Behaviour of connections in steel structures and design of mechanical fasteners and welds according to Eurocode 3

Steel Design 3

# Connections

J.W.B. Stark

Ernst & Sohn
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Behaviour of connections in steel structures and design of mechanical fasteners and welds according to Eurocode 3

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J.W.B. Stark

# Colophon

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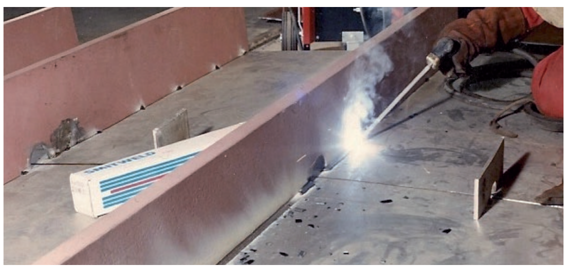
vm cover

# Content


| | | |
|---|---|---|
| **1** | **Connections in steel structures** | **1-2** |
| **1.1** | **The function of connections** | **1-2** |
| **1.2** | **Parts of connections** | **1-4** |
| **1.3** | **Common connections found in buildings** | **1-7** |
| | 1.3.1 Column splice | 1-8 |
| | 1.3.2 Column base connection | 1-8 |
| | 1.3.3 Beam-to-column connection | 1-11 |
| | 1.3.4 Beam-to-beam connection | 1-14 |
| | 1.3.5 Beam splice | 1-15 |
| | 1.3.6 Connection of bracings | 1-17 |
| **1.4** | **Design and detailling** | **1-17** |
| | 1.4.1 Requirements regarding connections | 1-18 |
| | 1.4.2 Cost-conscious design of connections | 1-19 |
| **1.5** | **Standards for connections** | **1-26** |
| | 1.5.1 EN 1993-1-8 | 1-26 |
| | 1.5.2 EN 1090-2 | 1-28 |
| | 1.5.3 Product standards | 1-28 |
| **1.6** | **The role of the computer** | **1-29** |
| **1.7** | **Literature** | **1-32** |
| **2** | **Bolts in clearance holes** | **2-2** |
| **2.1** | **Categories of bolted connections** | **2-3** |
| | 2.1.1 Bolted connections loaded in shear | 2-3 |
| | 2.1.2 Bolted connections loaded in tension | 2-5 |
| **2.2** | **Bolts** | **2-6** |
| | 2.2.1 Product standards | 2-7 |
| | 2.2.2 Screw-thread | 2-8 |
| | 2.2.3 Bolt/nut combinations | 2-8 |
| | 2.2.4 Washers | 2-9 |
| | 2.2.5 Mechanical characteristics | 2-10 |
| | 2.2.6 Hole clearance | 2-12 |
| | 2.2.7 Practical bolt choice | 2-12 |
| **2.3** | **Positioning of bolts** | **2-14** |




**2.4 Resistance of elements with holes** **2-15**

2.4.1 Net cross-section 2-15

2.4.2 Tension resistance of a plate with holes 2-18

2.4.3 Tension resistance of an angle with holes 2-19

2.4.4 Block tearing 2-20

**2.5 Resistance of bolts** **2-23**

2.5.1 Bolts loaded in shear 2-23

2.5.2 Bolts loaded in tension 2-28

2.5.3 Bolts loaded in shear and tension 2-29

2.5.4 Countersunk bolts 2-29

**2.6 Literature** **2-34**

## 3 Slip-resistant connections, rivets and pins 3-2

**3.1 Preloaded bolted connections** **3-3**

3.1.1 Tightening of preloaded bolts 3-3

3.1.2 Preloaded connection loaded in shear 3-6

3.1.3 Preloaded connection loaded in tension 3-12

3.1.4 Preloaded connection loaded in shear and tension 3-15

**3.2 Connections with fit bolts and injection bolts** **3-17**

3.2.1 Fit bolts 3-17

3.2.2 Injection bolts 3-18

**3.3 Rivets** **3-24**

**3.4 Pins** **3-26**

**3.5 Literature** **3-28**

## 4 Welds 4-2

**4.1 Welding processes** **4-2**

4.1.1 Arc welding 4-2

4.1.2 Resistance welding 4-8

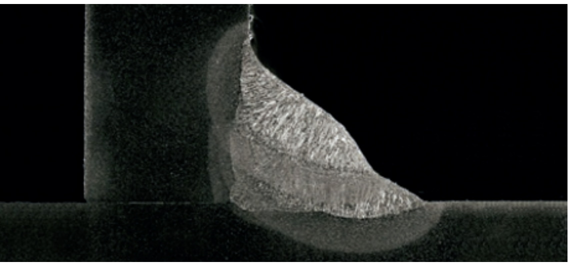
**4.2 Weld shapes** **4-8**

4.2.1 Fillet welds 4-10

4.2.2 Full penetration butt welds 4-11

4.2.3 Partial penetration butt welds 4-14

4.2.4 Plug welds and flare groove welds 4-14




| | | |
|---|---|---|
| **4.3** | **Welding procedures** | **4-15** |
| **4.4** | **Weld quality** | **4-16** |
| 4.4.1 | Welding errors | 4-17 |
| 4.4.2 | Welding inspection | 4-19 |
| **4.5** | **Weld design** | **4-21** |
| 4.5.1 | Fillet welds | 4-21 |
| 4.5.2 | Butt welds | 4-34 |
| **4.6** | **Literature** | **4-35** |
| **5** | **Design and detailing of connections** | **5-2** |
| **5.1** | **Design approach** | **5-2** |
| **5.2** | **Force distribution in connections** | **5-6** |
| 5.2.1 | Influence of relative stiffnesses | 5-6 |
| 5.2.2 | Centre of rotation | 5-9 |
| 5.2.3 | Non-linear distribution of bolt forces | 5-19 |
| 5.2.4 | Force distribution in long connections | 5-20 |
| 5.2.5 | Combination of different types of connections | 5-22 |
| **5.3** | **Transfer of axial compression or tension forces** | **5-23** |
| 5.3.1 | Butt welds | 5-23 |
| 5.3.2 | Plates | 5-24 |
| 5.3.3 | Gusset plates | 5-30 |
| **5.4** | **Transfer of shear forces** | **5-51** |
| **5.5** | **Introduction of tension forces** | **5-56** |
| 5.5.1 | Welded connections | 5-56 |
| 5.5.2 | Bolted connections and prying forces | 5-60 |
| **5.6** | **Transfer of compression forces** | **5-65** |
| **5.7** | **Transfer of shear forces** | **5-66** |
| **5.8** | **Literature** | **5-67** |



# Structural basics

## Steel Design 1

### CONTENT


1 Structural safety
2 Actions and deformations
3 Modelling
4 Analysis
5 Analysis methods
6 Assessment by code checking
7 Resistance of cross-sections


H.H. Snijder and H.M.G.M. Steenbergen, *Structural basics. Analysis and design of steel structures for buildings according to Eurocode 0, 1 and 3* (Steel Design 1), published by Bouwen met Staal, Zoetermeer 2019, ISBN 979-90-72830-98-2, format 23x25 cm, 272 p.
Also available as e-book at Wiley / Ernst & Sohn, at: www.ernst-und-sohn.de/en/steel-design.


# Fire

## Steel Design 2

### CONTENT


1 Fire safety
2 Calculation of the fire resistance
3 Fire safety engineering
4 Design tables


A.F. Hamerlinck, *Fire safety and fire resistant design of steel structures for buildings according to Eurocode 3* (Steel Design 2), published by Bouwen met Staal, Zoetermeer 2021, ISBN 979-90-75146-04-2, format 23x25 cm, 164 p.
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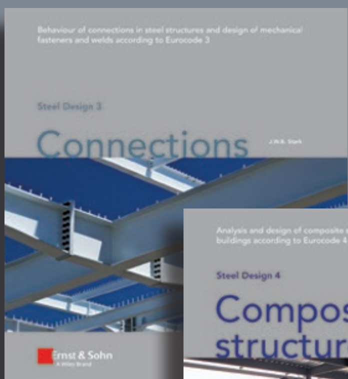


Steel Design 3


Steel Design 4


Steel Design 5

Education and high quality textbooks are crucial to developing an interest in steel structures and their benefits for clients, architects and designers. However, despite the need to inspire the industry's next generation, many textbooks on steel structures are commissioned on a low budget, resulting in material that lacks imagination and tends to feature, at best, moderate illustrations. These textbooks are usually intended for high school and university level students, as well as designers who are not yet specialised in steel and steel construction. Therefore, it is vital that lecturers have access to up-to-date books that offer clear and concise explanations, while inspiring readers about the possibilities of steel through beautiful graphics and images. Steel Design is a set of English textbooks translated from the original Dutch that are based on the EN version of Eurocode with differences in nationally defined parameters included in an annex. These textbooks are intended for high-school and university level students. The content is applicable to designers who are not specialised in steel and steel construction.

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worldsteel has supported the development of study material related to steel in construction since 2018. This allows future architects and designers to take advantage of steel products and their features that support designs that meet the circular economy principles.

A separate opt-in programme has been developed called 'constructsteel.org' and is able to be joined by steel producers and construction industry related organisations upon application. This programme focusses on the construction market sector exclusively to promote steel and steel products. Please see www.worldsteel.org and www.constructsteel.org for further details about the steel industry and specifically the construction market.

# Connections

1

## Connections in steel structures

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# 1 Connections in steel structures

A steel structure cannot exist without bolted and welded connections between the elements of the steel structure itself or with other materials or components. This chapter discusses the role of connections in steel structures, identifies the various components, and provides examples of the most common connections in buildings. Thereafter, important aspects of the design and the detailing are discussed in general. An overview is given of the most important codes and regulations for connections in steel. Finally, the role of the computer within the design of steel structures will be discussed.

NA In general, the term 'connection' is used for the location at which two or more structural elements (like plates and sections) meet and are connected (e.g. by bolting or welding). The focus is on the transfer of the relevant internal forces and moments at the connection.
The term 'joint' is generally used for the zone where two or more structural members (like beams and columns) are interconnected. The focus is on the structural properties (like resistance, stiffness, and rotation capacity).

## 1.1 The function of connections

Steel structures usually comprise sections and plates that are processed and assembled into structural parts in a fabrication shop, for example, a truss or a part of a bridge deck. The dimensions of these elements are limited, because they usually have to be transported and, subsequently,

1.1 Use of large parts on the construction site.

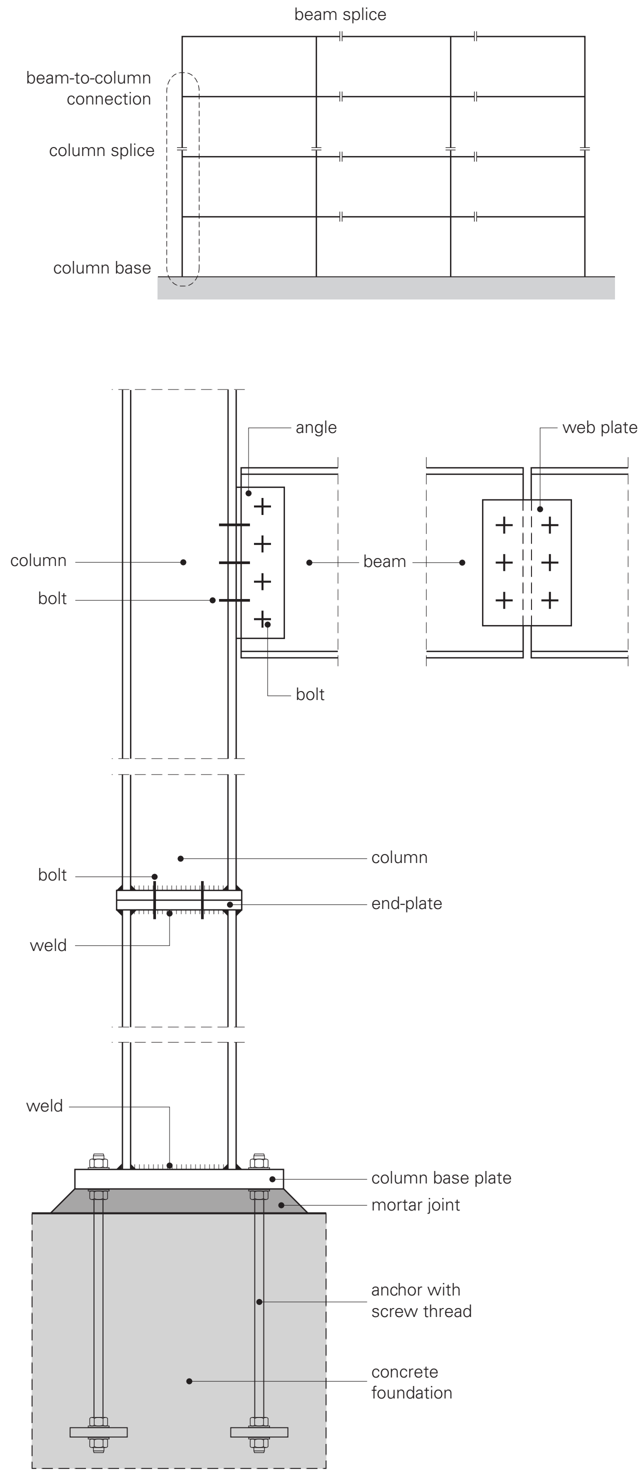
assembled (with a crane). The maximum dimensions depend on the capacity of the steel fabricator, the corrosion protection, the storage options, the method and route of transport to the construction site, and the capacity of the crane. In general, it is desirable to aim for the largest possible elements. This results in a reduced number of connections on site (fig. 1.1), where the elements are assembled to form the steel structure. So, the steel structure contains connections that are manufactured in the fabrication shop as well as on site. The conditions under which these two types of connections are made strongly vary and this should be taken into account when designing the connections.

Generally the number of connections in a steel structure is rather large. They are needed in the following situations.

– When structural elements meet from different directions. For instance, this is the case for connections between beams and columns, secondary and primary beams, and members in a truss.
– Connections on site are needed in order to limit the dimensions of the components considering transport, storage, and assembly. As an example: the columns in a building may contain a splice every two or three storeys. When elements are galvanized thermally, the length of the galvanizing bath must be considered. For example, the maximum length of a galvanizing bath in a European galvanizing plant is approximately 15 m.
– When the steel structure has to be connected to structural elements formed from other materials, or connections between different types of steel element. For example, the connection of a steel column to a concrete foundation, the connection of a steel beam to a concrete body such as a lift core, or the connection of steel sheeting to steel trusses;
– When the cross-section of a component changes, for example when the column size reduces at higher stories.

Figure 1.2 shows an example of a steel frame containing four storeys, in which the first three situations apply.

Connections are an important part of any steel structure. The structural properties of the connection affect the strength, stiffness, and stability of the complete steel structure. The number and complexity of connections have a decisive influence on the effort - and therefore, on the cost – that is needed to carry out the design calculations and produce construction drawings. Also, the manufacturing and assembly costs significantly depend on the chosen connection type.




1.2 Locations in a framework where connections are necessary.

## 1.2 Parts of connections

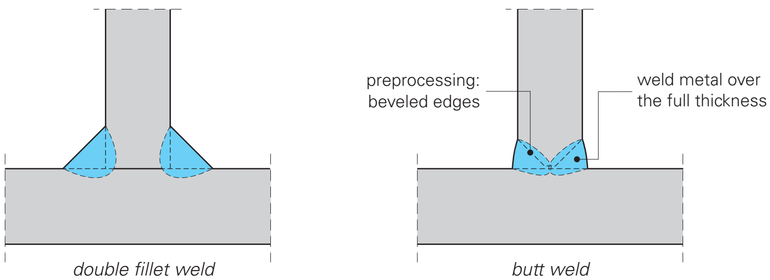
Welds and bolts are most commonly used for the connections in a steel structure. For buildings, welding is used in a workshop to create structural elements that are as large as possible. At the construction site the connections between these welded components are often realized with bolts. For bridges, both welded and bolted connections are used on site. For more detailed information on bolted and welded connections see *Connections 2* (Bolts in clearance holes), *Connections 3* (Slip-resistant connections, rivets, and pins), and *Connections 4* (Welds). Other components are often necessary to transfer the forces in a connection, such as angles, end-plates, or local stiffeners. These components are also part of the connection.

### *Welds*

In a welded joint, either fillet welds or butt welds may be used (fig. 1.3). For connections in a statically loaded building structure fillet welds are often chosen, especially when cost is important. These welds require no, or simple, preprocessing, whereas the weld edges for butt welds must be preprocessed (beveled). Additionally, butt welds require a more accurate fit during assembly. However, for connections between thick plates, the smaller weld content of butt welds can outweight the higher costs of the preprocessing.

Although welding on site is technically feasible, the costs are relatively high for the following reasons (see section 1.4.1):

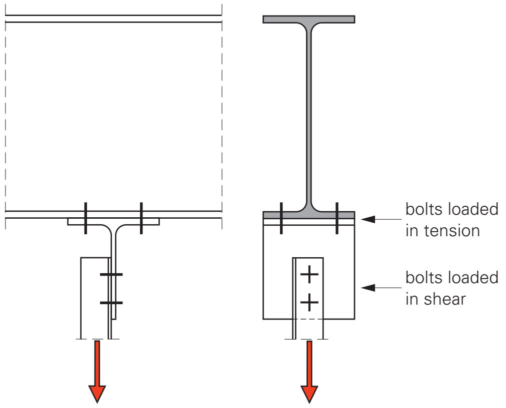
– temporary facilities, such as scaffolding and welding tents, are needed to create a suitable weld location that is safely accessible;
– a power source must be available at the location of the connection;
– bolts are often necessary in order to connect elements temporarily;
– inspections costs for the welded work;
– additional costs for repair of the conservation.



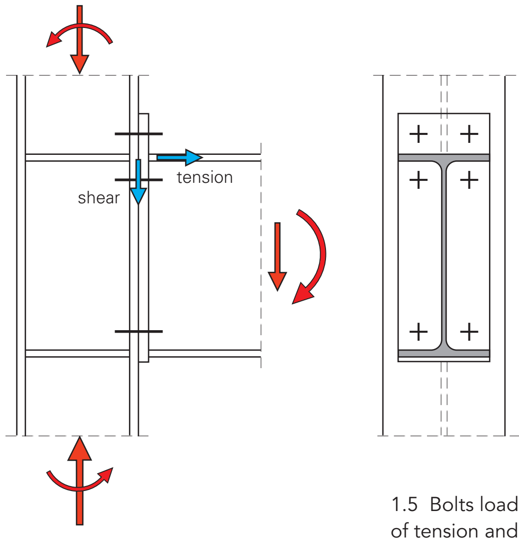

1.3 Fillet weld and butt weld.

### *Bolts*

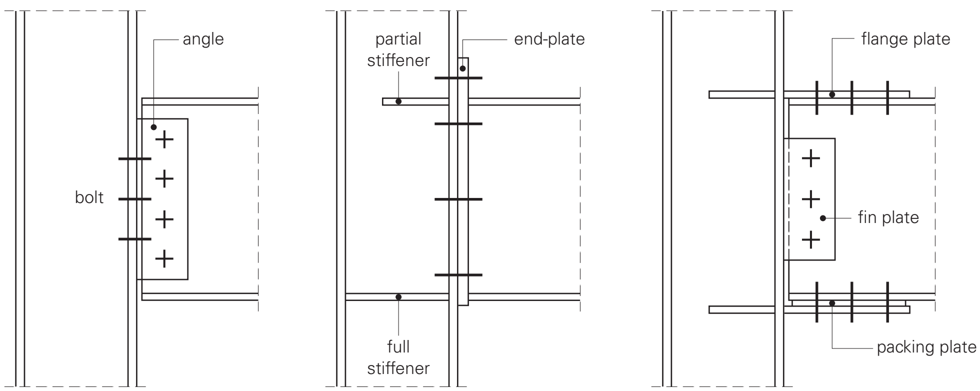
Connections in building structures assembled on site are often executed as bolted connections. Rationalizing the choice of bolt to one type (strength) is preferred, namely 8.8 bolts, in large clearance holes and hand-tight tightened, see *Connections 2*, section 2.2. The bolts are loaded in either tension or shear (fig. 1.4), or in a combination of tension and shear (fig. 1.5), depending on the loading, the type of connection, and the location of the bolts. A small amount of movement will occur between the elements due to movement of the bolts in the clearance in the holes under loading. When this movement of the bolts, together with the displacement of the connection is not allowed – for instance, because the resulting deformations are not acceptable – then a slip-resistant connection with preloaded bolts, fitting bolts, or injection bolts can be chosen. Such situations are covered in *Connections 3*, section 3.1 and 3.2. The use of slip resistant connections should be avoided as much as possible in statically loaded structures. Special treatment of the contact surfaces, and the checks that are needed to confirm whether the bolts are preloaded adequately, are expensive. In addition to the bolts themselves other components are often needed to transfer forces in a bolted connection, such as plates (stiffeners) or parts of steel sections. Figure 1.6 shows several examples of these elements in a beam-to-column connection.




1.4 Bolts loaded in tension or shear.




1.5 Bolts loaded in combination of tension and shear.




*angles*

(bolted to the web of the beam and to the flange of the column)

*end-plate*

(welded to the beam and bolted to the flange of the column)

*flange plates with fin plate*

(flange plates: welded to the flange of the column and bolted to the flange of the beam fin plate: welded to the flange of the column and bolted to the web of the beam)

1.6 Parts of bolted beam-to-column connections.

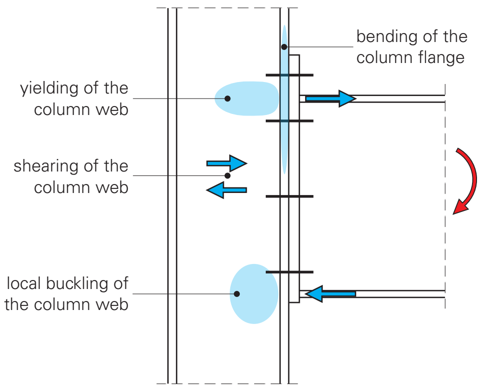
### *Other connection means*

As an alternative to welds and bolts, rivets or pins are sometimes used for connections in steel structures, see *Connections 3*, section 3.3 and 3.4. Pins are mainly used in hinged connections or structures that must be disassembled easily. Rivets are used for renovation and maintenance of historic steel structures, build before 1940.

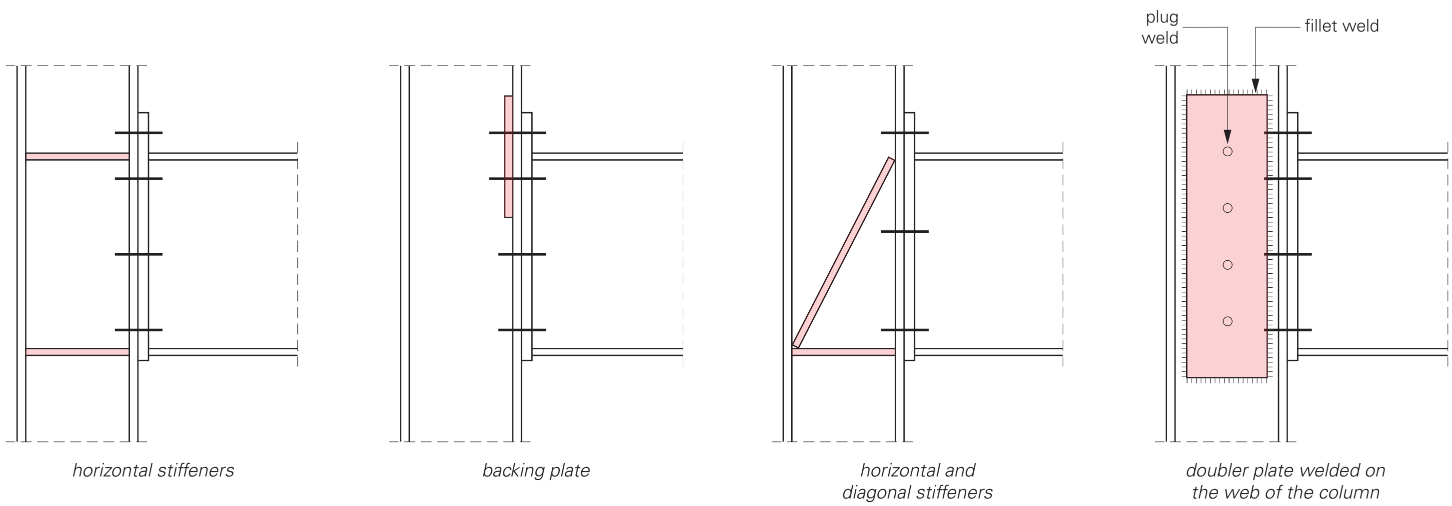
To connect cold formed sections and thin sheets, for example roof and facade claddings, special screws, rivets and nails are used.

### *Local reinforcements*

Sometimes it is necessary to reinforce the connected sections locally so they can transfer concentrated forces in the connection. Figure 1.7 shows an example of a beam-to-column connection, with the possible local failure modes of the column. Depending on the dimensions and the yield strength of the column flange and column web, it might be necessary to reinforce the flange and/or web locally or support it to prevent premature local failure of the column. Figure 1.8 shows a number of structural solutions that can be used to prevent local failure, for instance horizontal and diagonal stiffeners, application of a column flange backing plate, and column web doubler plates. Before choosing any one of these types of reinforcement, the structural designer should check whether it may be more economic to reconfigure the frame so that a smaller bending moment capacity of the connection is acceptable, or to choose heavier section(s).




1.7 Possible local failure modes in a non-stiffened beam-to-column connection.



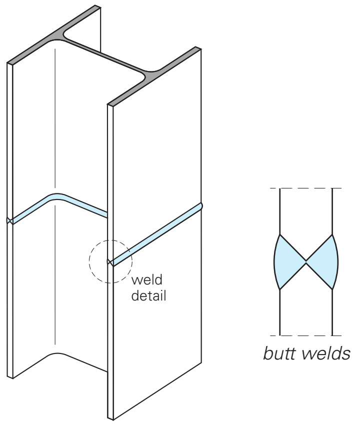

1.8 Possible types of stiffening of a beam-to-column connection.

## 1.3 Common connections found in buildings

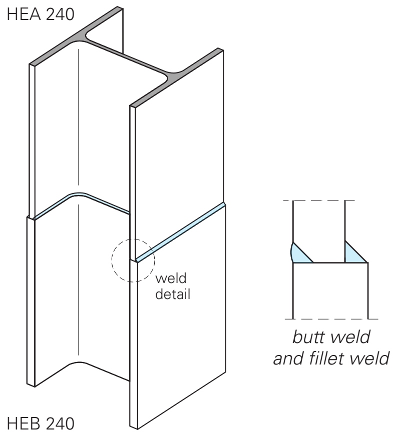
In a steel building structure, the following types of connection can occur, see also figure 1.2:
– column splice;
– column base;
– beam-to-column connection;
– beam-to-beam connection;
– beam splice;
– connection of bracings.

In addition, connections can occur 'within' beams and columns, for example a beam executed as a truss, or a build-up column.
Connections (and joints) must meet the requirements of EN 1993, which relates to the structural characteristics of strength, stiffness and deformation capacity. In addition, when choosing and designing a connection, the structural designer should pay attention to costs, aspects of manufacturing and assembly, and usability, see section 1.4.
Satisfying these requirements and conditions does not lead to unique solutions for detailing. The choice of the most appropriate type of connection also depends on the judgement and experience of the structural designer and which requirements are most relevant for a given situation. The choice of the type of connection is also influenced by the configuration of the fabrication shop that will produce the steel structure. Therefore, the detailing should preferably be decided by close collaboration between the designer and the steel fabricator. For these reasons, it is impossible to present a complete overview of all possible connections: each situation is different. However, due to the countless possibilities that are available when designing in steel, the designer is always able to find a suitable detail. To give an idea of the possibilities, this paragraph presents the most common types of connections. Professional journals and magazines – such as *Bouwen met Staal* (The Netherlands), *Info_Steel* (Belgium/Luxembourg), *Revue Construction Métallique* (France), *Stahlbau* (Germany), *Steel Construction* (international) and *Steeldoc* (Switserland) – regularly publish case studies of projects, where the chosen connections are shown in detail. It is also instructive to look at the joints in steel structures in buildings that are under construction, and in finished buildings.

The assumptions considered in the frame design calculations must always be reflected in the design of the connections and their associated mechanical properties, such as the rotational stiffness. Take for example a beam to beam connection, in a frame where it has been assumed that the secondary beams are restrained by the primary beams against lateral torsional buckling. This may mean that the connection between the secondary beam and the primary beam should prevent rotation along the longitudinal axis of the beam (twist). The properties of the beam to beam connection, achieved through its detailing, must be consistent with this assumption. When this is not the case, lateral torsional buckling of the secondary beams must be prevented in another way, for example by restraining the compression flange against side-ways movement using floor or roof plates.




1.9 Column splice between identical sections.



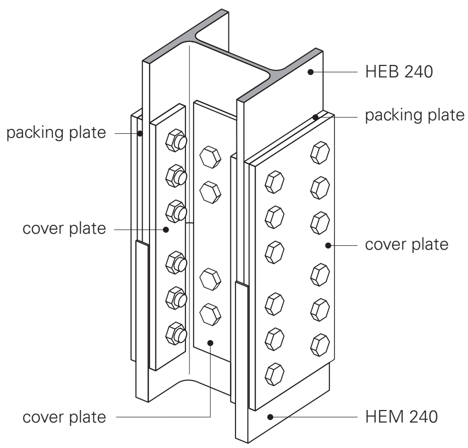

1.10 Column splice between two column parts with a different cross-section.

### 1.3.1 Column splice

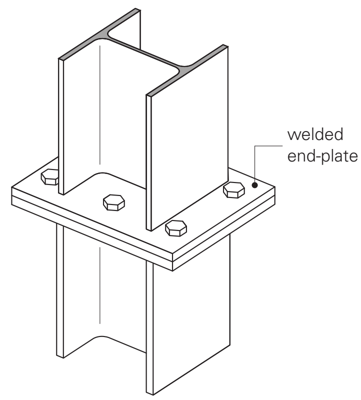
A column splice is a connection between two lengths of column, in the longitudinal direction. The simplest splice connection is a welded splice, in which the column ends are welded directly ('cold') against each other (fig. 1.9). A column splice is also possible when the two columns have a different size, provided the web and flanges are sitting above each other (fig. 1.10). When such a connection is to be used as part of a frame assembly on site, the connection will need to be temporary fixed with, for example, two strips until the connection is welded.
In a bolted splice connection where the column ends are placed directly ('cold') against each other – depending on the preloading of the contact surfaces – the forces are either fully or partially transferred by cover plates. In the case of two column parts with a different cross-section – or when there are dimensional variations (rolling tolerances) between the two parts – packing plates must be applied between the flanges and cover plates (fig. 1.11). Such a connection avoids the need for welding on site, but due to its greater size it is sometimes not desired. The connection requires more space locally and is visually less attractive.
Often, a bolted column splice with welded end-plates is used (fig. 1.12). It should be noted that the end-plates can deform during welding. In tender specifications it is sometimes stated that contact surfaces must be milled flat after welding, although structurally this is unnecessary and in the case of preloaded connections, deformed end-plates are even more favorable, see *Connections 3* (Slip-resistant connections, rivets, and pins), section 3.1.3.

### 1.3.2 Column base connection

Generally, a column base consists of a base plate – which may be stiffened with welded plates – and an anchorage to the foundations. The dimensions of the base plate must be such that the



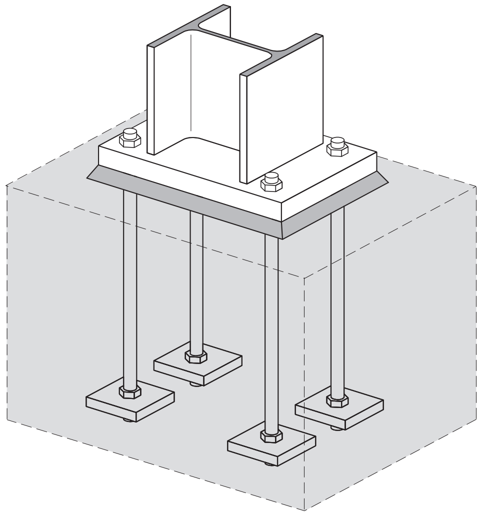

1.11 Column splice with cover plates and packing plates.




1.12 Column splice with welded end-plates.

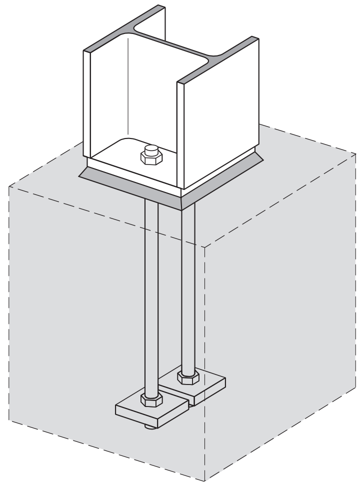
compression force in the steel column is sufficiently spread over the (less strong) concrete of the foundation or substructure. In the case of columns that are loaded eccentrically or in tension, the base plate must also be able to transfer the tension forces to the anchors.
A space must be left between the underside of the base plate and the top of the foundations. This space is needed to allow for adjustments to accommodate dimensional tolerances in both the steel structure and the concrete substructure. After the steel structure has been erected the space is filled with a non-shrink mortar or grout. The two common methods for placing columns are:

- *With adjustable nuts under the base plate*. With this method, four anchors are required in order to align the column in two directions. According to EN 1090-2, cl. 9.5.4 the adjustable nuts do not need to be turned back unless this is explicitly specified otherwise. When preloaded anchors are used, turn back of the adjustable nuts is necessary, because these nuts would otherwise prevent the anchor from being preloaded over a sufficient length.
- *With wedges*. The wedges are removed after pouring and hardening of the grout under the base plate.

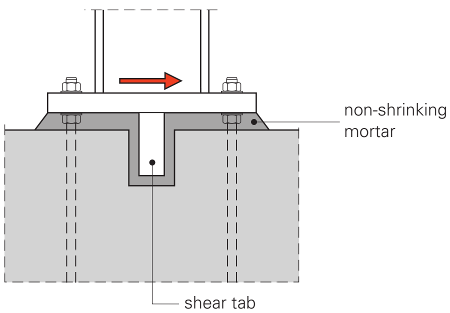


1.13 Column base connection with four anchors.

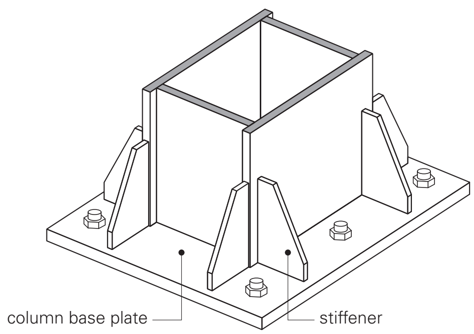
Figure 1.13 shows a column base connection with four anchors. In addition to shear forces and normal forces, this connection can transfer bending moments. When the anchors do not need to transfer bending moments, one can choose a base plate that does not extend outside the column and only uses two anchors (fig. 1.14). Since in this case alignment using the adjusting nuts is only possible in one direction, this solution is discouraged because of execution considerations. However, small columns and 'architectural steel' may be exceptions.
Shear forces can be transferred by friction and through the anchors. In the case of large shear forces, it may be necessary to weld a shear tab (or dowel) to the bottom side of the base plate that is then located in a recess in the concrete. The space between the shear tab and the base plate and the concrete must be filled with a non-shrinking mortar. A shear tab can consist of a solid steel strip or a short piece of a steel section (fig. 1.15). Figure 1.16 shows a column base connection with welded stiffeners. This solution should be avoided. Using a thicker base plate without stiffeners is preferable because, despite higher material costs, a thicker base plate without stiffeners is always cheaper than a thin plate with stiffeners.



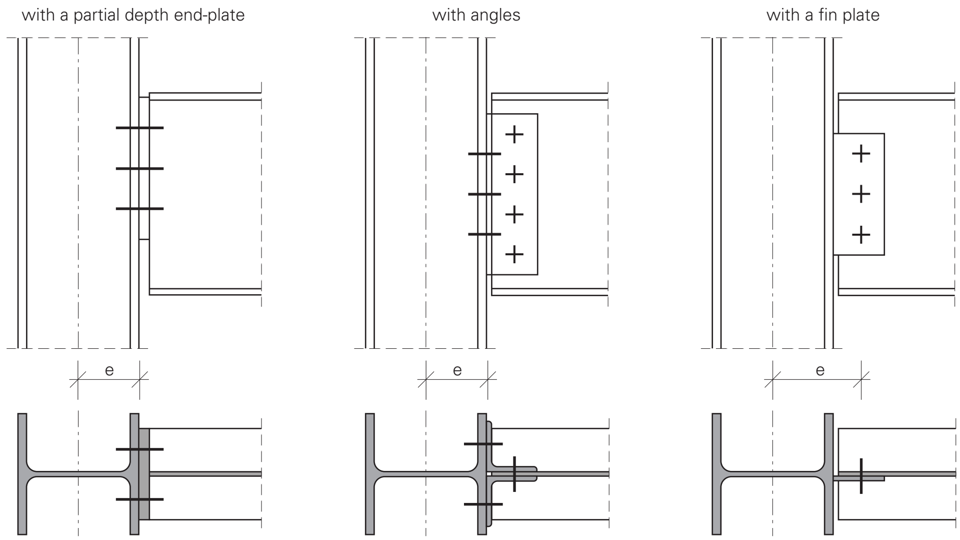
1.14 Flush base plate with two anchors.



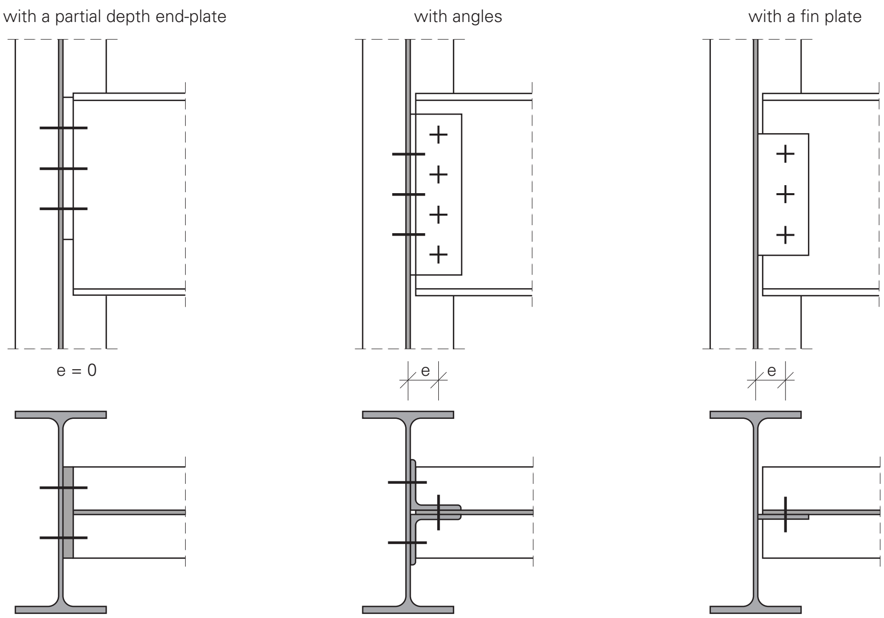

1.15 Shear-tab to transfer large horizontal forces.




1.16 Base plate connection with stiffeners.




*beam connected to the flange of the column: (top) elevation and (bottom) plan*




*beam connected to the web of the column: (top) elevation and (bottom) plan*

1.17 Connections for transferring shear and/or normal forces between beams and columns.