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OPENCOURSEWARE

Structural Steel and Timber Design SAB3233

Topic 10 Connections

Prof Dr Shahrin Mohammad

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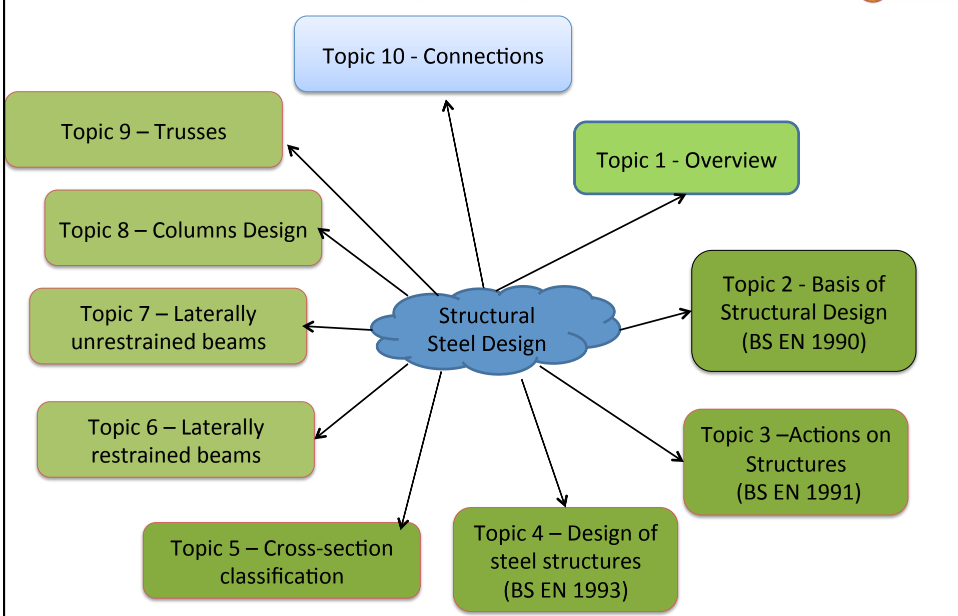

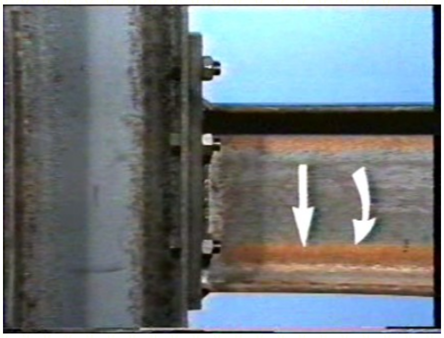

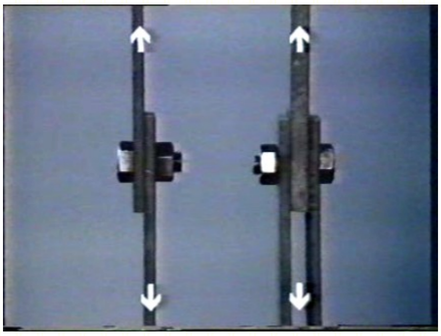

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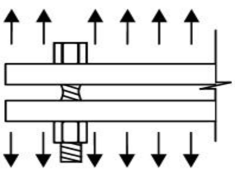
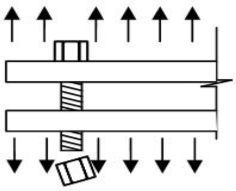
Bolt failure – in tension



Bolt yielded



Frictional loss

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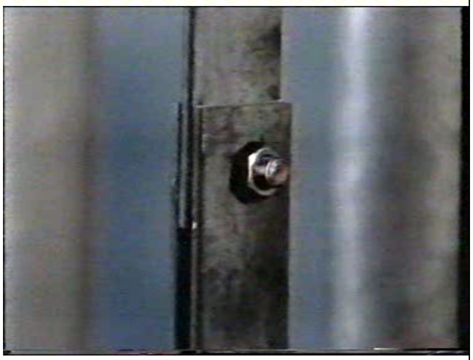

Bolt failure – in bearing

Bolt failure – in shear

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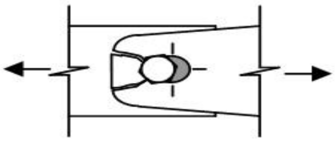
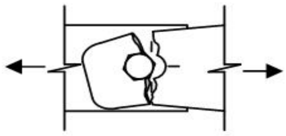


Tearing at the end



Crushing and tearing

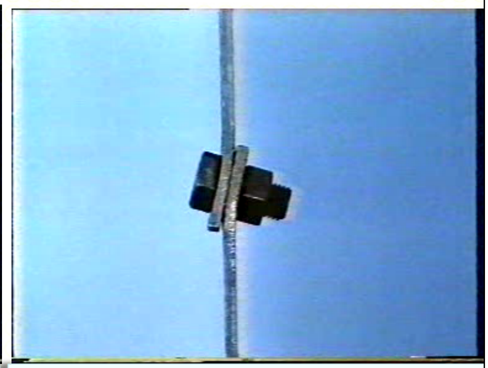


plate failure – end plate

plate failure – end plate

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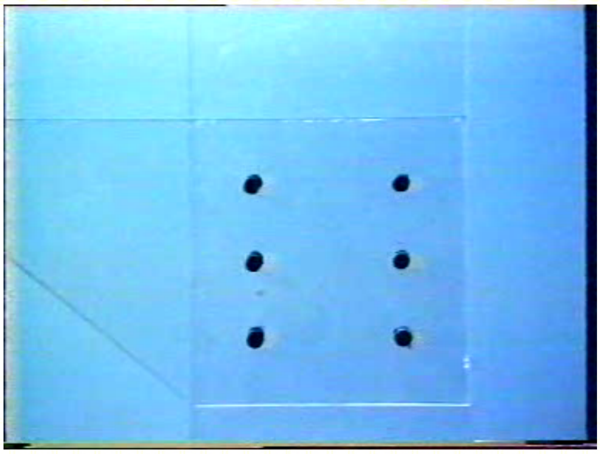

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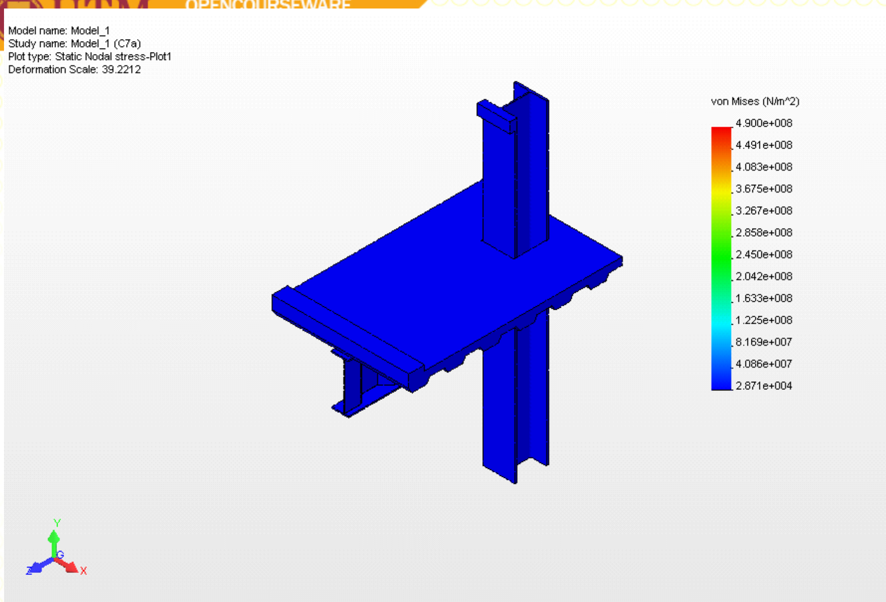

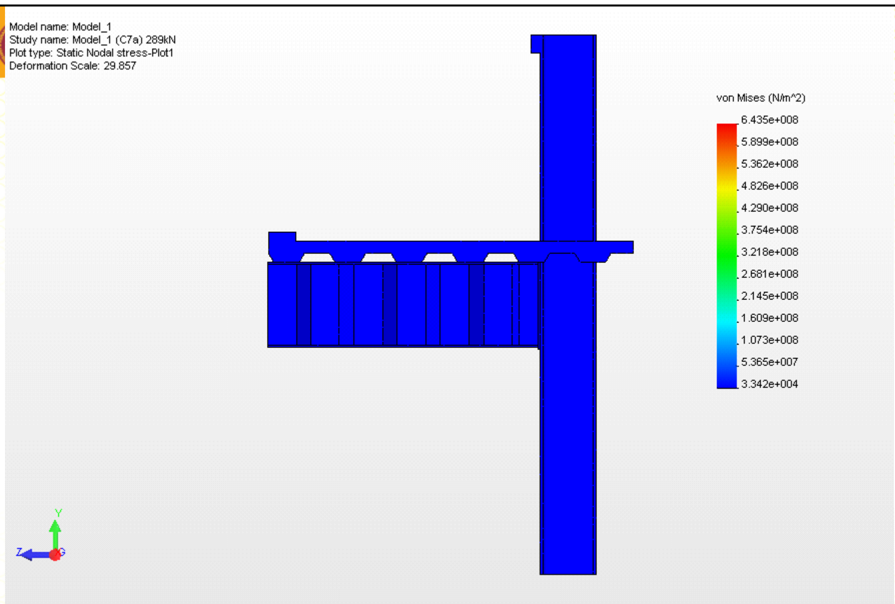
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Study name: Model_1 (C7a) 289kN
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Deformation Scale: 29.857
von Mises (N/m^2)
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5.899e+008
5.362e+008
4.826e+008
4.290e+008
3.754e+008
3.218e+008
2.681e+008
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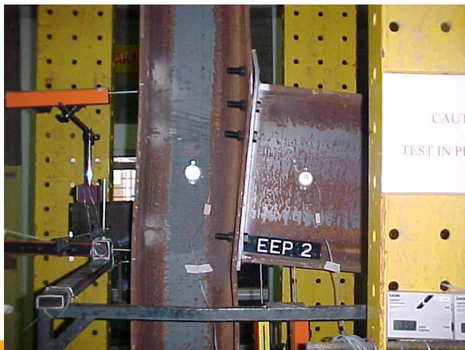
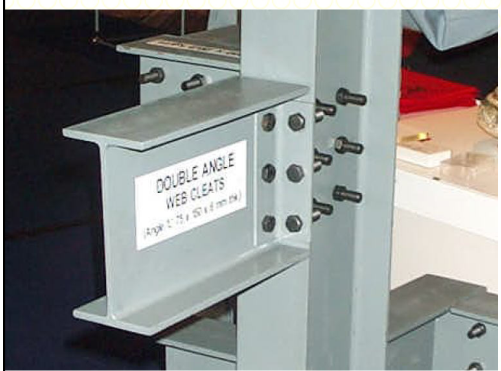
1.609e+008
1.073e+008
5.365e+007
3.342e+004

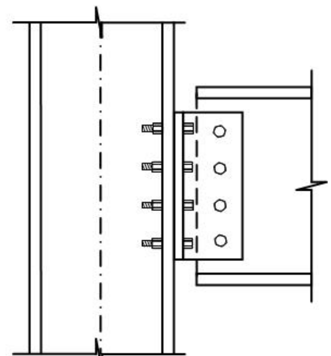

TEEP 1


FEP 3

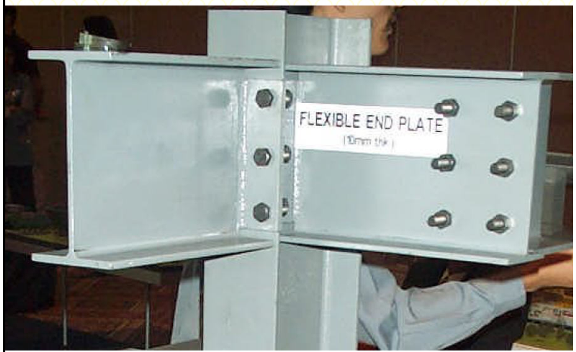

EEP 2

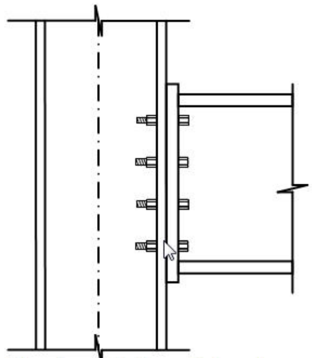
Modify





Web cleat (assumed to be simple construction)





Flush end plate (simple semi-continuous)

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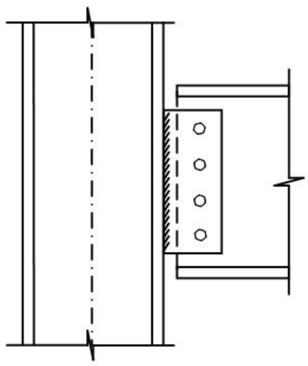

Fin plate (assumed to be simple construction, could be semi-continuous)

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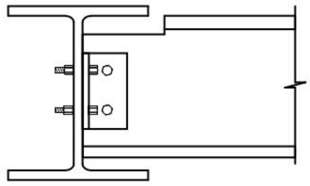

Secondary beam-main beam connection (web cleat) (assumed as pin connection)

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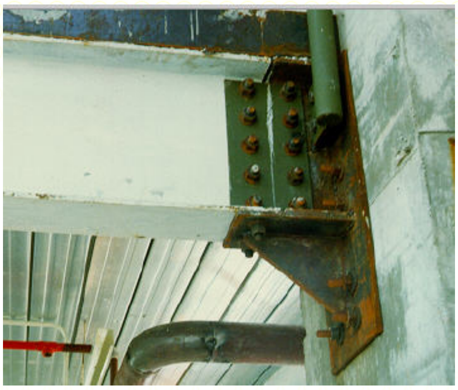

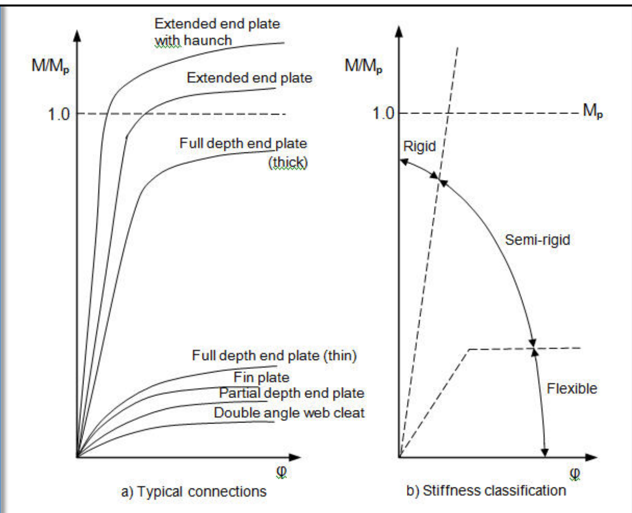

Figure 7.3 Moment rotation characteristic

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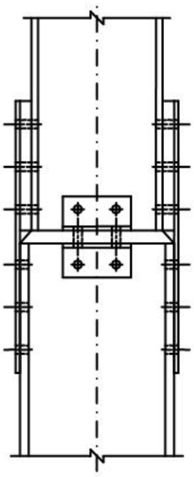

Column splice (continuous)

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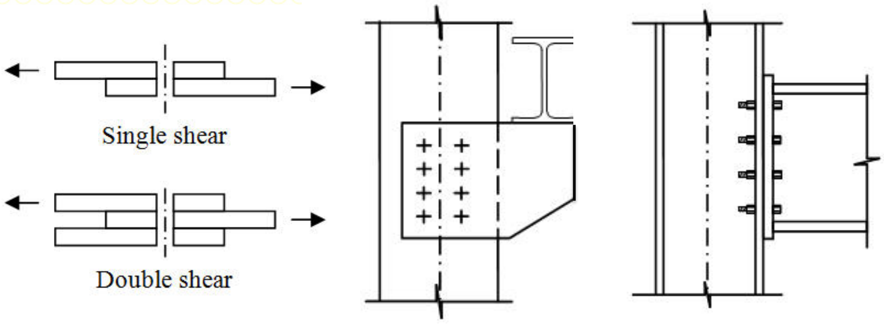
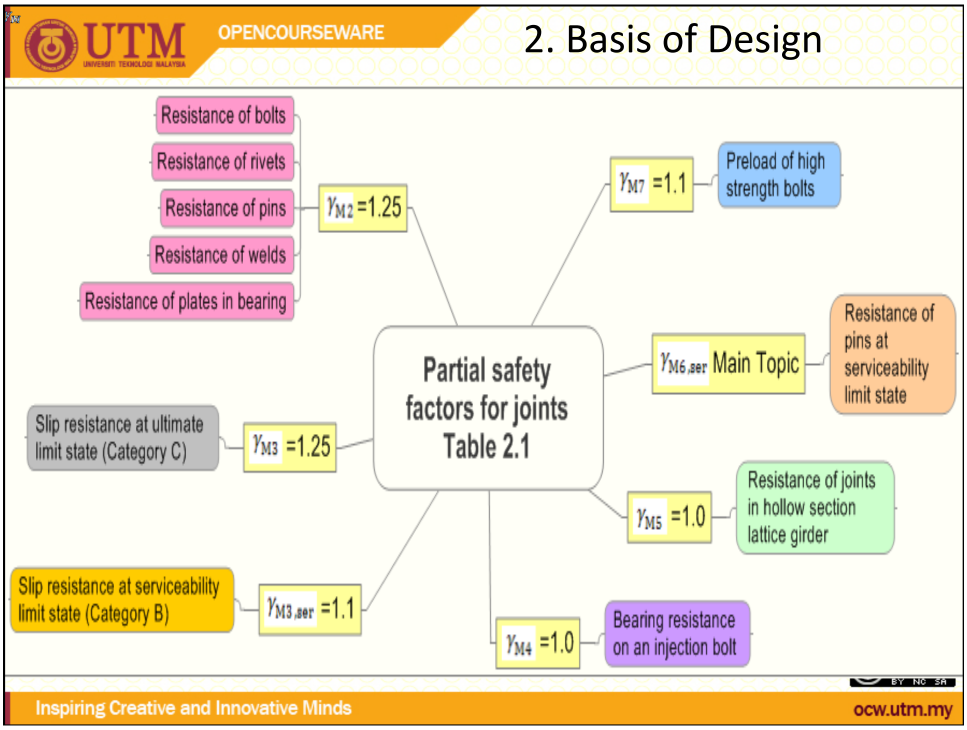

Single shear
Double shear

BS EN 1993-1-8:2005

Eurocode 3: Design of Steel Strutures
Part 1-8 : Design of Joints

1. Introduction
2. Basis of Design
3. Bolted Connections
4. Welded Connections
5. Analysis, Classification and Modelling
6. Structural Joints connecting H or I sections
7. Hollow section joints

- Connections, treated as structural elements
- Rules provided to determine the design parameters e.g. stiffness, strength and rotation capacity
- Connections modeled by using **component-based approach**



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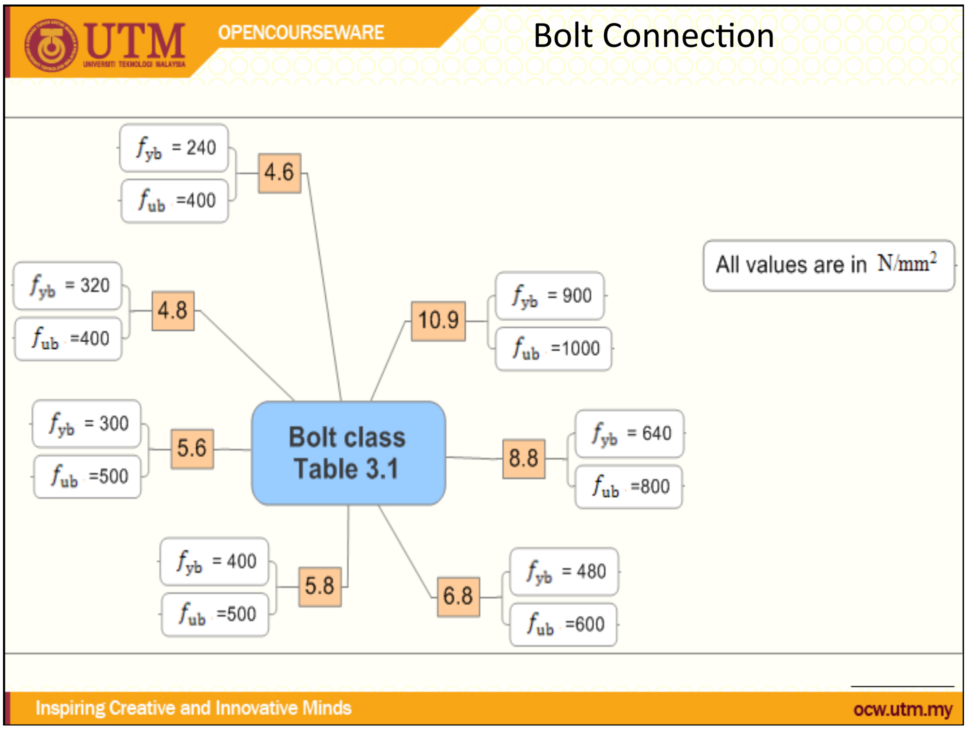
BOLTED CONNECTIONS

- Bolt classes 4.6, 4.8, 5.6, 5.8, 6.8, 8.8 and 10.9
- Bolted connection loaded in shear should be designed as:
  - Category A: Bearing type
  - Category B: Slip-resistant at serviceability limit state
  - Category C: Slip-resistant at ultimate limit state
- Bolted connection loaded in tension:
  - Category D: non-preloaded
  - Category E: preloaded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Bolt Connection
Bolt class Table 3.1
4.6
f_{yb} = 240
f_{ub} =400
4.8
f_{yb} = 320
f_{ub} =400
5.6
f_{yb} = 300
f_{ub} =500
5.8
f_{yb} = 400
f_{ub} =500
6.8
f_{yb} = 480
f_{ub} =600
8.8
f_{yb} = 640
f_{ub} =800
10.9
f_{yb} = 900
f_{ub} =1000
All values are in N/mm^2
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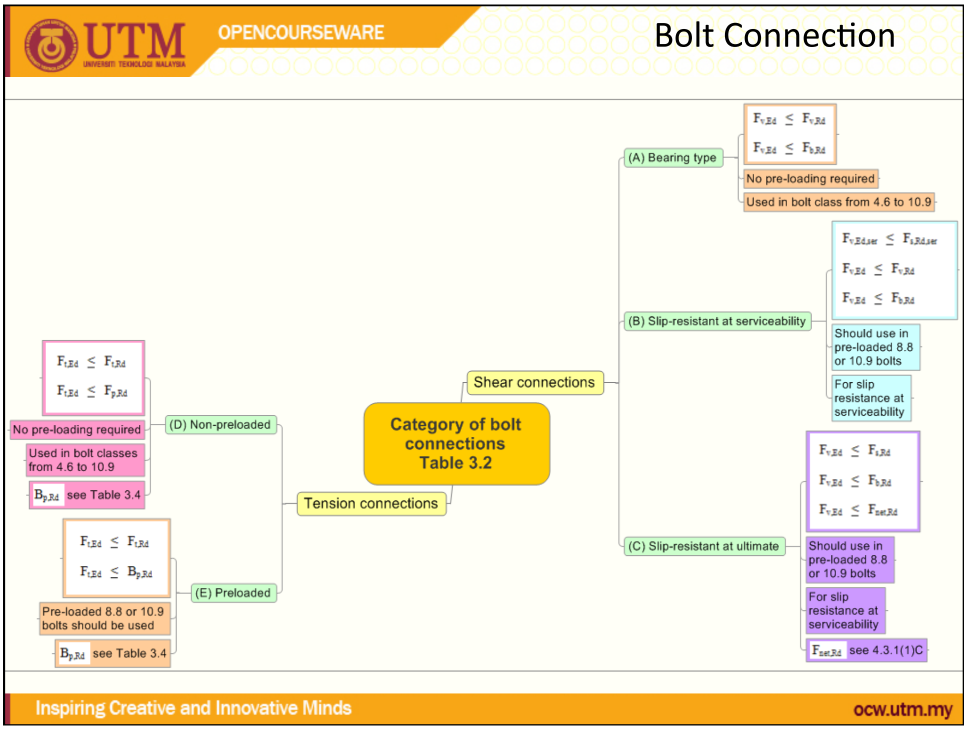
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Bolt Connection
Category of bolt connections Table 3.2
Shear connections
(A) Bearing type
$F_{v,Ed} \leq F_{v,Rd}$
$F_{v,Ed} \leq F_{b,Rd}$
No pre-loading required
Used in bolt class from 4.6 to 10.9
(B) Slip-resistant at serviceability
$F_{v,Ed,ser} \leq F_{s,Rd,ser}$
$F_{v,Ed} \leq F_{v,Rd}$
$F_{v,Ed} \leq F_{b,Rd}$
Should use in pre-loaded 8.8 or 10.9 bolts
For slip resistance at serviceability
(C) Slip-resistant at ultimate
$F_{v,Ed} \leq F_{s,Rd}$
$F_{v,Ed} \leq F_{b,Rd}$
$F_{v,Ed} \leq F_{net,Rd}$
Should use in pre-loaded 8.8 or 10.9 bolts
For slip resistance at serviceability
$F_{net,Rd}$ see 4.3.1(1)C
Tension connections
(D) Non-preloaded
$F_{t,Ed} \leq F_{t,Rd}$
$F_{t,Ed} \leq F_{p,Rd}$
No pre-loading required
Used in bolt classes from 4.6 to 10.9
$B_{p,Rd}$ see Table 3.4
(E) Preloaded
$F_{t,Ed} \leq F_{t,Rd}$
$F_{t,Ed} \leq B_{p,Rd}$
Pre-loaded 8.8 or 10.9 bolts should be used
$B_{p,Rd}$ see Table 3.4
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Positioning of holes

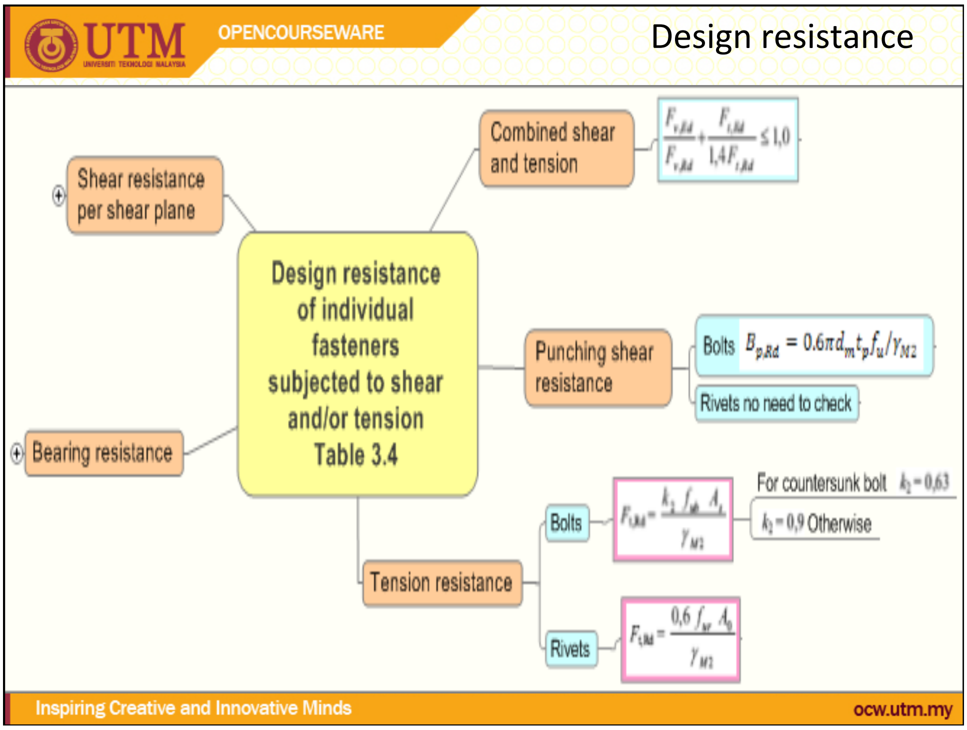
Table 3.3: Minimum and maximum spacing, end and edge distances

Distances and spacings, see Figure 3.1	Minimum	Maximum[1) 2) 3)]		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1,2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1,5d_0$ [4)]			
Distance e_4 in slotted holes	$1,5d_0$ [4)]			
Spacing p_1	$2,2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Modify cing p_2 [5)]	$2,4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm

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

DESIGN RESISTANCE

Failure mode	Bolts	Rivets
Shear resistance per shear plane	$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$ - where the shear plane passes through the threaded portion of the bolt (A is the tensile stress area of the bolt A_s): - for classes 4.6, 5.6 and 8.8: $\alpha_v = 0,6$ - for classes 4.8, 5.8, 6.8 and 10.9: $\alpha_v = 0,5$ - where the shear plane passes through the unthreaded portion of the bolt (A is the gross cross section of the bolt): $\alpha_v = 0,6$	$F_{v,Rd} = \frac{0,6\, f_{ur} A_0}{\gamma_{M2}}$
Bearing resistance [1), 2), 3)]	$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$ where α_b is the smallest of α_d; $\frac{f_{ub}}{f_u}$ or 1,0; in the direction of load transfer: - for end bolts: $\alpha_d = \frac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$ perpendicular to the direction of load transfer: - for edge bolts: k_1 is the smallest of $2,8\frac{e_2}{d_0} - 1,7$ or 2,5 - for inner bolts: k_1 is the smallest of $1,4\frac{p_2}{d_0} - 1,7$ or 2,5	
Tension resistance [2)]	$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$ where $k_2 = 0,63$ for countersunk bolt, otherwise $k_2 = 0,9$.	$F_{t,Rd} = \frac{0,6\, f_{ur} A_0}{\gamma_{M2}}$
Modify sistance	$B_{p,Rd} = 0,6\, \pi\, d_m\, t_p\, f_u / \gamma_{M2}$	No check needed
nd tension	$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1,4\, F_{t,Rd}} \le 1,0$	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Design resistance
Combined shear and tension
$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1,4F_{t,Rd}} \leq 1,0$
Shear resistance per shear plane
Design resistance of individual fasteners subjected to shear and/or tension Table 3.4
Punching shear resistance
Bolts $B_{p,Rd} = 0.6\pi d_m t_p f_u / \gamma_{M2}$
Rivets no need to check
Bearing resistance
Bolts
$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}}$
For countersunk bolt $k_2 = 0,63$
$k_2 = 0,9$ Otherwise
Tension resistance
Rivets
$F_{t,Rd} = \frac{0,6 f_{ur} A_0}{\gamma_{M2}}$
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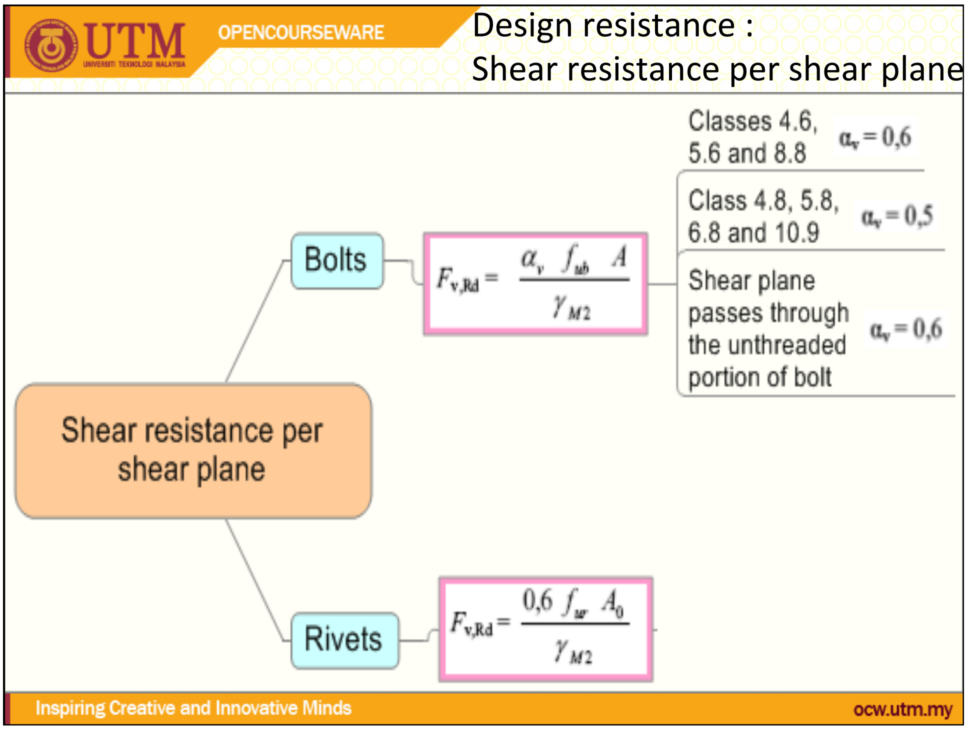
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Design resistance :
Shear resistance per shear plane
Classes 4.6, 5.6 and 8.8 $\alpha_v = 0,6$
Class 4.8, 5.8, 6.8 and 10.9 $\alpha_v = 0,5$
Bolts
$F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}$
Shear plane passes through the unthreaded portion of bolt $\alpha_v = 0,6$
Shear resistance per shear plane
Rivets
$F_{v,Rd} = \frac{0,6 f_{ur} A_0}{\gamma_{M2}}$
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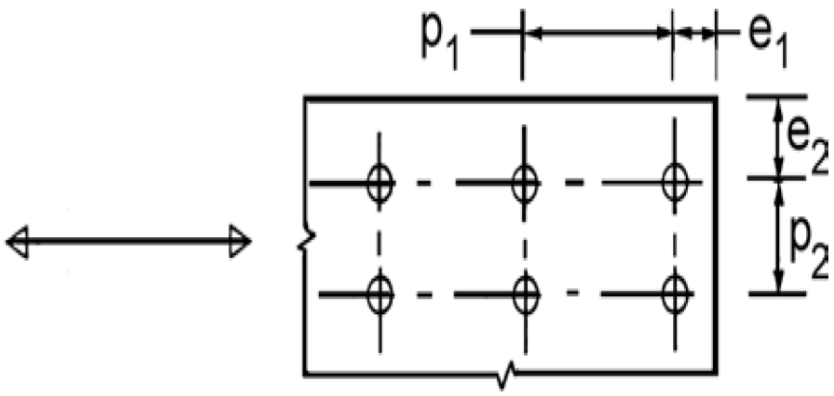
Design resistance : Bearing resistance

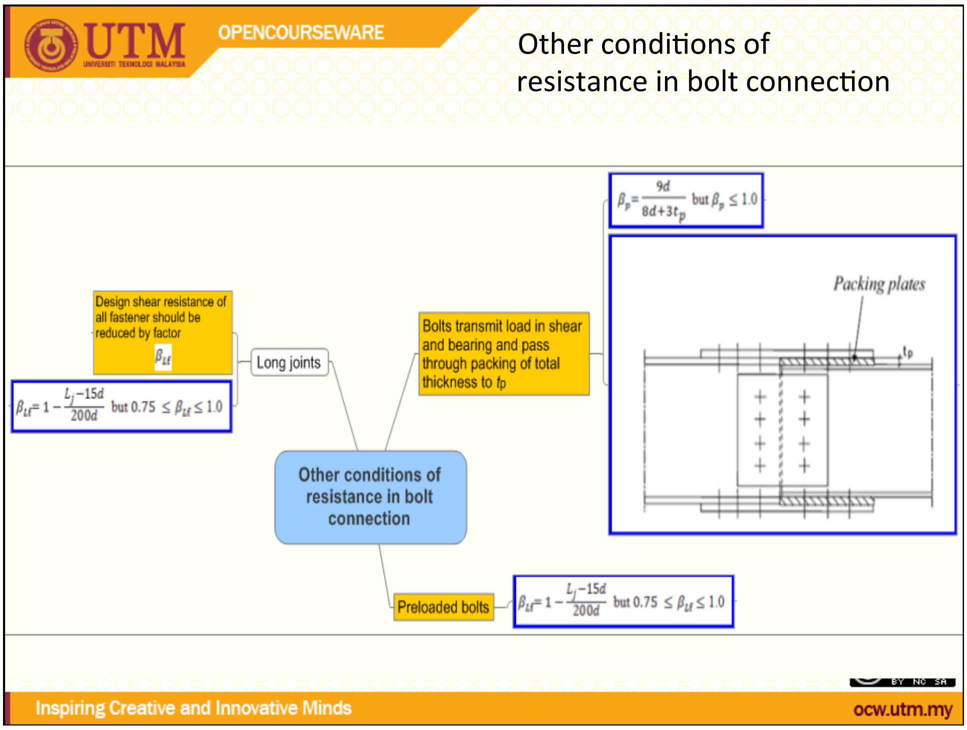
$$F_{b,Rd} = \frac{k_1 a_b f_u d t}{\gamma_{M2}}$$

Bearing resistance — Both Bolts and Rivets

- α_b smallest of α_d:
  - $\frac{f_{ub}}{f_u}$
  - 1.0
- In direction of load transfer:
  - For end bolts $\alpha_d = \frac{e_1}{3d_0}$
  - For inner bolts $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$
- Perpendicular to the direction of load transfer:
  - k_1 For edge bolts is smallest of:
    - $2,8\frac{e_2}{d_0} - 1,7$
    - 2.5
  - k_1 For inner bolts is smallest of:
    - $1,4\frac{p_2}{d_0} - 1,7$
    - 2.5

Definition of p1, e1, p2 and e2

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Other conditions of resistance in bolt connection
Design shear resistance of all fastener should be reduced by factor β_{Lf}
$\beta_{Lf} = 1 - \frac{L_j - 15d}{200d}$ but $0.75 \le \beta_{Lf} \le 1.0$
Long joints
Bolts transmit load in shear and bearing and pass through packing of total thickness to t_p
$\beta_p = \frac{9d}{8d + 3t_p}$ but $\beta_p \le 1.0$
Packing plates
t_p
Other conditions of resistance in bolt connection
Preloaded bolts
$\beta_{Lf} = 1 - \frac{L_j - 15d}{200d}$ but $0.75 \le \beta_{Lf} \le 1.0$
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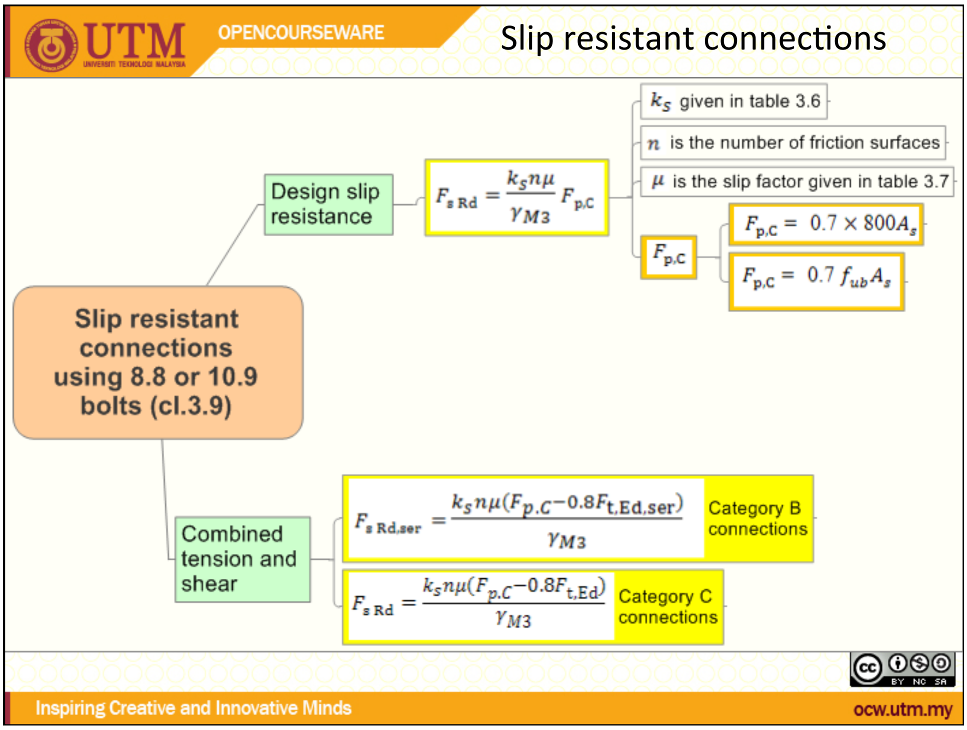
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Slip resistant connections
Slip resistant connections using 8.8 or 10.9 bolts (cl.3.9)
Design slip resistance
$F_{s\,Rd} = \frac{k_s n \mu}{\gamma_{M3}} F_{p,C}$
k_s given in table 3.6
n is the number of friction surfaces
μ is the slip factor given in table 3.7
$F_{p,C}$
$F_{p,C} = 0.7 \times 800 A_s$
$F_{p,C} = 0.7\, f_{ub} A_s$
Combined tension and shear
$F_{s\,Rd,ser} = \frac{k_s n \mu (F_{p,C} - 0.8 F_{t,Ed,ser})}{\gamma_{M3}}$
Category B connections
$F_{s\,Rd} = \frac{k_s n \mu (F_{p,C} - 0.8 F_{t,Ed})}{\gamma_{M3}}$
Category C connections
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Slip resistant connections (continue)

Table 3.6: Values of k_s

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

Modify

Slip resistant connections (continue)

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

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

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

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

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

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

Modify

Deduction for fastener holes

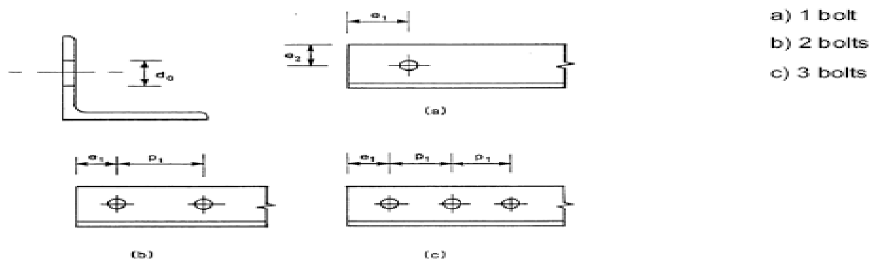
Deduction for fastener holes (Cl.3.10)

- Design for block tearing
  - Symmetric bolt group subject to concentric loading. $V_{eff,1,Rd} = \frac{f_u A_{nt}}{\gamma_{M2}} + \frac{(1/\sqrt{3}) f_y A_{nv}}{\gamma_{M0}}$
  - Bolt group subject to eccentric loading. $V_{eff,2,Rd} = \frac{0.5 f_u A_{nt}}{\gamma_{M2}} + \frac{(1/\sqrt{3}) f_y A_{nv}}{\gamma_{M0}}$
  - A_{nt} is net area subjected to tension
  - A_{nv} is net area subjected to shear
- Angles connected by one leg and other un-symmetrically connected members in tension
  - Design ultimate resistance for single angle in tension
    - $N_{u,Rd} = \frac{2.0\,(e_2 - 0.5 d_0) t f_u}{\gamma_{M2}}$ With 1 bolt
    - $N_{u,Rd} = \frac{\beta_2 A_{net} f_u}{\gamma_{M2}}$ With 2 bolts
    - $N_{u,Rd} = \frac{\beta_3 A_{net} f_u}{\gamma_{M2}}$ With 3 or more bolts
  - refer to Table 3.8 for values of β_2 and β_3

Angles connected by one leg

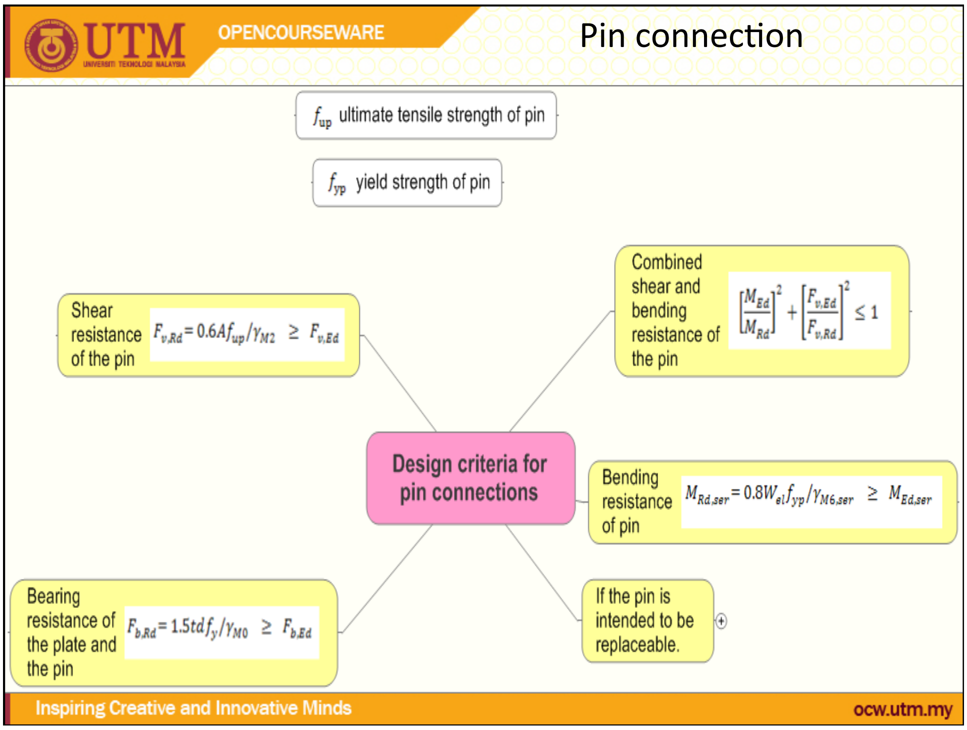
Table 3.8: Reduction factors β_2 and β_3

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



Modify

Figure 3.9: Angles connected by one leg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Pin connection
f_{up} ultimate tensile strength of pin
f_{yp} yield strength of pin
Shear resistance of the pin $F_{v,Rd} = 0.6 A f_{up} / \gamma_{M2} \geq F_{v,Ed}$
Combined shear and bending resistance of the pin $\left[\frac{M_{Ed}}{M_{Rd}}\right]^2 + \left[\frac{F_{v,Ed}}{F_{v,Rd}}\right]^2 \leq 1$
Design criteria for pin connections
Bending resistance of pin $M_{Rd,ser} = 0.8 W_{el} f_{yp} / \gamma_{M6,ser} \geq M_{Ed,ser}$
Bearing resistance of the plate and the pin $F_{b,Rd} = 1.5 t d f_y / \gamma_{M0} \geq F_{b,Ed}$
If the pin is intended to be replaceable.
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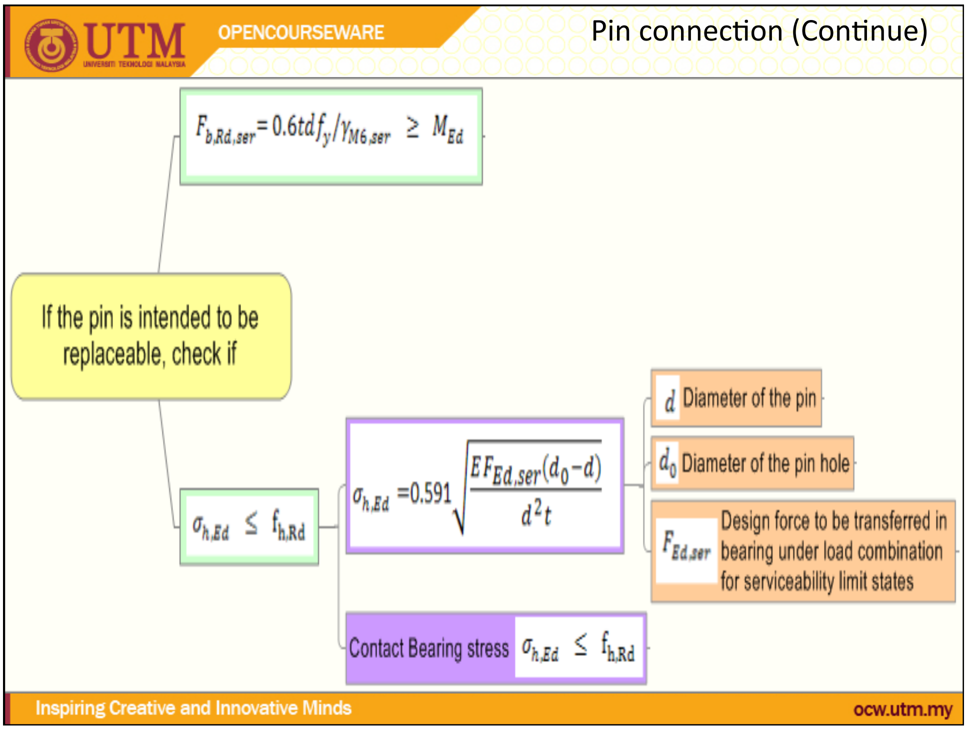
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Pin connection (Continue)
$F_{b,Rd,ser} = 0.6 t d f_y / \gamma_{M6,ser} \geq M_{Ed}$
If the pin is intended to be replaceable, check if
$\sigma_{h,Ed} \leq f_{h,Rd}$
$\sigma_{h,Ed} = 0.591 \sqrt{\frac{E F_{Ed,ser}(d_0 - d)}{d^2 t}}$
d Diameter of the pin
d_0 Diameter of the pin hole
$F_{Ed,ser}$ Design force to be transferred in bearing under load combination for serviceability limit states
Contact Bearing stress $\sigma_{h,Ed} \leq f_{h,Rd}$
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Pin connection (Continue)

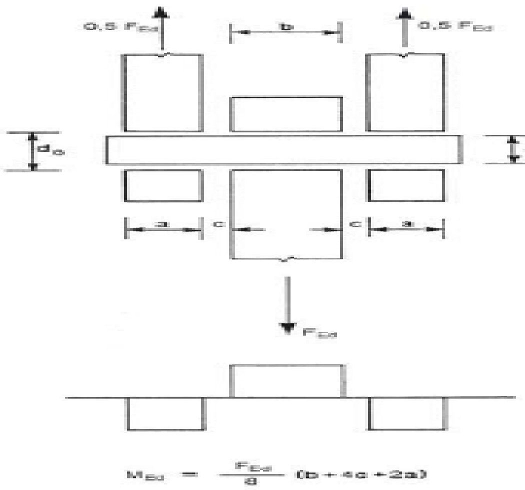


Figure 3.11: Bending moment in a pin

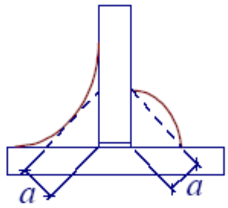
Modify

Welded Connection

- Type of weld and design resistance
- Long joints
- **Welded connections Section 4**
- Connection of the un-stiffened flanges

WELDED CONNECTIONS

- When using metal arc welding, the mechanical properties of weld metal should be compatible with the parent metal
- The material thickness should be at least 4 mm
- Welds are classified as fillet welds, butt welds, plug welds and flare groove welds
- For a fillet welds, the throat thickness, a is defined as below:



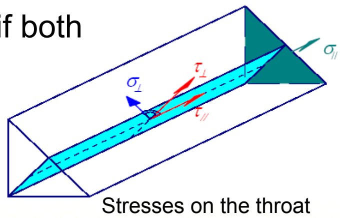
Design Resistance of Fillet Weld

Directional method

- The internal force is resolved into normal stresses and shear stresses on the critical plane of the weld throat.
- The design resistance is sufficient if both conditions below are satisfied:

$$\sqrt{\sigma_{\perp}^2 + 3\left(\tau_{\perp}^{\ 2} + \tau_{//}^{\ 2}\right)} \leq \frac{f_u}{\beta_w \gamma_{M2}}$$

$$\sigma_{\perp} \leq 0.9 \frac{f_u}{\gamma_{M2}}$$



Stresses on the throat section of a fillet weld

Modify

Design Resistance of Fillet Weld

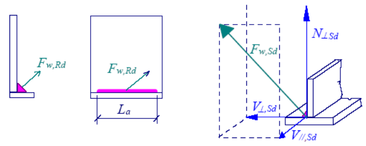
Simplified method

– Independent of the orientation of the weld throat plane to the applied force, the design resistance per unit length,

$$F_{w,Rd} = f_{vw.d}\, a$$

– The design shear strength $f_{vw.d}$ of the weld:

$$f_{vw.d} = \frac{f_u / \sqrt{3}}{\beta_w \gamma_{M2}}$$



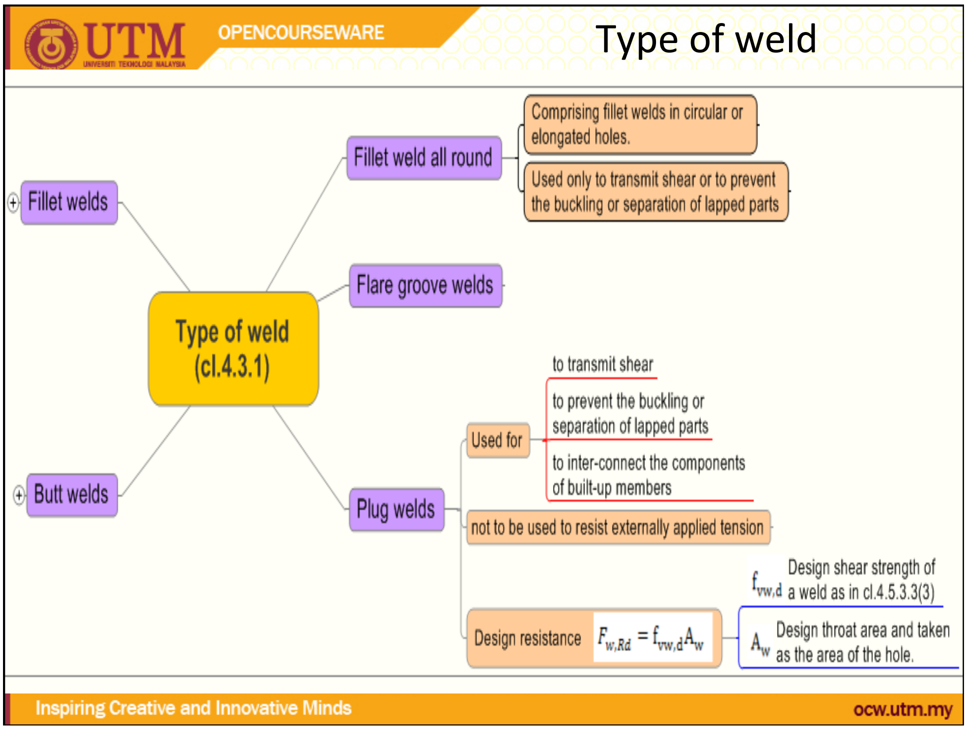
Design of fillet weld independent of the direction of loading

Modify

Table 3.1 Correlation factor βw for weld resistance

Standard and steel grade			Correlation factor βw
EN 10025	**EN 10210**	**EN 10219**	
S 235 S235 W	S 235 H	S 235 H	0,8
S 275 S 275 N/NL S 275 M/ML	S 275 H S 275 NH/NLH	S 275 H S 275 NH/NLH S 275 MH/MLH	0,85
S 355 S 355 N/NL S 355 M/ML S 355 W	S 355 H S 355 NH/NLH	S 355 H S 355 NH/NLH S 355 MH/MLH	0,9
S 420 N/NL S 420 M/ML		S 420 MH/MLH	1,0
S 460 N/NL S 460 M/ML S 460 Q/QL/QL1	S 460 NH/NLH	S 460 NH/NLH S 460 MH/MLH	1,0

Modify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Type of weld
Fillet welds
Butt welds
Type of weld (cl.4.3.1)
Fillet weld all round
Comprising fillet welds in circular or elongated holes.
Used only to transmit shear or to prevent the buckling or separation of lapped parts
Flare groove welds
Plug welds
Used for
to transmit shear
to prevent the buckling or separation of lapped parts
to inter-connect the components of built-up members
not to be used to resist externally applied tension
Design resistance
$F_{w,Rd} = f_{vw,d} A_w$
$f_{vw,d}$ Design shear strength of a weld as in cl.4.5.3.3(3)
A_w Design throat area and taken as the area of the hole.
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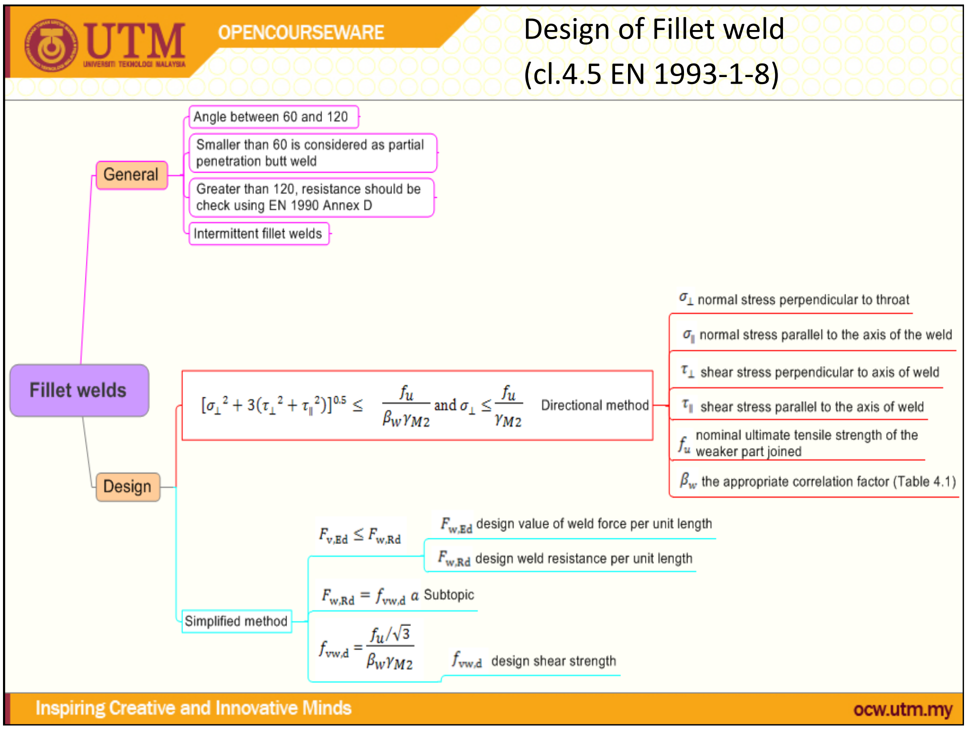
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Design of Fillet weld
(cl.4.5 EN 1993-1-8)
Fillet welds
General
Angle between 60 and 120
Smaller than 60 is considered as partial penetration butt weld
Greater than 120, resistance should be check using EN 1990 Annex D
Intermittent fillet welds
Design
$[\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_\parallel^2)]^{0.5} \le \frac{f_u}{\beta_w \gamma_{M2}}$ and $\sigma_\perp \le \frac{f_u}{\gamma_{M2}}$
Directional method
$\sigma_\perp$ normal stress perpendicular to throat
$\sigma_\parallel$ normal stress parallel to the axis of the weld
$\tau_\perp$ shear stress perpendicular to axis of weld
$\tau_\parallel$ shear stress parallel to the axis of weld
f_u nominal ultimate tensile strength of the weaker part joined
β_w the appropriate correlation factor (Table 4.1)
Simplified method
$F_{v,Ed} \le F_{w,Rd}$
$F_{w,Ed}$ design value of weld force per unit length
$F_{w,Rd}$ design weld resistance per unit length
$F_{w,Rd} = f_{vw,d}\, a$ Subtopic
$f_{vw,d} = \frac{f_u/\sqrt{3}}{\beta_w \gamma_{M2}}$
$f_{vw,d}$ design shear strength
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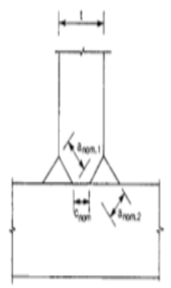
Design of butt weld (cl.4.7 EN 1993-1-8)

- **Butt welds**
  - **Full**
    - Complete penetration and fusion of weld and parent metal throughout the thickness of the joint
    - Design resistance should be taken equal to the design resistance of the weaker parts connected
  - **Partial**
    - Joint penetration is less that full thickness of the parent metal
    - Design resistance is accordance to deep penetration of fillet weld cl.4.5.2(3)
  - **T-but joints**



- $a_{nom,1} + a_{nom,2} \geq t$
- c_{nom} should be the smaller of $t/5$ and 3 mm

Long joints for weld

- **Long Joints (cl.4.11)**
  - Design resistance should be multiply with reduction factor β_{Lw}
    - Greater than $150a$
      - $\beta_{Lw.1} = 1.2 - 0.2L_j/150a$ but $\beta_{Lw.1} \leq 1.0$
      - L_j is overall length of the lap in the direction of the force transfer.
    - Greater than 1.7 m
      - $\beta_{Lw.2} = 1.1 - L_w/17$ but $\beta_{Lw.2} \leq 1.0 \beta_{Lw.2} \geq 0.6$
      - L_w is the length of the weld

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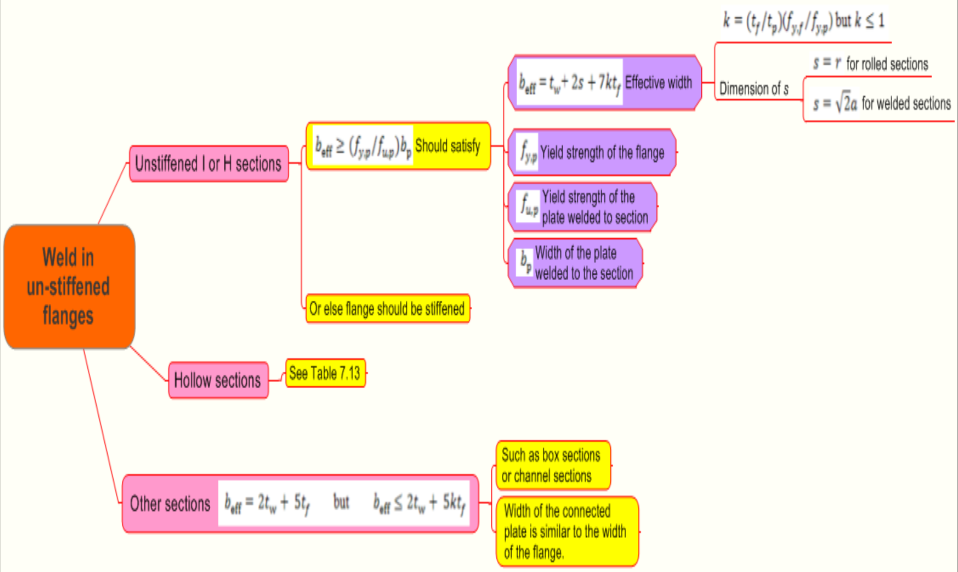
Weld unstiffened flanges (cl.4.10 EN 1993-1-8)



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Example 1 : Connections

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Thank You