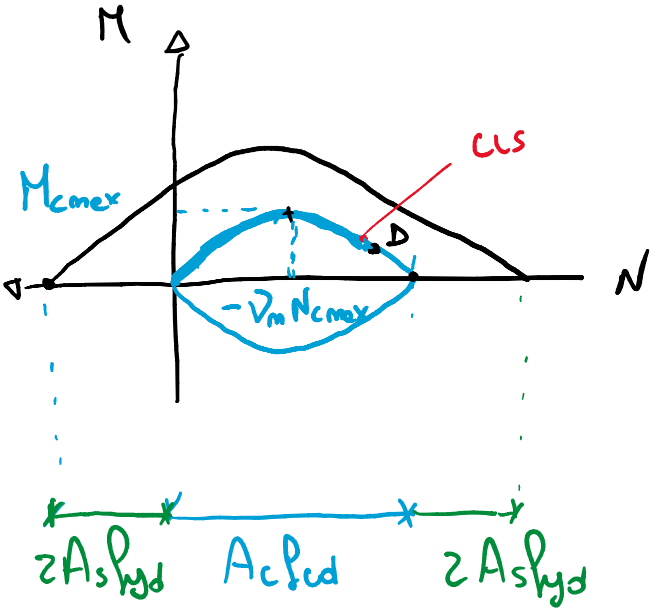
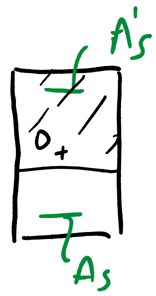
DOMINI M-N FORMULAZIONE APPROSSIMATA

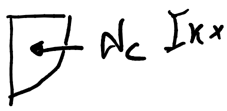
mercoledì 27 maggio 2020 14:01



SEZIONI RETTANGOLARI CON ARMATURA SIMMETRICA

$A_s = A'_s$





$N_{cmax} = A_c f_{cd}$

$N_{smax} = 2A_s f_{yd}$

CONTRIBUTO CLS

$\boxed{\text{FINO AL DIAGRAMMA LIMITE D:}}$ $\quad N_c = -\beta b x f_{cd} \quad 0 \le x \le h$

$\beta = 0.81$

SE SEZ. INTERAMENTE COMPRESSA $\quad N_c = -\beta b h f_{cd} \quad \beta$ NON È COST.

$$M_c = -N_c \left(\frac{h}{2} - kx\right)$$

RICAVO x DA $N_c \Rightarrow \quad x = -\dfrac{N_c}{\beta b f_{cd}}$

$$M_c = -N_c \cdot \left(\frac{h}{2} + \frac{k N_c}{\beta b f_{cd}}\right) \qquad k = 0.416$$

EQUAZIONE DI UNA PARABOLA

TROVO N_c TALE CHE $M_c = M_{cmax} \Rightarrow \dfrac{dM_c}{dN_c} = 0$

$$\frac{dM_c}{dN_c} = -\frac{h}{2} - \frac{K N_c}{\beta b f_{cd}} - \frac{K N_c}{\beta b f_{cd}} = 0$$

$$\frac{2K N_c}{\beta b f_{cd}} = -\frac{h}{2} \Rightarrow N_c = -\frac{\beta\, b h f_{cd}}{4K}$$

N_{cmax}

$$\nu_m = \frac{\beta}{4K} = \frac{0.810}{4 \times 0.416} = 0,4865 \Rightarrow$$

$$N_c = -\nu_m N_{cmax}$$

POSIZIONE CORRISPONDENTE DI x:

$$x = +\frac{\nu_m \cancel{b} h \cancel{f_{cd}}}{\beta \cancel{b} \cancel{f_{cd}}} = \frac{\cancel{\beta}}{4K\cancel{\beta}} h = \frac{1}{4K} \cdot h \Rightarrow$$

$$x_m = 0.601\, h$$

$$M_{cmax} = -N_c \left(\frac{h}{2} - Kx\right) = \nu_m N_{cmax} \left(\frac{h}{2} - \cancel{K} \cdot \frac{1}{4\cancel{K}} h\right)$$

$$= \frac{\beta}{4K} \cdot A_c f_{cd} \left(\underbrace{\frac{h}{2} - \frac{h}{4}}_{h/4}\right) = \frac{\beta}{16K} \cdot h A_c f_{cd}$$

$$\Rightarrow M_{cmax} = \frac{0.810}{16 \times 0.416} h A_c f_{cd} \rightarrow$$

$$\rightarrow M_{cmax} = 0.122\, h A_c f_{cd}$$

EQUAZIONE DELLA PARABOLA (MOMENTO RESISTENTE DEL CLS AL VARIARE DI N_{Ed})

$$M_c = M_{c\,max}\left[1-\left(\frac{N_{Ed}+\nu_m N_{c\,max}}{\nu_m N_{c\,max}}\right)^2\right]$$

VERIFICA :

se $N_{Ed} = 0 \rightarrow M_c = 0$

se $N_{Ed} = -\nu_m N_{c\,max} \Rightarrow M_c = M_{c\,max}$

CONTRIBUTO ARMATURE

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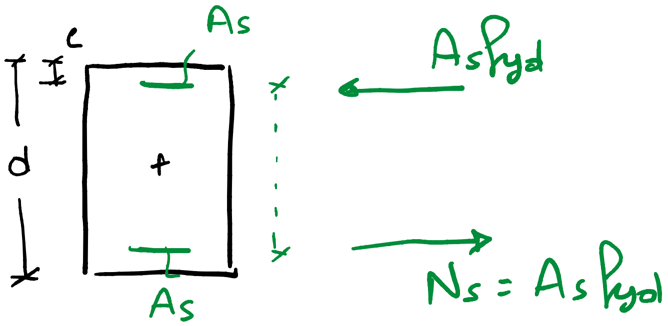
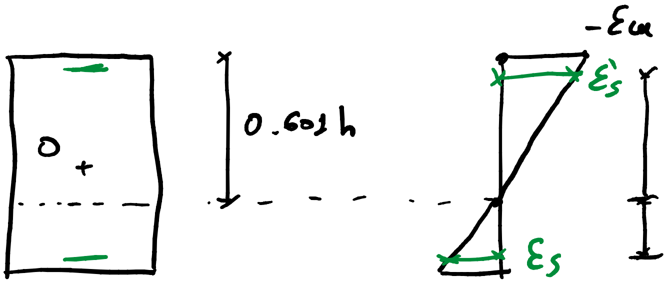


SE ENTRAMBE LE ARMATURE SONO SNERVATE

$$M_{s,max} = A_s f_{yd} (d-c)$$

PER $X = X_m = 0.601h$



$d - x = h - c - x$

$$\varepsilon_s : (h-c-x) = -\varepsilon_{cu} : (-x) \Longrightarrow$$

$$\varepsilon_s = \varepsilon_{cu} \frac{(h-c-x)}{x} \overset{?}{>} \varepsilon_{yd}$$

$$\varepsilon_{cu} \cdot h - \varepsilon_{cu} \cdot c - \varepsilon_{cu} x \geq \varepsilon_{yd} x$$

$$\cancel{\varepsilon_{cu}} \cdot c \leq \frac{\cancel{\varepsilon_{cu}} h}{\cancel{\varepsilon_{cu}}} - \frac{\cancel{\varepsilon_{cu}}\, 0.601 h}{\cancel{\varepsilon_{cu}}} - \frac{\varepsilon_{yd} \cdot 0.601 h}{\varepsilon_{cu}}$$

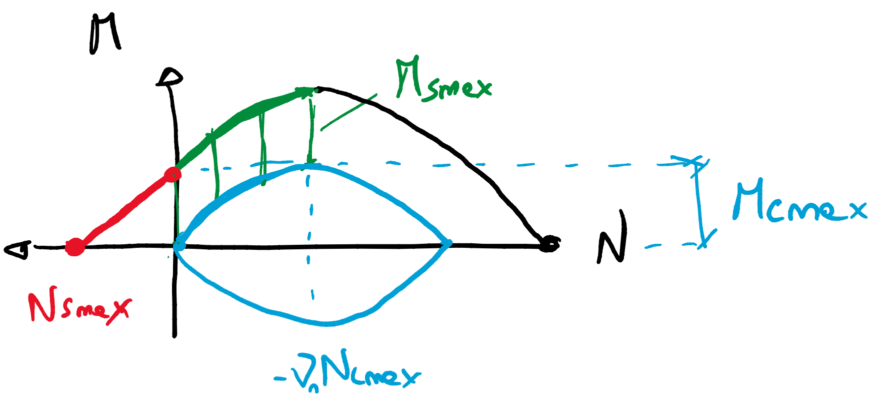
$$c \leq 0.399h - \frac{1,96}{3,5} \cdot 0.601 h \quad \boxed{f_{cu} \leq 50MPa}$$

$$\frac{c}{h} \leq 0.399 - 0.336 = 0.063 \quad \left(\text{VERA SE } h \text{ È GRANDE}\right)$$

NOTA: POTREBBE NON ESSERE VERO PER PILASTRI SOLLECITATI RISPETTO ALL'ASSE DEBOLE.
ANCHE IN QUESTO CASO, PER $x = x_m$, M_s SI DISCOSTA POCO DA $M_{s,max}$

FORMULE APPROSSIMATE PER DESCRIVERE IL DOMINIO

APPROSSIMAZIONE CON 3 TRATTI



TRATTO 1 : ANDAMENTO LINEARE

PER $N_{Ed} > 0$ $\Rightarrow$ $M_{Rd} = M_{smax}\left[1 - \frac{N_{Ed}}{N_{smax}}\right]$

TRATTO 2 : ANDAMENTO PARABOLICO

PER $N_{Ed} \leq 0$; $|N_{Ed}| \leq \vartheta_m N_{cmax}$ $\Rightarrow$

$$M_{Rd} = \underbrace{M_{smax}}_{\text{CONTRIBUTO ARMATURE}} + \underbrace{M_{cmax}\left[1 - \left(\frac{N_{Ed} + \vartheta_m N_{cmax}}{\vartheta_m N_{cmax}}\right)^2\right]}_{\text{CONTRIBUTO CLS}}$$

TRATTO 3: ANDAMENTO NON LINEARE

PER $N_{Ed} \leq 0$; $|N_{Ed}| \geq \vartheta_m N_{cmax}$

$$M_{Rd} = (M_{cmax} + M_{smax}) \cdot \left[1 - \left[\frac{|N_{Ed} + \vartheta_m N_{cmax}|}{(1-\vartheta_m) N_{cmax} + N_{smax}}\right]^n\right]$$

DOVE $n = 1 + \left[\frac{\vartheta_m N_{cmax}}{(1-\vartheta_m) N_{cmax} + N_{smax}}\right]^2$

VERIFICA

SE $N_{Ed} = -\vartheta_m N_{cmax} \Rightarrow \dfrac{N_{Ed} + \vartheta_m N_{cmax}}{(1-\vartheta_m) N_{cmax} + N_{smax}} = 0 \Rightarrow$

$$M_{Rd} = M_{cmax} + M_{smax}$$

SE $N_{Ed} = -N_{cmax} - N_{smax} \Rightarrow$

$$\frac{N_{Ed} + \vartheta_m N_{cmax}}{(1-\vartheta_m) N_{cmax} + N_{smax}} = \left| \underbrace{\frac{-N_{cmax} - N_{smax} + \vartheta_m N_{cmax}}{(1-\vartheta_m) N_{cmax} + N_{smax}}}_{=1} \right|$$

$$\Rightarrow M_{Rd} = 0$$

FORMULE APPROSSIMATE PER DESCRIVERE IL DOMINIO

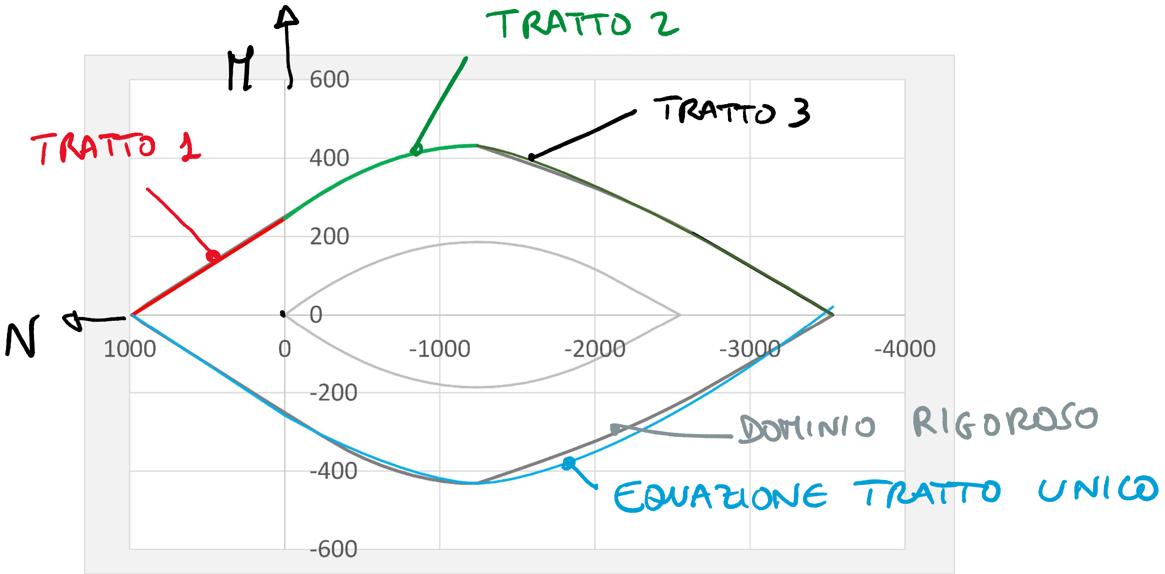
APPROSSIMAZIONE CON 1 TRATTO

$$\Rightarrow M_{Rd} = (M_{cmax} + M_{smax}) \left[1 - \left| \frac{N_{Ed} + \vartheta_m N_{cmax}}{\vartheta_m N_{cmax} + N_{smax}} \right|^m \right]$$

DOVE $\quad m = 1 + \dfrac{\vartheta_m N_{cmax}}{\vartheta_m N_{cmax} + N_{smax}}$

NOTO $N_{Ed} \Rightarrow M_{Rd}$ DA CONFRONTARE CON M_{Ed}

EFFICACIA DELLE FORMULAZIONI SEMPLIFICATE



FORMULA DI VERIFICA

L'ESPRESSIONE AD 1 TRATTO PUÒ ESSERE MANIPOLATA PER AVERE UN INDICE DI VERIFICA

$$\frac{M_{Ed}}{M_{c\,max} + M_{s\,max}} + \left(\frac{N_{Ed} + \vartheta_m N_{c\,max}}{\vartheta_m N_{c\,max} + N_{s\,max}} \right)^m \leq 1$$

ESEMPIO

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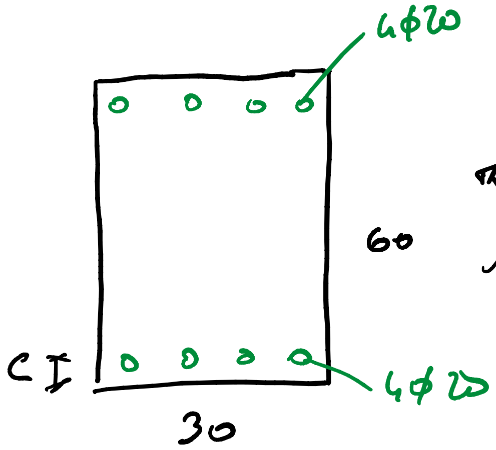


C25/30; B450 C

$N_{Ed} = -1200$ KN

$M_{Rd} = ?$

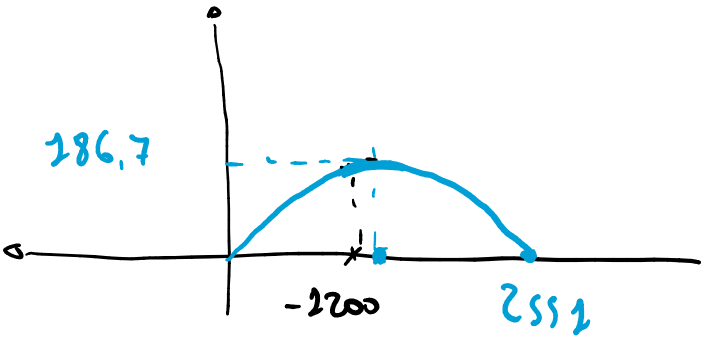
$A_s = A'_s = 12{,}56 \text{ cm}^2$

$$N_{cmax} = A_c f_{cd} = 30 \times 60 \times 14.17 \frac{N}{mm^2} \text{ cm}^2 \cdot \frac{1}{10} =$$

$$= 2550 \text{ KN}$$

$$M_{cmax} = 0.122 \cdot h N_{cmax} = 0.122 \times 0{,}60 \times 2550 \text{ KNm}$$

$$= 186.2 \text{ KNm}$$



$$\nu N_{cmax} = 0.486 \times 2550 =$$

$$= 1241.3 \text{ KN}$$

VERIFICA CON IL DOMINIO A 3 TRATTI :

RICADO NEL TRATTO 2

$$M_c = 186{,}7 \times \left[1 - \left(\frac{-1200 + 0{,}486 \times 2550}{0{,}486 \times 2550} \right)^2 \right]$$

$$= 186 \text{ KNm}$$

$$M_{s,max} = A_s f_{yd} (d-c) = \frac{12{,}56}{10} cm^2 \times 391.3 \frac{N}{mm^2} (0{,}55 - 0{,}05)$$

$$= 245.9 \ kNm$$

$$M_{Rd} = 186 + 245.9 = 431.9 \ kNm$$

IN ALTERNATIVA ... VERIFICA CON EQUAZIONE UNICA

$$M_{Rd} = (M_{smax} + M_{cmax}) \left[1 - \left| \frac{N_{Ed} + \vartheta_m N_{cmax}}{\vartheta_m N_{cmax} + N_{smax}} \right|^m \right]$$

$$m = 1 + \frac{\vartheta_m N_{cmax}}{\vartheta_m N_{cmax} + N_{smax}}$$

$$N_{s,max} = 2 A_s f_{yd} = 2 \times 12{,}56 \ cm^2 \times 391{,}3 \ N/mm^2 \ \frac{1}{10}$$

$$= 983.6 \ kN$$

$$m = 1 + \frac{1241.3}{1241.3 + 983.6} = 1.56$$

$$M_{Rd} = (245{,}9 + 186{,}7) \cdot \left[1 - \left[\frac{|-1200 + 1241|}{1241 + 983.6} \right]^{1{,}56} \right]$$

$$= 431{,}2 \ kNm$$

PROGETTO DI SEZIONI PRESSO INFLESSE

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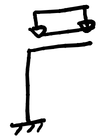
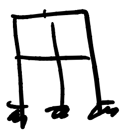
– STRUTTURE ISOSTATICHE



CONOSCO N_{Ed}, M_{Ed}

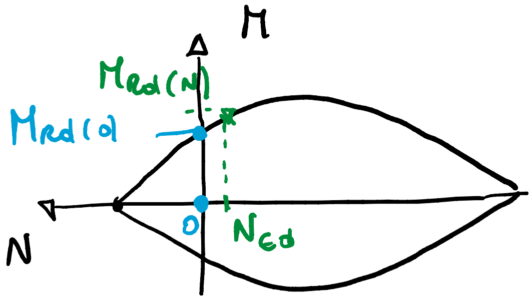
– STRUTTURE IPERSTATICHE



N_{Ed} ABBASTA STABILE

M_{Ed} FORTEMENTE DIPENDENTE DA I

STRUTTURE ISOSTATICHE CON BASSO $N_{Ed} < 0$



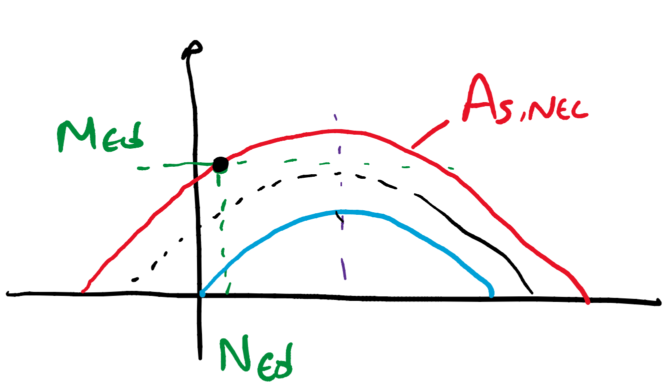
TRASCURO N_{Ed} (A VANTAGGIO DI SICUREZZA)

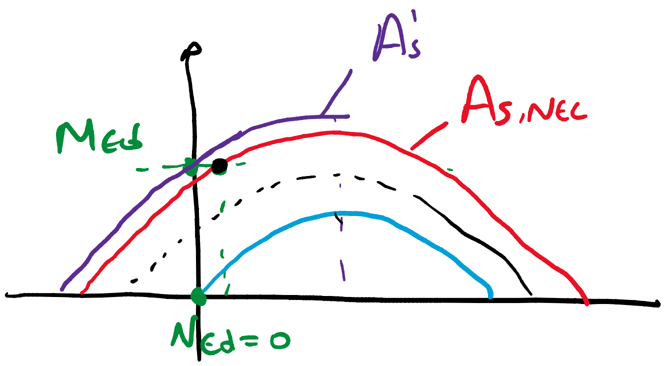
↓

PROGETTO SEZIONE CLS A FLESSIONE ⇒

$$M = \frac{bd^2}{r'^2} \Rightarrow d = r' \sqrt{\frac{M}{b}}$$

AL CRESCERE DI N_{Ed} DI COMPRESSIONE (FINO A $\nu_m N_{c\,max}$) CRESCE M_{Rd} ⇒ TRASCURANDO N_{Ed} IPOTIZZO PER LA SEZIONE UNA RESISTENZA INFERIORE A QUELLA REALE



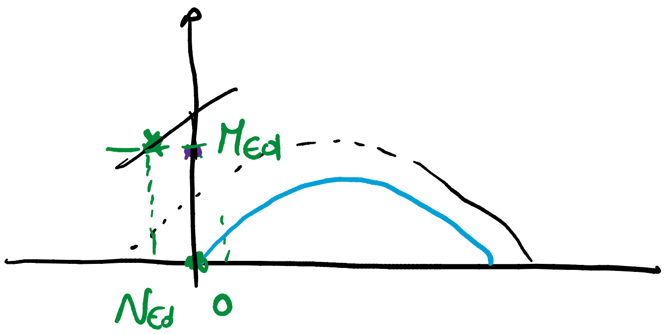


ATTENZIONE: SE $N_{Ed} > 0$

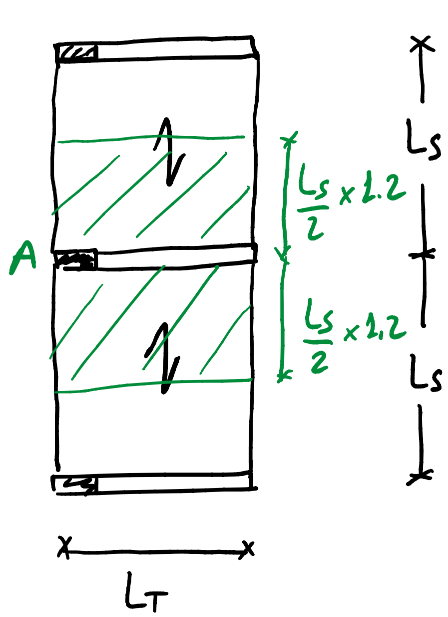
SE TRASCURO N_{Ed} NON OPERO A VANTAGGIO DI SICUREZZA

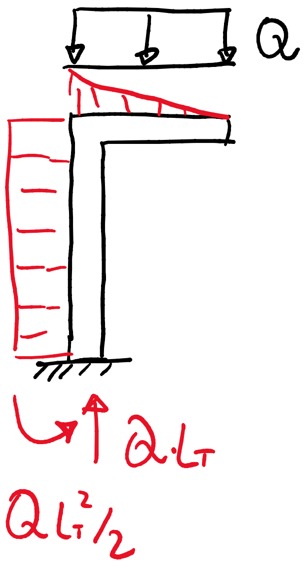
$\Rightarrow$ DETERMINATO d

INCREMENTO UN PO' h



ESEMPIO PENSILINA





$g_k = 5 \; KN/m^2$

$q_k = 1 \; KN/m^2$

$L_S = 5 \, m$

$L_T = 2{,}5 \, m$

$$g_d + q_d = 5 \times 1.3 + 1 \times 1.5 = 8.0 \; KN/m^2$$

$$Q = (g_d + q_d) \times \frac{L_S}{2} \times 2 \times 1{,}2 = 8 \times \frac{5}{2} \times 2 \times 1{,}2 = 48 \; KN/m$$

$$N_{Ed} = Q \cdot L_T = 48 \times 2{,}5 = -120 \; KN$$

$$M_{Ed} = Q \cdot L_T^2/2 = \frac{48 \times 2{,}5^2}{2} = 150 \; KNm$$

PROGETTO PER FLESSIONE:

$$d = 0.017 \sqrt{\frac{150}{0{,}3}} = 0{,}38 \, m \quad \Rightarrow \quad h = 43 \, cm$$

FISSO $h = 45 \, cm$

SE AVESSI PROGETTATO PER N_{Ed} $\Rightarrow$

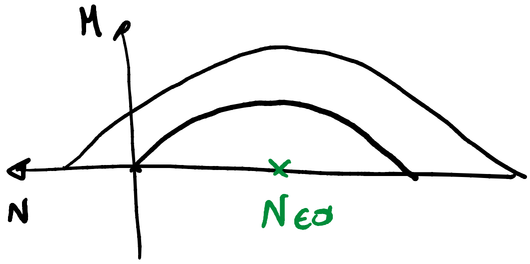
$$A_c = \frac{120\,kN}{14{,}17\ MPa} \times 10 = 85\,cm^2 \Rightarrow$$

NON HA SENSO PROGETTARE PER N_{Ed}

STRUTTURA IPERSTATICA CON N_{Ed} ELEVATO

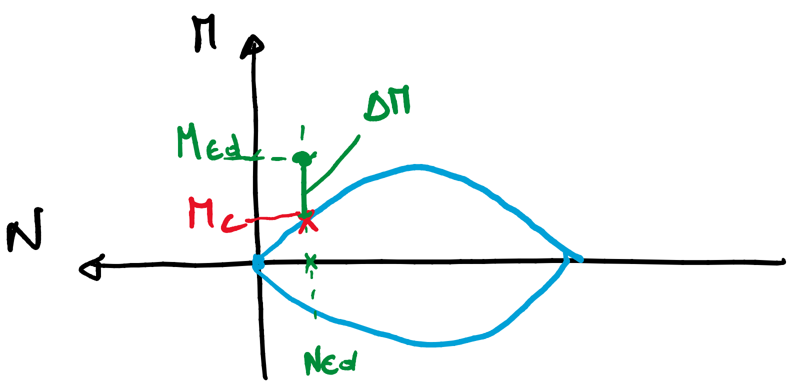
PROGETTO CON $A_c = \dfrac{N_{Ed}}{0{,}48\, f_{cd}}$

$\Rightarrow$ GARANTISCO DI POTER PORTARE UN VALORE ELEVATO DI M_{Ed}



PROGETTO ARMATURA

NOTO b, h $\Rightarrow$ COSTRUISCO DOMINIO CON RIFERIMENTO AL SOLO CONTRIBUTO DEL CLS

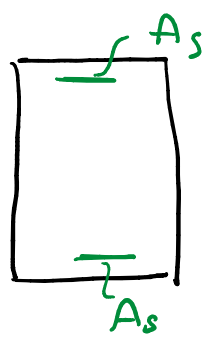


FISSATO $N = N_{Ed}$ $\Rightarrow$ $M_c = M_{cmax}\left[1 - \left(\dfrac{N_{Ed} + \nu_n N_{cmax}}{\nu_m N_{cmax}}\right)^2\right]$

AFFIDO ALLE ARMATURE $\Delta M = M_{Ed} - M_c$

$$M_s = A_s \cdot f_{yd} \cdot (d - c) \Rightarrow$$

$$A_s = \frac{\Delta M}{f_{yd}(d-c)}$$



ESEMPIO

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DALLA PENSILINA PRECEDENTE

$b = 30\,cm$

$h = 45\,cm$

$c = 5\,cm$

$N_{Ed} = -120\,KN$

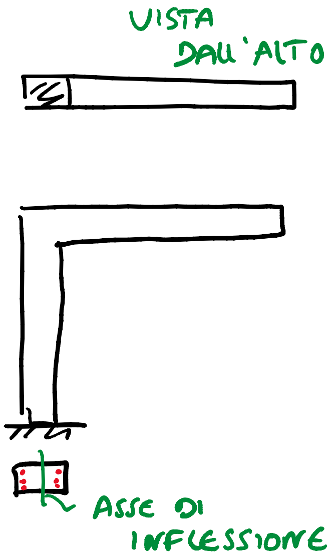
$M_{Ed} = 150\,KNm$

C25/30

$$N_{cmax} = 30 \times 45\,cm^2 \times 14{,}17\,\frac{N}{mm^2} \cdot \frac{1}{10} = 1912.9\,KN$$

$$M_{cmax} = 0.122 \times 0.45 \times 1912{,}9\,KNm$$

$$= 105{,}02\,KNm$$

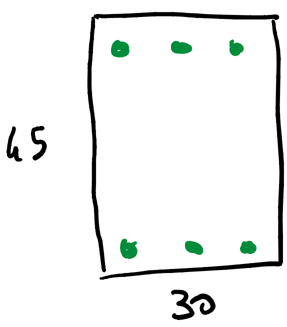


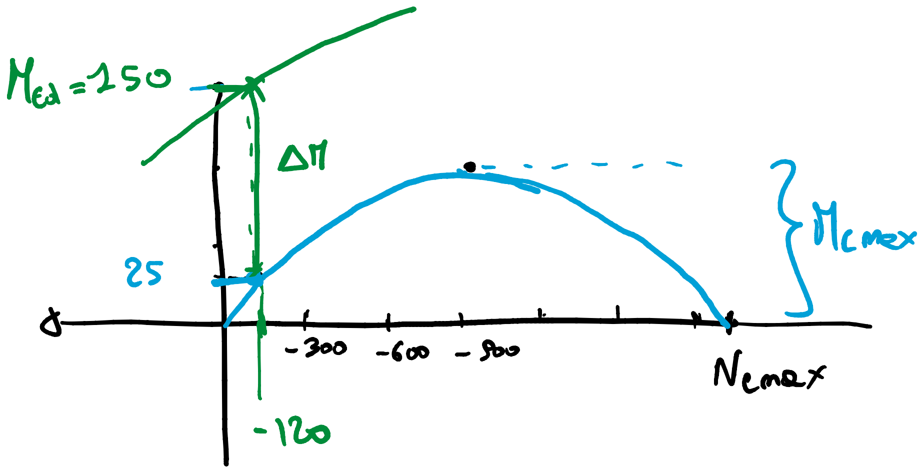
$$M_c = 105{,}02 \times \left[1 - \left(\frac{-120 + 0{,}4865 \times 1913}{0{,}4865 \times 1913}\right)^2\right]$$

$$= 25{,}34\,KNm$$

$$\Delta M = 150 - 25{,}34\,KNm = 124{,}66\,KNm$$

$$A_s = \frac{124{,}66\,KN\cancel{m} \times 10}{391{,}3\,\frac{N}{mm^2} \times (0{,}40 - 0{,}05)\,\cancel{m}} = 9.10\,cm^2 \Rightarrow 3\phi20 \text{ PER LATO}$$





PRESSO - FLESSIONE DEVIATA

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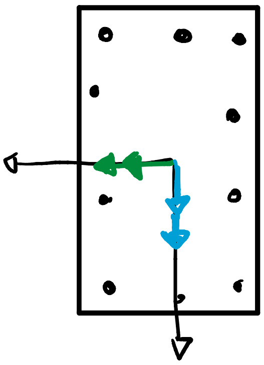
$M_{Ed,x}$

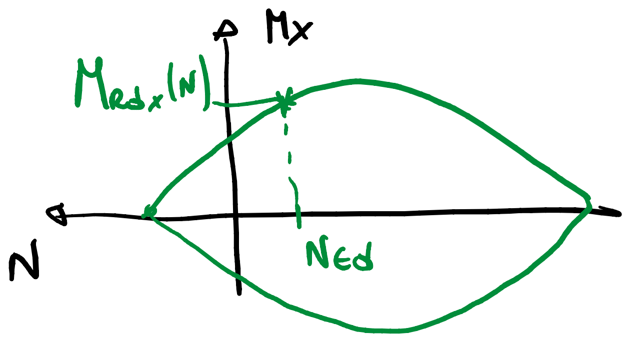
$M_{Ed,y}$

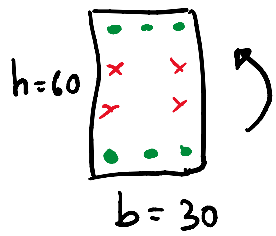
N_{Ed}



DETERMINO $M_{Rd,x}(N)$ TRASCURANDO ARMATURE // h

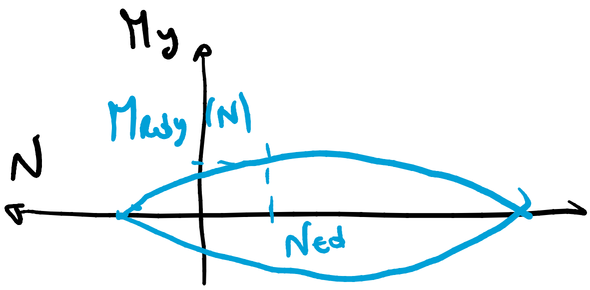
$M_y = 0$

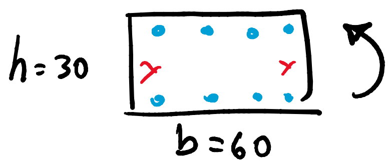




DETERMINO $M_{Rd,y}(N)$ TRASCURANDO ARMATURE // h

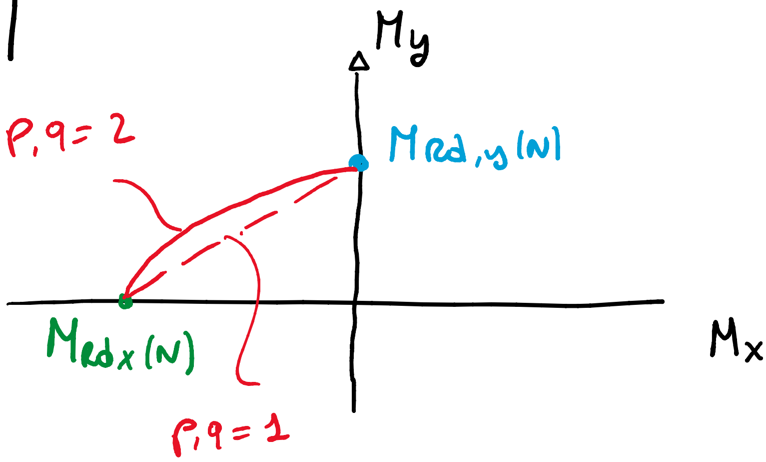
$M_x = 0$





VERIFICA NEL PIANO M_x, M_y

$$\left(\frac{M_{Ed,x}}{M_{Rd,x}(N)}\right)^p + \left(\frac{M_{Ed,y}}{M_{Rd,y}(N)}\right)^q \leq 1$$



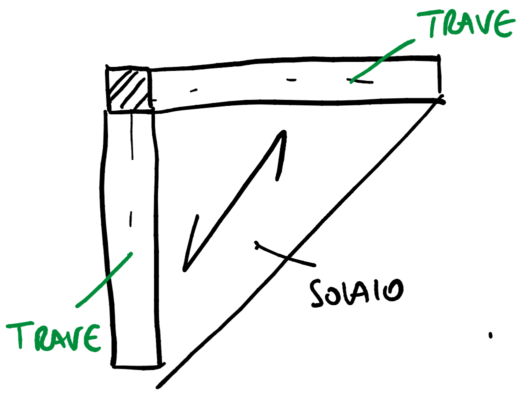
p, q = FUNZIONI DI N E DELLA FORMA DELLA SEZIONE

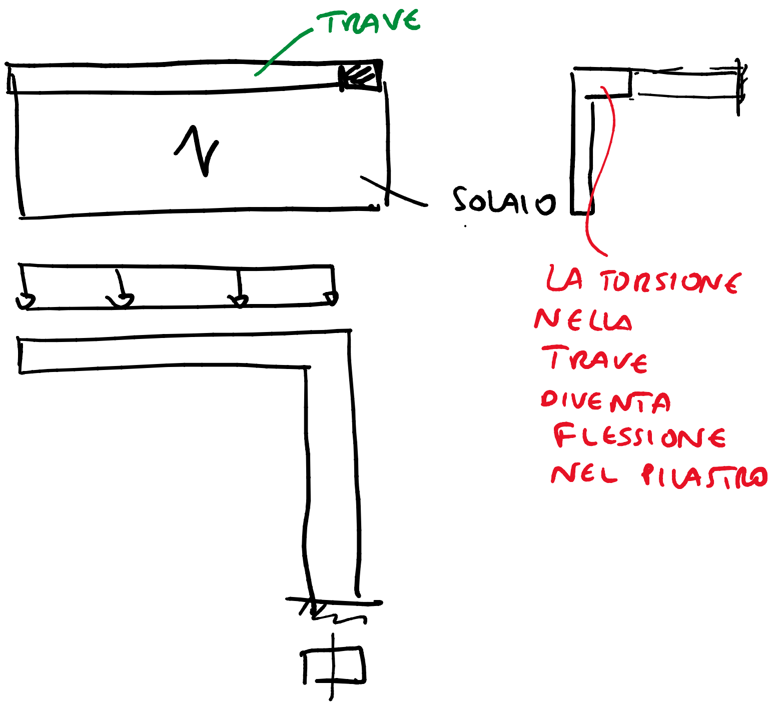
↓

PER VALORI DI

- N/N_{cmax} INTERMEDI
- SEZIONE RETTANGOLARE $\Rightarrow p = q = 1.5$ (VEDI NORMATIVA)

ESEMPI DI PILASTRI CON FLESSIONE COMPOSTA DEVIATA





PROGETTO TRAVE

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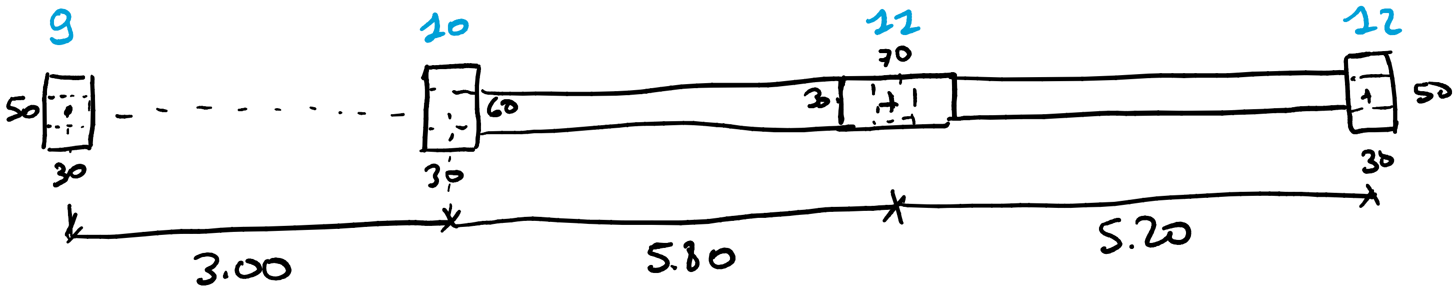


CAMPATA 9-10

$G_{d\,max} + Q_d = 72.53$ kN/m

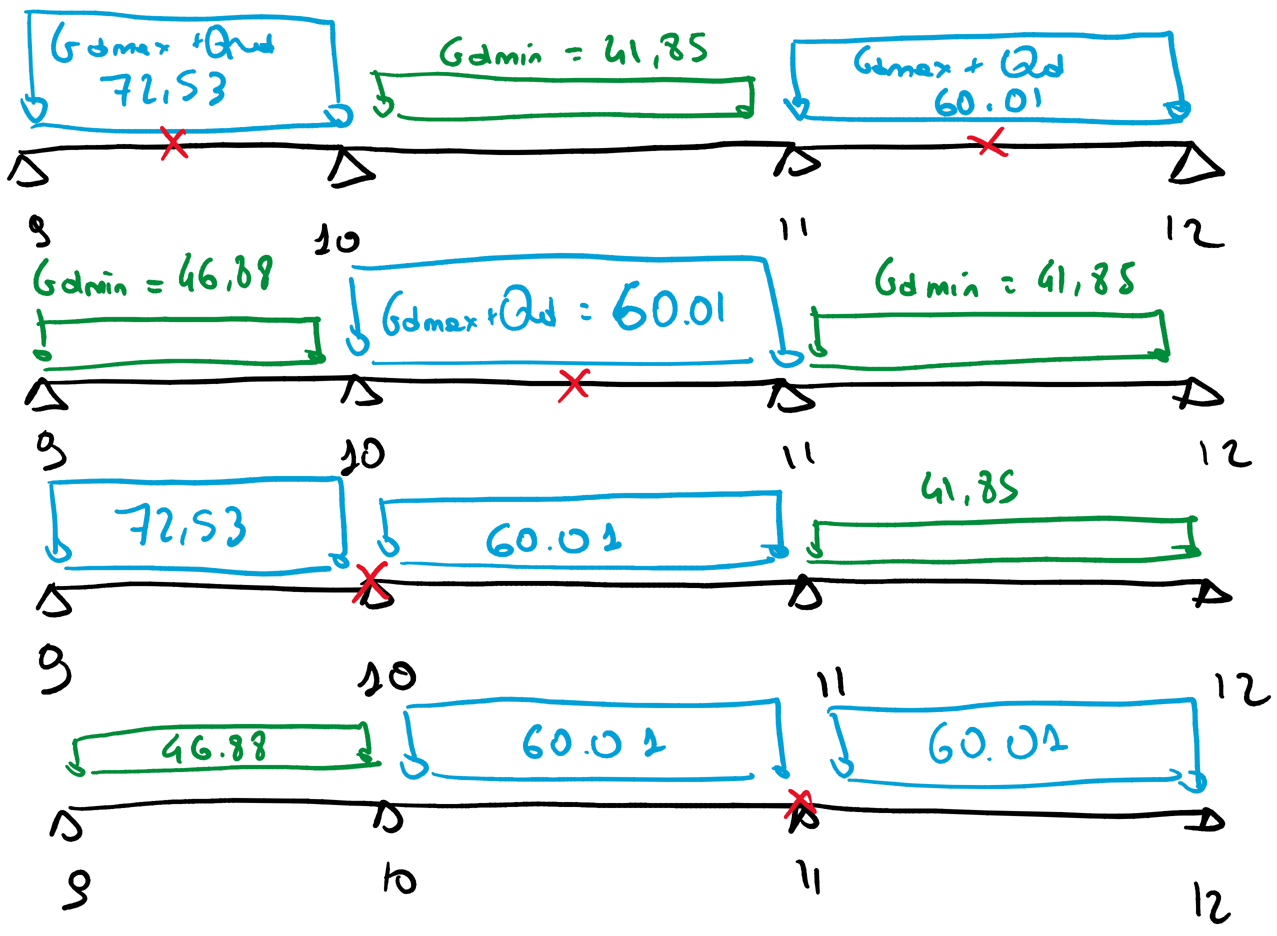
$G_{d\,min} = 46.88$ kN/m

CAMPATA 10-11
11-12

$G_{d\,max} + Q_d = 60.01$ kN/m

$G_{d\,min} = 41,85$ kN/m

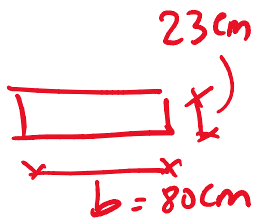
COMBINAZIONI DI CARICO



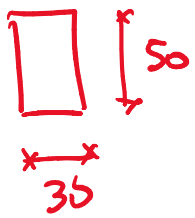
RISOLVO MEDIANTE "TRAVE CON"

ATTENZIONE

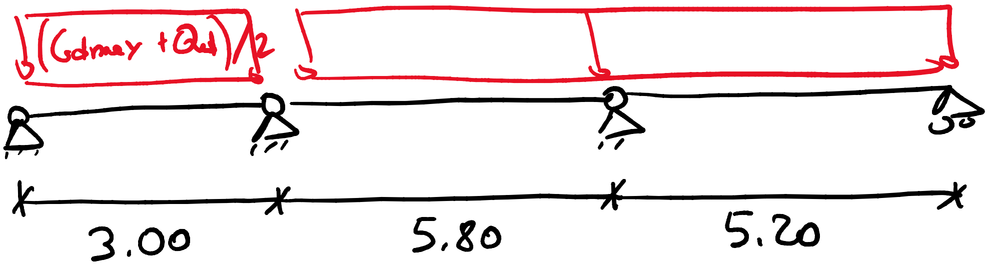
CAMPATA 9-10



CAMPATE 10-11
11-12

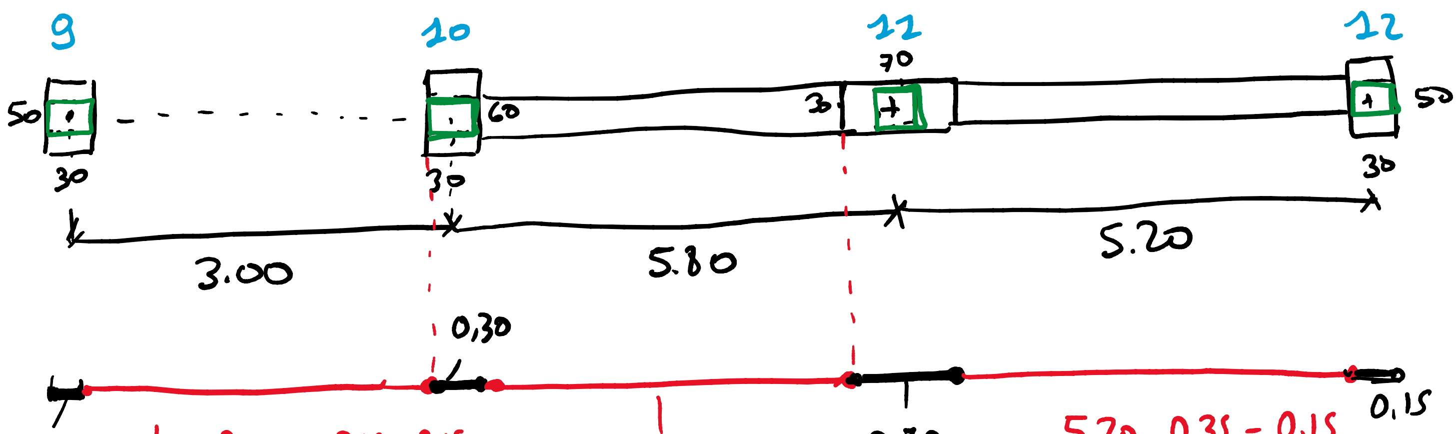


1° SCHEMA LIMITE



(DISEGNO CON MONCAD)

2° SCHEMA LIMITE

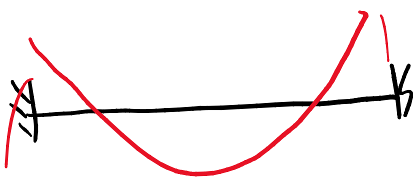


$L_n = 3.00 - 0{,}15 - 0{,}15$

$= 2{,}70\ m$

$L_n = 5{,}80 - 0{,}15 - \frac{0{,}70}{2}$

$5{,}20 - 0{,}35 - 0{,}15$



$$\frac{(G_{d,MAX} + Q_d) \cdot L^2_{NETTA}}{12}$$

NOTA SULLA TRAVE A SPESSORE

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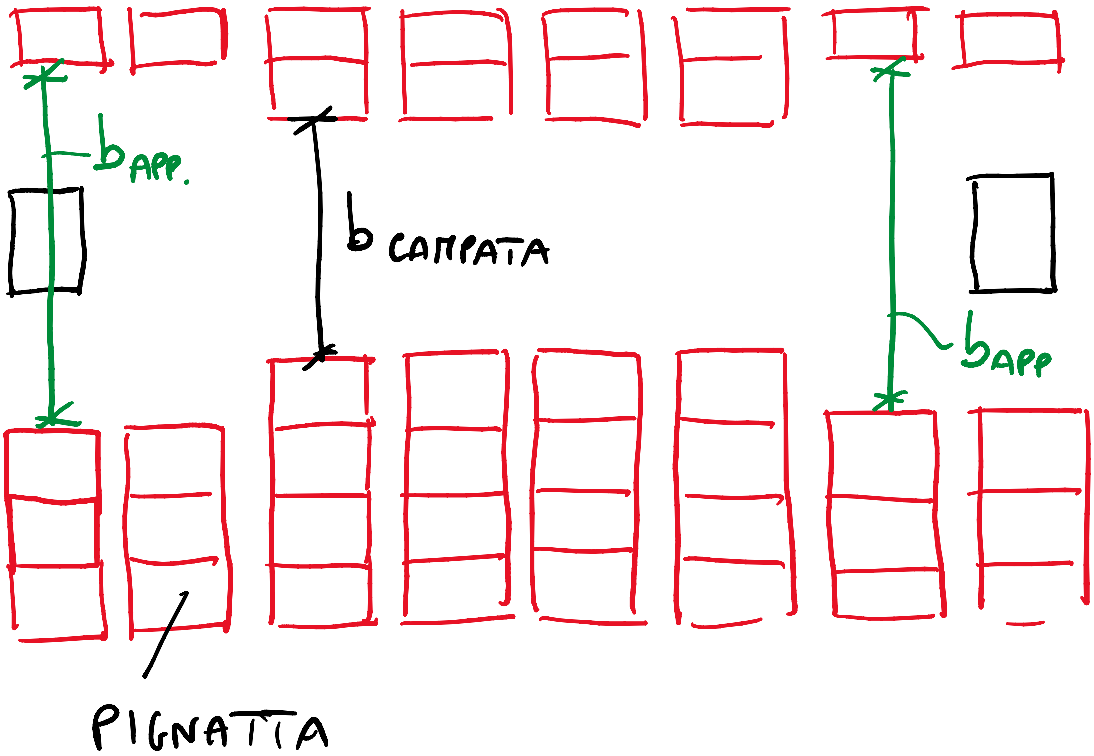
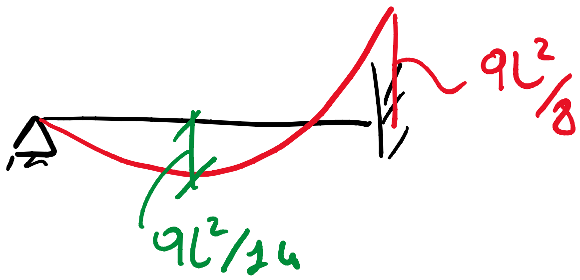
LA TRAVE A SPESSORE PUÒ AVERE b VARIABILE



$$M_{Ed,\,APP} > M_{Ed\ CAMP} \Rightarrow b_{APP} > b_{CAMP}$$



SE $M_{APP} \Rightarrow b = 100$ cm

$M_{CAMP} \Rightarrow b < 100$

INVILUPPO DIAGRAMMA MOMENTI

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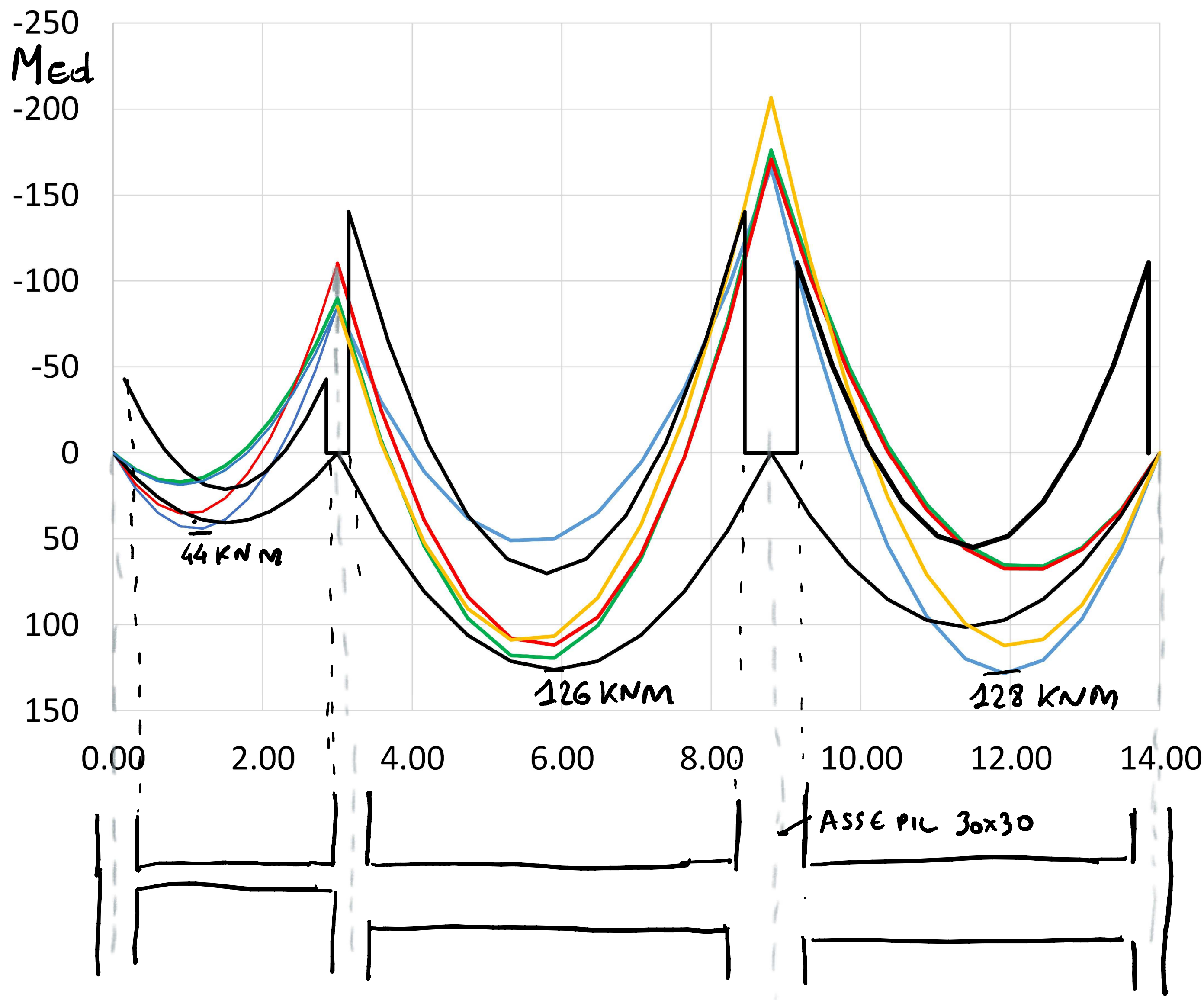
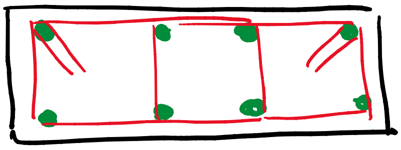


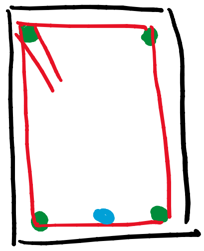
MINIMI DI ARMATURA

TRAVE A SPESSORE



4 BARRE SUP.
4 BARRE INF.

TRAVE EMERGENTE



2 BARRE
CONSIGLIO 3 IN ZONA TESA
(PER VERIFICA SLE DI FESSURAZIONE)

$$A_{s\,min} \geq 0.13\%\, bd$$
$$\geq 0{,}26 \frac{f_{ctm}}{f_{yk}} bd \quad (*)$$

$$f_{ctm} = 0{,}3 \sqrt[3]{f_{ck}^2} = 0{,}3 \sqrt[3]{25^2} = 2{,}56 \text{ MPa} \Rightarrow$$

$$(*) \quad A_{s\,min} \geq 0.26 \times \frac{2{,}56}{450} bd = 0.147\%\, bd$$

PER LA TRAVE EMERGENTE $30 \times 50 \Rightarrow d = 45$ cm

$$A_{s\,min} = \frac{0.147}{100} \times 30 \times 45 = 1.98 \text{ cm}^2 \rightarrow 2\phi 14$$

PER LA TRAVE A SPESSORE $80 \times 23 \Rightarrow$

$d = 19$ cm (c = 4 SI OTTIENE IMPONENDO IL RICOPRIMENTO MINIMO. POSSO ANCHE CONSIDERARE c = 5 cm)

$$A_{s\,min} = \frac{0.147}{100} \times 80 \times 19 = 2{,}23 \text{ cm}^2 \Rightarrow 4\phi 14$$

PROGETTO ARMATURA INFERIORE

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CAMPATA 9-10 (TRAVE SPESSORE)

$$A_s = \frac{M_{Ed}}{0{,}9\,d\,f_{yd}} = \frac{44\ \text{KNM} \times 10}{0{,}9 \times 0{,}19\,\text{m} \times 391{,}3\,\text{MPa}} = 6{,}57\ \text{cm}^2$$

$$A_{\phi 14} = 1{,}54 \Rightarrow n_{\phi 14} = \frac{6{,}57}{1{,}54} = 4{,}27 \Rightarrow$$ $5\phi 14$ OPPURE $3\phi 14 + 1\phi 20$

$(A_{\phi 20} = 2A_{\phi 14})$

CAMPATA 10-11-12 (TRAVE EMERGENTE)

$$A_s = \frac{M_{Ed}}{0{,}9\,d\,f_{yd}} = \frac{128\ \text{KNM} \times 10}{0{,}9 \times 0{,}45\ \text{m} \times 391{,}3\,\text{N/mm}^2} = 8.07\ \text{cm}^2$$

$$n_{\phi 14} = \frac{8.07}{1{,}54} = 5{,}24 \Rightarrow \quad 3\phi 20$$

DISPOSIZIONE ARMATURE INFERIORI

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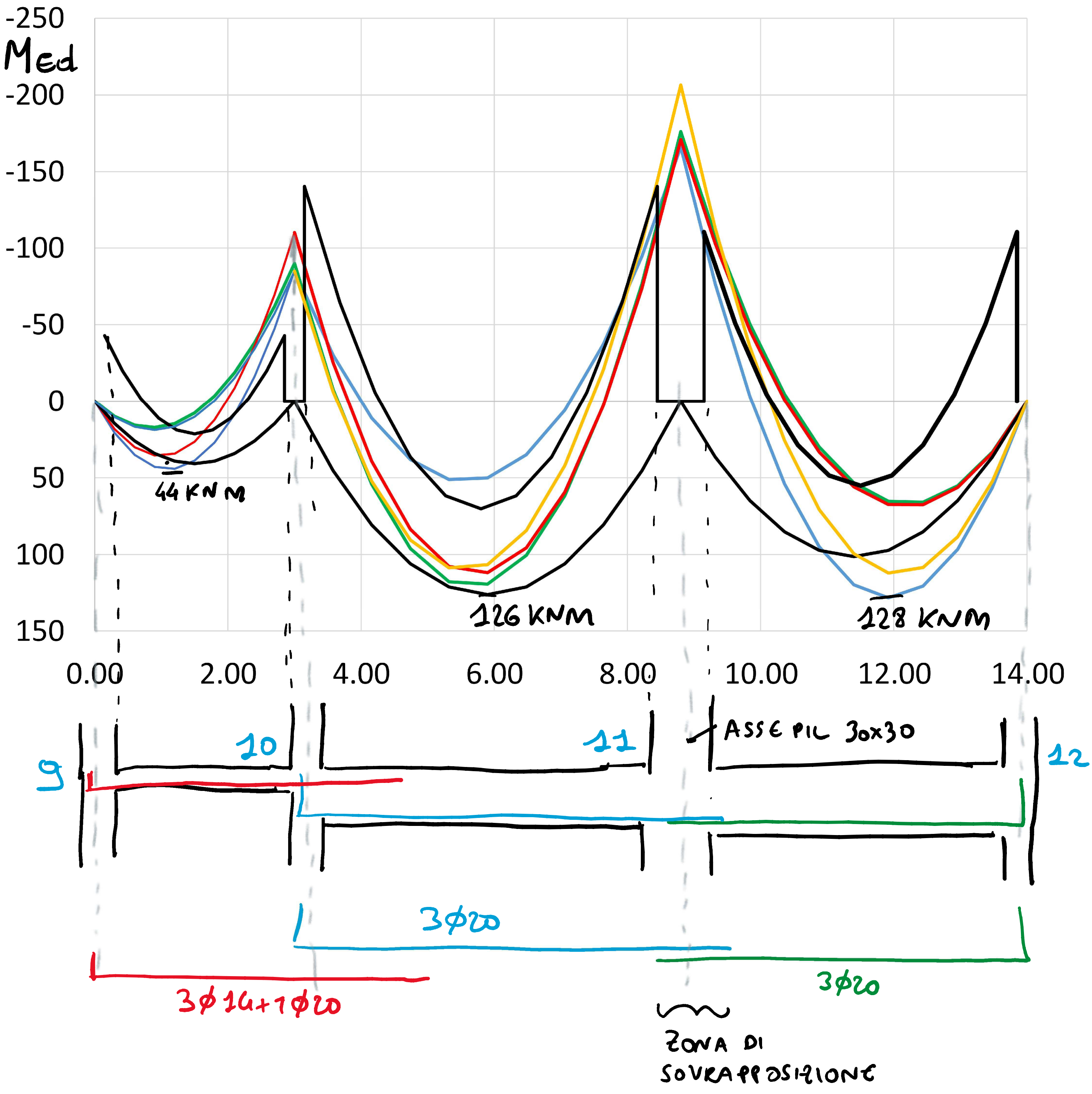
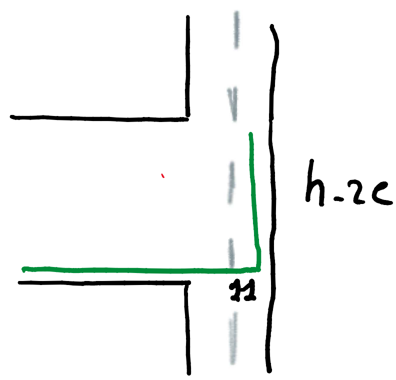
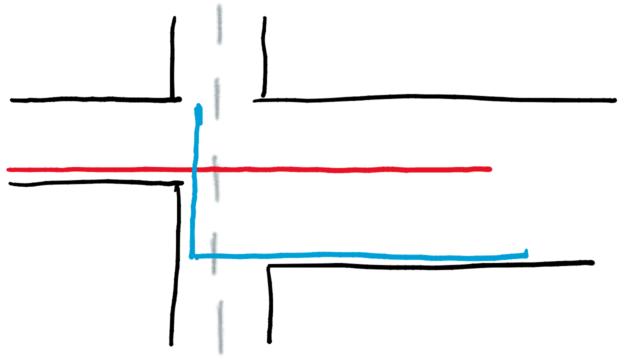


DETTAGLIO NODO PILASTRO 12



DETTAGLIO NODO PILASTRO 10



ZONA DI PERTINENZA TRAVE A SPESSORE