VERIFICA A FLESSIONE, I STADIO

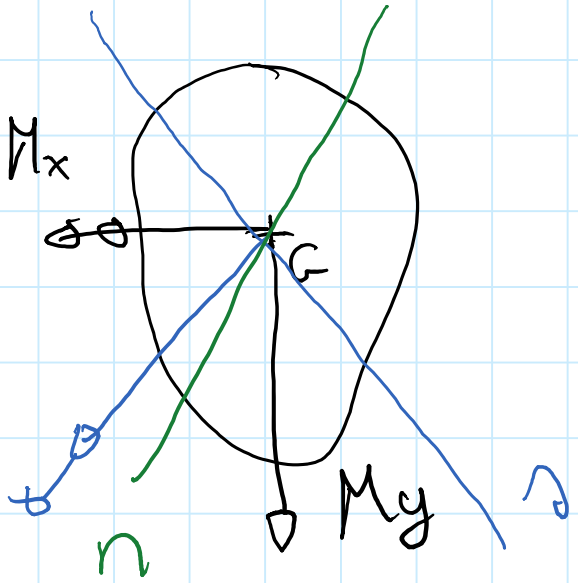
$$\varepsilon = \varepsilon_G + \chi_x X + \chi_y y$$

$$\varepsilon_G = \frac{N}{E_c A_{ci}} \quad ; \quad \chi_x = -\frac{M_y}{E_c I_y} \qquad \chi_y = \frac{M_x}{E_c I_x}$$

$$N = 0 \longrightarrow \varepsilon_G = 0 \Rightarrow$$

ASSE NEUTRO PASSA PER G (SEZ. OMOGEN.)

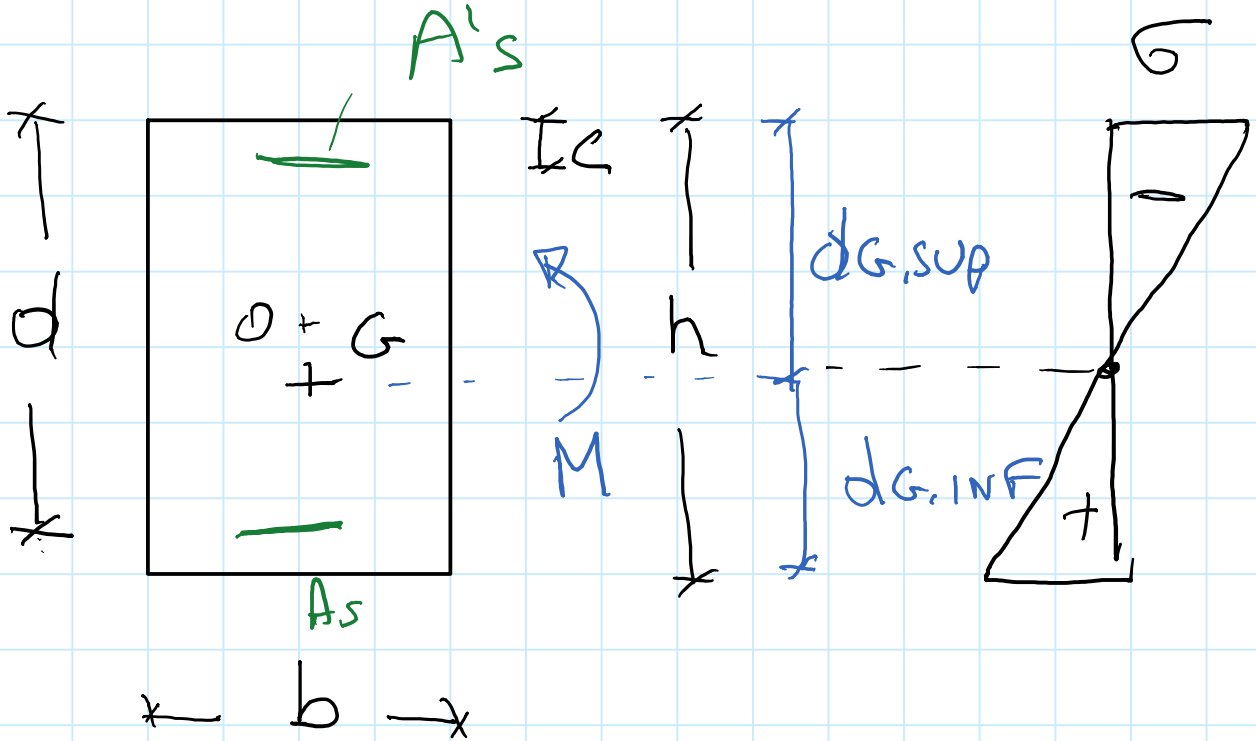
$$\sigma = -\frac{M_y}{I_y} x + \frac{M_x}{I_x} y$$



y = ASSE DI SOLLECITAZIONE M

n = ASSE NEUTRO

FLESSIONE RETTA



A_s ARMATURA TESA

A'_s " COMPRESSA

c COPRIFERRO

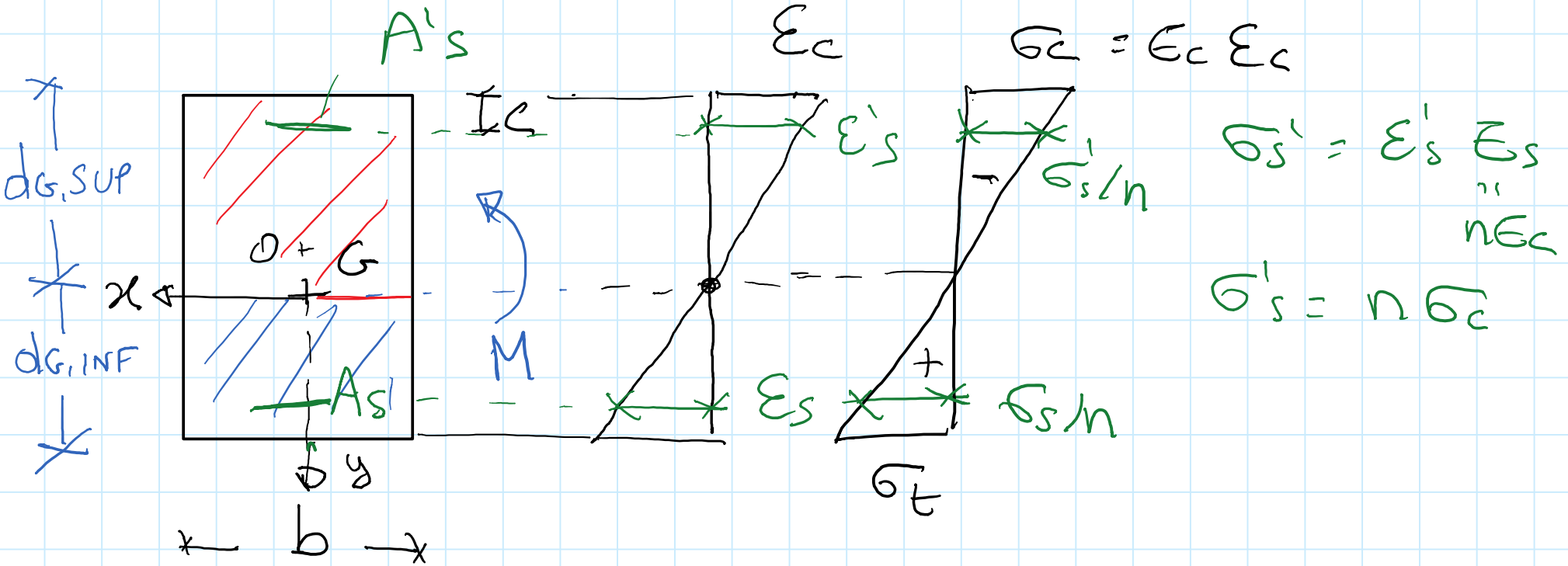
d ALTEZZA UTILE

$$d_{G,sup} = \frac{S_{sup}}{A}$$

$$S_{sup} = bh \cdot \frac{h}{2} + nA'_s c + nA_s d$$

$$A = bh + nA'_s + nA_s$$

$$n = \frac{E_s}{E_c}$$



$\sigma_s' = \varepsilon_s' E_s$

$\sigma_s' = n \varepsilon_c$

$\sigma_t = \frac{M}{I_x} \cdot d_{G,INF}$

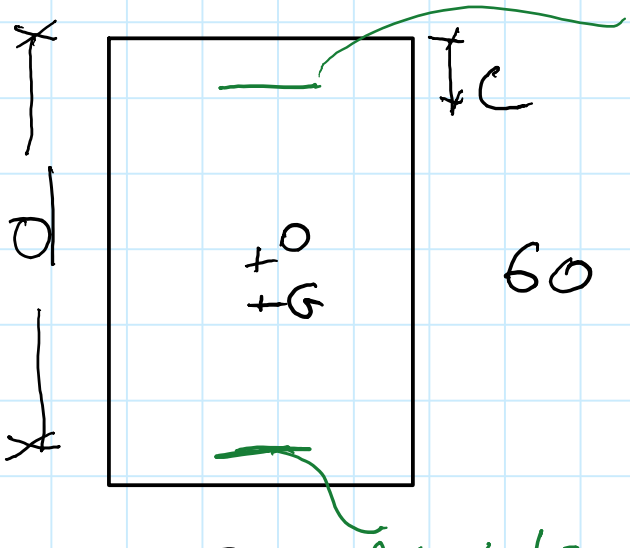
$\sigma_t \leq f_{cfk}$

$\sigma_s' = -n \frac{M}{I_x} (d_{GSUP} - c)$

$\sigma_s = n \frac{M}{I_x} (d_{GINF} - c)$

$I_x = \frac{b d_{G,SUP}^3}{3} + \frac{b d_{G,INF}^3}{3} + n A_s' (d_{G,SUP} - c)^2 + n A_s (d_{GINF} - c)^2$

ESEMPIO: VERIFICA A FESSURAZIONE



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

$M = 60\ kNm$

C30/37 → n = 6.1

B450C

c = 5 cm

$d = h - c = 55\ cm$

$A_s = 4\phi 20 = 4 \times 3.14 = 12.56\ cm^2$

$$S_{sup} = \frac{30 \times 60^2}{2} + 6.1 \times 6.28 \times 5 + 6.1 \times 12.56 \times 55$$

$$= 58405.4\ cm^3$$

$$A = 30 \times 60 + 6.1\,(6.28 + 12.56) = 1915\ cm^2$$

$$d_{G,sup} = \frac{58405.4}{1915} = 30.5\ cm \quad ; \quad d_{GIN} = 29.5\ cm$$

$$I_x = \frac{30 \times 30{,}5^3}{3} + \frac{30 \times 29{,}5^3}{3} +$$

$$+ 6.10 \times 6{,}28 \times (30{,}5 - 5)^2 + 6.10 \times 12{,}56 (29{,}5 - 5)^2$$

$$= 611349 \ cm^4$$

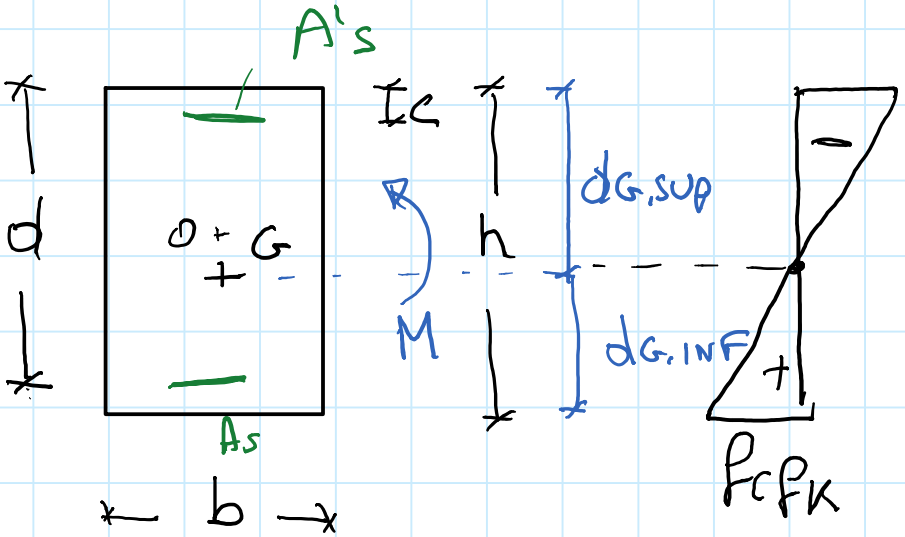
$$\sigma_{t,max} = \frac{M}{I_x} (d_{G,INF}) = \frac{60 \ kNm \cdot 10^3 \cdot 10^6}{611349 \ cm^4} \times 29{,}5 \ cm \cdot 10^{-3}$$

$$= 2{,}9 \ N/mm^2$$

$$f_{cfk} = 1{,}2 \, f_{ctk} = 1{,}2 \times 2{,}02 MPa = 2{,}4 \ MPa$$

$\sigma_{t,max} > f_{cfk} \Rightarrow$ SEZIONE FESSURATA

MOMENTO DI FESSURAZIONE



$$\sigma_t = \frac{M}{I_x} \; d_{G,INF} = f_{ctfk}$$

$$M_{fess} = f_{ctfk} \cdot \frac{I_x}{d_{G,INF}}$$

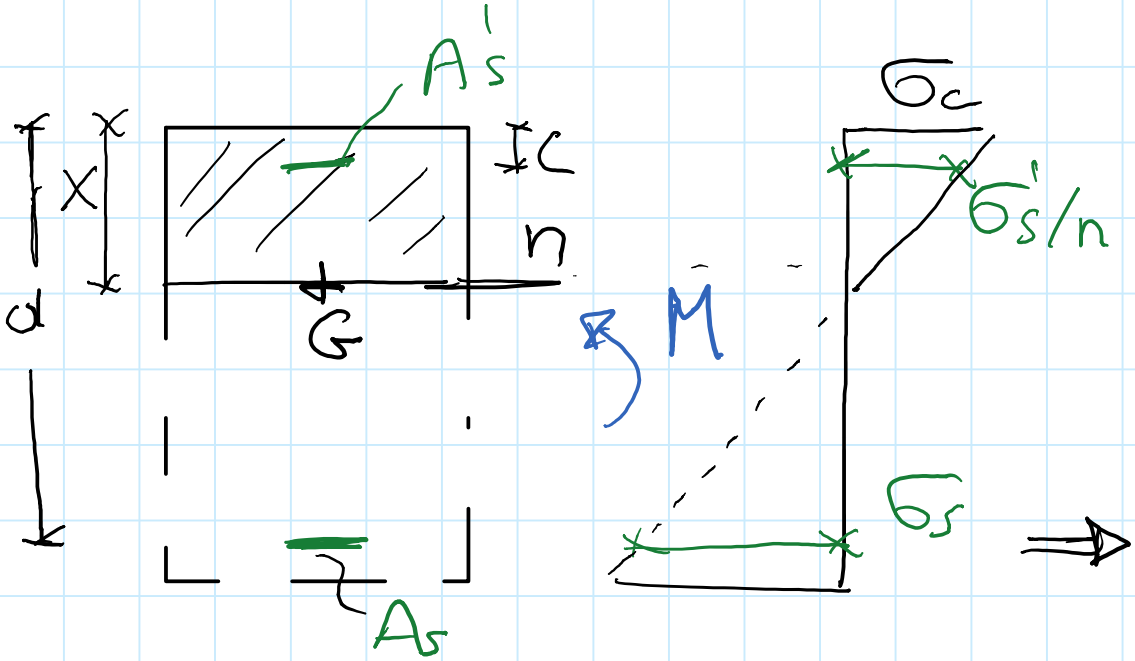
PER ESEMPIO PRECEDENTE

$$M_{fess} : f_{ctfk} = M : \sigma_t \Rightarrow$$

$$M_{fess} : 2{,}4\ MPa = 60\ KNm : 2{,}9\ MPa$$

$$M_{fess} = \frac{60 \times 2{,}4}{2{,}9} = 49{,}7\ KNm$$

VERIFICA A FLESSIONE AL II STADIO



$\varepsilon_G = 0$

(BARICENTRO DELLA SEZIONE REAGENTE OMOGENEIZZATA)

$\Rightarrow S_N = 0$

$$S_n = -bx\frac{x}{2} - nA'_s(x-c) + nA_s(d-x) = 0$$

$$+\frac{bx^2}{2} + xn(A'_s + A_s) - n(A'_s c + A_s d) = 0$$

$$x^2 + \frac{2n}{b}(A'_s + A_s)x - \frac{2n}{b}(A'_s c + A_s d) = 0$$

POSIZIONE ASSE NEUTRO

$$x^2 + \frac{2n}{b}(A'_s + A_s)x - \frac{2n}{b}(A'_s c + A_{sd}) = 0$$

$$x = -\frac{n}{b}(A'_s + A_s) \pm \sqrt{\frac{n^2}{b^2}(A'_s + A_s)^2 + \frac{2n}{b}(A'_s c + A_{sd})}$$

$$x = \underbrace{\frac{nd}{bd}(A'_s + A_s)}_{\psi d}\left[-1 + \sqrt{1 + \frac{2n}{b}(A'_s c + A_{sd})\cdot\frac{b^2 d}{d\,n^2(A'_s + A_s)}}\right]$$

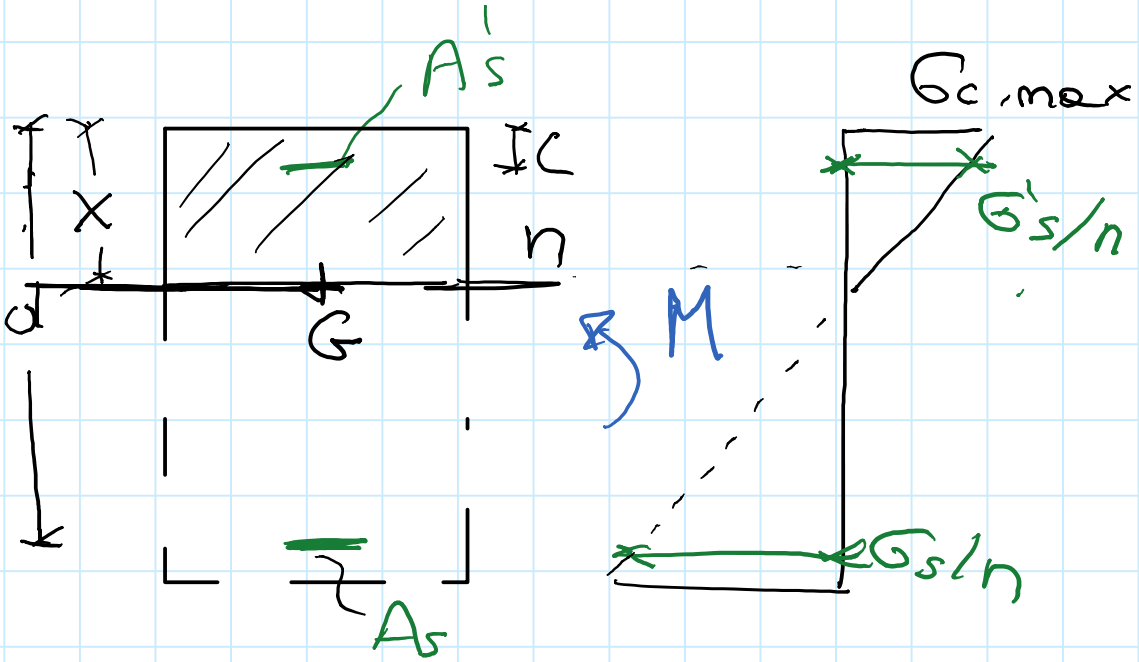
ψ = PERC. ELASTICA DI ARMATURA $= n\left(\frac{A_s + A'_s}{bd}\right)$

$$d_{GS} = \frac{A'_s c + A_{sd}}{A_s + A'_s}$$

DISTANZA BARICENTRO ARMATURE DAL BORDO SUPERIORE

$$x = \psi d\left[-1 + \sqrt{1 + \frac{2 d_{GS}}{\psi d}}\right]$$

CALCOLO DELLE TENSIONI



$$\sigma_{c\,max} = -\frac{M}{I_x} x$$

RISPETTO ASSE // x PASSANTE PER G

$$\sigma'_s = -n \frac{M}{I_x} (x - c) \quad ; \quad \sigma_s = n \frac{M}{I_x} (d - x)$$

$$I_x = \frac{bx^3}{3} + n A'_s (x - c)^2 + n A_s (d - x)^2$$

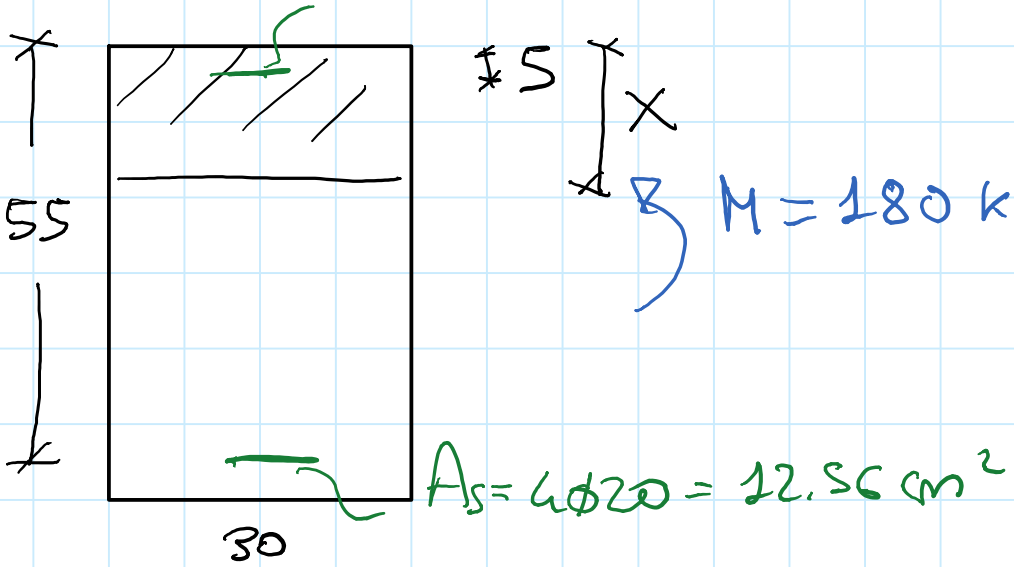
ESEMPIO

30×60

C30/37 ; B450C

CARICHI DI LUNGA DURATA

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



$M = 180\ kNm$

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

$\sigma_c \overset{?}{<} 0.45\, f_{ck}$

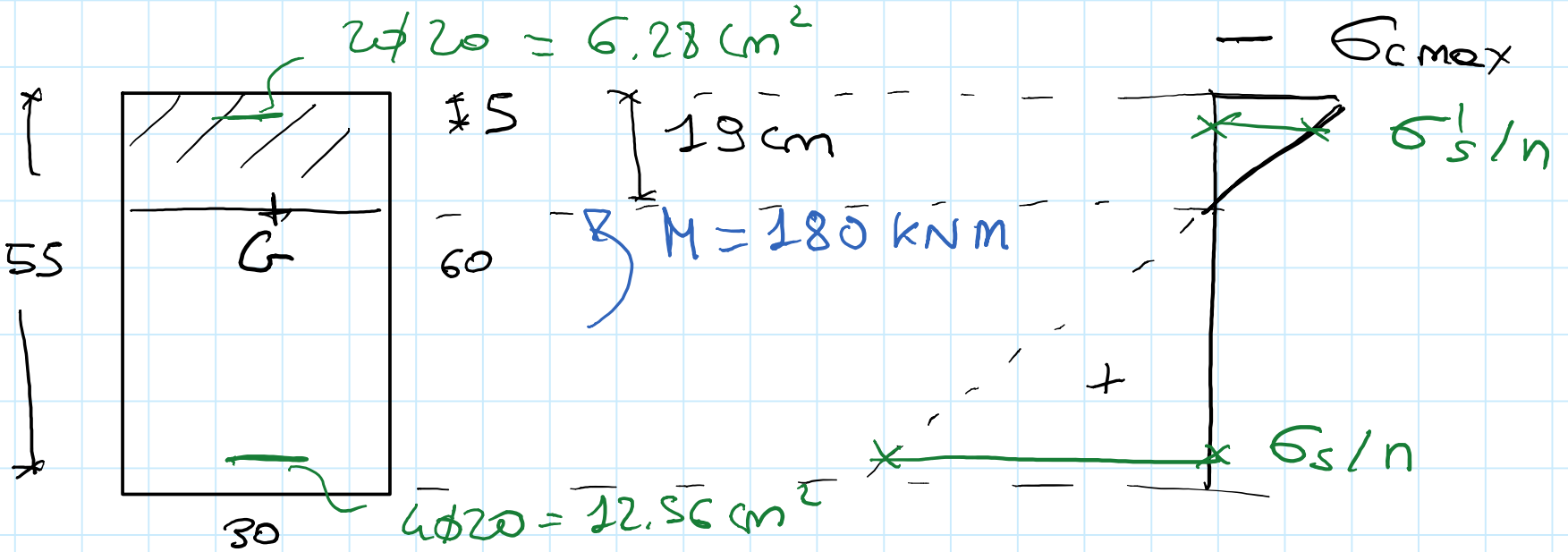
$\sigma_s \leq 0.8\, f_{yk}$

PER TROVARE x

$$\psi = \frac{n(A_s + A'_s)}{bd} = \frac{15(12.56 + 6.28)}{30 \times 55} = 0.17$$

$$d_{G.SUP} = \frac{6.28 \times 5 + 12.56 \times 55}{6.28 + 12.56} = 38.3\ cm$$

$$x = 0.17 \cdot 55 \left[-1 + \sqrt{1 + \frac{2 \times 38.3}{0.17 \times 55}} \right] = 19\ cm$$



$$I_x = \frac{30 \times 19^3}{3} + 15 \times 6{,}28 \times (19-5)^2 + 15 \cdot 12{,}56\,(55-19)^2 = 331219\ cm^4$$

$$\sigma_{cmax} = -\frac{180\ kNm}{331219\ cm^4} \cdot 19\ cm \times 10^3 = -10{,}33\ MPa$$

$$0.45\, f_{ck} = -0{,}45 \times 30\ N/mm^2 = -13{,}5\ MPa$$

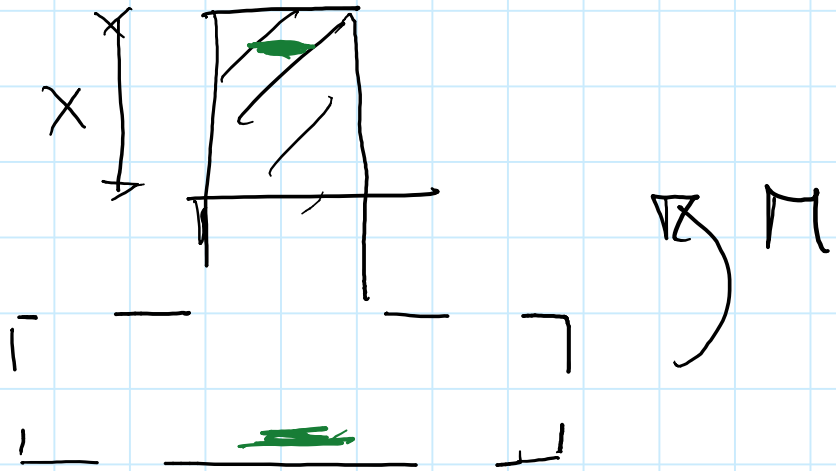
} OK

$$\sigma_s = 15 \times \frac{180\ kNm}{331219\ cm^4} \cdot (55-19)\ cm \times 10^3 = 293{,}5\ N/mm^2$$

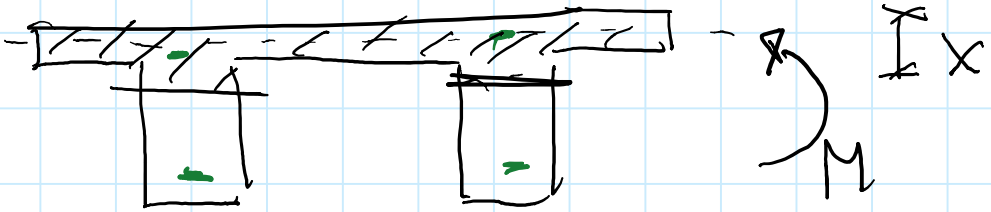
$$0.8\, f_{yk} = 0.8 \times 450\ N/mm^2 = 360\ N/mm^2$$

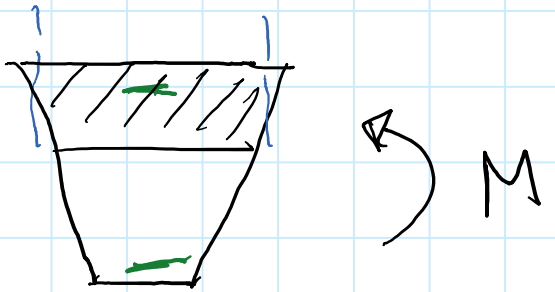
} OK

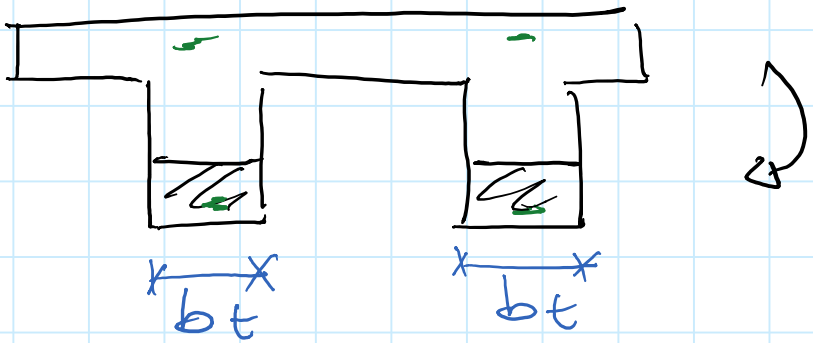
SEZIONI RICONDUCIBILI ALLA RETTANGOLARE



⟶ RIGOROSAMENTE RETTANGOLARE



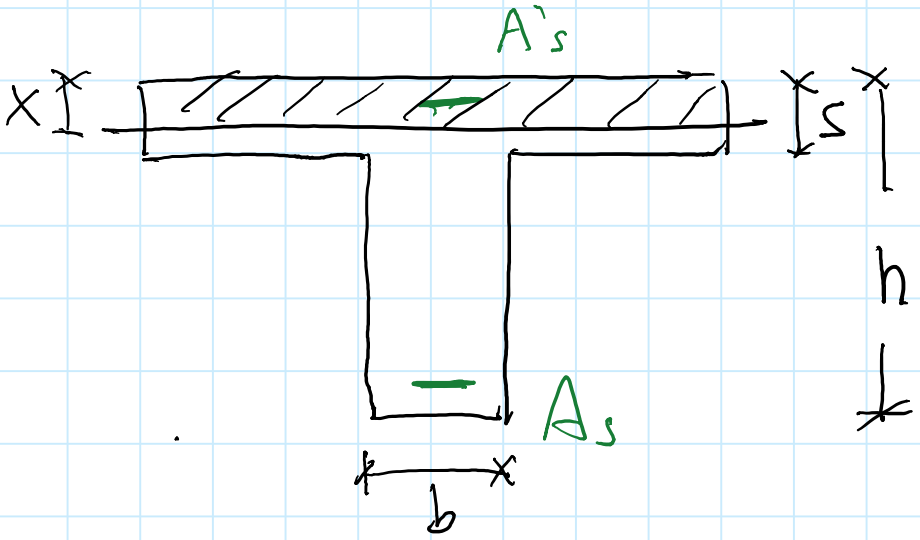




⟺ SEZ. RETTANGOLARE

$b = 2b_t$

SEZIONE A T



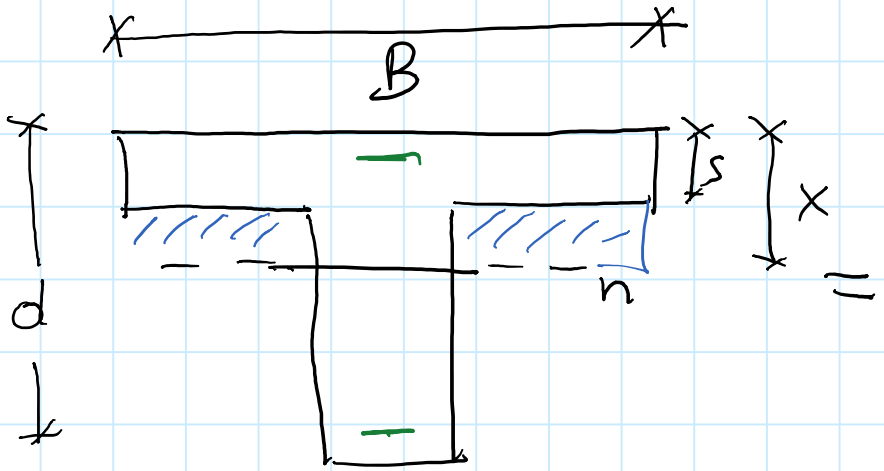
M

SUPPONGO $x \leq s$

⇒ APPLICO FORMULA SEZ. RETTANGOLARE

$$x = \psi d \left[-1 + \sqrt{1 + \frac{2 d G_S}{\psi d}} \right]$$

Se $x > s$ ⇒ SEZIONE A T



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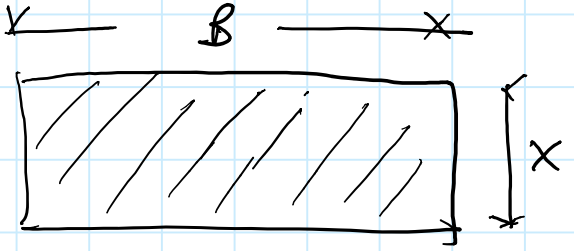

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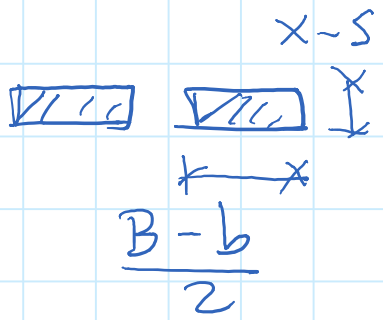
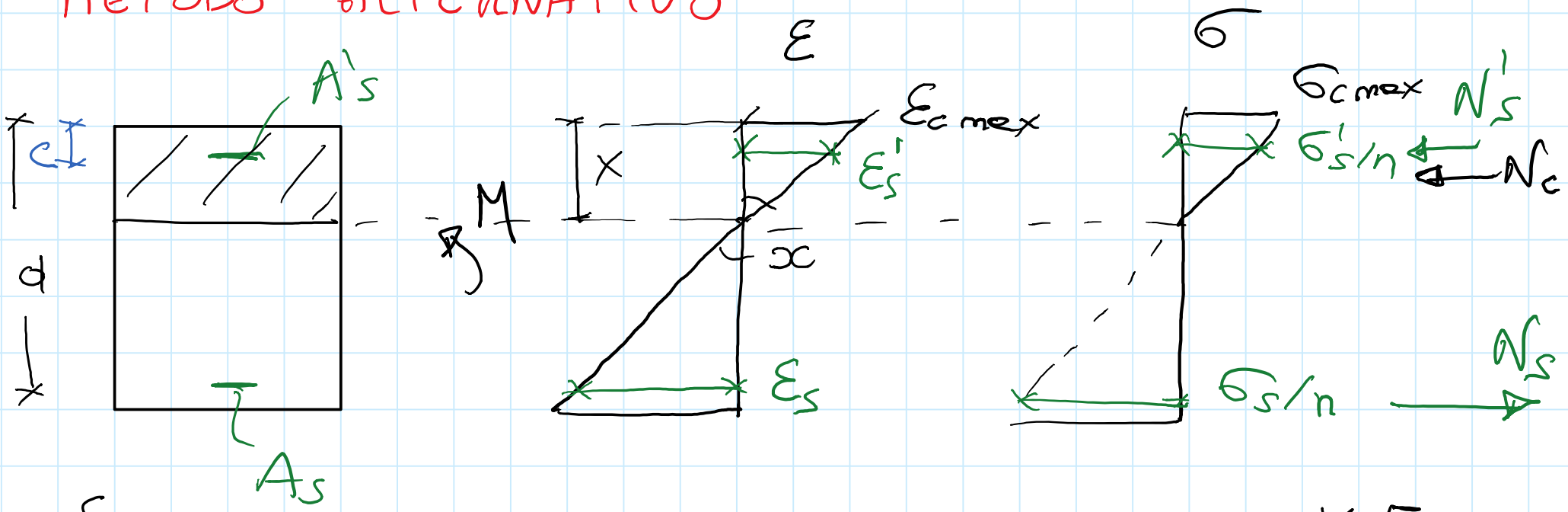


$S_{N=0}$

$$-Bx\frac{x}{2} + (B-b)\frac{(x-s)^2}{2} - nA'_s(x-c) + nA_s(d-x) = 0$$

METODO ALTERNATIVO



$$\varepsilon_{cmax} = -\chi X \rightarrow \sigma_{cmax} = E_c \varepsilon_{cmax} = -\chi X E_c$$

$$\varepsilon'_s = -\chi (X - c) \rightarrow \sigma'_s = E_s \varepsilon'_s = -n E_c \chi (X - c)$$

$$\varepsilon_s = \chi (d - X) \rightarrow \sigma_s = E_s \varepsilon_s = n E_c \cdot \chi (d - X)$$

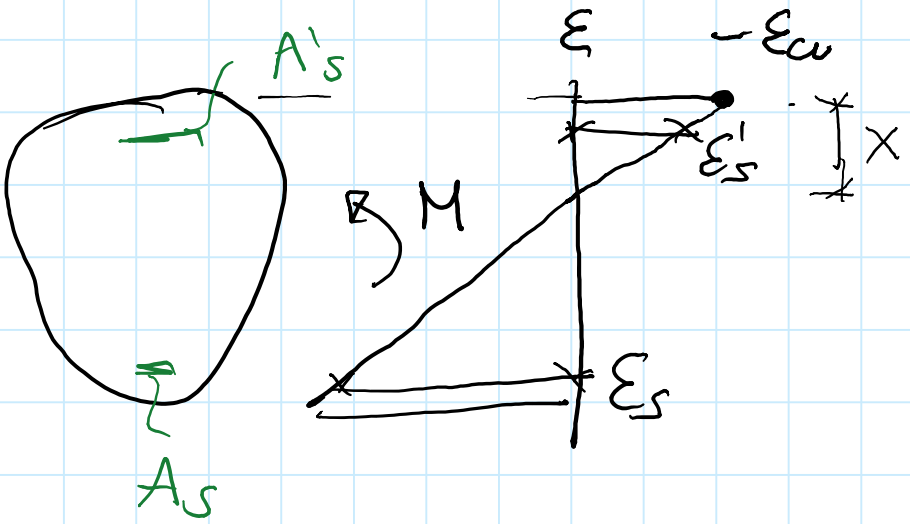
$$N_c = bx \cdot \frac{\sigma_{cmax}}{2} = -\chi E_c b \frac{X^2}{2}$$

$$N_s = \sigma_s A_s = \chi E_c \cdot n A_s (d - X)$$

$$N'_s = \sigma'_s A'_s = -\chi E_c n A'_s (X - c)$$

$$\boxed{N_c + N'_s + N_s = 0}$$

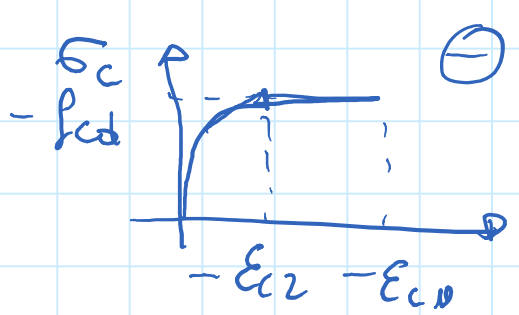
VERIFICA AL III STADIO (APPROCCIO GENERALE)

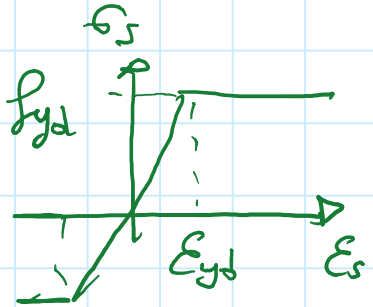


CALCOLARE

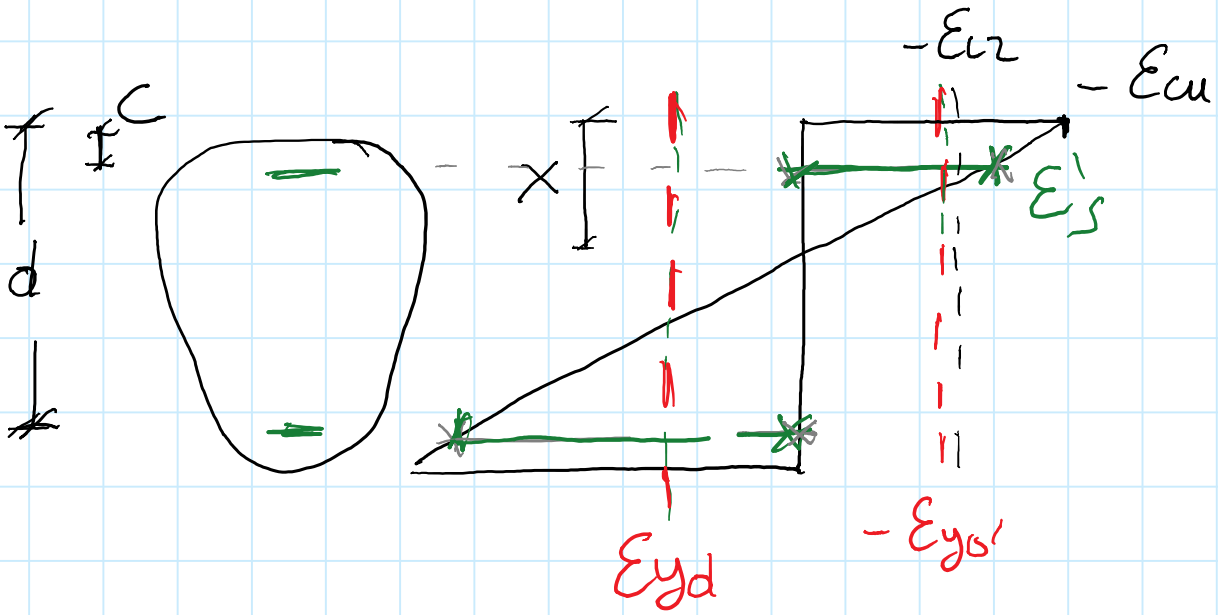
$M_{Rd} \geq M_{Ed}$

1. FISSO DIAGR. ε LIMITE $(\varepsilon = -\varepsilon_{cu})$
2. IPOTIZZO x
3. CALCOLO σ
4. CALCOLO N_c, N_s, N'_s
5. EQ. TRASLAZIONE $\rightarrow x$
6. EQ. ROTAZIONE $\rightarrow M_{Rd}$





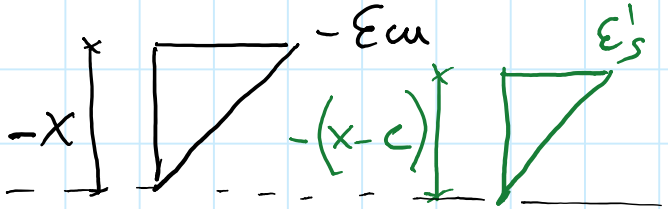
CALCOLO E ARMATURE



$\varepsilon_{cu} = 3.5\,‰$

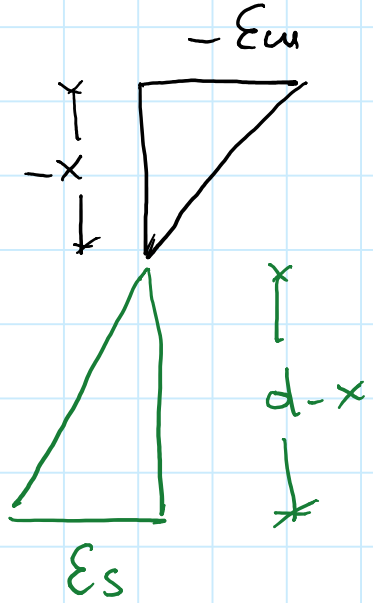
$\varepsilon_{c2} = 2{,}00\,‰$

$\varepsilon_{yd} = \dfrac{f_{yd}}{E_s} = 1.96\,‰$



$$-\varepsilon_{cu} : (-x) = \varepsilon'_s : [-(x-c)]$$

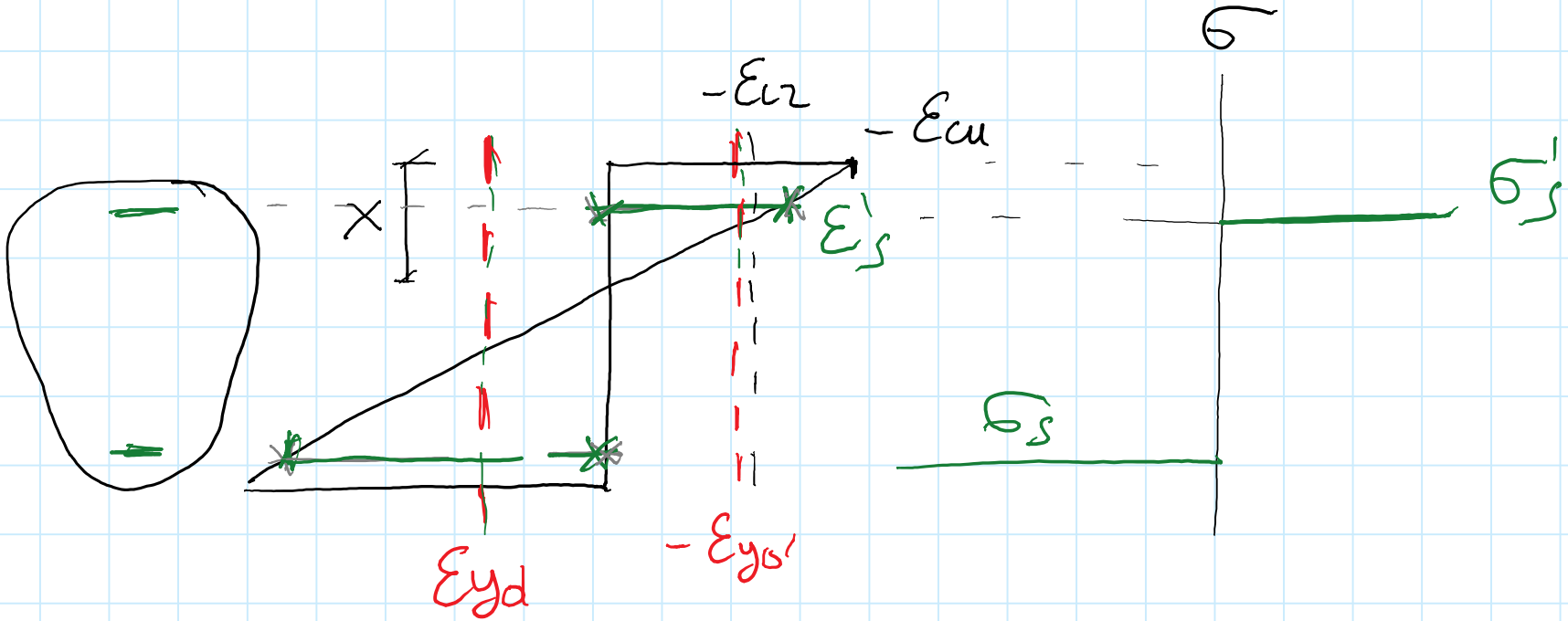
$$\varepsilon'_s = -\frac{\varepsilon_{cu}}{x}(x-c)$$

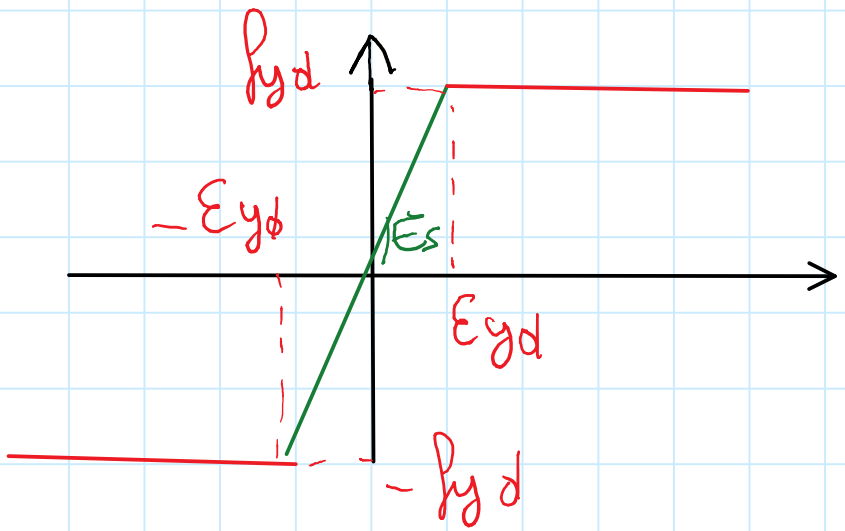


$$-\varepsilon_{cu} : (-x) = \varepsilon_s : (d-x)$$

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

TENSIONI NELL'ARMATURA



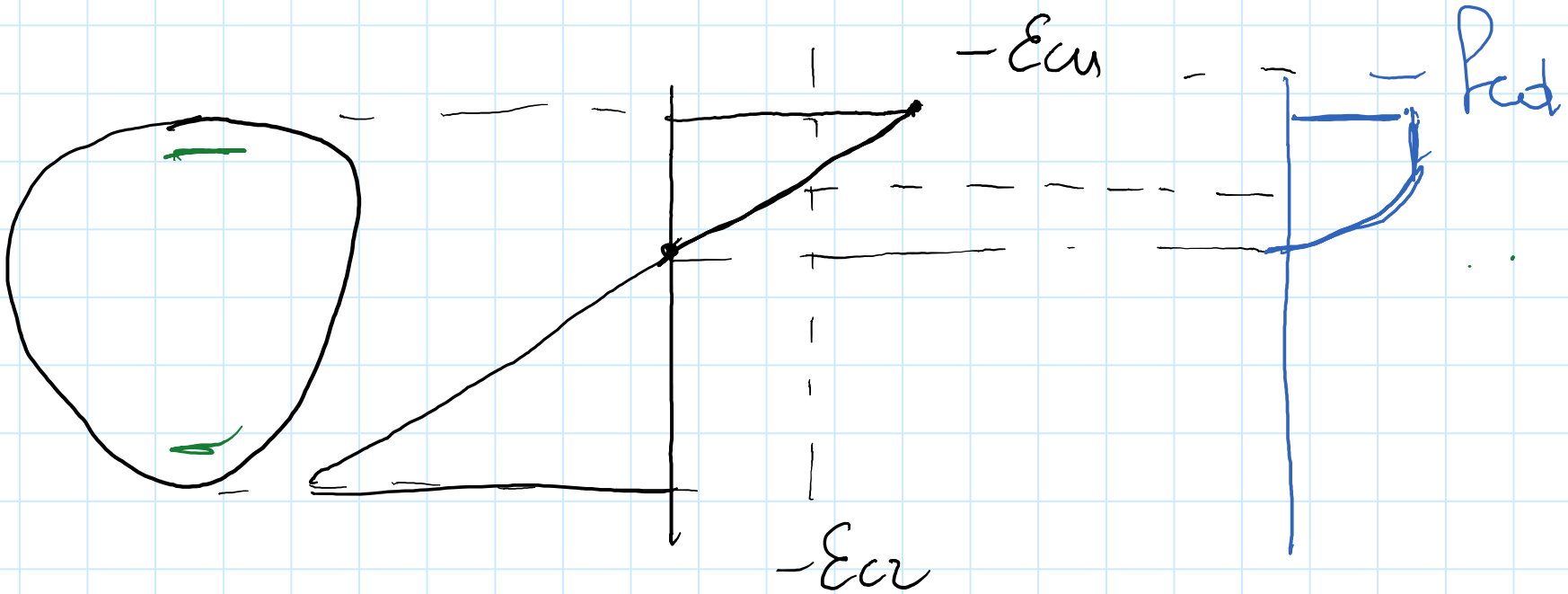


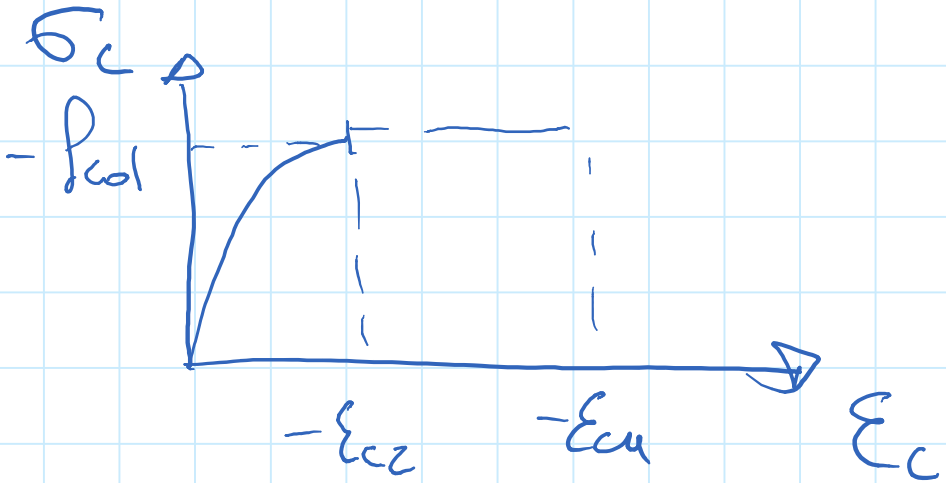
se $\varepsilon_s \geq \varepsilon_{yd} \rightarrow \sigma_s = f_{yd}$

se $-\varepsilon_{yd} < \varepsilon_s < \varepsilon_{yd} \rightarrow \sigma_s = E_s \varepsilon_s$

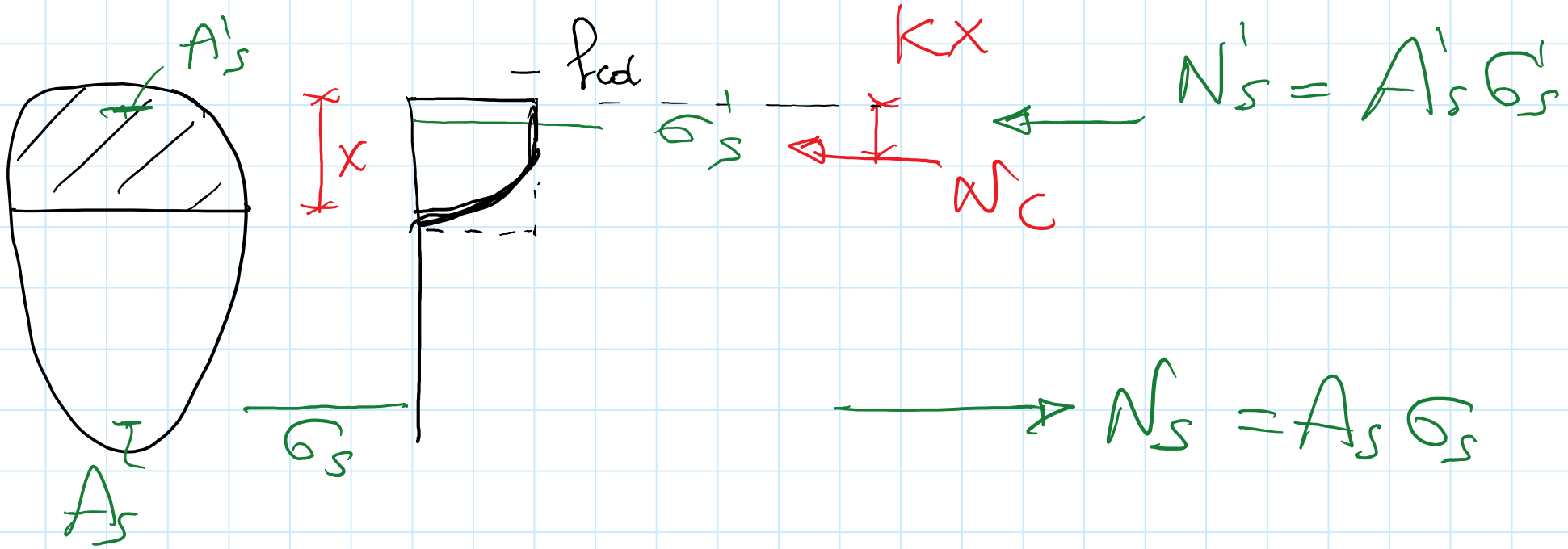
se $\varepsilon_s < -\varepsilon_{yd} \rightarrow \sigma_s = -f_{yd}$

TENSIONI NEL CALCESTRUZZO





CALCOLO RISULTANTI



$$N_c = \int_{A_c} \sigma \, dA = -\beta f_{cd} A_c$$

β = COEFF. DI RIEMPIMENTO $= \dfrac{\int \sigma \, dA_c}{-f_{cd} A_c}$

k = COEFF. DI PROFONDITÀ