

Eurocode 3: Design of steel structures —

Part 1-8: Design of joints

ICS 91.010.30; 91.080.10

National foreword

This British Standard is the UK implementation of EN 1993-1-8:2005, incorporating corrigenda December 2005 and July 2009. It supersedes DD ENV 1993-1-1:1992, which is withdrawn.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN corrigendum. For example, text altered by December 2005 corrigendum is indicated by **AC1** **AC1**.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials: concrete, steel, composite concrete and steel, timber, masonry and aluminium; this is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the co-existence period, after all the EN Eurocodes of a package are available.

Following publication of the EN, there is a period allowed for national calibration during which the National Annex is issued, followed by a co-existence period of a maximum three years. During the co-existence period Member States are encouraged to adapt their national provisions. At the end of this co-existence period, the conflicting parts of national standard(s) will be withdrawn.

In the UK, the primary corresponding national standards are:

BS 449-2:1969, *Specification for the use of structural steel in building. Metric units*

BS 4604-1:1970, *Specification for the use of high strength friction grip bolts in structural steelwork. Metric series. General grade*

BS 4604-2:1970, *Specification for the use of high strength friction grip bolts in structural steelwork. Metric series. Higher grade (parallel shank)*

BS 5400-3:2000, *Steel, concrete and composite bridges. Code of practice for design of steel bridges*

BS 5950-1:2000, *Structural use of steelwork in building. Code of practice for design. Rolled and welded sections*

BS EN 1993-1-1 partially supersedes BS 449-2, BS 4604-1, BS 4604-2, BS 5400-3, and BS 5950-1, which will be withdrawn by March 2010.

The UK participation in its preparation was entrusted by Technical Committee B/525, *Building and civil engineering structures*, to Subcommittee B/525/31, *Structural use of steel*.

Amendments/corrigenda issued since publication

Amd. No.	Date	Comments
16291 Corrigendum No. 1	June 2006	Implementation of CEN corrigendum December 2005
16571 Corrigendum No. 2	September 2006	Revision of national foreword and supersession details
	28 February 2010	Implementation of CEN corrigendum July 2009
	31 August 2010	Correction to 'brace failure' equation on Table 7.14

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A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Where a normative part of this EN allows for a choice to be made at the national level, the range and possible choice will be given in the normative text as Recommended Values, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN.

To enable EN 1993-1-8 to be used in the UK, the NDPs have been published in a National Annex, which has been issued separately by BSI.

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

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

English version

Eurocode 3: Design of steel structures - Part 1-8: Design of joints

Eurocode 3: Calcul des structures en acier - Partie 1-8:
Calcul des assemblages

Eurocode 3: Bemessung und Konstruktion von Stahlbauten
- Teil 1-8: Bemessung von Anschlüssen

This European Standard was approved by CEN on 16 April 2004.

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

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

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



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Foreword

This European Standard EN 1993, Eurocode 3: Design of steel structures, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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 November 2005, and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-1-1.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement these European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Background to the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonization of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonized technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980s.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement¹ between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links *de facto* the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (*e.g.* the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN 1990	Eurocode 0:	Basis of Structural Design
EN 1991	Eurocode 1:	Actions on structures
EN 1992	Eurocode 2:	Design of concrete structures
EN 1993	Eurocode 3:	Design of steel structures
EN 1994	Eurocode 4:	Design of composite steel and concrete structures
EN 1995	Eurocode 5:	Design of timber structures
EN 1996	Eurocode 6:	Design of masonry structures
EN 1997	Eurocode 7:	Geotechnical design
EN 1998	Eurocode 8:	Design of structures for earthquake resistance
EN 1999	Eurocode 9:	Design of aluminium structures

¹ Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

BS EN 1993-1-8:2005 EN 1993-1-8:2005 (E)

Eurocode standards recognize the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of eurocodes

The Member States of the EU and EFTA recognize that Eurocodes serve as reference documents for the following purposes :

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 – Mechanical resistance and stability – and Essential Requirement N°2 – Safety in case of fire;
- as a basis for specifying contracts for construction works and related engineering services;
- as a framework for drawing up harmonized technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents² referred to in Article 12 of the CPD, although they are of a different nature from harmonized product standards³. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National annex.

The National annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, *i.e.* :

- values and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc.), *e.g.* snow map,
- the procedure to be used where alternative procedures are given in the Eurocode.

It may contain

- decisions on the application of informative annexes,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and harmonized technical specifications (ENs and ETAs) for products

² According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for harmonized ENs and ETAs/ETAGs.

³ According to Art. 12 of the CPD the interpretative documents shall :

- give concrete form to the essential requirements by harmonizing the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;
- indicate methods of correlating these classes or levels of requirement with the technical specifications, *e.g.* methods of calculation and of proof, technical rules for project design, etc. ;
- serve as a reference for the establishment of harmonized standards and guidelines for European technical approvals.

The Eurocodes, *de facto*, play a similar role in the field of the ER 1 and a part of ER 2.

There is a need for consistency between the harmonized technical specifications for construction products and the technical rules for works⁴. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

National annex for EN 1993-1-8

This standard gives alternative procedures, values and recommendations with notes indicating where national choices may have to be made. The National Standard implementing EN 1993-1-8 should have a National Annex containing all Nationally Determined Parameters for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-1-8 through:

- 2.2(2)
- 1.2.6 (Group 6: Rivets)
- 3.1.1(3)
- 3.4.2(1)
- 5.2.1(2)
- 6.2.7.2(9)

⁴ see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

1 Introduction

1.1 Scope

- (1) This part of EN 1993 gives design methods for the design of joints subject to predominantly static loading using steel grades S235, S275, **AC2** S355, S420, S450 and S460 **AC2**.

1.2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard, only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

1.2.1 Reference Standards, Group 1: Weldable structural steels

EN 10025-1:2004	Hot rolled products of structural steels. General technical delivery conditions
EN 10025-2:2004	Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels
EN 10025-3:2004	Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels
EN 10025-4:2004	Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels
EN 10025-5:2004	Hot rolled products of structural steels. Technical delivery conditions for structural steels with improved atmospheric corrosion resistance
EN 10025-6:2004	Hot rolled products of structural steels. Technical delivery conditions for flat products of high yield strength structural steels in quenched and tempered condition

1.2.2 Reference Standards, Group 2: Tolerances, dimensions and technical delivery conditions

EN 10029:1991	Hot rolled steel plates 3 mm thick or above - Tolerances on dimensions, shape and mass
EN 10034:1993	Structural steel I- and H-sections - Tolerances on shape and dimensions
EN 10051:1991	Continuously hot-rolled uncoated plate, sheet and strip of non-alloy and alloy steels - Tolerances on dimensions and shape
EN 10055:1995	Hot rolled steel equal flange tees with radiused root and toes - Dimensions and tolerances on shape and dimensions
EN 10056-1:1995	Structural steel equal and unequal leg angles - Part 1: Dimensions
EN 10056-2:1993	Structural steel equal and unequal leg angles - Part 2: Tolerances on shape and dimensions
EN 10164:1993	Steel products with improved deformation properties perpendicular to the surface of the product - Technical delivery conditions

1.2.3 Reference Standards, Group 3: Structural hollow sections

EN 10219-1:1997	Cold formed welded structural hollow sections of non-alloy and fine grain steels - Part 1: Technical delivery requirements
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EN 10219-2:1997	Cold formed welded structural hollow sections of non-alloy and fine grain steels - Part 2: Tolerances, dimensions and sectional properties
EN 10210-1:1994	Hot finished structural hollow sections of non-alloy and fine grain structural steels - Part 1: Technical delivery requirements
EN 10210-2:1997	Hot finished structural hollow sections of non-alloy and fine grain structural steels - Part 2: Tolerances, dimensions and sectional properties

1.2.4 Reference Standards, Group 4: Bolts, nuts and washers

EN 14399-1:2002	High strength structural bolting for preloading - Part 1 : General Requirements
EN 14399-2:2002	High strength structural bolting for preloading - Part 2 : Suitability Test for preloading
EN 14399-3:2002	High strength structural bolting for preloading - Part 3 : System HR -Hexagon bolt and nut assemblies
EN 14399-4:2002	High strength structural bolting for preloading - Part 4 : System HV -Hexagon bolt and nut assemblies
EN 14399-5:2002	High strength structural bolting for preloading - Part 5 : Plain washers for system HR
EN 14399-6:2002	High strength structural bolting for preloading - Part 6 : Plain chamfered washers for systems HR and HV
EN ISO 898-1:1999	Mechanical properties of fasteners made of carbon steel and alloy steel - Part 1: Bolts, screws and studs (ISO 898-1:1999)
EN 20898-2:1993	Mechanical properties of fasteners - Part 2: Nuts with special proof load values - Coarse thread (ISO 898-2:1992)
EN ISO 2320:1997	Prevailing torque type steel hexagon nuts - Mechanical and performance requirements (ISO 2320:1997)
EN ISO 4014:2000	Hexagon head bolts - Product grades A and B (ISO 4014:1999)
EN ISO 4016:2000	Hexagon head bolts - Product grade C (ISO 4016:1999)
EN ISO 4017:2000	Hexagon head screws - Product grades A and B (ISO 4017:1999)
EN ISO 4018:2000	Hexagon head screws - Product grade C (ISO 4018:1999)
EN ISO 4032:2000	Hexagon nuts, style 1 - Product grades A and B (ISO 4032:1999)
EN ISO 4033:2000	Hexagon nuts, style 2 - Product grades A and B (ISO 4033:1999)
EN ISO 4034:2000	Hexagon nuts - Product grade C (ISO 4034:1999)
EN ISO 7040:1997	Prevailing torque hexagon nuts (with non-metallic insert), style 1 - Property classes 5, 8 and 10
EN ISO 7042:1997	Prevailing torque all-metal hexagon nuts, style 2 - Property classes 5, 8, 10 and 12
EN ISO 7719:1997	Prevailing torque type all-metal hexagon nuts, style 1 - Property classes 5, 8 and 10
ISO 286- 2:1988	ISO system of limits and fits - Part 2: Tables of standard tolerance grades and limit deviations for hole and shafts
ISO 1891:1979	Bolts, screws, nuts and accessories - Terminology and nomenclature - Trilingual edition
EN ISO 7089:2000	Plain washers- Nominal series- Product grade A
EN ISO 7090:2000	Plain washers, chamfered - Normal series - Product grade A
EN ISO 7091:2000	Plain washers - Normal series - Product grade C
EN ISO 10511:1997	Prevailing torque type hexagon thin nuts (with non-metallic insert)
EN ISO 10512:1997	Prevailing torque type hexagon nuts thin nuts, style 1, with metric fine pitch thread - Property classes 6, 8 and 10
EN ISO 10513:1997	Prevailing torque type all-metal hexagon nuts, style 2, with metric fine pitch thread - Property classes 8, 10 and 12

1.2.5 Reference Standards, Group 5: Welding consumable and welding

- EN 12345:1998 Welding-Multilingual terms for welded joints with illustrations. September 1998.
- EN ISO 14555:1998 Welding-Arc stud welding of metallic materials. May 1995
- EN ISO 13918:1998 Welding-Studs for arc stud welding-January 1997
- EN 288-3:1992 Specification and approval of welding procedures for metallic materials. Part 3: Welding procedure tests for arc welding of steels. 1992
- EN ISO 5817:2003 Arc-welded joints in steel - Guidance for quality levels for imperfections

1.2.6 Reference Standards, Group 6: Rivets

NOTE: Information may be given in the National Annex.

1.2.7 Reference Standard, Group 7: Execution of steel structures

- EN 1090-2 Requirements for the execution of steel structures

1.3 Distinction between Principles and Application Rules

- (1) The rules in EN 1990 clause 1.4 apply.

1.4 Terms and definitions

- (1) The following terms and definitions apply:

1.4.1

basic component (of a joint)

Part of a joint that makes a contribution to one or more of its structural properties.

1.4.2

connection

Location at which two or more elements meet. For design purposes it is the assembly of the basic components required to represent the behaviour during the transfer of the relevant internal forces and moments at the connection.

1.4.3

connected member

Any member that is joined to a supporting member or element.

1.4.4

joint

Zone where two or more members are interconnected. For design purposes it is the assembly of all the basic components required to represent the behaviour during the transfer of the relevant internal forces and moments between the connected members. A beam-to-column joint consists of a web panel and either one connection (single sided joint configuration) or two connections (double sided joint configuration), see Figure 1.1.

1.4.5

joint configuration

Type or layout of the joint or joints in a zone within which the axes of two or more inter-connected members intersect, see Figure 1.2.

1.4.6

rotational capacity

The angle through which the joint can rotate for a given resistance level without failing.

1.4.7

rotational stiffness

The moment required to produce unit rotation in a joint.

1.4.8

structural properties (of a joint)

Resistance to internal forces and moments in the connected members, rotational stiffness and rotation capacity.

1.4.9

uniplanar joint

In a lattice structure a uniplanar joint connects members that are situated in a single plane.

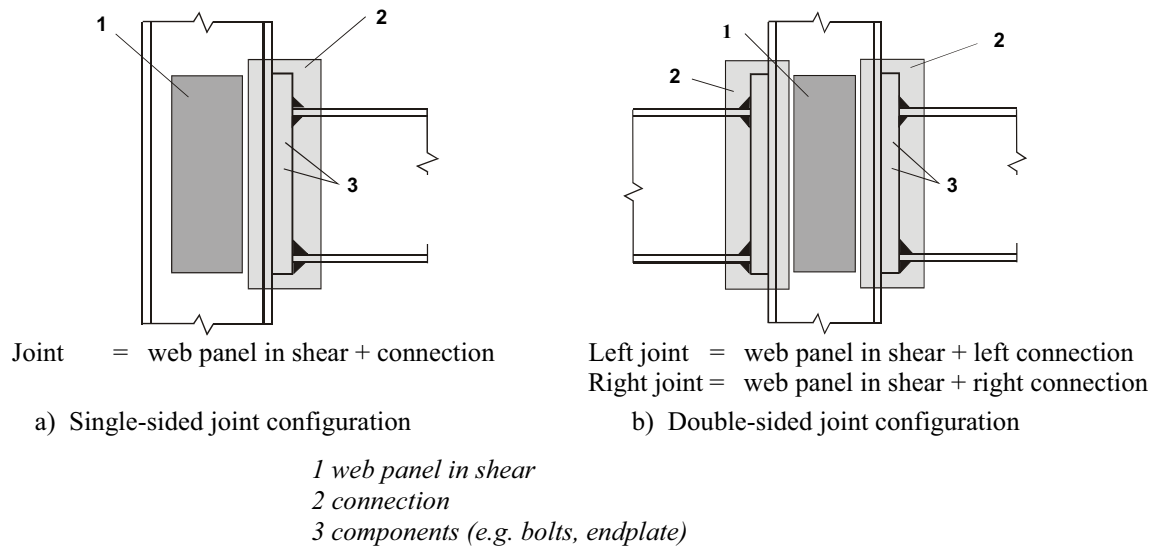
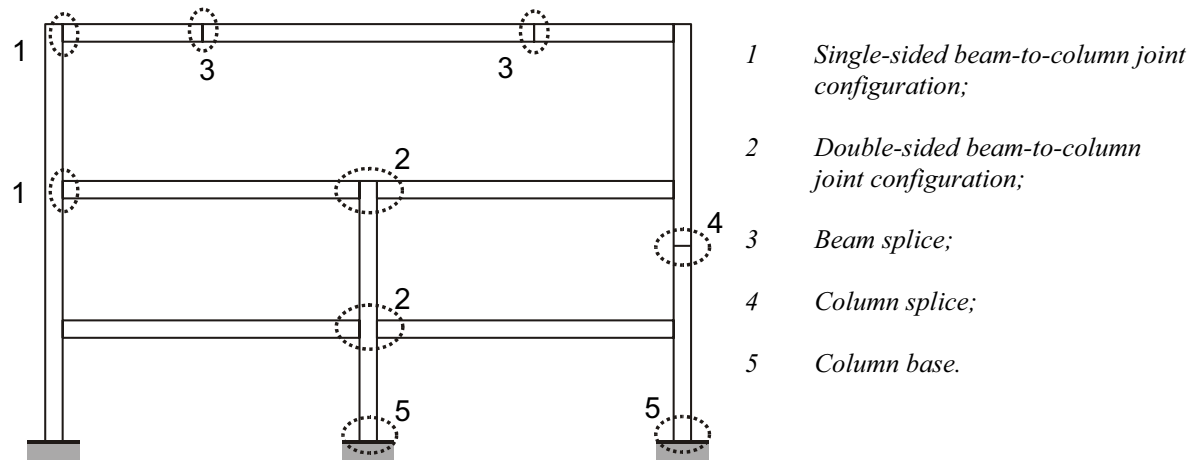
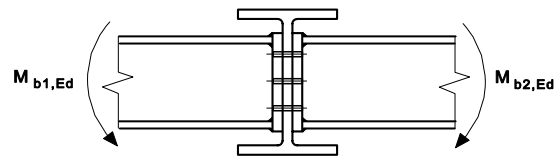
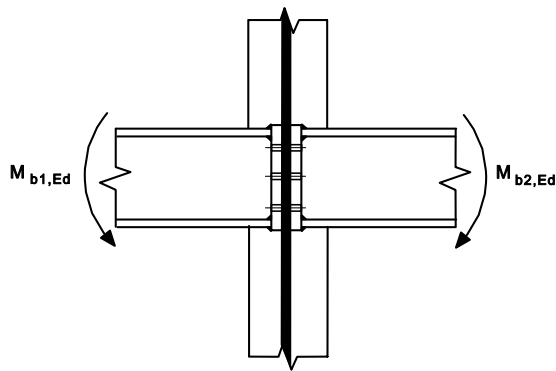


Figure 1.1: Parts of a beam-to-column joint configuration



a) Major-axis joint configurations



Double-sided beam-to-column joint configuration

Double-sided beam-to-beam joint configuration

b) Minor-axis joint configurations (to be used only for balanced moments $M_{b1,Ed} = M_{b2,Ed}$)

Figure 1.2: Joint configurations

1.5 Symbols

(1) The following symbols are used in this Standard:

d	is	the nominal bolt diameter, the diameter of the pin or the diameter of the fastener;
d_0	is	the hole diameter for a bolt, a rivet or a pin ;
$d_{0,t}$	is	the hole size for the tension face, generally the hole diameter, but for a slotted holes perpendicular to the tension face the slot length should be used;
$d_{0,v}$	is	the hole size for the shear face, generally the hole diameter, but for slotted holes parallel to the shear face the slot length should be used;
d_c	is	the clear depth of the column web;
d_m	is	the mean of the across points and across flats dimensions of the bolt head or the nut, whichever is smaller;
$f_{H,Rd}$	is	the design value of the Hertz pressure;
f_{ur}	is	the specified ultimate tensile strength of the rivet;
e_1	is	the end distance from the centre of a fastener hole to the adjacent end of any part, measured in the direction of load transfer, see Figure 3.1;
e_2	is	the edge distance from the centre of a fastener hole to the adjacent edge of any part, measured at right angles to the direction of load transfer, see Figure 3.1;
e_3	is	the distance from the axis of a slotted hole to the adjacent end or edge of any part, see Figure 3.1;
e_4	is	the distance from the centre of the end radius of a slotted hole to the adjacent end or edge of any part, see Figure 3.1;
ℓ_{eff}	is	the effective length of fillet weld;
n	is	the number of the friction surfaces or the number of fastener holes on the shear face;
p_1	is	the spacing between centres of fasteners in a line in the direction of load transfer, see Figure 3.1;
$p_{1,0}$	is	the spacing between centres of fasteners in an outer line in the direction of load transfer, see Figure 3.1;
$p_{1,i}$	is	the spacing between centres of fasteners in an inner line in the direction of load transfer, see Figure 3.1;
p_2	is	the spacing measured perpendicular to the load transfer direction between adjacent lines of fasteners, see Figure 3.1;
r	is	the bolt row number;

NOTE: In a bolted connection with more than one bolt-row in tension, the bolt-rows are numbered starting from the bolt-row furthest from the centre of compression.

s_s	is	the length of stiff bearing;
t_a	is	the thickness of the angle cleat;
t_{fc}	is	the thickness of the column flange;
t_p	is	the thickness of the plate under the bolt or the nut;
t_w	is	the thickness of the web or bracket;
t_{wc}	is	the thickness of the column web;
A	is	the gross cross-section area of bolt;
A_0	is	the area of the rivet hole;
A_{vc}	is	the shear area of the column, see EN 1993-1-1;
A_s	is	the tensile stress area of the bolt or of the anchor bolt;

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$A_{v,eff}$ is the effective shear area;
 $B_{p,Rd}$ is the design punching shear resistance of the bolt head and the nut
 E is the elastic modulus;
 $F_{p,Cd}$ is the design preload force;
 $F_{t,Ed}$ is the design tensile force per bolt for the ultimate limit state;
 $F_{t,Rd}$ is the design tension resistance per bolt;
 $F_{T,Rd}$ is the tension resistance of an equivalent T-stub flange;
 $F_{v,Rd}$ is the design shear resistance per bolt;
 $F_{b,Rd}$ is the design bearing resistance per bolt;
 $F_{s,Rd,ser}$ is the design slip resistance per bolt at the serviceability limit state;
 $F_{s,Rd}$ is the design slip resistance per bolt at the ultimate limit state;
 $F_{v,Ed,ser}$ is the design shear force per bolt for the serviceability limit state;
 $F_{v,Ed}$ is the design shear force per bolt for the ultimate limit state;
 $M_{j,Rd}$ is the design moment resistance of a joint;
 S_j is the rotational stiffness of a joint;
 $S_{j,ini}$ is the initial rotational stiffness of a joint;
 $V_{wp,Rd}$ is the plastic shear resistance of a column web panel;
 z is the lever arm;
 μ is the slip factor;
 ϕ is the rotation of a joint.

(2) The following standard abbreviations for hollow sections are used in section 7:

CHS for “circular hollow section”;

RHS for “rectangular hollow section”, which in this context includes square hollow sections.

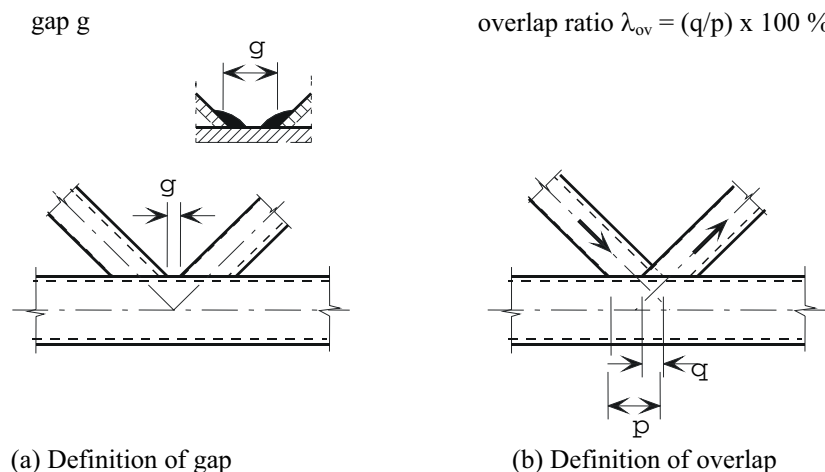


Figure 1.3: Gap and overlap joints

(3) The following symbols are used in section 7:

A_i is the cross-sectional area of member i ($i = 0, 1, 2$ or 3);

A_v is the shear area of the chord;

$A_{v,eff}$ is the effective shear area of the chord;

L	is	the system length of a member;
$M_{ip,i,Rd}$	is	the design value of the resistance of the joint, expressed in terms of the in-plane internal moment in member i ($i = 0, 1, 2$ or 3);
$M_{ip,i,Ed}$	is	the design value of the in-plane internal moment in member i ($i = 0, 1, 2$ or 3);
$M_{op,i,Rd}$	is	the design value of the resistance of the joint, expressed in terms of the out-of-plane internal moment in member i ($i = 0, 1, 2$ or 3);
$M_{op,i,Ed}$	is	the design value of the out-of-plane internal moment in member i ($i = 0, 1, 2$ or 3);
$N_{i,Rd}$	is	the design value of the resistance of the joint, expressed in terms of the internal axial force in member i ($i = 0, 1, 2$ or 3);
$N_{i,Ed}$	is	the design value of the internal axial force in member i ($i = 0, 1, 2$ or 3);
$W_{el,i}$	is	the elastic section modulus of member i ($i = 0, 1, 2$ or 3);
$W_{pl,i}$	is	the plastic section modulus of member i ($i = 0, 1, 2$ or 3);
b_i	is	the overall out-of-plane width of RHS member i ($i = 0, 1, 2$ or 3);
b_{eff}	is	the effective width for a brace member to chord connection;
$b_{e,ov}$	is	the effective width for an overlapping brace to overlapped brace connection;
$b_{e,p}$	is	the effective width for punching shear;
b_p	is	the width of a plate;
b_w	is	the effective width for the web of the chord;
d_i	is	the overall diameter of CHS member i ($i = 0, 1, 2$ or 3);
d_w	is	the depth of the web of an I or H section chord member;
e	is	the eccentricity of a joint;
f_b	is	the buckling strength of the chord side wall;
f_{yi}	is	the yield strength of member i ($i = 0, 1, 2$ or 3);
f_{y0}	is	the yield strength of a chord member;
g	is	the gap between the brace members in a K or N joint (negative values of g represent an overlap q); the gap g is measured along the length of the connecting face of the chord, between the toes of the adjacent brace members, see Figure 1.3(a);
h_i	is	the overall in-plane depth of the cross-section of member i ($i = 0, 1, 2$ or 3);
$\boxed{AC_2} h_z$	is	the distance between centres of gravity of the effective width parts of a rectangular section beam connected to a I or H section column; $\boxed{AC_2}$
k	is	a factor defined in the relevant table, with subscript g, m, n or p ;
ℓ	is	the buckling length of a member;
p	is	the length of the projected contact area of the overlapping brace member onto the face of the chord, in the absence of the overlapped brace member, see Figure 1.3(b);
q	is	the length of overlap, measured at the face of the chord, between the brace members in a K or N joint, see Figure 1.3(b);
r	is	the root radius of an I or H section or the corner radius of a rectangular hollow section;
t_f	is	the flange thickness of an I or H section;
t_i	is	the wall thickness of member i ($i = 0, 1, 2$ or 3);
t_p	is	the thickness of a plate;
t_w	is	the web thickness of an I or H section;
α	is	a factor defined in the relevant table;
θ_i	is	the included angle between brace member i and the chord ($i = 1, 2$ or 3);
κ	is	a factor defined where it occurs;
μ	is	a factor defined in the relevant table;
φ	is	the angle between the planes in a multiplanar joint.

(4) The integer subscripts used in section 7 are defined as follows:

i is an integer subscript used to designate a member of a joint, $i = 0$ denoting a chord and $i = 1, 2$ or 3 the brace members. In joints with two brace members, $i = 1$ normally denotes the compression brace and $i = 2$ the tension brace, see Figure 1.4(b). For a single brace $i = 1$ whether it is subject to compression or tension, see Figure 1.4(a);

i and j are integer subscripts used in overlap type joints, i to denote the overlapping brace member and j to denote the overlapped brace member, see Figure 1.4(c).

(5) The stress ratios used in section 7 are defined as follows:

n is the ratio $(\sigma_{0,Ed}/f_{y0})/\gamma_{M5}$ (used for RHS chords);

n_p is the ratio $(\sigma_{p,Ed}/f_{y0})/\gamma_{M5}$ (used for CHS chords);

$\sigma_{0,Ed}$ is the maximum compressive stress in the chord at a joint;

$\sigma_{p,Ed}$ is the value of $\sigma_{0,Ed}$ excluding the stress due to the components parallel to the chord axis of the axial forces in the braces at that joint, see Figure 1.4.

(6) The geometric ratios used in section 7 are defined as follows:

β is the ratio of the mean diameter or width of the brace members, to that of the chord:

- for T, Y and X joints:

$$\frac{d_1}{d_0}; \frac{d_1}{b_0} \text{ or } \frac{b_1}{b_0}$$

- for K and N joints:

$$\frac{d_1 + d_2}{2 d_0}; \frac{d_1 + d_2}{2 b_0} \text{ or } \frac{b_1 + b_2 + h_1 + h_2}{4 b_0}$$

- for KT joints:

$$\frac{d_1 + d_2 + d_3}{3 d_0}; \frac{d_1 + d_2 + d_3}{3 b_0} \text{ or } \frac{b_1 + b_2 + b_3 + h_1 + h_2 + h_3}{6 b_0}$$

β_p is the ratio b_i/b_p ;

γ is the ratio of the chord width or diameter to twice its wall thickness:

$$\frac{d_0}{2 t_0}; \frac{b_0}{2 t_0} \text{ or } \frac{b_0}{2 t_f}$$

η is the ratio of the brace member depth to the chord diameter or width:

$$\frac{h_i}{d_0} \text{ or } \frac{h_i}{b_0}$$

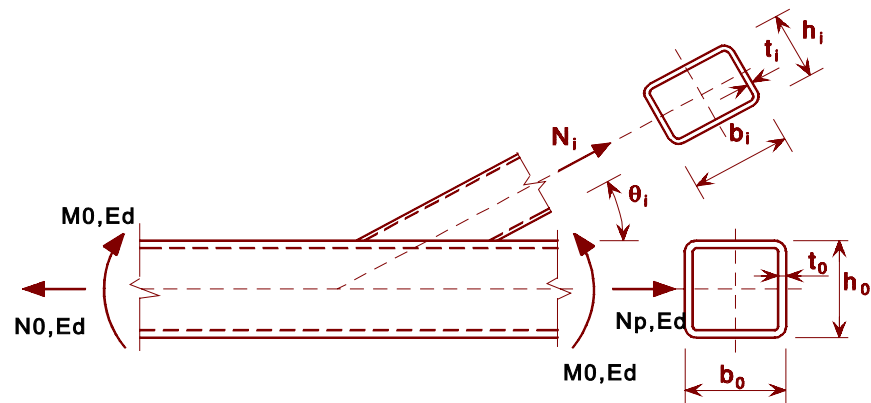
η_p is the ratio h_i/b_p ;

λ_{ov} is the overlap ratio, expressed as a percentage ($\lambda_{ov} = (q/p) \times 100\%$) as shown in figure 1.3(b);

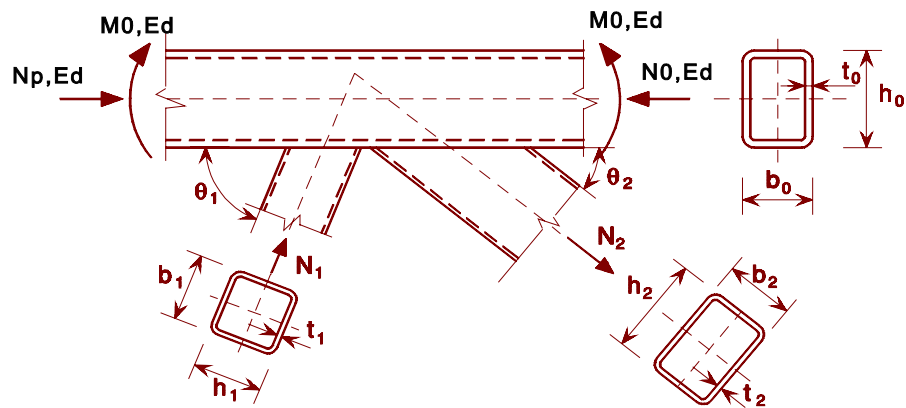
AC2 $\lambda_{ov,lim}$ is the overlap for which shear between braces and chord face may become critical. **AC2**

(7) Other symbols are specified in appropriate clauses when they are used.

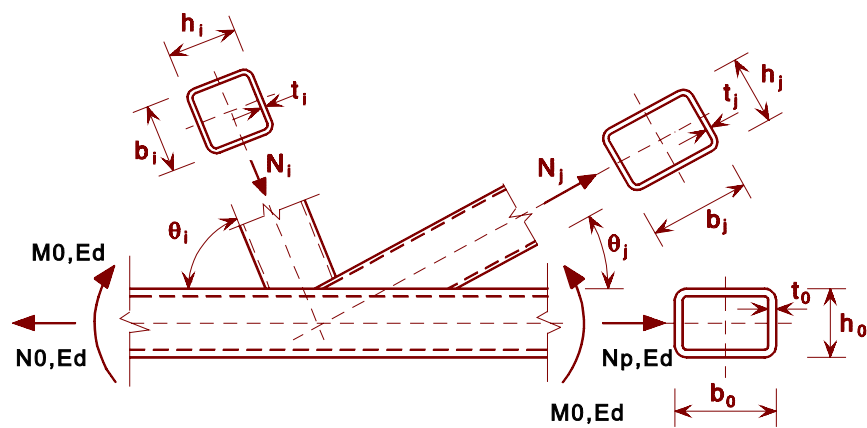
NOTE: Symbols for circular sections are given in Table 7.2.



a) Joint with single brace member



b) Gap joint with two brace members



c) Overlap joint with two brace members

Figure 1.4: Dimensions and other parameters at a hollow section lattice girder joint

2 Basis of design

2.1 Assumptions

- (1) The design methods given in this part of EN 1993 assume that the standard of construction is as specified in the execution standards given in 1.2 and that the construction materials and products used are those specified in EN 1993 or in the relevant material and product specifications.

2.2 General requirements

- AC1** (1)P All joints shall have a design resistance such that the structure is capable of satisfying all the basic design requirements given in this Standard and in EN 1993-1-1. **AC1**
- (2) The partial safety factors γ_M for joints are given in Table 2.1.

Table 2.1: Partial safety factors for joints

Resistance of members and cross-sections	γ_{M0} , γ_{M1} and γ_{M2} see EN 1993-1-1
Resistance of bolts	γ_{M2}
Resistance of rivets	
Resistance of pins	
Resistance of welds	
Resistance of plates in bearing	
Slip resistance - at ultimate limit state (Category C) - at serviceability limit state (Category B)	γ_{M3} $\gamma_{M3,ser}$
Bearing resistance of an injection bolt	γ_{M4}
Resistance of joints in hollow section lattice girder	γ_{M5}
Resistance of pins at serviceability limit state	$\gamma_{M6,ser}$
Preload of high strength bolts	γ_{M7}
Resistance of concrete	γ_c see EN 1992

NOTE: Numerical values for γ_M may be defined in the National Annex. Recommended values are as follows: $\gamma_{M2} = 1,25$; $\gamma_{M3} = 1,25$ and $\gamma_{M3,ser} = 1,1$; $\gamma_{M4} = 1,0$; $\gamma_{M5} = 1,0$; $\gamma_{M6,ser} = 1,0$; $\gamma_{M7} = 1,1$.

- AC1** (3)P Joints subject to fatigue shall also satisfy the principles given in EN 1993-1-9. **AC1**

2.3 Applied forces and moments

- AC1** (1)P The forces and moments applied to joints at the ultimate limit state shall be determined according to the principles in EN 1993-1-1. **AC1**

2.4 Resistance of joints

- (1) The resistance of a joint should be determined on the basis of the resistances of its basic components.
- (2) Linear-elastic or elastic-plastic analysis may be used in the design of joints.

- (3) Where fasteners with different stiffnesses are used to carry a shear load the fasteners with the highest stiffness should be designed to carry the design load. An exception to this design method is given in 3.9.3.

2.5 Design assumptions

- AC1** (1)P Joints shall be designed on the basis of a realistic assumption of the distribution of internal forces and moments. The following assumptions shall be used to determine the distribution of forces:
- (a) the internal forces and moments assumed in the analysis are in equilibrium with the forces and moments applied to the joints,
 - (b) each element in the joint is capable of resisting the internal forces and moments,
 - (c) the deformations implied by this distribution do not exceed the deformation capacity of the fasteners or welds and the connected parts,
 - (d) the assumed distribution of internal forces shall be realistic with regard to relative stiffnesses within the joint,
 - (e) the deformations assumed in any design model based on elastic-plastic analysis are based on rigid body rotations and/or in-plane deformations which are physically possible, and
 - (f) any model used is in compliance with the evaluation of test results (see EN 1990). **AC1**
- (2) The application rules given in this part satisfy 2.5(1).

2.6 Joints loaded in shear subject to impact, vibration and/or load reversal

- (1) Where a joint loaded in shear is subject to impact or significant vibration one of the following jointing methods should be used:
- welding
 - bolts with locking devices
 - preloaded bolts
 - injection bolts
 - other types of bolt which effectively prevent movement of the connected parts
 - rivets.
- (2) Where slip is not acceptable in a joint (because it is subject to reversal of shear load or for any other reason), preloaded bolts in a Category B or C connection (see 3.4), fit bolts (see 3.6.1), rivets or welding should be used.
- (3) For wind and/or stability bracings, bolts in Category A connections (see 3.4) may be used.

2.7 Eccentricity at intersections

- (1) Where there is eccentricity at intersections, the joints and members should be designed for the resulting moments and forces, except in the case of particular types of structures where it has been demonstrated that it is not necessary, see 5.1.5.
- (2) In the case of joints of angles or tees attached by either a single line of bolts or two lines of bolts any possible eccentricity should be taken into account in accordance with 2.7(1). In-plane and out-of-plane eccentricities should be determined by considering the relative positions of the centroidal axis of the member and of the setting out line in the plane of the connection (see Figure 2.1). For a single angle in tension connected by bolts on one leg the simplified design method given in 3.10.3 may be used.

NOTE: The effect of eccentricity on angles used as web members in compression is given in EN 1993-1-1, Annex BB 1.2.

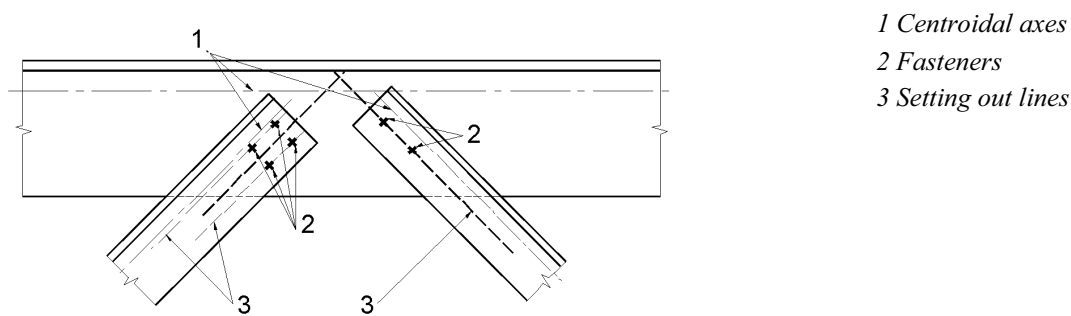


Figure 2.1: Setting out lines

3 Connections made with bolts, rivets or pins

3.1 Bolts, nuts and washers

3.1.1 General

- (1) All bolts, nuts and washers should comply with 1.2.4 Reference Standards: Group 4.
- (2) The rules in this Standard are valid for the bolt classes given in Table 3.1.
- (3) The yield strength f_{yb} and the ultimate tensile strength f_{ub} for bolt classes 4.6, 4.8, 5.6, 5.8, 6.8, 8.8 and 10.9 are given in Table 3.1. These values should be adopted as characteristic values in design calculations.

Table 3.1: Nominal values of the yield strength f_{yb} and the ultimate tensile strength f_{ub} for bolts

Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb} (N/mm ²)	240	320	300	400	480	640	900
f_{ub} (N/mm ²)	400	400	500	500	600	800	1000

NOTE: The National Annex may exclude certain bolt classes.

3.1.2 Preloaded bolts

- (1) Only bolt assemblies of classes 8.8 and 10.9 conforming to the requirements given in 1.2.4 Reference Standards: Group 4 for High Strength Structural Bolting for preloading with controlled tightening in accordance with the requirements in 1.2.7 Reference Standards: Group 7 may be used as preloaded bolts.

3.2 Rivets

- (1) The material properties, dimensions and tolerances of steel rivets should comply with the requirements given in 1.2.6 Reference Standards: Group 6.

3.3 Anchor bolts

- (1) The following materials may be used for anchor bolts:
- Steel grades conforming to 1.2.1 Reference Standards: Group 1;
 - Steel grades conforming to 1.2.4 Reference Standards: Group 4;
 - Steel grades used for reinforcing bars conforming to EN 10080;

provided that the nominal yield strength does not exceed 640 N/mm^2 when the anchor bolts are required to act in shear and not more than 900 N/mm^2 otherwise.

3.4 Categories of bolted connections

3.4.1 Shear connections

- (1) Bolted connections loaded in shear should be designed as one of the following:

a) Category A: Bearing type

In this category bolts from class 4.6 up to and including class 10.9 should be used. No preloading and special provisions for contact surfaces are required. The design ultimate shear load should not exceed the design shear resistance, obtained from 3.6, nor the design bearing resistance, obtained from 3.6 and 3.7.

b) Category B: Slip-resistant at serviceability limit state

In this category preloaded bolts in accordance with 3.1.2(1) should be used. Slip should not occur at the serviceability limit state. The design serviceability shear load should not exceed the design slip resistance, obtained from 3.9. The design ultimate shear load should not exceed the design shear resistance, obtained from 3.6, nor the design bearing resistance, obtained from 3.6 and 3.7.

c) Category C: Slip-resistant at ultimate limit state

In this category preloaded bolts in accordance with 3.1.2(1) should be used. Slip should not occur at the ultimate limit state. The design ultimate shear load should not exceed the design slip resistance, obtained from 3.9, nor the design bearing resistance, obtained from 3.6 and 3.7. In addition for a connection in tension, the design plastic resistance of the net cross-section at bolt holes $N_{\text{net,Rd}}$ (see 6.2 of EN 1993-1-1), should be checked, at the ultimate limit state.

The design checks for these connections are summarized in Table 3.2.

3.4.2 Tension connections

- (1) Bolted connection loaded in tension should be designed as one of the following:

a) Category D: non-preloaded

In this category bolts from class 4.6 up to and including class 10.9 should be used. No preloading is required. This category should not be used where the connections are frequently subjected to variations of tensile loading. However, they may be used in connections designed to resist normal wind loads.

b) Category E: preloaded

In this category preloaded 8.8 and 10.9 bolts with controlled tightening in conformity with 1.2.7 Reference Standards: Group 7 should be used.

The design checks for these connections are summarized in Table 3.2.

Table 3.2: Categories of bolted connections

Category	Criteria	Remarks
Shear connections		
A bearing type	$F_{v,Ed} \leq F_{v,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	No preloading required. Bolt classes from 4.6 to 10.9 may be used.
B slip-resistant at serviceability	$F_{v,Ed,ser} \leq F_{s,Rd,ser}$ $F_{v,Ed} \leq F_{v,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	Preloaded 8.8 or 10.9 bolts should be used. For slip resistance at serviceability see 3.9.
C slip-resistant at ultimate	$F_{v,Ed} \leq F_{s,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$ $\alpha_2 \sum F_{v,Ed} \leq N_{net,Rd} \alpha_2$	Preloaded 8.8 or 10.9 bolts should be used. For slip resistance at ultimate see 3.9. $N_{net,Rd}$ see 3.4.1(1) c).
Tension connections		
D non-preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	No preloading required. Bolt classes from 4.6 to 10.9 may be used. $B_{p,Rd}$ see Table 3.4.
E preloaded	$F_{t,Ed} \leq F_{t,Rd}$ $F_{t,Ed} \leq B_{p,Rd}$	Preloaded 8.8 or 10.9 bolts should be used. $B_{p,Rd}$ see Table 3.4.
The design tensile force $F_{t,Ed}$ should include any force due to prying action, see 3.11. Bolts subjected to both shear force and tensile force should also satisfy the criteria given in Table 3.4.		

NOTE: If preload is not explicitly used in the design calculations for slip resistances but is required for execution purposes or as a quality measure (e.g. for durability) then the level of preload can be specified in the National Annex.

3.5 Positioning of holes for bolts and rivets

- (1) Minimum and maximum spacing and end and edge distances for bolts and rivets are given in Table 3.3.
- (2) Minimum and maximum spacing, end and edge distances for structures subjected to fatigue, see EN 1993-1-9.

Table 3.3: Minimum and maximum spacing, end and edge distances

Distances and spacings, see Figure 3.1	Minimum	Maximum ^{1) 2) 3)}		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1,5d_0$ ⁴⁾			
Distance e_4 in slotted holes	$1,5d_0$ ⁴⁾			
Spacing p_1	$2,2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{\min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Spacing p_2 ⁵⁾	$2,4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{\min}$ or 175 mm
¹⁾ Maximum values for spacings, edge and end distances are unlimited, except in the following cases: – for compression members in order to avoid local buckling and to prevent corrosion in $\overline{\text{AC2}}$ exposed members (the limiting values are given in the table) and; $\overline{\text{AC2}}$ – for exposed tension members $\overline{\text{AC2}}$ to prevent corrosion (the limiting values are given in the table). $\overline{\text{AC2}}$ ²⁾ The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0,6 p_1$ as buckling length. Local buckling between the fasteners need not to be checked if p_1/t is smaller than 9ε. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement. ³⁾ t is the thickness of the thinner outer connected part. ⁴⁾ The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7. ⁵⁾ For staggered rows of fasteners a minimum line spacing of $p_2 = 1,2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2,4d_0$, see Figure 3.1b).				

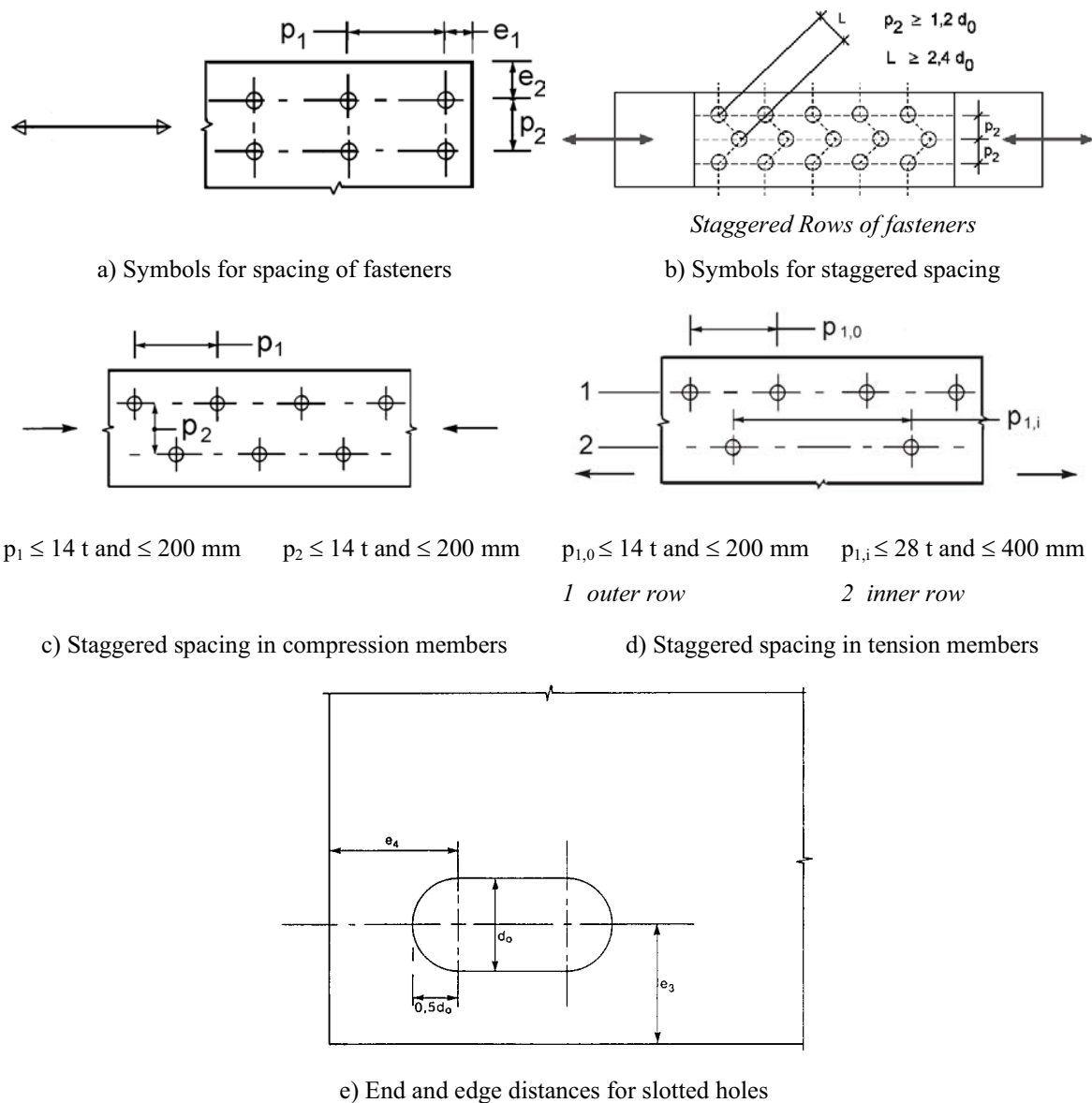


Figure 3.1: Symbols for end and edge distances and spacing of fasteners

3.6 Design resistance of individual fasteners

3.6.1 Bolts and rivets

- (1) The design resistance for an individual fastener subjected to shear and/or tension is given in Table 3.4.
- (2) For preloaded bolts in accordance with 3.1.2(1) the design preload, $F_{p,Cd}$, to be used in design calculations should be taken as:

$$F_{p,Cd} = 0,7 f_{ub} A_s / \gamma_{M7} \quad \dots (3.1)$$

NOTE: Where the preload is not used in design calculations see note to Table 3.2.

- (3) The design resistances for tension and for shear through the threaded portion of a bolt given in Table 3.4 should only be used for bolts manufactured in conformity with 1.2.4 Reference Standard: Group 4.

For bolts with cut threads, such as anchor bolts or tie rods fabricated from round steel bars where the threads comply with EN 1090, the relevant values from Table 3.4 should be used. For bolts with cut threads where the threads do not comply with EN 1090 the relevant values from Table 3.4 should be multiplied by a factor of 0,85.

- (4) The design shear resistance $F_{v,Rd}$ given in Table 3.4 should only be used where the bolts are used in holes with nominal clearances not exceeding those for normal holes as specified in 1.2.7 Reference Standards: Group 7.
- (5) M12 and M14 bolts may also be used in 2 mm clearance holes provided that the design resistance of the bolt group based on bearing $[AC_2]$ is less than or equal to $[AC_2]$ the design resistance of the bolt group based on bolt shear. In addition for class 4.8, 5.8, 6.8, 8.8 and 10.9 bolts the design shear resistance $F_{v,Rd}$ should be taken as 0,85 times the value given in Table 3.4.
- (6) Fit bolts should be designed using the method for bolts in normal holes.
- (7) The thread of a fit bolt should not be included in the shear plane.
- (8) The length of the threaded portion of a fit bolt included in the bearing length should not exceed 1/3 of the thickness of the plate, see Figure 3.2.
- (9) The hole tolerance used for fit bolts should be in accordance with 1.2.7 Reference Standards: Group 7.
- (10) In single lap joints with only one bolt row, see Figure 3.3, the bolts should be provided with washers under both the head and the nut. The design bearing resistance $F_{b,Rd}$ for each bolt should be limited to:

$$F_{b,Rd} \leq 1,5 f_u d t / \gamma_{M2} \quad \dots (3.2)$$

NOTE: Single rivets should not be used in single lap joints.

- (11) In the case of class 8.8 or 10.9 bolts, hardened washers should be used for single lap joints with only one bolt or one row of bolts.
- (12) Where bolts or rivets transmitting load in shear and bearing pass through packing of total thickness t_p greater than one-third of the nominal diameter d , see Figure 3.4, the design shear resistance $F_{v,Rd}$ calculated as specified in Table 3.4, should be multiplying by a reduction factor β_p given by:

$$\beta_p = \frac{9d}{8d + 3t_p} \quad \text{but } \beta_p \leq 1 \quad \dots (3.3)$$

- (13) For double shear connections with packing on both sides of the splice, t_p should be taken as the thickness of the thicker packing.
- (14) Riveted connections should be designed to transfer shear forces. If tension is present the design tensile force $F_{t,Ed}$ should not exceed the design tension resistance $F_{t,Rd}$ given in Table 3.4.
- (15) For grade S 235 steel the "as driven" value of f_{ur} may be taken as 400 N/mm².
- (16) As a general rule, the grip length of a rivet should not exceed 4,5d for hammer riveting and 6,5d for press riveting.

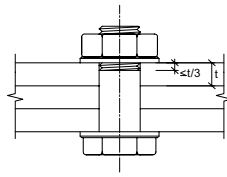


Figure 3.2: Threaded portion of the shank in the bearing length for fit bolts

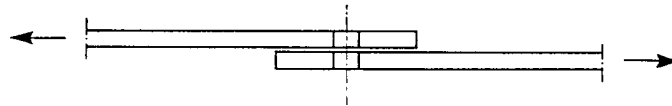


Figure 3.3: Single lap joint with one row of bolts

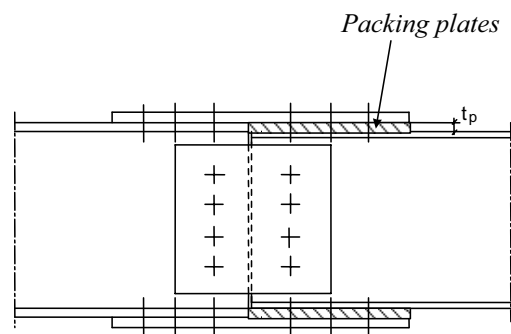


Figure 3.4: Fasteners through packings

Table 3.4: Design resistance for individual fasteners subjected to shear and/or tension

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$ - where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_s): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0,6$ - for classes 4.8, 5.8, 6.8 and 10.9: $\alpha_v = 0,5$ - where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt): $\alpha_v = 0,6$	$F_{v,Rd} = \frac{0,6 f_{ur} A_0}{\gamma_{M2}}$
Bearing resistance ^{1), 2), 3)}	$\langle AC2 \rangle F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}} \langle AC2 \rangle$ where α_b is the smallest of α_d; $\frac{f_{ub}}{f_u}$ or 1,0; in the direction of load transfer: - for end bolts: $\alpha_d = \frac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$ perpendicular to the direction of load transfer: $\langle AC2 \rangle$ - for edge bolts: k_1 is the smallest of $2,8 \frac{e_2}{d_0} - 1,7$, $1,4 \frac{p_2}{d_0} - 1,7$ and $2,5 \langle AC2 \rangle$ - for inner bolts: k_1 is the smallest of $1,4 \frac{p_2}{d_0} - 1,7$ or 2,5	
Tension resistance ²⁾	$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$ where $k_2 = 0,63$ for countersunk bolt, otherwise $k_2 = 0,9$.	$F_{t,Rd} = \frac{0,6 f_{ur} A_0}{\gamma_{M2}}$
Punching shear resistance	$B_{p,Rd} = 0,6 \pi d_m t_p f_u / \gamma_{M2}$	No check needed
Combined shear and tension	$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1,4 F_{t,Rd}} \leq 1,0$	
¹⁾ The bearing resistance $F_{b,Rd}$ for bolts - in oversized holes is 0,8 times the bearing resistance for bolts in normal holes. - in slotted holes, where the longitudinal axis of the slotted hole is perpendicular to the direction of the force transfer, is 0,6 times the bearing resistance for bolts in round, normal holes. ²⁾ For countersunk bolt: - the bearing resistance $F_{b,Rd}$ should be based on a plate thickness t equal to the thickness of the connected plate minus half the depth of the countersinking. - for the determination of the tension resistance $F_{t,Rd}$ the angle and depth of countersinking should conform with 1.2.4 Reference Standards: Group 4, otherwise the tension resistance $F_{t,Rd}$ should be adjusted accordingly. ³⁾ When the load on a bolt is not parallel to the edge, the bearing resistance may be verified separately for the bolt load components parallel and normal to the end.		

3.6.2 Injection bolts

3.6.2.1 General

- (1) Injection bolts may be used as an alternative to ordinary bolts and rivets for category A, B and C connections specified in 3.4.
- (2) Fabrication and erection details for injection bolts are given in 1.2.7 Reference Standards: Group 7.

3.6.2.2 Design resistance

- (1) The design method given in 3.6.2.2(2) to 3.6.2.2(6) should be used for connections with injection bolts of class 8.8 or 10.9. Bolt assemblies should conform with the requirements given in 1.2.4 Reference Standards: Group 4, but see 3.6.2.2(3) for when preloaded bolts are used.
- (2) The design ultimate shear load of any bolt in a Category A connection should not exceed the smaller of the following: the design shear resistance $F_{t,Rd}$ of the bolt or a group of bolts as obtained from 3.6 and 3.7; the design bearing resistance of the resin as obtained from 3.6.2.2(5).
- (3) Preloaded injection bolts should be used for category B and C connections, for which preloaded bolt assemblies in accordance with 3.1.2(1) should be used.
- (4) The design serviceability shear load of any bolt in a category B connection and the design ultimate shear load of any bolt in a category C connection should not exceed the design slip resistance of the bolt as obtained from 3.9 at the relevant limit state plus the design bearing resistance of the resin as obtained from 3.6.2.2(5) at the relevant limit state. In addition the design ultimate shear load of a bolt in a category B or C connection should not exceed either the design shear resistance of the bolt as obtained from 3.6, nor the design bearing resistance of the bolt as obtained from 3.6 and 3.7.
- (5) The design bearing resistance of the resin, $F_{b,Rd,resin}$, may be determined according to the following equation:

$$F_{b,Rd,resin} = \frac{k_t k_s d t_{b,resin} \beta f_{b,resin}}{\gamma_{M4}} \quad \dots (3.4)$$

where:

$F_{b,Rd,resin}$ is the bearing strength of an injection bolt

β is a coefficient depending of the thickness ratio of the connected plates as given in Table 3.5 and Figure 3.5

$f_{b,resin}$ is the bearing strength of the resin to be determined according to the 1.2.7 Reference Standards: Group 7.

$t_{b,resin}$ is the effective bearing thickness of the resin, given in Table 3.5

k_t is 1,0 for serviceability limit state (long duration)
is 1,2 for ultimate limit state

k_s is taken as 1,0 for holes with normal clearances or (1,0 - 0,1 m), for oversized holes

m is the difference (in mm) between the normal and oversized hole dimensions. In the case of short slotted holes as specified in 1.2.7 Reference Standards: Group 7, $m = 0,5 \cdot$ (the difference (in mm) between the hole length and width).

- (6) When calculating the bearing resistance of a bolt with a clamping length exceeding $3d$, a value of not more than $3d$ should be taken to determine the effective bearing thickness $t_{b,resin}$ (see Figure 3.6).

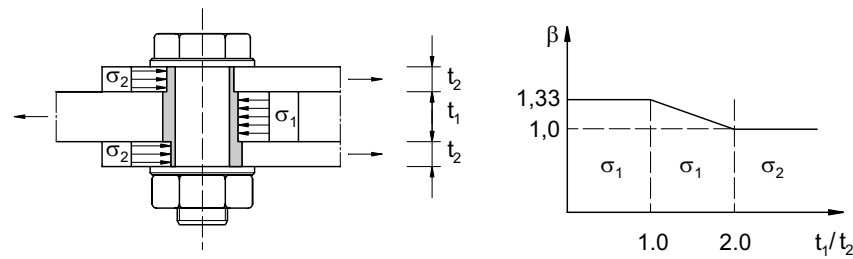


Figure 3.5: Factor β as a function of the thickness ratio of the connected plates

Table 3.5: Values of β and $t_{b,resin}$

t_1 / t_2	β	$t_{b,resin}$
$\geq 2,0$	1,0	$2 t_2 \leq 1,5 d$
$1,0 < t_1 / t_2 < 2,0$	$1,66 - 0,33 (t_1 / t_2)$	$t_1 \leq 1,5 d$
$\leq 1,0$	1,33	$t_1 \leq 1,5 d$

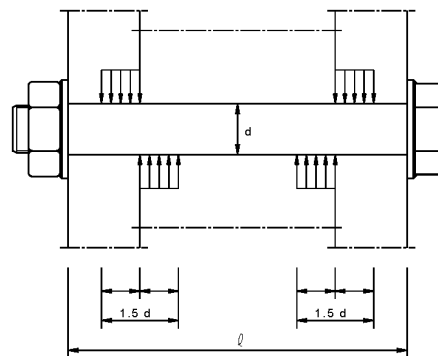


Figure 3.6: Limiting effective length for long injection bolts

3.7 Group of fasteners

- (1) The design resistance of a group of fasteners may be taken as the sum of the design bearing resistances $F_{b,Rd}$ of the individual fasteners provided that the design shear resistance $F_{v,Rd}$ of each individual fastener is greater than or equal to the design bearing resistance $F_{b,Rd}$. Otherwise the design resistance of a group of fasteners should be taken as the number of fasteners multiplied by the smallest design resistance of any of the individual fasteners.

3.8 Long joints

- (1) Where the distance L_j between the centres of the end fasteners in a joint, measured in the direction of force transfer (see Figure 3.7), is more than $15 d$, the design shear resistance $F_{v,Rd}$ of all the fasteners calculated according to Table 3.4 should be reduced by multiplying it by a reduction factor β_{Lf} , given by:

$$\beta_{Lf} = 1 - \frac{L_j - 15 d}{200 d} \quad \dots (3.5)$$

but $\beta_{Lf} \leq 1,0$ and $\beta_{Lf} \geq 0,75$

- (2) The provision in 3.8(1) does not apply where there is a uniform distribution of force transfer over the length of the joint, e.g. the transfer of shear force between the web and the flange of a section.

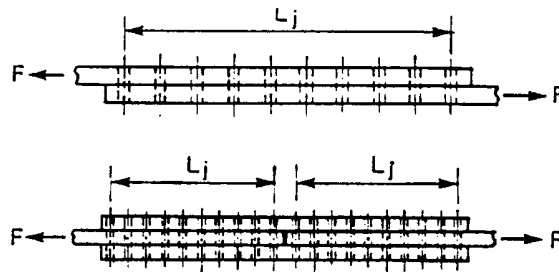


Figure 3.7: Long joints

3.9 Slip-resistant connections using 8.8 or 10.9 bolts

3.9.1 Design Slip resistance

- (1) The design slip resistance of a preloaded class 8.8 or 10.9 bolt should be taken as:

$$F_{s,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C} \quad \text{AC2} \dots (3.6a) \text{AC2}$$

$$\text{AC2} F_{s,Rd,ser} = \frac{k_s n \mu}{\gamma_{M3,ser}} F_{p,C} \quad \dots (3.6b) \text{AC2}$$

where:

k_s is given in Table 3.6

n is the number of AC2 the friction planes AC2

μ is the slip factor obtained either by specific tests for the friction surface in accordance with 1.2.7 Reference Standards: Group 7 or when relevant as given in Table 3.7.

- (2) For class 8.8 and 10.9 bolts conforming with 1.2.4 Reference Standards: Group 4, with controlled tightening in conformity with 1.2.7 Reference Standards: Group 7, the preloading force $F_{p,C}$ to be used in equation (3.6) should be taken as:

$$F_{p,C} = 0,7 f_{ub} A_s \quad \dots (3.7)$$

Table 3.6: Values of k_s

Description	k_s
Bolts in normal holes.	1,0
Bolts in either oversized holes or short slotted holes with the axis of the slot perpendicular to the direction of load transfer.	0,85
Bolts in long slotted holes with the axis of the slot perpendicular to the direction of load transfer.	0,7
Bolts in short slotted holes with the axis of the slot parallel to the direction of load transfer.	0,76
Bolts in long slotted holes with the axis of the slot parallel to the direction of load transfer.	0,63

Table 3.7: Slip factor, μ , for pre-loaded bolts

Class of friction surfaces (see 1.2.7 Reference Standard: Group 7)	Slip factor μ
A	0,5
B	0,4
C	0,3
D	0,2

NOTE 1: The requirements for testing and inspection are given in 1.2.7 Reference Standards: Group 7.

NOTE 2: The classification of any other surface treatment should be based on test specimens representative of the surfaces used in the structure using the procedure set out in 1.2.7 Reference Standards: Group 7.

NOTE 3: The definitions of the class of friction surface are given in 1.2.7 Reference Standards: Group 7.

NOTE 4: With painted surface treatments a loss of pre-load may occur over time.

3.9.2 Combined tension and shear

- (1) If a slip-resistant connection is subjected to an applied tensile force, $F_{t,Ed}$ or $F_{t,Ed,ser}$, in addition to the shear force, $F_{v,Ed}$ or $F_{v,Ed,ser}$, tending to produce slip, the design slip resistance per bolt should be taken as follows:

for a category B connection:
$$F_{s,Rd,ser} = \frac{k_s n \mu (F_{p,C} - 0,8 F_{t,Ed,ser})}{\gamma_{M3,ser}} \quad \dots (3.8a)$$

for a category C connection:
$$F_{s,Rd} = \frac{k_s n \mu (F_{p,C} - 0,8 F_{t,Ed})}{\gamma_{M3}} \quad \dots (3.8b)$$

- (2) If, in a moment connection, a contact force on the compression side counterbalances the applied tensile force no reduction in slip resistance is required.

3.9.3 Hybrid connections

- (1) As an exception to 2.4(3), preloaded class 8.8 and 10.9 bolts in connections designed as slip-resistant at the ultimate limit state (Category C in 3.4) may be assumed to share load with welds, provided that the final tightening of the bolts is carried out after the welding is complete.

3.10 Deductions for fastener holes

3.10.1 General

- (1) Deduction for holes in the member design should be made according to EN 1993-1-1.

3.10.2 Design for block tearing

- (1) Block tearing consists of failure in shear at the row of bolts along the shear face of the hole group accompanied by tensile rupture along the line of bolt holes on the tension face of the bolt group. Figure 3.8 shows block tearing.
- (2) For a symmetric bolt group subject to concentric loading the design block tearing resistance, $V_{\text{eff},1,\text{Rd}}$ is given by:

$$V_{\text{eff},1,\text{Rd}} = f_u A_{\text{nt}} / \gamma_{\text{M}2} + (1 / \sqrt{3}) f_y A_{\text{nv}} / \gamma_{\text{M}0} \quad \dots (3.9)$$

where:

A_{nt} is net area subjected to tension;

A_{nv} is net area subjected to shear.

- (3) For a bolt group subject to eccentric loading the design block shear tearing resistance $V_{\text{eff},2,\text{Rd}}$ is given by:

$$V_{\text{eff},2,\text{Rd}} = 0,5 f_u A_{\text{nt}} / \gamma_{\text{M}2} + (1 / \sqrt{3}) f_y A_{\text{nv}} / \gamma_{\text{M}0} \quad \dots (3.10)$$

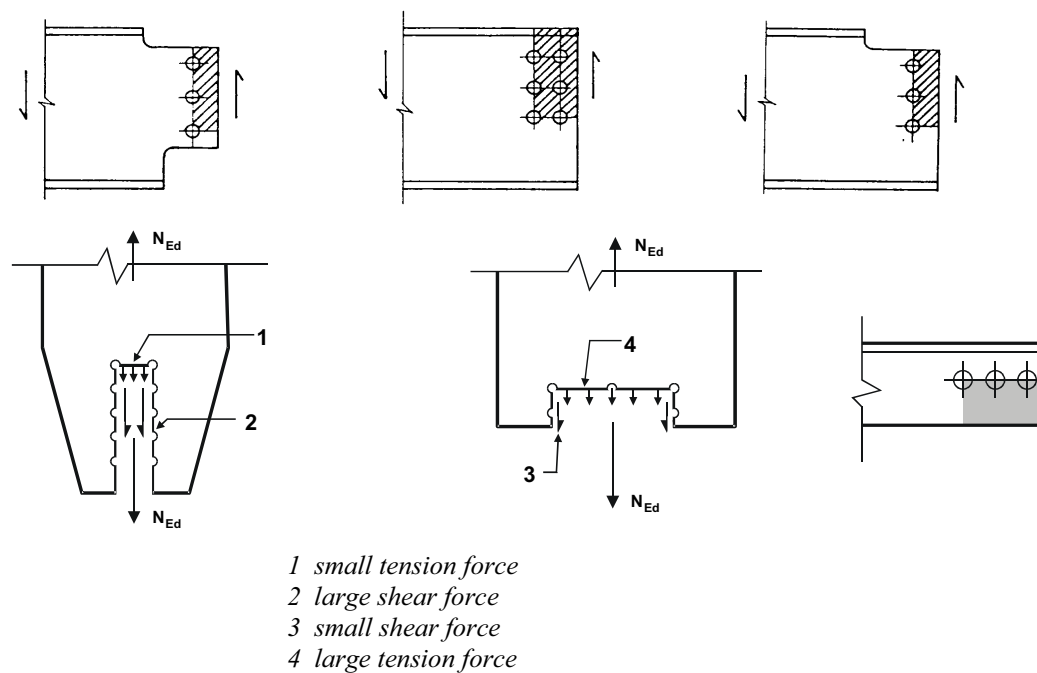


Figure 3.8: Block tearing

3.10.3 Angles connected by one leg and other unsymmetrically connected members in tension

- (1) The eccentricity in joints, see 2.7(1), and the effects of the spacing and edge distances of the bolts, should be taken into account in determining the design resistance of:
 - unsymmetrical members;
 - symmetrical members that are connected unsymmetrically, such as angles connected by one leg.
- (2) A single angle in tension connected by a single row of bolts in one leg, see Figure 3.9, may be treated as concentrically loaded over an effective net section for which the design ultimate resistance should be determined as follows:

with 1 bolt:

$$N_{u,Rd} = \frac{2,0(e_2 - 0,5d_0)t f_u}{\gamma_{M2}} \quad \dots (3.11)$$

with 2 bolts:

$$N_{u,Rd} = \frac{\beta_2 A_{net} f_u}{\gamma_{M2}} \quad \dots (3.12)$$

with 3 or more bolts:

$$N_{u,Rd} = \frac{\beta_3 A_{net} f_u}{\gamma_{M2}} \quad \dots (3.13)$$

where:

β_2 and β_3 are reduction factors dependent on the pitch p_1 as given in Table 3.8. For intermediate values of p_1 the value of β may be determined by linear interpolation;

A_{net} is the net area of the angle. For an unequal-leg angle connected by its smaller leg, A_{net} should be taken as equal to the net section area of an equivalent equal-leg angle of leg size equal to that of the smaller leg.

Table 3.8: Reduction factors β_2 and β_3

Pitch	p_1	$\leq 2,5 d_0$	$\geq 5,0 d_0$
2 bolts	β_2	0,4	0,7
3 bolts or more	β_3	0,5	0,7

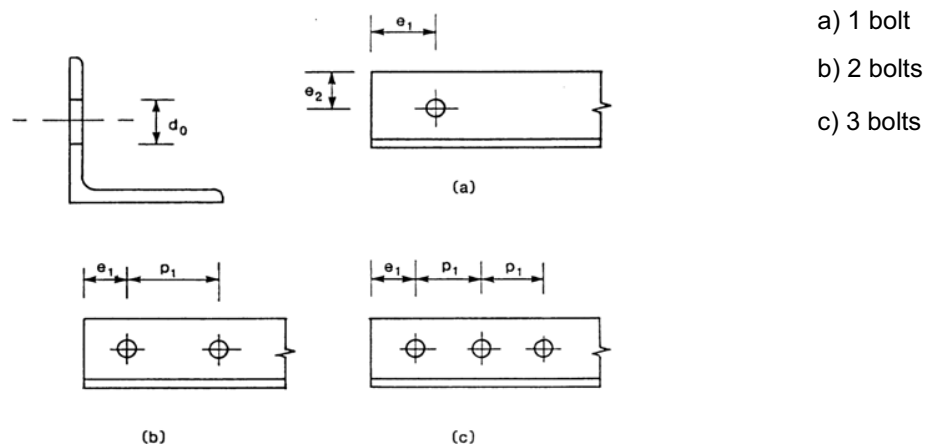


Figure 3.9: Angles connected by one leg

3.10.4 Lug angles

- (1) The Lug angle shown in Figure 3.10 connects angle members and their fasteners to a gusset or other supporting part and should be designed to transmit a force 1,2 times the force in the outstand of the angle connected.
- (2) The fasteners connecting the lug angle to the outstand of the angle member should be designed to transmit a force 1,4 times the force in the outstand of the angle member.
- (3) Lug angles connecting a channel or a similar member should be designed to transmit a force 1,1 times the force in the channel flanges to which they are attached.
- (4) The fasteners connecting the lug angle to the channel or similar member should be designed to transmit a force 1,2 times the force in the channel flange which they connect.
- (5) In no case should less than two bolts or rivets be used to attach a lug angle to a gusset or other supporting part.
- (6) The connection of a lug angle to a gusset plate or other supporting part should terminate at the end of the member connected. The connection of the lug angle to the member should run from the end of the member to a point beyond the direct connection of the member to the gusset or other supporting part.

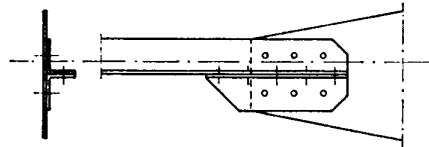


Figure 3.10: Lug angles

3.11 Prying forces

- (1) Where fasteners are required to carry an applied tensile force, they should be designed to resist the additional force due to prying action, where this can occur.

NOTE: The rules given in 6.2.4 implicitly account for prying forces.

3.12 Distribution of forces between fasteners at the ultimate limit state

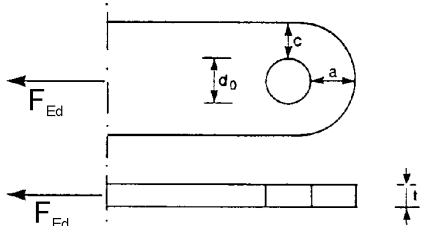
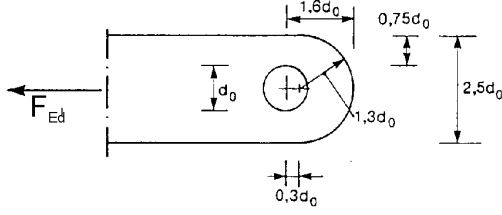
- (1) When a moment is applied to a joint, the distribution of internal forces may be either linear (i.e. proportional to the distance from the centre of rotation) or plastic, (i.e. any distribution that is in equilibrium is acceptable provided that the resistances of the components are not exceeded and the ductility of the components is sufficient).
- (2) The elastic linear distribution of internal forces should be used for the following:
 - when bolts are used creating a category C slip-resistant connection,
 - in shear connections where the design shear resistance $F_{v,Rd}$ of a fastener is less than the design bearing resistance $F_{b,Rd}$,
 - where connections are subjected to impact, vibration or load reversal (except wind loads).
- (3) When a joint is loaded by a concentric shear only, the load may be assumed to be uniformly distributed amongst the fasteners, provided that the size and the class of fasteners is the same.

3.13 Connections made with pins

3.13.1 General

- (1) Wherever there is a risk of pins becoming loose, they should be secured.
- (2) Pin connections in which no rotation is required may be designed as single bolted connections, provided that the length of the pin is less than 3 times the diameter of the pin, see 3.6.1. For all other cases the method given in 3.13.2 should be followed.
- (3) In pin-connected members the geometry of the unstiffened element that contains a hole for the pin should satisfy the dimensional requirements given in Table 3.9.

Table 3.9: Geometrical requirements for pin ended members

<u>Type A:</u>	Given thickness t
 $a \geq \frac{F_{Ed} \gamma_{M0}}{2 t f_y} + \frac{2 d_0}{3} : c \geq \frac{F_{Ed} \gamma_{M0}}{2 t f_y} + \frac{d_0}{3}$	
<u>Type B:</u>	Given geometry
 $t \geq 0,7 \sqrt{\frac{F_{Ed} \gamma_{M0}}{f_y}} : d_0 \leq 2,5 t$	

- (4) Pin connected members should be arranged such to avoid eccentricity and should be of sufficient size to distribute the load from the area of the member with the pin hole into the member away from the pin.

3.13.2 Design of pins

- (1) The design requirements for solid circular pins are given in Table 3.10.
- (2) The moments in a pin should be calculated on the basis that the connected parts form simple supports. It should be generally assumed that the reactions between the pin and the connected parts are uniformly distributed along the length in contact on each part as indicated in Figure 3.11.
- (3) If the pin is intended to be replaceable, in addition to the provisions given in 3.13.1 to 3.13.2, the contact bearing stress should satisfy:

$$\sigma_{h,Ed} \leq f_{h,Rd} \quad \dots (3.14)$$

where:

$$\langle AC2 \rangle \sigma_{h,Ed} = 0,591 \sqrt{\frac{E F_{b,Ed,ser} (d_0 - d)}{d^2 t}} \langle AC2 \rangle \quad \dots (3.15)$$

$$\langle AC2 \rangle f_{h,Rd} = 2,5 f_y / \gamma_{M6,ser} \langle AC2 \rangle \quad \dots (3.16)$$

where:

d is the diameter of the pin;

d_0 is the diameter of the pin hole;

$\langle AC2 \rangle F_{b,Ed,ser} \langle AC2 \rangle$ is the design value of the force to be transferred in bearing, under the characteristic load combination for serviceability limit states.

Table 3.10: Design criteria for pin connections

Failure mode	Design requirements
Shear resistance of the pin	$F_{v,Rd} = 0,6 A f_{up} / \gamma_{M2} \geq F_{v,Ed}$
Bearing resistance of the plate and the pin	$F_{b,Rd} = 1,5 t d f_y / \gamma_{M0} \geq F_{b,Ed}$
If the pin is intended to be replaceable this requirement should also be satisfied.	$F_{b,Rd,ser} = 0,6 t d f_y / \gamma_{M6,ser} \geq F_{b,Ed,ser}$
Bending resistance of the pin	$M_{Rd} = 1,5 W_{el} f_{yp} / \gamma_{M0} \geq M_{Ed}$
If the pin is intended to be replaceable this requirement should also be satisfied.	$M_{Rd,ser} = 0,8 W_{el} f_{yp} / \gamma_{M6,ser} \geq M_{Ed,ser}$
Combined shear and bending resistance of the pin	$\left[\frac{M_{Ed}}{M_{Rd}} \right]^2 + \left[\frac{F_{v,Ed}}{F_{v,Rd}} \right]^2 \leq 1$
d is the diameter of the pin; f_y is $\langle AC2 \rangle$ the lower of the yield strengths $\langle AC2 \rangle$ of the pin and the connected part; f_{up} is the ultimate tensile strength of the pin; f_{yp} is the yield strength of the pin; t is the thickness of the connected part; A is the cross-sectional area of a pin.	

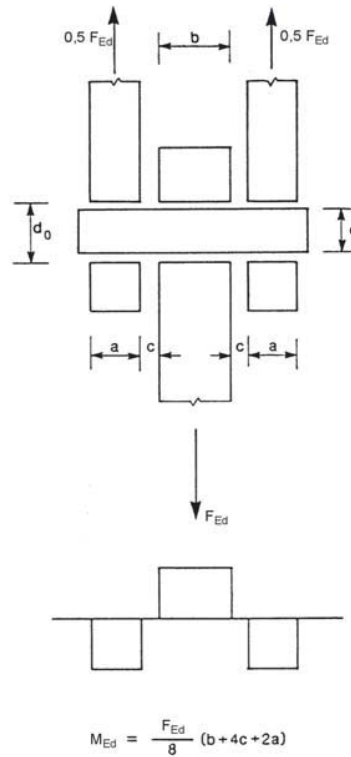


Figure 3.11: Bending moment in a pin

4 Welded connections

4.1 General

- (1) The provisions in this section apply to weldable structural steels conforming to EN 1993-1-1 and to material thicknesses of 4 mm and over. The provisions also apply to joints in which the mechanical properties of the weld metal are compatible with those of the parent metal, see 4.2.

For welds in thinner material reference should be made to EN 1993 part 1.3 and for welds in structural hollow sections in material thicknesses of 2,5 mm and over guidance is given section 7 of this Standard.

For stud welding reference should be made to EN 1994-1-1.

NOTE: Further guidance on stud welding can be found in EN ISO 14555 and EN ISO 13918.

AC1 (2)P Welds subject to fatigue shall also satisfy the principles given in EN 1993-1-9. **AC1**

- (3) Quality level C according to EN ISO 25817 is usually required, if not otherwise specified. The frequency of inspection of welds should be specified in accordance with the rules in 1.2.7 Reference Standards: Group 7. The quality level of welds should be chosen according to EN ISO 25817. For the quality level of welds used in fatigue loaded structures, see EN 1993-1-9.
- (4) Lamellar tearing should be avoided.
- (5) Guidance on lamellar tearing is given in EN 1993-1-10.

4.2 Welding consumables

- (1) All welding consumables should conform to the relevant standards specified in 1.2.5 Reference Standards; Group 5.
- (2) The specified yield strength, ultimate tensile strength, elongation at failure and minimum Charpy V-notch energy value of the filler metal, should be equivalent to, or better than that specified for the parent material.

NOTE: Generally it is safe to use electrodes that are overmatched with regard to the steel grades being used.

4.3 Geometry and dimensions

4.3.1 Type of weld

- (1) This Standard covers the design of fillet welds, fillet welds all round, butt welds, plug welds and flare groove welds. Butt welds may be either full penetration butt welds or partial penetration butt welds. Both fillet welds all round and plug welds may be either in circular holes or in elongated holes.
- (2) The most common types of joints and welds are illustrated in EN 12345.

4.3.2 Fillet welds

4.3.2.1 General

- (1) Fillet welds may be used for connecting parts where the fusion faces form an angle of between 60° and 120°.