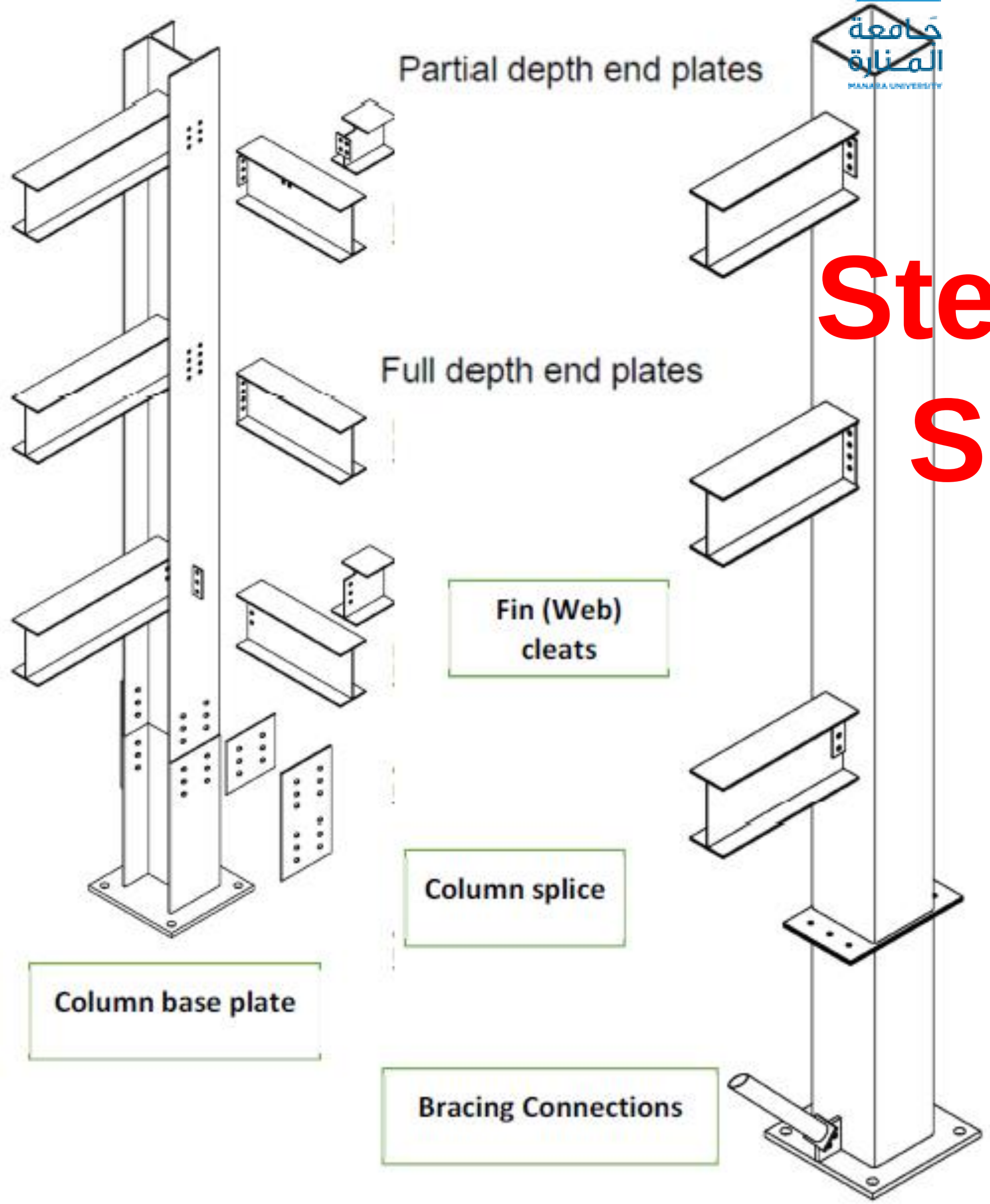


Steel Structures 2
Summer Sem.
2023-2024

أ.د. نايل محمد حسن

Lecture 19-20

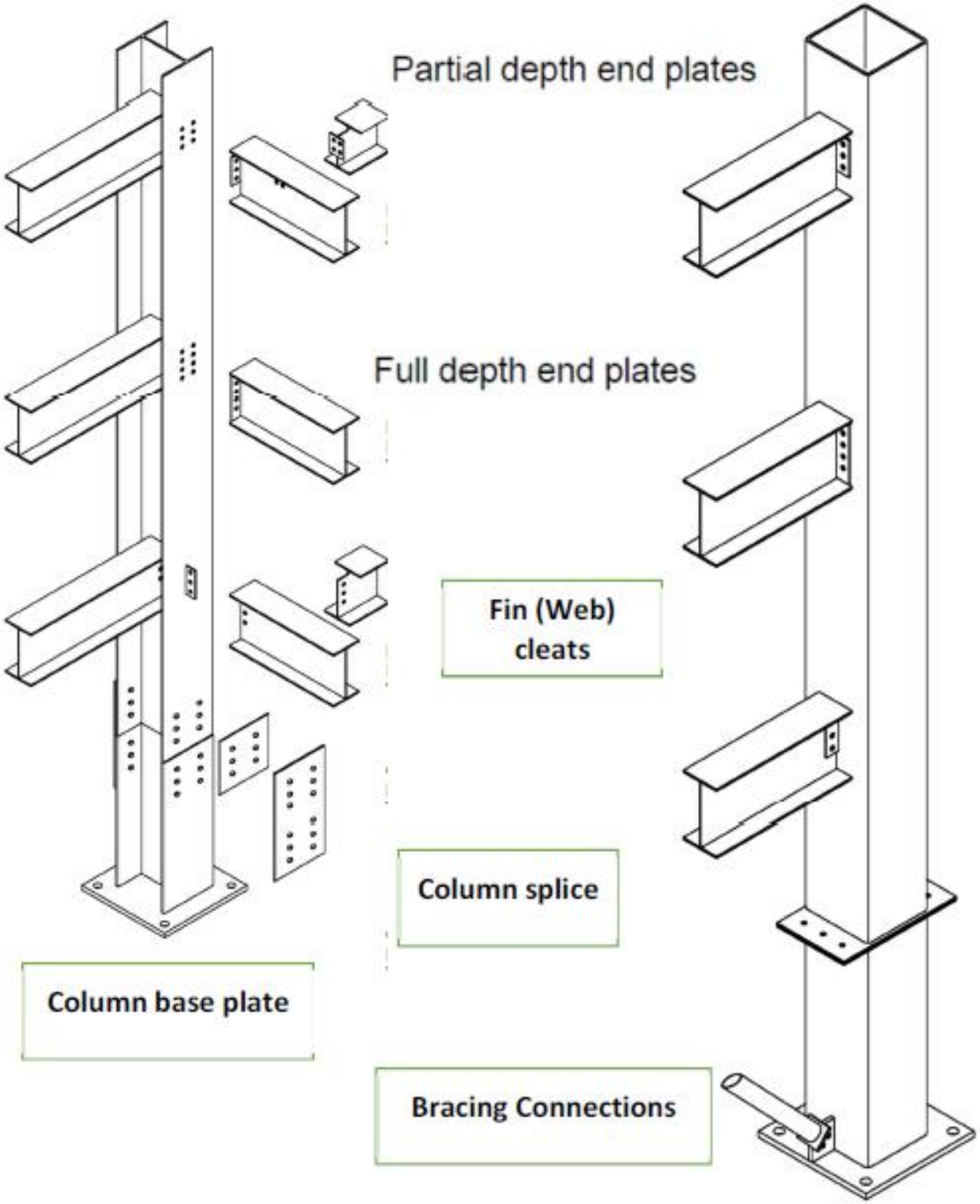
- Flexural Members

- ✓ -I- Laterally Restrained Beams
- ✓ II- Laterally Unrestrained Beams
- ✓ Beam-Column Members
- ✓ Beam-Column Members (problems))
- DESIGN OF CONNECTIONS (1)
- DESIGN OF CONNECTIONS (2)
- **Worked examples (2)**

جَامعة
المَنارة

DESIGN OF CONNECTIONS

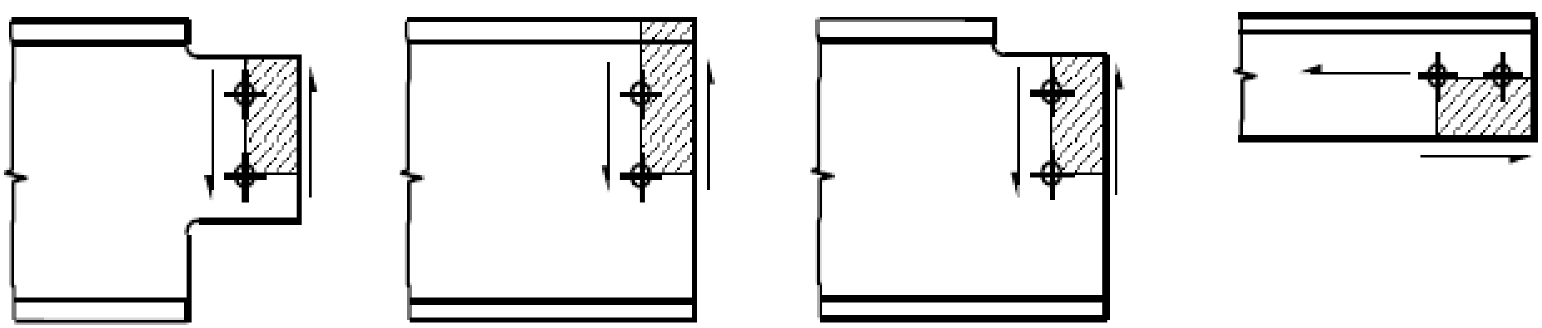
Design of Joints (connections)



Review

Block tearing

Failure in shear at the row of bolts
along the shear face of the hole group
accompanied by
Tensile rupture
along the line of bolt holes
on the tension face of the bolt group



The design block tearing resistance

Design model

Symmetric bolt group subject to concentric loading

$$V_{eff,1,Rd} = f_u A_{nt} / \gamma_{M2} + (1/\sqrt{3}) f_y A_{nv} / \gamma_{M0}$$

A_{nt} net area subjected to tension

A_{nv} net area subjected to shear

Eccentric loading

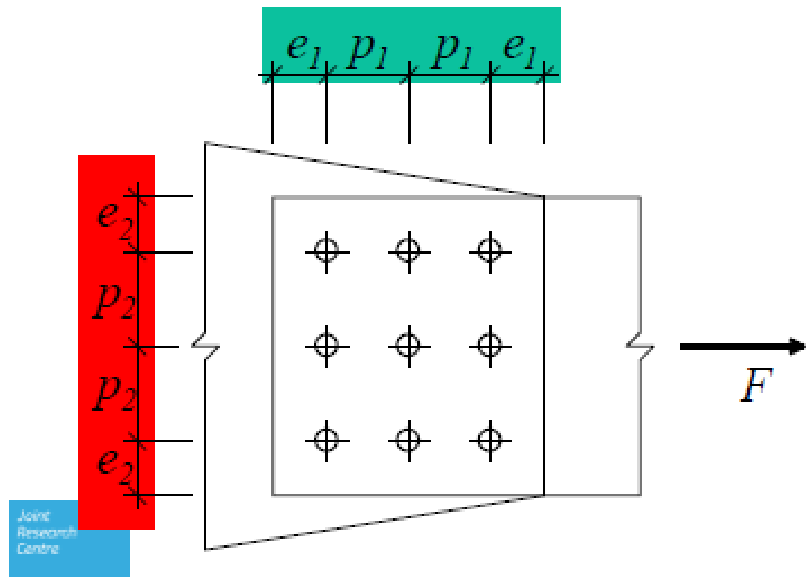
$$V_{eff,2,Rd} = 0,5 f_u A_{nt} / \gamma_{M2} + (1/\sqrt{3}) f_y A_{nv} / \gamma_{M0}$$

Influence of distances to force

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

Prallel to acting force

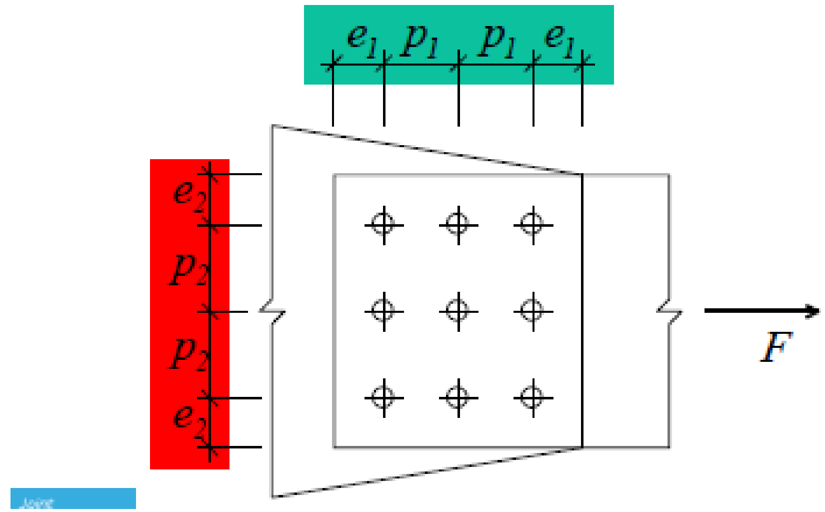
$$\alpha_b = min \begin{Bmatrix} \dfrac{e_1}{3\,d_0} \\ \dfrac{p_1}{3\,d_0} - 0{,}25 \\ \dfrac{f_{ub}}{f_u} \\ 1 \end{Bmatrix}$$



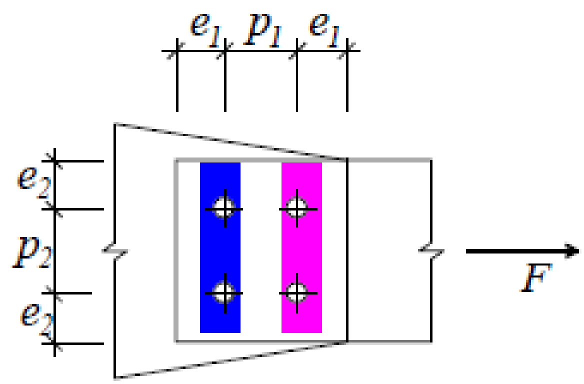
Perpendicular to acting force

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

$$k_1 = \min \begin{Bmatrix} 2{,}8 \dfrac{e_2}{d_0} - 1{,}7 \\ 1{,}4 \dfrac{p_2}{d_0} - 1{,}7 \\ 2{,}5 \end{Bmatrix}$$



Influence of distances



Nomimal transversal distances:

$e_1 = 1{,}2\ d_0$

$p_1 = 2{,}2\ d_0$

$e_2 = 1{,}2\ d_0$

$p_2 = 2{,}4\ d_0$

$$k_1 = \min\begin{Bmatrix} 2{,}8\,\dfrac{e_2}{d_o} - 1{,}7 \\ 1{,}4\,\dfrac{p_2}{d_o} - 1{,}7 \\ 2{,}5 \end{Bmatrix} = \min\begin{Bmatrix} 2{,}8\,\dfrac{1{,}2\ d_o}{d_o} - 1{,}7 \\ 1{,}4\,\dfrac{2{,}4\ d_o}{d_o} - 1{,}7 \\ 2{,}5 \end{Bmatrix} = \min\begin{Bmatrix} 1{,}66 \\ 1{,}66 \\ 2{,}5 \end{Bmatrix} = 1{,}66$$

End bolts

$$\alpha_b = \frac{e_1}{3\ d_o} = \frac{1{,}2\ d_o}{3\ d_o} = 0{,}400$$

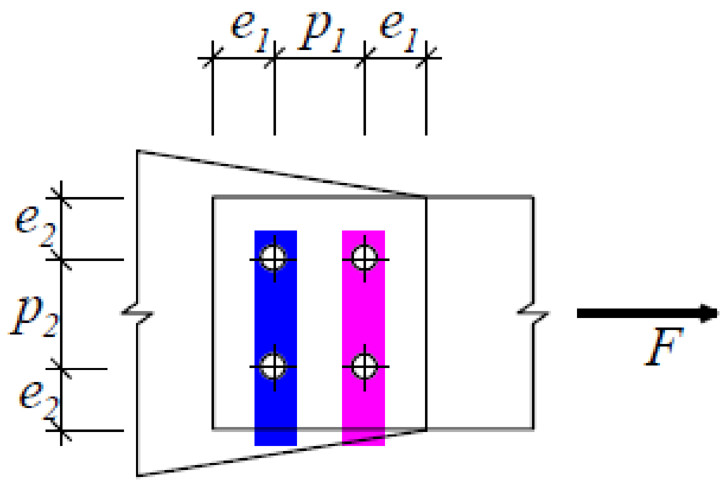
$$F_{b,Rd} = \frac{k_1\ a_b\ d\ t\ f_u}{\gamma_{M2}} = \frac{1{,}66 \cdot 0{,}400\ d\ t\ f_u}{\gamma_{M2}} = 0{,}664\ \frac{d\ t\ f_u}{\gamma_{M2}}$$

Internal bolts

$$\alpha_b = \frac{p_1}{3\ d_o} - 0{,}25 = \frac{2{,}2\ d_o}{3\ d_o} - 0{,}25 = 0{,}483$$

$$F_{b,Rd} = \frac{k_1\ a_b\ d\ t\ f_u}{\gamma_{M2}} = \frac{1{,}66 \cdot 0{,}483\ d\ t\ f_u}{\gamma_{M2}} = 0{,}802\ \frac{d\ t\ f_u}{\gamma_{M2}}$$

Sum



$e_1 = 1,2\ d_0$
$p_1 = 3,0\ d_0$
$e_2 = 1,5\ d_0$
$p_2 = 3,0\ d_0$

Sum of resistances

$$F_{b,Rd} = 2 \cdot 1,875 \frac{d\,t\,f_u}{\gamma_{M2}} + 2 \cdot 1,00 \frac{d\,t\,f_u}{\gamma_{M2}} = 5,75 \frac{d\,t\,f_u}{\gamma_{M2}}$$

Minimal resistance

$$F_{b,Rd} = 4 \cdot 1,0 \frac{d\,t\,f_u}{\gamma_{M2}} = 4,0 \frac{d\,t\,f_u}{\gamma_{M2}}$$

Pitch distances

Min

$p_1 = 2{,}2\ d_0$

$p_2 = 2{,}4\ d_0$

optimum e_1 from $1{,}2\ d_0$ to $1{,}45\ d_0$

$e_2 = 1{,}2\ d_0$

$$F_{b,Rd} = \frac{k_1\ a_b\ d\ t\ f_u}{\gamma_{M2}} = \frac{1{,}66 \cdot 0{,}483\ d\ t\ f_u}{\gamma_{M2}} = 0{,}802\,\frac{d\ t\ f_u}{\gamma_{M2}}$$

Large

$p_1 = 3{,}75\ d_0$

$p_2 = 3{,}0\ d_0$

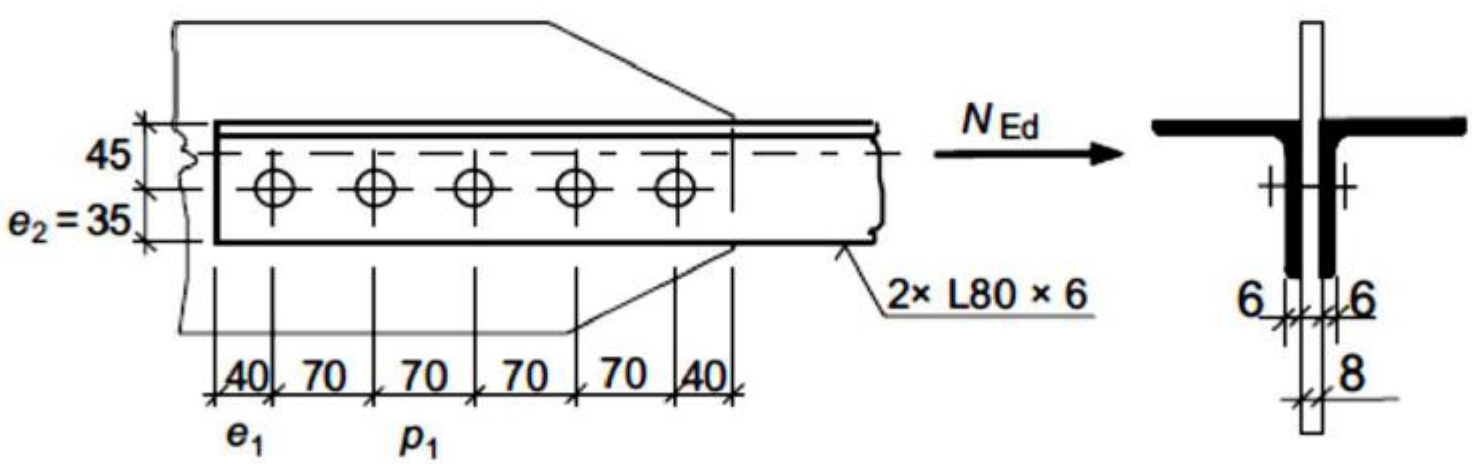
$e_1 = 3{,}0\ d_0$

$e_2 = 1{,}5\ d_0$

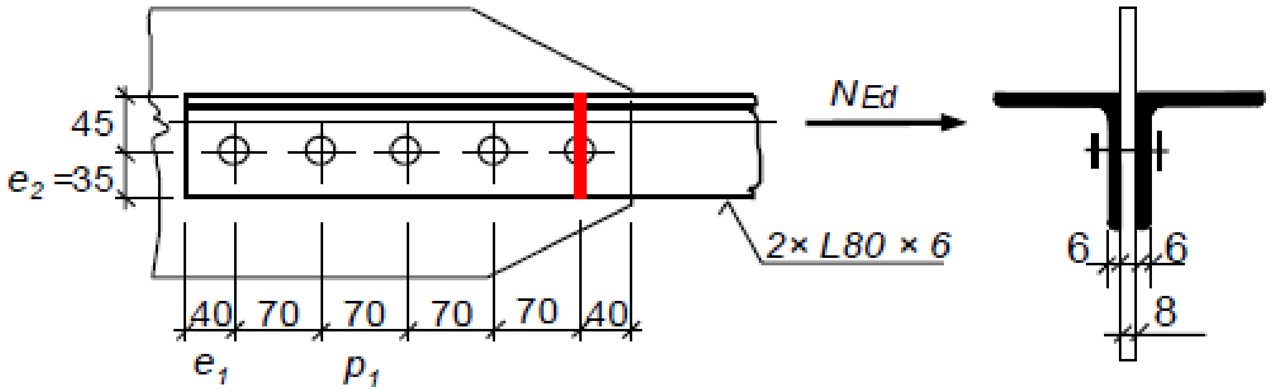
$$F_{b,Rd} = \frac{k_1\ a_b\ d\ t\ f_u}{\gamma_{M2}} = \frac{2{,}5 \cdot 1{,}0\ d\ t\ f_u}{\gamma_{M2}} = 2{,}5\,\frac{d\ t\ f_u}{\gamma_{M2}}$$

Bolted connection of double angle bar

Design the bolted connection of the tension member from double angle of L 80 × 6, steel S235.The element is loaded by tensile force, N_{Ed} = 400 kN and is connected to a gusset plate of 8mm



Solved Example: Bolted Connections



Bolts M20 class 5.6 fully treated

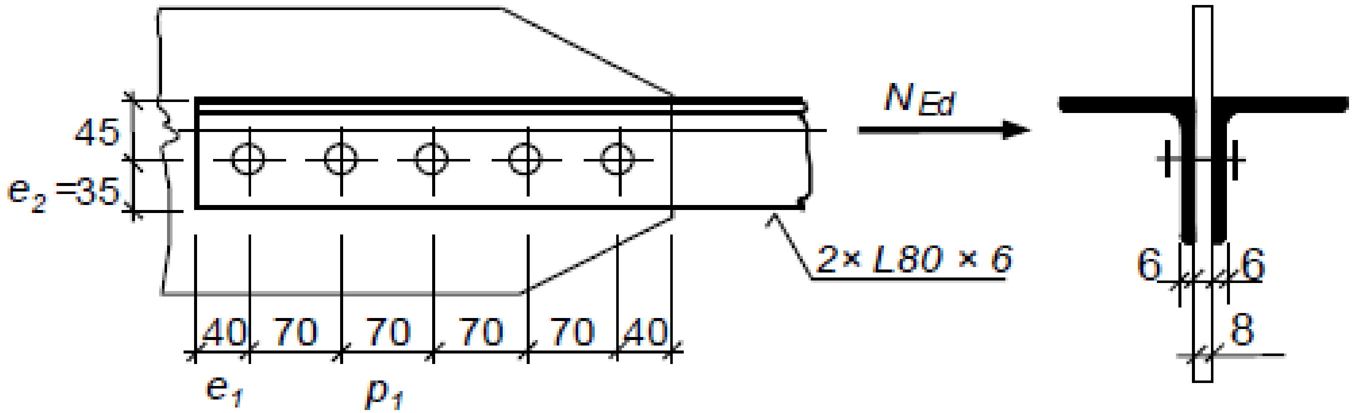
Loading N_{Ed} = 400 kN

Angle net section

$$N_{u,Rd} = \frac{0{,}9\, A_{net}\, f_u}{\gamma_{M2}} = \frac{0{,}9 \cdot 2 \cdot (935 - 22 \cdot 6) \cdot 360}{1{,}25} = 416{,}3\,\text{kN} > N_{Ed} = 400\,\text{kN}$$

Satisfactory

Solved Example: Bolted Connections



Bolts in shear

Two shear planes

Shear in bolt thread

Resistance for one bolt $$F_{v.Rd} = 2\frac{\alpha_v A_s f_{ub}}{\gamma_{M2}} = 2 \cdot \frac{0{,}6 \cdot 245 \cdot 500}{1{,}25} = 117{,}6\,\text{kN}$$

Solved Example: **Bolted connection of double angle bar**

For preloaded bolts, only bolt assemblies of classes 8.8 and 10.9 may be used. Bolt areas for common sizes of structural bolts are given in Table 3.1 below, where A is the gross section area of the bolt and As is the tensile stress area (threaded portion) of the bolt.

Table 3.1 Bolt areas in accordance with EN ISO 898 (CEN, 2013)

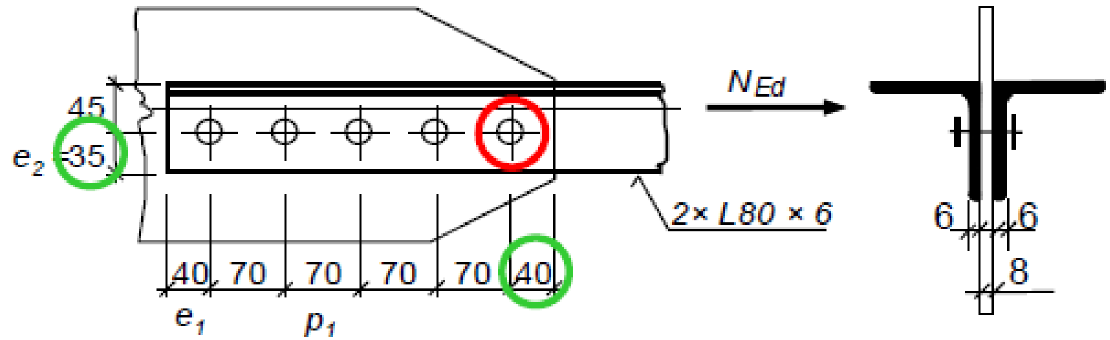
d (mm)	10	12	14	16	18	20	22	24	27	30	36
A (mm^2)	78	113	154	201	254	314	380	452	573	707	1018
A_s (mm^2)	58	84	115	157	192	245	303	353	459	561	817

The clearance = 1mm for M12 and M14 bolts

= 2 mm for bolts $\leq$ 24 mm diameter

= 3 mm for bolts > 24 mm diameter.

Solved Example: Bolted Connections



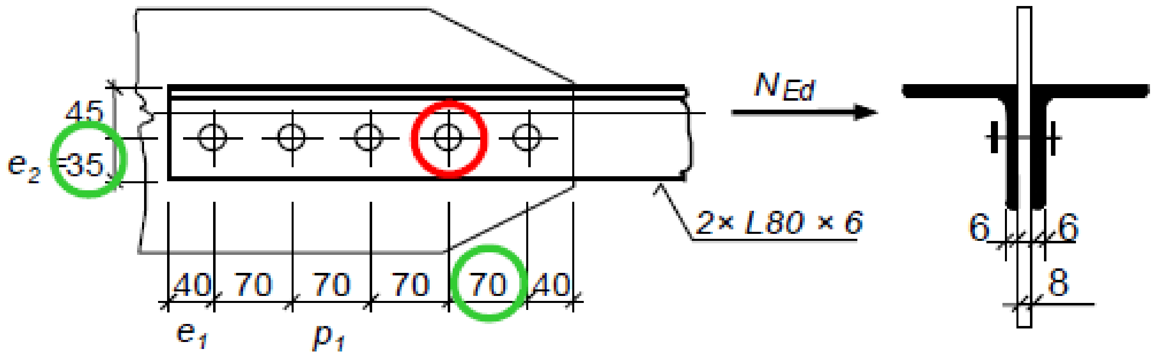
Bearing of end bolt

$$k_1 = \min\left(2{,}8\,\frac{e_2}{d_0} - 1{,}7;\ 2{,}5\right) = \min\left(2{,}8 \cdot \frac{35}{22} - 1{,}7;\ 2{,}5\right) = \min(2{,}75;\ 2{,}5) \ \rightarrow\ k_1 = 2{,}5$$

$$\alpha_b = \min\begin{Bmatrix} \dfrac{e_1}{3\,d_0} \\ \dfrac{f_{ub}}{f_u} \\ 1{,}0 \end{Bmatrix} = \min\begin{Bmatrix} \dfrac{40}{3 \cdot 22} \\ \dfrac{500}{360} \\ 1{,}0 \end{Bmatrix} = \min\begin{Bmatrix} 0{,}606 \\ 1{,}389 \\ 1{,}0 \end{Bmatrix} = 0{,}606$$

$$F_{b,Rd} = \frac{k_1\ \alpha\ d\ t\ f_u}{\gamma_{M2}} = \frac{2{,}5 \cdot 0{,}606 \cdot 20 \cdot 8 \cdot 360}{1{,}25} = 87{,}3\ \text{kN}$$

Solved Example: Bolted Connections



Bearing of internal bolt

$$k_1 = \min\left(2{,}8\frac{e_2}{d_0} - 1{,}7;\ 2{,}5\right) = \min\left(2{,}8\cdot\frac{35}{22} - 1{,}7;\ 2{,}5\right) = \min(2{,}75;\ 2{,}5) \quad \rightarrow \quad k_1 = 2{,}5$$

$$\alpha_b = \min\begin{Bmatrix} \dfrac{p_1}{3\,d_0} - \dfrac{1}{4} \\ \dfrac{f_{ub}}{f_u} \\ 1{,}0 \end{Bmatrix} = \min\begin{Bmatrix} \dfrac{70}{3\cdot 22} - \dfrac{1}{4} \\ \dfrac{500}{360} \\ 1{,}0 \end{Bmatrix} = \min\begin{Bmatrix} 0{,}811 \\ 1{,}389 \\ 1{,}0 \end{Bmatrix} = 0{,}811$$

$$F_{b,Rd} = \frac{2{,}5\cdot 0{,}811\cdot 20\cdot 8\cdot 360}{1{,}25} = 93{,}4\ \text{kN}$$

Solved Example: Bolted Connections

Bolted connection of double angle bar

Check of bolts

Shear resistance	117,6 kN
Bearing resistance – end bolt	87,3 kN
Bearing resistance – internal bolt	93,4 kN

Shear is not guiding the resistance, e.g. bearing as sum
For connection with five bolts

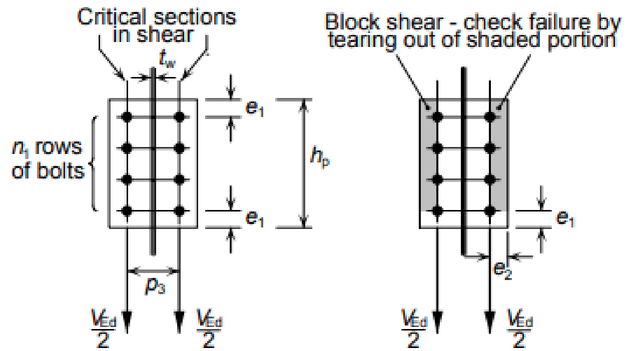
$$87{,}3 + 3 \cdot 94{,}3 + 87{,}3 = 457{,}5\,\text{kN} > 400\,\text{kN} = N_{\text{Ed}}$$ Satisfactory

Conservatively elastic (minimal) resistance

Lower resistance from bearings

$$5 \cdot 87{,}3 = 436{,}5\,\text{kN} > 400\,\text{kN} = N_{\text{Ed}}$$ Unsatisfactory

CHECK 9	**Connection – End plate in shear**



Shear resistance of the end plate connected to the supporting beam or column

For shear:

Basic requirement:

$V_{Ed} \leq V_{Rd,min}$

$V_{Rd,min}$ is the shear resistance of the end plate
= smaller of the gross section shear resistance $V_{Rd,g}$, net section shear resistance, $V_{Rd,n}$ and block tearing resistance, $V_{Rd,b}$

End plate in shear: gross section

$$V_{Rd,g} = \frac{2h_p t_p}{1.27}\frac{f_{y,p}}{\sqrt{3}\gamma_{M0}}$$

The coefficient 1.27 takes into account the reduction in shear resistance due to the presence of bending[25].

End plate in shear: net section

$$V_{Rd,n} = 2A_{v,net}\frac{f_{u,p}}{\sqrt{3}\gamma_{M2}}$$

End plate in shear: block tearing

$$V_{Rd,b} = 2\left(\frac{f_{u,p}A_{nt}}{\gamma_{M2}} + \frac{f_{y,p}A_{nv}}{\sqrt{3}\gamma_{M0}}\right)$$

But if $h_p < 1.36p_3$ and $n_1 > 1$ then:

$$V_{Rd,b} = 2\left(\frac{0.5f_{u,p}A_{nt}}{\gamma_{M2}} + \frac{f_{y,p}A_{nv}}{\sqrt{3}\gamma_{M0}}\right)$$

where:

$A_{v,net} = t_p\left(h_p - n_1 d_0\right)$

$A_{nt} = t_p\left(e_2 - \frac{d_0}{2}\right)$

$A_{nv} = t_p\left(h_p - e_1 - (n_1 - 0.5)d_0\right)$

d_0 is the diameter of the holes

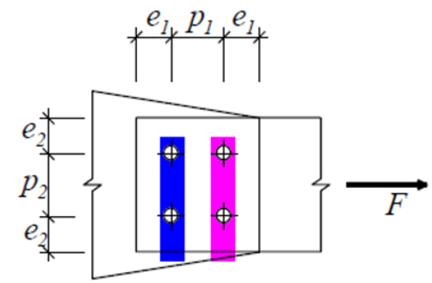
t_p is the thickness of the end plate

h_p is the height of the end plate

p_3 is the gauge (cross centres)

n_1 is the number of bolt rows

γ_{M2} is the partial factor for the ultimate tension resistance of cross sections (γ_{M2} = 1.1 as given in the National Annex to BS EN 1993-1-1)



$e_1 = 1{,}2\ d_0$
$p_1 = 3{,}0\ d_0$
$e_2 = 1{,}5\ d_0$
$p_2 = 3{,}0\ d_0$

$A_{v,net} = t_p\left(h_p - n_1 d_0\right)$

$A_{nt} = t_p\left(e_2 - \frac{d_0}{2}\right)$

$A_{nv} = t_p\left(h_p - e_1 - (n_1 - 0.5)d_0\right)$

d_0 is the diameter of the holes

t_p is the thickness of the end plate

h_p is the height of the end plate

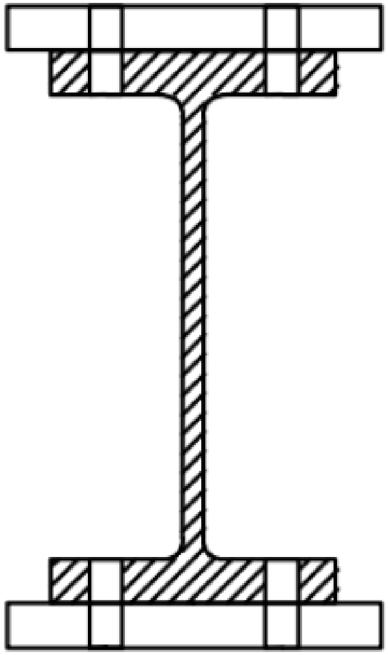
p_3 is the gauge (cross centres)

n_1 is the number of bolt rows

γ_{M2} is the partial factor for the ultimate tension resistance of cross sections (γ_{M2} = 1.1 as given in the National Annex to BS EN 1993-1-1)

Solved problem

A UB 610 x 229 x 125 is used as a tension member and is connected to two 10 mm gusset plates as shown below. S355 steel is used for tension member and the gusset plate. The member has been designed to resist a tension factored load $N_{t,Ed}$= 4000 KN. Use full thread bolts M20 8.8 bolts in four lines, two in each flange as shown below. **Design the tension member and the bearing type connection**.



Solved problem

Solution:

- Design Loads = 4000 KN.
- Section Properties, $A = 159\ cm^2$, $t_f = 19.6\ mm$, b = 229 mm
- Bolt data, M20, class 8.8, $d_o = 20 + 2 = 22\ mm$

  $f_{yb} = 640\ N/mm^2$, $f_{ub} = 800\ N/mm^2$, $A = 314\ mm^2$, $A_s = 245\ mm^2$
- Material Properties, $f_y = 345\ N/mm^2$, $f_u = 490\ N/mm^2$

1. Design of tension member

- $N_{pl,Rd} = \frac{A\ f_y}{\gamma_{M0}} = \frac{159 \times 10^2 \times 345}{1.0} \times 10^{-3} = 5485.5\ KN > 4000\ KN$
- $A_{net} = 159 \times 10^2 - 4 \times (22 \times 19.6) = 14175.2\ mm^2$
- $N_{u,Rd} = \frac{0.9 A_{net}\ f_u}{\gamma_{M2}} = \frac{0.9 \times 14175.2 \times 490}{1.25} \times 10^{-3} = 5001\ KN > 4000\ KN.$
- So, the member is satisfactory.

Solved problem

3. Shear Resistance design of M20 bolts.

- $F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}} = \frac{0.6*800*245}{1.25} = 94.08\ KN$

- No. of bolts $= \frac{N_{Ed}}{F_{s,d}} = \frac{4000}{94.08} = 42.51\ bolts\ use\ 44\ bolts\ in\ four\ lines$

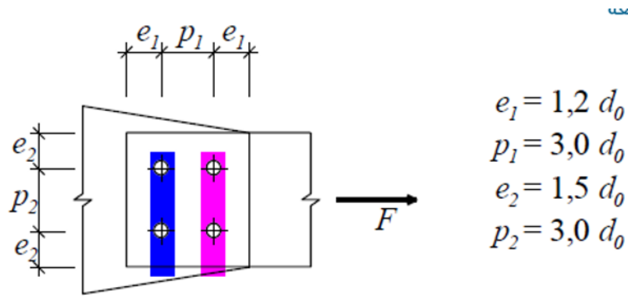
4. Assume bolts layout for 44 bolts 11 bolts in each line

- Minimum spacing limits

$$e_1 = e_2 = 1.2 * 22 = 26.4\ mm\ use\ 50\ mm$$

$$p_1 = 2.2 * 22 = 48.4\ mm\ use\ 50\ mm$$

$$p_2 = 2.4 * 22 = 52.8\ mm\ use\ 129\ mm$$



Solved problem

5. Bearing resistance for end bolts

- $k_1 = \min\left(2.8 * \left(\frac{50}{22}\right) - 1.7 \; or \; 2.5\right) = \min(6.36 \; or \; 2.5) = 2.5$

- $\alpha_b = \min\left(\frac{50}{3*22} \; or \frac{800}{490} \; or \; 1\right) = \min(0.757 \; or \; 1.63 \; or \; 1) = 0.757$

- $f_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}} = \frac{2.5*0.757*490*20*10}{1.25} = 148.48 \; KN$

6. Bearing resistance for inner bolts

- $k_1 = \min\left(1.4 * \left(\frac{129}{22}\right) - 1.7 \; or \; 2.5\right) = \min(8.2 \; or \; 2.5) = 2.5$

- $\alpha_b = \min\left(\frac{50}{3*22} - \frac{1}{4} \; or \frac{800}{490} \; or \; 1\right) = \min(0.507 \; or \; 1.63 \; or \; 1) = 0.507$

- $f_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}} = \frac{2.5*0.507*490*20*10}{1.25} = 99.37 \; KN$

7. Bearing design resistance for 44 bolts

$$= 4 * 148.48 + 40 * 99.37 = 4568.72 \; KN > 4000 \; KN$$

Solved problem

8. Check Long Joint

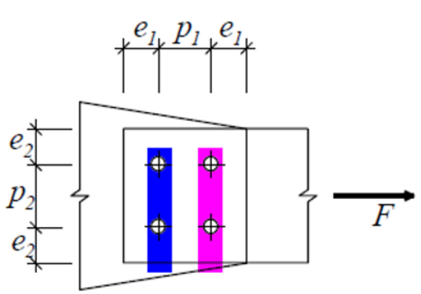
- Limiting $L_j = 15 * d = 15 * 20 = 300\ mm$
- Available $L_j = 10 * 50 = 500\ mm$
- $\beta_{Lf} = 1 - \frac{500-300}{200*20} = 0.95$
- Design shear resistance $= \beta_{Lf} * NOB * F_{v,Rd}$
- $= 0.95 * 44 * 94.08 = 3932.54\ KN < 4000\ KN \rightarrow Not\ OK$
- Try using 48 bolts in four lines 12 bolt in each line
- Limiting $L_j = 15 * d = 15 * 20 = 300\ mm$
- Available $L_j = 11 * 50 = 550\ mm$
- $\beta_{Lf} = 1 - \frac{550-300}{200*20} = 0.9375$
- Design shear resistance $= \beta_{Lf} * NOB * F_{v,Rd}$
- $= 0.9375 * 48 * 94.08 = 4233.6\ KN > 4000\ KN \rightarrow OK$

Solved problem

9. Check Block shear for one gusset plate

- $A_{nt} = (129 - 22) * 10 = 1070\ mm^2$
- $A_{nv} = 2 * (11 * 50 + 50 - 22 * 11.5) * 10 = 6940\ mm^2$
- $V_{eff,1,Rd} = \frac{f_u A_{nt}}{\gamma_{M2}} + \frac{1}{\sqrt{3}} \left(\frac{f_y A_{nv}}{\gamma_{M0}} \right)$
- $= \frac{490 * 1070}{1.25} + \frac{1}{\sqrt{3}} \left(\frac{345 * 6940}{1} \right) = 1801.78\ KN\ for\ one\ gusset\ plate$
- For both gusset plate =2*1801.78=3603.57 KN <4000 KN Not Ok.

Try increasing p_1 to 60 mm



$e_1 = 1{,}2\ d_0$
$p_1 = 3{,}0\ d_0$
$e_2 = 1{,}5\ d_0$
$p_2 = 3{,}0\ d_0$

$A_{v,net}$	=	$t_p (h_p - n_1 d_0)$
A_{nt}	=	$t_p \left(e_2 - \frac{d_0}{2} \right)$
A_{nv}	=	$t_p (h_p - e_1 - (n_1 - 0.5) d_0)$
d_0		is the diameter of the holes
t_p		is the thickness of the end plate
h_p		is the height of the end plate
p_3		is the gauge (cross centres)
n_1		is the number of bolt rows
γ_{M2}		is the partial factor for the ultimate tension resistance of cross sections (γ_{M2} = 1.1 as given in the National Annex to BS EN 1993-1-1)

Solved problem

10. Bearing resistance for inner bolts

- $k_1 = \min\left(1.4 * \left(\frac{129}{22}\right) - 1.7 \; or \; 2.5\right) = \min(8.2 \; or \; 2.5) = 2.5$
- $\alpha_b = \min\left(\frac{60}{3*22} - \frac{1}{4} \; or \; \frac{800}{490} \; or \; 1\right) = \min(0.909 \; or \; 1.63 \; or \; 1) = 0.909$
- $f_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}} = \frac{2.5*0.909*490*20*10}{1.25} = 178.16 \; KN$

11. Bearing design resistance for 48 bolts

$$= 4 * 148.48 + 44 * 178.16 = 8432.96 \; KN > 4000 \; KN$$

Solved problem

12. Check Long Joint

- Limiting $L_j = 15 * d = 15 * 20 = 300\ mm$
- Available $L_j = 11 * 60 = 660\ mm$
- $\beta_{Lf} = 1 - \frac{660-300}{200*20} = 0.91$
- Design shear resistance $= \beta_{Lf} * NOB * F_{v,Rd}$
- $= 0.91 * 48 * 94.08 = 4109.41KN > 4000\ KN \rightarrow OK$

13. Check Block shear for one gusset plate

- $A_{nt} = (129 - 22) * 10 = 1070\ mm^2$
- $A_{nv} = 2 * (11 * 60 + 50 - 22 * 11.5) * 10 = 9140\ mm^2$
- $V_{eff,1,Rd} = \frac{f_u\,A_{nt}}{\gamma_{M2}} + \frac{1}{\sqrt{3}}\left(\frac{f_y\,A_{nv}}{\gamma_{M0}}\right)$
- $= \frac{490*1070}{1.25} + \frac{1}{\sqrt{3}}\left(\frac{345*9140}{1}\right) = 2234\ KN\ for\ one\ gusset\ plate$
- For both gusset plate =2*2234=4468 KN >4000 KN Ok.

Extra Ideas

- Use more line of bolts on web.
- Try using Slip resistance connection.
- Using M22 bolts.

$$A_{v,net} = t_p\left(h_p - n_1 d_0\right)$$

$$A_{nt} = t_p\left(e_2 - \frac{d_0}{2}\right)$$

$$A_{nv} = t_p\left(h_p - e_1 - (n_1 - 0.5)d_0\right)$$

d_0 is the diameter of the holes

t_p is the thickness of the end plate

h_p is the height of the end plate

p_3 is the gauge (cross centres)

n_1 is the number of bolt rows

γ_{M2} is the partial factor for the ultimate tension resistance of cross sections (γ_{M2} = 1.1 as given in the National Annex to BS EN 1993-1-1)

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t_p is the end plate thickness

$V_{pl,N,Rd}$ is the shear resistance at the notch for single notched beams

$$= \frac{A_{v,N} f_{y,b1}}{\sqrt{3}\,\gamma_{M0}}$$

$$A_{v,N} = A_{Tee} - b t_{f,b1} + (t_{w,b1} + 2r_{b1})\frac{t_{f,b1}}{2}$$

$V_{pl,DN,Rd}$ is the shear resistance at the notch for double notched beams

$$= \frac{A_{v,DN} f_{y,b1}}{\sqrt{3}\,\gamma_{M0}}$$

$$A_{v,DN} = 0.9\,(h_{b1} - d_{nt} - d_{nb})\,t_{w,b1}$$

$t_{f,b1}$ is the flange thickness of the supported beam

$t_{w,b1}$ is the web thickness of the supported beam

h_{b1} is the height of the supported beam

A_{Tee} is the area of the Tee section

$W_{el,N,y}$ is the elastic modulus of the Tee section at the notch