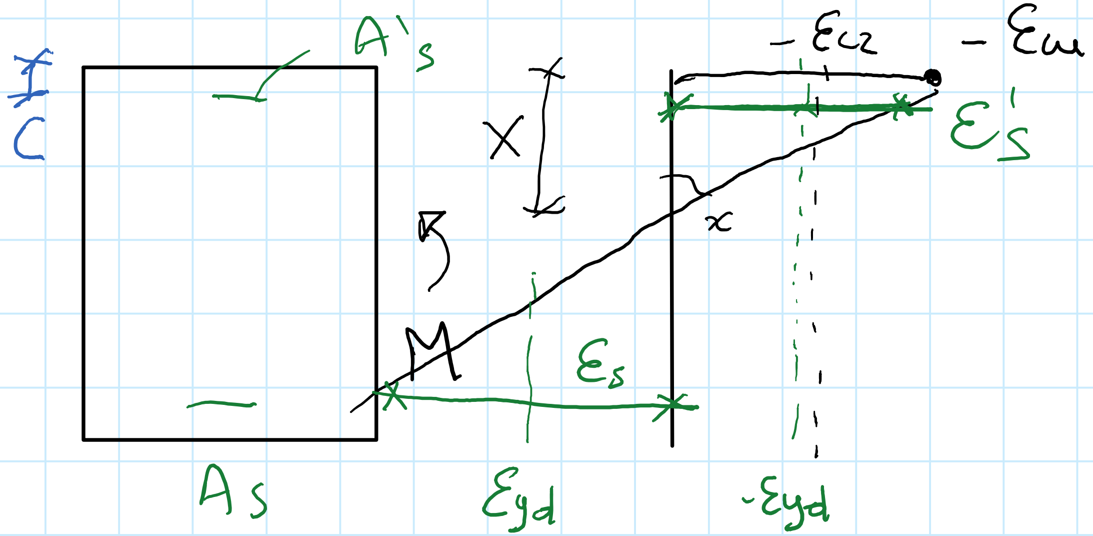
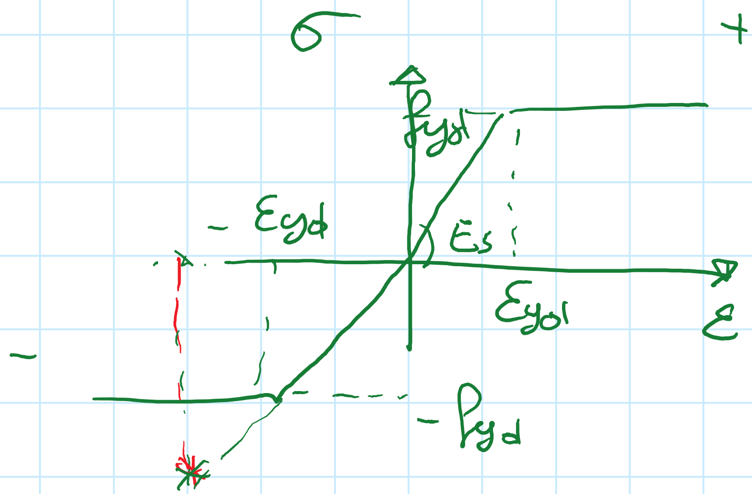
VERIFICA III STADIO



DATI: A_s, A'_s, b, h
MATERIALI

INCOGNITA: M_{Rd}



$$\chi = \frac{\varepsilon_{cu}}{x}$$

$$\varepsilon'_s = -\frac{\varepsilon_{cu}}{x}(x-c)$$

$$\varepsilon_s = \frac{\varepsilon_{cu}}{x}(d-x)$$

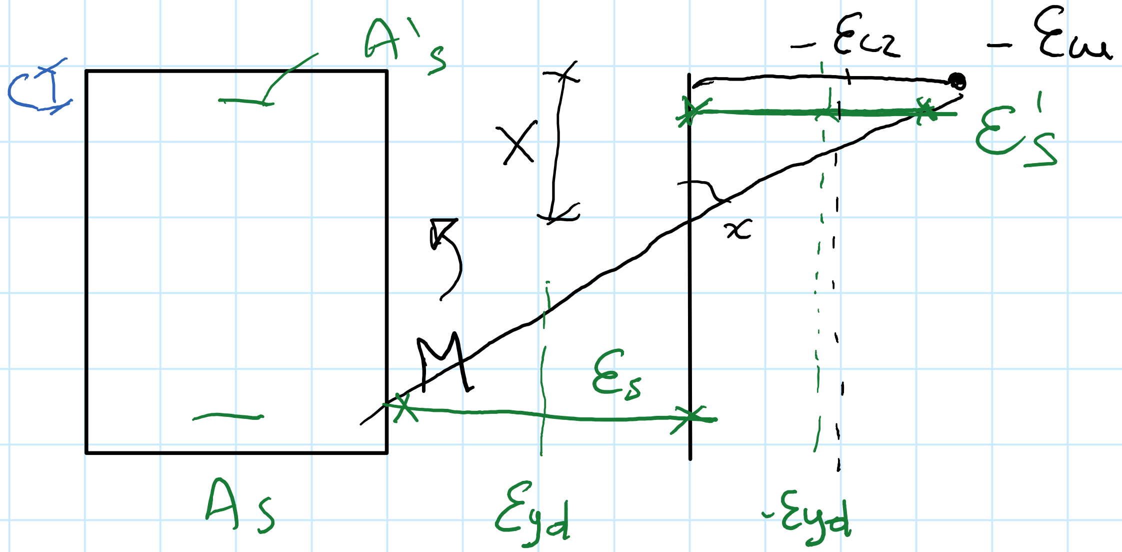
Se $\varepsilon'_s \leq -\varepsilon_{yd} \rightarrow \sigma'_s = -f_{yd}$

$\varepsilon'_s > -\varepsilon_{yd}$ $\quad \sigma'_s = E_s \cdot \varepsilon'_s = -\frac{f_{yd}}{\varepsilon_{yd}} \frac{\varepsilon_{cu}}{x}(x-c) = -s' f_{yd}$

$$s' = \frac{\varepsilon_{cu}}{\varepsilon_{yd}} \frac{(x-c)}{x} \quad \boxed{\leq 1}$$

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

VERIFICA III STADIO



(ARMATURA TESA SEMPRE SNERVATA IN CASO DI FLESSIONE SEMPLICE)

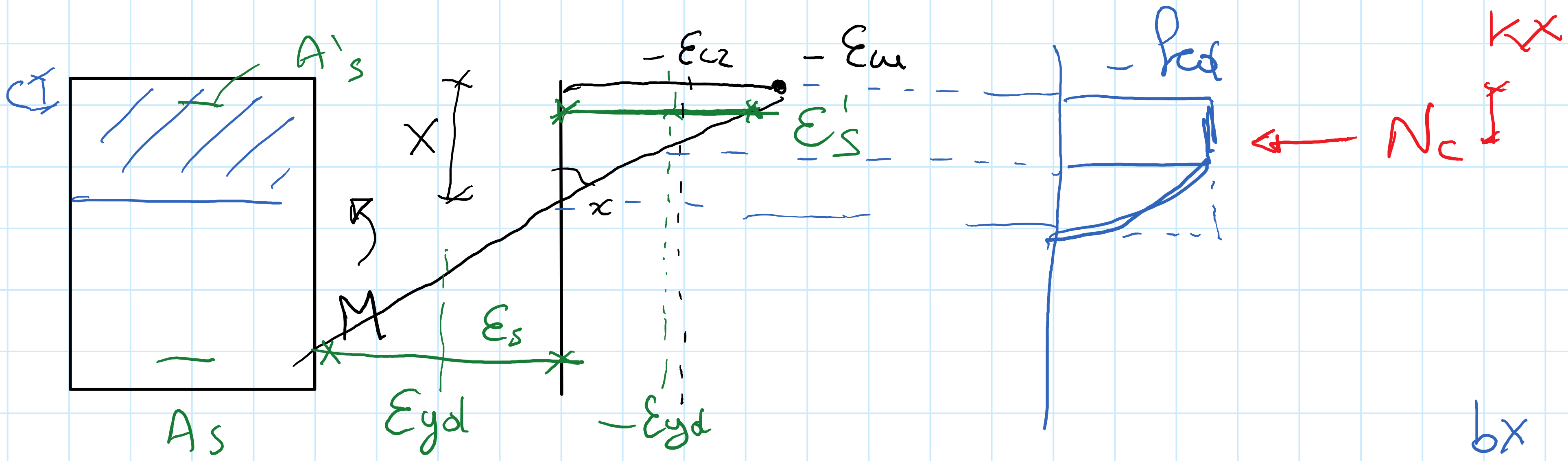
$$\varepsilon_s = \frac{\varepsilon_{cu}}{x}(d-x)$$

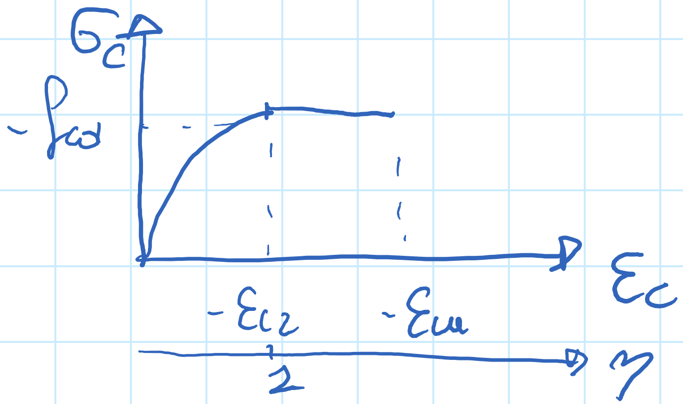
se $\varepsilon_s \geq \varepsilon_{yd} \rightarrow \sigma_s = f_{yd}$

$\varepsilon_s < \varepsilon_{yd} \rightarrow \sigma_s = E_s \varepsilon_s = \delta f_{yd}$ con $E_s = \dfrac{f_{yd}}{\varepsilon_{yd}}$

$$\varepsilon_s = \frac{\varepsilon_{cu}}{x}(d-x) \rightarrow \delta = \frac{\varepsilon_{cu}}{\varepsilon_{yd}} \cdot \frac{(d-x)}{x} \leq 1$$

VERIFICA III STADIO





$$\sigma = \begin{cases} -f_{cd}\,\eta(2-\eta) & \eta \leq 1 \\ -f_{cd} & \eta > 1 \end{cases}$$

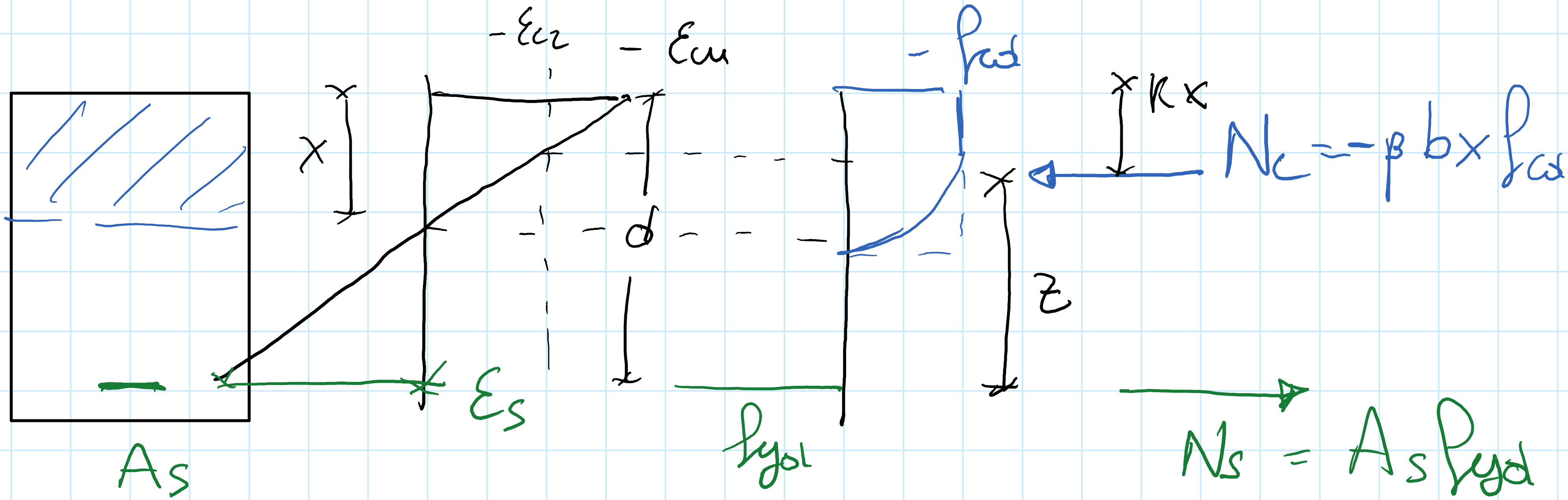
$$N_c = \int \sigma \, dA_c = -\beta \underbrace{A_c}_{bx} f_{cd}$$

$$\beta = \frac{-\int \sigma \, dA_c}{A_c f_{cd}} = 0.81$$

$$N_c = -0.810 \, b x f_{cd}$$

$$K = 0.416$$

SEZIONE A SEMPLICE ARMATURA



ASSE NEUTRO: $N_c + N_s = 0$

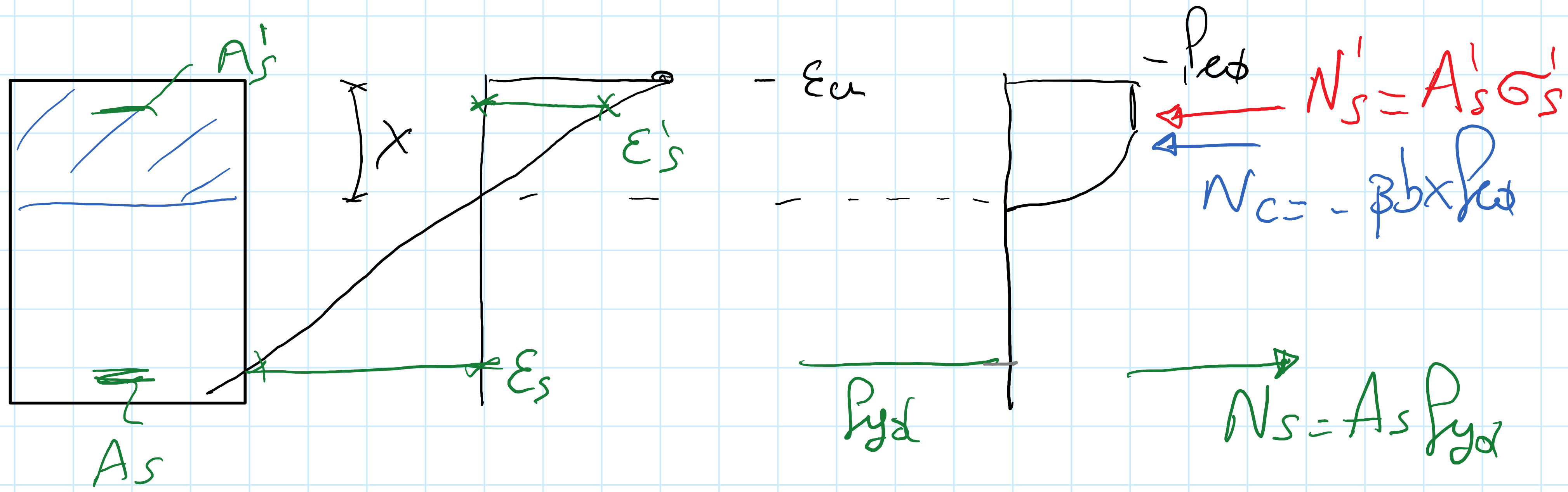
$$-\beta b x f_{cd} + A_s f_{yd} = 0$$

$$x = \frac{A_s f_{yd}}{\beta b f_{cd}}$$

z = BRACCIO COPPIA INTERNA $= d - kx$

$$M_{Rd} = N_s \cdot z = A_s f_{yd} (d - kx)$$

SEZIONE A DOPPIA ARMATURA



SUPPONGO $\varepsilon'_s < -\varepsilon_{yd}$ $\quad \sigma'_s = -f_{yd}$

EQUILIBRIO TRASL. $\quad N_c + N'_s + N_s = 0$

$$-\beta b x f_{cd} - A'_s f_{yd} + A_s f_{yd} = 0$$

$$x = \frac{(A_s - A'_s)\, f_{yd}}{\beta b f_{cd}}$$

VERIFICO IPOTESI $\varepsilon'_s \leq -\varepsilon_{yd}$

$$-\frac{\varepsilon_{cu}}{x}(x-c) \leq -\varepsilon_{yd}$$

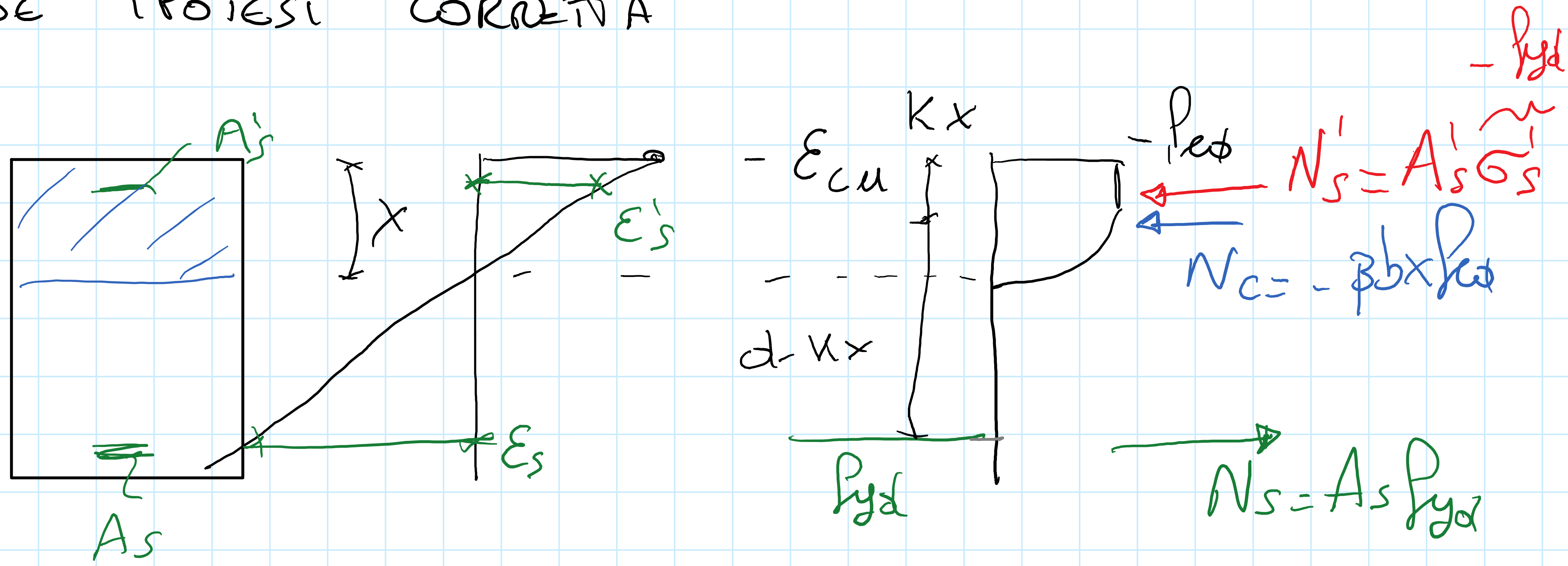
$$-\varepsilon_{cu} x + \varepsilon_{cu} c \leq -\varepsilon_{yd} x$$

$$(\varepsilon_{cu} - \varepsilon_{yd})\, x \geq \varepsilon_{cu}\, c$$

$$x \geq \frac{\varepsilon_{cu}}{\varepsilon_{cu} - \varepsilon_{yd}}\, c = \frac{3{,}5}{3{,}5 - 1{,}96} \cdot c = 2{,}27\, c$$

ARMATURA COMPRESSA SNERVATA SE $x \geq 2{,}27 c$

SE IPOTESI CORRETTA



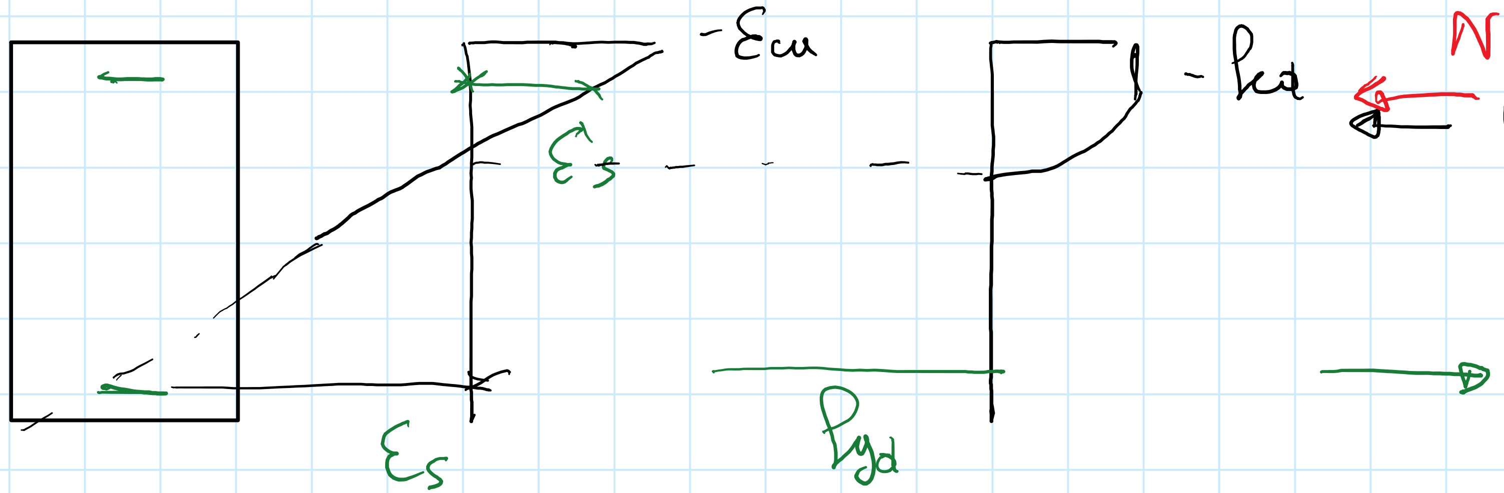
$$M_{Rd} = N_s (d - Kx) - N'_s (Kx - c)$$

$$= A_s f_{yd} (d - Kx) + A'_s f_{yd} (Kx - c)$$

$$\mu = \frac{A'_s}{A_s} \Rightarrow M_{Rd} = A_s f_{yd} \left[(d - Kx) + \mu (Kx - c) \right]$$

$$= A_s f_{yd} (d - Kx) \left[1 + \frac{\mu (Kx - c)}{d - Kx} \right]$$

ARMATURA COMPRESSA IN CAMPO ELASTICO



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

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

$$N_s = A_s f_{yd}$$

$$|\sigma'_s| < f_{yd}$$

$$\sigma'_s = -\underbrace{\frac{f_{yd}}{\varepsilon_{yd}}}_{E_s} \underbrace{\frac{\varepsilon_{cu}}{x}(x-c)}_{\varepsilon'_s}$$

EQUILIBRIO ALLA TRASLAZIONE $N_c + N'_s + N_s = 0$

$$-\beta b x f_{cd} - f_{yd} \frac{\varepsilon_{cu}}{\varepsilon_{yd}} \frac{(x-c)}{x} A'_s + A_s f_{yd} = 0$$

$$\beta b x^2 f_{cd} + \frac{f_{yd}}{\varepsilon_{yd}} \varepsilon_{cu} (x - c) A'_s - A_s f_{yd} x = 0$$

$$\beta b f_{cd} x^2 - \left(A_s f_{yd} - f_{yd} \frac{\varepsilon_{cu}}{\varepsilon_{yd}} A'_s\right) x - f_{yd} \frac{\varepsilon_{cu}}{\varepsilon_{yd}} c A'_s = 0$$

$$A'_s = \mu A_s$$

$$x^2 - \frac{A_s f_{yd} d}{\beta b f_{cd} d} \left(1 - \mu \frac{\varepsilon_{cu}}{\varepsilon_{yd}}\right) x - \mu \frac{A_s f_{yd} \varepsilon_{cu} c d}{\beta b f_{cd} \varepsilon_{yd} d} = 0$$

$$\mu_1 = \mu \frac{\varepsilon_{cu}}{\varepsilon_{yd}}$$

ω = PERC. MECCANICA DI ARMATURA $= \dfrac{A_s f_{yd}}{b d f_{cd}}$

$$x^2 - \frac{A_s f_{yd}\, d}{\beta b f_{cd}\, d}\left(1 - \mu \frac{\varepsilon_{cu}}{\varepsilon_{yd}}\right) x - \mu \frac{A_s f_{yd}\, \varepsilon_{cu}\, c\, d}{\beta b f_{cd}\, \varepsilon_{yd}\, d} = 0$$

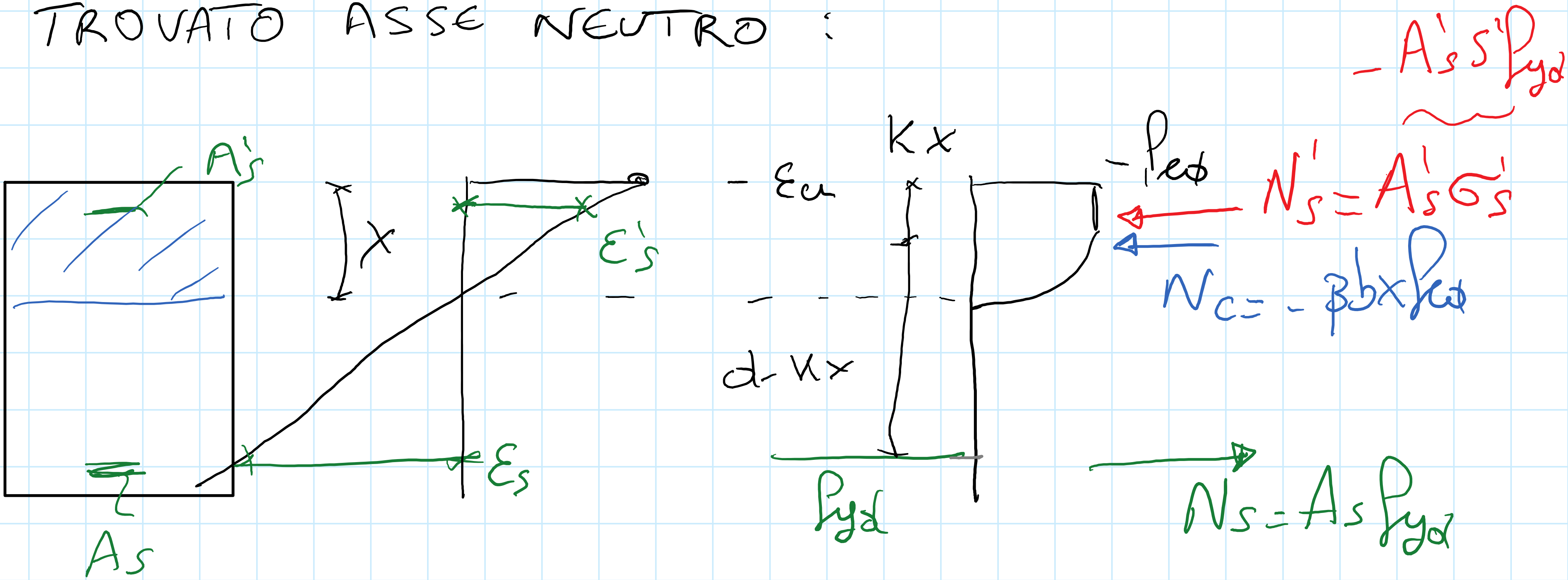
$$x^2 - \frac{\omega d}{\beta}\left(1 - \mu_1\right) x - \mu_1 \frac{\omega d}{\beta} c = 0$$

$$x = \frac{\omega d}{2\beta}\left(1 - \mu_1\right) \pm \sqrt{\frac{\omega^2 d^2}{4\beta^2}\left(1 - \mu_1\right)^2 + \mu_1 \frac{\omega d}{\beta} c}$$

$$= \frac{\omega d}{2\beta}\left(1 - \mu_1\right) + \sqrt{\frac{\omega^2 d^2}{4\beta^2}\left[\left(1 - \mu_1\right)^2 + \mu_1 \frac{\omega d}{\beta} c \frac{4\beta^2}{\omega^2 d^2}\right]}$$

$$x = \frac{\omega d}{2\beta}\left[\left(1 - \mu_1\right) + \sqrt{\left(1 - \mu_1\right)^2 + \frac{4\beta}{\omega}\frac{c}{d}\mu_1}\right]$$

TROVATO ASSE NEUTRO :



$$s' = + \frac{\varepsilon_{cu}}{\varepsilon_{yd}} \frac{x-c}{x} \Rightarrow \sigma'_s = - s' f_{yd}$$

EQ. ROTAZIONE RISPETTO A N_c

$$M_{rd} = N_s (d-kx) - N'_s (kx-c) =$$

$$A_s f_{yd} (d-kx) + A'_s s' f_{yd} (kx-c)$$

$$A'_s = \mu A_s \Longrightarrow$$

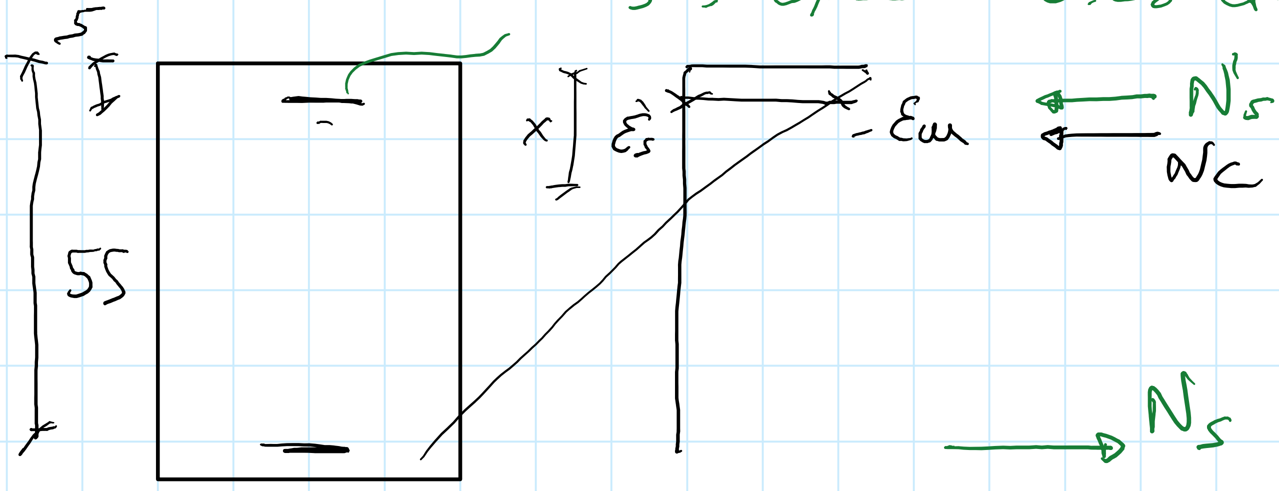
$$M_{Rd} = A_s f_{yd} (d - kx) + \mu A_s s' f_{yd} (kx - c)$$

$$= A_s f_{yd} (d - kx) \left[1 + \mu s' \frac{(kx - c)}{d - kx} \right]$$

CONTRIBUTO ARMATURA COMPRESSA

ESEMPIO

$A'_s = 2\phi 20 = 6.28\ cm^2$



$h = 60\ cm$

B450C

C30/37 CLS

$M_{Rd} = ?$

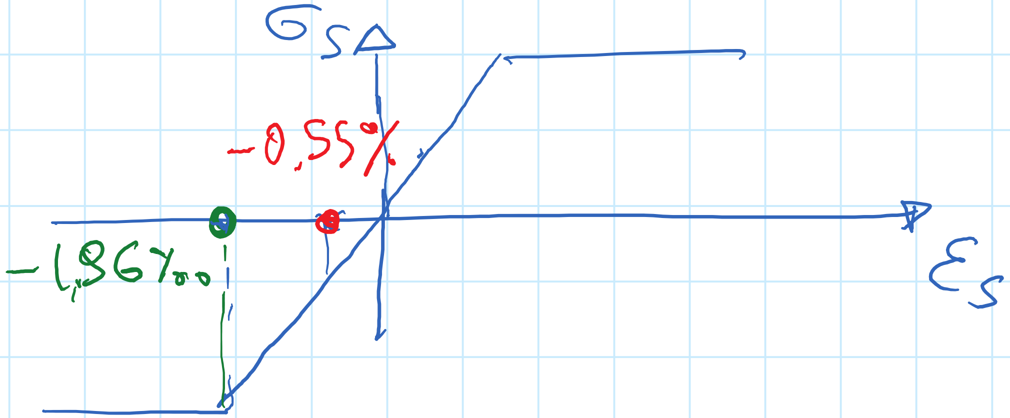
$A_s = 4\phi 20 = 12.56\ cm^2$

$b = 30$

IPOTESI: $\varepsilon'_s < -\varepsilon_{yd}$ $\longrightarrow$ $x = \dfrac{(A_s - A'_s)\, f_{yd}}{\beta\, b\, f_{cd}}$

$$x = \frac{(12.56 - 6.28)\ cm^2 \times 391.3\ MPa}{0.81 \times 30\ cm \times 17\ MPa} = 5.94\ cm$$

$$\varepsilon'_s = -\frac{\varepsilon_{cu}}{x}(x - c) = -\frac{3.5}{1000} \cdot \frac{5.94 - 5}{5.94} = -0.55‰$$



→ IPOTESI ERRATA

$$x = \frac{\omega d}{2\beta}\left[(1-\mu_1) + \sqrt{(1-\mu_1)^2 + \frac{4\beta}{\omega}\frac{c}{d}\mu_1}\right]$$

$$\mu_1 = \mu \times \frac{\varepsilon_{cu}}{\varepsilon_{yd}} = \frac{6.28}{12.56} \times \frac{3.5}{1000} \times \frac{1000}{1.86} = 0.89$$

$$\omega = \frac{A_s f_{yd}}{b d f_{cd}} = \frac{12.56 \text{ cm}^2}{30 \times 55 \text{ cm}^2} \frac{391.3}{17} = 0.17$$

$$\gamma = \frac{c}{d} = \frac{5}{55} = 0.091$$

$$X = \frac{0.17 \times 55}{2 \times 0.81}\left[(1-0.89) + \sqrt{(1-0.89)^2 + \frac{4 \times 0.81 \times 0.091}{0.17}\, 0.89}\right]$$

$$= 7{,}83 \text{ cm}$$

$$\varepsilon'_s = -\frac{\varepsilon_{cu}}{x}(x-c) = -\frac{3{,}5}{1000}\left(\frac{7{,}83-5}{7.83}\right) = -1.26\text{‰}$$

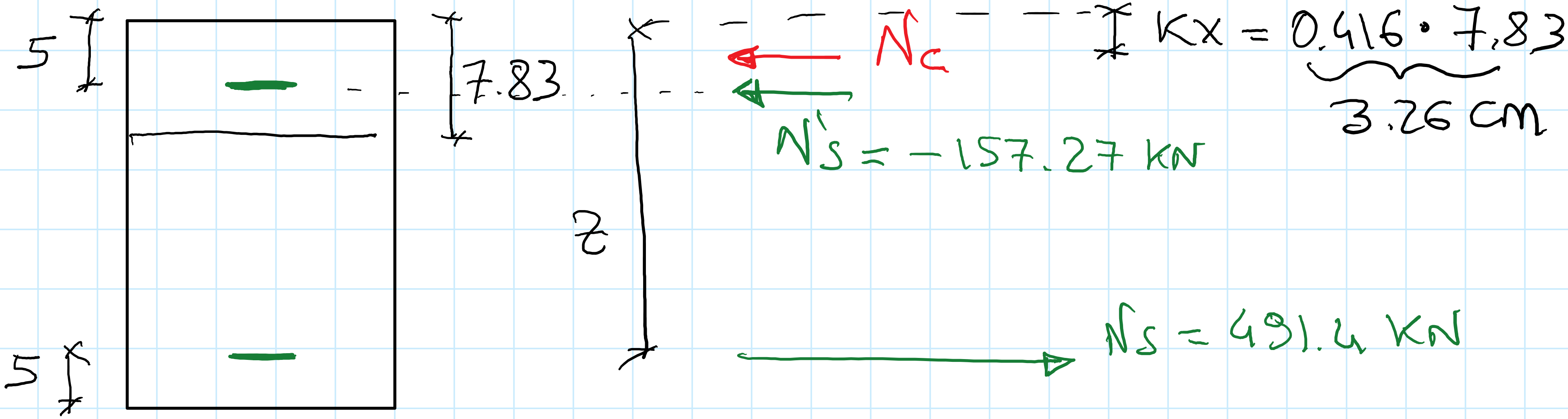
$$S' = -\frac{\varepsilon'_s}{\varepsilon_{yd}} = \frac{1.26}{1.96} = 0.64$$

TASSO DI LAVORO ARMATURA COMPRESSA

$$N'_s = -A'_s\, S'\, f_{yd} = -6.28 \text{ cm}^2 \times 0.64 \times 391{,}3 \frac{N}{mm^2} =$$

$$-157{,}27 \text{ kN}$$

$$N_s = A_s f_{yd} = 12.56 \text{ cm}^2 \times 391{,}3 \frac{1}{10} = 491{,}4 \text{ kN}$$



$$M_{rd} = \Big[491,4 \cdot \big[\underbrace{55 - 3,26}_{d - kx}\big] + \underbrace{157.27}_{-N'_s} \big(\underbrace{3,26 - 5}_{kx - c}\big) \Big] \times \frac{1}{100}$$

$$= 251 \text{ KNm}$$