A course on
Design of Cold-formed Steel Structures

Connections

Professor Dan Dubina

Connections

- Introduction
- Fastening techniques of cold-formed steel constructions
- Mechanical properties of connections
- Design of connections
- Design assisted by testing of cold-formed steel connections

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Introduction

- important part of every structure
- account for a minimum of 50% of the total value of constructional steelwork
- in cold-formed steel structures are used for:
  - connecting steel sheets to supporting structure (thin-to-thick), e.g. roof sheeting to purlins, cladding sheeting to side-rails etc.
  - interconnecting two or more sheets (thin-to-thin), e.g. seam fastening of sheeting
  - assembling bar members (thin-to-thin or thick-to-thick), e.g. for framed structures, trusses etc.
- influenced by the reduced stiffness of thin walls => additional effects
  - tilting of the fastener in hole bearing failure under the shear distortion of the sheet when the fastener is loaded in tension and the sheet is pulled over the head of the fastener

Connections

Introduction

- **Joining methods (Toma et al, 1993; Yu, 2000)**
  - **fastenings with mechanical fasteners**
  - **fastenings based on welding**
  - **fastenings based on adhesive bonding**

- **three main groups depending on the thickness of the parts**

Thin-to-thin	Thin-to-thick or thin-to-hot rolled	Thick-to-thick or thick-to-hot rolled
- self-drilling, self-tapping screws; - blind rivets; - press-joints; - single-flare V welds; - spot welds; - seam welding; - adhesive bonding.	- self-drilling, self-tapping screws; - fired pins; - bolts; - arc spot puddle welds; - adhesive bonding.	- bolts; - arc welds.

Connections

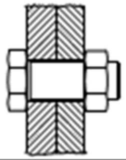
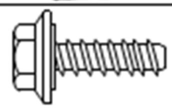
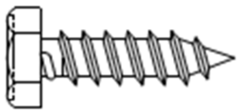
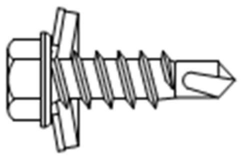
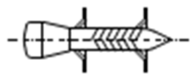
Introduction

- Factors influencing the selection of suitable fasteners (Davies, 1991)
  - Load-bearing requirements
    - Strength
    - Stiffness
    - Ductility (deformation capacity)
  - Economic requirements
    - Number of fasteners required
    - Cost of labour and materials
    - Skill required in fabrication
    - Design life
    - Maintenance
    - Ability to be dismantled
  - Durability
  - Water tightness
  - Appearence (architectural aspect)

Connections

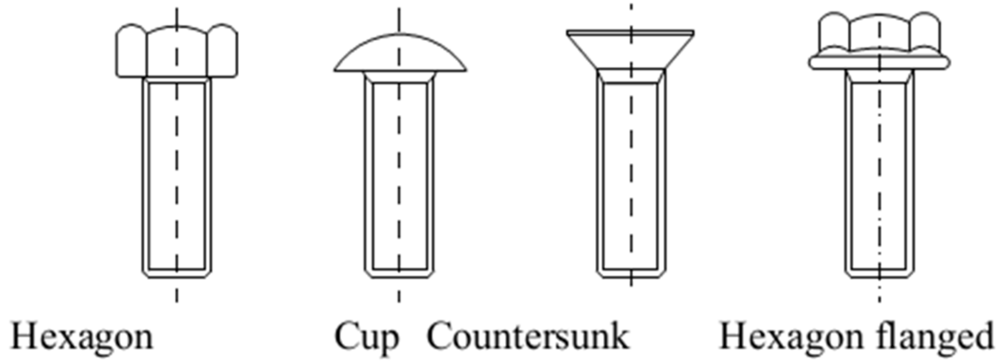
Fastening techniques of cold-formed steel constructions

- **Mechanical fasteners – usual fasteners (Yu et al, 1993)**

Thin -to- thick	Steel -to- wood	Thin -to-thin	Fasteners	Remark
X		X		Bolts M5-M16
X				Self-tapping screw ϕ6.3 with washer ≥ 16 mm, 1 mm thick with elastomer
	X	X		Hexagon head screw ϕ6.3 or ϕ6.5 with washer ≥ 16 mm, 1 mm thick with elastomer
X		X		Self-drilling screws with diameters: - ϕ4.22 or ϕ4.8 mm - ϕ5.5 mm - ϕ6.3 mm
		X		Blind rivets with diameters: - ϕ4.0 mm - ϕ4.8 mm - ϕ6.4 mm
X				Shot (fired) pins
X				Nuts

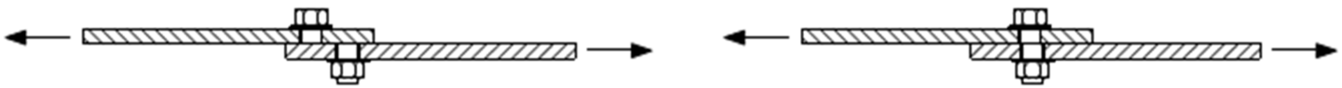
Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Bolts with nuts



M5 to M16
8.8 and 10.9

- Failure modes in shear:



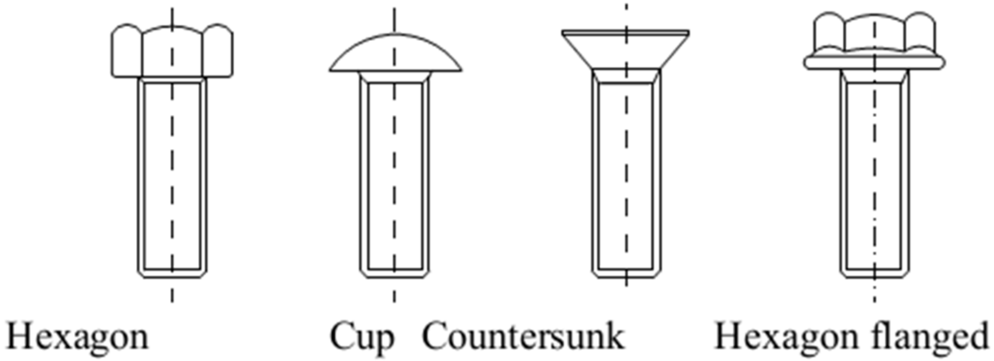
shearing of the bolt (rupture)

shearing of the bolt (crushing)

Connections

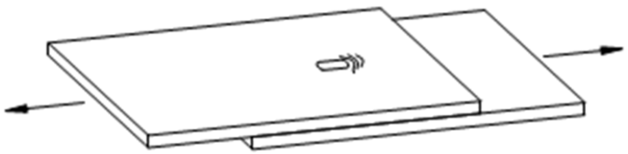
Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Bolts with nuts

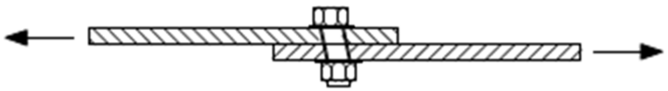


M5 to M16
8.8 and 10.9

- Failure modes in shear:



bearing or piling
of thinner material

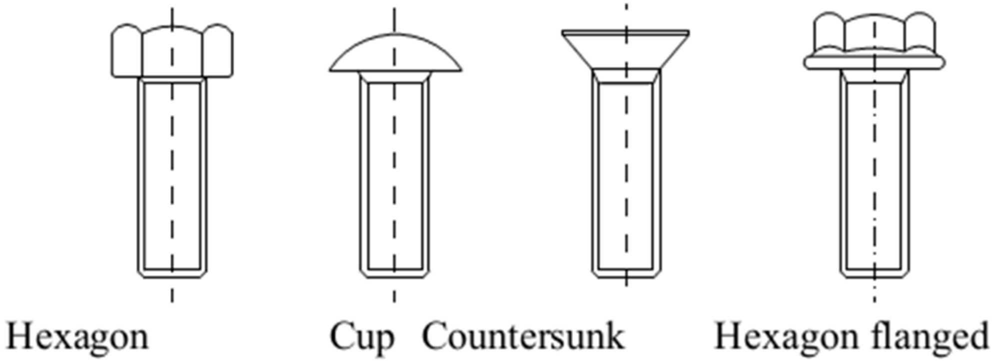


yielding

Connections

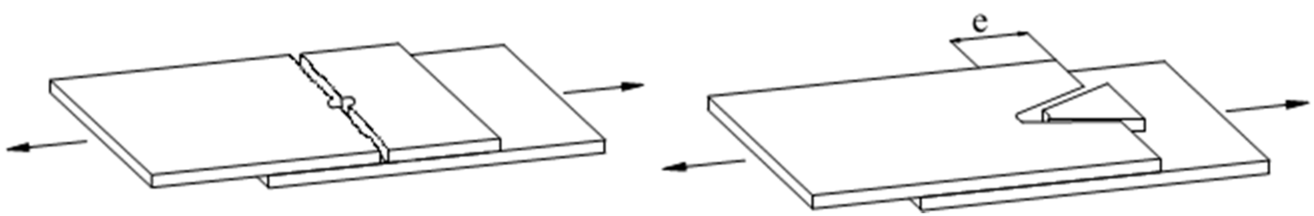
Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Bolts with nuts



M5 to M16
8.8 and 10.9

- Failure modes in shear:



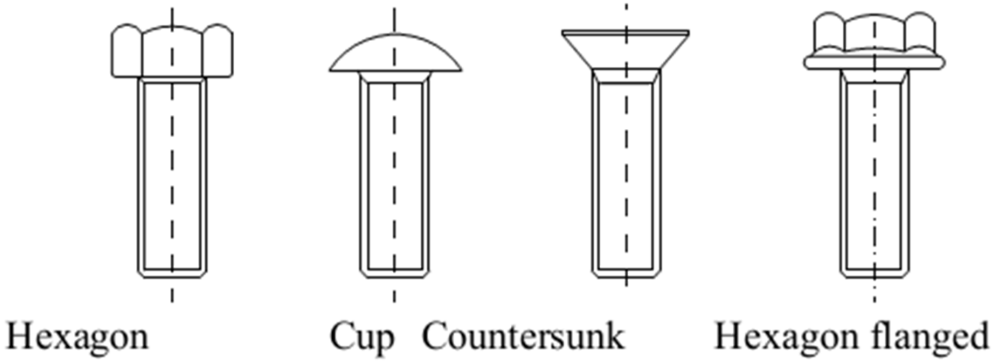
tearing of the sheet in the net sections

end failure by shearing of thin material

Connections

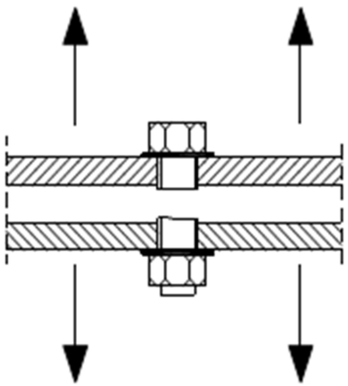
Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Bolts with nuts

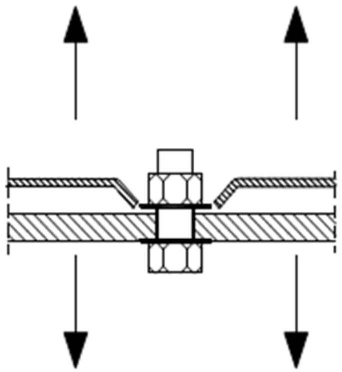


M5 to M16
8.8 and 10.9

- Failure modes in tension:



tension failure or rupture of bolt

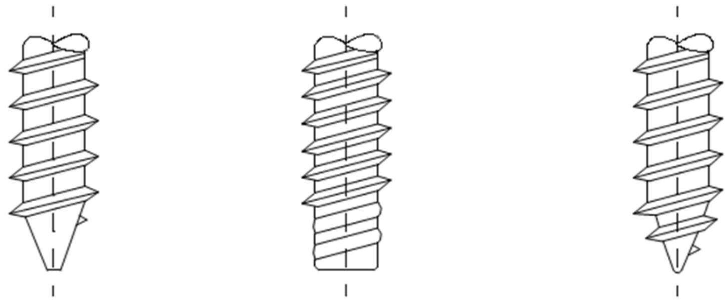


Pull-through failure

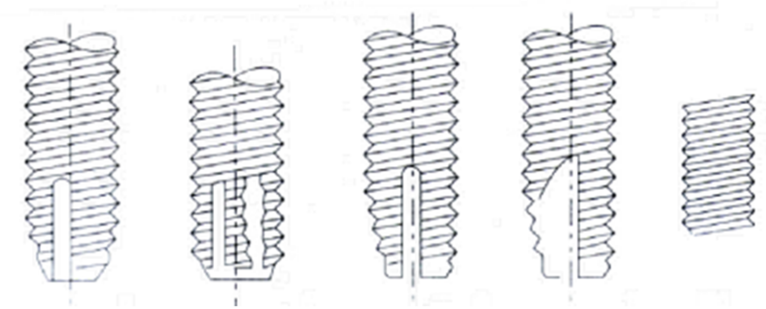
Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Screws (self-tapping and self-drilling)
      - *Self-tapping screws*



thread types for thread-forming screws

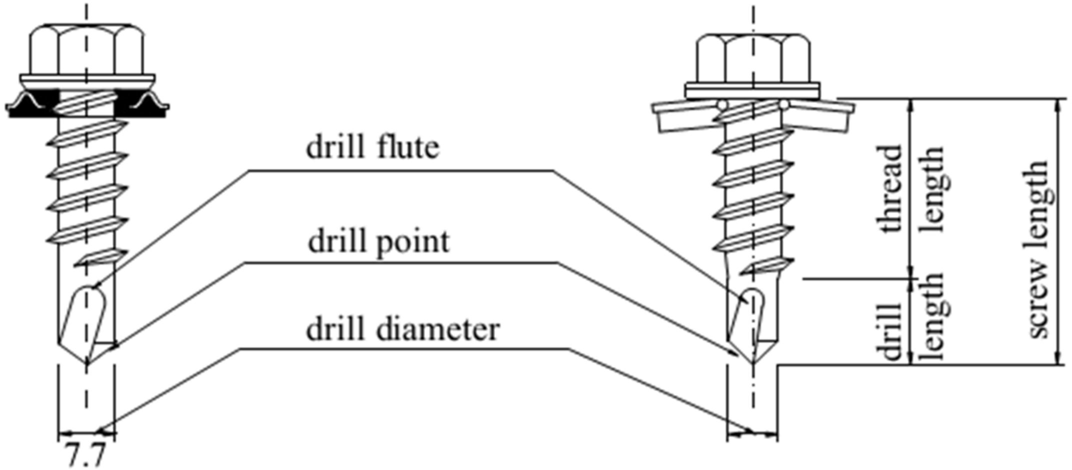


threads and points of thread-cutting screws

Connections

Fastening techniques of cold-formed steel constructions

- **Mechanical fasteners – usual fasteners**
  - **Mechanical fasteners for sections**
    - **Screws (self-tapping and self-drilling)**
      - ***Self-drilling screws***



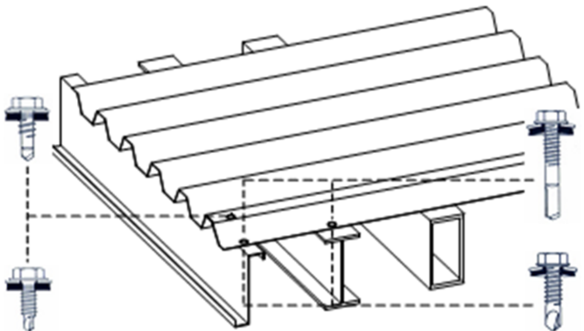
threads and points of thread-cutting screws

washers for self-tapping/self-drilling screws:

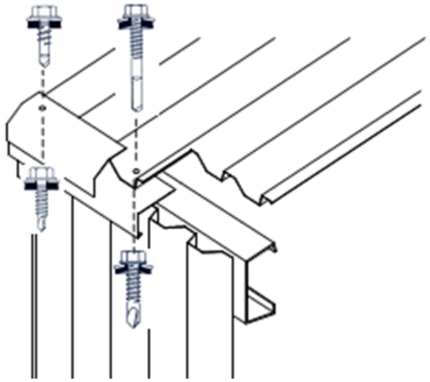
Connections

Fastening techniques of cold-formed steel constructions

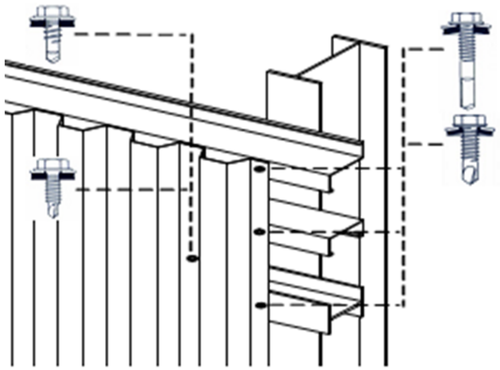
- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Screws (self-tapping and self-drilling)
      - Application examples



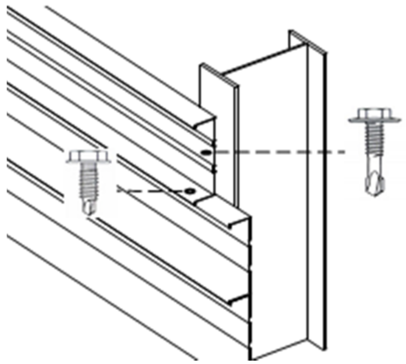
fastenings of roof sheeting on purlins



fastening of sheeting at an eave detail



fastening of wall sheeting on side rails



fastenings of wall cassettes on stanchions

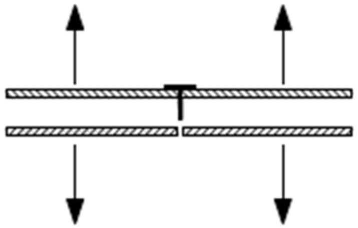
Connections

Fastening techniques of cold-formed steel constructions

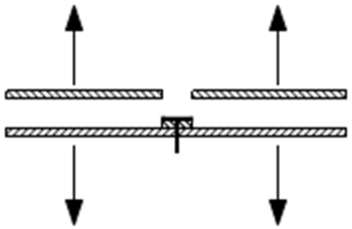
- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Screws (self-tapping and self-drilling)
      - Failure modes
        - In shear

tilting and pull-out of fastener (inclination failure)

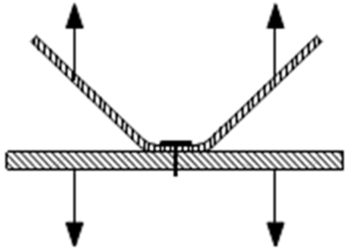
        - In tension (in addition to usual steel connections)



pull-out



pull-over

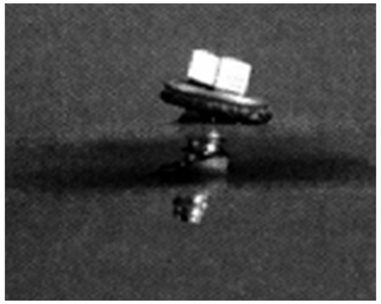


gross distortion of sheeting

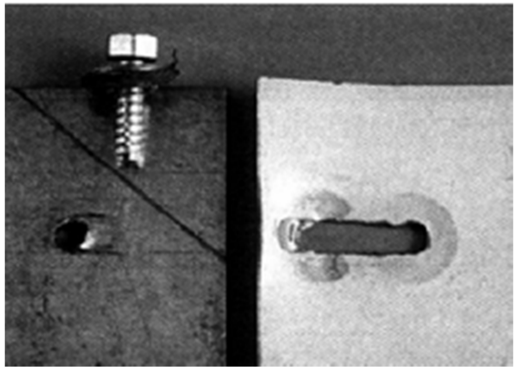
Connections

Fastening techniques of cold-formed steel constructions

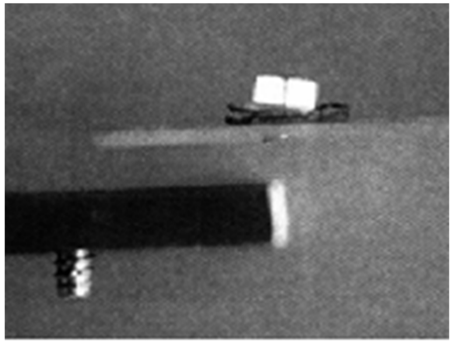
- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Screws (self-tapping and self-drilling)
      - Failure modes



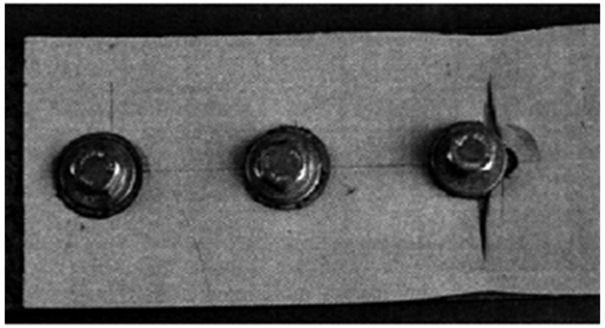
Tilling and pull-out of screw



Tearing of upper sheet



Shearing of screw

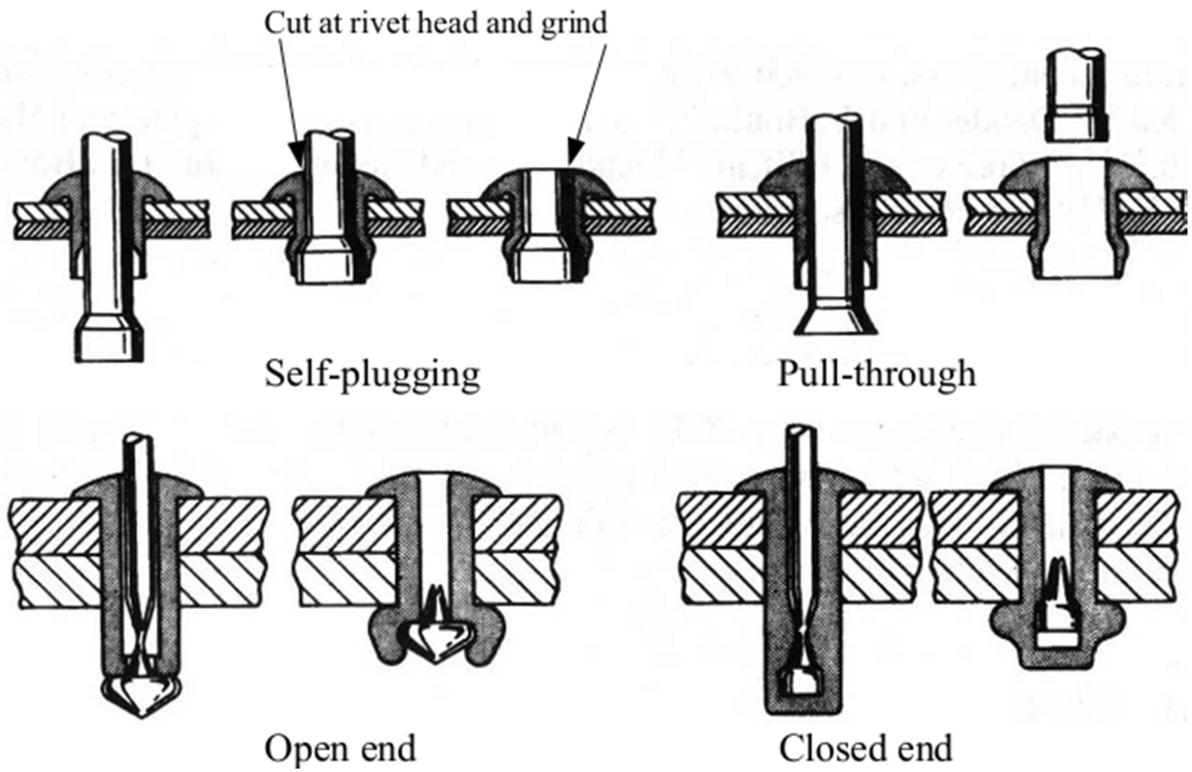


Net section failure

Connections

Fastening techniques of cold-formed steel constructions

- **Mechanical fasteners – usual fasteners**
  - **Mechanical fasteners for sections**
    - **Rivets – blind rivets (Yu, 2000)**

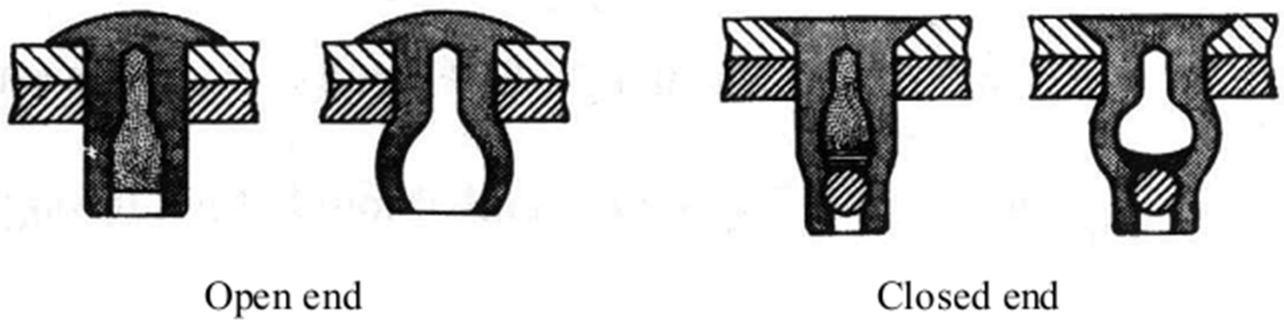


Pull-stem Rivets

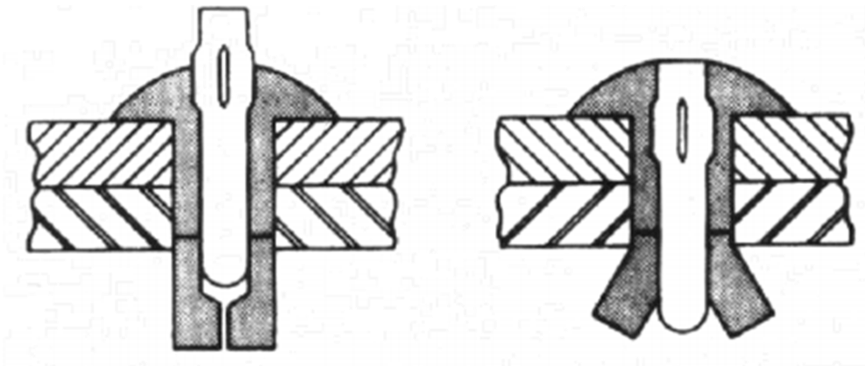
Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Rivets – blind rivets (Yu, 2000)



Explosive Rivets



Drive-pin Rivets

Connections

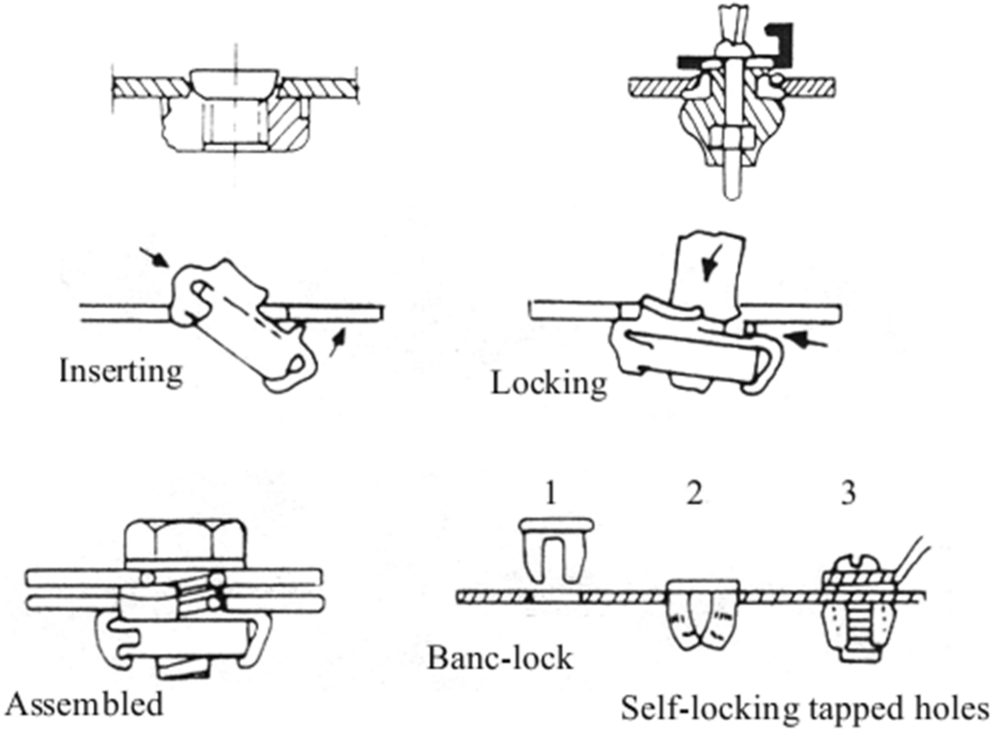
Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Rivets – tubular rivets
      - Diameter from 0.8 to 7.9mm
      - Length from 0.8 to 6.4mm
    - Failure modes
      - similar to those of screwed connections
      - the mode of failure of a connection preferred to be ductile
      - aluminium blind rivets are particularly prone to shear failure
      - other modes of failure, adequate deformation capacity of connections may be taken (Davies, 1991):
        - for seam fasteners between adjacent cladding elements: 0.5 mm;
        - for all other connections: 3.0 mm.

Connections

Fastening techniques of cold-formed steel constructions

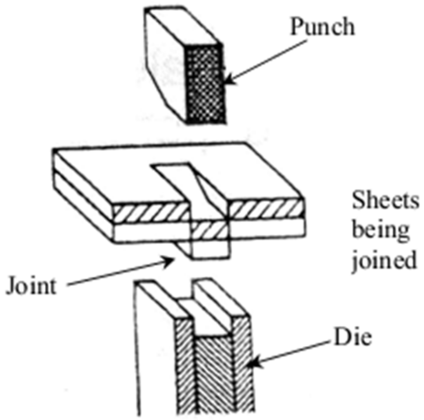
- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Special Mechanical Fastenings
      - Nuts

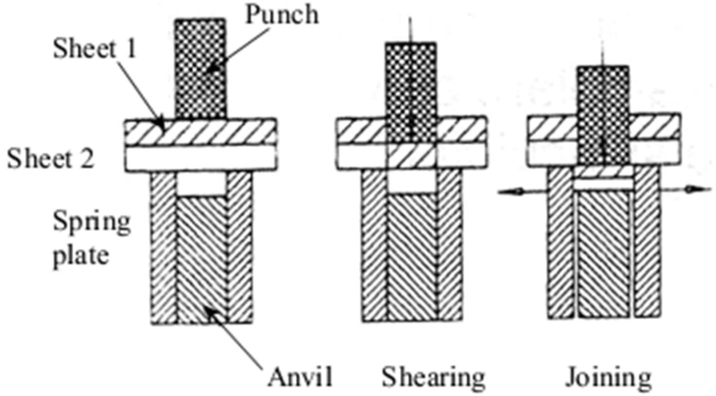


Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Special Mechanical Fastenings
      - Press joints (Clinched connections)



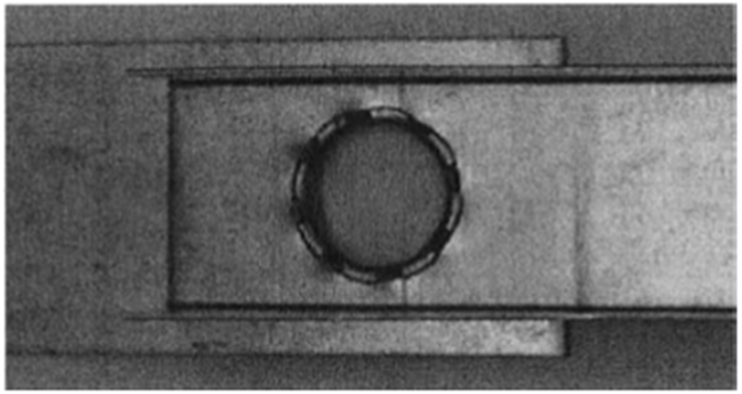


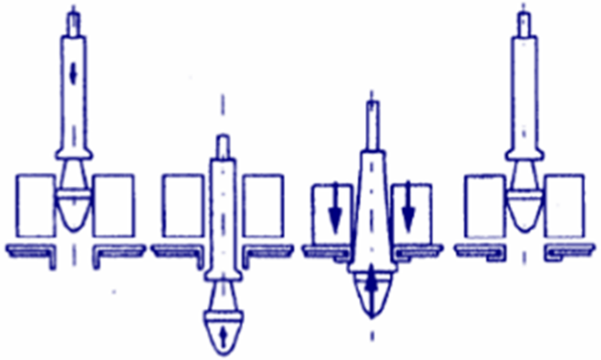
  - Advantages
    - no additional items are required
    - it does not destroy protective coatings
    - it is very rapid, taking less than one second to form a joint
    - it is very efficient, requiring about 10% of the energy for spot welding
    - multipoint joining tools can produce several joints simultaneously
    - the joint can be made air and water tight

Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sections
    - Special Mechanical Fastenings
      - “Rosette” system

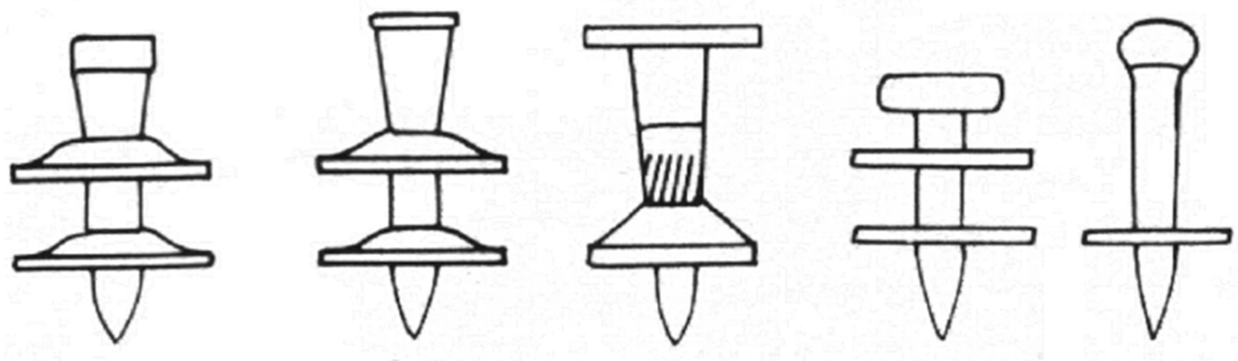




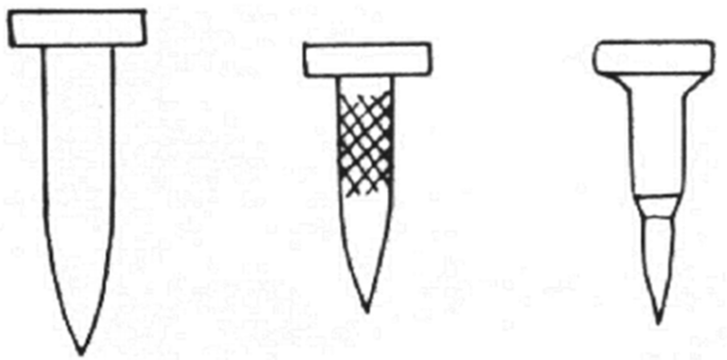
Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
    - Mechanical fasteners for sheeting



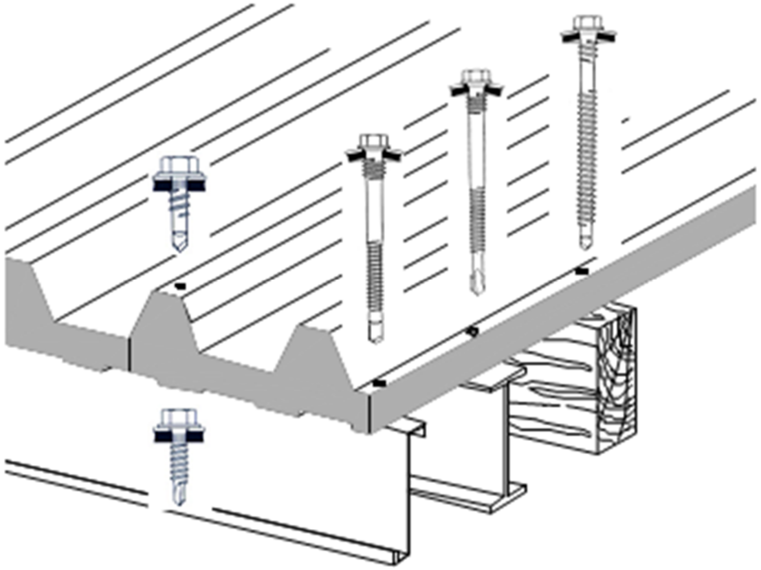
Five types of powder actuated fasteners

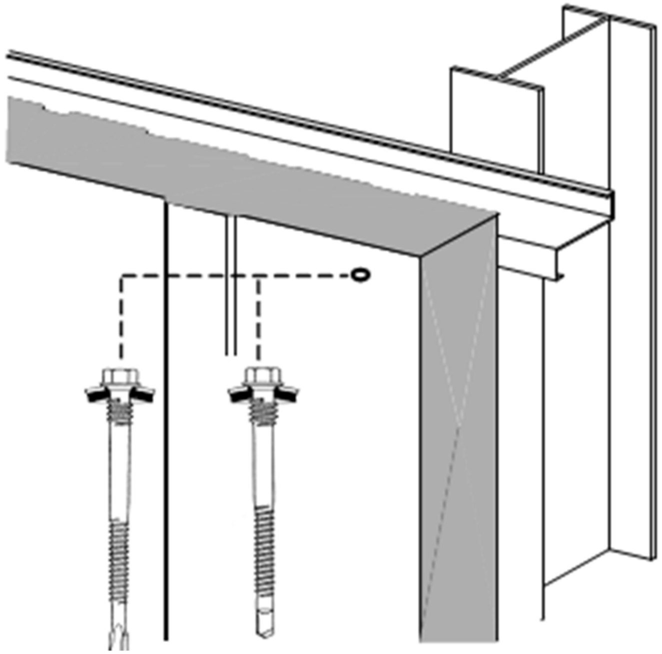


Three types of air driven fasteners

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sandwich panels





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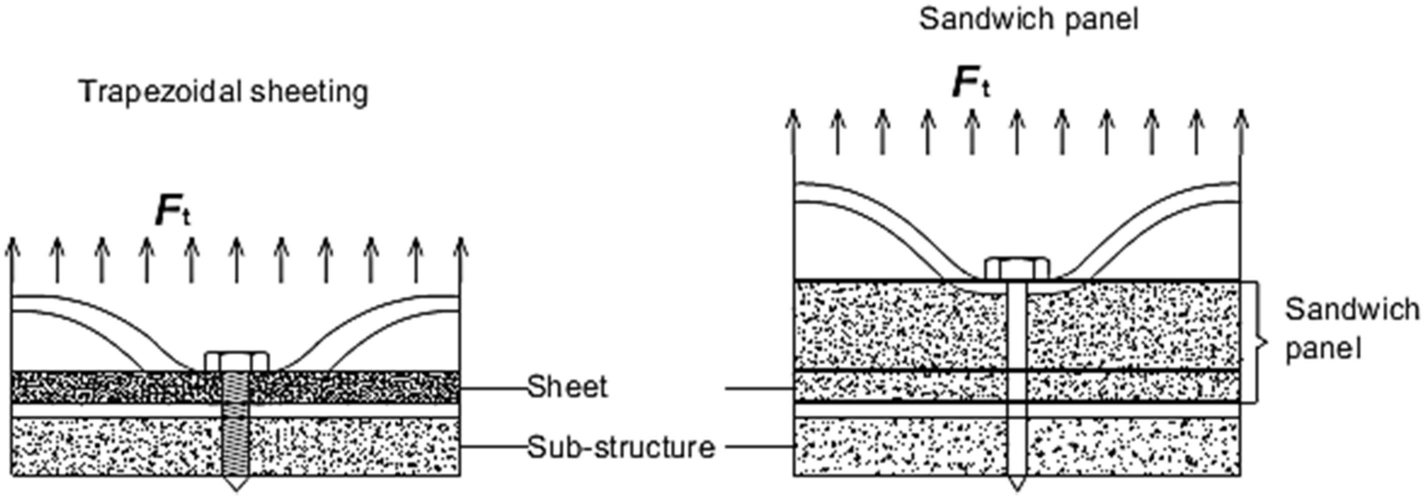
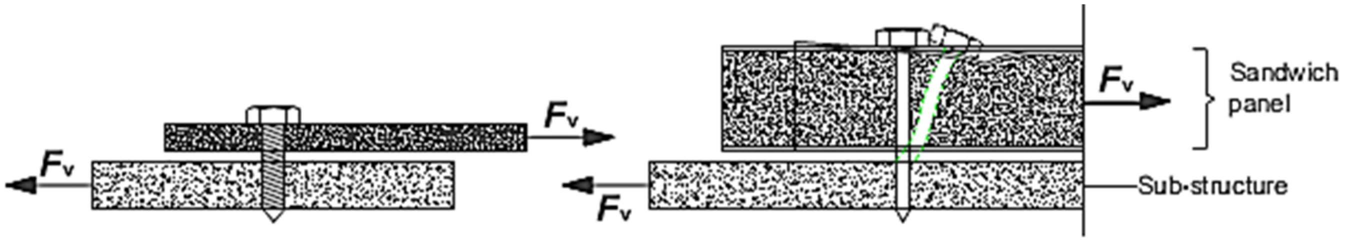
Connections

Fastening techniques of cold-formed steel constructions

- Mechanical fasteners – usual fasteners
  - Mechanical fasteners for sandwich panels



Connection loaded by tensile force



Connection loaded by shear force

Connections

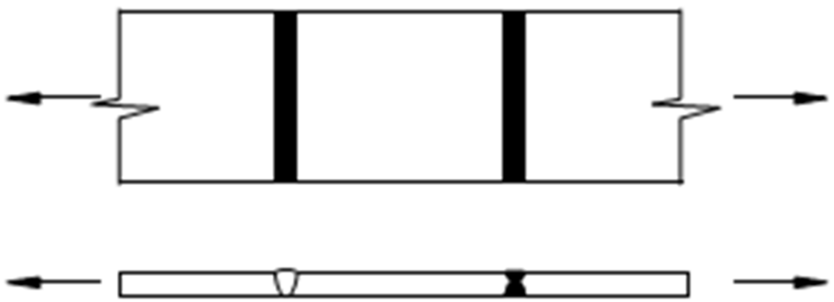
Fastening techniques of cold-formed steel constructions

- Welding
  - arc welds
    - fusing material together by an electric arc and the addition of weld filler material
  - resistance welds
    - commonly used for connecting thin sheets steels in the automotive industry

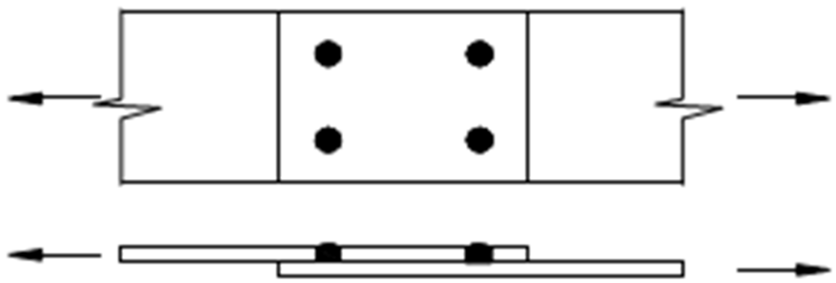
Connections

Fastening techniques of cold-formed steel constructions

- Welding
  - Fusion arc welding
    - SMA – Shield Metal Arc Welding;
    - FCA – Flux Cored Arc Welding
    - SA – Submerged Arc Welding
    - GMA – Gas Metal Arc Welding
    - GTA – Gas Tungsten Arc
    - TIG – Tungsten Inert Gas Welding and Plasma Welding



Grove welds in butt joints

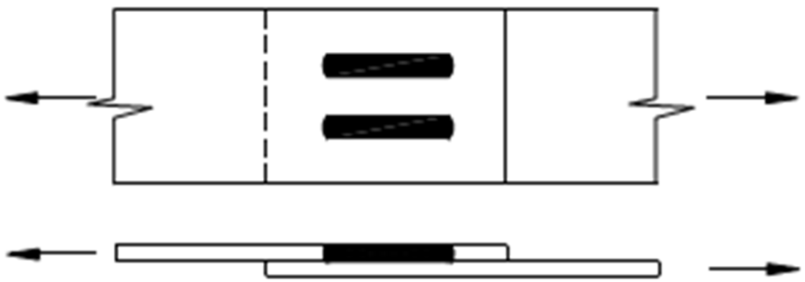


Arc spot weld (puddle weld)

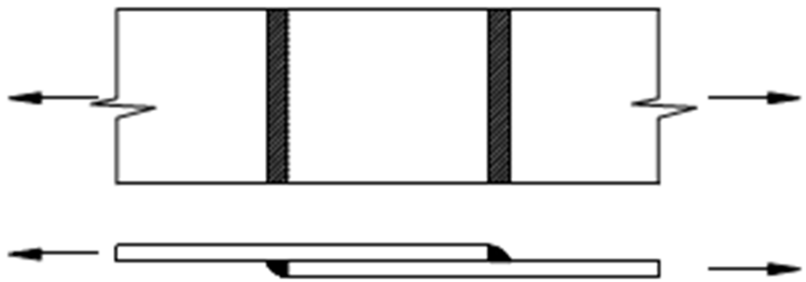
Connections

Fastening techniques of cold-formed steel constructions

- Welding
  - Fusion arc welding
    - SMA – Shield Metal Arc Welding;
    - FCA – Flux Cored Arc Welding
    - SA – Submerged Arc Welding
    - GMA – Gas Metal Arc Welding
    - GTA – Gas Tungsten Arc
    - TIG – Tungsten Inert Gas Welding and Plasma Welding



Plug and slot welds

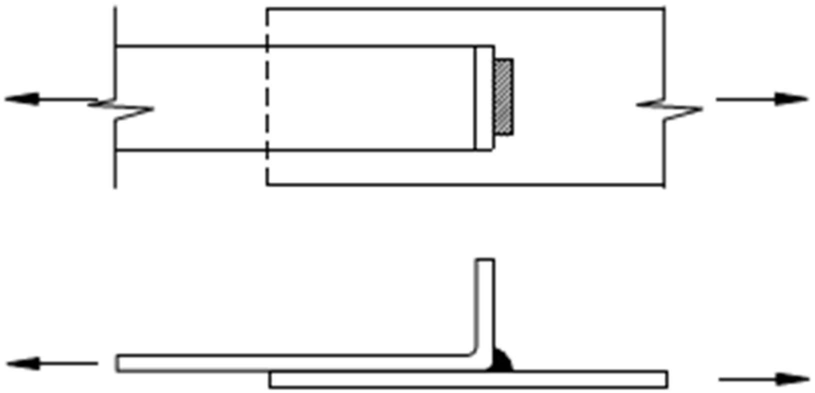


Fillet welds

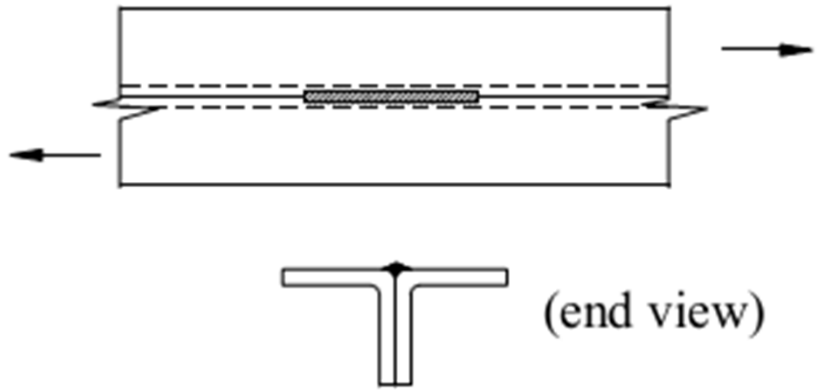
Connections

Fastening techniques of cold-formed steel constructions

- Welding
  - Fusion arc welding
    - SMA – Shield Metal Arc Welding;
    - FCA – Flux Cored Arc Welding
    - SA – Submerged Arc Welding
    - GMA – Gas Metal Arc Welding
    - GTA – Gas Tungsten Arc
    - TIG – Tungsten Inert Gas Welding and Plasma Welding



Flare bevel grove weld

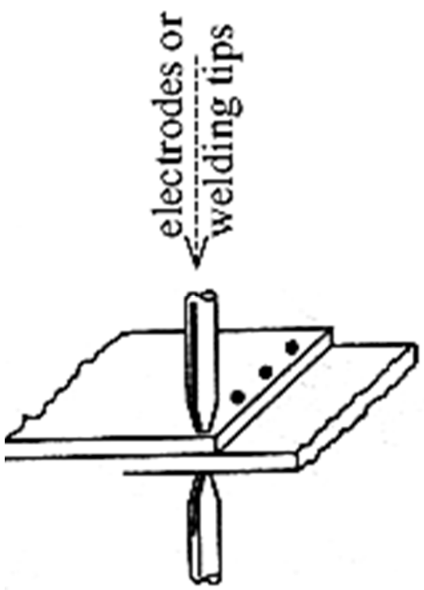


Flare V-grove weld

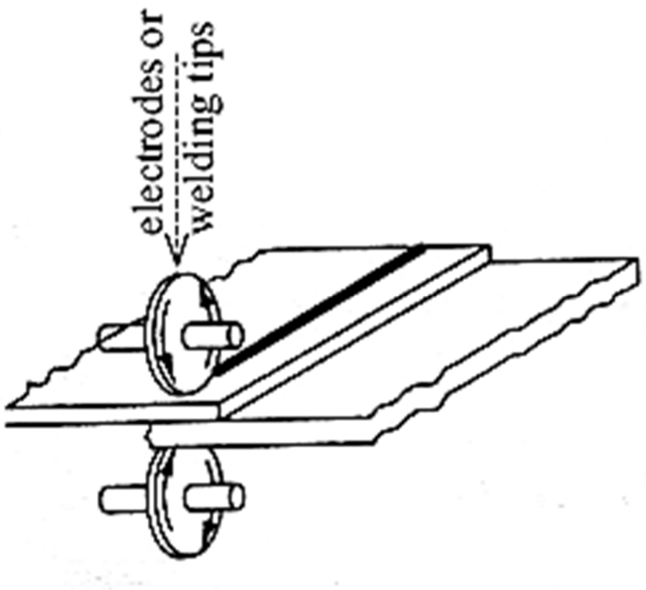
Connections

Fastening techniques of cold-formed steel constructions

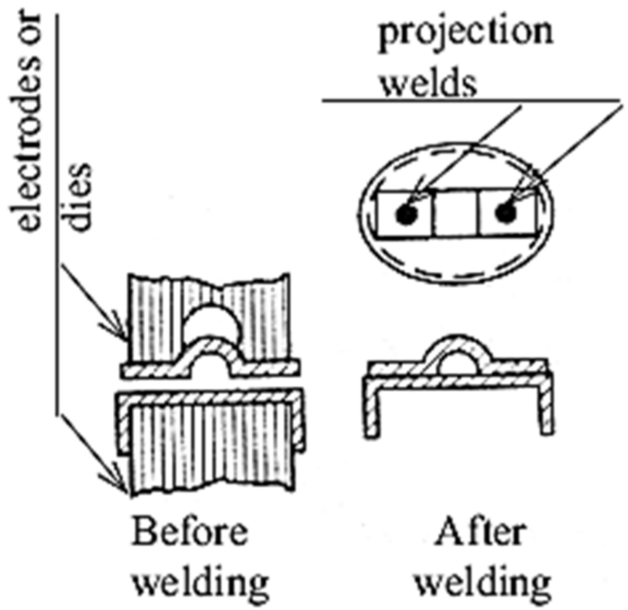
- **Welding**
  - **Resistance welding**



spot welding



seam welding

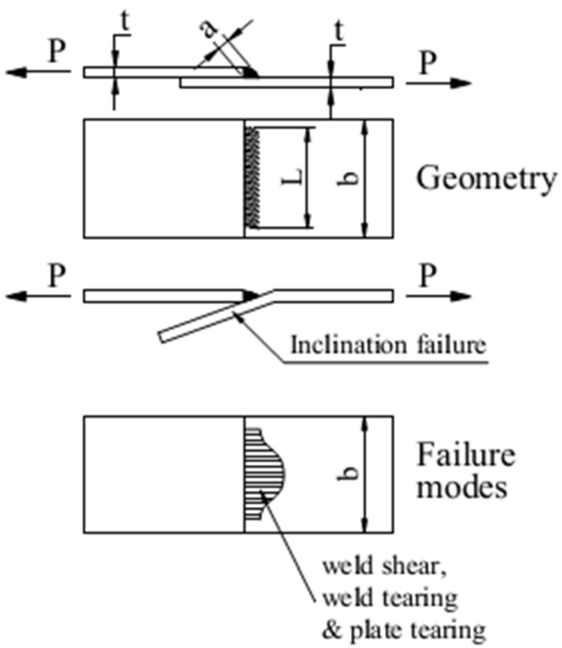


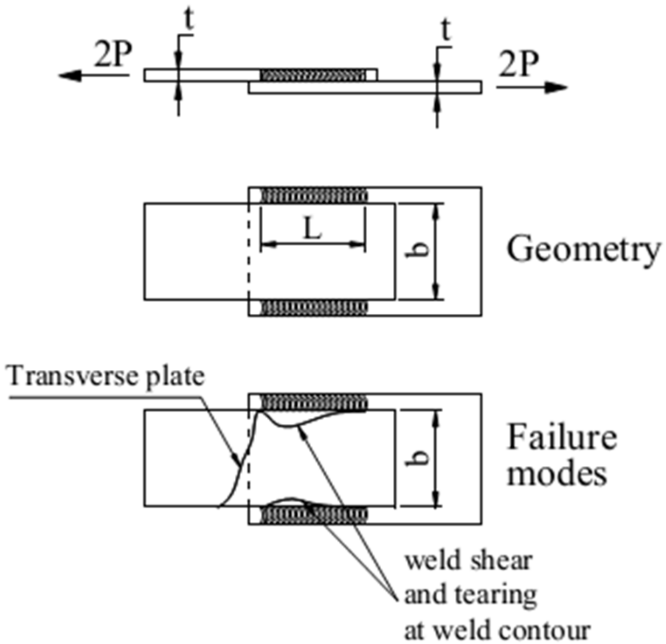
projection welding

Connections

Fastening techniques of cold-formed steel constructions

- **Welding**
  - **Behaviour of cold-formed steel welds (Yu, 2000)**
    - Stress resisting areas are more difficult to define
    - Welds such as spot and slot welds are made through the welded sheet without any preparation
    - Galvanising and paint are not normally removed prior to welding
    - Failure modes are complex and difficult to categorise





Connections

Fastening techniques of cold-formed steel constructions

- Welding
  - Behaviour of cold-formed steel welds (Yu, 2000)
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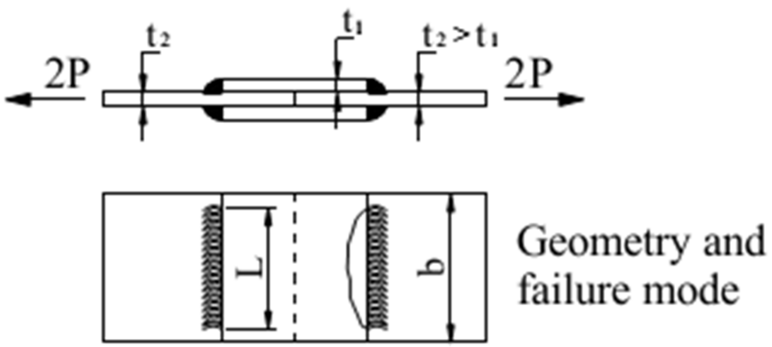

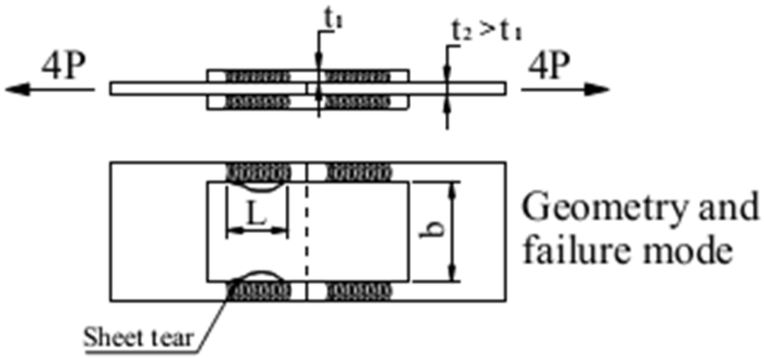

Connections

Fastening techniques of cold-formed steel constructions

- Welding
  - Behaviour of cold-formed steel welds (Yu, 2000)
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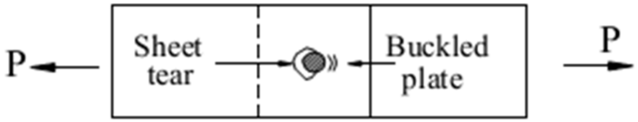
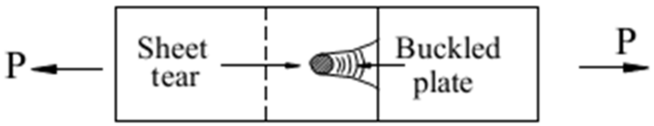
    - Failure modes are complex and difficult to categorise

inclination failure

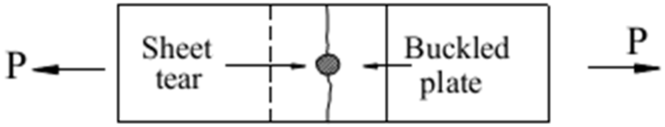


tearing and bearing at weld contour

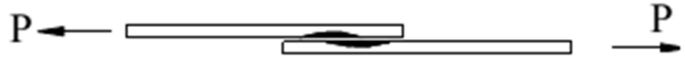


edge failure

net section failure



weld shear failure



Connections

Fastening techniques of cold-formed steel constructions

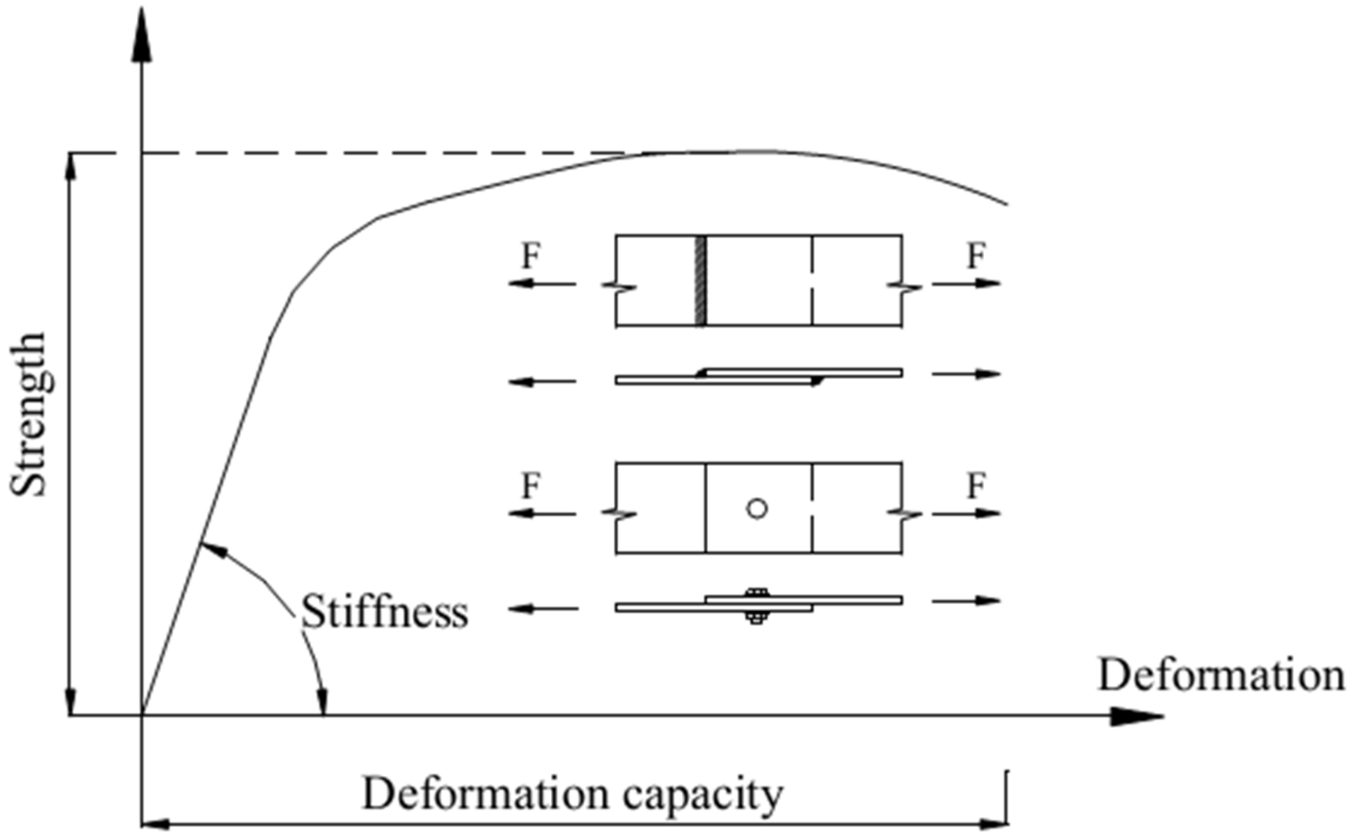
- Fastening based on adhesive bonding
  - epoxy adhesive types – best hardening will appear under elevated temperature (typically 80-120°C);
  - acrylic adhesive types – more flexible than the epoxy types.

  - Advantages
    - uniform distribution of forces over the connection
    - high resistance to repeated loading

  - Disdvantages
    - the surface should be flat and clean
    - hardening time

Connections

Mechanical Properties of Connections



Connections

Mechanical Properties of Connections

- Strength (Ultimate Limit State)
  - type of the fastener
  - properties of connected elements e.g. thickness and yield stress

- Stiffenes
  - pinned
  - rigid
  - semirigid (recent research)

- Deformation capacity
  - ductile behaviour is required in order to allow local redistribution of forces without detrimental effects
  - local overloading > brittle fracture

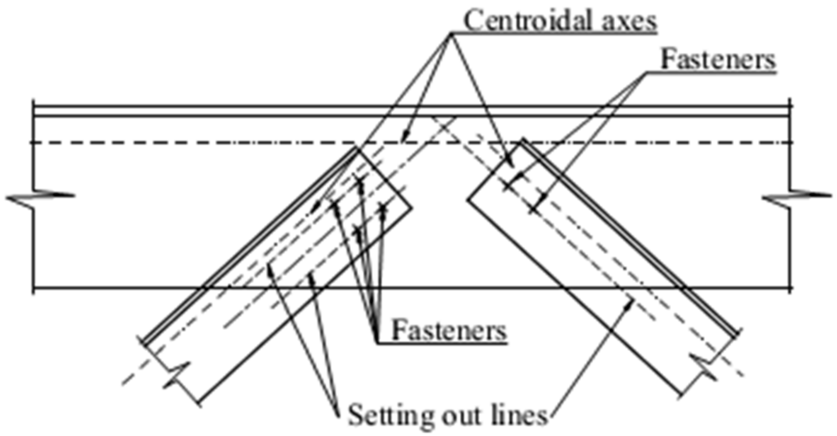
Design of Connections

- General design considerations
  - 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
  - Joint
    - zone where two or more members are interconnected. 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 between the connected members.
  - 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.

Connections

Design of Connections

- General design considerations
  - General design assumptions
    - Realistic assumption of the distribution of internal forces and moments, having regard to relative stiffness within the joint
    - Allowance may be made for the ductility of steel in facilitating the redistribution of internal forces generated within a joint
    - Ease of fabrication and erection shall be taken into account in the detailing of connections and splices
    - Determination of any structural property of fastener or joint shall be based on design assisted by testing



Connections

Design of Connections

- **Design of connections with mechanical fasteners**
  - **bolts, self-tapping screws, blind rivets and cartridge fired pins**

$$F_{i,Ed} \leq F_{i,Rd}$$

where

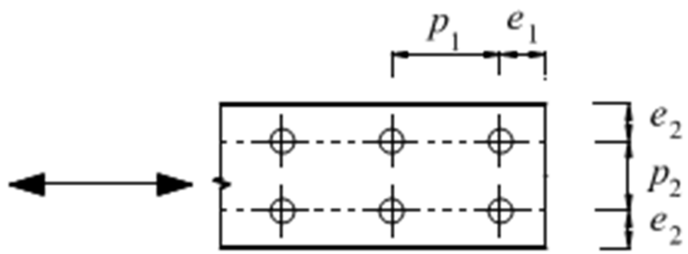
$F_{i,Ed}$ is the design stress for the fastener, corresponding to failure mode i;

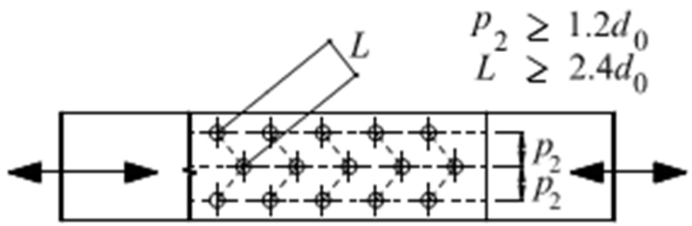
$F_{i,Rd}$ is the design strength for the fastener, corresponding to failure mode i.

Connections

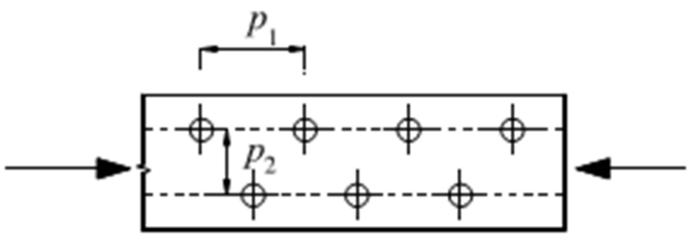
Design of Connections

- Design of connections with mechanical fasteners
  - General rules
    - should be compact in shape
    - positions of the fasteners should be such as to prevent corrosion and local buckling and to facilitate their installation
    - maximum and minimum spacing are imposed in terms of d_0

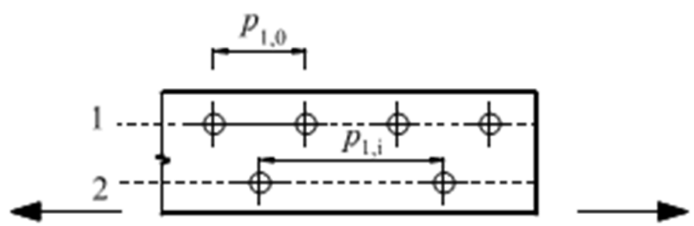




Staggered rows of fasteners



$p_1 \leq 14\,t$ and $\leq$ 200 mm
$p_2 \leq 14\,t$ and $\leq$ 200 mm



$p_{1,0} \leq 14\,t$ and $\leq$ 200 mm
1 outer row
$p_{1,i} \leq 28\,t$ and $\leq$ 400 mm
2 inner row

- Design of connections with mechanical fasteners
  - General rules
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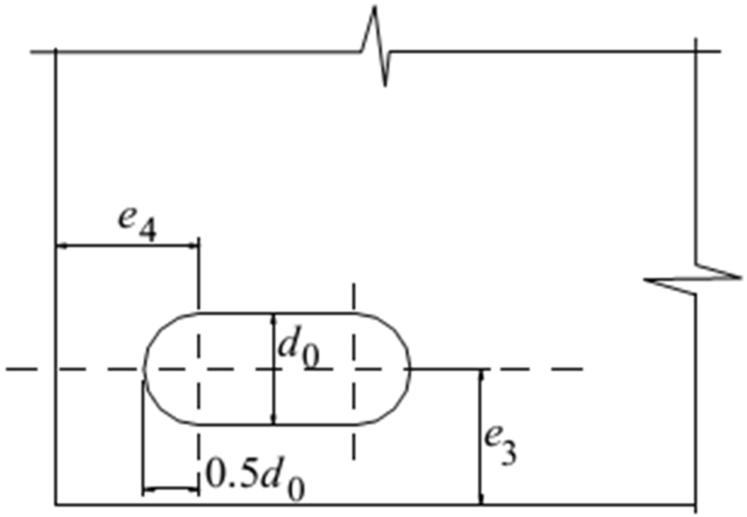

Design of Connections

- Design of connections with mechanical fasteners
  - General rules
    - should be compact in shape
    - positions of the fasteners should be such as to prevent corrosion and local buckling and to facilitate their installation
    - maximum and minimum spacing are imposed in terms of d_0
    - shear forces on individual mechanical fasteners in a connection may be assumed to be equal
      - the fasteners have sufficient ductility
      - shear is not the critical failure mode

Nominal f_{yb} and f_{ub} for bolts

Bolt grade	4.6	4.8	5.6	5.8	6.8	8.8	10
f_{yb} (N/mm^2)	240	320	300	400	480	640	90
f_{ub} (N/mm^2)	400	400	500	500	600	800	10

Design of Connections

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    - should be compact in shape
    - positions of the fasteners should be such as to prevent corrosion and local buckling and to facilitate their installation
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      - shear is not the critical failure mode

Characteristic shear resistance $F_{v,Rk}$ of self-tapping screws (N/screw)

The outside diameter of the thread (mm)	The material of the screw	
	Hardened steel	Stainless steel
4.8	5200	4600
5.5	7200	6500
6.3	9800	8500
8.0	16300	14300

Connections

Design of Connections

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    - shear forces on individual mechanical fasteners in a connection may be assumed to be equal
      - the fasteners have sufficient ductility
      - shear is not the critical failure mode

Characteristic shear resistance $F_{v,Rk}$ of blind rivets (N/blind rivet)

The diameter of the shank (mm)	The material of the blind rivet			
	Steel	Stainless steel	Monel	Aluminium
4.0	1600	2800	2400	800
4.8	2400	4200	3500	1100
5.0	2600	4600	-	-
6.4	4400		6200	2000

Connections

Design of Connections

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    - maximum and minimum spacing are imposed in terms of d_0
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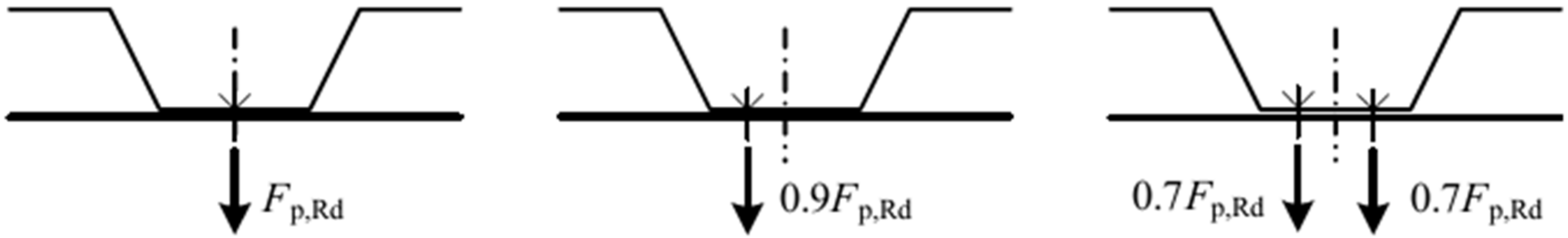
      - the fasteners have sufficient ductility
      - shear is not the critical failure mode



$$\frac{F_{t,Ed}}{\min(F_{p,Rd}, F_{o,Rd})} + \frac{F_{v,Ed}}{\min(F_{b,Rd}, F_{n,Rd})} \leq 1$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - General rules
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    - maximum and minimum spacing are imposed in terms of d_0

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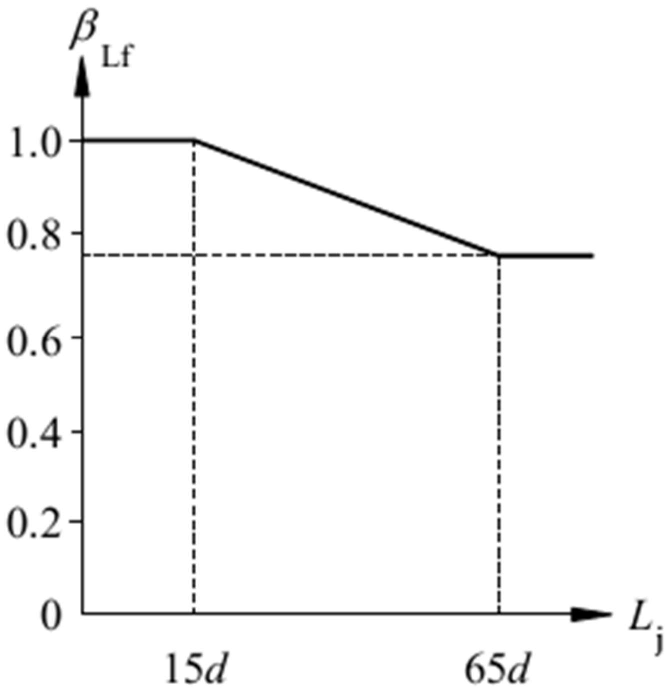

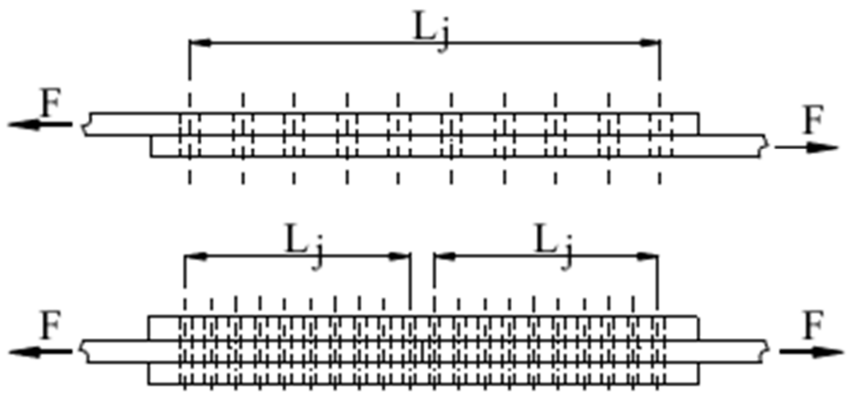

Connections

Design of Connections

- Design of connections with mechanical fasteners
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    - should be compact in shape
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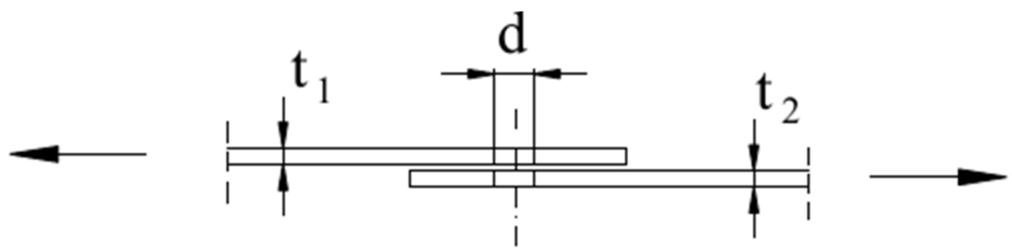
    - maximum and minimum spacing are imposed in terms of d_0
    - shear forces on individual mechanical fasteners in a connection may be assumed to be equal
      - the fasteners have sufficient ductility
      - shear is not the critical failure mode
    - The design rules for blind rivets are valid only if the diameter of the hole is not more than 0.1 mm larger than the diameter of the rivet
    - In single lap joints with only one bolt row the bolts should be provided with washers under both the head and the nut



Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of bolted connection
    - normally used as shear, tension or moment resistant connections
    - Design resistances for bolts (bolts loaded in shear)
      - Bearing resistance (for t<3mm)

$$F_{b,Rd} = 2.5 \cdot \alpha_b \cdot k_t \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

      - Net-section resistance

$$F_{n,Rd} = (1 + 3 \cdot r \cdot (d_o / u - 0.3)) \cdot A_{net} \cdot f_u / \gamma_{M2} \text{ but } F_{n,Rd} \leq A_{net} \cdot f_u / \gamma_{M2}$$

      - Shear resistance

- for strength grades 4.6, 5.6 and 8.8: $F_{v,Rd} = 0.6 \cdot f_{ub} \cdot A_s / \gamma_{M2}$
- for strength grades 4.8, 5.8, 6.8 and 10.9: $F_{v,Rd} = 0.5 \cdot f_{ub} \cdot A_s / \gamma_{M2}$

      - Condition (if deformation capacity is needed)

$$F_{v,Rd} \geq 1.2 F_{b,Rd} \text{ or } \sum F_{v,Rd} \geq 1.2 \cdot F_{n,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of bolted connection
    - normally used as shear, tension or moment resistant connections

    - Design resistances for bolts (bolts loaded in tension)
      - Pull-through resistance

        $F_{p,Rd}$ to be determined by testing.

      - Pull-out resistance

        Not relevant for bolts.

      - Tension resistance

        $$F_{t,Rd} = 0.9 \cdot f_{ub} \cdot A_s / \gamma_{M2}$$

      - Condition (if deformation capacity is needed)

        $$F_{t,Rd} \geq \sum F_{p,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of bolted connection
    - normally used as shear, tension or moment resistant connections
    - Rage of validity

$e_1 \geq 1.0 \cdot d_o$ $\quad p_1 \geq 3 \cdot d_o$ $\quad 3\,\text{mm} > t \geq 0.75\,\text{mm}$

$e_2 \geq 1.5 \cdot d_o$ $\quad p_2 \geq 3 \cdot d_o$

Minimum bolt size: M6

Strength grades: 4.6-10.9

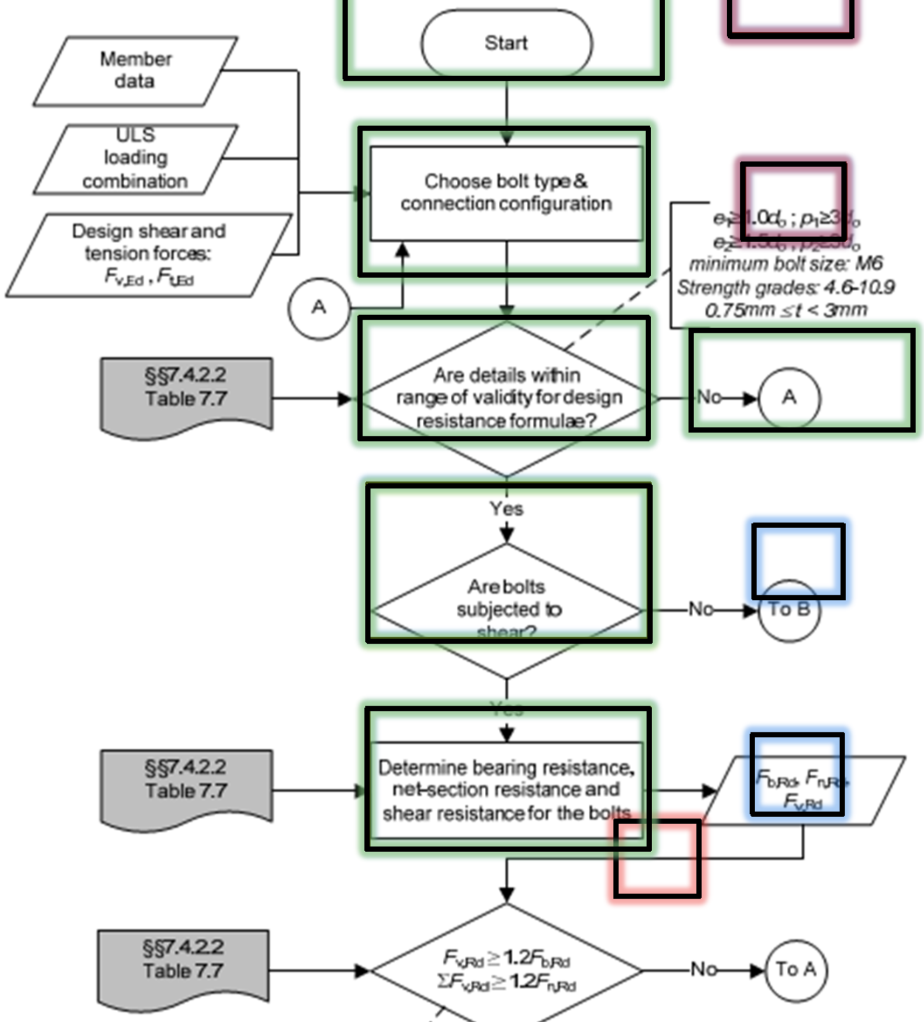
$f_u \leq 550\ \text{N/mm}^2$

- Bolts may be used beyond this range of validity if the resistance is determined from the results of tests

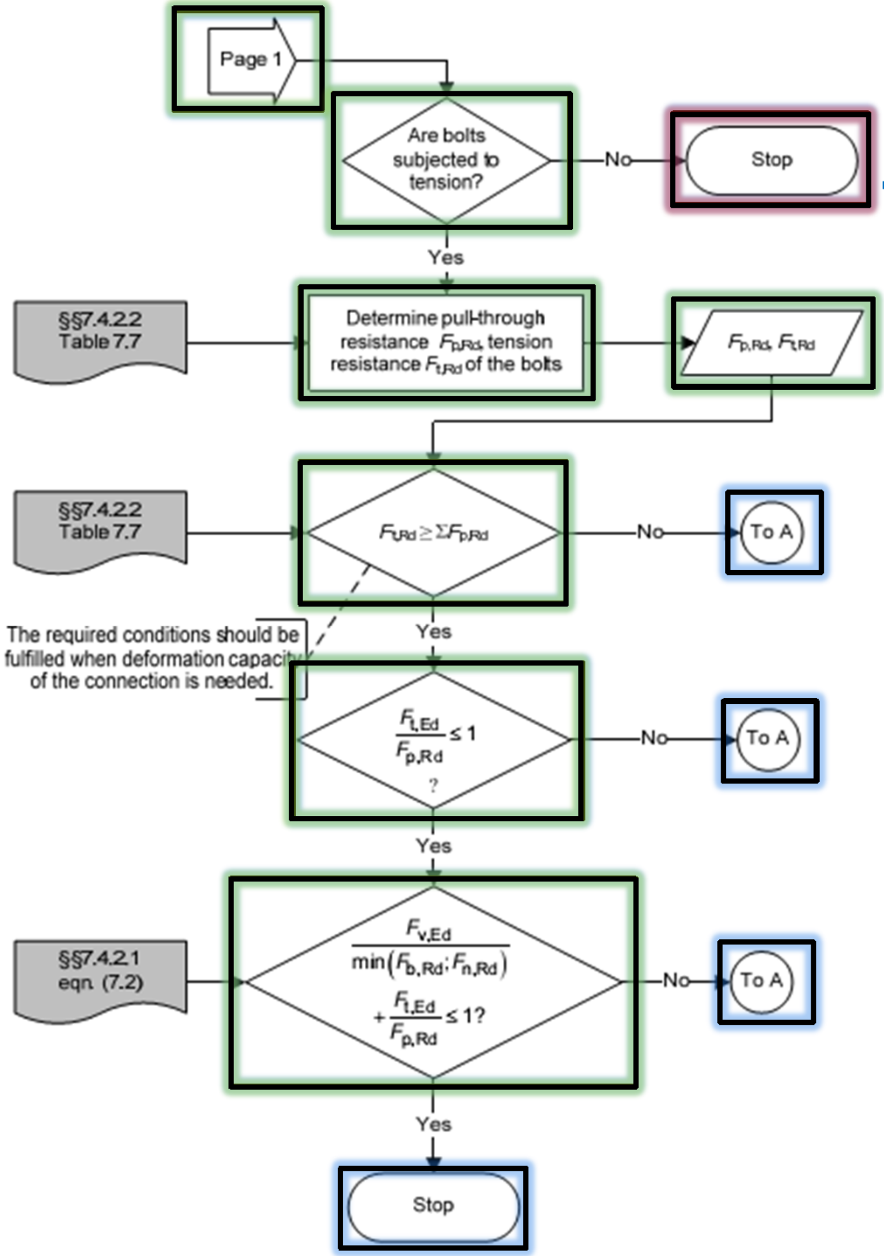
Connections

Design of Connections

- **Design of connections with mechanical fasteners**



Connect



Page 1
Are bolts subjected to tension?
No
Stop
Yes
§§7.4.2.2 Table 7.7
Determine pull-through resistance $F_{p,Rd}$, tension resistance $F_{t,Rd}$ of the bolts
$F_{p,Rd}$, $F_{t,Rd}$
§§7.4.2.2 Table 7.7
$F_{t,Rd} \geq \Sigma F_{p,Rd}$
No
To A
The required conditions should be fulfilled when deformation capacity of the connection is needed.
Yes
$\frac{F_{t,Ed}}{F_{p,Rd}} \leq 1$?
No
To A
Yes
§§7.4.2.1 eqn. (7.2)
$\frac{F_{v,Ed}}{\min(F_{b,Rd}; F_{n,Rd})} + \frac{F_{t,Ed}}{F_{p,Rd}} \leq 1$?
No
To A
Yes
Stop

Connections

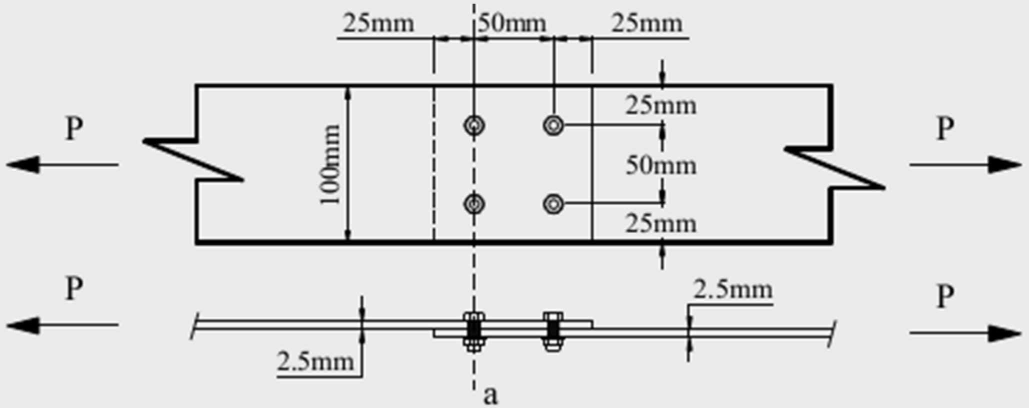
Design of Connections

- ***EXAMPLE 1: Design resistance of the lap bolted connection in tension***

Given: Steel grade S350GD+Z

Connected part: f_{yb}=350 N/mm^2, f_u=420 N/mm^2

Bolt grade 8.8 with a bolt diameter d=12 mm; d_o=13 mm, f_{ub}=800 N/mm^2; A_s=84.3 mm^2.

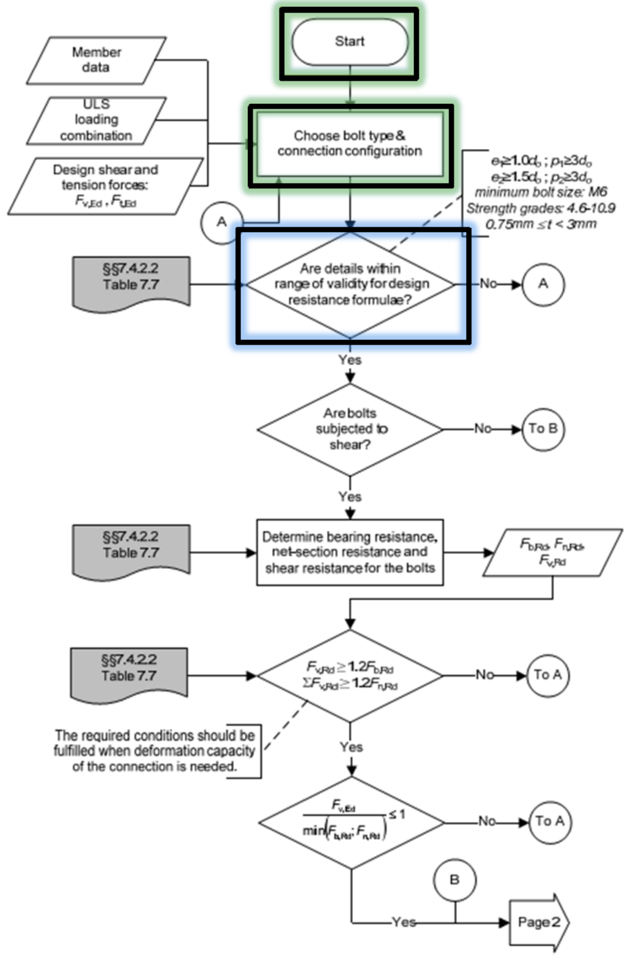


Bolt pitch distance between centre of the holes:

$$p_1 = p_2 = 50 \text{ mm} > 3d = 36 \text{ mm};$$

Distance from the centre of the hole to the end of part:

$$e_1 = 25 \text{ mm} > 1.5d = 18 \text{ mm}.$$

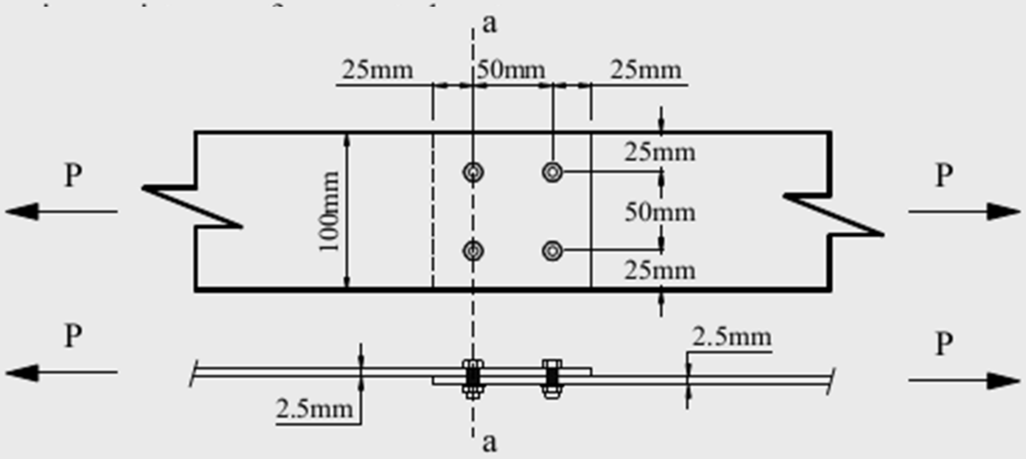


Connections

Design of Connections

- ***EXAMPLE 1: Design resistance of the lap bolted connection in tension***

T(



E

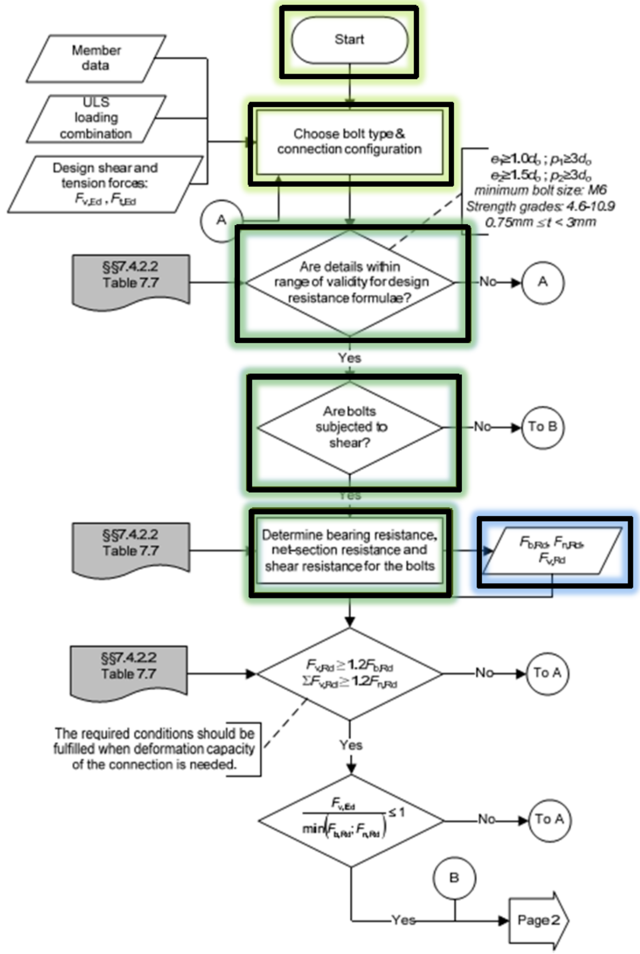
=

= 58.4 kN

$$A_{net} \cdot f_u / \gamma_{M2} = 185\,\text{mm}^2 \times 420\,N/\text{mm}^2 / 1.25/1000 = 62.6\,\text{kN}$$

$$F_{n,Rd} = 58.4\,\text{kN} < 62.6\,\text{kN}$$

The tension resistance of the connected part is governed by the net section resistance of connection.



Connections

Design of Connections

- ***EXAMPLE 1: Design resistance of the lap bolted connection in tension***

Bearing resistance:

$$F_{b,Rd} = 2.5 \cdot \alpha_b \cdot k_t \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

$$= 2.5 \times 0.694 \times 1 \times 420\, N/\text{mm}^2 \times 12\text{mm} \times 2.5\,\text{mm}/1.25/1000 = 17.5\,\text{kN/bolt}$$

where

$k_t = 1.0$ for $t > 1.25$mm

$\alpha_b = \min(1, e_1/(3d)) = \min(1, 25/(3\cdot 12)) = \min(1,\ 0.694) = 0.694$

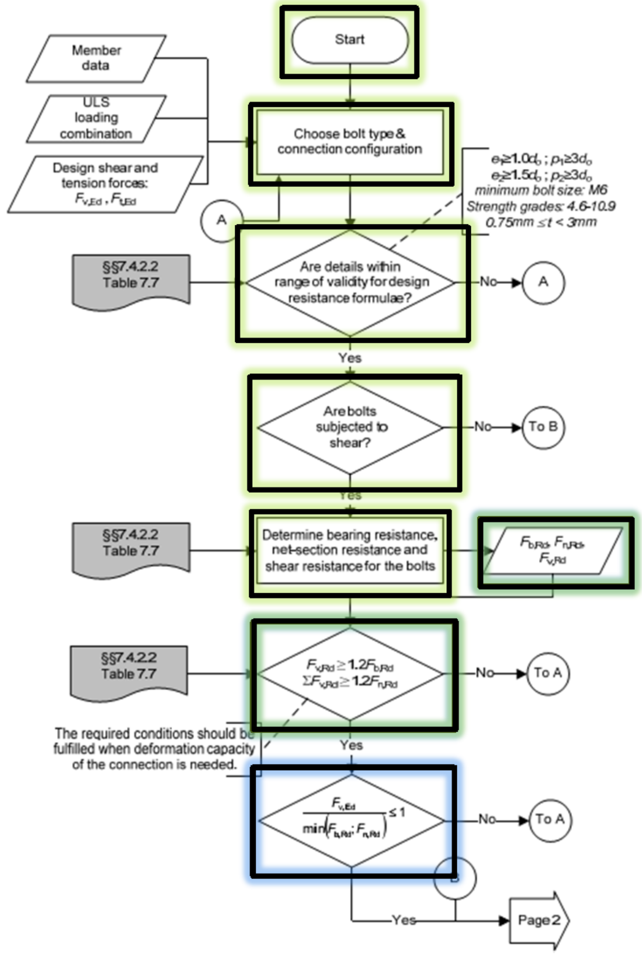
Total bearing resistance = 4 bolts×17.5 kN/bolt = 70 kN.

Shear resistance of bolts:

$$F_{u,Rd} = 0.6 \cdot f_{ub} \cdot A_s / \gamma_{M2}$$

$$= 0.6 \times 800\,\text{N/mm}^2 \times 84.3\,\text{mm}^2 / 1.25/1000 = 32.4\,\text{kN/bolt}$$

Total bolt shear resistance = 4 bolts×32.4 kN/bolt = 129.6 kN > 70 kN



Connections

Design of Connections

- ***EXAMPLE 1: Design resistance of the lap bolted connection in tension***

Bearing resistance:

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where

$k_t = 1.0$ for $t > 1.25$mm

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Total bearing resistance = 4 bolts×17.5 kN/bolt = 70 kN.

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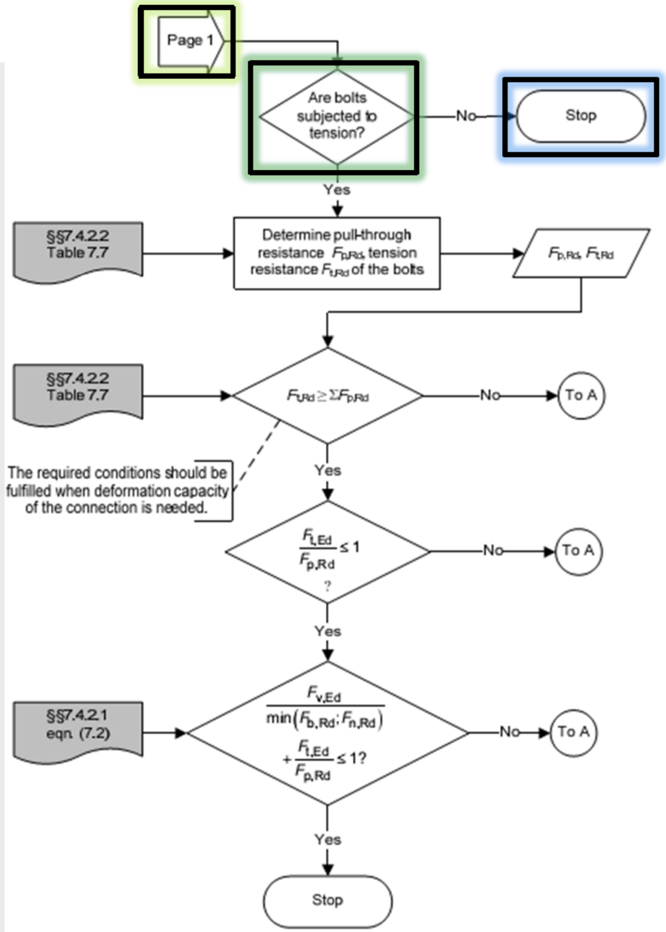
Total bolt shear resistance = 4 bolts×32.4 kN/bolt = 129.6 kN > 70 kN

Conclusions: The net section resistance of the connection governs the connection resistance, $F_{n,Rd} = 58.4\,\text{kN}$.



Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections

    - Design resistance for self-tapping screws (screws loaded in shear)
      - Bearing resistance

        $$F_{b,Rd} = \alpha \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

      - Net-section resistance

        $$F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$$

      - Shear resistance

        $F_{v,Rd}$ to be determined by testing and

        $$F_{v,Rd} = F_{v,Rk} / \gamma_{M2}$$

      - Condition (if deformation capacity is needed)

$$F_{v,Rd} \geq 1.2\, F_{b,Rd} \quad \text{or} \quad \Sigma F_{v,Rd} \geq 1.2\, F_{n,Rd}$$

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections
    - Design resistance for self-tapping screws (screws loaded in tension)
      - Pull-through resistance

- for static loads: $F_{p,Rd} = d_w \cdot t \cdot f_u / \gamma_{M2}$

- for screws subjected to wind loads and combination of wind loads and static loads: $F_{p,Rd} = 0.5 \cdot d_w \cdot t \cdot f_u / \gamma_{M2}$

      - Pull-out resistance

If $t_{sup} / s < 1$: $F_{o,Rd} = 0.45 \cdot d \cdot t_{sup} \cdot f_{u,sup} / \gamma_{M2}$ (s is the thread pitch)

If $t_{sup} / s \geq 1$: $F_{o,Rd} = 0.65 \cdot d \cdot t_{sup} \cdot f_{u,sup} / \gamma_{M2}$

      - Tension resistance

$F_{t,Rd}$ to be determined by testing.

      - Condition (if deformation capacity is needed)

$$F_{t,Rd} \geq \sum F_{p,Rd} \quad \text{or} \quad F_{t,Rd} \geq F_{o,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections
    - Rage of validity

Generally: $e_1 \geq 3 \cdot d$ $p_1 \geq 3 \cdot d$; $3\,\text{mm} \leq d \leq 8\,\text{mm}$; $e_2 \geq 1.5 \cdot d$; $p_2 \geq 3 \cdot d$

For tension: $0.5\,\text{mm} \leq t \leq 1.5\,\text{mm}$ and $t_1 \geq 0.9\,\text{mm}$

$f_u \leq 550\ \text{N/mm}^2$

Pull-through resistance, $F_{p,Rd}$ (kN) for SFS Intec screws

f_y (N/mm^2)	Thickness of the fastened plate, t, in mm									
	0.40	0.50	0.60	0.65	0.70	0.80	0.90	1.00	1.25	1.50
250	1.50	1.88	2.25	2.44	2.63	3.00	3.38	3.75	4.69	5.63
280	1.68	2.10	2.52	2.73	2.94	3.36	3.78	4.20	5.25	6.30
350	2.10	2.63	3.15	3.41	3.68	4.20	4.73	5.25	6.56	7.88

Note: The diameter of washers is d_w=14 mm.

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections

    - Rage of validity

Generally: $e_1 \geq 3 \cdot d$ $\quad p_1 \geq 3 \cdot d$; $3\,\text{mm} \leq d \leq 8\,\text{mm}$; $e_2 \geq 1.5 \cdot d$; $p_2 \geq 3 \cdot d$

For tension: $0.5\,\text{mm} \leq t \leq 1.5\,\text{mm}$ and $t_1 \geq 0.9\,\text{mm}$

$f_u \leq 550\ \text{N/mm}^2$

Pull-out resistance, $F_{o,Rd}$ (kN) for d=5.5 mm SFS Intec screws

f_y (N/mm^2)	t (mm)												
	0.60	0.65	0.70	0.80	0.90	1.00	1.25	1.50	2.00	2.50	3.00	4.00	5.00
270	0.38	0.42	0.47	0.58	0.69	0.81	1.13	1.49	2.29	3.21	4.21	6.49	9.07
320	0.45	0.50	0.56	0.69	0.82	0.96	1.34	1.77	2.72	3.80	4.99	7.69	10.75
350	0.49	0.55	0.62	0.75	0.9	1.05	1.47	1.93	2.97	4.16	5.46	8.41	11.75

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections
    - Pull-through resistance
      - Assume a sheet of steel grade S280GD+Z with f_y= 320 N/mm^2 and f_u = 360 N/mm^2 and consider five different thicknesses i.e. 1) t = 0.4 mm; 2) t = 0.5 mm; 3) t = 0.7 mm; 4) t = 1.0 mm; and 5) t = 1.5 mm. The washer diameter d_w= 14 mm. (static loads only)

t (m[illegible]	$F_{p,Rd}$ (kN)	
	[illegible] $= d_w \cdot t \cdot f_u / \gamma_{M2}$	[illegible]0
0.40	[illegible]	[illegible].68
0.50	[illegible]	2.10
0.70	[illegible]	[illegible]
1[illegible]	4.03	[illegible]
1.5[illegible]	6.05	6.30

for wind loading, the producer values overestimate the resistance

the calculated va[illegible] [illegible]hose offered by producers [illegible]ell

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with self-tapping screws
    - used for thin-to-thin and thin-to-moderate thick connections
    - Pull-out resistance
      - Assume a supporting member of steel grade S350GD+Z with f_y=350N/mm^2 and f_u = 420 N/mm^2, and consider five different thicknesses, i.e. 1) t= 0.6 mm; 2) t= 1.0 mm; 3) t= 1.25 mm; 4) t= 1.5 mm and 5) t= 2.5 mm. The nominal diameter of the screw is d = 5.5 mm.

t (mm)	$F_{o,Rd}$ (kN)	
	$F_{o,Rd} = 0.45 \cdot d \cdot t_{sup} \cdot f_{u,sup} / \gamma_{M2}$	Table 7.11
0.60	0.49	0.49
1.00	0.83	1.05
1.25	1.04	1.47
1.50	1.25	1.93
2.50	2.08	4.16

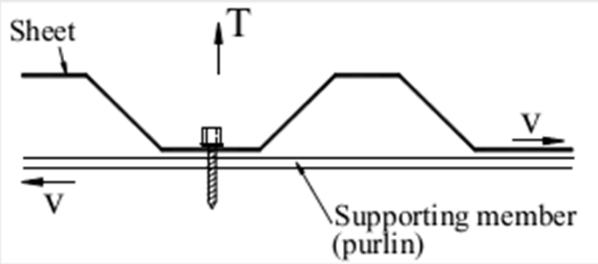
Connections

Design of Connections

- ***EXAMPLE 2: Sheeting-to-purlin connection. Determine the design resistance of the screwed connection of the sheeting on the purlin***

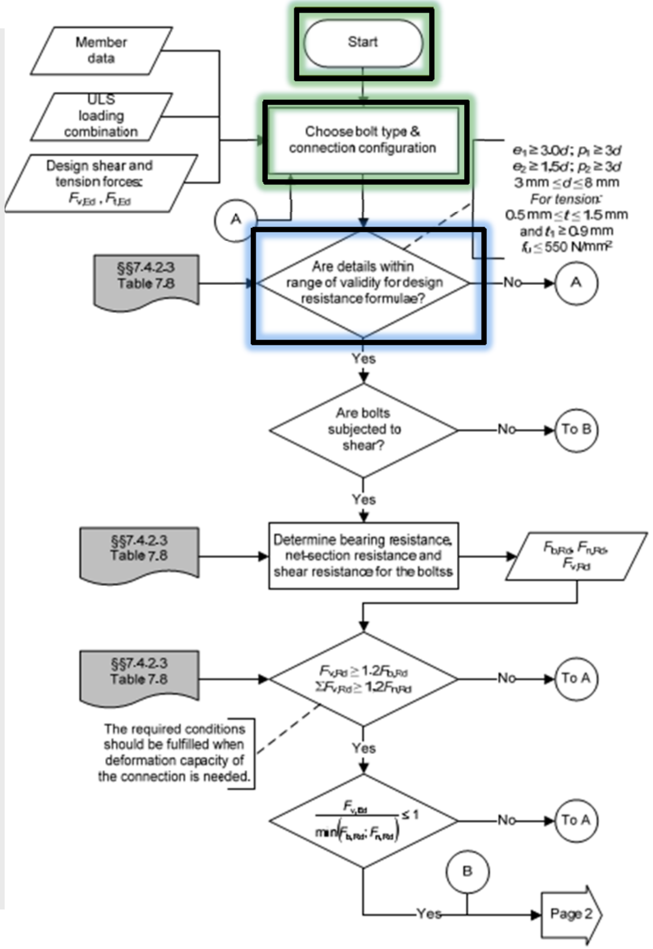
Given:

Sheet material, $t = 0.6$ mm, S250GD+Z: $f_y = 250$ N/mm^2, $f_u = 330$ N/mm^2;
Base material, $t = 2.5$ mm, S350GD+Z: $f_y = 350$ N/mm^2, $f_u = 420$ N/mm^2.
Screw $d = 4.8$ mm, washer $d_w = 16$ mm and $F_{v,Rk} = 5.2$ kN, $F_{t,Rd} = 5.0$ kN.



Distance between centres of fastener: p_1=36mm > 3d
Distance from centre of fastener to the end of part: e_1=36 mm > 3d

Tension Resistance: Tension resistance must be evaluated for pull-through, pull-out, and screw tension resistance.



Connections

Design of Connections

- ***EXAMPLE 2: Sheeting-to-purlin connection. Determine the design resistance of the screwed connection of the sheeting on the purlin***

Pull-through resistance (screws subjected to wind load)

$$F_{p,Rd} = 0.5 \cdot d_w \cdot t \cdot f_u / \gamma_{M2}$$

$$= 0.5 \times 16\,\text{mm} \times 0.6\,\text{mm} \times 330\,\text{N/mm}^2 / 1.25 = 1.27\,\text{kN}$$

Pull-out

$$F_{o,Rd} = 0.65 \cdot d \cdot t_{sup} \cdot f_{u,sup} / \gamma_{M2}$$

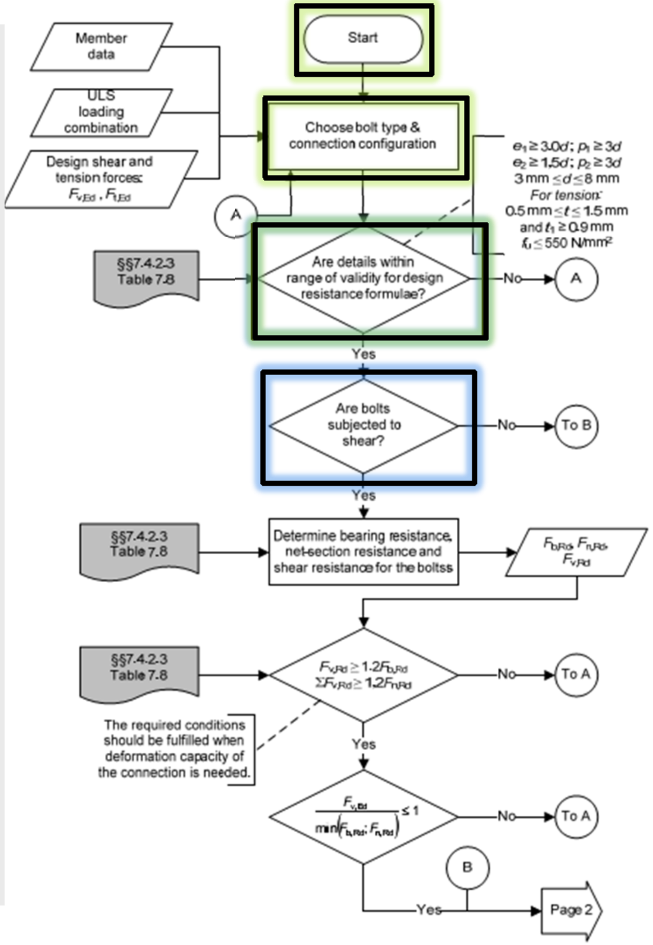
$$= 0.65 \times 4.8\,\text{mm} \times 2.5\,\text{mm} \times 420\,\text{N/mm}^2 / 1.25 = 2.62\,\text{kN}$$

Tension resistance of screw

Consider that one sheet is fixed on the supporting member with the screw

$$F_{t,Rd} \geq F_{p,Rd}$$

The manufacturers tested tension resistance of screw $F_{t,Rd} = 5.0\,\text{kN} > F_{p,Rd} = 1.27\,\text{kN}$, therefore the screw is adequate. Tension resistance is governed by the pull-through of the fastener in the connection.



Connections

Design of Connections

- ***EXAMPLE 2: Sheeting-to-purlin connection. Determine the design resistance of the screwed connection of the sheeting on the purlin***

Bearing resistance:

t=0.6 mm, t_1=2.5 mm

t_1/t=4.17, therefore linear interpolation must be used to determine α.

Because $t_1 \geq 2.5 \cdot t$ and $t < 1.0$ mm: $\alpha = 3.2 \cdot \sqrt{t/d}$ but $\alpha \leq 2.1$

t_1=2.5 mm > 2.5 ×0.6 mm = 1.5 mm, t = 0.6mm < 1.0 mm

$$\Rightarrow \alpha = 3.2 \cdot \sqrt{t/d} = 3.2\sqrt{0.6/4.8} = 1.13 \leq 2.1, \text{ use } \alpha = 1.13$$

$$F_{b,Rd} = \alpha \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

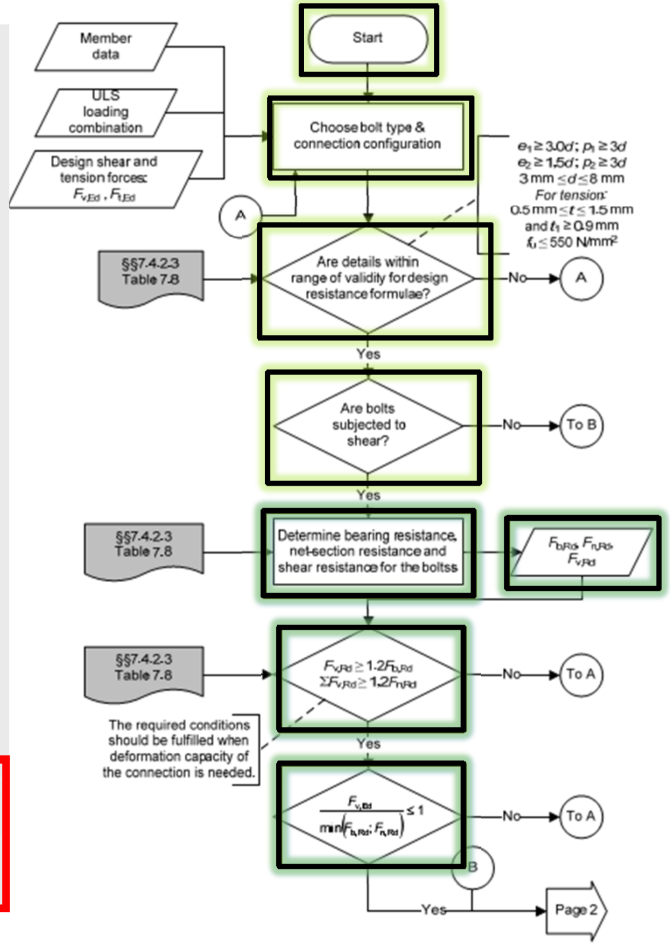
$$= 1.13 \times 330\,\text{N/mm}^2 \times 4.8\,\text{mm} \times 0.6\,\text{mm} / 1.25 = 0.86\,\text{kN/screw}$$

Shear resistance of screw:

$$F_{v,Rd} = F_{v,Rk} / \gamma_{M2} = 5.2\text{kN} / 1.25 = 4.16\text{kN}$$

$$F_{v,Rd} > 1.2 \cdot F_{b,Rd} = 1.2 \times 0.86\text{kN} = 1.03\text{kN/screw}$$

Conclusion: The shear resistance of the connection is governed by the bearing resistance = 1.03 kN. The tension resistance of the connection is governed by the pull-through resistance = 1.27 kN.



Connections

Design of Connections

- ***EXAMPLE 3: Sheeting-to-sheeting seam connection in shear – the shear resistance capacity of 1m length seam fastener line***

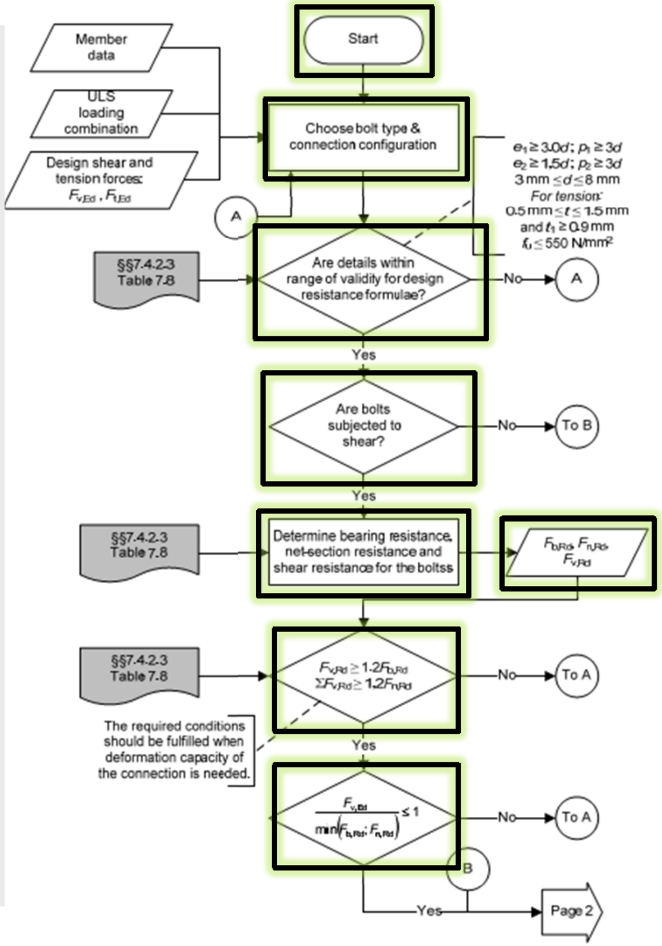
When sheeting is acting as a diaphragm, the seam connectors are working in shear. The shear performance of the diaphragm is strongly dependent on the seam fastening performance, which usually is the weakest component of the system. Figure 7.35 shows a decking system with seam and edge connections. The floor decking system is assumed to be covered with corrugated sheet of 0.7 mm thickness and with a steel grade of S350GD+Z (f_y = 350 N/mm^2 and f_u = 420 N/mm^2). Seam fastening is realized with d = 4.8 mm self-tapping screws, d_w = 16 mm, $F_{v,Rd}$ = 4.2 kN, $F_{t,Rd}$ = 5.0 kN. Four seam fasteners are installed per meter along the seam line.

Determine the shear resistance capacity of 1m length seam fastener line.

Bearing resistance (shear of sheeting and fastener tilting)

$$t = t_1 = 0.7 \text{ mm}$$

$$t/t_1 = 1.0;\ \alpha = 3.2 \cdot \sqrt{t/d} = 3.2\sqrt{0.7/4.8} = 1.22 < 2.1$$



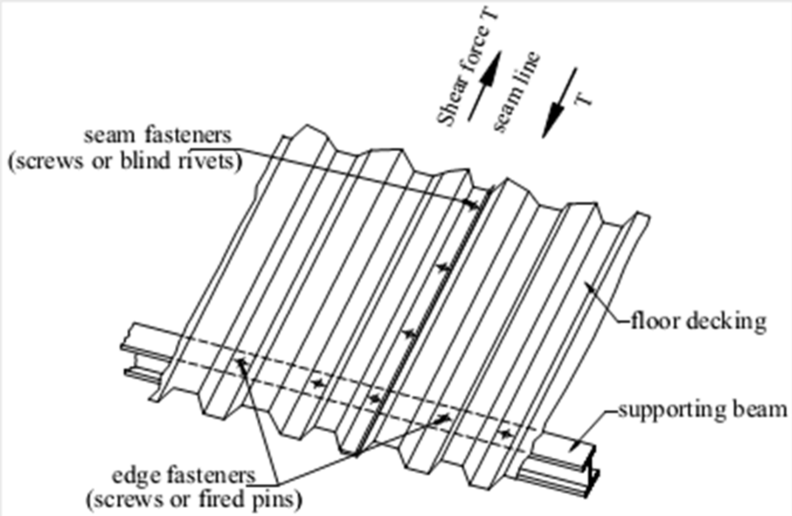
Connections

Design of Connections

- *EXAMPLE 3: Sheeting-to-sheeting seam connection in shear*

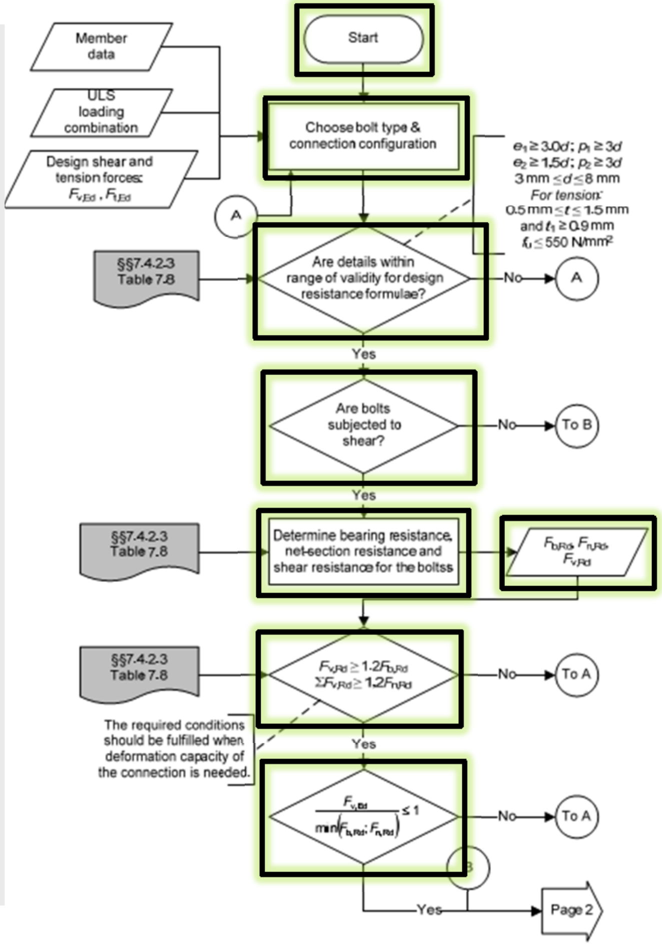
$$F_{b,Rd} = \alpha \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

$$= 1.22 \times 420\,\text{N/mm}^2 \times 4.8\,\text{mm} \times 0.7\,\text{mm} / 1.25 = 1.38\,\text{kN/screw} < 4.2\,\text{kN}$$



The shear resistance capacity of one meter length of seam fastener line is:

4 screws/m × 1.38 kN/screw=5.52 kN/m.



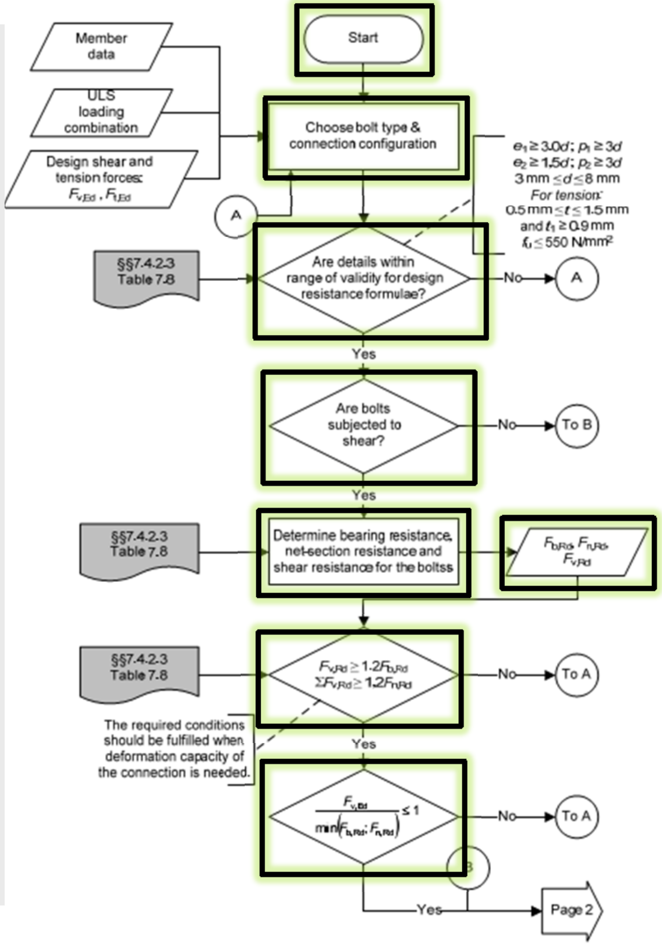
Connections

Design of Connections

- ***EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud***

Basic Data

Nominal diameter of the screw	$d = 6.3$ mm
Total number of screws	$n_f = 4$
End and edge distance for screw	$e_1 = 20$ mm ; $e_2 = 25$ mm
Spacing of screws	$p_1 = 25$ mm
The dimensions of the stud cross section are:	
Total height	$h_1 = 150$ mm
Total width of flange	$b_1 = 50$ mm
Total width of edge fold	$c_1 = 17.5$ mm
Nominal thickness	$t_{1,nom} = 2.0$ mm
Steel core thickness	$t_1 = 1.96$ mm
Gross area of the stud cross section:	$A_1 = 543$ mm^2
The dimensions of the rail cross section:	
Total height	$h = 155$ mm
Total width of flange	$b = 70$ mm
Nominal thickness	$t_{nom} = 1.5$ mm
Steel core thickness	$t = 1.46$ mm

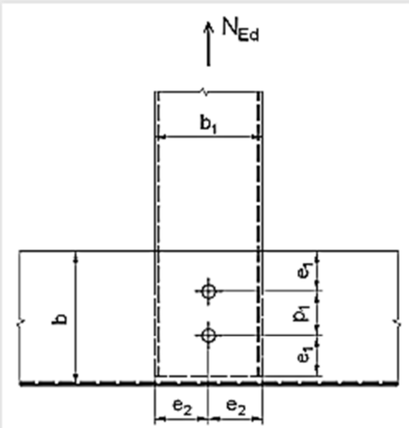


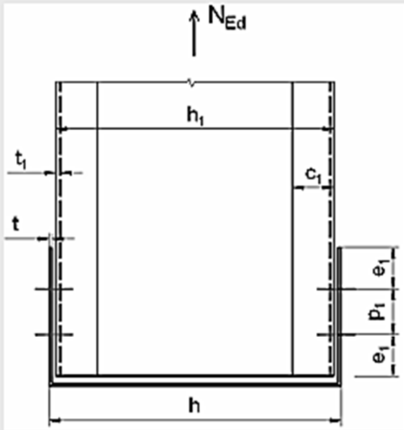
Connections

Design of Connections

- *EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud*

Basic Data

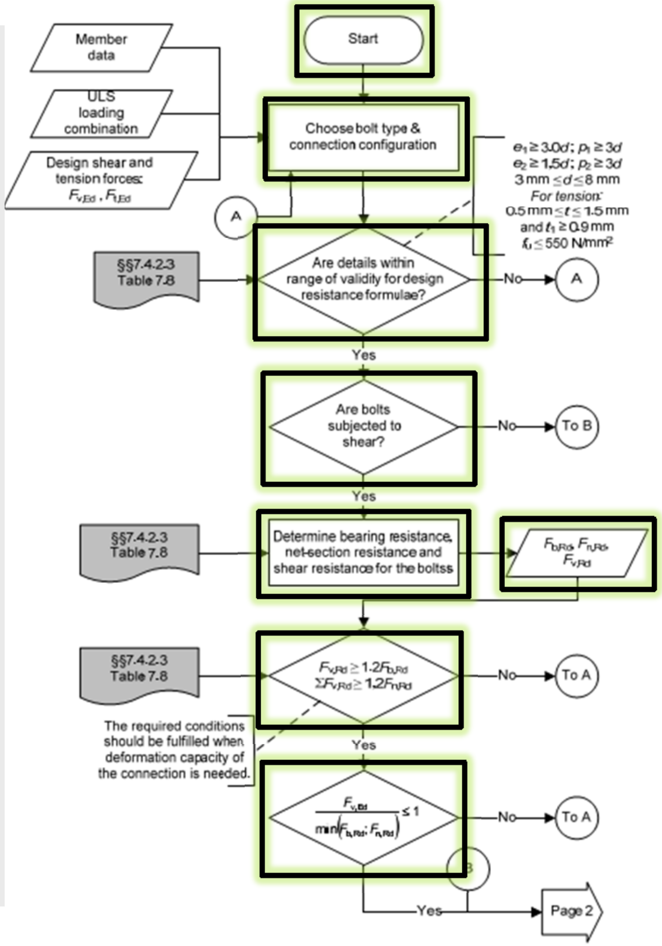




The material properties are (S320GD+Z):

Basic yield strength	$f_{yb} = 320\ \text{N/mm}^2$
Ultimate strength	$f_u = 390\ \text{N/mm}^2$
Modulus of elasticity	$E = 210000\ \text{N/mm}^2$
Poisson's ratio	$\nu = 0.3$

The design force on the connection is: $N_{Ed} = 17.6\ \text{kN}$.



Connections

Design of Connections

- ***EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud***

Net-section resistance:

$$F_{n,Rd} = \frac{A_{net} f_u}{\gamma_{M2}}$$

where the net cross sectional area is:

$$A_{net} = A_1 - 2dt_1 = 543 - 2 \times 6.3 \times 1.96 = 518.3\ \text{mm}^2$$

The net-section resistance is:

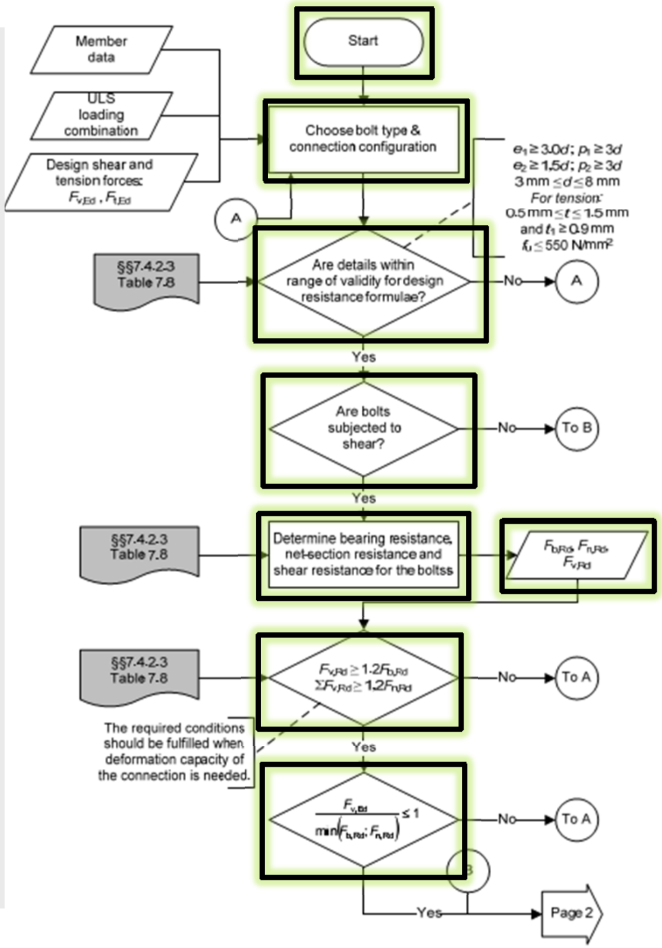
$$F_{n,Rd} = \frac{A_{net} f_u}{\gamma_{M2}} = \frac{518.3 \times 390}{1.25} = 161711\ \text{N} = 161.71\text{kN}$$

Shear resistance

$$F_{v,Rd} = F_{v,Rk} / \gamma_{M2}$$

$$F_{v,Rk} = 13500\ \text{N}\ \ \text{(according to manufacturer catalogue)}$$

$$F_{v,Rd} = F_{v,Rk} / \gamma_{M2} = 13500/1.25 = 10800\ \text{N} = 10.8\ \text{kN}$$



Connections

Design of Connections

- ***EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud***

The design shear force per screw in the ultimate limit state is: $F_{v,Ed} = N_{Ed}/n_f = 17.6/4 = 4.4\ \text{kN}$.

Check the range of validity for design resistance formulas

The following conditions should be satisfied:

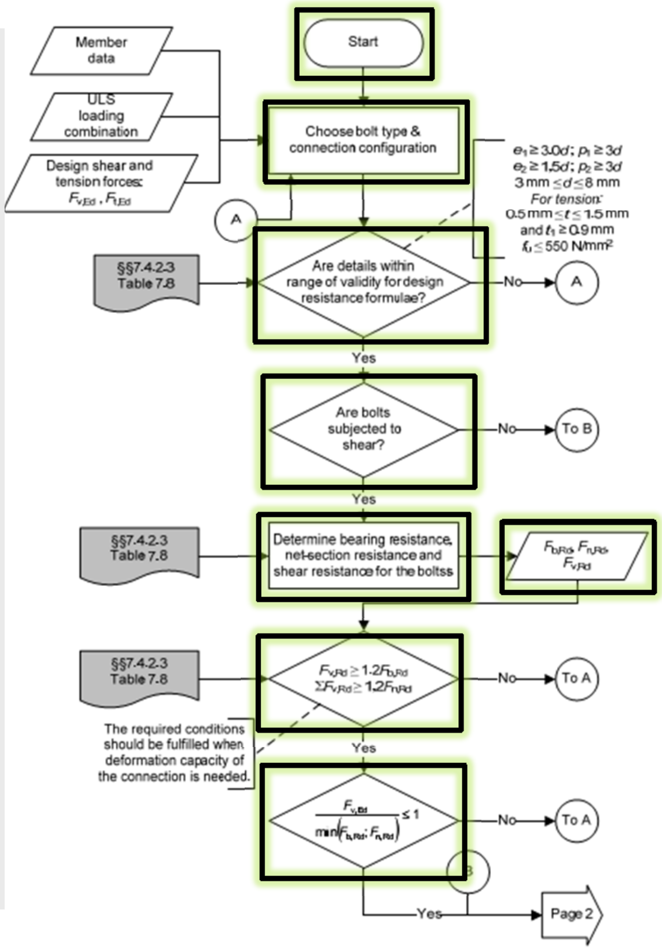
$$e_1 \geq 3d \quad ; \quad p_1 \geq 3d \quad ; \quad e_2 \geq 1.5d \quad ; \quad 3.0\,\text{mm} \leq d \leq 8.0\,\text{mm}$$

$e_1 = 20\ \text{mm} \quad > \quad 3d = 3 \times 6.3 = 18.9\ \text{mm}$ OK

$e_2 = 25\ \text{mm} \quad > \quad 1.5d = 1.5 \times 6.3 = 9.45\ \text{mm}$ OK

$p_1 = 25\ \text{mm} \quad > \quad 3d = 3 \times 6.3 = 18.9\ \text{mm}$ OK

$3.0\,\text{mm} \quad < \quad d = 6.3\,\text{mm} \quad < \quad 8.0\ \text{mm}$ OK



Connections

Design of Connections

- ***EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud***

Resistance check for self-tapping screws loaded in shear

Bearing resistance

$$F_{b,Rd} = \frac{\alpha f_u d t}{\gamma_{M2}}$$

where:

$t < t_1 < 2.5t$ so α is obtained by linear interpolation:

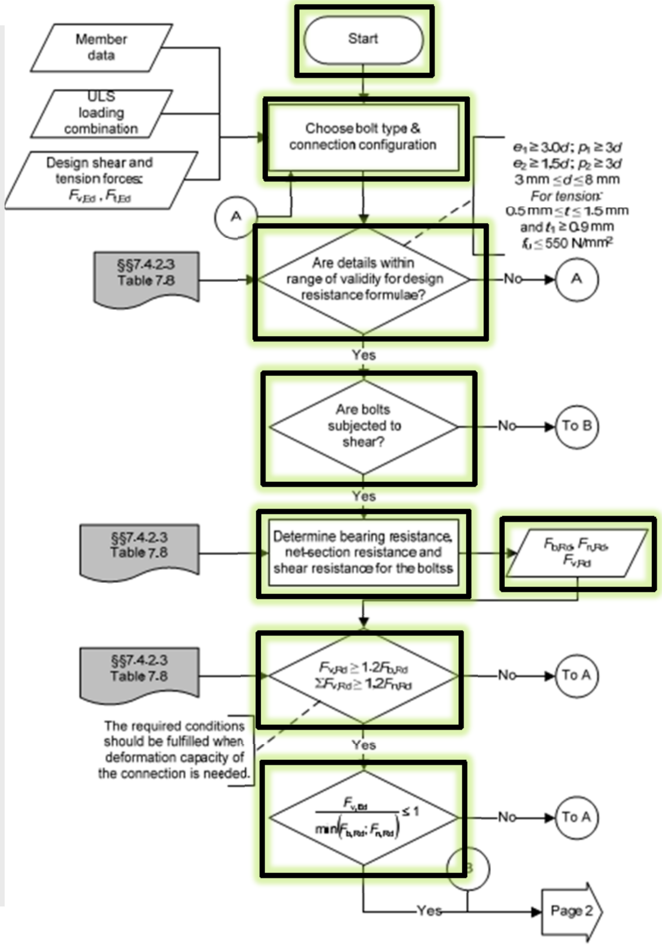
for $t_1 = t$: $\alpha = 3.2\sqrt{t/d} = 3.2 \times \sqrt{1.16/6.3} = 1.54$

for $t_1 \geq 2.5t$ and $t \geq 1.0$ mm : $\alpha = 2.1$

$\Rightarrow$ for $t_1/t = 1.96/1.46 = 1.342$, by linear interpolation: $\alpha = 1.683$

The bearing resistance of one screw is:

$$F_{b,Rd} = \frac{\alpha f_u d t}{\gamma_{M2}} = \frac{1.683 \times 390 \times 6.3 \times 1.46}{1.25} = 4830 \text{ N} = 4.83 \text{ kN}$$



Connections

Design of Connections

- ***EXAMPLE 4: Design resistance of a screwed connection of cold-formed members. Screwed connection of a lipped channel section wall stud***

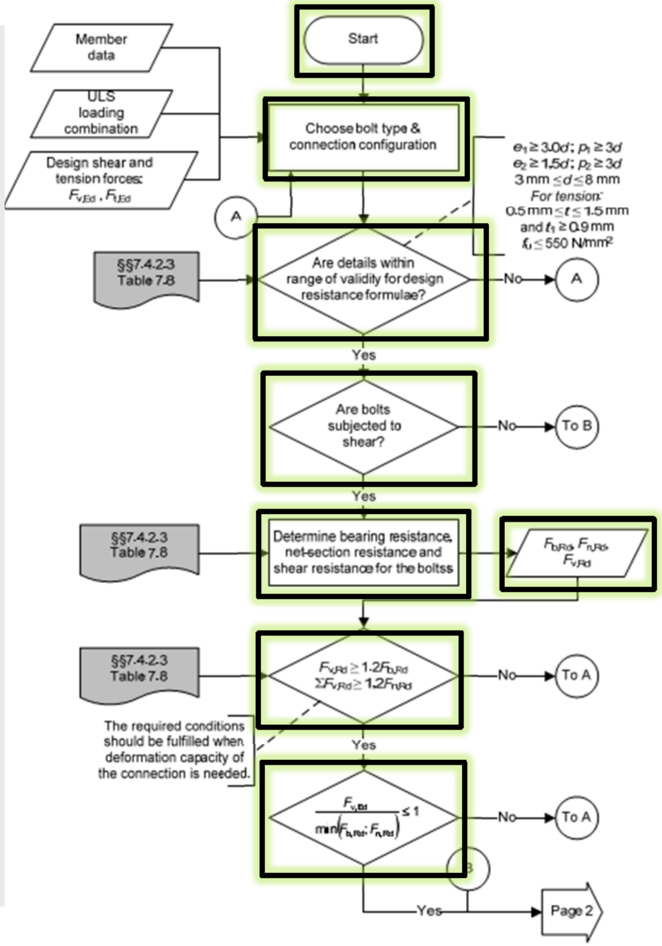
When deformation capacity of the connection is needed, the shear resistance should satisfy the following conditions (not required for this example): $F_{n,Rd}$

$$F_{v,Rd} \geq 1.2\, F_{b,Rd} \text{ or } \sum F_{v,Rd} \geq 1.2\, F_{n,Rd}$$

The resistance of a fastener in shear may be verified using:

$$\frac{F_{v,Ed}}{\min\left(F_{b,Rd};\, F_{n,Rd}/n_f;\, F_{v,Rd}\right)} \leq 1$$

$$\frac{4.40}{\min\left(4.83;\, 161.71;\, 10.8\right)} = \frac{4.40}{4.83} = 0.911 < 1 \qquad \text{OK}$$



- Design of connections with mechanical fasteners
  - Design of connections with blind rivets
    - used for thin-to-thin connections mainly as seam fasteners for sheeting panels
    - work in shear and/or tension
    - Design resistance for blind rivets (rivets loaded in shear)
      - Baring resistance

$$F_{b,Rd} = \alpha \cdot f_u \cdot d \cdot t / \gamma_{M2} \quad \text{but} \quad F_{b,Rd} \leq f_u \cdot e_1 \cdot t / (1.2 \cdot \gamma_{M2})$$

      - Net-section resistance

$$F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$$

      - Shear resistance

$F_{v,Rd}$ to be determined by testing and $F_{v,Rd} = F_{v,Rk} / \gamma_{M2}$

      - Condition (if deformation capacity is needed)

$$F_{v,Rd} \geq 1.2 \cdot F_{b,Rd} / (n_f \cdot \beta_{Lf}) \quad \text{or} \quad F_{v,Rd} \geq 1.2 \cdot F_{n,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with blind rivets
    - used for thin-to-thin connections mainly as seam fasteners for sheeting panels
    - work in shear and/or tension
    - Design resistance for blind rivets (rivets loaded in tension – not usual)
      - Pull-through resistance

        Pull-through resistance $F_{p,Rd}$ to be determined by testing
      - Pull-out resistance

        Not relevant
      - Tension resistance

        $F_{t,Rd}$ to be determined by testing.
      - Condition

$$F_{t,Rd} \geq \sum F_{p,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with blind rivets
    - used for thin-to-thin connections mainly as seam fasteners for sheeting panels
    - work in shear and/or tension
    - Range of validity

$e_1 \geq 1.5 \cdot d$ $\quad p_1 \geq 3 \cdot d$ $\quad 2.6\,\text{mm} \leq d \leq 6.4\,\text{mm}$

$e_2 \geq 1.5 \cdot d$ $\quad p_2 \geq 3 \cdot d$ $\quad f_u \leq 550\ \text{N/mm}^2$

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with fired pins
    - used for thin-to-thick connections (usually to fasten roof and floor decking)

    - Design resistance for cartridge fired pins (pins loaded in shear)
      - Bearing resistance

$$F_{b,Rd} = 3.2 \cdot f_u \cdot d \cdot t / \gamma_{M2}$$

      - Net section resistance

$$F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$$

      - Shear resistance

$F_{v,Rd}$ to be determined by testing and $F_{v,Rd} = F_{v,Rk} / \gamma_{M2}$

      - Condition (if deformation capacity is needed)

$$F_{v,Rd} \geq 1.5 \cdot \sum F_{b,Rd} \quad \text{or} \quad F_{v,Rd} \geq 1.5 \cdot F_{n,Rd}$$

Connections

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with fired pins
    - used for thin-to-thick connections (usually to fasten roof and floor decking)

    - Design resistance for blind rivets (pins loaded in tension – not usual)
      - Pull-through resistance

      - for static loads: $F_{p,Rd} = d_w \cdot t \cdot f_u / \gamma_{M2}$

      - for wind loads and combination of wind loads and static loads:

      $$F_{p,Rd} = 0.5 \cdot d_w \cdot t \cdot f_u / \gamma_{M2}$$

      - Pull-out resistance

      $F_{o,Rd}$ to be determined by testing

      - Tension resistance

      $F_{t,Rd}$ to be determined by testing

      - Condition

$$F_{o,Rd} \geq \sum F_{p,Rd} \quad \text{or} \quad F_{t,Rd} \geq F_{o,Rd}$$

Design of Connections

- Design of connections with mechanical fasteners
  - Design of connections with fired pins
    - used for thin-to-thick connections (usually to fasten roof and floor decking)

    - Range of validity

Generally:

$e_1 \geq 4.5 \cdot d$ $\qquad 3.7\,\text{mm} \leq d \leq 6.0\,\text{mm}$

$e_2 \geq 4.5 \cdot d$ $\qquad$ for $d = 3.7\,\text{mm}; t_{sup} \geq 4.0\,\text{mm}$

$p_1 \geq 4.5 \cdot d$ $\qquad$ for $d = 4.5\,\text{mm}; t_{sup} \geq 6.0\,\text{mm}$

$p_2 \geq 4.5 \cdot d$ $\qquad$ for $d = 5.2\,\text{mm}; t_{sup} \geq 8.0\,\text{mm}$

$f_u \leq 550\ \text{N/mm}^2$

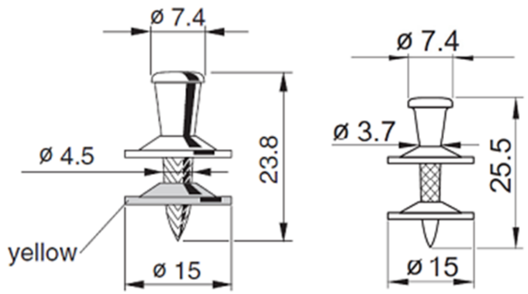
For tension: $0.5\,\text{mm} \leq t \leq 1.5\,\text{mm}$ $\qquad t_{sup} \geq 6.0\,\text{mm}$

Connections

Design of Connections

- **Design of connections with mechanical fasteners**
  - **Design of connections with fired pins**

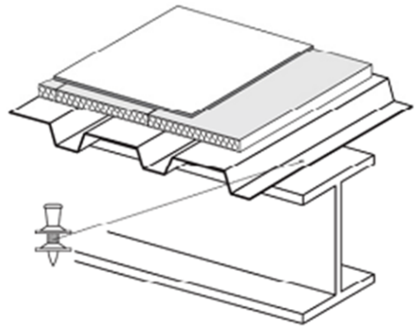
X – ENP Siding and Decking Nail



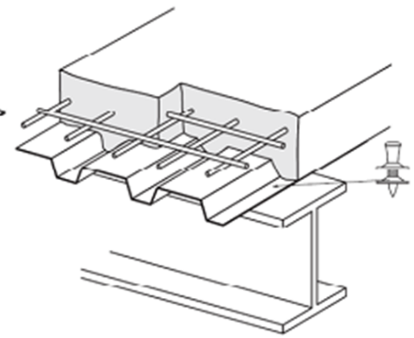
Carbon steel shank: HRC 58
Zinc coating: 8 – 16 µm

(www.hilti.com)

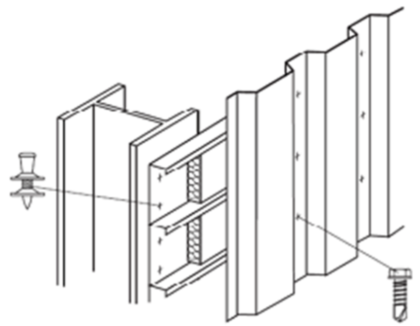
Roof decking



Floor decking



Wall liners



Connections

Design of Connections

- **Design of connections with mechanical fasteners**
  - **Design of connections with fired pins**

X – ENP Siding and Decking Nail

Roof decking

Floor decking

Characteristic loads – steel sheeting

Sheeting thickness t_I [mm]	Trapezoidal profile (symmetric loading) Char. resistance according to ETA-04/0101		Liner trays [1] (asymmetric loading) Char. resistance keeping to ETA-04/0101	
nominal	**Shear** V_{Rk} [kN]	**Tension** N_{Rk} [kN]	**Shear** V_{Rk} [kN]	**Tension** N_{Rk} [kN]
0.75	4.70	6.30	3.30	4.40
0.88	5.40	7.20	3.80	5.00
1.00	6.00	8.00	4.20	5.60
1.13	7.00	8.40	4.90	5.90
1.25	8.00	8.80	5.60	6.20
1.50	8.60	8.80	6.00	6.20
1.75	8.60	8.80	6.00	6.20
2.00	8.60	8.80	6.00	6.20
2.50	8.60	8.80	6.00	6.20

- N_{Rk} and V_{Rk} are valid for steel sheet with minimum tensile strength ≥ 360 N/mm² (≥ S280 EN 10326).
- For intermediate sheet thicknesses, use recommended load for next smaller thickness or linear interpolation.

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Connections

Design of Connections

- **Design of connections with mechanical fasteners**
  - **Design of connections with fired pins**

X – ENP Siding and Decking Nail

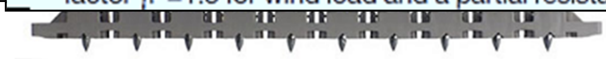
Roof decking

Floor decking

Recommended loads – steel sheeting

Sheeting thickness t_I [mm] nominal	Trapezoidal profile (symmetric loading) Recommended loads Shear V_{rec} [kN]	Tension N_{rec} [kN]	Liner trays [1] (asymmetric loading) Recommended loads Shear V_{rec} [kN]	Tension N_{rec} [kN]
0.75	2.50	3.35	1.75	2.35
0.88	2.90	3.85	2.00	2,70
1.00	3.20	4.25	2.25	3.00
1.13	3.75	4.50	2.65	3.15
1.25	4.25	4.70	3.00	3.30
1.50	4.60	4.70	3.20	3.30
1.75	4.60	4.70	3.20	3.30
2.00	4.60	4.70	3.20	3.30
2.50	4.60	4.70	3.20	3.30

- N_{rec} and V_{rec} are valid for steel sheet with minimum tensile strength ≥ 360 N/mm² (≥ S280 EN 10326).
- For intermediate sheet thicknesses, use recommended load for next smaller thickness or linear interpolation.
- Recommended loads N_{rec} and V_{rec} are appropriate for Eurocode 1 wind loading design with a partial safety factor γ_F =1.5 for wind load and a partial resistance factor γ_M = 1.25 for the fastening.



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Connections

Design of Connections

- **Design of welded connections**
  - **General design and workmanship consideration**

EN1993-1-3 (CEN, 2006a) provides procedures to calculate the resistances of spot welds, fillet welds and arc spot welds. The provisions will be presented in the following paragraphs §§7.4.3.2 to §§7.4.3.4. They apply to thin materials only ($t < 3$ mm for spot welds, or $t < 4$ mm for fillet and arc spot welds). For thicker materials ($t > 4$ mm) the welds have to be designed according to EN1993-1-8 (CEN, 2005e), which provides design procedures for welded connections (that are not presented in this book). EN1993-1-8 also refers to groove butt and flare groove bevel welds.

  - **main difference between the strength of a welded connection in cold-formed steel and a welded connection in hot-rolled steel is the dominance of sheet/weld tearing as failure mode in cold-formed steel connections**

Connections

Design of Connections

- Design of welded connections
  - General design and workmanship consideration
    - generally, the design is limited by the tearing of the base metal
    - design project specifications must stipulate details pertaining to welded connections that require special loading procedures, special levels of quality control, special inspection procedures, or special tests procedures
    - welding of steel sheets shall not be done when the ambient temperature is lower than –30^{o}C or when the surfaces are wet
    - visual inspection is always necessary

- Design of welded connections
  - Design of spot welds
    - resistance welded or fusion welded
    - generally made using an arc welding procedure
    - may be used as rolled or galvanised parent material up to 4.0 mm thick, provided that the thinner connected part is not more than 3.0mm thick

Connections

Design of Connections

- Design of welded connections
  - Design of spot welds
    - Design resistance for spot welds
      - Tearing and bearing resistance
        - if $t \leq t_1 \leq 2.5t$ $\quad F_{tb,Rd} = 2.7 \cdot \sqrt{t} \cdot d_s \cdot f_u / \gamma_{M2}$ [with t in mm]
        - if $t_1 \geq 2.5t$

        $F_{tb,Rd} = 2.7 \cdot \sqrt{t} \cdot d_s \cdot f_u / \gamma_{M2}$, but $F_{tb,Rd} \leq 0.7 \cdot d_s^2 \cdot f_u / \gamma_{M2}$ and $F_{tb,Rd} \leq 3.1 \cdot t \cdot d_s \cdot f_u / \gamma_{M2}$

      - End resistance

        $F_{e,Rd} = 1.4 \cdot t \cdot e_1 \cdot f_u / \gamma_{M2}$

      - Net section resistance

        $F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$

      - Shear resistance

        $$F_{v,Rd} = \frac{\pi}{4} \cdot d_s^2 \cdot f_u / \gamma_{M2}$$

      - Conditions

        $F_{v,Rd} \geq 1.25 \cdot F_{tb,Rd}$ or $F_{v,Rd} \geq 1.25 \cdot F_{e,Rd}$ or $\sum F_{v,Rd} \geq 1.25 \cdot F_{n,Rd}$

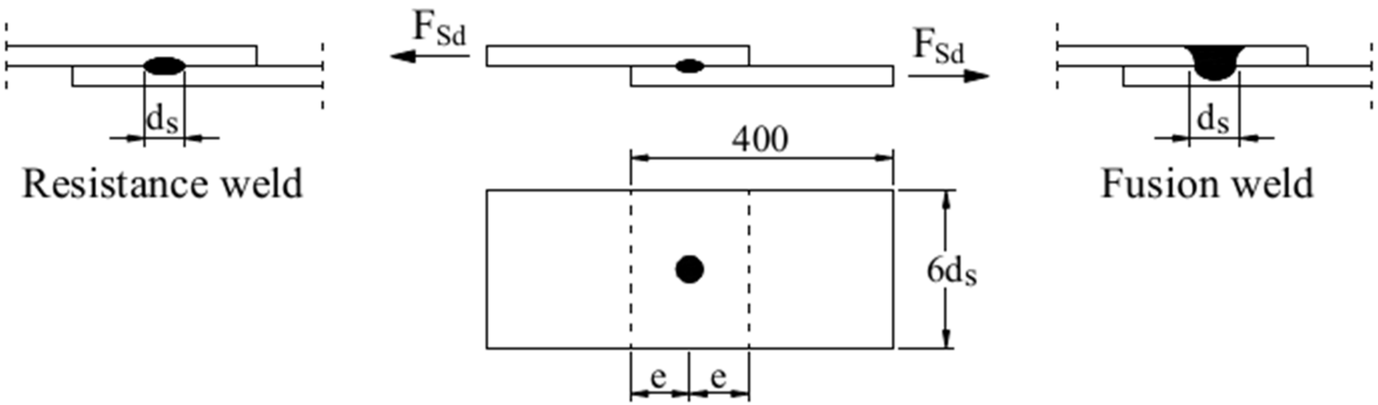
Connections

Design of Connections

- Design of welded connections
  - Design of spot welds
    - Design resistance for spot welds
      - Range of validity

$$2 \cdot d_s \leq e_1 \leq 6 \cdot d_s$$
$$e_2 \leq 4 \cdot d_s$$

$$3 \cdot d_s \leq p_1 \leq 8 \cdot d_s$$
$$3 \cdot d_s \leq p_2 \leq 6 \cdot d_s$$



Design of Connections

- Design of welded connections
  - Design of fillet lap welds
    - The procedure shall be used for the design of arc-welded lap welds where the parent material is 4.0 mm thickness or less
    - The weld size shall be chosen such that the resistance of the connection is governed by the thickness of the connected part or sheet.

Connections

Design of Connections

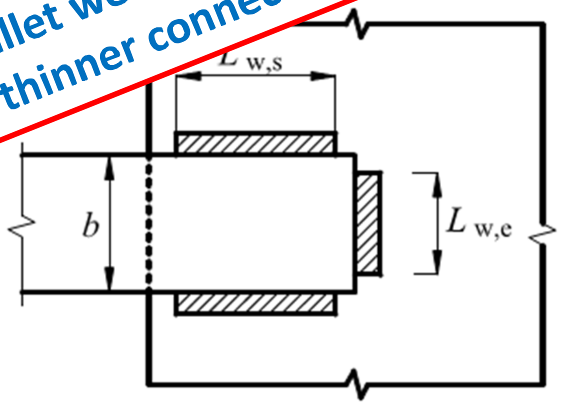
- **Design of welded connections**
  - **Design of fillet lap welds**
    - **The design resistance**
    - for a side fillet that is one of a pair of side fillets:

$$F_{w,Rd} = t \cdot L_{w,s} \cdot (0.9 - 0.45 \cdot L_{w,s} / b) \cdot f_u / \gamma_{M_2}$$

$$F_{w,Rd} = 0.45 \cdot t \cdot b \cdot f_u / \gamma_{M_2}$$ ... $L_{w,s} > b$

- for end fillet:

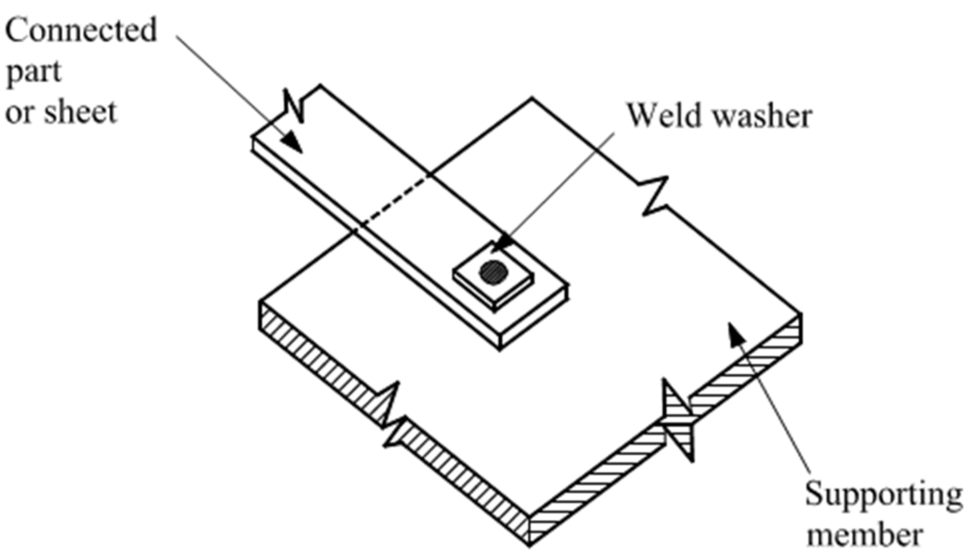
$$F \ldots {}_{w,e} / b) \cdot f_u / \gamma_{M_2}$$



for one weld and if $L_{w,s} \leq b$

Fillet welds with effective lengths less than 8 times the thickness of the thinner connected part should not be designed to transmit any forces.

- **Design of welded connections**
  - **Design of arc spot welds**
    - **often made by melting through the top sheet and fusing the sheets together with additional filler metal**
    - **should have an interface diameter d_s of not less than 10 mm**



end and edge distance

- if $f_u / f_y < 1.15$

$$e_{min} = 1.8 \cdot \frac{F_{w,Sd}}{t \cdot f_u / \gamma_{M2}}$$

- if $f_u / f_y \geq 1.15$

$$e_{min} = 2.1 \cdot \frac{F_{w,Sd}}{t \cdot f_u / \gamma_{M2}}$$

$F_{w,Sd}$ is the design stress (load)

Design of Connections

- **Design of welded connections**
  - **Design of arc spot welds**
    - **Circular arc spot welds**
      - **The design shear resistance**

$$F_{w,Rd} = (\pi / 4) \cdot d_s^2 \cdot 0.625 \cdot f_{uw} / \gamma_{M_2}$$

where

f_{uw} is the ultimate tensile strength of the welding electrodes.

- if $d_p / \Sigma t \leq 18 \cdot (420 / f_u)^{0.5}$:

$$F_{w,Rd} = 1.5 \cdot d_p \cdot \Sigma t \cdot f_u / \gamma_{M2}$$

- if $18 \cdot (420 / f_u)^{0.5} < d_p / \Sigma t < 30 \cdot (420 / f_u)^{0.5}$:

$$F_{w,Rd} = 27 \cdot (420 / f_u)^{0.5} \cdot (\Sigma t)^2 \cdot f_u / \gamma_{M2}$$

- if $d_p / \Sigma t \geq 30 \cdot (420 / f_u)^{0.5}$:

$$F_{w,Rd} = 0.9 \cdot d_p \cdot \Sigma t \cdot f_u / \gamma_{M2}$$

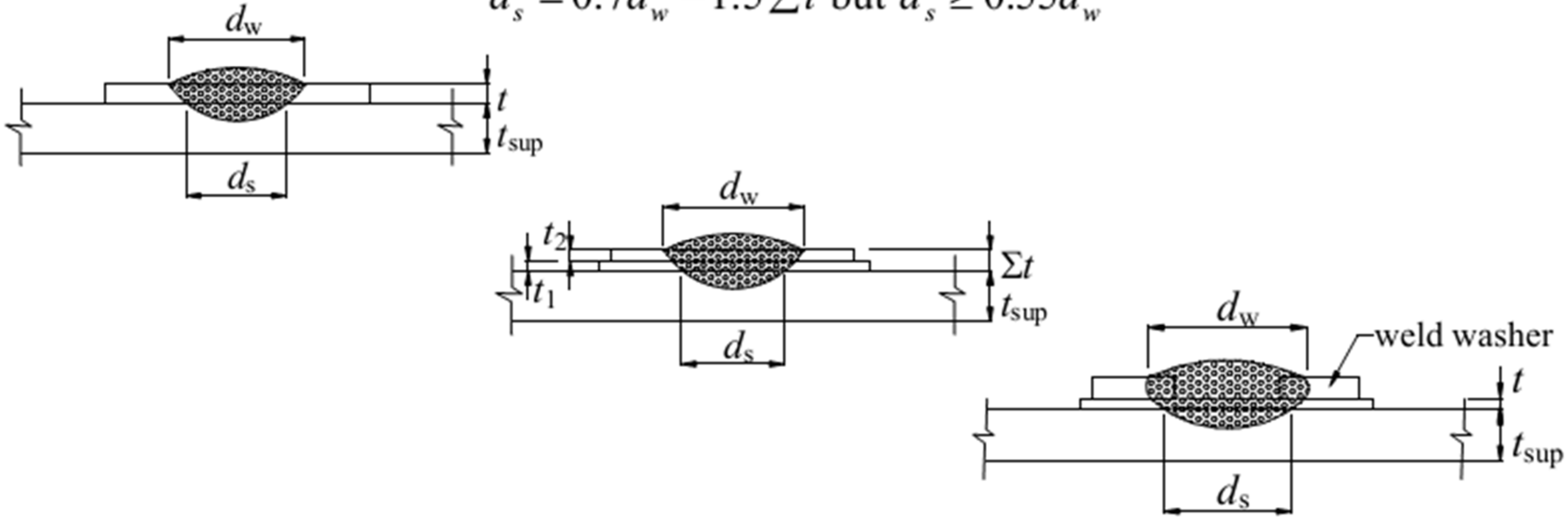
- Design of welded connections
  - Design of arc spot welds
    - Circular arc spot welds
      - The design shear resistance

$$F_{w,Rd} = (\pi / 4) \cdot d_s^2 \cdot 0.625 \cdot f_{uw} / \gamma_{M_2}$$

where

f_{uw} is the ultimate tensile strength of the welding electrodes.

$$d_s = 0.7 d_w - 1.5 \sum t \text{ but } d_s \geq 0.55 d_w$$



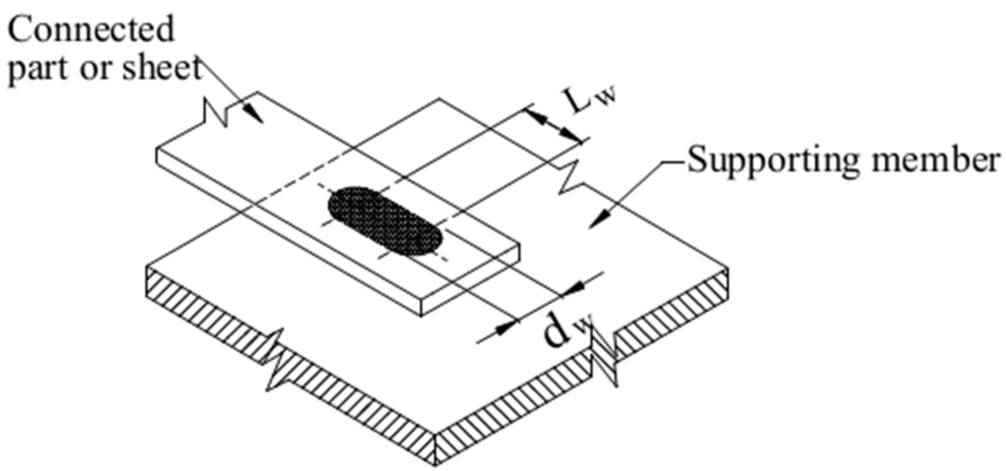
Connections

Design of Connections

- Design of welded connections
  - Design of arc spot welds
    - Elongated arc spot weld
      - The design shear resistance

$$F_{w,Rd} = [(\pi/4)\cdot d_s^2 + L_w \cdot d_s]\cdot 0.625 \cdot f_{uw}/\gamma_{M2}$$

$$F_{w,Rd} = (0.5\cdot L_w + 1.67\cdot d_p)\cdot \Sigma t \cdot f_u/\gamma_{M2}$$



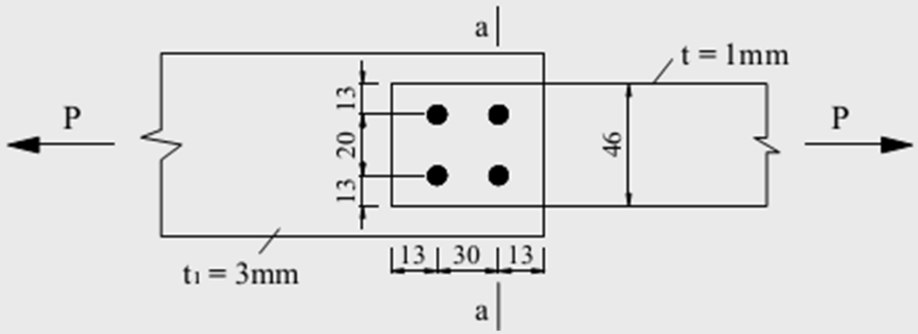
Connections

Design of Connections

- ***EXAMPLE 5: Resistance of the spot weld lap joint***

Given: Base material, Steel grade S355 MC, f_y=355 N/mm^2, f_u=430 N/mm^2 of thickness t = 1.0 mm and t_1 = 3.0 mm;

Fusion welds: d_s=0.5·t + 5mm = 5.5 mm.



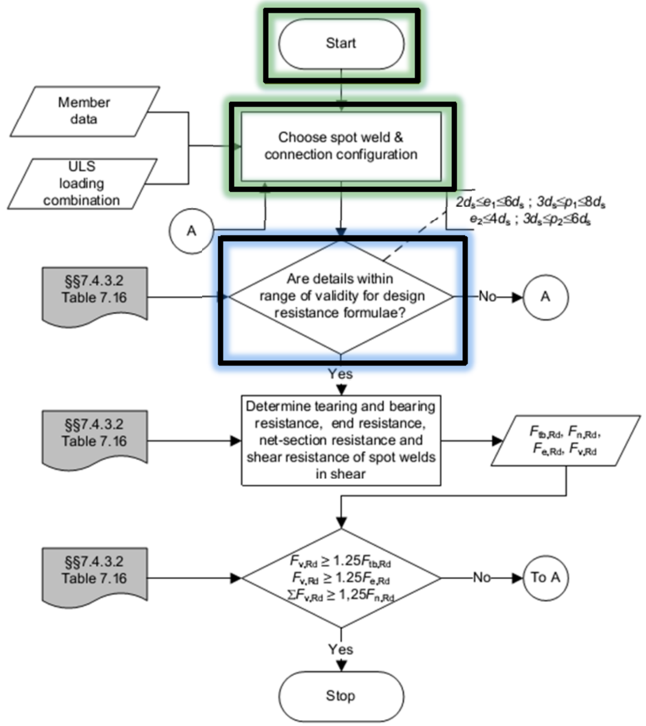
Weld position:

$$2 \cdot d_s = 11\,\text{mm} < e_1 = 13\,\text{mm} < 6 \cdot d_s = 33\,\text{mm}$$

$$e_2 = 13\,\text{mm} < 4 \cdot d_s = 22\,\text{mm}$$

$$3 \cdot d_s = 16.5\,\text{mm} < p_1 = 30\text{mm} < 8 \cdot d_s = 44\,\text{mm}$$

$$3 \cdot d_s = 16.5\,\text{mm} < p_2 = 20\text{mm} < 6 \cdot d_s = 33\,\text{mm}$$



Connections

Design of Connections

- *EXAMPLE 5: Resistance of the spot weld lap joint*

Tearing and bearing resistance:

$$t = 1.0\,\text{mm};\ t_1 = 3.0\,\text{mm and } t_1 > 2.5t$$

$$F_{tb,Rd} = 2.7 \cdot \sqrt{t} \cdot d_s \cdot f_u / \gamma_{M2}$$

$$= 2.7 \cdot \sqrt{1.0} \cdot 5.5 \cdot 430 / 1.25 / 1000 = 5.11\,\text{kN/ weld}$$

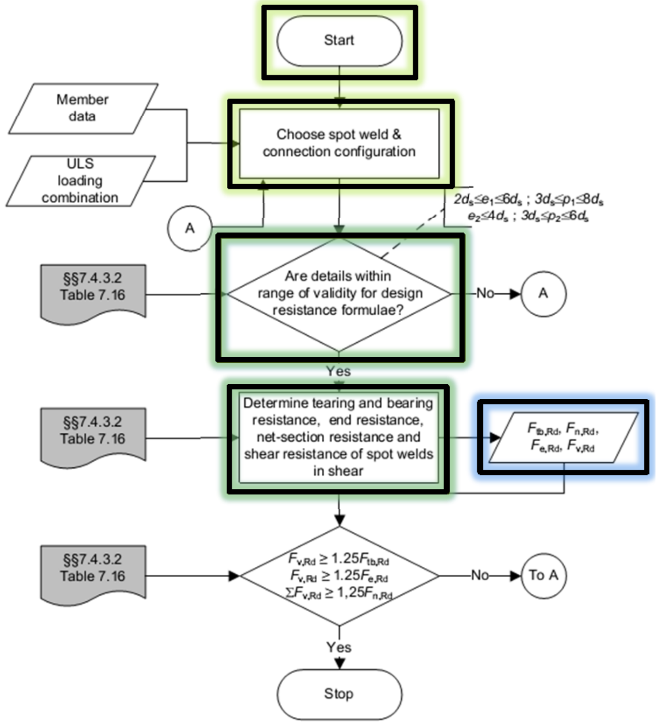
but

$$F_{tb,Rd} \le 0.7 \cdot d_s^{\,2} \cdot f_u / \gamma_{M2} = 0.7 \cdot 5.5^2 \cdot 430 / 1.25 / 1000 = 7.28\,\text{kN/ weld}$$

and

$$F_{tb,Rd} \le 3.1 \cdot t \cdot d_s \cdot f_u / \gamma_{M2} = 3.1 \cdot 1 \cdot 5.5 \cdot 430 / 1.25 / 1000 = 5.87\,\text{kN/ weld}$$

$$\Rightarrow F_{tb,Rd} = 5.11\,\text{kN/ weld}$$



Connections

Design of Connections

- ***EXAMPLE 5: Resistance of the spot weld lap joint***

End resistance:

$$F_{e,Rd} = 1.4 \cdot t \cdot e_1 \cdot f_u / \gamma_{M2} = 1.4 \cdot 1.0 \cdot 13 \cdot 430/1.25/1000 = 6.26\,\text{kN/weld}$$

Net section resistance:

$$F_{n,Rd} = A_{net} \cdot f_u / \gamma_{M2}$$

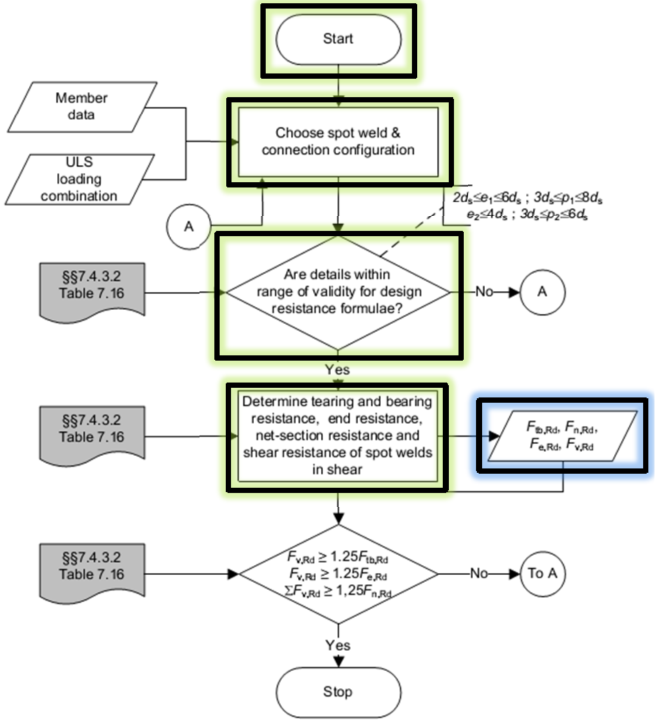
Corresponding to section *a-a*

$$A_{net} = 1 \cdot (46 - 2 \cdot 5.5) = 35\,\text{mm}^2$$

$$F_{n,Rd} = 35 \cdot 430/1.25/1000 = 12.04\,\text{kN}$$

Weld shear resistance:

$$F_{v,Rd} = \frac{\pi}{4} \cdot d_s^2 \cdot f_u / \gamma_{M2} = \frac{\pi}{4} \cdot 5.5^2 \cdot 430/1.25/1000 = 8.17\,\text{kN/ weld}$$



Design of Connections

- *EXAMPLE 5: Resistance of the spot weld lap joint*

Checking ductility conditions:

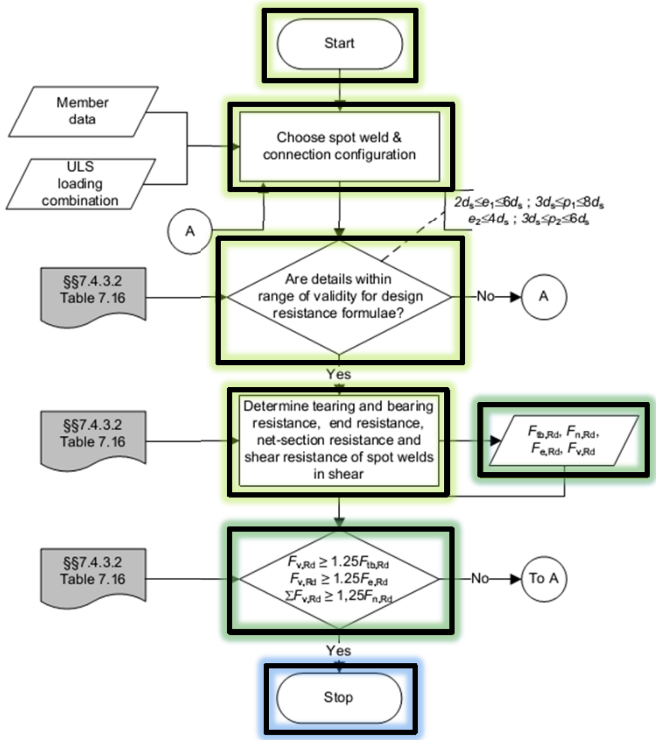
$$F_{v,Rd} = 8.17\,\text{kN} > 1.25 \cdot F_{tb,Rd} = 6.39\,\text{kN}$$

$$F_{v,Rd} = 8.17\,\text{kN} > 1.25 \cdot F_{e,Rd} = 7.83\,\text{kN}$$

$$nF_{v,Rd} = 16.34\,\text{kN} > 1.25 \cdot F_{n,Rd} = 15.05\,\text{kN}\,(n_w = 2)$$

The total resistance of the connection is governed by the tearing and bearing resistance and is:

$$4\,\text{welds} \cdot 5.11\,\text{kN/weld} = 20.44\,\text{kN} \quad (n_w = 4)$$

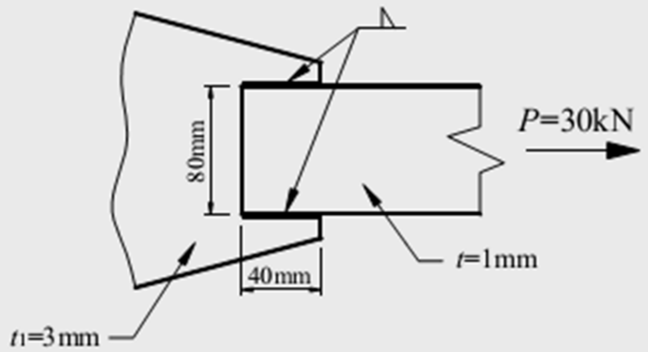


Connections

Design of Connections

- ***EXAMPLE 6: Fillet lap joint. Design resistance of the lap side welded strap-to-gusset connection***

$t_1 = 3$ mm, $t = 1$ mm and $f_u = 420$ N/mm^2



Design resistance of weld:

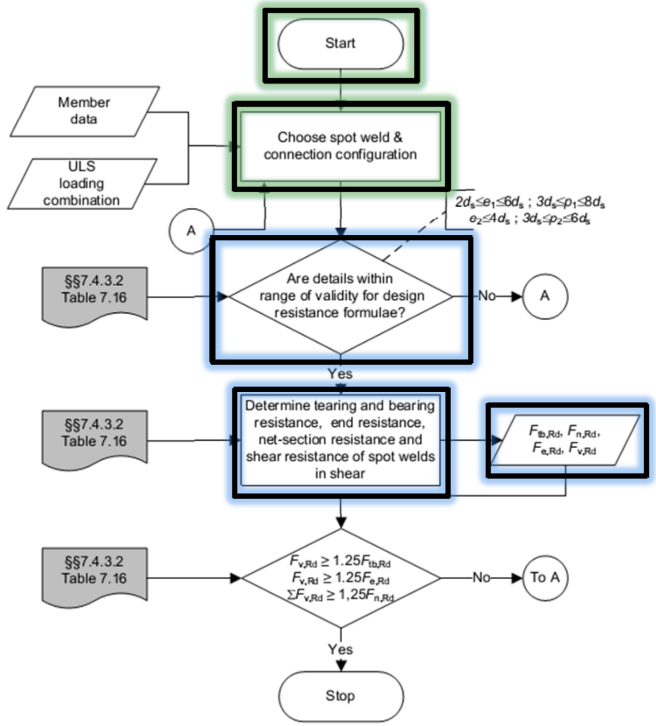
$$L_{w,s} = 40\,\text{mm} < b = 80\,\text{mm}$$

$$L_{w,Rd} = t \cdot L_{w,s} \cdot (0.9 - 0.45 \cdot L_{w,s} / b) \cdot f_u / \gamma_{M2}$$

$$= 1.0 \cdot 40 \cdot (0.9 - 0.45 \cdot 40/80) \cdot 420/1.25/1000 = 9.07\,\text{kN/weld}$$

The total welded connection resistance, for two sided fillet weld is:

$$2 \cdot 9.07\,\text{kN/weld} = 18.14\,\text{kN} \quad < P = 30\text{kN}$$

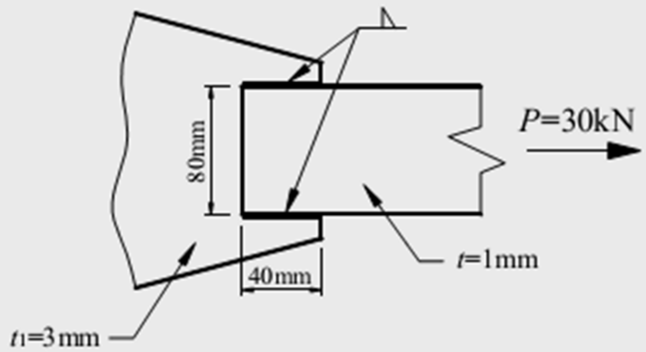


Connections

Design of Connections

- ***EXAMPLE 6: Fillet lap joint. Design resistance of the lap side welded strap-to-gusset connection***

$t_1 = 3$ mm, $t = 1$ mm and $f_u = 420$ N/mm^2



In order to improve the resistance of the connection an end fillet is added, with a supplementary capacity of:

$$F_{w,Rd} = t \cdot L_{w,e} \cdot (1 - 0.3 \cdot L_{w,e} / b) \cdot f_u / \gamma_{M2}$$
$$= 1.0 \cdot 80 \cdot (1 - 0.3 \cdot 80/80) \cdot 420/1.25 = 18.82\,\text{kN}$$

The total resistance of connection in this case is:

$18.14\text{kN} + 18.82\text{kN} \cong 37\text{kN}$ Thus, the force $P = 30\text{kN} \leq 37\,\text{kN}$