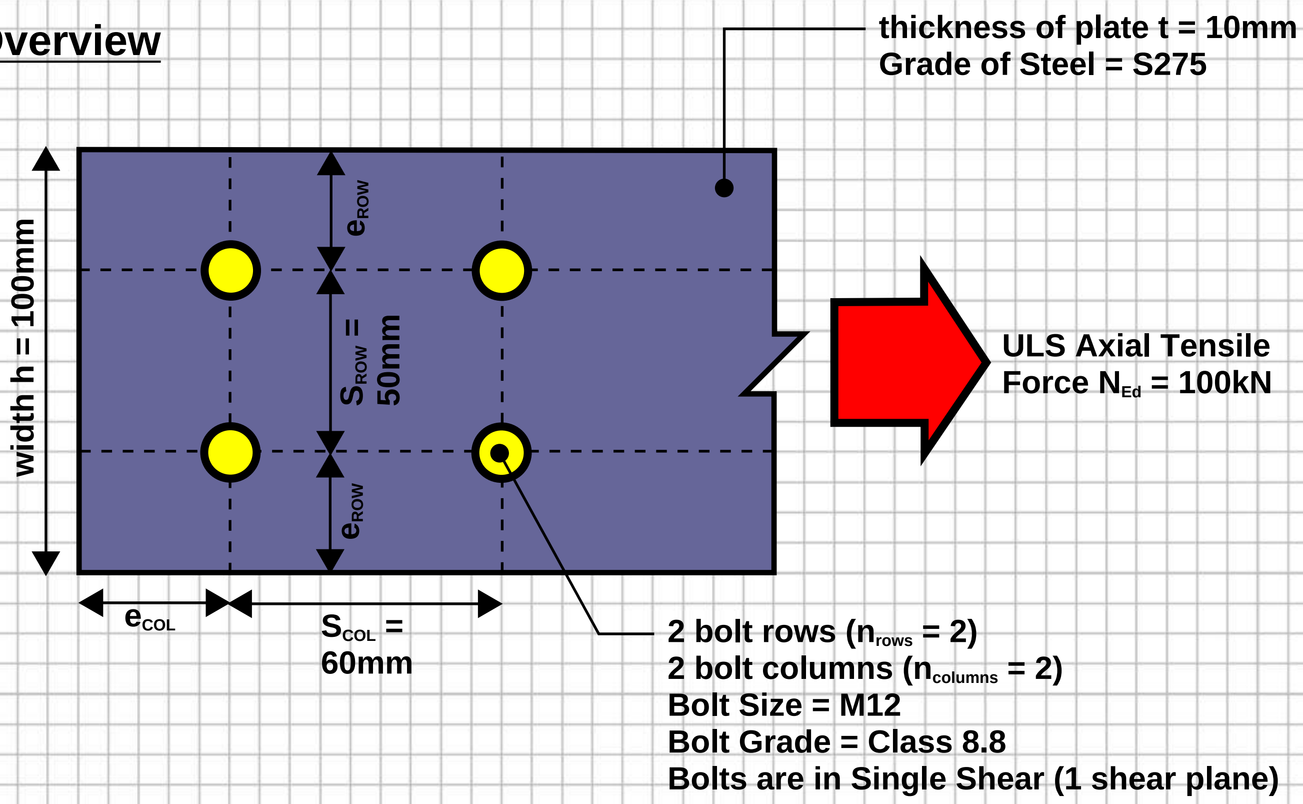
	Design Spreadsheet:	Date:
	Flat Plate X-Bracing Design v1.0.xlsm	Dec 2021
		By: AL
	Subtitle: Worked Example 1	Version: 1

Overview



Geometric Checks

Check Bolt Spacing Between Consecutive Bolt Rows

The centre-to-centre spacing of the bolt rows must be no less than 2.5 * bolt diameter

In this instance we're using M12 bolts which means the gross bolt diameter is 12mm
Therefore the minimum spacing of bolt rows is: 2.5 * 12mm = 30mm
Our current spacing is 50mm which exceeds this so we're ok.

Check Bolt Spacing Between Consecutive Bolt Columns

The centre-to-centre spacing of the bolt columns must be no less than 2.5 * bolt diameter

In this instance we're using M12 bolts which means the gross bolt diameter is 12mm
Therefore the minimum spacing of bolt columns is: 2.5 * 12mm = 30mm
Our current spacing is 60mm which exceeds this so we're ok.

Check Bolt Edge Distance (e_{row})

$e_{row} = h - [(n_{rows} - 1) * S_{ROW}]$
e_{row} = 100mm - [(2 bolt rows - 1) * 50mm row spacing]
e_{row} = 25mm

The edge distance must be no less than 1.25 * bolt diametre

In this instance we're using M12 bolts which means the gross bolt diameter is 12mm
Therefore the minimum spacing of bolt columns is: 1.25 * 12mm = 15mm
Our current edge distance is 25mm which exceeds this so we're ok.

Find the Other Bolt Edge Distance (e_{col})

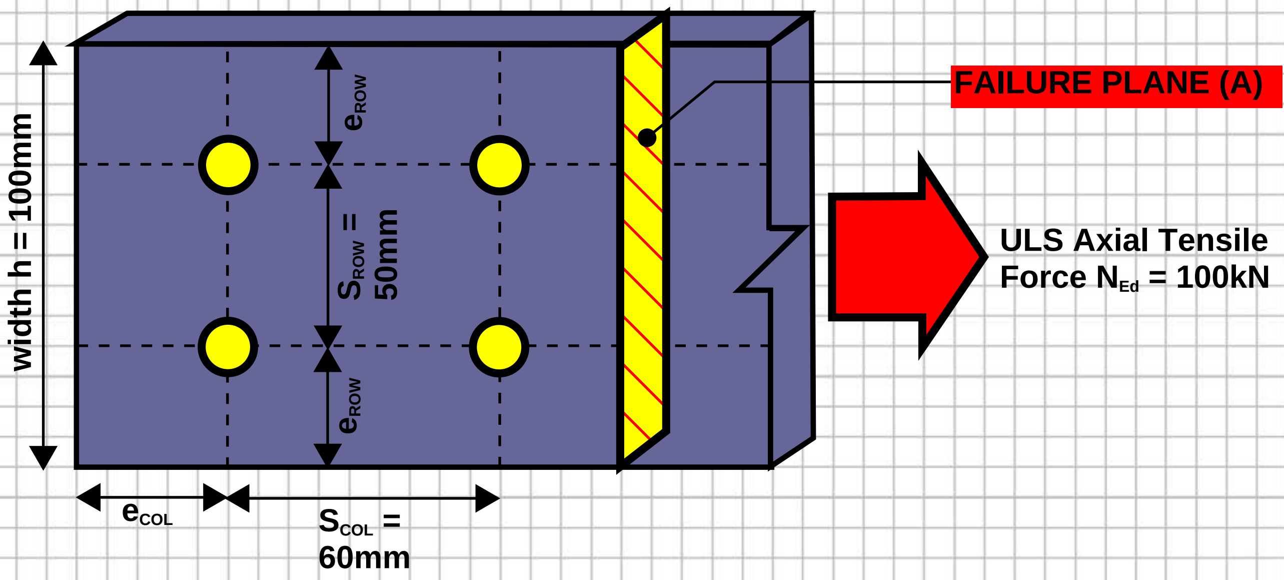
The spreadsheet always sets this as being the minimum but care should be taken to ensure localised tearing or yielding doesn't occur around the bolt holes.

e_{col} = max{25mm ; 1.25 * bolt diameter} = max{25mm ; 1.25 * 12mm} = 25mm

Capacity Checks

Resistance of Plate: Gross Cross Section

The resistance of the gross cross section considers a failure through the entire gross cross sectional area of the plate i.e.



Gross Cross Sectional Area of the Plate (i.e failure plane)

A = h * t

A = 100mm plate width * 10mm plate thickness

A = 1000mm^2

Yield Strength of the Steel Plate f_y = see table below

EN10025-2 - YIELD STRENGTH OF STEEL f_y (N/mm^2)					
Steel Grade	Plate Thickness				
	≤ 16	16< t ≤40	40 < t ≤ 63	63 < t ≤ 80	80 < t ≤ 100
S235	235	225	215	215	215
S275	275	265	255	245	235
S355	355	345	335	325	315

In this instance the yield stress of the steel f_y = 275N/mm^2

However please note that this yield stress can decrease if you increase the thickness of the steel plate

Design Plastic Resistance of Gross Cross Section:

$N_{pl,Rd}$ = A * f_y * (1/γ_{M0})

$N_{pl,Rd}$ = 1000mm^2 * 275N/mm^2 * (1 / 1.0)

$N_{pl,Rd}$ = 275kN

BS EN1993-1-1 Eq 6.6

Utilisation = N_{Ed} / $N_{pl,Rd}$ = 100kN / 275kN = 36% --> OK

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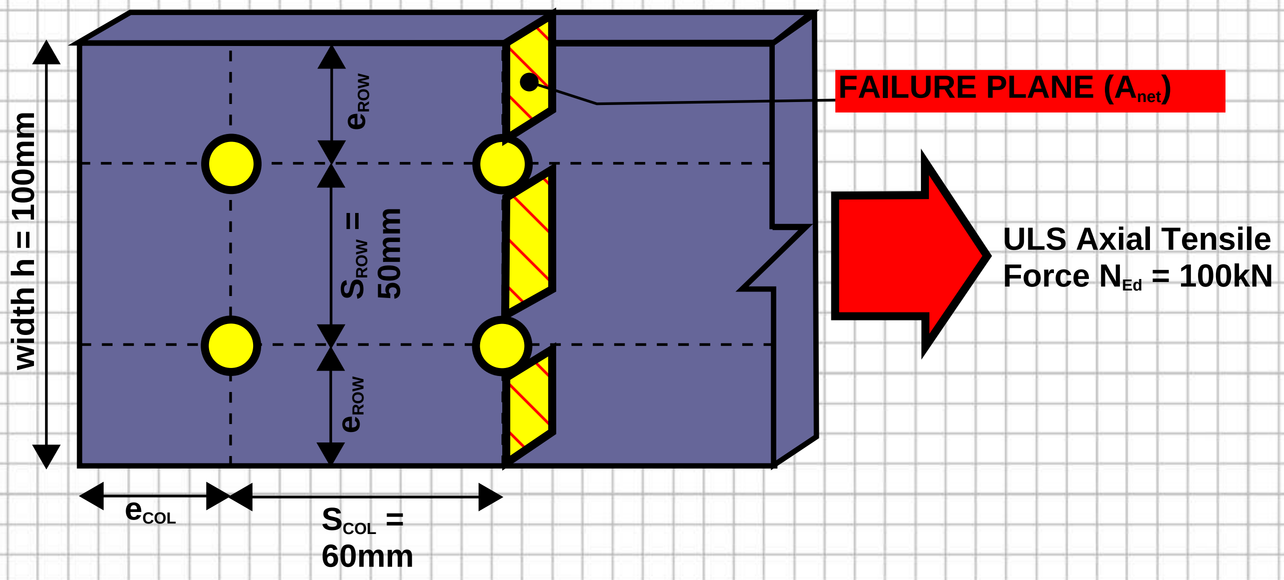
Resistance of Plate: Net Cross Section

The resistance of the net cross section considers a failure through a partial cross section where the bolt holes occur. There are special considerations for this when considering staggered holes however the spreadsheet and following example doesn't support staggered holes.



It should be noted that whilst we are using M12 bolts, the hole through the steel plate will be larger than 12mm in order to provide clearance for the bolts themselves. In this instance a typical value has been chosen from the table below however you should double check to make sure the automatic values in the spreadsheet reflect what you intend to install. Sometimes slightly larger bolt clearance holes will be used.

BOLT CLEARANCE HOLE	
Size	**Hole Diametre (mm)**
M12	13.5
M16	17.5
M20	22
M24	26
M30	33

d_{bolt} = 13.5mm

Area of net cross section:

A_{net} = [h - (n_{rows} * d_{bolt})] * t

A_{net} = [100mm - (2 bolt rows * 13.5mm clearance hole diametre)] * 10mm plate thickness

A_{net} = 730mm^2

Find Ultimate Tensile Stress of Steel Material Chosen

EN10025-2 - ULTIMATE TENSILE STRENGTH OF STEEL f_u (N/mm^2)		
Steel Grade	**Plate Thickness**	
	<3	**3 ≤ t ≤ 100**
S235	360-510	360-510
S275	430-580	410-560
S355	510-680	470-630

Ultimate Tensile Stress f_u = 410N/mm^2
(i.e. taking the lower bound from the range in the table)

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Design Ultimate Resistance of Cross Section

$N_{u,Rd} = (0.9 * A_{net} * f_u) * (1 / \gamma_{M2})$

$N_{u,Rd}$ = (0.9 * 730mm2 * 410N/mm2) * (1 / 1.25)

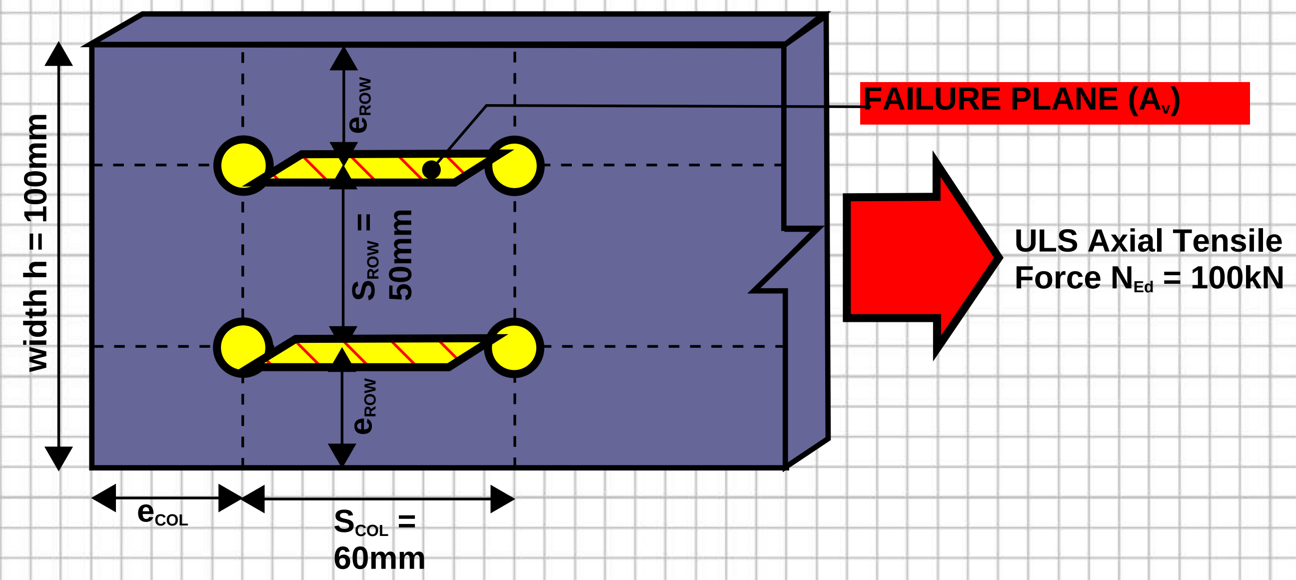
$N_{u,Rd}$ = 215.5kN

BS EN1993-1-1 Eq 6.7

Utilisation = N_{Ed} / $N_{u,Rd}$ = 100kN / 215.5kN = 46.4% --> OK

Resistance of Plate: Shear Between Bolt Columns

The shear resistance considers a failure plane between 2 adjacent columns of bolts. This failure plane acts in shear.



Shear Area

$A_v = (S_{COL} - d_{bolt}) * t * n_{rows}$

A_v = (60mm bolt column spacing - 13.5mm clearance hole) * 10mm plate thickness * 2 bolt rows

$A_v = 930mm^2$

Shear Capacity

$V_{Rd} = A_v * f_y * (1/\sqrt{3}) * (1/\gamma_{M0})$

$V_{Rd} = 930mm^2 * 275N/mm^2 * (1/\sqrt{3}) * (1/1.0)$

V_{Rd} = 147.7kN

BS EN1993-1-1 Eq 6.18

Utilisation = N_{Ed} / V_{Rd} = 100kN / 147.7kN = 67.7% --> OK

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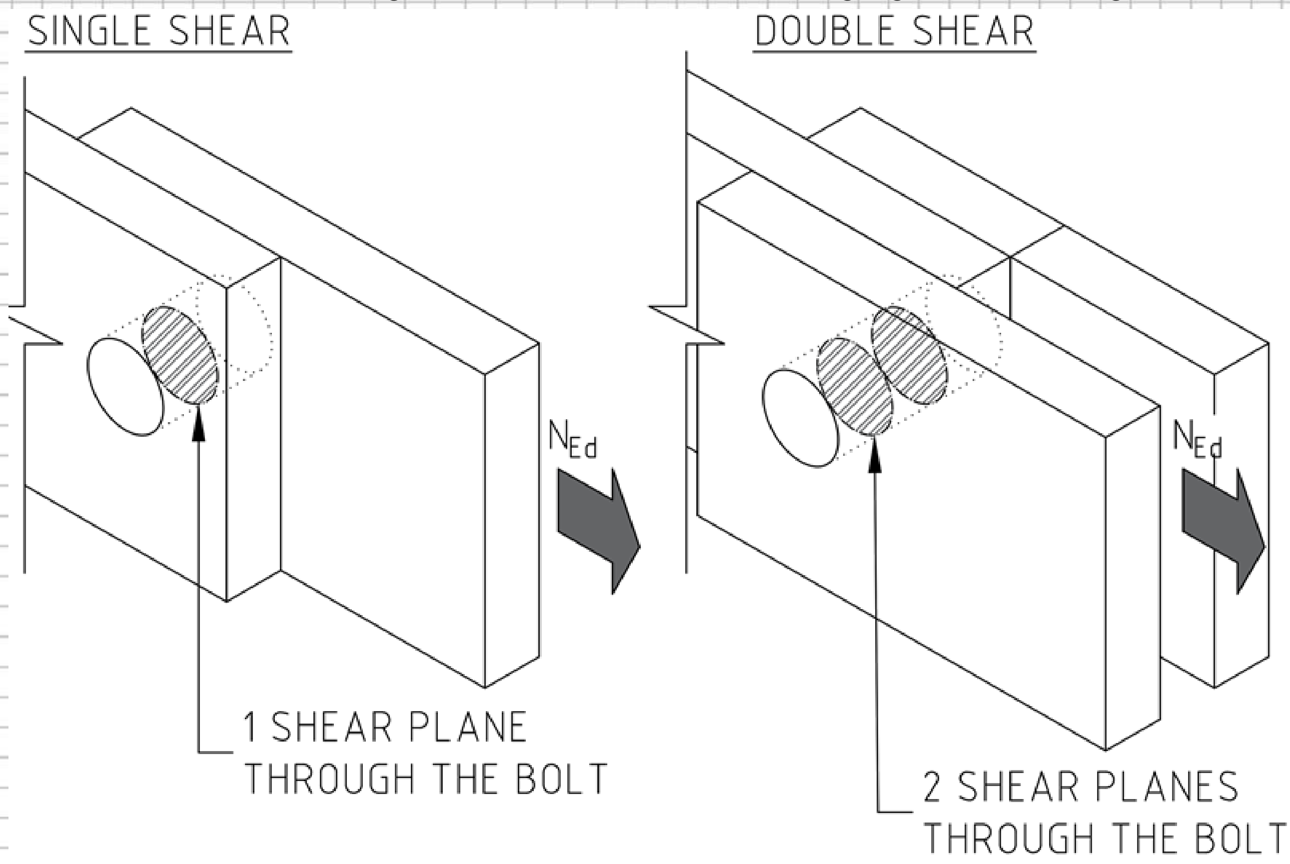
Resistance of Bolts in Shear

Capacity of the bolts in shear is taken from the steel building design: design data (blue book). The tables from this book are replicated below:

BOLT SHEAR CAPACITY					
Single Shear	**M12**	**M16**	**M20**	**M24**	**M30**
Class 4.6 Hexagon Head Bolts	13.8	30.1	47	67.8	108
Class 8.8 Hexagon Head Bolts	27.5	60.3	94.1	136	215
Class 10.9 Hexagon Head Bolts	28.7	62.8	98	141	224

BOLT SHEAR CAPACITY					
Double Shear	**M12**	**M16**	**M20**	**M24**	**M30**
Class 4.6 Hexagon Head Bolts	27.5	60.3	94.1	136	215
Class 8.8 Hexagon Head Bolts	55	121	188	271	431
Class 10.9 Hexagon Head Bolts	57.3	126	196	282	449

The difference between single shear and double shear is highlighted in the diagram below



Single shear capacity of a single M12 class 8.8 bolt $V_{Ed,bolt}$ = 27.5kN
Total number of bolts $N_{bolts} = n_{rows} * n_{columns}$ = 2 bolt rows * 2 bolt columns = 4
Total Shear Capacity of Bolts $V_{Ed,\Sigma bolts} = N_{bolts} * V_{Ed,bolt}$ = 27.5kN * 4 bolts = 110kN

Utilisation = $N_{Ed} / V_{Ed,\Sigma bolts}$ = 100kN / 110kN = 91% --> OK

Further Comments on Flat Plate Bracing

Avoiding "Flappy" Bracing

If the length of the flat plate needed to form the cross bracing is large then there is the risk that the brace will be "flappy". This poses several problems:

- It's harder to install on site as it will flap around all over the place when it's being lifted and bolted into place. This poses both a constructibility issue and a site safety issue.

- The flat plate is likely to have a bow in it when it is installed i.e. it's difficult to install the flat plate without any slack in the member when it's long and slender. This is bad because the cross bracing is typically used to limit the lateral displacements of a building. If there is slack in the brace because it is bowing then this slack will be taken up by the lateral deflection of the building before the flat plate can start to do anything. This is amplified if you've got many stories with the same type of bracing arrangement involved. To remedy this consider using 2 back-to-back angles instead of flat plates for the cross bracing to prevent this bow from developing.

Localised Yielding

The calculations in the spreadsheet and in the worked example above only consider the main failure modes of the flat plate bracing. In reality there are more complex failure modes which can develop when the arrangement of the bolts is more complex (i.e. staggered).

As an example the edge distance e_{col} is set to always be a minimum of 25mm as a pragmatic way of preventing localised tearing of the bolts with the edge of the plate. Depending on the loading this dimension could be smaller or bigger depending on the specific design requirements.

For more complex geometries and where a tension member is a critical single point of failure for a structure a more in depth assessment using a finite element analysis is recommended. This type of analysis can consider things such as the following:

- Localised tearing/yielding around the bolt holes
- Progressive "unzipping" of the bolts should a single bolt carry disproportionate load to the others (i.e. 1 bolt fails and the failure jumps from bolt to bolt failing the entire connection).
- Slippage in the bolts themselves leading to onerous deflections over the full height of the braced bay
- Extension of the flat plate cross bracing leading to onerous deflections over the full height of the braced bay.

Project	N/A	Flat Plate X-Bracing BS EN1993-1-1			
Client	N/A	Made by	Date	Job No	
Description	Worked Example 1	AL	5-12-21	N/A	
		Checked	Revision		
Flat Plate X-Bracing Design v1.0		N/A	1		

1.0 - CROSS SECTION GEOMETRY

Thickess of Flat Plate t (mm)	10
Width of Flat Plate h (mm)	100

2.0 - MATERIAL PROPERTIES

Grade of Steel	S275
Ultimate Tensile Strength	AUTO
Yield Strength f_y (N/mm^2)	275
Ultimate Tensile Strength (final) f_u (N/mm^2)	410

3.0 - BOLTS

Size of Fixing Bolts	M12
Bolt Class	Class 8.8
Bolt Type	Hexagon Head Bolts
Single Shear / Double Shear	Single Shear
Number of Bolt Rows n_{rows}	2
Number of Bolt Columns $n_{columns}$	2
Spacing Between Bolt Rows S_{ROW} (mm)	50
Spacing Between Bolt Columns S_{COL} (mm)	60
Bolt Hole Clearance Diametre	AUTO
Bolt Clearance Hole Diametre d_{bolt} (mm)	13.5
Minimum Edge Distance for Bolt Columns e_{col} (mm)	25
Edge Distance for Bolt Rows e_{row} (mm)	25

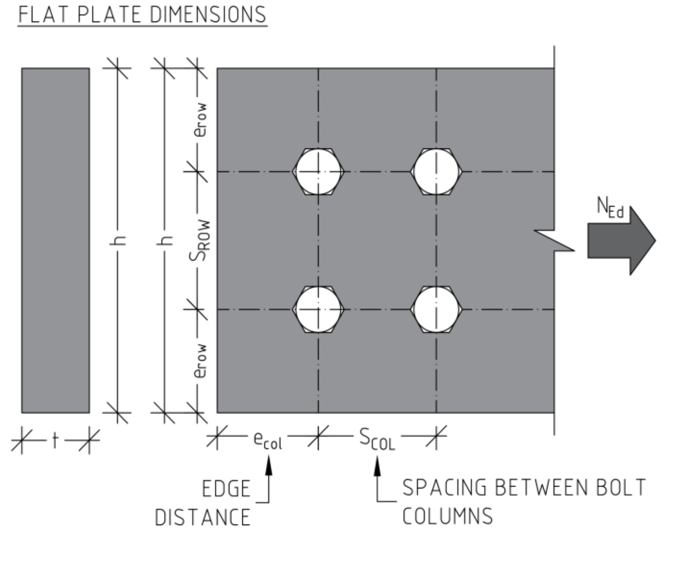
4.0 - AXIAL TENSION LOADING @ ULS

Applied Axial Tension N_{Ed} (kN)	100

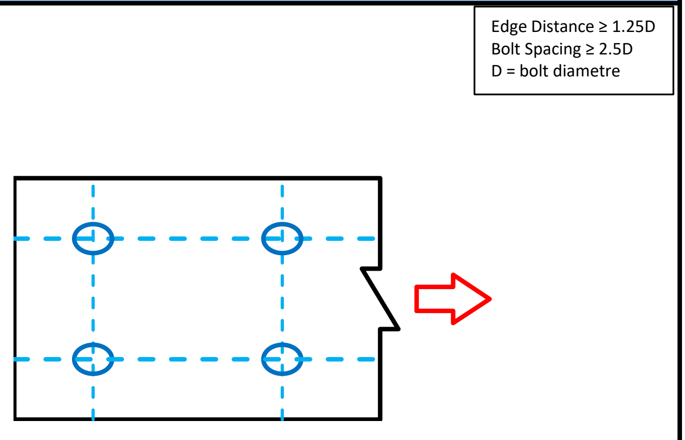
7.0 - CHECK BOLT EDGE DISTANCE AND GEOMETRY

Spacing of Bolt Rows	PASS: Bolt Spacing >= 30mm
Spacing of Bolt Columns	PASS: Bolt Spacing >= 30mm
Bolt Edge Distance	PASS: Bolt Edge Dist >= 15mm
Verdict	**PASS: Bolt Spacing OK**

INPUT GEOMETRY OF FLAT PLATE



INPUT GEOMETRY OF FLAT PLATE (PLOTTED)



6.0 - RESISTANCE OF PLATE - GROSS CROSS SECTION

Gross Cross Sectional Area of Plate A (mm^2)	1000	$A = h * t$
Partial Material Factor of Safety γ_{M0} (mm^2)	1.0	γ_{M0} = 1.0 as per BS EN1993-1-1
Design Plastic Resistance of Gross Cross Section $N_{pl,Rd}$ (kN)	275.0	$N_{pl,Rd} = (A * f_y) / \gamma_{M0}$ BS EN1993-1-1 Eq 6.6
Utilisation %	**36%**	$N_{Ed} / N_{pl,Rd}$

7.0 - RESISTANCE OF PLATE - NET CROSS SECTION (I.E. REDUCED CROSS SECTION ACCOUNTING FOR THE BOLT HOLES)

Net Cross Sectional Area of Plate A_{net} (mm^2)	730.0	$A_{net} = (h - (d_{bolt} * n_{rows})) * t$
Partial Material Factor of Safety γ_{M2} (mm^2)	1.25	γ_{M2} = 1.25 as per BS EN1993-1-1
Design Ultimate Resistance of Cross Section $N_{u,Rd}$ (kN)	215.5	$N_{u,Rd} = (0.9 * A_{net} * f_u) / \gamma_{M2}$ BS EN1993-1-1 Eq 6.7
Utilisation %	**46%**	$N_{Ed} / N_{u,Rd}$

8.0 - RESISTANCE OF PLATE - SHEAR BETWEEN 2 ADJACENT BOLT HOLE COLUMNS

Total Shear Area Between 2 Adjacent Bolt Columns A_v (mm^2)	930	$A_v = (S_{COL} - d_{bolt}) * n_{rows} * t$
Shear Capacity Between 2 Adjacent Bolt Columns V_{Rd} (kN)	147.66	$V_{Rd} = A_v * f_y * (1/\sqrt{3}) * (1/\gamma_{M0})$ BS EN1993-1-1 Eq 6.18
Utilisation %	**68%**	N_{Ed} / V_{Rd}

9.0 - RESISTANCE OF BOLTS

Total Number of Bolts N_{bolts}	4	$N_{bolts} = n_{rows} * n_{columns}$
Shear Capacity of a Single Bolt $V_{Ed,bolt}$ (kN)	27.5	Steel Building Design Data (Blue Book)
Total Shear Capacity of Bolts $V_{Ed,\Sigma bolts}$ (kN)	110	$V_{Ed,\Sigma bolts} = N_{bolts} * V_{Ed,bolt}$
Utilisation %	**91%**	$N_{Ed} / V_{Ed,\Sigma bolts}$

DESIGN STATUS	**PASS**
OVERALL UTILISATION	**91%**