory	7.6, 8.3.3
Record of assembly	Mandatory	Not mandatory	Not mandatory	8.7
Quality process	Mandatory	Mandatory	Not mandatory	8.6
Lifetime inspection	Mandatory	Not mandatory	Not mandatory	8.9
Personnel competency	Mandatory	Mandatory	Not mandatory	5
^a according to guidelines/standards for strength calculation of mechanical bolted joints following the provisions given in 7.2 (e.g. NF E 25-030-2 or VDI 2230) and/or by testing				

If other standards for railway applications also specify requirements for bolted joints, the more conservative requirements shall be used.

6.2.2 Electrical connections

Table 3 summarizes the requirements of electrical connections depending on safety category.

Table 3 — Requirements of electrical connections

Safety category	High	Medium	Low	Subclause
Design requirements	Consideration of common design rules for electrical connections			7.1, 7.3
Design documents	Detailed and unique designation of elements to use (e.g. material, surface treatment, lubrication, relevant installation parameters)			7.3
Securing method	See 7.5			7.5
Corrosion protection	See 7.4			7.4
Dimensioning	According to EN 50343	According to EN 50343	Recommended	7.3
Strength proof	Not mandatory	Not mandatory	Not mandatory	-
Information for assembly in technical documents	Mandatory	Mandatory	Not mandatory	7.6, 8.3.3
Record of assembly	Mandatory	Not mandatory	Not mandatory	8.7
Quality process	Mandatory	Mandatory	Not mandatory	8.6
Lifetime inspection	Mandatory	Not mandatory	Not mandatory	8.9
Personnel competency	Mandatory	Mandatory	Not mandatory	5

If other standards for railway applications also specify requirements for bolted joints, the more conservative requirements shall be used.

7 Design

7.1 Design rules

7.1.1 General

The design rules give provisions for the fasteners themselves and for the connected components.

7.1.2 Thread

The dimensions of the thread and the fasteners shall be in accordance with the metric system.

This document is based on the use of standard threads in accordance with ISO 261 and tolerance class 'medium' (6g/6H) in accordance with ISO 965-1.

The application of coatings (e.g. EN ISO 10683 for zinc flake coatings or EN ISO 4042 for galvanic coatings) may require other tolerance classes.

7.1.3 Bolts and nuts

For standard applications, bolts should be chosen in accordance with EN ISO 4017 or EN ISO 4014. Nuts should be chosen in accordance with EN ISO 4032. Prevailing torque nuts should be chosen in accordance with EN ISO 7040 or EN ISO 7042. For specific applications, other types of bolts are also allowed. For specific fasteners other than recommended (e.g. bolt and nut assemblies according to EN 14399-10), special strength requirements shall be considered.

The shape of the driving feature for torque application of fasteners should be internal or external hexagons as well as internal hexalobes. Table 4 gives relevant standards for the dimensions of torque application driving features. The dimensions of torque application driving features shall be in accordance with standards given in Table 4 depending on specific shape.

Table 4 — Shape for driving features

Shape	Standard
External hexagon	EN ISO 4014, EN ISO 4017
Internal hexagon	EN ISO 4762
Internal hexalobe	EN ISO 10664

7.1.4 Mechanical properties of fasteners

The mechanical properties of bolts and nuts shall comply with the delivery conditions of the relevant standards. Table 5 gives recommendations for mechanical properties of fasteners used in mechanical and electrical connections.

Table 5 — Mechanical properties

	Carbon steel	Stainless steel
Bolt	EN ISO 898-1	EN ISO 3506-1
Nut	EN ISO 898-2	EN ISO 3506-2
Preferable property class	8.8 / 8	A2-70

Higher property classes as 10.9 for carbon steel fasteners or class 80 for stainless steel fasteners may be used. Bolts of property class 12.9 should be avoided because of the low ductility and the tendency of hydrogen-induced brittle fracture.

NOTE The application of some surface protections (e.g. galvanic or hot dip zinc coatings) can cause hydrogen-induced brittle fracture of carbon steel bolts with higher property classes or liquid metal embrittlement.

To ensure the design principle of a bolted joint, the property class of the nut shall match with the property class of the bolt. The material grade of the bolt as well as the threaded part shall be considered in the joint calculation. The thread engagement can be higher than the standard nut height for softer materials.

Stainless steel fasteners shall be made from austenitic stainless steel grade A2 or A4 in accordance with Table 19.

For flat washers the minimum hardness in accordance with Table 6 should be used. The material of the washer should be chosen in accordance with the material of the bolts. For different materials of washers, the surface pressure shall be checked in accordance with 7.2.5.

Table 6 — Hardness of washers

Property class	Minimum hardness of flat washers
Stainless steel 70 and 80	200 HV
8.8	200 HV
10.9	300 HV
12.9	380 HV
NOTE More information can be taken from EN ISO 898-3.	

7.1.5 Design of component

7.1.5.1 Spacing and pattern of nominal distances

The failure of the clamped components in the direction transverse to the bolt axis shall be reliably avoided. The edge distances e_1 and e_2 and the spacing p_1 and p_2 are related to the hole diameter d_h of the clamped components and start from the axis of the hole (see Figure 1). The following distances are recommended depending on the load direction:

- up to the edges $e_1 \geq 3 d_h$ and $e_2 \geq 1,5 d_h$;
- between the holes p_1 and $p_2 \geq 3 d_h$.

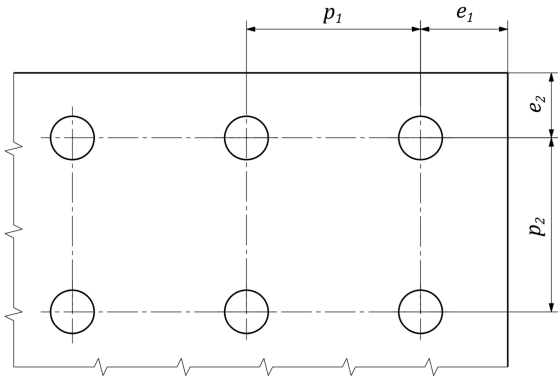


Figure 1 — Example of a pattern of holes in a component

The contact between the bolt shaft and the component hole shall be taken into consideration when using fitted bolts, due to manufacturing tolerances and deformations, and when slipping may occur in the joint. The safety verification against bolt bearing pressure is based on the shear cross-section, under the assumption that the transverse loads are completely absorbed by the shafts of the fitted bolts. The bearing pressure on the holes also shall be verified.

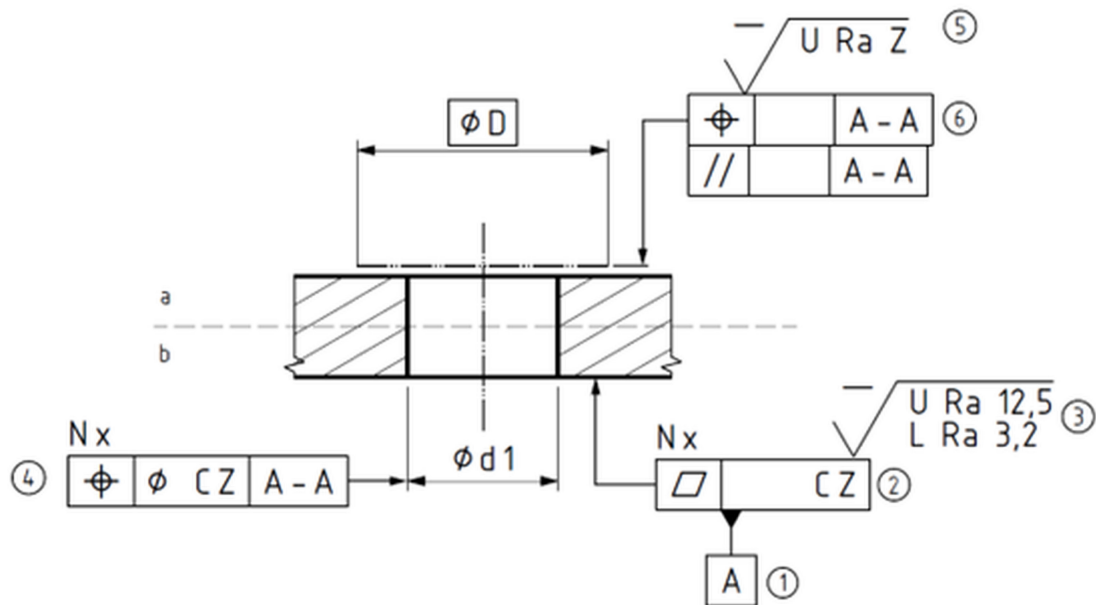
If the edge distance is less than the recommended distance, an eccentrically loaded joint can be expected.

7.1.5.2 Geometrical specification in accordance with ISO 8015:2011

Dimensional and geometrical imperfections are limited by tolerances and specifications on technical drawings or equivalent technical data packages.

Tolerances and specifications are independent from the means of production and can be measured at stable state of each finished individual component.

The following are guidelines to reinforce design, share common means of proof and to achieve consistent verification of products. Figure 2 gives an example for specifying a component as part of a bolted joint.



Key

- a bolt head or nut side
- b interface side in contact with other component to be joined
- 1 datum feature indicator, Nx integral plane(s) on interface side contact (not a specification)
- 2 individual/global flatness condition of interface surface
- 3 individual general roughness condition of interface surface
- 4 assembly condition
- 5 individual specific roughness condition for the bolt head or nut bearing surface
- 6 position and orientation specification of the bolt contact from datum

Figure 2 — ISO-GPS specification inventory for a component in a bolted joint

7.1.5.3 Functional interface identification (1)

In case of single bolted joint, the datum A should be in accordance with ISO 5459. Figure 2 gives an example for a multi bolted joint. The datum features A are several nominally coplanar planes. They become a common datum (A-A).

7.1.5.4 Interface geometrical quality (global flatness condition) (2)

The interface surfaces of each clamped component, especially of a multi bolted joint (e.g. a flange), should be flat with the appropriate flatness specification. In case of multiple interface surfaces a combined zone should be applied (CZ notation in accordance with ISO 1101).

In a multi bolted joint the gap due to flatness tolerances of the interface surfaces may be closed by the preload of the bolts. The part of the preload to close the gap is not available to fulfil the functional requirement of the bolted joint. Using up the full preload to close the gaps should be avoided. A closed gap should be ensured before final tightening.

7.1.5.5 General micro-geometrical specifications (3)

Figure 2 gives recommendations for values of roughness for interface surfaces of a bolted joint. The roughness of interface surfaces affects the friction coefficients for shear loads and influences the embedding of the bolted joint.

7.1.5.6 Interface hole pattern (assembling condition) (4)

In a multi bolt joint, the hole pattern should be specified depending on the minimum hole diameter in each component in such way that the bolts can be inserted without any force during assembly. Table 7 gives recommendations for tolerances of pattern.

Table 7 — Tolerances on bolted joint patterns

Nominal diameter	Minimum diameter of hole	Pattern specification applicable on each element	
d mm	$(d_1)^a$ mm	Bolted joint $\varnothing T CZ$ mm	Screwed joint $\varnothing T CZ$ mm
M4	4,5	0,5	0,25
M5	5,5	0,5	0,25
M6	6,6	0,6	0,3
M8	9	1	0,5
M10	11	1	0,5
M12	13,5	1,5	0,75
M16	17,5	1,5	0,75
M20	22	2	1
M24	26	2	1
M30	33	3	1,5
M36	39	3	1,5
^a d_1 determined with size tolerance applied on nominal hole diameter d_h			

7.1.5.7 Interface micro-geometrical quality (5)

The roughness of bolt head and nut contact surface affects the loss of preload due to embedding. Recommendations for roughness are given in Table 8.

Table 8 — Tolerances on bolted joint roughness

Nominal diameter mm	Roughness Z μm
$\leq M16$	3,2
$> M16$	6,4

7.1.5.8 Position/orientation specification of the bolt contact from datum (6)

The bolt head and nut contact surfaces of the clamped components should be parallel to one another to avoid additional bending stresses in the bolt, which reduce the fatigue resistance.

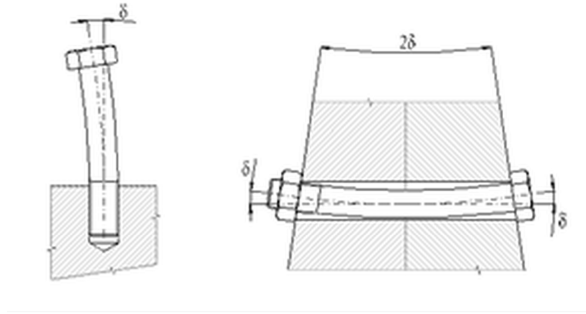


Figure 3 — Angle for bolted joints

The bending of a bolt is proportional to the parallelism between the surfaces in contact with the bolt head (side a) and the nut (side b) (see Figure 3). Table 9 gives recommendations for tolerances of parallelism for one component.

Table 9 — Recommended parallelism tolerances

Property class		8.8 / 70 / 80					10.9				
Joint angle 2δ [°]		0,5	0,8	1	1,5	2	0,3	0,4	0,5	0,8	1
Clamping length ratio		$l_k/d \leq 2$	$2 < l_k/d \leq 3$	$3 < l_k/d \leq 4$	$4 < l_k/d \leq 5$	$5 < l_k/d$	$l_k/d \leq 2$	$2 < l_k/d \leq 3$	$3 < l_k/d \leq 4$	$4 < l_k/d \leq 5$	$5 < l_k/d$
d	D ^a mm	Tolerance of parallelism for one component ^b mm									
M4	9	0,04	0,06	0,08	0,12	0,16	0,02	0,03	0,04	0,06	0,08
M5	10	0,04	0,07	0,09	0,13	0,17	0,03	0,03	0,04	0,07	0,09
M6	12	0,05	0,08	0,10	0,16	0,21	0,03	0,04	0,05	0,08	0,10
M8	16	0,07	0,11	0,14	0,21	0,28	0,04	0,06	0,07	0,11	0,14
M10	20	0,09	0,14	0,17	0,26	0,35	0,05	0,07	0,09	0,14	0,17
M12	24	0,10	0,17	0,21	0,31	0,42	0,06	0,08	0,10	0,17	0,21
M16	30	0,13	0,21	0,26	0,39	0,52	0,08	0,10	0,13	0,21	0,26
M20	37	0,16	0,26	0,32	0,48	0,65	0,10	0,13	0,16	0,26	0,32
M24	44	0,19	0,31	0,38	0,58	0,77	0,12	0,15	0,19	0,31	0,38
M30	56	0,24	0,39	0,49	0,73	0,98	0,15	0,20	0,24	0,39	0,49
M36	66	0,29	0,46	0,58	0,86	1,15	0,17	0,23	0,29	0,46	0,58
^a D in accordance with outer diameter of washers EN ISO 7089											
^b tolerances in relation to 1δ (one component)											

7.1.6 Resilience of a bolted joint

The resilience ratio of a bolted joint can be expressed by the load factor Φ . The load factor can be determined by the ratio of the resilience of the clamped components and the sum of the resiliences of the clamped components and the bolt. Therefore, the load factor expresses the proportion of an external load acting on a bolted joint, which is taken by the bolt itself (see Figure 4).

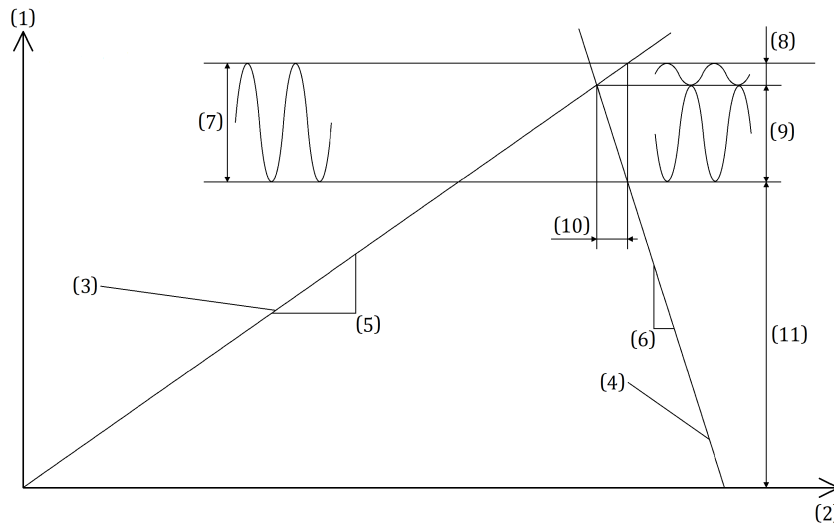


Figure 4 — Joint diagram and load factor

The aim of a proper design of a bolted joint is to minimize the additional load in the bolt caused by an external load action on the bolted joint. This is achieved by minimizing the load factor by increasing the resilience of the bolt and decreasing the resilience of the clamped components.

The resilience of a bolted joint can be improved by enlarging the clamping length of the bolted joint or by adding spring washers. If spring washers are used to improve the resilience of the bolted joint, the stiffness and the residual load of the spring washer should correspond to the property class of the bolt. For load-transmitting bolted joints spring washers are not recommended to improve the resilience.

The advantages of clamping length increasing are:

- the outer diameter of the deformation cone in the interfaces increases relatively;
- higher flexibility of the bolt;
- as a result of the relative resilience of the bolt and the clamped components, a greater proportion of the external axial load is supported by the clamped components relative to the proportion of the external axial load supported by the bolt; this results in a lower utilization of the bolt strength;
- the preload loss due to amount of embedding is lower.

For load transmitting joints and joints with high fatigue loads the clamping length of the assembled components should be in a range from 3 to 5 times the diameter of the bolt. Lower clamping lengths can work provided preloads are sufficient.

However, increasing the clamping length also results in a reduction of the residual clamping load.

7.1.7 Length of engagement

The design principle of the bolted joint is that the overstressed bolt fractures in the part of free loaded thread or in the shank prior to a failure of the threads in a tapped hole. The minimum length of engagement can be calculated (see 7.2.7). Alternatively, the effective length of engagement m_{eff} related to the bolt nominal diameter d , the shear strength of the internal thread material τ_{BM} and the quality class can be obtained from Figure 5.

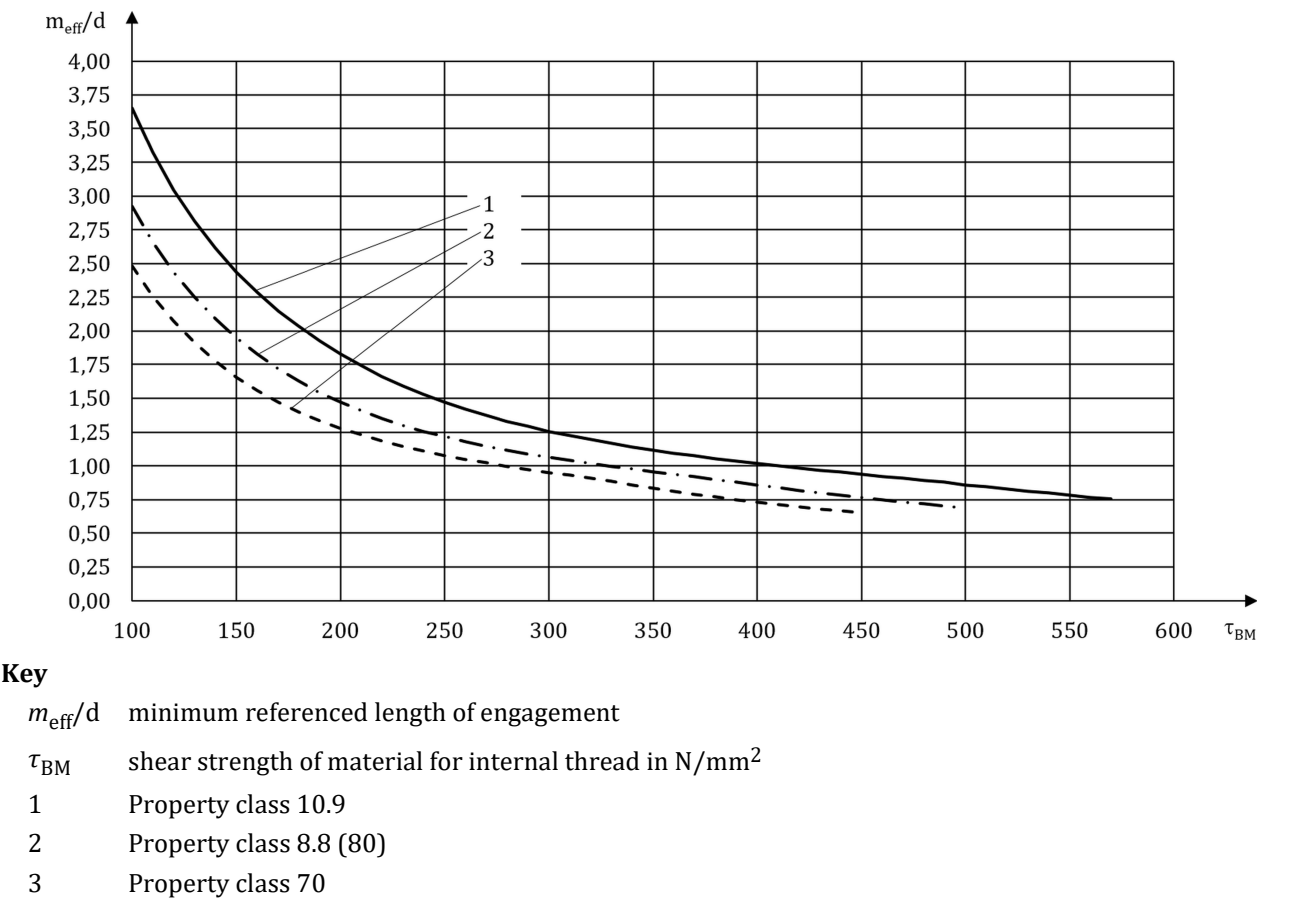


Figure 5 — Standard values for the minimum referred effective length of engagement m_{eff}/d

- The graphs in Figure 5 are valid for:
- ductile material of the threaded part, which allows full plasticization of inner thread;
 - distance centre drilled hole to edge $> 0,95 d$ and “nut outer diameter” $> 1,9 d$;
 - regular thread M4 to M24 for property class 70 and 80 or regular thread M4 to M39 for property class 8.8, 10.9 according to EN ISO 898-1;
 - bolt tensile load calculated with the stress cross section at nominal size and $R_{\text{m,max}} = (8.8, 80: 1\,000\text{ N/mm}^2, 10.9: 1\,200\text{ N/mm}^2, 70: 840\text{ N/mm}^2)$

The shear strength values τ_{BM} can be obtained based on the tensile strength R_{m} and the shear strength ratio $\tau_{\text{B}}/R_{\text{m}}$. Examples for the shear strength ratio $\tau_{\text{B}}/R_{\text{m}}$ are given in Table 10.

Table 10 — Shear strength ratio

Material type		Shear strength ratio τ_B/R_m
Structural steel		0,8 to 0,85
Heat-treatable steel		0,65 to 0,85
Case-hardening steel		0,85 to 1,0
Cast steel		0,8
Austenite (solution-annealed)		0,8
Austenite F90/60		0,65 to 0,75
Cast iron	GJL	1,15
	GJS	0,9
Aluminium	casting	0,52
	forgeable	0,6

The diagram given by Figure 5 allows the graphical estimation of minimum length of engagement of screwed joints. Alternatively, the minimum length of engagement can be calculated according to commonly used guidelines for mechanical bolted joints.

The effective length of the engagement m_{eff} does not include countersinks, chamfers, incomplete thread areas and parts of the thread which are not fully load-bearing.

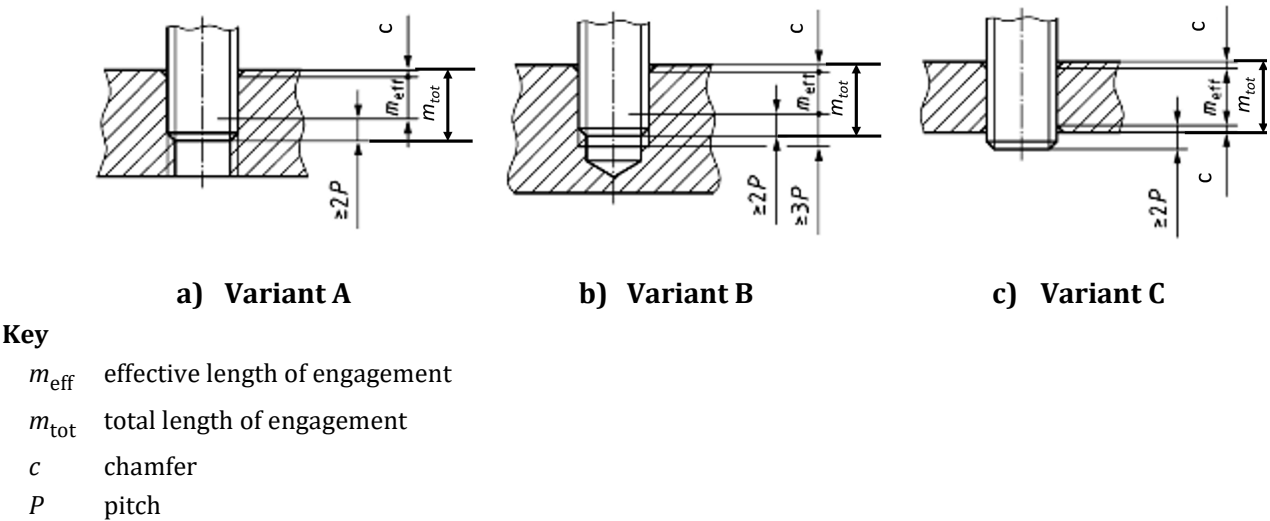


Figure 6 — Engagement, different design solutions

The required total engagement length m_{tot} is calculated from the effective engagement length m_{eff} (load-bearing thread length) and the design of the threaded parts.

The last two threads of a bolt are incomplete (see e.g. EN ISO 4014). In case of unspecified chamfers of the threaded parts, they may be assumed with a length of $1,0 P$. Thickness tolerances of the components and thickness of possible shims shall also be considered.

The minimum total engagement length m_{tot} for the screwed joint ("blind holes" Variant A + Variant B in Figure 6) is

$$m_{\text{tot}} = m_{\text{eff}} + 2 \cdot P + c + l_{\text{tol}}$$

For bolted joints with nuts made of construction materials (Variant C in Figure 6) the total engagement length m_{tot} is

$$m_{\text{tot}} = m_{\text{eff}} + 2 \cdot c + l_{\text{tol}}$$

This relationship only applies as long as the bolt protrudes by $2,0 P$ (Variant C in Figure 6); otherwise, the calculation relationship for blind holes shall be used.

7.1.8 Chamfers

The dimension for input chamfers should be 10 % of the diameter of the bolt for the depth and the angle shall be 45° .

7.1.9 Thread protrusions

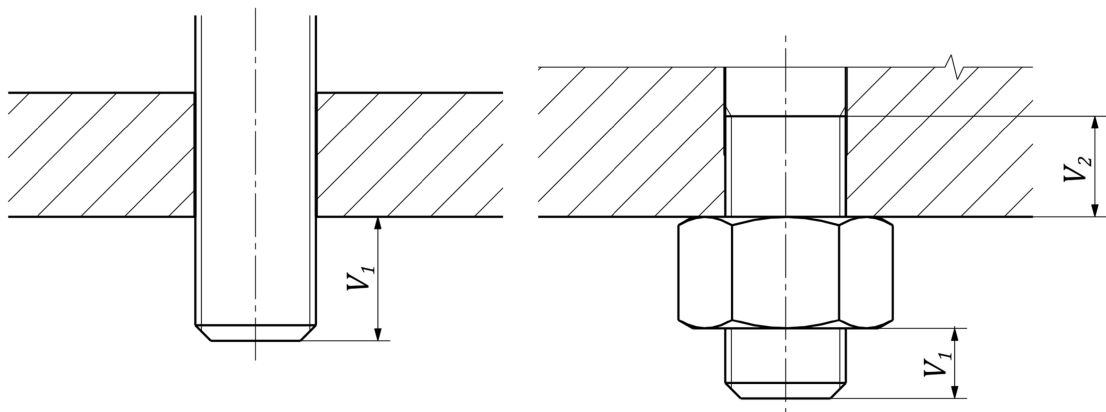


Figure 7 — Protrusions

For the design the thread protrusion V_1 (see Figure 7) shall be equal to or larger than $2,0 P$ for standard nuts (e.g. EN ISO 4032) and should be equal to or larger than $3,0 P$ in case of prevailing torque nuts (e.g. EN ISO 7040, EN ISO 7042) considering the maximum thickness of the components. V_1 may be reduced for threaded plates if the strength proof of engagement is given. The length of the loaded thread V_2 is recommended to be larger than $6,0 P$ for load transmitting joints and joints with high loads. In case of $V_2 < 6,0 P$ ductile failure behaviour of the bolted joint should be ensured.

NOTE More information about protrusion is provided in DIN 78.

7.1.10 Clearance hole for bolt

The diameters and the tolerances of the clearance holes d_h for fine, medium and coarse series are given in EN 20273 (see Table 11). In the absence of any specific requirements, medium series should be used.

The dimensions d_h for fine and medium series threads are appropriate to use as widths for slotted holes. Direct contact of bolt head and nut bearing surfaces with interface of slotted holes should be avoided. In case of slotted holes, washers with appropriate thickness and diameter should be used to compensate for the contact area reduction.

The contact area reduced by slot and deformational cone respectively needs to be considered for calculation of safety against surface pressure.

7.1.11 Counterbore/countersink

In Table 11 and Table 12, the recommended diameters for counterbores and countersinks are given. The appropriate tolerance class for all diameters is H13.

Table 11 — Dimensions for clearance holes and counterbores

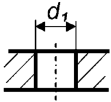
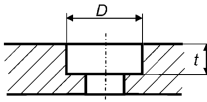
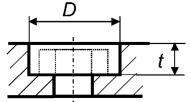
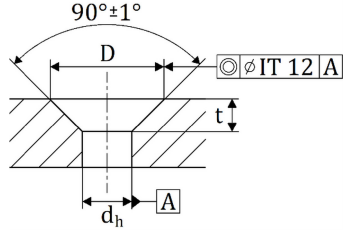
Thread size								
	Clearance hole according to EN 20273			counterbore for cylindrical head bolt EN ISO 4762		counterbore for hexagon socket EN ISO 4014 and EN ISO 4017 and sockets according to ISO 2725-2		
	fine	medium	coarse			wrench size		
	d_h	d_h	d_h	D	t_{min}	SW	D_{min}	t_{min}
M4	4,3	4,5	4,8	8	4,4	7	15	3,3
M5	5,3	5,5	5,8	10	5,4	8	18	4
M6	6,4	6,6	7	11	6,4	10	20	4,5
M8	8,4	9	10	15	8,6	13	26	6
M10	10,5	11	12	18	10,6	16	33	7,3
M12	13	13,5	14,5	20	12,6	18	36	8,3
M16	17	17,5	18,5	26	16,6	24	46	10,8
M20	21	22	24	33	20,6	30	54	13,5
M24	25	26	28	40	24,8	36	73	16,2
M30	31	33	35	50	31	46	82	20
M36	37	39	42	58	37	55	93	24
NOTE DIN 974-1 and DIN 974-2 give more detailed information.								

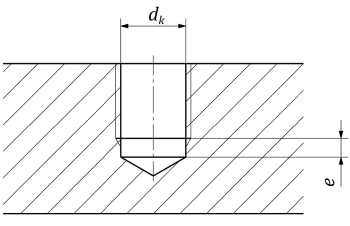
Table 12 — Diameters for countersinks

			
Thread size	Diameter of the clearance hole ^a d_h [mm]	countersink ^b	
		D_{min} [mm]	$t \approx$ [mm]
M2,5	2,9	5,5	1,35
M3	3,4	6,3	1,55
M4	4,5	9,4	2,55
M5	5,5	10,4	2,58
M6	6,6	12,6	3,13
M8	9	17,3	4,28
M10	11	20	4,65
M12	13,5	26 ^c	6,5 ^c
M16	17,5	32 ^c	7,5 ^c
M20	22	39 ^c	8,5 ^c
^a Diameter of the clearance hole according to EN 20273-M ^b Dimensions of the countersink according to EN ISO 15065, series medium, tolerance H13 ^c Not included in EN ISO 15065, calculated by the head diameter k of hexagon socket countersink head screws according to EN ISO 10642.			

7.1.12 Core hole diameter and thread runout

Table 13 gives diameters and length for run outs for drill sizes d_k for metric threads according to ISO 261 and coarse pitch series are according to ISO 2306. The appropriate accuracy class for all diameters is H13.

Table 13 — Dimensions for core hole diameter and thread runout

Thread in accordance with ISO 261			
Thread size	Pitch P	d_k	$e_{\min}$
M4	0,7	3,3	3,8
M5	0,8	4,2	4,2
M6	1	5	5,1
M8	1,25	6,8	6,2
M10	1,5	8,5	7,3
M12	1,75	10,2	8,3
M16	2	14	9,3
M20	2,5	17,5	11,2
M24	3	21	13,1
M30	3,5	26,5	15,2
M36	4	32	16,8
NOTE DIN 76-1 gives further design and dimensions for thread run out			

7.1.13 Accessibility for tools and tightening

The design of the bolted joint shall take into account the accessibility of the bolted joint during initial assembly and during reassembly for maintenance. Accessibility should be ensured on both sides for through-bolt joints. In case of maintenance, other equipment may be dismantled beforehand.

For this purpose, the assembly procedures for initial assembly and reassembly as well as the location of the load application of the tightening process (nut and / or bolt head) should be determined. At the location of load application, sufficient installation space shall be kept free so that the assembly tool can be applied, handled and removed. When using torque wrenches, sufficient movement space and good accessibility for the rotary movement of the entire tool is necessary during handling. A rotary movement of at least 60° without interruption should be achievable.

For assembly tools that require torque support (e.g. torque-controlled tightening with hydraulic tool), a suitable support point shall be provided close to the bolted joint.

In the case of through-bolt joints, the opposite side of the load application shall be secured against rotation while tightening with rotational tools. A suitable installation space should also be provided for counter-holding in order to be able to apply a suitable tool.