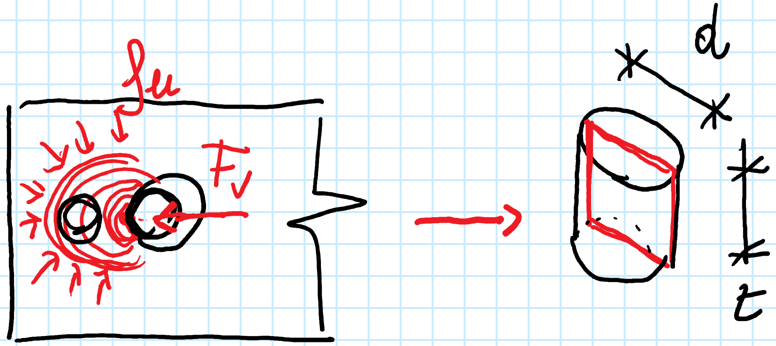
Rifollamento delle lamiere



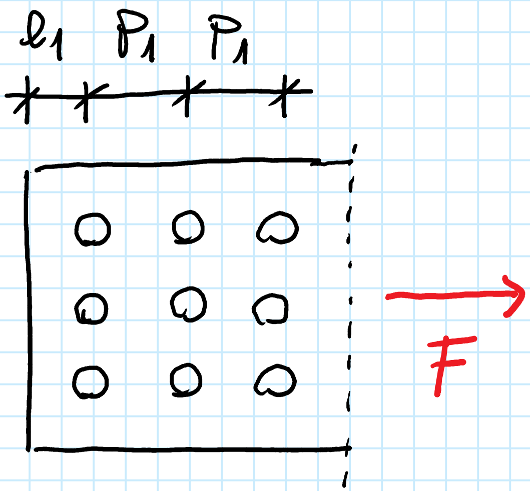
d : diametro del bullone
t = spessore della lamiera

d t è l'area della sezione "convenzionale" che resiste a rifollamento.
Per considerare che la sezione che "realmente" resiste a rifollamento è ben più grande si assume una tensione di rottura maggiorata:

$k_\alpha f_u$ con k_α che può essere ≥ 1 fino ad un massimo di 2,5

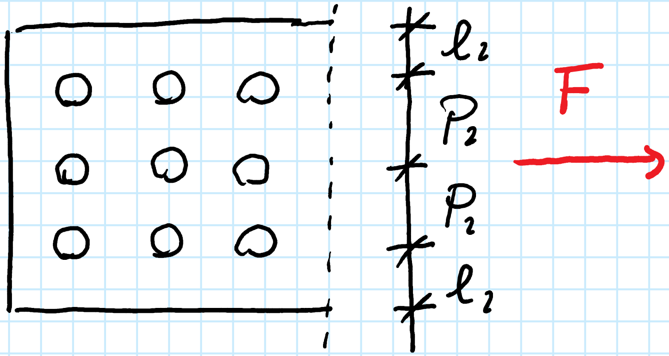
Si ottiene $F_{v,rif.} = F_{b,Rd} = k_\alpha \, d \, t \, f_u$

α e K dipendono dalle distanze dei fori dai bordi delle piastre e dalle distanze tra i bulloni



$\alpha = \alpha(e_1, P_1) \leq 1{,}0$

cresce con e_1 e P_1



$K = K(e_2, P_2) \leq 2{,}5$

cresce con e_2 e P_2

$K\alpha$ può essere al massimo $1{,}0 \times 2{,}5 = 2{,}5$

Resistenza a rifollamento, formule di normativa

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

f_u tensione di rottura della lamiera

$$\alpha = \min\left(\frac{e_1}{3d_0} ; \frac{f_{ub}}{f_u} ; 1\right)$$ Bullone vicino al bordo

$$\alpha = \min\left(\frac{P_1}{3d_0} - 0,25 ; \frac{f_{ub}}{f_u} ; 1\right)$$ Bullone interno

$$K = \min\left(2,8 \frac{e_2}{d_0} - 1,7 ; 2,5\right)$$ Bullone vicino al bordo

$$K = \min\left(1,4 \frac{P_2}{d_0} - 1,7 ; 2,5\right)$$ Bullone interno

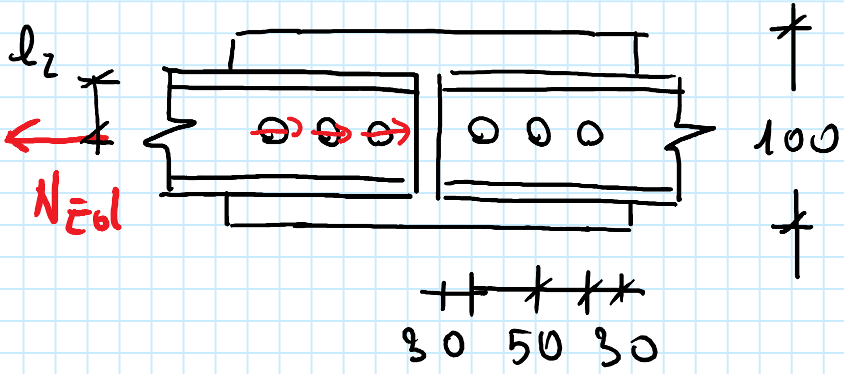
K vale 2,5 se:

$$\frac{\ell_2}{d_0} \geq 1,5$$

$$K = 2,8\,\frac{\ell_2}{d_0} - 1,7 = 2,8 \times 1,5 - 1,7 = 2,5$$

$$\frac{P_2}{d_0} \geq 3,0$$

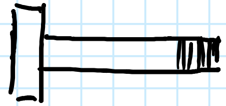
$$K = 1,4\,\frac{P_2}{d_0} - 1,7 = 1,4 \times 3,0 - 1,7 = 2,5$$



UPN 65×42 S235

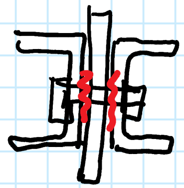
$t_p = 12$ S235

M14 6.8



$N_{Ed} = 250$ KN

$n_s = 2$



1. Verifica a taglio dei bulloni

$$F_{v,Ed} = \frac{N_{Ed}}{n_b \, n_s} = \frac{250}{3 \times 2} = 41,7 \text{ KN}$$

OK!

$$F_{v,Rd} = \frac{0,6 \, A \, f_{ub}}{\gamma_{M2}} = \frac{0,6 \times 154 \times 600}{1,25 \times 10^3} = 44,4 \text{ KN}$$

2. Verifica a rifollamento delle lamiere

$t_p = 12$ mm $\quad 2t_w = 2 \times 5,5 = 11.0$ mm $\quad$ l'elemento più debole è l'anima dell'UPN

$$F_{b,Ed} = 2F_{V,Ed} = 2 \times 41,7 = 83,4 \text{ KN}$$

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

$$K = \min\left(2,8\frac{e_2}{d_0} - 1,7 \, , \, 2,5\right) = 2,5$$

$$e_2 = \frac{h}{2} = \frac{65}{2} = 32,5 \text{ mm} \qquad \frac{e_2}{d_0} = \frac{32,5}{15} = 2,17 > 1,5$$

$$\alpha = \min\left(\frac{e_1}{3d_0} ; \frac{f_{ub}}{f_u} ; 1\right)$$

$$\frac{e_1}{3d_0} = \frac{30}{3 \times 15} = 0{,}6667 \qquad \frac{f_{ub}}{f_u} = \frac{600}{360} = 1{,}667$$

$$\alpha = \min\left(\frac{P_1}{3d_0} - 0{,}25 ; \frac{f_{ub}}{f_u} ; 1\right)$$

$$\frac{P_1}{3d_0} - 0{,}25 = \frac{50}{3 \times 15} - 0{,}25 = 0{,}8611$$

$$F_{b,Rd} = 2{,}5 \times 0{,}6666 \times 14 \times 11 \times \frac{360}{1{,}25} \times \frac{1}{10^3} = 73{,}9 \, KN$$

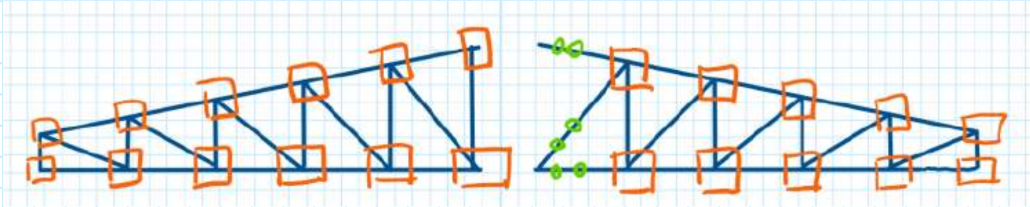
$$F_{b,Ed} = 83{,}4 \, KN \leq F_{b,Rd} = 73{,}9 \, KN$$ NO

Corrente superiore 2 UPN 50x38

Corrente inferiore 2L 55x5

Diagonali e montanti 2L 50x30x5

Progetto dei collegamenti



Sforzo normale del corrente inferiore

Asta	1° comb.	2° comb.	3° comb.	Max traz.	Max Comp.
1	0.00	5.50	0.00	5.50	0.00
2	105.13	87.24	-69.47	105.13	-69.47
3	135.93	105.86	-89.18	135.93	-89.18
4	140.18	101.93	-91.13	140.18	-91.13
5	131.93	87.40	-84.72	131.93	-84.72
6	131.93	62.82	-84.72	131.93	-84.72
7	140.18	56.98	-91.13	140.18	-91.13
8	135.93	48.15	-89.18	135.93	-89.18
9	105.13	32.97	-69.47	105.13	-69.47
10	0.00	0.00	0.00	0.00	0.00

Sforzo normale del corrente superiore

Asta	1° comb.	2° comb.	3° comb.	Max traz.	Max Comp.
11	-107.21	-83.47	71.92	71.92	-107.21
12	-138.62	-102.68	94.15	94.15	-138.62
13	-142.95	-98.90	98.27	98.27	-142.95
14	-134.54	-84.30	93.86	93.86	-134.54
15	-119.13	-63.75	84.76	84.76	-119.13
16	-119.13	-64.31	84.76	84.76	-119.13
17	-134.54	-60.93	93.86	93.86	-134.54
18	-142.95	-55.87	98.27	98.27	-142.95
19	-138.62	-47.76	94.15	94.15	-138.62
20	-107.21	-33.17	71.92	71.92	-107.21

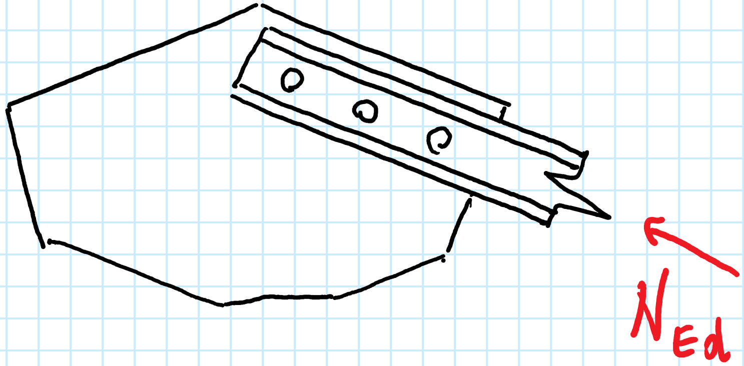
Sforzo normale dei diagonali

Asta	1° comb.	2° comb.	3° comb.	Max traz.	Max Comp.
21	110.82	86.16	-73.23	110.82	-73.23
22	34.90	21.10	-22.34	34.90	-22.34
23	5.27	-4.87	-2.41	5.27	-4.87
24	-11.28	-19.88	8.77	8.77	-19.88
25	-22.85	-30.79	16.65	16.65	-30.79
26	-22.85	6.35	16.65	16.65	-22.85
27	-11.28	7.99	8.77	8.77	-11.28
28	5.27	10.95	-2.41	10.95	-2.41
29	34.90	17.21	-22.34	34.90	-22.34
30	110.82	34.75	-73.23	110.82	-73.23

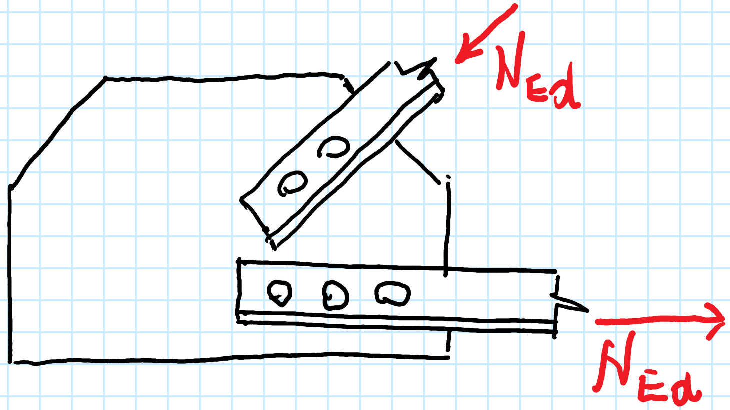
Sforzo normale dei montanti

Asta	1° comb.	2° comb.	3° comb.	Max traz.	Max Comp.
31	-62.30	-50.40	41.40	41.40	-62.30
32	-35.04	-27.25	23.16	23.16	-35.04
33	-16.42	-9.93	10.52	10.52	-16.42
34	-3.11	2.88	1.43	2.88	-3.11
35	7.70	13.57	-5.99	13.57	-5.99
36	34.27	18.33	-24.97	34.27	-24.97
37	7.70	-5.45	-5.99	7.70	-5.99
38	-3.11	-6.48	1.43	1.43	-6.48
39	-16.42	-8.10	10.52	10.52	-16.42
40	-35.04	-10.99	23.16	23.16	-35.04
41	-62.30	-17.51	41.40	41.40	-62.30

Nodo sul corrente superiore



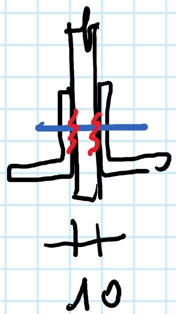
Nodo sul corrente inferiore



n_b
d ⇐ | Verifica dei bulloni
classe

Uso M12 6.8 

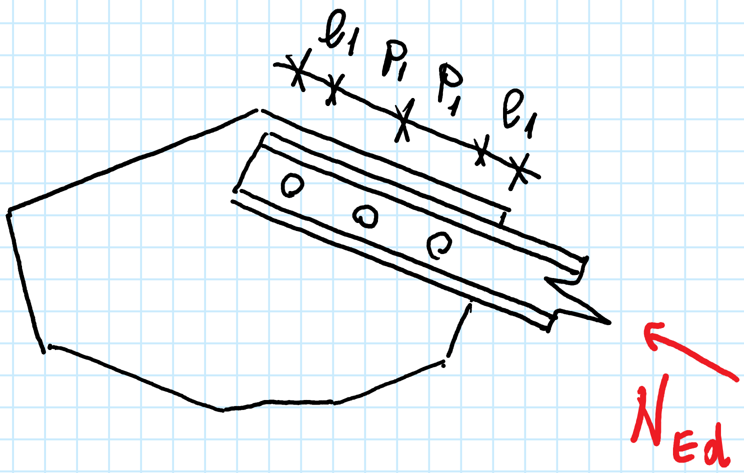
e_1 . p_1 ⇐ | Verifica a rifollamento
e_2 . ~~p_2~~



2 sezioni resistenti per bullone

e_2 è assegnato ($e_2 = h/2$ del profilato)

Corrente superiore



$N_{Ed} = 119.1$ KN

S235

M12 di classe 6.8 con gambo interamente filettato

sigla	M12	M14	M16
A (mm²)	113	154	201
A_{res} (mm²)	84.3	115	157
A_{res} / A	0.75	0.75	0.78

1. Progetto dei bulloni

$$F_{v,Ed} = \frac{N_{Ed}}{2 n_b} \leq F_{v,Rd}$$

$$F_{v,Rd} = 0{,}5\, A_{res} \frac{f_{ub}}{\gamma_{M2}} = 0{,}5 \times 84{,}3 \times \frac{600}{1{,}25} \times \frac{1}{10^3} = 20{,}2 \text{ KN}$$

$$\frac{N_{Ed}}{2 n_b} = F_{v,Rd} \Rightarrow n_b = \frac{N_{Ed}}{2 F_{v,Rd}} = \frac{119{,}1}{2 \times 20{,}2} = ~~2{,}95~~$$

3 bulloni

2. Progetto delle distanze e_1 e p_1

$t_p = 10\ mm \qquad 2t_w = 2 \times 5 = 10\ mm$

$$F_{v,Ed} = \frac{N_{Ed}}{n_s\, n_b} = \frac{119,1}{2 \times 3} = 19,8\ KN$$

$$F_{b,Ed} = 2F_{v,Ed} \leq \frac{k\, \alpha\, d\, t_p\, f_u}{\gamma_{M2}} \Rightarrow \alpha = \frac{\gamma_{M2} F_{b,Ed}}{k\, d\, t_p\, f_u}$$

$$e_2 = \frac{h}{2} = \frac{50}{2} = 25\ mm \qquad \frac{e_2}{d_0} = \frac{25}{13} = 1,92 > 1,5 \Rightarrow k = 2,5$$

$$\alpha = \frac{39,7 \times 1,25 \times 10^3}{2,5 \times 12 \times 10 \times 360} = 0,4594$$

$$\frac{e_1}{3d_0} = \alpha \Rightarrow e_1 = 3\alpha d_0 = 3 \times 0,4594 \times 13 = \underline{~~17,9~~}\ mm \quad 20\ mm$$

$$e_1 \geq 1,2\, d_0 = 1,2 \times 13 = 15,7\ mm$$

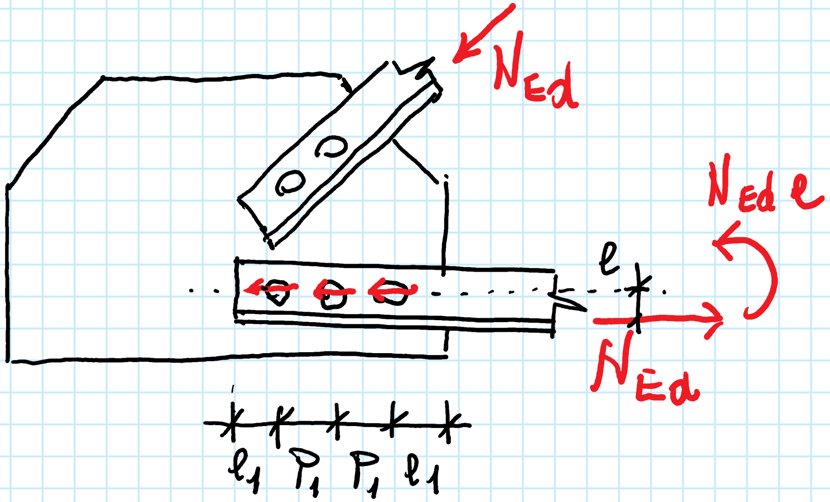
$$\frac{P_1}{3d_0} - 0,25 = \alpha \Rightarrow \frac{P_1}{3d_0} = \alpha + 0,25 \Rightarrow P_1 = 3(\alpha + 0,25)\, d_0$$

$$P_1 = 3 \times (0,4594 + 0,25) \times 13 = 27,7 \text{ mm}$$

$$P_1 \geq 2.2\, d_0 = 2,2 \times 13 = \underline{28,6}$$ 30 mm

Adesso che conosciamo il numero di bulloni e tutte le distanze si può eseguire le verifica del collegamento.

Corrente inferiore



$N_{Ed} = 131,9$ KN

S235

M12 di classe 6.8 con gambo interamente filettato

sigla	M12	M14	M16
A (mm²)	113	154	201
A_{res} (mm²)	84.3	115	157
A_{res} / A	0.75	0.75	0.78

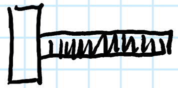
$N_{Ed}\,e$ è la coppia parassita

In prima battuta la trascuro ma "abbondo" su numero di bulloni e distanze ottenute dal progetto

Dopo aver dimensionato il collegamento, lo verifico considerando anche l'effetto della coppia parassita

1. Progetto dei bulloni

$F_{V,Rd} = 20{,}2 \text{ KN}$ bulloni M12 di classe 6.8



$$n_b = \frac{N_{Ed}}{2 F_{V,Rd}} = \frac{131{,}9}{2 \times 20{,}2} = ~~3{,}26~~$$ **4 bulloni**

2. Progetto delle distanze e_1 e P_1

$t_p = 10 \text{ mm}$ $2 t_w = 2 \times 5 = 10 \text{ mm}$

$$\alpha = \frac{F_{b,Ed}\, \gamma_{M2}}{k\, d\, t_p\, f_u} = \frac{33{,}0 \times 1{,}25 \times 10^3}{2{,}5 \times 12 \times 10 \times 360} = 0{,}3819$$

$$e_2 = \frac{h}{2} = \frac{50}{2} = 25 \text{ mm} \qquad \frac{e_2}{d_0} = \frac{25}{13} = 1{,}92 > 1{,}5 \Rightarrow k = 2{,}5$$

$$F_{b,Ed} = \frac{N_{Ed}}{4} = \frac{131{,}9}{4} = 33{,}0 \text{ KN}$$

$$\frac{e_1}{3d_0} = \alpha \Rightarrow e_1 = 3\alpha d_0 = 3 \times 0{,}3819 \times 13 = 14{,}9\ mm$$

$$e_1 \geq 1{,}2\, d_0 = 1{,}2 \times 13 = \underline{15{,}7}\ mm \quad 20\ mm$$

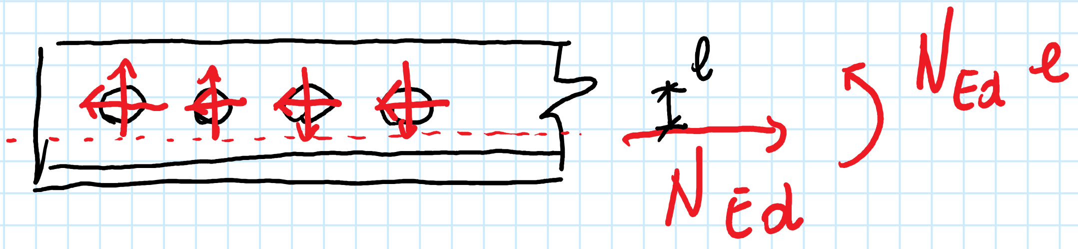
$$\frac{p_1}{3d_0} - 0{,}25 = \alpha \Rightarrow \frac{p_1}{3d_0} = \alpha + 0{,}25 \Rightarrow p_1 = 3(\alpha + 0{,}25)\, d_0$$

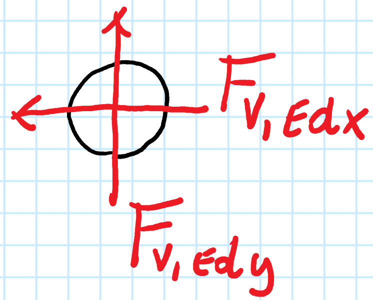
$$p_1 = 3 \times (0{,}3819 + 0{,}25) \times 13 = 24{,}6\ mm$$

$$p_1 \geq 2.2\, d_0 = 2{,}2 \times 13 = \underline{28{,}6} \quad 35\ mm$$

Adesso che conosciamo il numero di bulloni e tutte le distanze eseguo le verifiche del collegamento...

3. Verifica del collegamento

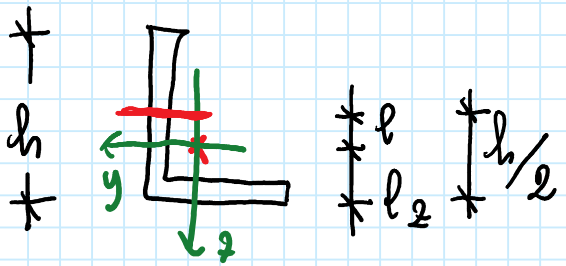




$$F_{V,Edx} = \frac{N_{Ed}}{2 \times n_b} = \frac{131,9}{2 \times 4} = 16,5 \text{ KN}$$ (lo avevamo già determinato)

$$\frac{N_{Ed}\, e}{2} - F_{V,Edy}\,(3 P_1) - F_{V,Edy}\, P_1 = 0$$

$$F_{V,Edy} = \frac{N_{Ed}\, e}{2\,(4 P_1)} = \frac{131,9 \times 12,3}{2 \times 4 \times 35} = 5,8 \text{ KN}$$



$$e = \frac{h}{2} - e_z = \frac{55}{2} - 15,2 = 12,3 \text{ mm}$$

$$F_{v,Ed} = \sqrt{F_{v,Edx}^2 + F_{v,Edy}^2} = \sqrt{16{,}5^2 + 5{,}8^2} = 17{,}5 \text{ KN}$$

$$F_{v,Ed} = 17{,}5 \text{ KN} \leq F_{v,Rd} = 20{,}2 \text{ KN}$$ OK!

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

$$F_{b,Rd} = k \, \alpha \, d \, t_p \frac{f_u}{\gamma_{M2}} = 2{,}5 \times 0{,}5128 \times 12 \times 10 \times \frac{360}{1{,}25} \times \frac{1}{10^3} = 44{,}3 \text{ KN}$$

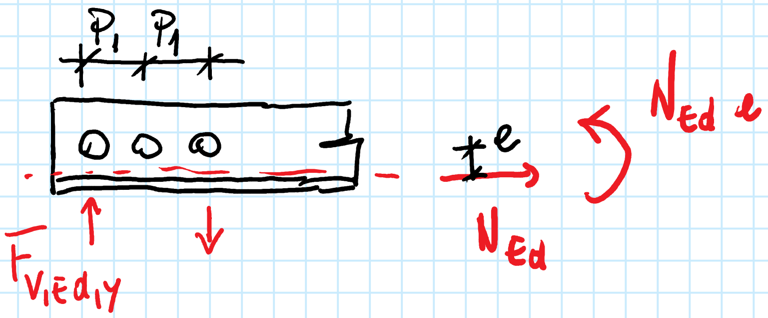
$$\alpha = \frac{e_1}{3d_0} = \frac{20}{3 \times 13} = \underline{0{,}5128}$$

$$\alpha = \frac{P_1}{3d_0} - 0{,}25 = \frac{35}{3 \times 13} - 0{,}25 = 0{,}6474$$

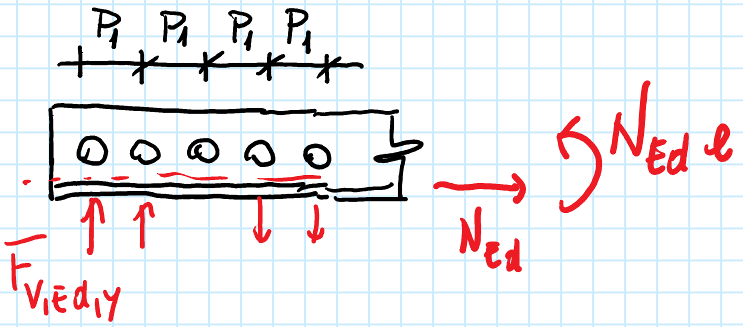
OK!

$$F_{b,Ed} = 2F_{v,Ed} = 2 \times 17{,}5 = 35{,}0 \text{ KN} \leq F_{b,Rd} = 44{,}3 \text{ KN}$$

Valutazione dell'effetto della coppia parassita con collegamento con 3 o 5 bulloni



$$2\,F_{V,Ed,y}\,(2\,p_1) = N_{Ed}\,e \Rightarrow F_{V,Ed,y} = \frac{N_{Ed}\,e}{4\,p_1}$$



$$2\,F_{V,Ed,y}\,(4\,p_1) + 2\,F_{V,Ed,y}\,(2\,p_1) = N_{Ed}\,e \Rightarrow F_{V,Ed,y} = \frac{N_{Ed}\,e}{12\,p_1}$$