

11 COLD-FORMED CONNECTIONS

11.1 Connections

A variety of joining methods is available for thin-walled structures. In comparison with thicker connections ($t > 3 \text{ mm}$) the behaviour of connections in thin-walled elements is characterised by the small plates stiffness [Davies, 1991]. Therefore, additional effects may appear in the ultimate limit state and serviceability state and the level of safety may be more depend on the quality control. Such effects are, for example, the tilting of the fastener in hole bearing failure or the big distortion of the sheet when the fastener is loaded in tension and the sheet is pulled over the head of the fastener. This is the reason why design procedures for connections in cold-formed elements have been developed which are, in a number of cases, different from the procedures for thicker steel. Connections to thin walled members are used for:

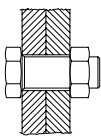
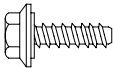
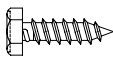
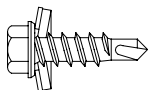

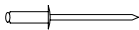
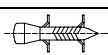
- connecting steel sheets to the supporting structure, e.g. to a purlin;
- interconnecting two or more sheets, e.g. longitudinal seams of sheets;
- assemble linear cold-formed sections, e.g. in storage racking.

11.2 Fastenings

For thin-walled constructions three types of fastenings can be identified [Toma et al, 1993] and [Yu, 2000]:

- fastenings with mechanical fasteners;
- fastenings based on welding;
- fastenings based on adhesive bonding.

Table 11.1 Global survey of application field for mechanical fasteners

Thin to thick	Steel to wood	Thin to thin	Fastener	Remark
X		X		Bolts M5-M16
X				Self-tapping screw $\phi 6,3$ with washer $\geq 16 \text{ mm}$, 1 mm thick with elastomer
	X	X		Hexagon head screw $\phi 6,3$ or $6,5$ with washer $\geq 16 \text{ mm}$, 1 mm thick with elastomer
X		X		Self-drilling screws with diameters: $\phi 4,22$ or $4,8 \text{ mm}$ $\phi 5,5 \text{ mm}$ $\phi 6,3 \text{ mm}$
X				Thread-cutting screw $\phi 8 \text{ mm}$ with washer $\geq 16 \text{ mm}$, 1 mm thick with or without elastomer
				Blind rivets with diameters: $\phi 4,0 \text{ mm}$ $\phi 4,8 \text{ mm}$ $\phi 6,4 \text{ mm}$
X				Shot pins

Mechanical fasteners

Table 1 shows a global field of application of the different mechanical fasteners according to Toma [Toma et al, 1993]. In the following part some short information is given concerning the different mechanical fasteners. Bolts with nuts are threaded fasteners, which are assembled in preformed holes through the material elements to be joined [Hancock, 1998]. Thin members will necessitate the use of bolts threaded close to the head [Wong, Chung, 2002]. For thin-walled sections the bolt diameter is usually M5-M16. The preferred property classes are 8.8 or 10.9. Results of tests indicate that the following four basic types of failure usually occur [Fan, 1995] in the cold-formed steel bolted connections:

- longitudinal shearing of the sheet along two parallel lines, see Figure 11.1a;
- bearing or piling up of material in front of the bolt, see Figure 11.1b;
- tearing of the sheet in the net section, see Figure 11.1c;
- shearing of the bolt, see Figure 11.1d.

In many cases, a joint is subject to a combination of different types of failure. The tearing of the sheet is often caused by the excessive bolt rotation and dishing of the sheet material. Screws can provide a rapid and effective means to fasten sheet metal siding and roofing to framing members and to make joints in siding and roofing, as shown in Figure 11.2. They can also be used in steel framing systems and roof trusses and to fasten drywall panels to metal channels and runners. Two main types of screws can be distinguished:

- self tapping screws, i.e. thread-forming screws and thread-cutting screws,
- self-drilling screws.

Most of the screws will be combined with washers to improve the load-bearing capacity of the fastening and/or to make the fastening self-sealing. Some types have plastic heads or plastic caps are available for additional corrosion resistance and colour matching.

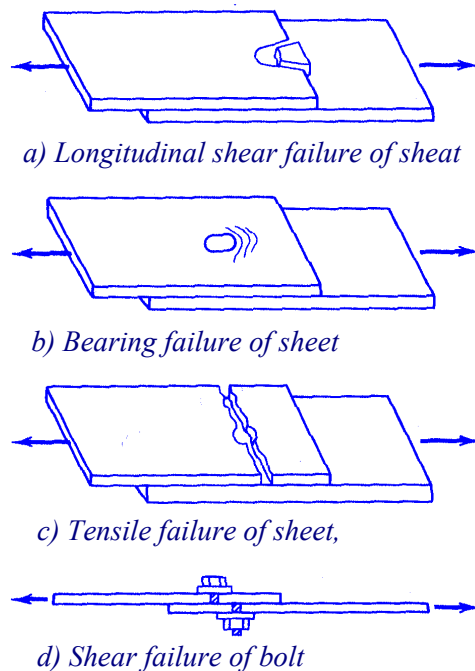


Figure 11.1 Failures of bolted connections

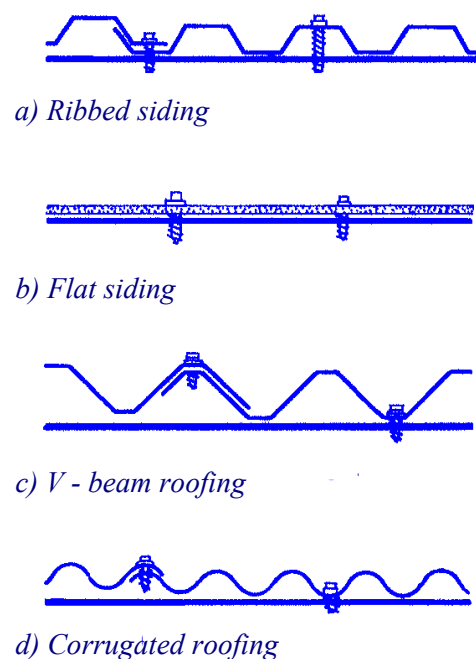


Figure 11.2 Application of self-tapping screws

Figure 11.3 shows the thread types for thread-forming screws. Type A is used for fastening thin-to-thin sheets. Type B is used for fixings to steel base of a thickness greater than 2 mm. Type C is usually used for fixings to thin steel bases of a thickness up to 4 mm. Thread-forming screws normally are fabricated from carbon steel (plated with zinc and lubricant).

Figure 11.4 shows some examples of thread and point of thread-cutting screws. Thread-cutting screws are used for fastening to thicker metal bases. Self-drilling screws drill their own hole and form their mating thread in one operation. Figure 11.5 shows two examples of self-drilling screws.

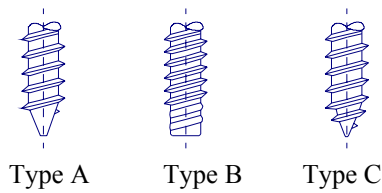


Figure 11.3

Thread types for thread-forming screws

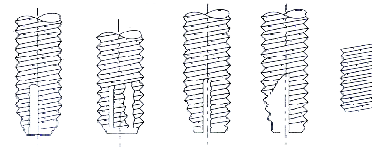


Figure 11.4

Thread and point of thread-cutting screws

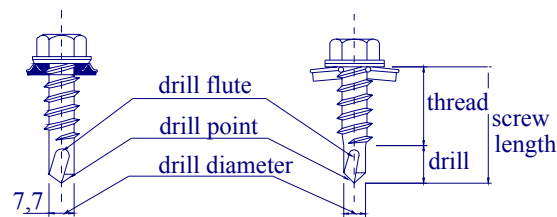


Figure 11.5 Examples of self-drilling screws

Blind rivets and tubular rivets are often used in cold-formed steel construction [Kaitila et al, 2001]. They are used to simplify assembly, improve appearance, and reduce the cost of connection. A blind rivet is a mechanical fastener capable of joining work pieces together where access to the assembly is limited to one side only. Based on the method of setting, blind rivets can be classified into

- pull-stem rivets, see Figure 11.6;
- explosive rivets (with a chemical charge in the body, which is expanded by applying heat to the rivet head),
- drive-pin rivets (two-piece rivets, which consist of a rivet body and a separate pin installed from the head side of the rivet).

Tubular rivets are often used to fasten sheet metal. The strength in shear or compression is comparable to that of solid rivets. Nominal body diameters range from 0,8 to 7,9 mm. The corresponding minimum lengths range from 0,8 to 6,4 mm.

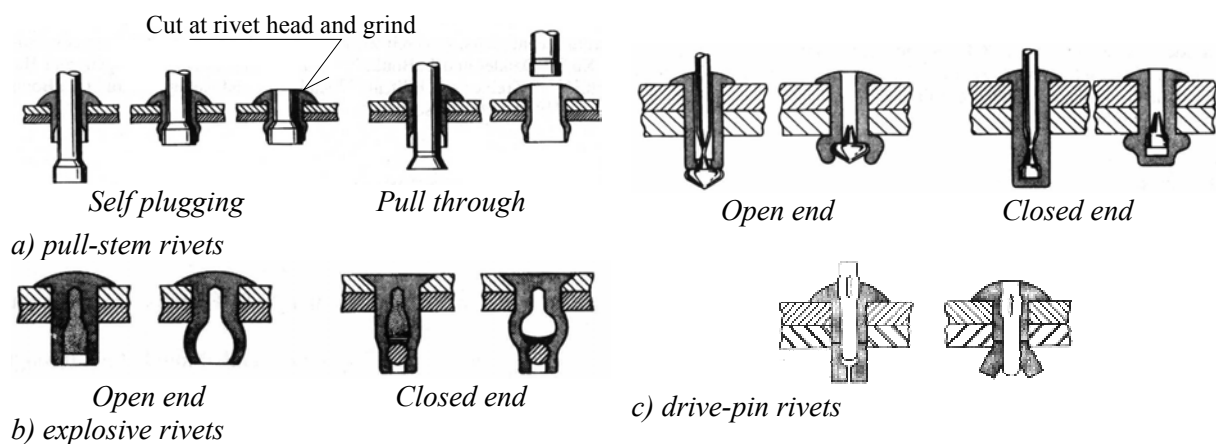


Figure 11.6 Blind rivets

Shot pins, examples are shown in Figure 11.7, are fasteners driven through the connecting plate into the base metal by powder shot or by air.

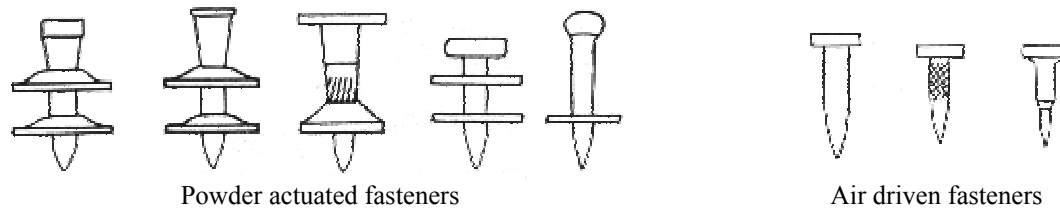


Figure 11.7 Shot pins

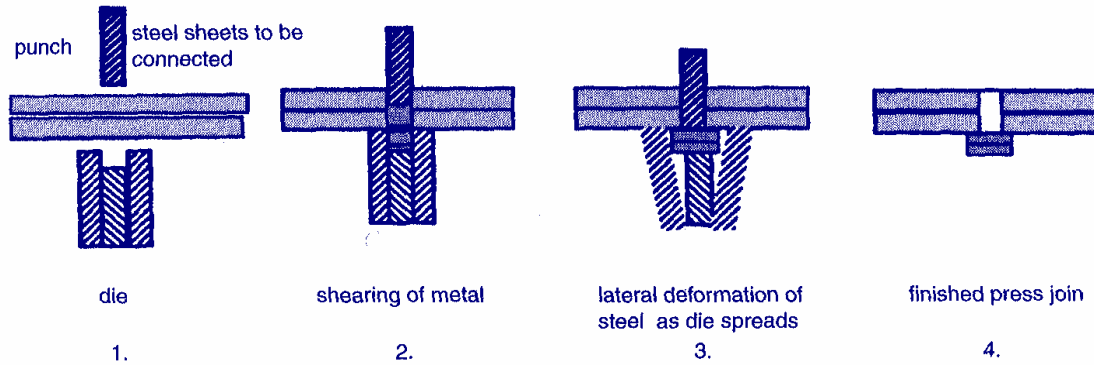


Figure 11.8 Sequence of forming press-joint

Press joining is a relatively new technique for joining cold-formed steel sections. The joint is formed using the parent metal of the sections to be connected [Kolari K., 1999]. The tools used to form a press-joint consist of a male and female punch and die. Figure 11.8 shows the sequence of forming a press-joint.

Rosette-joining, see Figure 11.9, is also a new automated approach for fabricating cold-formed steel components such as stud wall panels and roof trusses. It is formed in pairs between prefabricated holes in one jointed part and collared holes in the other part. The joining process is shown in Figure 11.9.

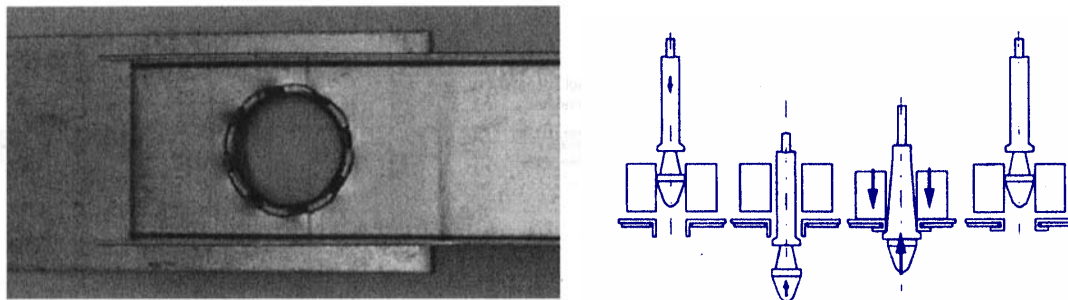


Figure 11.9 Rosette-joint and rosette-joining process [Makelainen et al, 1999]

Welding

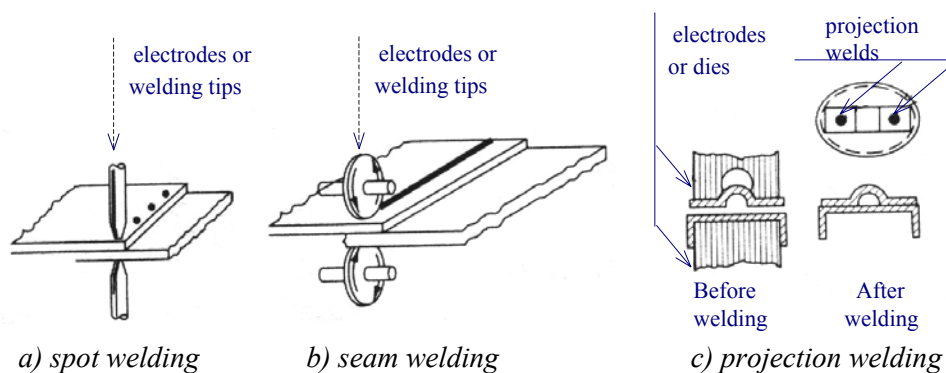
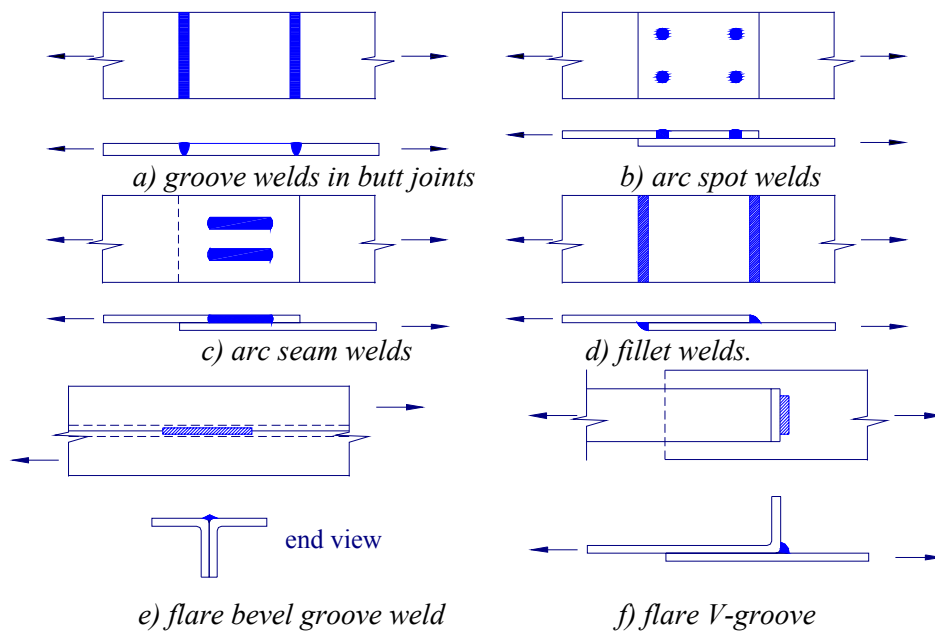
Cold-formed sections joints can be made by the open arc process as well as by resistance welding. The following welding procedures are used for thin-walled sections, see [Toma et al, 1993]:

- GMA – welding (gas metal arc welding),
- manual arc welding (welding with covered electrodes),
- TIG welding (tungsten-inert gas welding),
- plasma welding.

The following types of arc welds are generally used in cold-formed steel constructions, see Figure 11.10 [Yu, 2000]:

- groove welds,
- arc spot welds (puddle welds),
- arc seam welds,
- fillet welds,
- flare groove welds.

Resistance welding is done without open arc. In contrary to the open arc welding process there is no need of protection of the molten metal by shielding gas slag. Figure 11.11 demonstrates the resistance welding procedures.



Adhesive bonding

For fastening by means of bonding it is important to realise that a bonded connection possesses a good shear resistance and mostly a bad peeling resistance, see Figure 11.12. For that reason a combination of bonding and mechanical fastening may be chosen. Adhesives used for thin walled steels are as follows:

- epoxy adhesive types – best hardening will appear under elevated temperature (order of magnitude 80-120°C);
- acrylic adhesive types – more flexible than the epoxy types.

Advantages of bonded connections are a uniform distribution of forces over the connection and a good repeated load behaviour. Some disadvantages are that the surface should be flat and clear and there is a hardening time.

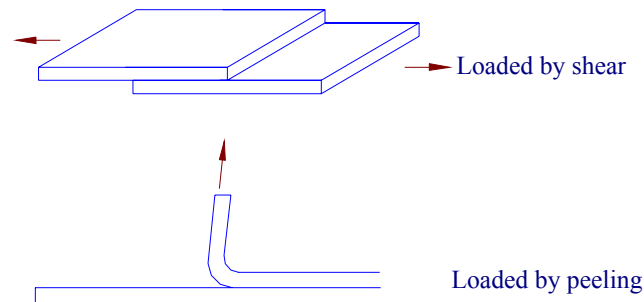


Figure 11.12 Shear and peeling of connections by means of adhesive bonding

11.3 Design considerations

Design considerations for cold-formed members are specified in Chapter 8 of standard prEN 1993-1-3 [prEN 1993-1-3, 2003]. Concerning the Mechanical fastenings, it has to underline that bearing resistance, shearing resistance, tension resistance and net section resistance of connected members are calculated in the same way as for thick sections, for any type of connector. There are differences at the numerical coefficients from formulas, which are specified by the standard. Specific failure modes are checked for the pull through and pull out resistance. Connections with mechanical fasteners are treated in paragraph 8.4 of the norm like blind rivets (Table 8.1), self-tapping screws (Table 8.2), cartridge fired pins (Table 8.3) and bolts (Table 8.4). Concerning the welded connections, spot welds represent a fastening technology, which is specific for thin walled metal structures and specific design provisions have been developed. They are specified in Eurocode 3-1-3. Design resistances for spot welds connections are given in paragraph 8.5, Table 8.5, while for lap welds in paragraph 8.6, with fillet welds in (8.6.2) and arc spot welds in (8.6.3), respectively. Specifications for connections based on adhesive bonding are included in the standard for aluminium structures ENV 1999-1. Special mechanical connections, press- and rosette-joints are in the same situation and they have to be treated in the same way as the previous ones. When design by testing is used, provisions of ENV 1993-1-3, Chapter 9 and Annex Z of ENV 1993-1-3 has to be used.

Q&A 11.1 Increased Yield Strength by Cold-Forming

Can the increase in yield strength due to cold working be utilized in the design of connections that are welded after the member is formed?

In the design formula for the weld strength in prEN 1993-1-3, however, the strength parameter for the material is the ultimate strength f_u of the plate material, which is not influenced by cold forming. It is noted that due to the heat input during welding, the increased yield strength near the welds disappears, which means that at those cross sections no positive effect of the cold forming is allowed to be taken into account.

Q&A 11.2 Deformation Capacity of Shear Connections

Why is the limit $F_{y,Rd} \geq 1,2 F_{u,Rd}$ in the standard prEN 1993-1-3?

This question refers to prEN 1993-1-3, Table Design resistance for self-tapping screws. The design criterion for shear deformation capacity of connection is expressed as:

$$F_{V,Rd} \geq 1,2 F_{n,Rd} \quad (11.1)$$

where $F_{V,Rd}$ is the shear resistance, see Figure 11.1, or evaluated by testing and

$$F_{n,Rd} = \frac{A_{net} f_u}{\gamma_{M2}} \quad (11.2)$$

is the net section resistance.

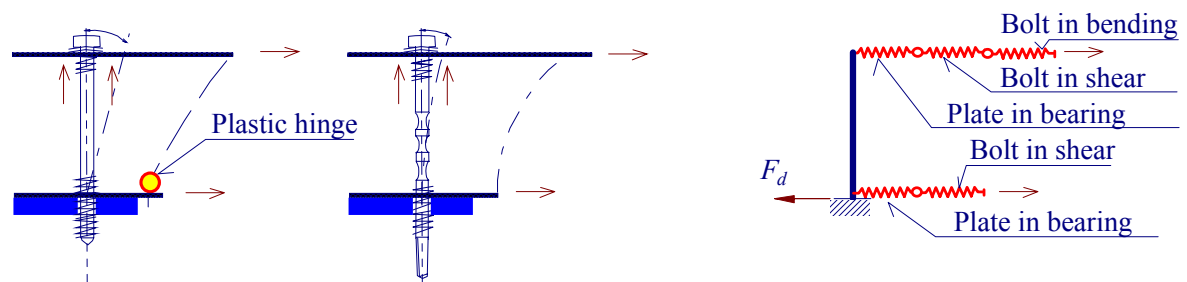
The multiplier 1,2 in formula (11.1) is to ascertain that the failure mode of the connection is bearing or net section failure and not failure of the screw. Failure of the screw gives brittle behaviour of the connection, because of the small deformation capacity of the screw in shear [LaBoube, Yu, 1999].

The factor 1,2 is taken into account the possible unfavourable mechanical properties of the steel compared to the screw (the real strength of the steel may be much higher than the nominal value, while the strength of the screw may be just the nominal value). The required conditions should be fulfilled when deformation capacity of the connection is needed. When these conditions are not fulfilled it should be proved that the required deformation capacity will be provided by other parts of the structure.

Q&A 11.3 Screws in Sandwich Panels

How is the resistance of bolts in sandwich panels subject to shear and tension evaluated?

Self-tapping screws are used to connect sandwich panels [prEN 14509, 2002]. The loading by temperature, wind and dead load is mostly cyclic. The screws of austenitic steels with special shapes are used to prevent the fracture under serviceability loading, see 11.13a. The flexibility of the structure (stress skin method) is taken into account to prevent the collapse under loading by the differences of temperature [Davies, 1986] and [De Matteis, Landolfo, 1999]. The distribution of forces into the internal and external plate of the sandwich panel may be taken into account using the component method, see 11.13b [Mareš et al, 2000]. Two failure modes of bolted connection of sandwich panel were observed the bearing in the internal hole, see Fig. 11.14a, and the fracture of the screw shank, see Fig. 11.14b. By the horizontal loading of panels the membrane forces due to deflection of sandwich panel, see [ECCS 66, 2000], are taken into account including the prying forces caused by additional fixing moments, see Fig. 11.14c,.



a) deflection curve of traditional screw and of screw with notches on shank

b) component model of bolt in sandwich panel [Mareš et al, 2000]

Figure 11.13 Bolted connection of sandwich panel

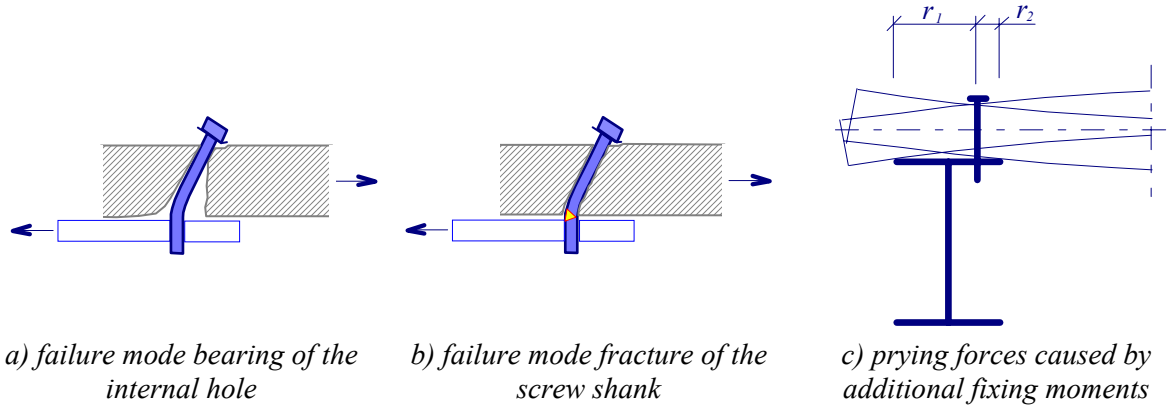


Figure 11.14 Bolted connection of sandwich panel

Q&A 11.4 Bearing of Thin Plates

What is the difference between the bearing resistance of thick and of thin (thin walled) plates?

The prediction models for the bearing resistance are based on the experimental evidence. The formula for bolts in thick plates (for thickness larger or equal to 3 mm) is included in Table 3.4 of prEN1993-1-8 and for bolts in thin plates in Table 8.1 of prEN 1993-1-3, where rivets, self tapping screws and pins are also included. The bearing resistance of thick plates takes into account the spacing into the perpendicular direction, by using the factor k_l ,

$$F_{b,Rd} = \frac{k_l \alpha_b f_u d t}{\gamma_{M2}}, \quad (11.3)$$

where α_b is the smallest of α_d ; f_{ub}/f_u or 1,0. In the direction of load transfer for end bolts $\alpha_d = e_1/(3 d_0)$ and for inner bolts $\alpha_d = p_1/(3 d_0) - 0,25$. Factor k_l is for edge bolts the smallest of 2,8 (e_2/d_0) - 1,7 or 2,5 and for inner bolts the smallest of 1,4 (p_2/d_0) - 1,7 or 2,5. e_1 , e_2 , p_1 , p_2 are end distance, edge distance and spacing for fasteners. d_0 is diameter of the hole, d is the bolt diameter and t is the sum of thickness of connected plates in the checked direction. The bearing resistance of thin plates uses the factor k_t to take into account the thinners of the plate,

$$F_{b,Rd} = \frac{2,5 \alpha_b k_t f_u d t}{\gamma_{M2}}, \quad (11.4)$$

where α_b is smallest of $\alpha_b = e_1/(3 d)$ and $\alpha_b = 1,0$; while k_t for $0,75 \text{ mm} \leq t \leq 1,25 \text{ mm}$ is $k_t = (0,8 t + 1,5) / 2,5$ and for $t > 1,25 \text{ mm}$ is $k_t = 1,0$. The resistance for the thickness beyond this range of validity is determined from the tests.