

— VERIFICA DIRETTA : NOTI M_{ed} , N_{ed}
 CERCO DIAGRAMMA DI DEFORMAZIONE
 LIMITE TALE CHE

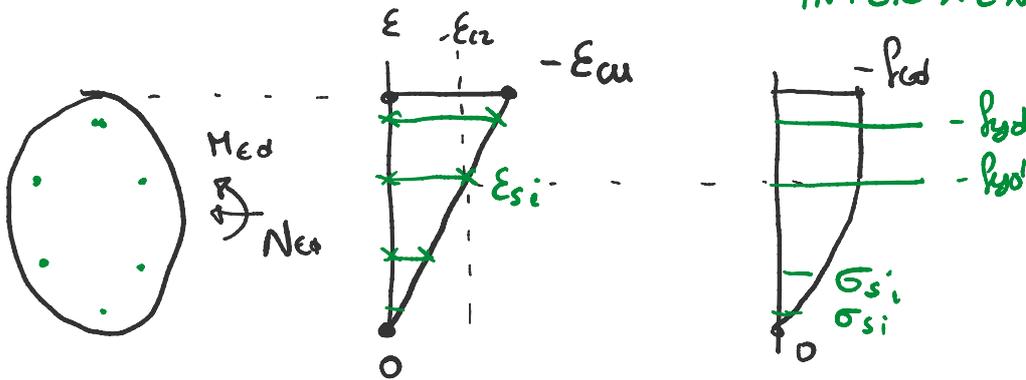
$$N_c + \sum N_{si} = N_{ed}$$

$$M_{ed} \geq M_{ed}$$

— DOTTINI MN

VERIFICA DIRETTA

PASSO 1 CAPIRE SE LA SEZ. E' PARZIALIZZATA O
 INTERAMENTE COMPRESSA



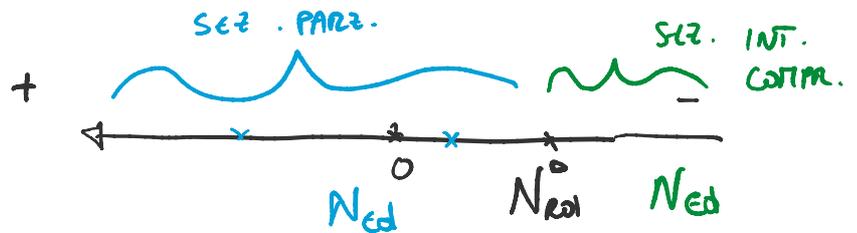
$$N_c = \int \sigma dA_c$$

$$N_{si} = \sigma_{si} A_{si}$$

$$N_{TOT} = N_c + \sum N_{si}$$

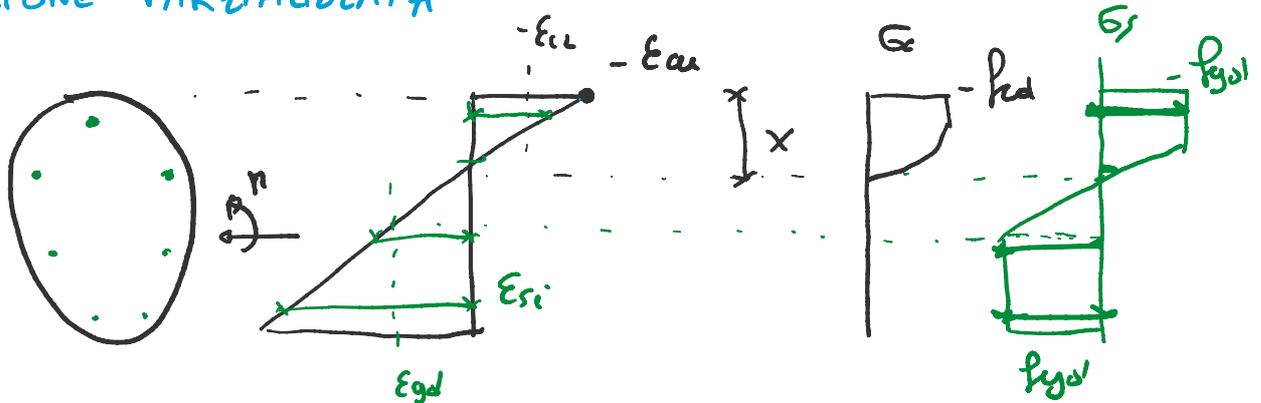
$\overset{N_{ed}}{\underset{N_{ed}}{}}$

CONFRONTO CON N_{ed}



PASSO 2 TROVARE DIAGRAMMA E LIMITI : $N_{TOT} = N_{ED}$

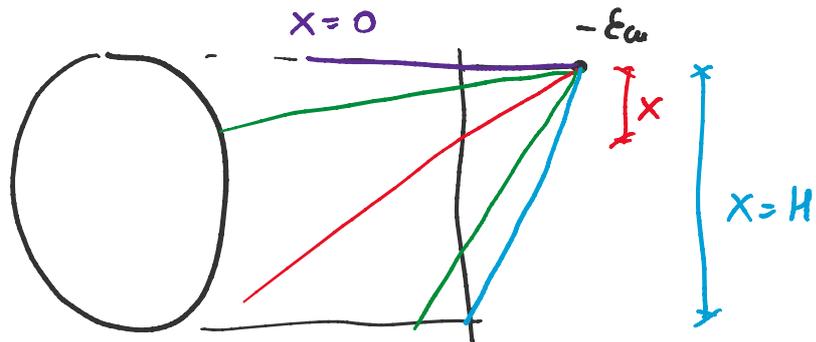
SEZIONE PARZIALIZZATA



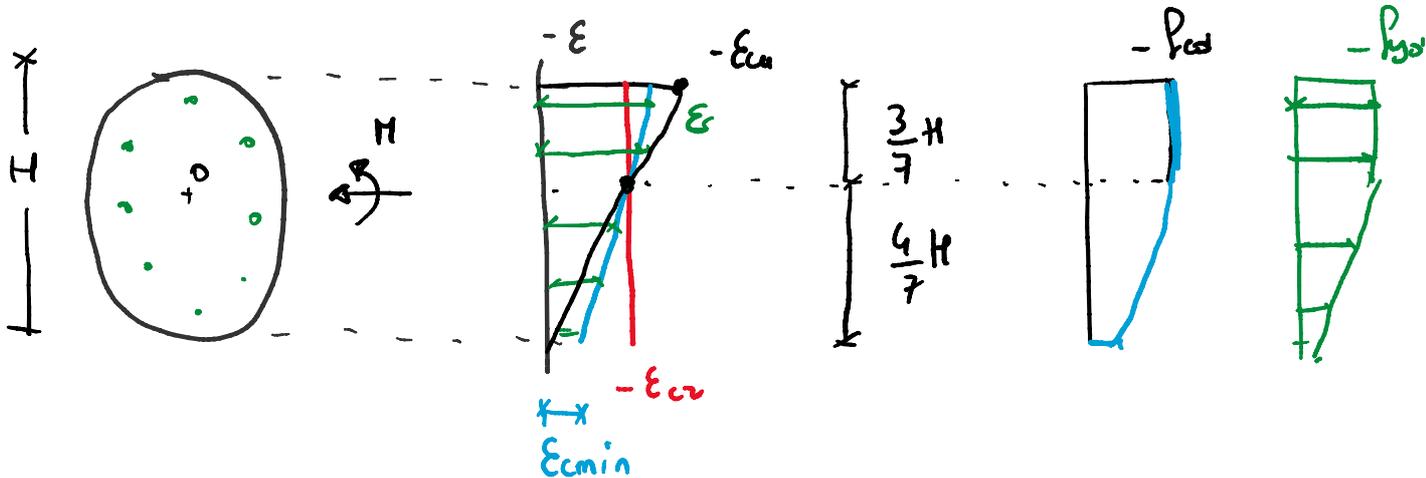
$$N_c = \int \sigma dA_c \quad N_s = \sum A_{s_i} \sigma_{s_i} \quad N_{TOT} = N_c + \sum N_{s_i}$$

VARIO X FINO A QUANDO $N_{TOT} = N_{ED}$

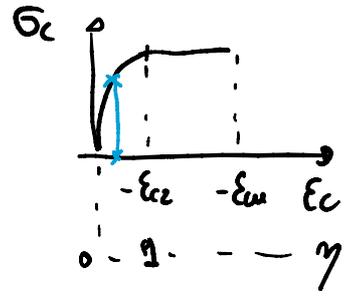
$$0 \leq x \leq H$$



SEZIONE INTERAMENTE COMPRESSA



$$\eta = -\frac{\epsilon_{cmin}}{\epsilon_{c2}} \Rightarrow 0 \leq \eta \leq 1$$



FISSO η

$$N_c = \int \sigma_c dA_c ; N_s = A_{si} \sigma_{si}$$

VARIO η FINO A QUANDO $N_{TOT} = N_c + \sum N_{si} = N_{ed}$

PASSO 3

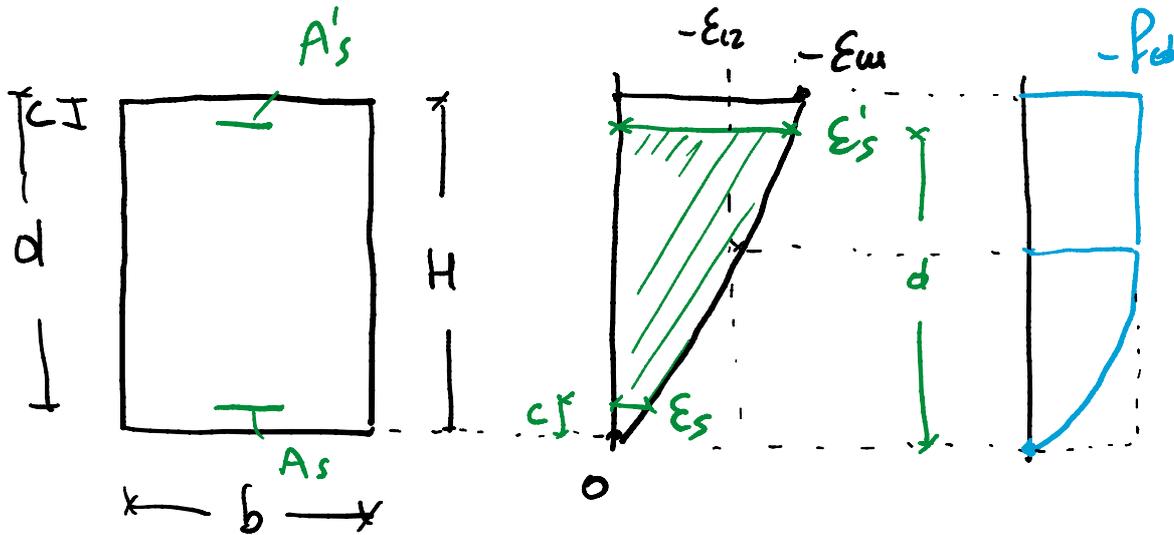
TROVATO DIAGRAMMA E LIMITE \Rightarrow

CALCOLO M_{rd} (EQ. ROTAZIONE RISPETTO IL CENTRO GEOMETRICO O)

SEZIONE RETTANGOLARE

mercoledì 20 maggio 2020 14:28

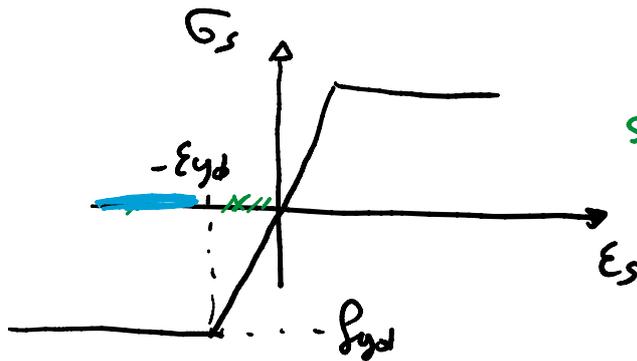
PASSO 1



$$N_c = \int \sigma dA_c = -\beta b h f_{cd} \quad \beta = 0,82$$

$$\epsilon_s : c = -\epsilon_{cu} : H \quad \rightarrow \quad \epsilon_s = -\frac{c}{H} \epsilon_{cu}$$

$$\epsilon'_s : d = -\epsilon_{cu} : H \quad \rightarrow \quad \epsilon'_s = -\frac{d}{H} \epsilon_{cu}$$



$$\text{se } |\epsilon_s| \leq \epsilon_{yd} \Rightarrow \sigma_s = \epsilon_s E_s$$

$$\text{se } |\epsilon_s| > \epsilon_{yd} \rightarrow \sigma_s = -f_{yd}$$

$$N_s = A_s \cdot \sigma_s$$

$$N'_s = A'_s \cdot \sigma'_s$$

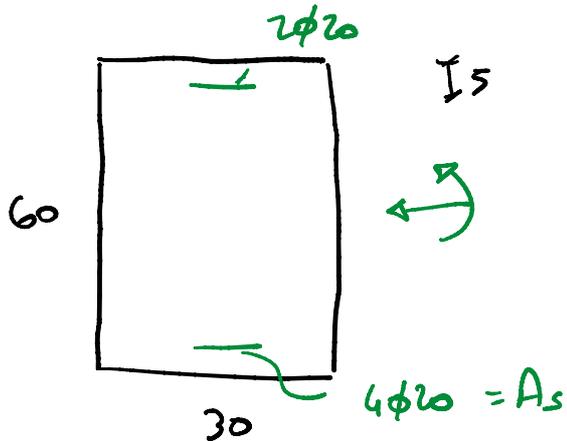
$$N_{Rd}^> = N_c + N_s + N'_s$$

DA CONFRONTARE CON N_{Ed}

ESEMPIO

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VERIFICARE LA SEZIONE ASSEGNATA SOGGETTA A

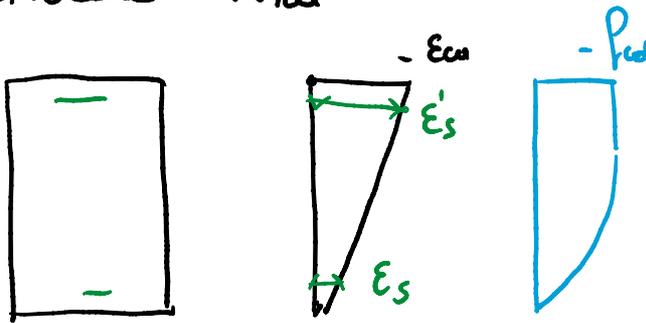


$$N_{ed} = -1000 \text{ KN} \quad C25/30$$
$$M_{ed} = 200 \text{ KNm}$$

1. STABILIRE SE DIAGRAMMA LIMITE DA CONSIDERARE CORRISPONDE A SEZIONE PARZIALIZZATA
2. CALCOLARE M_{rd}

PASSO 1:

CALCOLO N_{rd}^D



$$\epsilon'_s = \frac{55}{60} \times \left(-\frac{3,5}{1000} \right) = -3,2\%$$

$$\Rightarrow \sigma'_s = -f_{yd}$$

$$\epsilon_s = \frac{5}{60} \times \left(-\frac{3,5}{1000} \right) = -0,29\%$$

$$\sigma_s = \epsilon_s \cdot E_s = 200'000 \text{ MPa} \times \left(\frac{-0,29}{1000} \right) = -58,33 \text{ MPa}$$

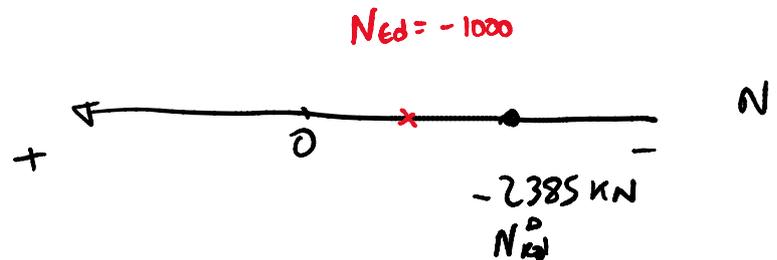
$$N_c = -b \cdot h \cdot \beta f_{cd} = -30 \times 60 \text{ cm}^2 \times 0,81 \times 14,17 \frac{\text{N}}{\text{mm}^2} \times \frac{1}{10} = -2066 \text{ KN}$$

$$N_s = A_s \times \sigma_s = 12,56 \text{ cm}^2 \times (-58,33) \frac{\text{N}}{\text{mm}^2} \times \frac{1}{10} = -73,26 \text{ KN}$$

$$N'_s = A'_s \sigma'_s = 6,28 \text{ cm}^2 \times (-391,3) \frac{\text{N}}{\text{mm}^2} \times \frac{1}{10} = -245,7 \text{ KN}$$

$$N_{Rd}^D = -2066 \text{ kN} - 73,26 - 245,7 \text{ kN} = -2385 \text{ kN}$$

$$N_{Ed} = -1000 \text{ kN} \Rightarrow \text{SEZ. PARZIALIZZATA}$$



$$\text{SE FOSSE STATO } N_{Ed} = -2385 \text{ kN}$$

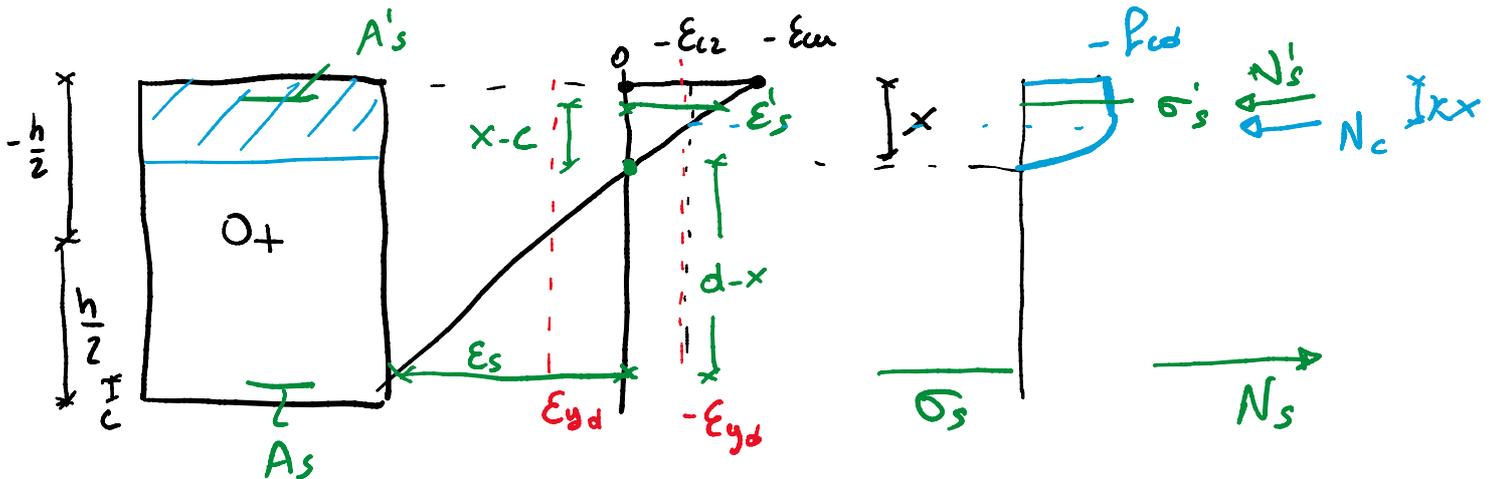
\Rightarrow DIAGRAMMA LIMITE CORRETTO \Rightarrow
CALCOLO M_{Rd}

$$\text{SE AVESSI AVUTO } N_{Ed} = -3000 \text{ kN} \Rightarrow$$

DIAGRAMMA LIMITE DA CERCARE TRA
QUELLI PER SEZIONE INTERAMENTE
COMPRESSA

DETERMINAZIONE DIAGRAMMA LIMITE (SEZ. PARZIALIZZATA)

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$$\epsilon'_s = - \frac{x-c}{x} \epsilon_{cu} \quad \rightarrow \quad \sigma'_s \quad \rightarrow \quad N'_s = A'_s \sigma'_s$$

$$\epsilon_s = \frac{d-x}{x} \epsilon_{cu} \quad \rightarrow \quad \sigma_s \quad \rightarrow \quad N_s = A_s \sigma_s$$

$$N_c = - \beta b x f_{cd}$$

MODIFICO x FINO A QUANDO $N_{TOT} = N_{ed}$

TROVATO $x \Rightarrow$

$$M_{ed} = N_s \cdot \left(\frac{h}{2} - c \right) - N'_s \left(\frac{h}{2} - c \right) - N_c \left(\frac{h}{2} - kx \right)$$

VERIFICO CHE $M_{rd} > M_{ed}$

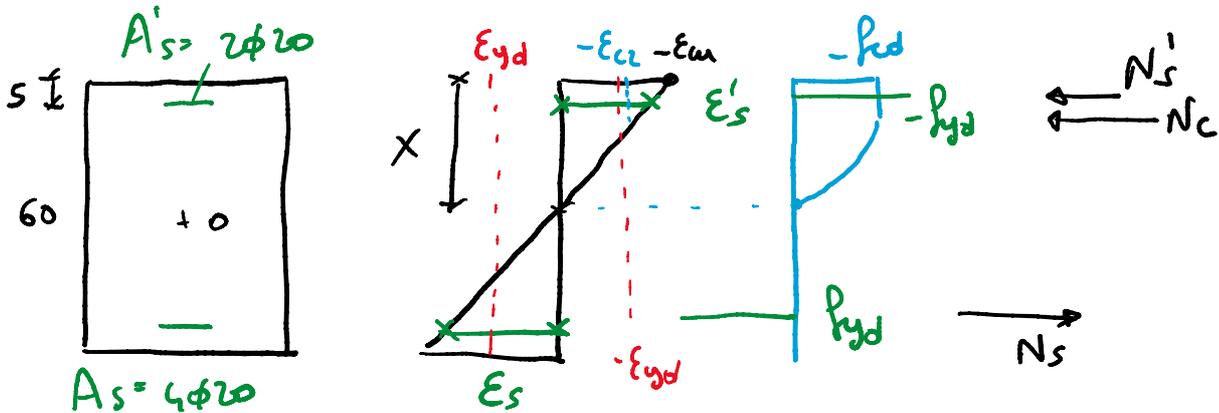
$$M_{rd}(N_{ed}) > M_{ed}$$

ESEMPIO

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VERIFICARE LA SEZIONE SOGGETTA A $N_{ed} = -1000 \text{ KN}$
 $M_{ed} = 200 \text{ KNM}$

DA ESEMPIO PRECEDENTE \Rightarrow CERCARE DIAGRAMMA LIMITE PER SEZIONE PARZIALIZZATA



IPOTIZZO $x = 30 \text{ CM}$

$$\epsilon'_s = - \frac{30 - 5}{30} \times \frac{3,5}{1000} = - 2,92\% \Rightarrow \text{SNERVATA}$$

$$\epsilon_s = 2,92\% \rightarrow \text{SNERVATA}$$

$$N_s = A_s \cdot f_{yd} = 12,56 \text{ cm}^2 \times 391,3 \frac{\text{N}}{\text{mm}^2} \frac{1}{10} = 491,5 \text{ KN}$$

$$N'_s = -A'_s f_{yd} = -6,28 \text{ cm}^2 \times 391,3 \frac{\text{N}}{\text{mm}^2} \frac{1}{10} = -245,7 \text{ KN}$$

$$N_c = -\beta b x f_{cd} = -0,81 \times 30 \times 30 \times 14,17 \cdot \frac{1}{10} = -1033 \text{ KN}$$

$$N_{TOT} = -1033 - 245,7 + 491,5 = -787,2 \text{ KN}$$

X ERRATA PERCHÉ $N_{ed} = -1000 \text{ KN}$

ITERANDO TROVO $x = 35,71 \text{ CM} \Rightarrow$

$$N_c = -0,81 \times 30 \times 35,71 \times 14,17 \frac{1}{10} = -1229,3 \text{ KN}$$

$$N_c = -0,81 \times 30 \times 35,71 \times 14,17 \frac{1}{10} = -1229,3 \text{ KN}$$

$$\varepsilon'_s \rightarrow N'_s = -245,86 \text{ KN}$$

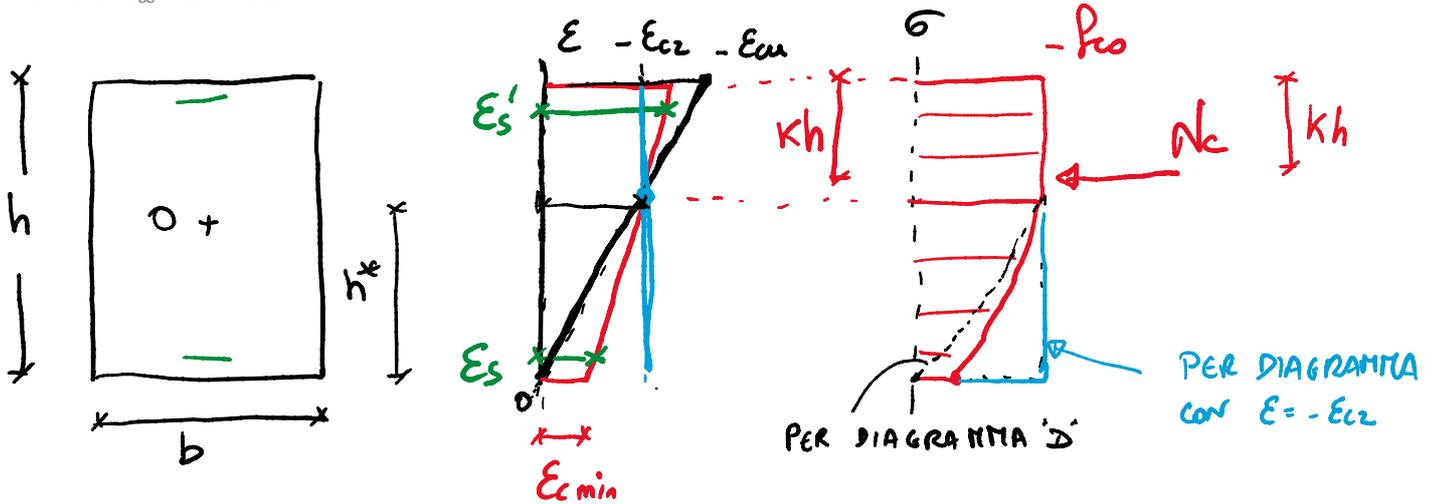
$$\varepsilon_s \rightarrow N_s = 475,2 \text{ KN}$$

$$\begin{aligned} M_{rd} &= N_s \left(\frac{h}{2} - c \right) - N'_s \left(\frac{h}{2} - c \right) - N_c \left(\frac{h}{2} - kx \right) \\ &= 475,2 \frac{(30-5) \text{ cm}}{100} + 245,86 \frac{(30-5) \text{ cm}}{100} + \\ &\quad + 1229,3 \times \frac{(30 - 0,416 \times 35,71) \text{ cm}}{100} = \\ &= 366,5 \text{ KNM} \end{aligned}$$

$$M_{rd} > M_{ed} \Rightarrow \text{SEZIONE VERIFICATA}$$

DIAGRAMMI LIMITE PER SEZIONE INTERAMENTE COMPRESSA

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$$-\epsilon_{c2} : h^* = -\epsilon_{cu} : h \Rightarrow h^* = -\frac{\epsilon_{c2}}{-\epsilon_{cu}} \cdot h = \frac{2}{3,5} \cdot h = \frac{4}{7} h$$

$$N_c = \int \sigma dA = -\beta \rho_c \sigma \cdot b h \quad \eta_{min} = -\frac{\epsilon_{cmin}}{\epsilon_{c2}}$$

$$\beta = \frac{-\int \sigma dA}{A_c \rho_c \sigma}$$

$$0.81 \leq \beta = f(\eta_{min}) \leq 1.00$$

PER SEZ. RETTANGOLARE

$$\beta = 1 - \frac{4}{21} (1 - \eta_{min})^2$$

$$M_c = \int \sigma y dA = N_c \cdot K \cdot h \quad (\text{se misuro } y \text{ dal bordo superiore})$$

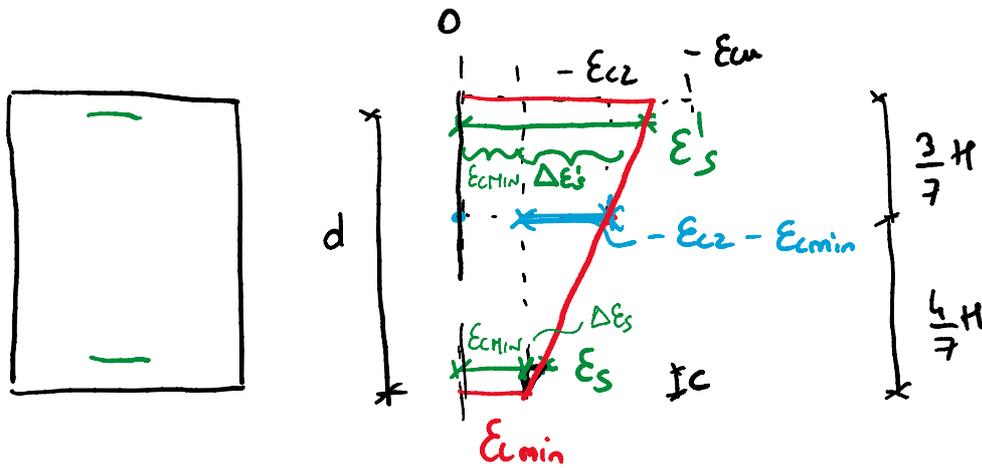
$$0.416 \leq K = f(\eta_{min}) \leq 0.5$$

PER SEZ. RETTANGOLARE

$$K = \frac{1}{2} \cdot \frac{1 - 16/49 (1 - \eta_{min})^2}{1 - 4/21 (1 - \eta_{min})^2}$$

Se $\eta_{min} = 0 \rightarrow \epsilon_{cmin} = 0 \quad \beta = 1 - \frac{4}{21} = 0.810 ; K = 0.416$

Se $\eta_{min} = 1 \rightarrow \epsilon_{cmin} = -\epsilon_{c2} \rightarrow \beta = 1 \quad K = 0.50$



$$\epsilon_s = \epsilon_{cmin} + \Delta\epsilon_s$$

$$\epsilon'_s = \epsilon_{cmin} + \Delta\epsilon'_s$$

$$\Delta\epsilon_s : c = (-\epsilon_{c2} - \epsilon_{cmin}) : \frac{4}{7}H$$

$$\Delta\epsilon_s = -\frac{c}{\frac{4}{7}H} \cdot (\epsilon_{c2} + \epsilon_{cmin}) = -\frac{+\epsilon_{c2}}{+\epsilon_{c2}} (\epsilon_{c2} + \epsilon_{cmin}) \cdot \frac{c}{\frac{4}{7}H}$$

$$= -\epsilon_{c2} \cdot \frac{c}{\frac{4}{7}H} (1 - \eta_{min})$$

$$\epsilon_s = \epsilon_{cmin} + \Delta\epsilon_s = -\eta_{min} \epsilon_{c2} - \epsilon_{c2} \frac{c}{\frac{4}{7}H} (1 - \eta_{min}) \Rightarrow$$

$$\boxed{\epsilon_s = -\epsilon_{c2} \left[\eta_{min} + \frac{c}{\frac{4}{7}H} (1 - \eta_{min}) \right]}$$

$$\Delta\epsilon'_s : d = (-\epsilon_{c2} - \epsilon_{cmin}) : \frac{4}{7}H \rightarrow$$

$$\boxed{\epsilon'_s = -\epsilon_{c2} \left[\eta_{min} + \frac{d}{\frac{4}{7}H} (1 - \eta_{min}) \right]}$$

NOTE $\epsilon'_s, \epsilon_s \Rightarrow$ CALCOLO σ'_s, σ_s DA LEGGE
LSTITUTIVO

$$N_s = A_s \sigma_s$$

$$N'_s = A'_s \sigma'_s$$

$$\Rightarrow N_{TOT} = N_c + N_s + N'_s$$

PROCEDURA ITERATIVA

FISSO $\gamma_{min} \Rightarrow N_{TOT}$ FINO A QUANDO
 $N_{TOT} = N_{ED}$

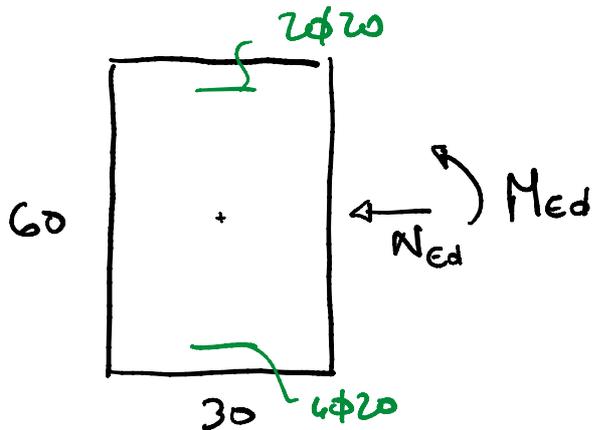
TROVATO DIAGRAMMA LIMITE \Rightarrow CALCOLO M_{ED}

$$M_{ED} = N_s \left(\frac{h}{2} - c \right) - N'_s \left(\frac{h}{2} - c \right) - N_c \left(\frac{h}{2} - kh \right)$$

ESEMPIO

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VERIFICARE LA SEZIONE SOGGETTA A



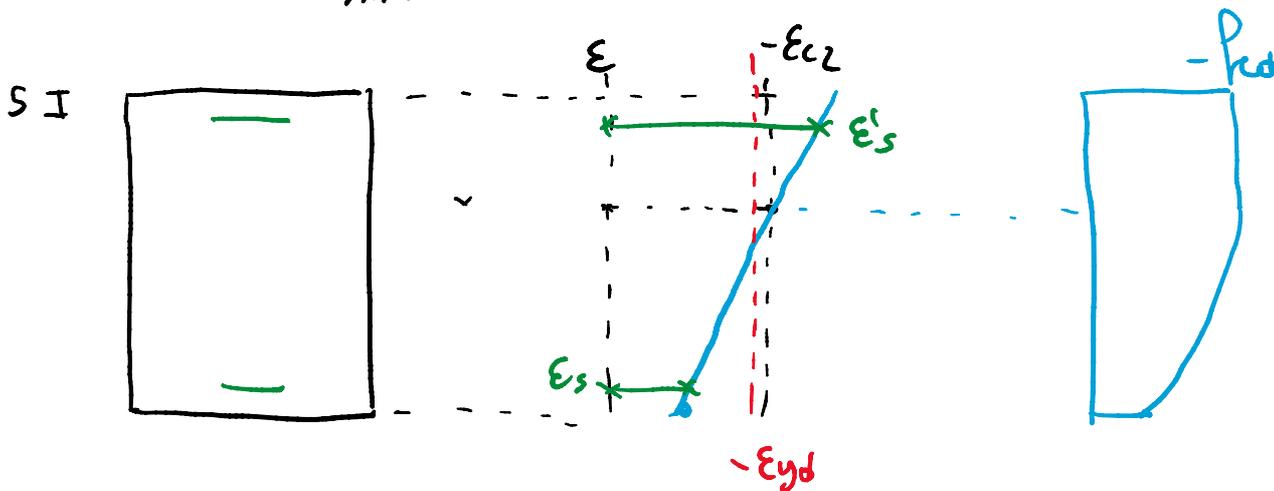
$$N_{Ed} = -3000 \text{ KN}$$

$$M_{Ed} = 200 \text{ kNm}$$

C25/30

HO GIÀ TROVATO CHE PER $N_{Ed} = -3000 \text{ KN} \Rightarrow$
SEZ. TUTTA COMPRESSA

$$\text{FISSO } \eta_{min} = 0.5$$



$$\epsilon_s = -\epsilon_{c2} \cdot \left[\eta_{min} + \frac{c}{\frac{4}{7}h} (1 - \eta_{min}) \right]$$

$$= -\frac{2}{1000} \left[0.5 + \frac{5}{\frac{4}{7} \times 60} (1 - 0.5) \right] = -1.14 \%$$

$$\sigma_s = E_s \cdot \epsilon_s = -200'000 \text{ MPa} \times \frac{1.14}{1000} = -228.17 \text{ MPa}$$

$$\begin{aligned}\epsilon'_s &= -\epsilon_{c2} \left[\eta_{min} + \frac{d}{\frac{4}{7}h} (1 - \eta_{min}) \right] \\ &= -\frac{2}{1000} \left[0,5 + \frac{55}{\frac{4}{7} \times 60} 0,5 \right] = -2,6\%\end{aligned}$$

$$\sigma'_s = -\rho_{yd} = -391,3 \text{ MPa}$$

$$N_s = A_s \sigma_s = -12,56 \text{ cm}^2 \times 229,17 \text{ MPa} \frac{1}{10} = -287,84 \text{ kN}$$

$$N'_s = A'_s \sigma'_s = -6,28 \text{ cm}^2 \times 391,3 \text{ MPa} \frac{1}{10} = -245,74 \text{ kN}$$

$$\begin{aligned}N_c &= -\beta b h \rho_{cd} \quad \text{con} \quad \beta = 1 - \frac{4}{21} (1 - \eta_{min})^2 \\ &= 1 - \frac{4}{21} \cdot 0,5^2 = 0,95\end{aligned}$$

$$N_c = -0,95 \times 30 \times 60 \times 14,17 \times \frac{1}{10} = -2423 \text{ kN}$$

$$N_{TOT} = -2423 - 245,74 - 287,84 = -2956,57 \text{ kN}$$

⇒ DEVO INCREMENTARE η_{min}
ITERANDO $\eta_{min} = 0,542$

$$\begin{aligned}\Rightarrow \epsilon'_s &= -2,55\% \quad \Rightarrow \sigma'_s = -391,3 \text{ N/mm}^2 \\ \epsilon_s &= -1,22\% \quad \Rightarrow \sigma_s = -244 \text{ N/mm}^2 \\ \beta &= 0,96\end{aligned}$$

$$N'_s = -245,86 \text{ KN}$$

$$N_s = -306,0 \text{ KN}$$

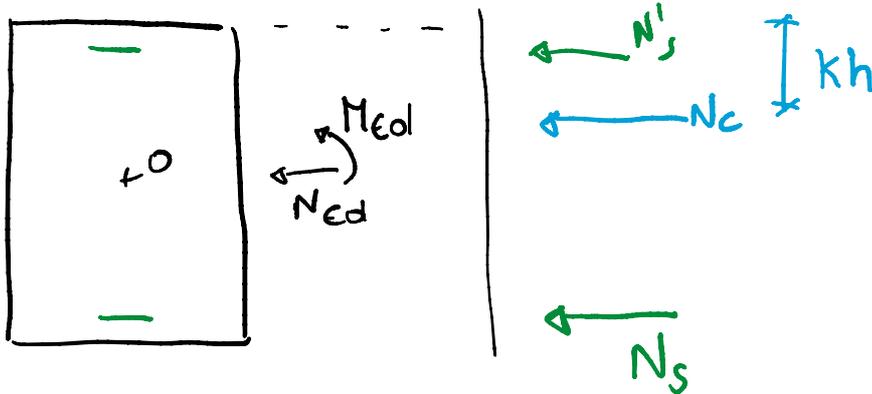
$$N_c = -2448,1 \text{ KN}$$

$$\Rightarrow N_{\text{TOT}} = -3000 \text{ KN}$$

CALCOLO M_{rd}

$$k = \frac{1}{2} \cdot \frac{1 - \frac{16}{49} (1 - \eta_{\min})^2}{1 - \frac{4}{21} (1 - \eta_{\min})^2} = \frac{1}{2} \cdot \frac{1 - \frac{16}{49} (1 - 0,542)^2}{1 - \frac{4}{21} (1 - 0,542)^2}$$
$$= 0,485$$

$$M_{ed} = N_s \cdot \left(\frac{h}{2} \cdot c\right) - N'_s \left(\frac{h}{2} \cdot c\right) - N_c \left(\frac{h}{2} \cdot kh\right)$$



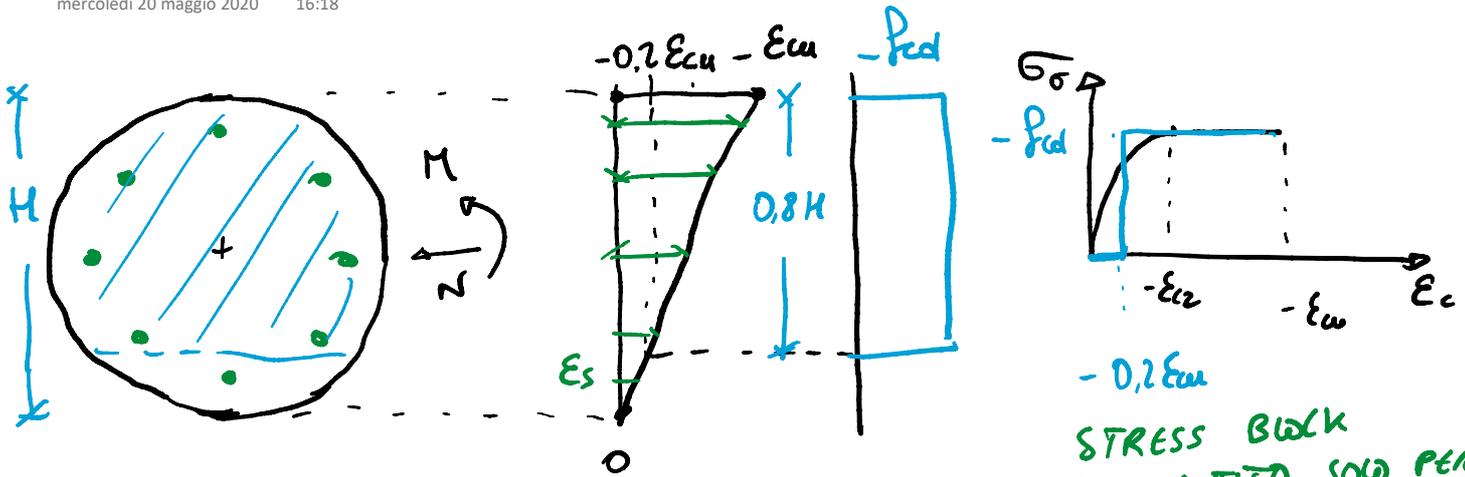
$$M_{ed} = -306 \left(\frac{30-5}{100}\right) + 245,86 \times \left(\frac{30-5}{100}\right)$$

$$+ 2448,1 \times \left(\frac{30 - 0,485 \times 60}{100}\right) = 6,8 \text{ KNM}$$

$M_{ed} > M_{rd} \Rightarrow$ sez. non verificata

SEZIONE GENERICA

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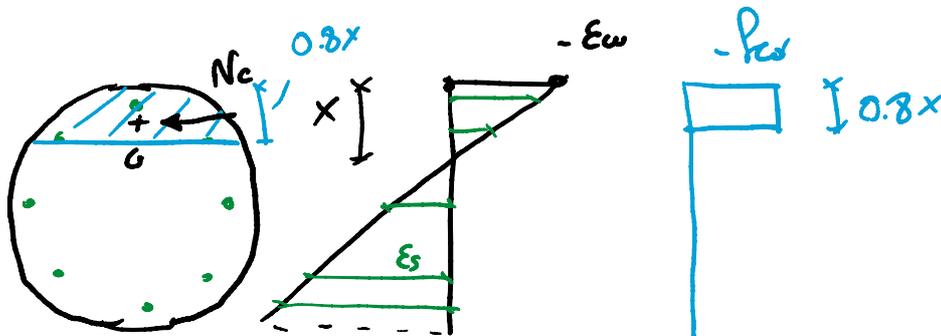
STRESS BLOCK
CONSENTITO SOLO PER
SEZ. PARZIALIZZATA

$$N_{TOT} = N_c + N_s + N'_s$$

CONFRONTO CON N_{ed} PER CAPIRE SE
RICERCARE IL DIAGRAMMA LIMITE NEI CASI DI

PARZIALIZZATA
INTERAMENTE
COMPRESSA

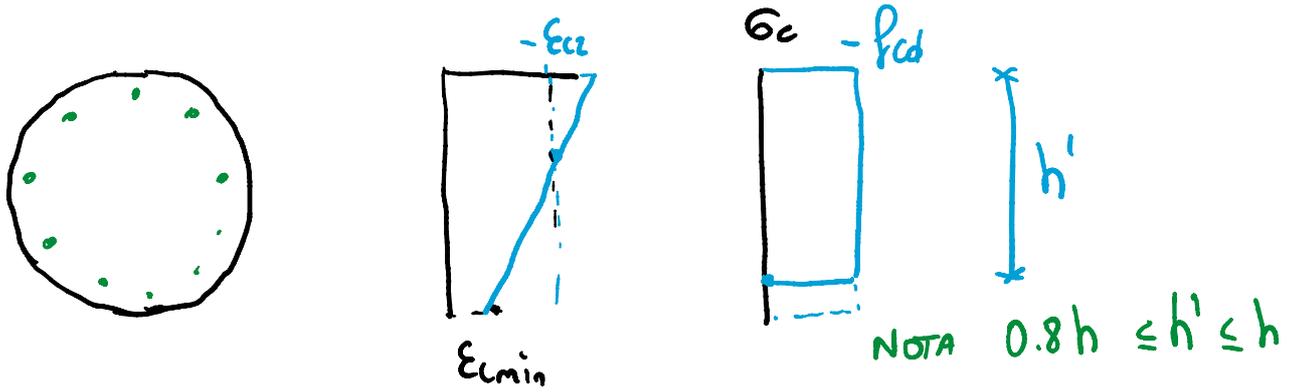
DIAGRAMMI LIMITE PER SEZIONE PARZIALIZZATA



ITERO FINO A QUANDO $N_{TOT} = N_{ed}$

TROVATO $x \Rightarrow$ CALCOLO M_{ed}

DIAGRAMMI LIMITE PER SEZIONE COMPRESSA



$$h' = \left[1 - 0.2 (1 - \eta_{min})^2 \right] h$$

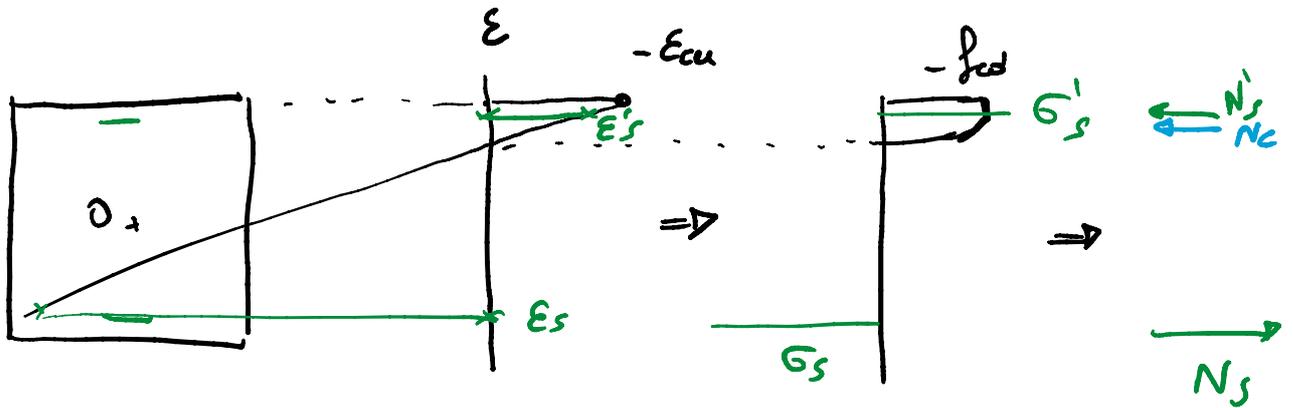
$$\text{Se } \eta_{min} = 0 \quad \rightarrow \quad h' = 0.8 h$$

$$\text{se } \eta_{min} > 1 \quad h' = h$$

DOMINI DI RESISTENZA M-N

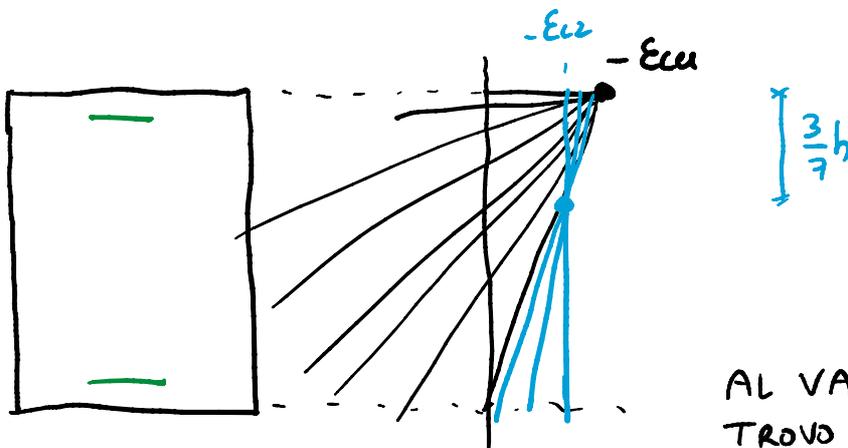
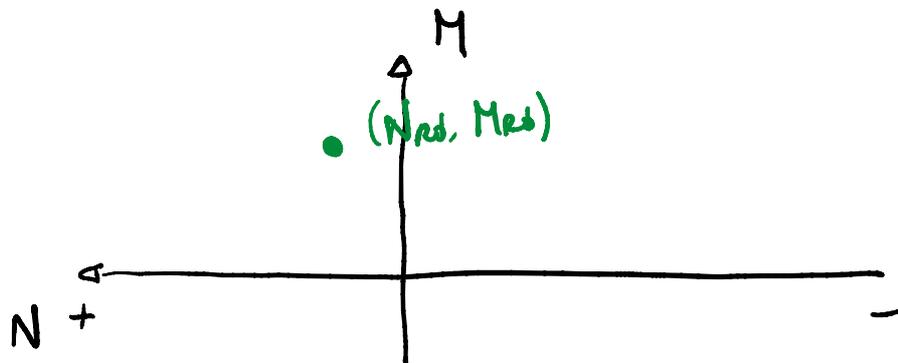
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INSIEME DELLE COPPIE M-N CHE PORTANO LA SEZIONE IN CONDIZIONI LIMITE $\Rightarrow \epsilon_c = \epsilon_{lim}$ IN ALMENO UN PUNTO DELLA SEZIONE



$$N_{rd} = N_c + N'_s + N_s$$

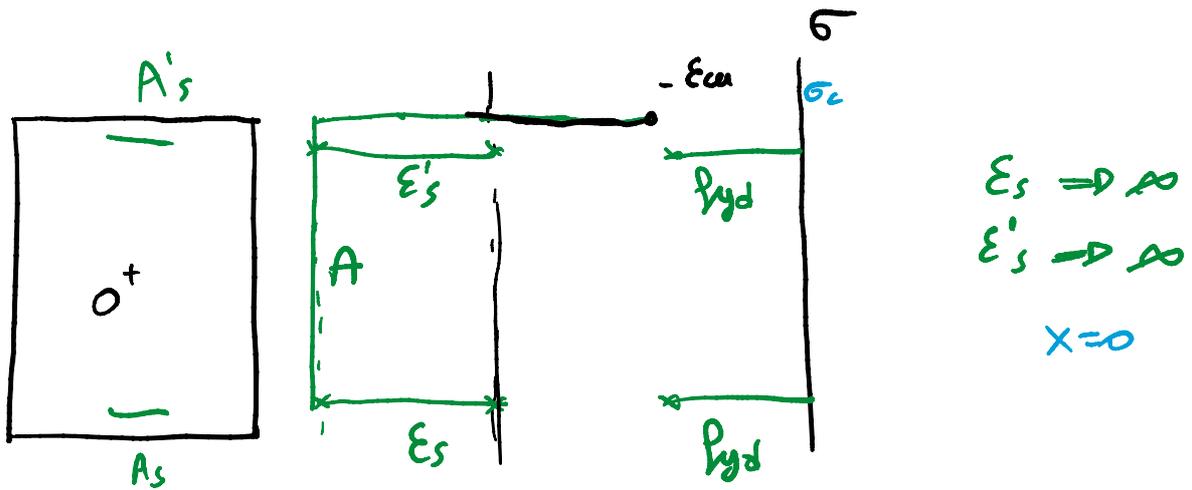
$$M_{rd} = N_s \left(\frac{h}{2} - c \right) - N'_s \left(\frac{h}{2} - c \right) - N_c \left(\frac{h}{2} - kx \right)$$



INFINITI
POSSIBILI
DIAGRAMMI
LIMITE

AL VARIARE DEL DIAGRAMMA
TROVO I PUNTI DEL DOMINIO

DIAGRAMMA LIMITE "A"



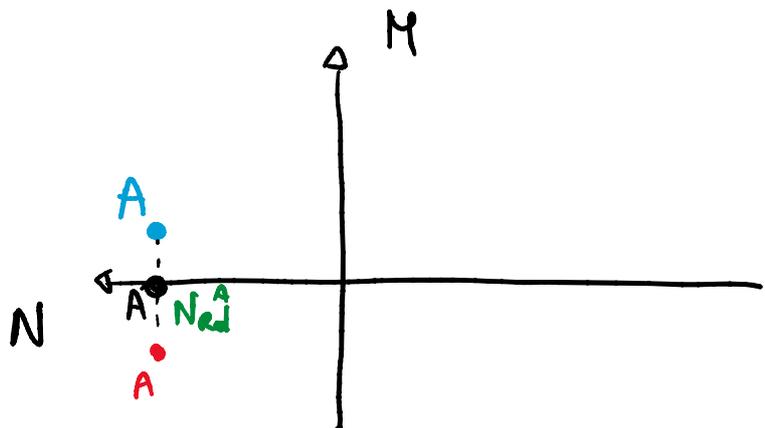
$$N_{red}^A = N_s + N'_s = A_s P_{yd} + A'_s P_{yd}$$

$$\begin{aligned}
 M_{red}^A &= N_s \cdot \left(\frac{h}{2} - c\right) - N'_s \left(\frac{h}{2} - c\right) = \\
 &= A_s P_{yd} \left(\frac{h}{2} - c\right) - A'_s P_{yd} \left(\frac{h}{2} - c\right) = \\
 &= (A_s - A'_s) P_{yd} \left(\frac{h}{2} - c\right)
 \end{aligned}$$

$$A_s > A'_s$$

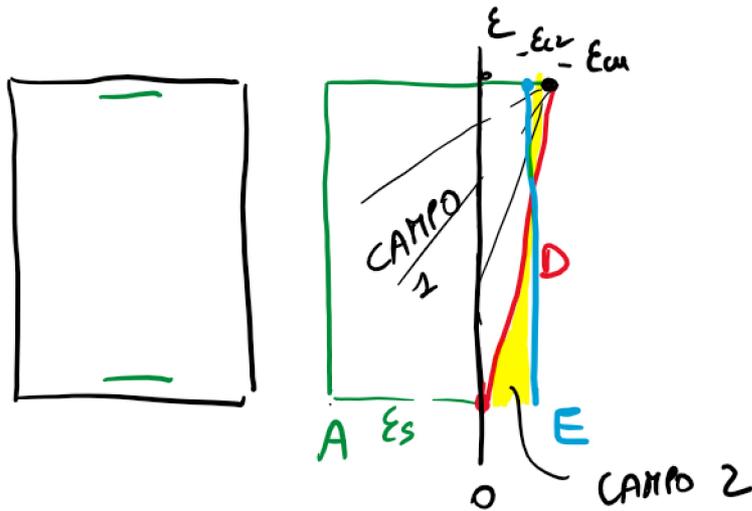
$$A_s = A'_s$$

$$A_s < A'_s$$



DIAGRAMMI LIMITE PARTICOLARI

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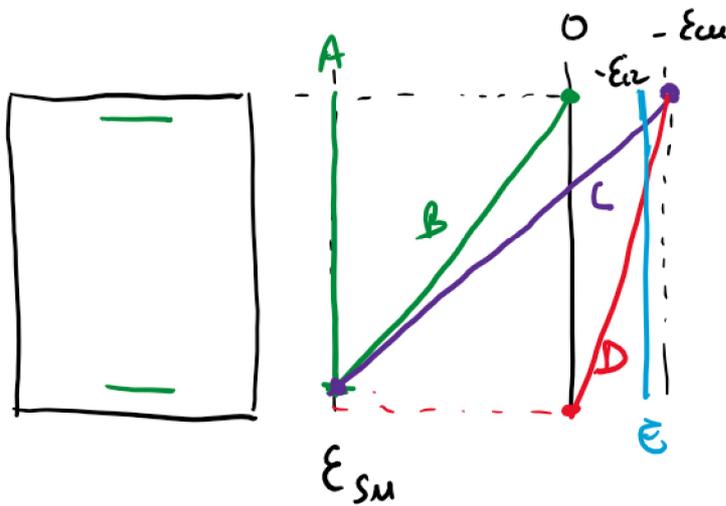
OGGI

NOTA: NEL DIAGRAMMA A

$$E_s > E_{yd}$$

$$E'_s > E_{yd}$$

IN NORMATIVE PASSATE

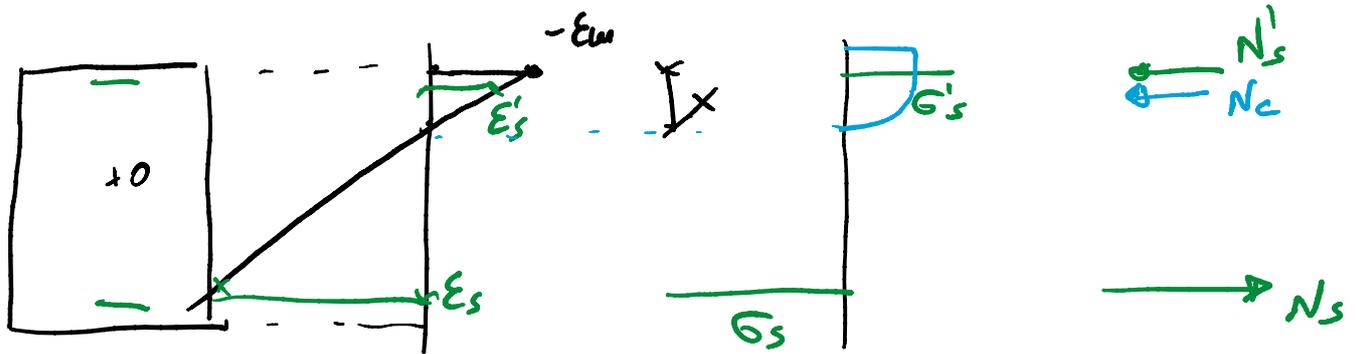


SI IMPONEVA ANCHE
LIMITE CONVENZIONALE
SU E_s

$$(E_{su} = 1\%)$$

DIAGRAMMI DEFORMATIVI LIMITE : CAMPO 1

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$$\epsilon'_s = -\epsilon_{cu} \frac{x-c}{x} \Rightarrow \sigma'_s \Rightarrow N'_s = A'_s \sigma'_s$$

$$\epsilon_s = \epsilon_{cu} \frac{d-x}{x} \rightarrow \sigma_s \Rightarrow N_s = A_s \sigma_s$$

$$N_c = -\beta b x f_{cd} \Rightarrow$$

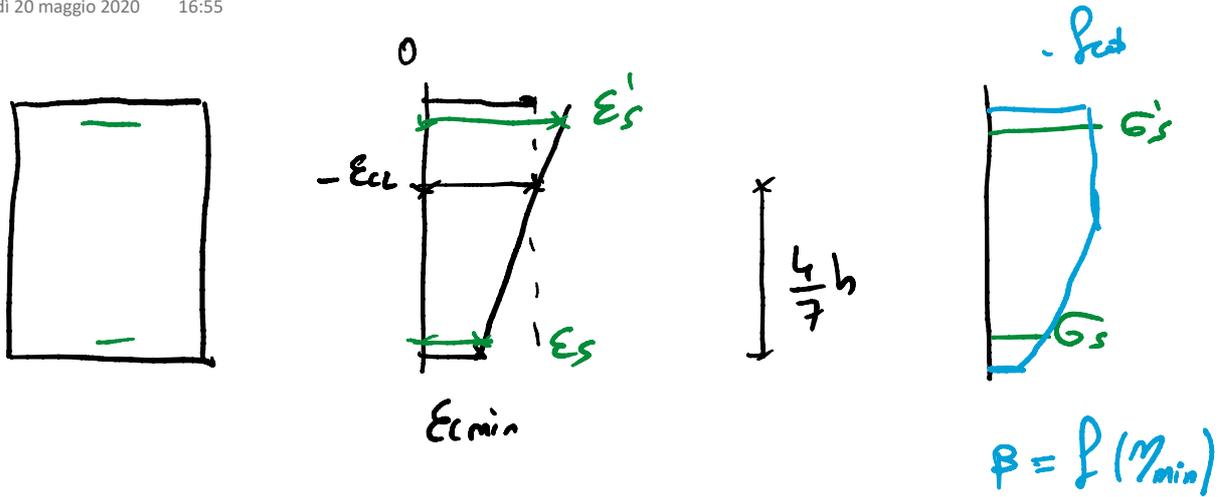
$$N_{rd} = N_c + N_s + N'_s$$

$$M_{rd} = N_s \left(\frac{h}{2} - c \right) - N'_s \left(\frac{h}{2} - c \right) - N_c \left(\frac{h}{2} - kx \right)$$

CASO PARTICOLARE $x = h \Rightarrow$ DIAGRAMMA D

DIAGRAMMI DEFORMATIVI LIMITE : CAMPO 2

mercoledì 20 maggio 2020 16:55

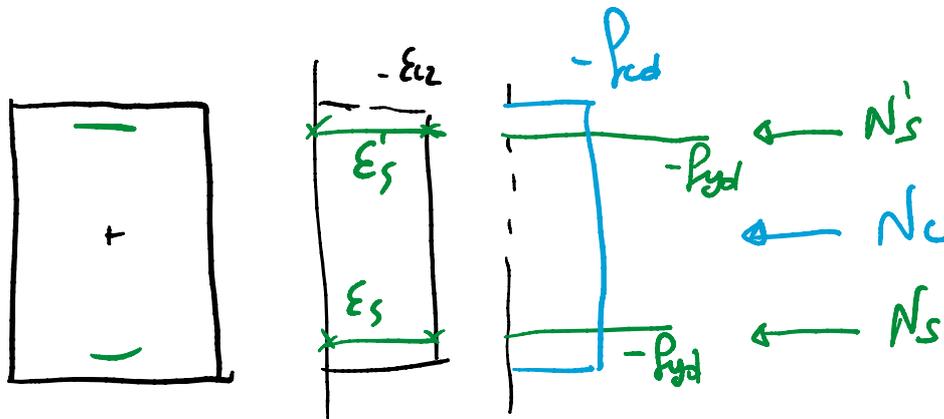


$$N_{red} = N_c + N_s + N'_s$$

$$M_{red} = N_s \cdot \left(\frac{h}{2} - c\right) - N'_s \left(\frac{h}{2} - c\right) - N_c \left(\frac{h}{2} - kh\right)$$

$$k = f(\eta_{min})$$

CASO LIMITE DIAGRAMMA \in ($\epsilon_{cmin} = -\epsilon_{c2}$)

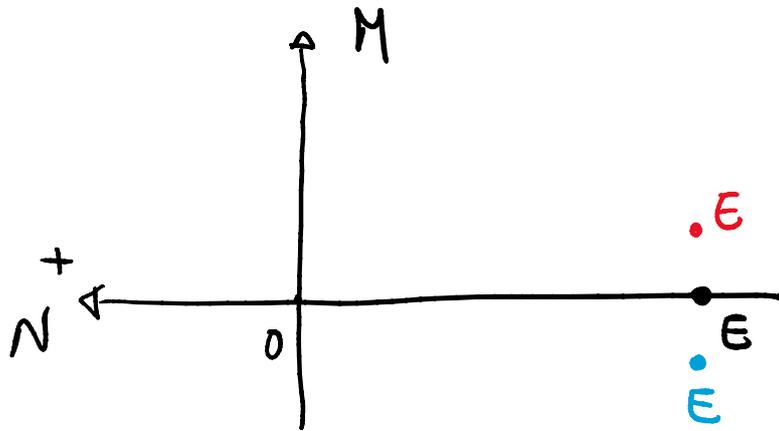


$$N_{red}^e = -A_c P_{red} - A_s P_{yd} - A'_s P_{yd}$$

$$M_{red}^e = N_s \left(\frac{h}{2} - c\right) - N'_s \left(\frac{h}{2} - c\right) =$$

$$= -A_s P_{yd} \left(\frac{h}{2} - c\right) + A'_s P_{yd} \left(\frac{h}{2} - c\right) \rightarrow$$

$$M_{red}^E = (A'_s - A_s) P_{yd} \left(\frac{h}{2} - c \right)$$



$$A_s < A'_s$$

$$(A_s = A'_s)$$

$$A_s > A'_s$$