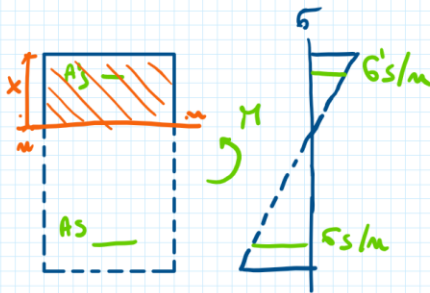


II STADIO

$$\sigma_c \leq 0.45 f_{ck} \quad (\text{COMB. QUASI PERMANENTE})$$

$$\left. \begin{array}{l} \sigma_c \leq 0.6 f_{ck} \\ \sigma_s \leq 0.8 f_{yk} \end{array} \right\} \text{COMB. RARA}$$

$$\sigma = \frac{M}{I_x} y \quad \text{SEZ. REAGENTE OMogeneizzata}$$

PROCEDIMENTO

1) Determinare asse neutro $\Rightarrow x$

$$S_m(x) = 0 \Rightarrow x$$

2) calcolare I_m



$$y_c = -x$$

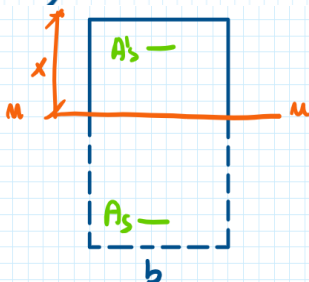
$$y_s = d - x$$

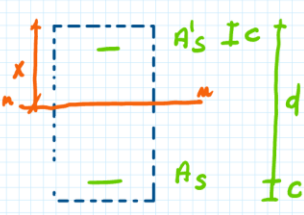
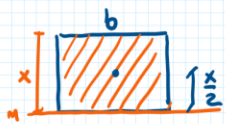
$$3) \quad \sigma_c = \frac{M}{I_m} y_c$$

$$\sigma_s = m \frac{M}{I_m} y_s$$

1) DETERMINARE L'ASSE NEUTRO $\Rightarrow x$

$$S_m(x) = 0$$



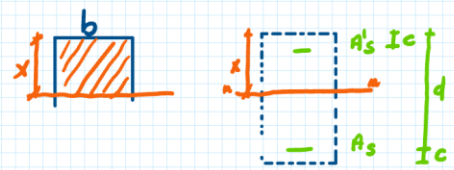
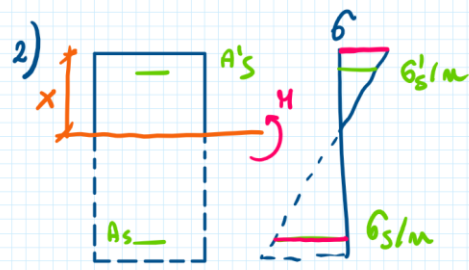


$$b x \left(-\frac{x}{2}\right) - n A'_S (x-c) + n A_S (d-x) = 0$$

$$-\frac{b}{2} x^2 - n A'_S x + n A'_S c + n A_S d - n A_S x = 0$$

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

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



$$I_u = \frac{b x^3}{3} + n A'_S (x-c)^2 + n A_S (d-x)^2$$

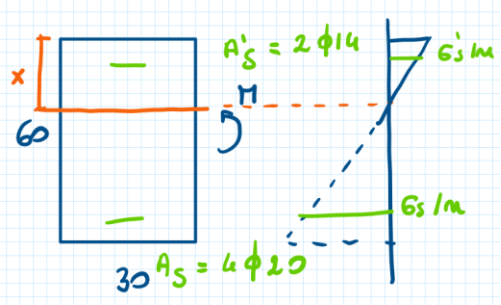
$$y_c = -x$$

$$y_s = d-x$$

$$3) \sigma_c = \frac{M}{I_u} y_c$$

$$\sigma_s = n \frac{M}{I_u} y_s$$

ESEMPIO



$$M = 70 \text{ kNm}$$

$$c = 5 \text{ cm}$$

$$A_{1\phi14} = 1.54 \text{ cm}^2$$

$$d = 60 - 5 = 55 \text{ cm}$$

$$A_{1\phi20} = 3.14 \text{ cm}^2$$

CARICHI COMB. RARA

II STADIO \Rightarrow VER. TENSIONI IN ESERCIZIO

$$\sigma_c \leq 0.6 f_{ck}$$

$$\sigma_s \leq 0.8 f_{yk} \Rightarrow \sigma = \frac{M}{I_u} y$$

1) DETERMINO x

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

$n = 15$ per calce di lunga durata

$$\frac{30}{2} x^2 + 15 (2 \times 1.54 + 4 \times 3.14) x - 15 (2 \times 1.54 \times 5 + 4 \times 3.14 \times 55) = 0$$

$$15 x^2 + 234.7 x - 10593 = 0$$

$$x = \frac{-234.7 \pm \sqrt{234.7^2 + (4 \times 15 \times 10593)}}{2 \times 15}$$

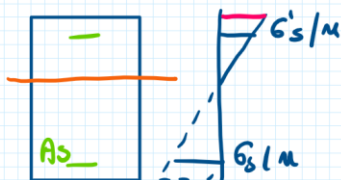
(-) NON È ACCETTABILE
(m deve tagliare la sezione)

(+) $x = 19.9 \text{ cm}$

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

$$I_n = \frac{30}{3} 19.9^3 + 15 \times 2 \times 1.54 (19.9 - 5)^2 + 15 \times 4 \times 3.14 (55 - 19.9)^2$$

$$I_n = 78806.0 + 10256.36 + 232110.7 = 321173 \text{ cm}^4$$



$$y_c = -19.9 \text{ cm}$$

$$y_s = 55 - 19.9 = 35.1 \text{ cm}$$

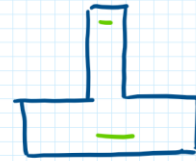
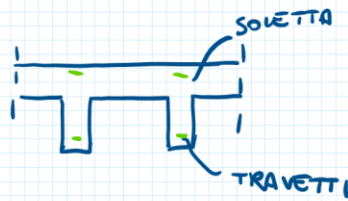
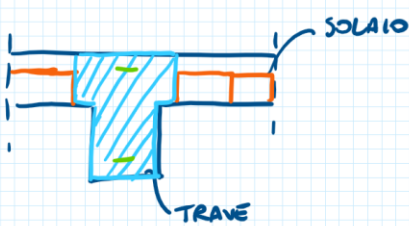
$$3) \sigma_c = \frac{70}{321173} \cdot (-19.9) \times 10^3 = -4.34 \text{ MPa}$$

$$4.34 < 0.6 f_{ck} = 15 \text{ OK!}$$

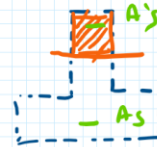
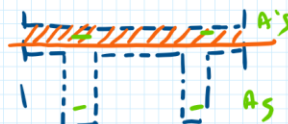
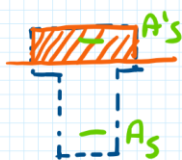
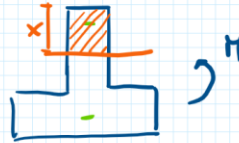
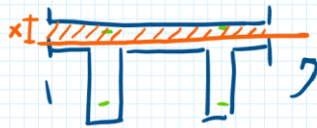
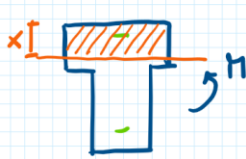
$$\sigma_s = 15 \left(\frac{70}{321173} \times 35.1 \right) \times 10^3 = 114.75 \text{ MPa}$$

$$114.75 < 0.8 f_{yk} = 360 \text{ MPa OK!}$$

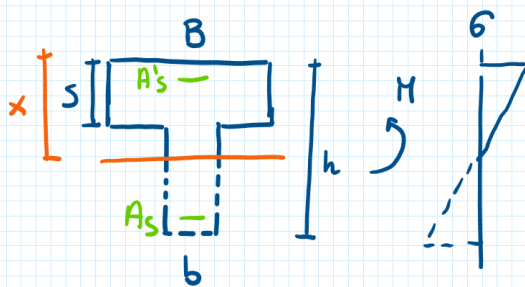
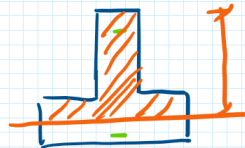
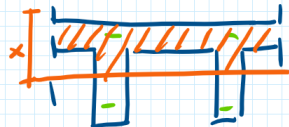
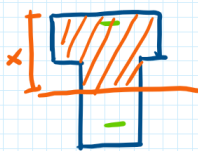
SEZIONI DIVERSE DALLA SEZIONE RETTANGOLARE



• sezioni riconducibili a quella rettangolare



• sez. non rettangolari



$$\sigma_c \leq 0.45 f_{ck}$$

$$\sigma_c \leq 0.6 f_{cr}$$

$$\sigma_s \leq 0.3 f_{yk}$$

$$\sigma = \frac{M}{I_n} y$$

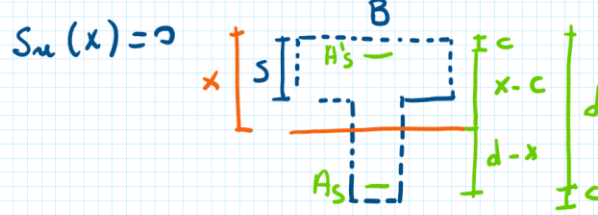
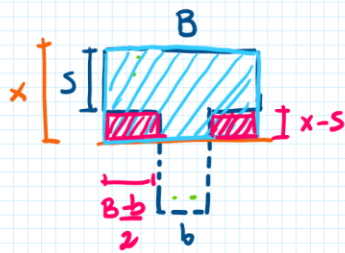
1) DET. ASSE NEUTRO $\Rightarrow x$

$$\Rightarrow S_n(x) = 0$$

2) I_n , y_s , y_c

3) σ_c
 σ_s

1) DETERMINO x



$$S_m(x) = 0$$

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

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

$$-\frac{B}{2}x^2 + \left(\frac{B-b}{2}\right)(x^2 + s^2 - 2xs) - nA'_sx + nA'_sc + nA_sd - nA_sx = 0$$

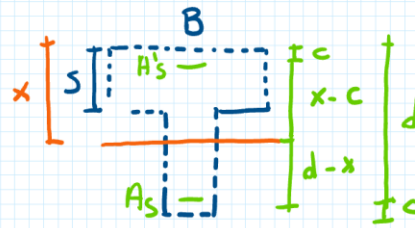
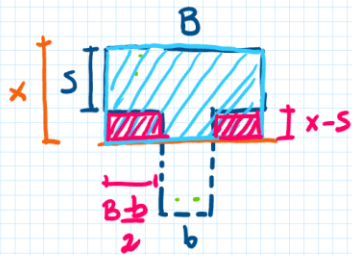
$$-\cancel{\frac{B}{2}x^2} + \cancel{\frac{B}{2}x^2} + \frac{B}{2}s^2 - \frac{B}{2}x \times s - \frac{b}{2}x^2 - \frac{b}{2}s^2 + \frac{b}{2}x \times s - nA'_sx + nA'_sc + nA_sd - nA_sx = 0$$

$$-\frac{b}{2}x^2 + \left[(b-B)s - n(A'_s + A_s) \right] x + (B-b)\frac{s^2}{2} + n(A'_sc + A_sd) = 0$$

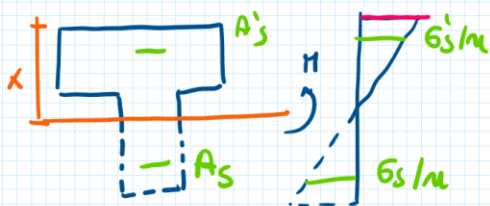
$$\frac{b}{2}x^2 + \left[(B-b)s + n(A'_s + A_s) \right] x - \left[(B-b)\frac{s^2}{2} + n(A'_sc + A_sd) \right] = 0$$

↳ EQ. 2° GRADO $\Rightarrow x$

2) DETERMINO I_m , y_c , y_s



$$I_m = \frac{Bx^3}{3} - 2 \left[\left(\frac{B-b}{2} \right) \left(\frac{x-s}{3} \right)^3 \right] + nA'_s(x-c)^2 + nA_s(d-x)^2$$



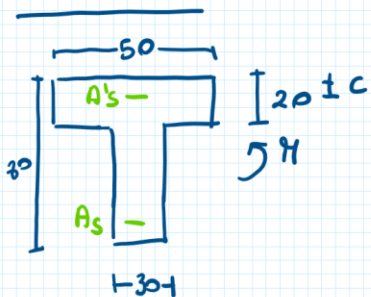
$$y_c = -x$$

$$y_s = d-x$$

3) $\sigma_c = \frac{M}{I_m} y_c \leq 0.6 f_{ck}$ (oppure $0.45 f_{ck}$)

$$\sigma_s = n \frac{M}{I_m} y_s \leq 0.8 f_{yk}$$

ESEMPIO



$$A'_s = 2\phi 14$$

$$A_s = 6\phi 20$$

$$c = 5 \text{ cm}$$

$$d = 80 - 5 = 75 \text{ cm}$$

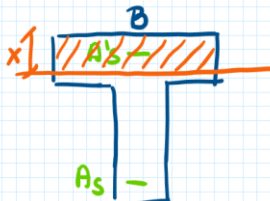
$$M = 180 \text{ kNm}$$

CARICHI DI LUNGA DURATA

CARICHI COMB. RARA

VER. TENSIONI IN ESERCIZIO

• IPOTIZZO ASSE NEUTRO TAGLI LA FLANGIA \Rightarrow SEZ. RETTANGOLARE



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

$$\frac{50}{2} x^2 + 15 (2 \times 1.54 + 6 \times 3.14) x - 15 (2 \times 1.54 \times 5 + 6 \times 3.14 \times 75) = 0$$

$$25 x^2 + 328.8 x - 21426 = 0$$

$$x = \frac{-328.8 \pm \sqrt{328.8^2 + 4 \times 25 \times 21426}}{2 \times 25} = \begin{cases} (-) \text{ NON ACCETTABILE} \\ (+) x = 23.4 \text{ cm} \end{cases}$$

Poiché $x = 23.4 \text{ cm} > s = 20 \text{ cm} \Rightarrow$ asse neutro sta al di sotto della flangia



Ripeto il calcolo di x per sezione non rettangolare

• CALCOLO x PER SEZIONI NON RETTANGOLARI

$$\frac{b}{2} x^2 + \left[(B-b)s + n(A'_S + A_S) \right] x - \left[(B-b) \frac{s^2}{2} + n(A'_S c + A_S d) \right] = 0$$

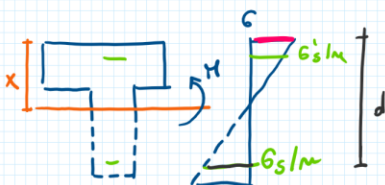
$$\frac{30}{2} x^2 + \left[(50-30)20 + 15(2 \times 1.54 + 6 \times 3.14) \right] x - \left[(50-30) \frac{20^2}{2} + 15(2 \times 1.54 \times 5 + 6 \times 3.14 \times 75) \right] = 0$$

$$15 x^2 + 728.8 x - 25426 = 0$$

$$x = \frac{-728.8 \pm \sqrt{728.8^2 + 4 \times 15 \times 25426}}{2 \times 15} = \begin{cases} (-) \\ (+) x = 23.5 \text{ cm} \end{cases}$$

$$2) I_M = \frac{b x^3}{3} - 2 \left[\left(\frac{B-b}{2} \right) \left(\frac{x-s}{3} \right)^3 \right] + n A'_S (x-c)^2 + n A_S (d-x)^2$$

$$I_M = 50 \times \frac{23.5^3}{3} - 2 \left[\left(\frac{50-30}{2} \right) \left(\frac{23.5-20}{3} \right)^3 \right] + 15 \times 2 \times 1.54 (23.5-5)^2 + 15 \times 6 \times 3.14 (75-23.5)^2 = 921349.8 \text{ cm}^4$$



$$y_c = -x$$

$$y_s = d-x$$

$$3) \quad \sigma_c = \frac{180}{931349.8} (-23.5) \times 10^3 = -4.3 \text{ MPa}$$

$$|4.3| < 0.6 f_{ck} = 15 \text{ MPa} \quad \underline{\text{OK!}}$$

$$\sigma_s = 15 \frac{180}{931349.8} (75 - 23.5) \times 10^3 = 141.7 \text{ MPa}$$

$$141.7 \leq 0.8 f_{yk} = 360 \text{ MPa} \quad \underline{\text{OK!}}$$