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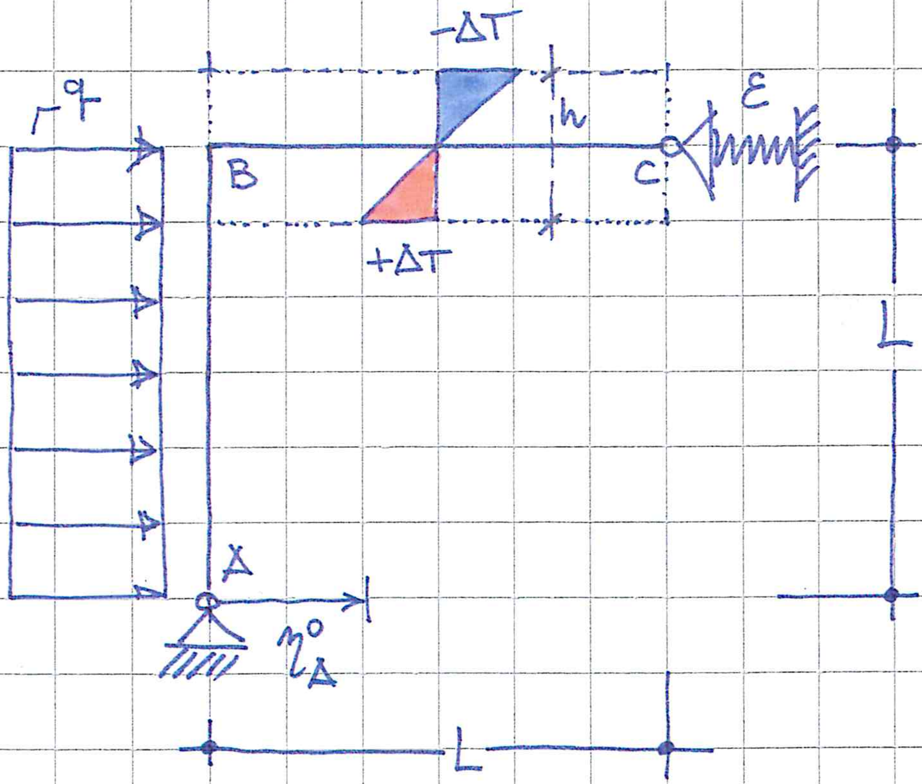
A.PISANO

MECCANICA delle STRUTTURE - P.FUSCHI - A.A. 2016-17

TEST IN ITINERE del 12 GENNAIO 2017

RISOLVERE LA STRUTTURA UNA VOLTA IPERSTATICA SEGUENTE.
TRACCIARE IL DIAGRAMMA DEL MOMENTO TENENDO CONTO DELLE POSIZIONI RIPORTATE IN FIGURA.



POSIZIONI:

$$|\varepsilon| = \frac{L^3}{3EI}$$

$$|\eta^0_A| = \frac{qL^4}{EI}$$

$$\left|\frac{\alpha \Delta T}{h}\right| = \frac{qL^2}{EI}$$

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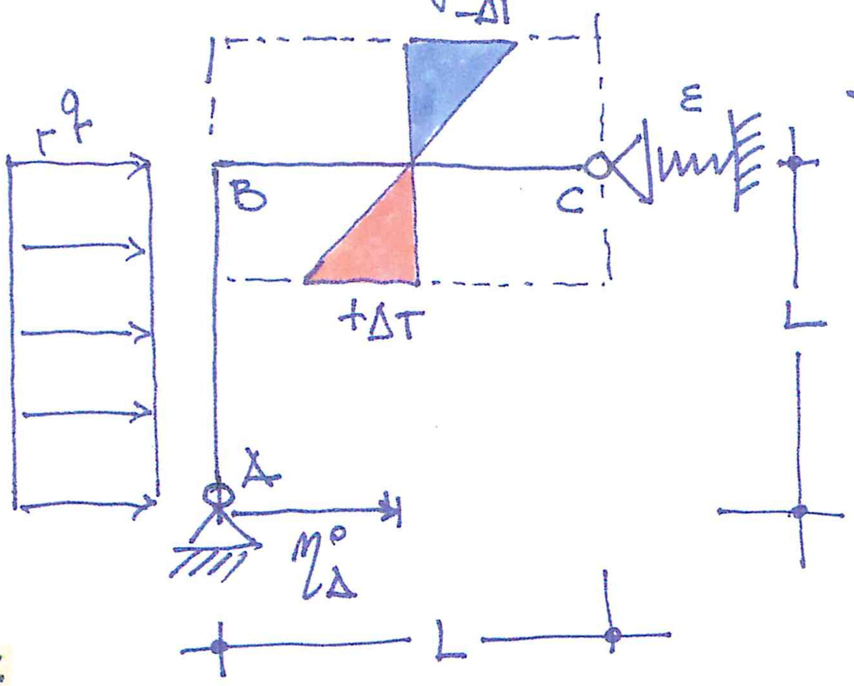
Risolvere la struttura una volta iperstatica riportata nella figura seguente tracciando il diagramma dei momenti.



Posizioni:

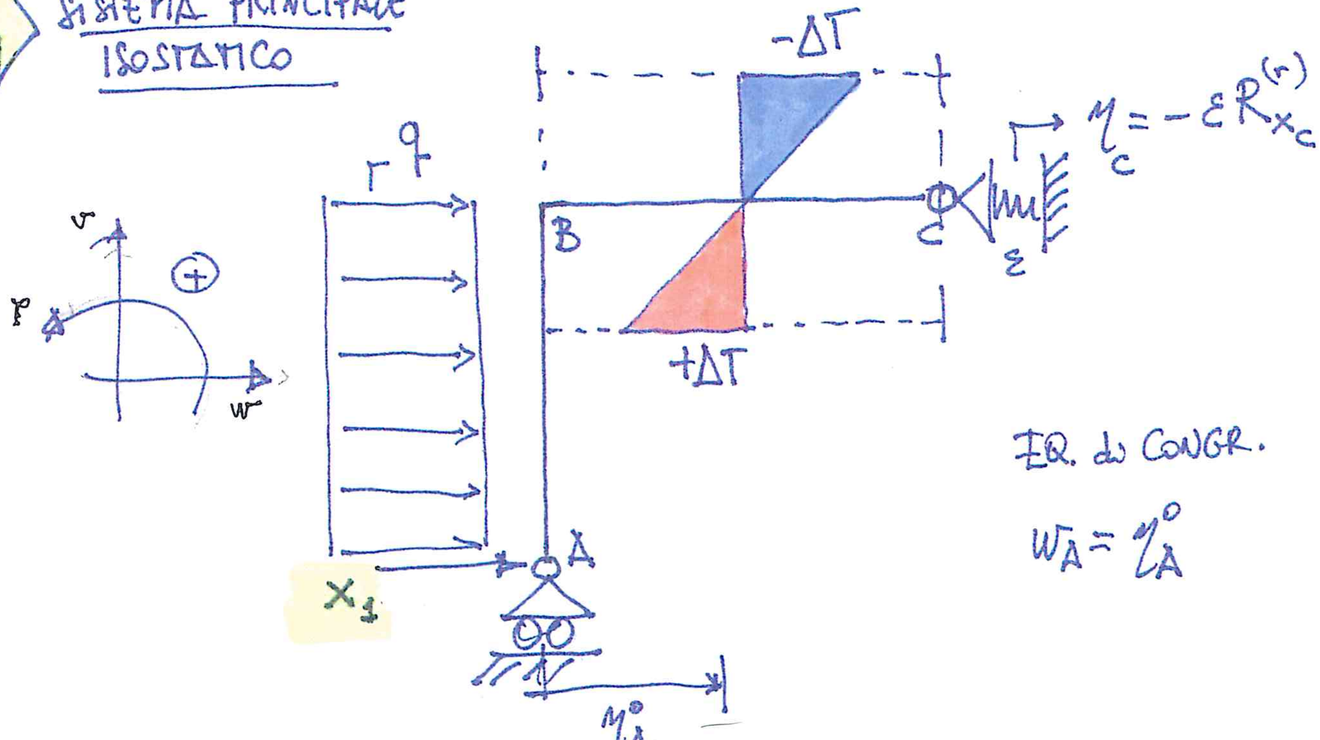
$$|\varepsilon| = \frac{L^3}{3EI}$$

$$|\eta_A^0| = \frac{qL^4}{EI}$$

$$\left|\frac{\alpha\,\Delta T}{h}\right| = \frac{qL^2}{EI}$$

SOLUZIONE n. 1

SISTEMA PRINCIPALE ISOSTATICO



EQ. di CONGR.

$$w_A = \eta_A^0$$

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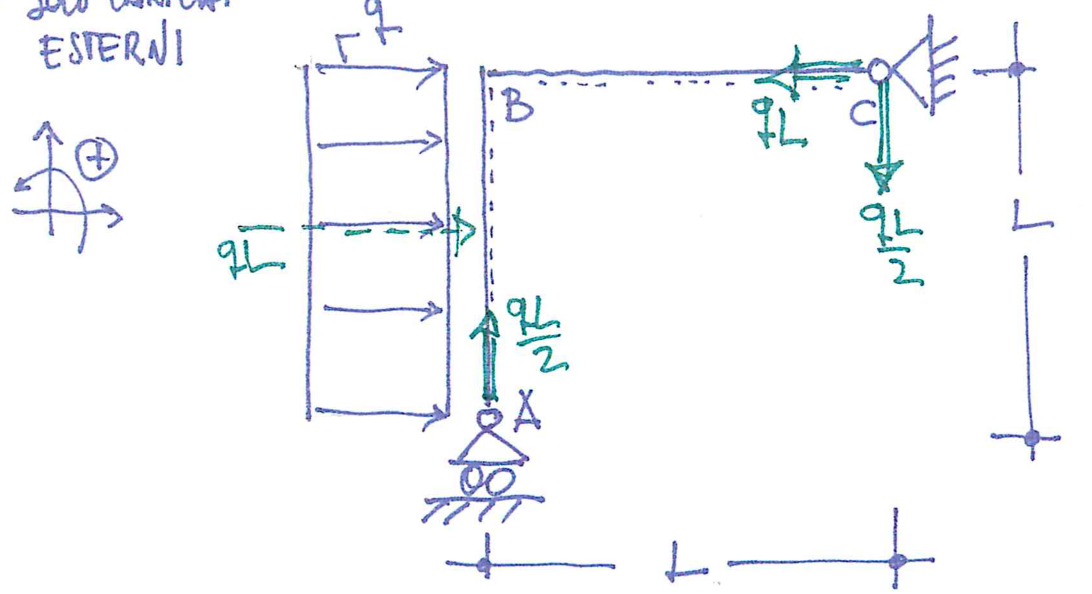
SCHEMA [0]
SOLO CARICHI ESTERNI



RV con metodo grafico!

Calcoliamo $M^{(0)}(z)$:

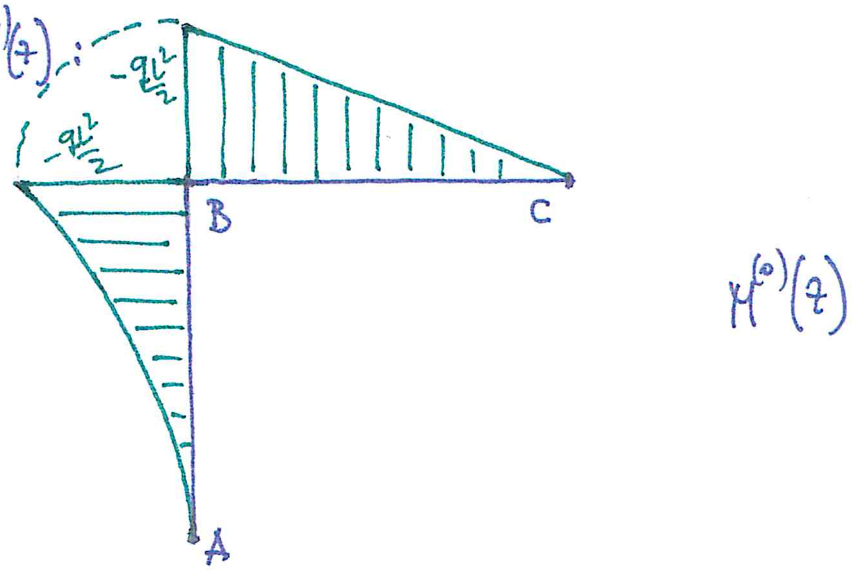
TRATTO AB $\quad 0 \le z \le L$

$$\boxed{M^{(0)}(z) = -\frac{q z^2}{2}} \qquad \begin{cases} M_A = \phi \\ M_B = -\frac{qL^2}{2} \end{cases}$$

TRATTO BC $\quad 0 \le z \le L$

$$\boxed{M^{(0)}(z) = -\frac{qL}{2}\left[L - z\right]} \qquad \begin{cases} M_B = -\frac{qL^2}{2} \\ M_C = \phi \end{cases}$$

Diagramma $M^{(0)}(z)$:



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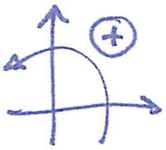
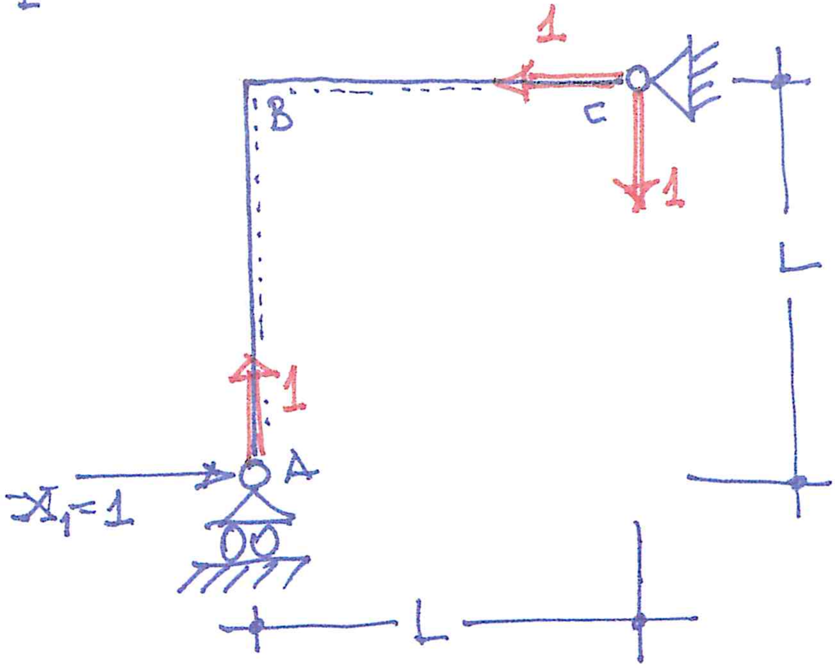
SCHEMA [1]

Solo $X_1 = 1$

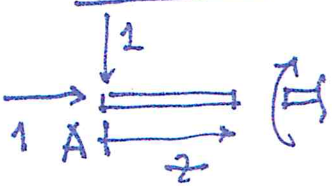




RV con metodo grafico!

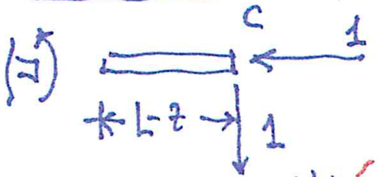
Calcoliamo $M^{(1)}(z)$:

TRATTO AB $0 \le z \le L$



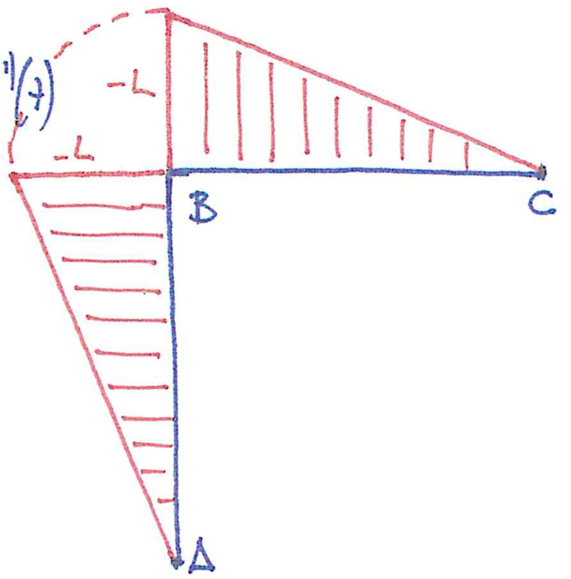
$$\boxed{M^{(1)}(z) = -z} \qquad \begin{cases} M_A = \phi \\ M_B = -L \end{cases}$$

TRATTO BC $0 \le z \le L$



$$\boxed{M^{(1)}(z) = z - L} \qquad \begin{cases} M_B = -L \\ M_C = \phi \end{cases}$$

Diagramma $M^{(1)}(z)$



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L'unica equazione di Müller-Breslau, corrispondente all'unica incognita iperstatica X_1, si scrive nella forma $L_{ve}=L_{vi}$ assumendo come sistema lavorante o fittizio lo schema [1] e come sistema reale la struttura iperstatica data. Si ha:

$$L_{ve} = \overset{X_i^{(f)}=1}{\overset{\|}{1}} \cdot \eta_i^{(r)} + \sum_j R_j^{(f)} \eta_j^{(r)} =$$

$$= 1\cdot \eta_A^0 + \underbrace{R_{x_C}^{(1)}}_{-1} \, \underbrace{\eta_C^{(r)}}_{-\varepsilon \underbrace{R_{x_C}^{(r)}}_{\underbrace{R_{x_C}^{(0)}+R_{x_C}^{(1)}X_1}_{[-qL-X_1]}}} =$$

$$= \eta_A^0 - \varepsilon\left[qL+X_1\right]$$

$$L_{vi} = \int_{Str} M^{(f)} \frac{M^{(r)}}{EI}\, dStr + \int_{Str} \underbrace{M^{(f)}}_{<0} \underbrace{\frac{\alpha\Delta T}{h}}_{>0}\, dStr =$$

↳ con $M^{(r)} = M^{(0)} + M^{(1)} X_1$

$$= \int_{Str} M^{(1)}\frac{M^{(0)}}{EI}\, dStr + X_1 \int_{Str} \frac{\left[M^{(1)}\right]^2}{EI}\, dStr. + \int_{Str} M^{(1)} \frac{\alpha\Delta T}{h}\, dStr =$$

$$= \frac{1}{EI}\left[\int_{\overline{AB}} [-z]\left[-\frac{qz^2}{2}\right]dz + \int_{\overline{BC}} [z-L]\left[-\frac{qL}{2}[L-z]\right]dz\right] +$$

$$+ \frac{X_1}{EI}\left[\int_{\overline{AB}} z^2\,dz + \int_{\overline{BC}} (z-L)^2\,dz\right] + \int_{\overline{BC}} [z-L]\,\alpha\frac{\overline{\Delta T}}{h}\,dz =$$

$$= \frac{1}{EI}\left[\int_0^L \frac{qz^3}{2}\,dz + \int_0^L \frac{qL}{2}\overbrace{(z-L)^2}^{z^2+L^2-2Lz}\,dz\right] +$$

$$+ \frac{X_1}{EI}\left[\int_0^L z^2\,dz + \int_0^L (z^2+L^2-2zL)\,dz\right] + \alpha\frac{\overline{\Delta T}}{h}\int_0^L (z-L)\,dz =$$

$$= \frac{1}{EI}\left[\frac{q}{2}\left[\frac{z^4}{4}\right]_0^L + \frac{qL}{2}\left\{\left[\frac{z^3}{3}\right]_0^L + L^2[z]_0^L - \cancel{2}L\left[\frac{z^2}{\cancel{2}}\right]_0^L\right\}\right] +$$

$$+ \frac{X_1}{EI}\left[\left[\frac{z^3}{3}\right]_0^L + \left[\frac{z^3}{3}\right]_0^L + L^2[z]_0^L - \cancel{2}L\left[\frac{z^2}{\cancel{2}}\right]_0^L\right] + \alpha\frac{\overline{\Delta T}}{h}\left\{\left[\frac{z^2}{2}\right]_0^L - L[z]_0^L\right\} =$$

$$= \frac{1}{EI}\left[\frac{qL^4}{8} + \frac{qL^4}{6} + \cancel{\frac{qL^4}{2}} - \cancel{\frac{qL^4}{2}}\right] +$$

$$+ \frac{X_1}{EI}\left[\frac{L^3}{3} + \frac{L^3}{3} + \cancel{L^3} - \cancel{L^3}\right] + \alpha\frac{\overline{\Delta T}}{h}\underbrace{\left[\frac{L^2}{2} - L^2\right]}_{-\frac{L^2}{2}} =$$

$$= \frac{7}{24}\frac{qL^4}{EI} + \frac{2}{3}\frac{X_1 L^3}{EI} - \frac{\alpha\overline{\Delta T}}{h}\frac{L^2}{2}$$

In definitiva $L_{ve} = L_{vi}$ fornisce:

$$\mathcal{M}_A^0 - \varepsilon qL - \varepsilon X_1 = \frac{7}{24}\frac{qL^4}{EI} + \frac{2}{3}\frac{L^3}{EI}X_1 - \alpha\frac{\overline{\Delta T}}{h}\frac{L^2}{2}$$

e quindi:

$$X_1\left[\frac{2L^3}{3EI} + \varepsilon\right] = \mathcal{M}_A^0 - \varepsilon qL - \frac{7}{24}\frac{qL^4}{EI} + \alpha\frac{\overline{\Delta T}}{h}\frac{L^2}{2}$$

VI

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Tenendo conto delle posizioni iniziali, che permettono di esprimere tutto in funzione di q, L ed EI e cioè:

$$|\varepsilon| = \frac{L^3}{3EI} \; ; \quad |\eta_A^0| = \frac{qL^4}{EI} \; ; \quad \left|\frac{\alpha \Delta T}{h}\right| = \frac{qL^2}{EI}$$

la X_1 può scriversi nella forma:

$$X_1 \underbrace{\left[\frac{2L^3}{3EI} + \frac{L^3}{3EI}\right]}_{\frac{\cancel{L^3}}{\cancel{EI}}} = \underbrace{\frac{qL^4}{EI} - \frac{qL^4}{3EI} - \frac{7}{24}\frac{qL^4}{EI} + \frac{qL^4}{2EI}}_{\frac{qL^{\cancel{4}}}{\cancel{EI}}\underbrace{\left[1 - \frac{1}{3} - \frac{7}{24} + \frac{1}{2}\right]}_{\frac{24-8-7+12}{24} = \frac{\cancel{21}\,7}{\cancel{24}\,8}}}$$

e in definitiva:

$$X_1 = \frac{7}{8} qL \quad \text{POSITIVA}$$

VERSO IPOTIZZATO CORRETTO!

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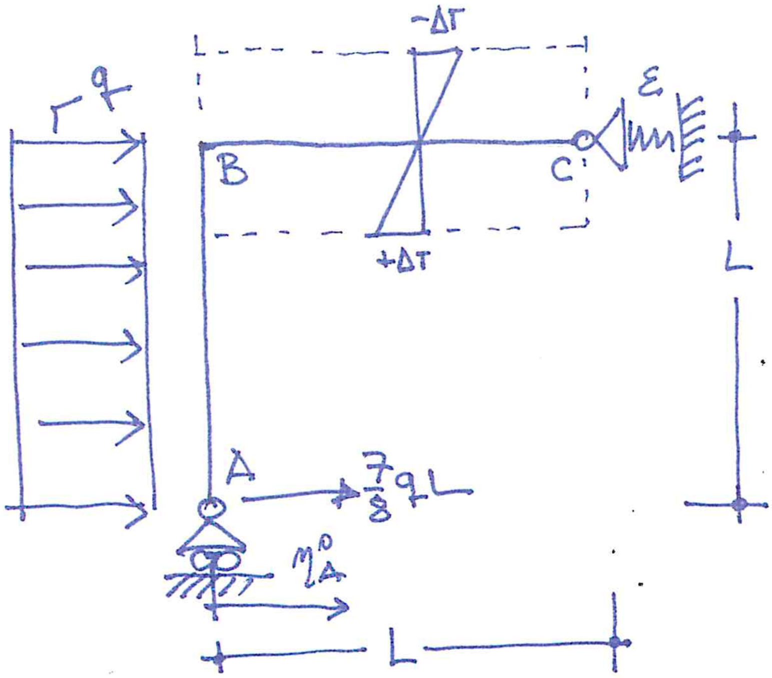
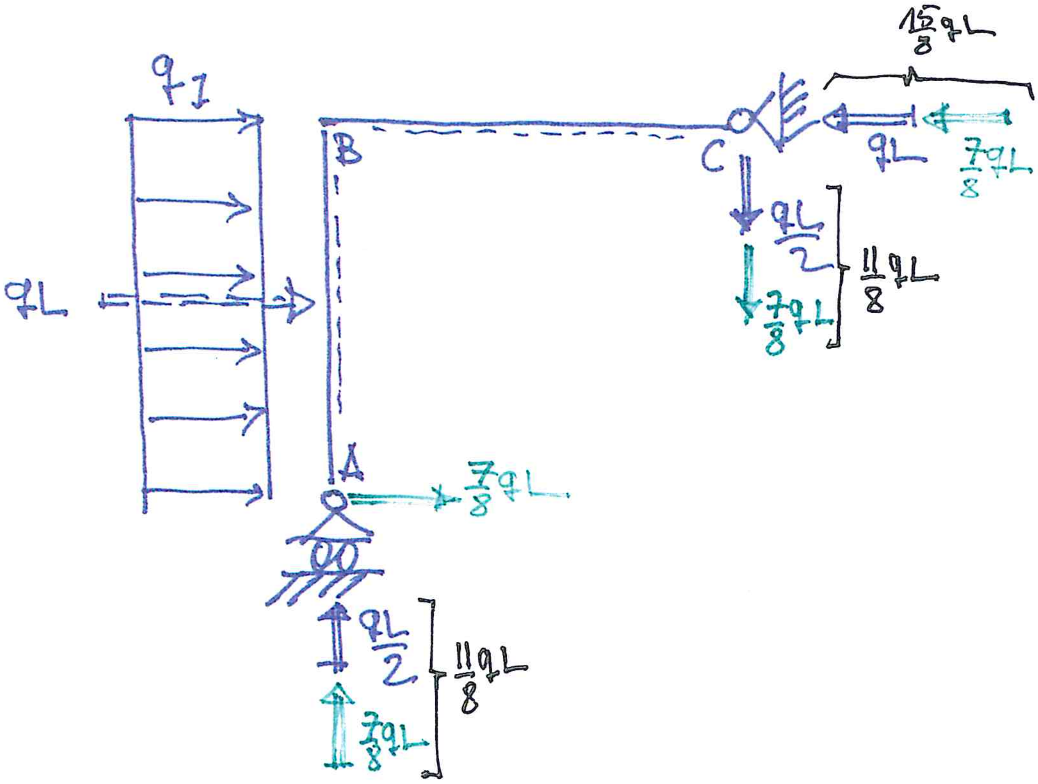
Il diagramma dei momenti sulla struttura iperstatica assegnata potrà determinarsi sul sistema principale isostatico soggetto ai carichi assegnati e alla $X_1 = \frac{7}{8} qL$ prima determinata. Si ha:



Rem.: Cedimenti e distorsioni possono manifestarsi liberamente in questo schema isostatico!

Si determinano le RV per via grafica applicando il principio di sovrapposizione degli effetti e, a seguire, la legge del momento $M^{(r)}(z)$.



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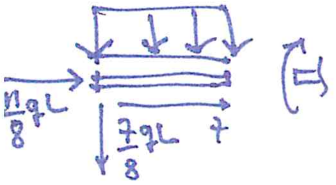
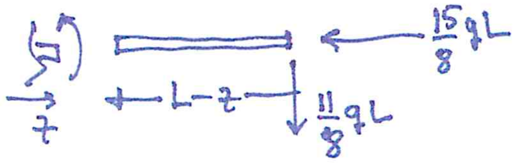
Leggi di $M^{(r)}(z)$ e diagrammi:

TRATTO AB $\quad 0 \le z \le L$



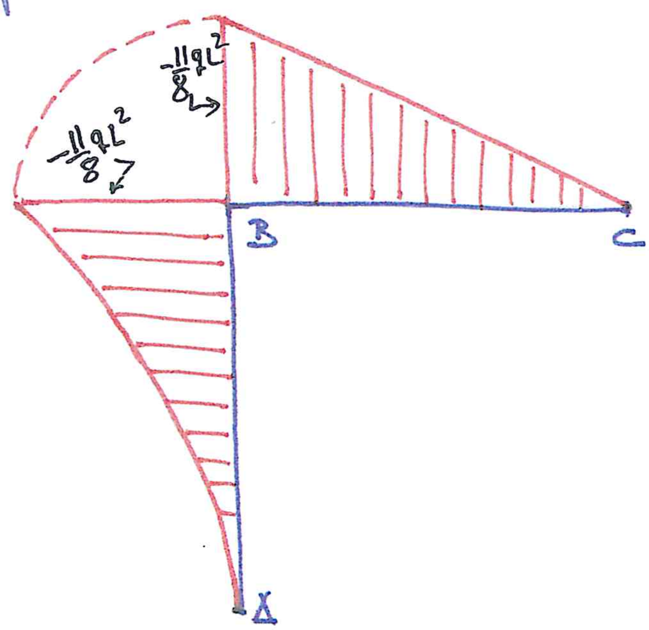
$$M^{(r)}(z) = -\frac{7}{8}qLz - \frac{qz^2}{2} \quad \begin{cases} M_A = 0 \\ M_B = -\frac{7}{8}qL^2 - \frac{qL^2}{2} = -\frac{11}{8}qL^2 \end{cases}$$

TRATTO BC $\quad 0 \le z \le L$



$$M^{(r)}(z) = -\frac{11}{8}qL(L-z) \quad \begin{cases} M_B = -\frac{11}{8}qL^2 \\ M_C = 0 \end{cases}$$

Si ha in definitiva:



SOLUZIONE 2

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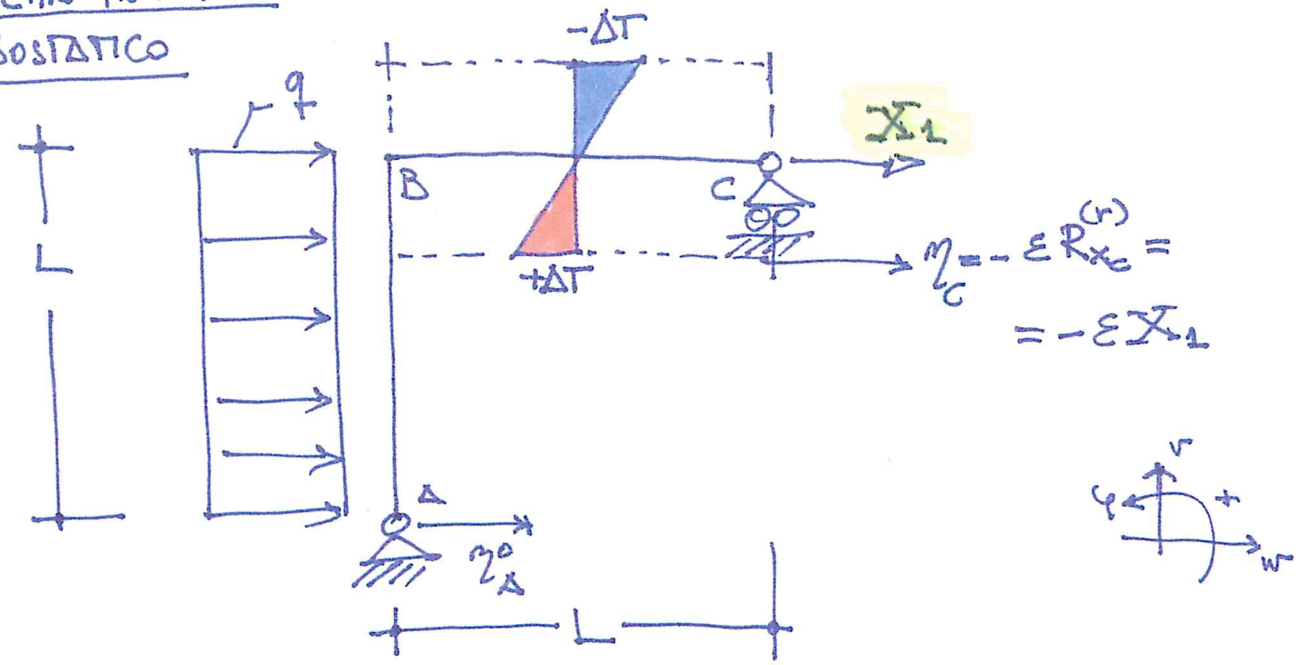
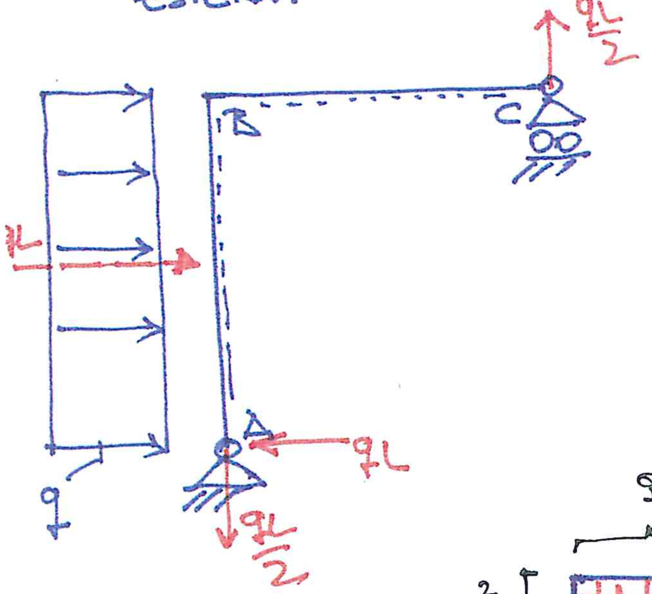
⇨ SISTEMA PRINCIPALE ISOSTATICO



$$\eta_C = -\varepsilon R^{(r)}_{x_C} = -\varepsilon X_1$$

⇨ SCHEMA [0] SOLO CARICHI ESTERNI



TRATTO AB $0 \le z \le L$

$$\boxed{M^{(0)}(z) = qLz - \frac{qz^2}{2}}$$

$M_A = 0$

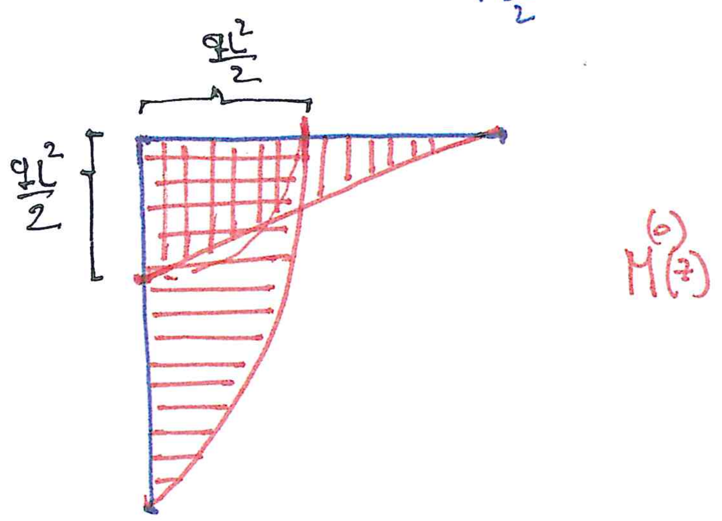
$M_B = \frac{qL^2}{2}$

TRATTO BC $0 \le z \le L$

$$\boxed{M^{(0)}(z) = \frac{qL}{2}(L-z)}$$

$M_B = \frac{qL^2}{2}$

$M_C = \emptyset$



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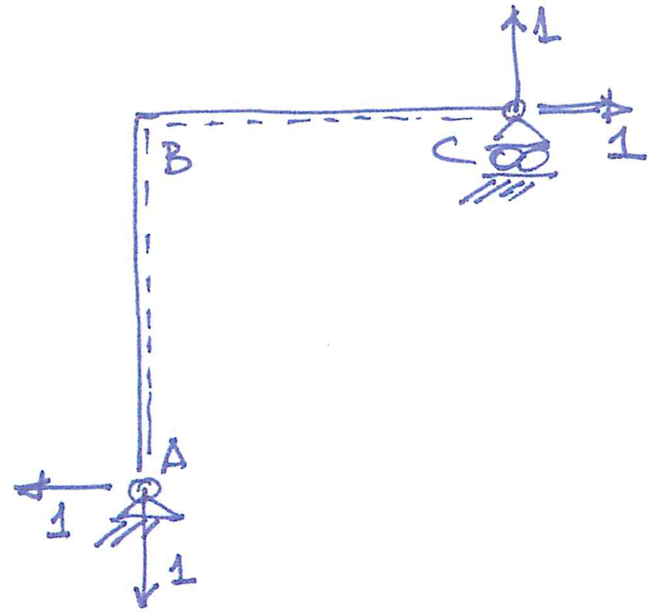
X

SCHEMA [1]

Solo $X_1 = 1$

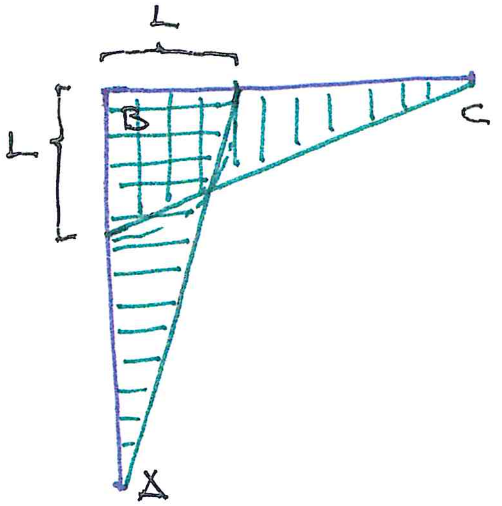


TRATTO AB $0 \le z \le L$

$$\boxed{M^{(1)}(z) = z} \qquad \begin{cases} M_A = 0 \\ M_B = L \end{cases}$$

TRATTO BC $0 \le z \le L$

$$\boxed{M^{(1)}(z) = L - z} \qquad \begin{cases} M_B = L \\ M_C = \phi \end{cases}$$



$M^{(1)}(z)$

L'unica equazione di Müller-Breslau, corrispondente all'unica incognita iperstatica X_1, si scrive nella forma $L_{ve} = L_{vi}$ assumendo come sistema fittizio o lavorante lo schema [1] e come sistema reale la struttura iperstatica data. Si ha:

$$L_{ve} = X_i^{(f)} \cdot \eta_i^{(r)} + \sum_j R_j^{(f)} \eta_j^{(r)} = \underset{1}{X^{(1)}} \cdot \eta_C^{(r)} + R_{x_A} \eta_A^{0} =$$

$$= 1 \cdot (-\varepsilon X_1) + (-1) \eta_A^{0} = -\frac{X_1 L^3}{3EI} - \frac{qL^4}{EI}$$

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$$L_{vi} = \int_{Str} M^{(f)} \frac{M^{(r)}}{EI} ds_{tr} + \int_{Str} M^{(f)} \alpha \frac{\overline{\Delta T}}{h} ds_{tr} =$$

$$= \int_{Str} M^{(1)} \underbrace{\frac{M^{(r)}}{EI}}_{M^{(0)} + M^{(1)} X_1} ds_{tr} + \int_{Str} M^{(1)} \alpha \frac{\overline{\Delta T}}{h} ds_{tr} =$$

$$= \int_{Str} \frac{M^{(1)} M^{(0)}}{EI} ds_{tr} + X_1 \int_{Str} \frac{[M^{(1)}]^2}{EI} ds_{tr} + \int_{Str} M^{(1)} \frac{\alpha \overline{\Delta T}}{h} ds_{tr} =$$

$$\frac{qL}{2}(L-z)^2 \Rightarrow \frac{qL}{2}(L^2 + z^2 - 2zL)$$

$$= \frac{1}{EI}\left[\int_{\overline{AB}} z\left(qLz - \frac{qz^2}{2}\right) dz + \int_{\overline{BC}} \overbrace{(L-z)\left[\frac{qL}{2}(L-z)\right]} dz\right] +$$

$$+ \frac{X_1}{EI}\left[\int_{\overline{AB}} z^2 dz + \int_{\overline{BC}} (L-z)^2 dz\right] + \int_{\overline{BC}} (L-z) \frac{\alpha \overline{\Delta T}}{h} dz =$$

$$= \frac{1}{EI}\left\{\int_0^L \left[qLz^2 - \frac{qz^3}{2}\right] dz + \int_0^L \left[\frac{qL^3}{2} + \frac{qL}{2}z^2 - qL^2 z\right]\right\} +$$

$$+ \frac{X_1}{EI}\left\{\int_0^L z^2 dz + \int_0^L \left[L^2 + z^2 - 2Lz\right] dz\right\} + \frac{\alpha \overline{\Delta T}}{h} \int_0^L (L-z) dz =$$

$$= \frac{1}{EI}\left[qL\left[\frac{z^3}{3}\right]_0^L - \frac{q}{2}\left[\frac{z^4}{4}\right]_0^L + \frac{qL^3}{2}\left[z\right]_0^L + \frac{qL}{2}\left[\frac{z^3}{3}\right]_0^L - qL^2\left[\frac{z^2}{2}\right]_0^L\right] +$$

$$+ \frac{X_1}{EI}\left[\left[\frac{z^3}{3}\right]_0^L + L^2\left[z\right]_0^L + \left[\frac{z^3}{3}\right]_0^L - 2L\left[\frac{z^2}{2}\right]_0^L\right] + \frac{\alpha \overline{\Delta T}}{h}\left\{L\left[z\right]_0^L - \left[\frac{z^2}{2}\right]_0^L\right\} =$$

$$= \frac{1}{EI}\left[\frac{qL^4}{3} - \frac{qL^4}{8} + \cancel{\frac{qL^4}{2}} + \frac{qL^4}{6} - \cancel{\frac{qL^4}{2}}\right] +$$

$$+ \frac{X_1}{EI}\left[\frac{L^3}{3} + \cancel{L^3} + \frac{L^3}{3} - \cancel{L^3}\right] + \alpha \frac{\overline{\Delta T}}{h}\left\{L^2 - \frac{L^2}{2}\right\} =$$

$$= \frac{9}{24}\frac{qL^4}{EI} + \frac{2}{3}\frac{L^3}{EI} X_1 + \frac{\alpha \overline{\Delta T}}{h}\frac{L^2}{2}$$

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In definitiva $L_{ve} = L_{vi}$ fornisce:

$$-\frac{X_1 L^3}{3EI} - \frac{qL^4}{EI} = \frac{9}{24}\frac{qL^4}{EI} + \frac{2}{3}\frac{L^3}{EI} X_1 + \underbrace{\frac{2\alpha\Delta T}{h}\frac{L^2}{2}}_{L_\Delta = \frac{qL^4}{2EI}}$$

tenendo conto delle posizioni iniziali!

$$X_1 \underbrace{\left[\frac{2L^3}{3EI} + \frac{L^3}{3EI}\right]}_{\cancel{\frac{L^3}{EI}}} = \frac{qL^{\cancel{4}}}{\cancel{EI}} \underbrace{\left[-1 - \frac{9}{24} - \frac{1}{2}\right]}_{\frac{-24-9-12}{24} = -\frac{\cancel{45}^{15}}{\cancel{24}_{8}}}$$

$$X_1 = -\frac{15}{8} qL$$

VERSO OPPOSTO A QUELLO IPOTIZZATO! OK!

CFR CON RV SU SIST. PRINCIPALE ISOSTATICO RISOLTO A PAG. VII! NEL QUALE APPUNTO $R_{x_C} = \frac{15}{8} qL$ VERSO SX!

VALGONO OVVIAMENTE I CALCOLI DI PAG. VIII!

SOLUZIONE 3

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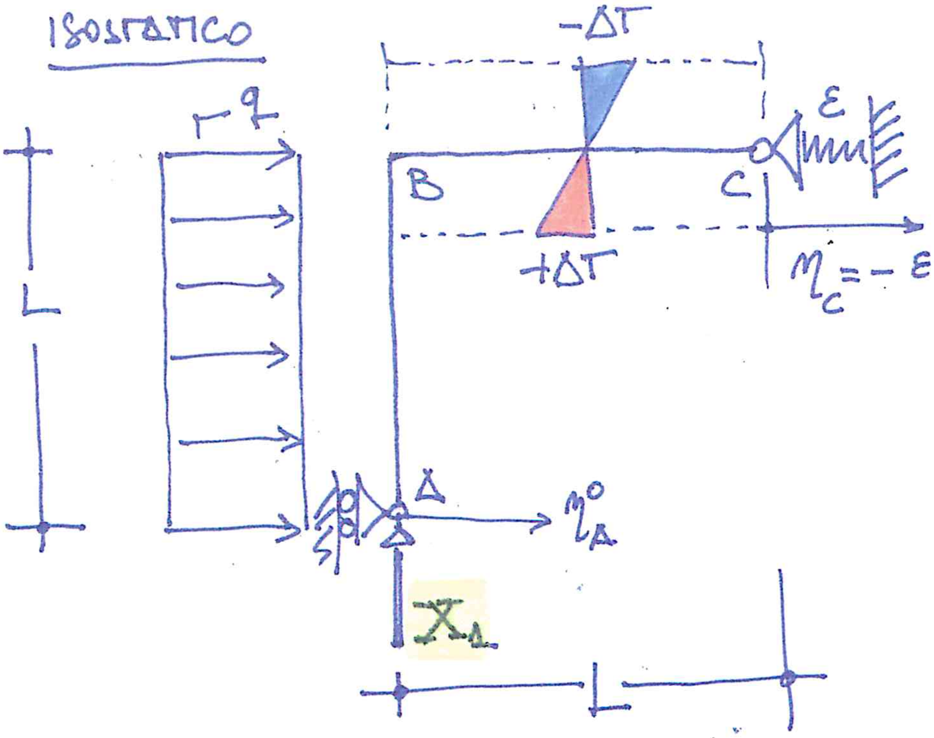
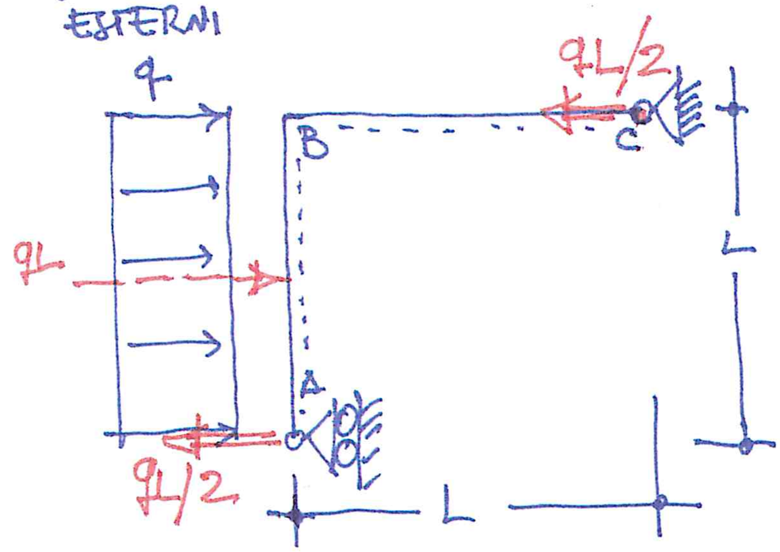
SISTEMA PRINCIPALE ISOSTATICO

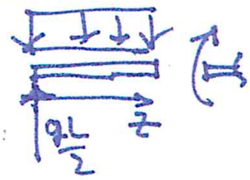


$$\mathcal{M}_C = -\varepsilon \underbrace{R_{x_C}^{(r)}}_{R_{x_C}^{(0)} + R_{x_C}^{(1)} X_1}$$

SCHEMA [0]
SOLO CARICHI ESTERNI



TRATTO AB $\quad 0 \le z \le L$



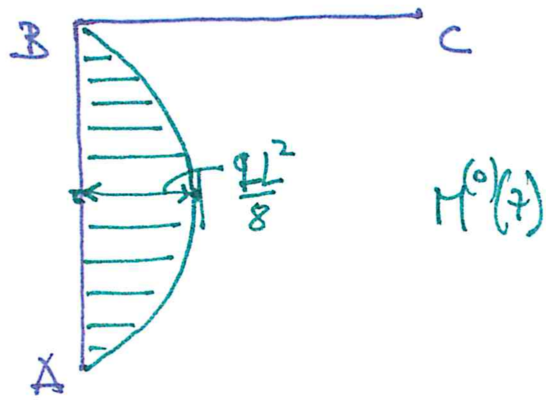
$$\boxed{M^{(0)}(z) = \frac{qL}{2} z - \frac{qz^2}{2}}$$

$$\begin{cases} M_A = 0 \\ M_B = 0 \end{cases}$$

$$M\Big|_{z=\frac{L}{2}} = \frac{qL^2}{4} - \frac{qL^2}{8} = \frac{qL^2}{8}$$

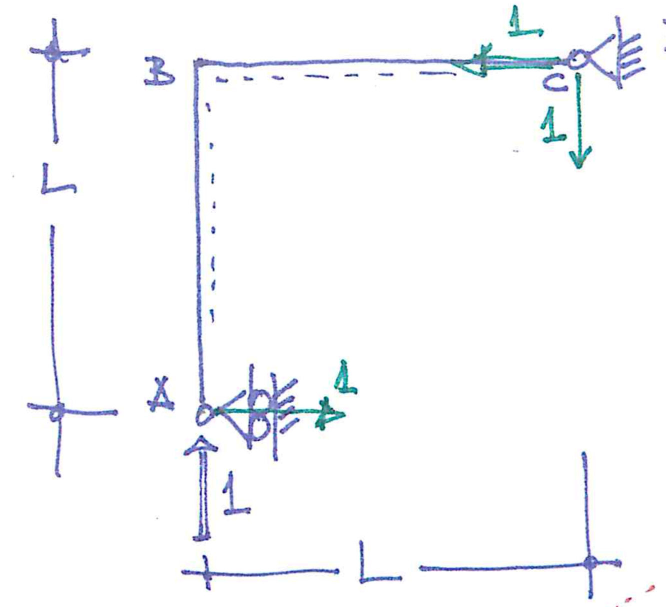
TRATTO BC

$$\boxed{M^{(0)}(z) = \emptyset}$$

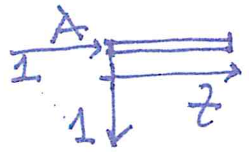


SCHEMA [1]

solo $X_1 = 1$

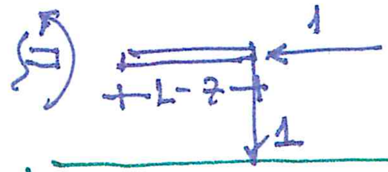


TRATTO AB $0 \le z \le L$

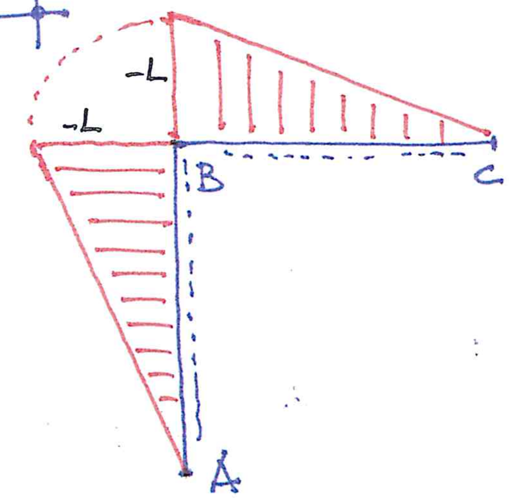


$\Longrightarrow \boxed{M^{(1)}(z) = -z}$ $\begin{cases} M_A = \phi \\ M_B = -L \end{cases}$

TRATTO BC $0 \le z \le L$



$\boxed{M^{(1)}(z) = -(L-z) = z-L}$ $\begin{cases} M_B = -L \\ M_C = \phi \end{cases}$



$M^{(1)}(z)$

L'unica equazione di Müller-Breslau, corrispondente all'unica incognita iperstatica X_1, si scrive nella forma $L_{ve} = L_{vi}$ assumendo come sistema fittizio o lavorante lo schema [1] e come sistema reale la struttura iperstatica data. Si ha:

$$L_{ve} = \underset{\overset{\parallel}{1}}{X_i^{(f)}} \cdot \eta_i^{(r)} + \sum_j R_j^{(f)} \eta_j^{(r)} =$$

$$\eta_c^{(r)} = -\varepsilon R_{x_c}^{(r)}, \qquad R_{x_c}^{(r)} = R_{x_c}^{(o)} + R_{x_c}^{(1)} X_1 = -\frac{qL}{2} - X_1$$

$$= 1 \cdot \phi + \underbrace{\underbrace{R_{x_A}^{(1)}}_{1} \cdot \eta_A^{o} + \underbrace{R_{x_c}^{(1)}}_{-1}}_{\text{CONCORDI}} \cdot \underbrace{\eta_c^{(r)}}_{-\varepsilon\left[\frac{qL}{2} + X_1\right]}$$

Tenendo conto delle posizioni iniziali può scriversi:

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$$L_{ve} = \underbrace{\eta_A^0}_{\frac{qL^4}{EI}} - \underset{\uparrow \frac{L^3}{3EI}}{\varepsilon}\left[\frac{qL}{2} + X_1\right] = \frac{qL^4}{EI} - \frac{L^3}{3EI}\left[\frac{qL}{2} + X_1\right] =$$

$$= \frac{qL^4}{EI} - \frac{qL^4}{6EI} - \frac{L^3}{3EI}X_1 = \frac{5}{6}\frac{qL^4}{EI} - \frac{L^3}{3EI}X_1$$

$$L_{vi} = \int_{Str} M^{(f)}\frac{M^{(r)}}{EI}\,dStr + \int_{Str} M^{(f)}\frac{\alpha\overline{\Delta T}}{h}\,dStr =$$

$$= \int_{Str} M^{(1)}\frac{M^{(r)}}{EI}\,dStr + \int_{Str} M^{(1)}\frac{\alpha\overline{\Delta T}}{h}\,dStr =$$

$$M^{(r)} = M^{(0)} + M^{(1)}X_1$$

$$= \int_{Str}\frac{M^{(1)}M^{(0)}}{EI}\,dStr + \left[\int_{Str}\frac{[M^{(1)}]^2}{EI}\,dStr\right]X_1 + \int_{Str} M^{(1)}\frac{\alpha\overline{\Delta T}}{h}\,dStr =$$

$$= \frac{1}{EI}\int_{\overline{AB}}[-z]\left[\frac{qL}{2}z - \frac{qz^2}{2}\right]dz +$$

$$+ \frac{X_1}{EI}\left[\int_{\overline{AB}} z^2\,dz + \int_{\overline{BC}}(z-L)^2\,dz\right] + \int_{\overline{BC}}(z-L)\frac{\alpha\overline{\Delta T}}{h}\,dz =$$

$$= \frac{1}{EI}\left[\int_0^L\left(-\frac{qL}{2}z^2 + \frac{qz^3}{2}\right)dz\right]$$

$$+ \frac{X_1}{EI}\left[\int_0^L z^2\,dz + \int_0^L\left(z^2 + L^2 - 2Lz\right)dz\right] + \frac{\alpha\overline{\Delta T}}{h}\int_0^L (z-L)\,dz =$$

$$= \frac{1}{EI}\left[-\frac{qL}{2}\left[\frac{z^3}{3}\right]_0^L + \frac{q}{2}\left[\frac{z^4}{4}\right]_0^L\right] + \frac{X_1}{EI}\left[\left[\frac{z^3}{3}\right]_0^L + \left[\frac{z^3}{3}\right]_0^L + L^2\left[z\right]_0^L - 2L\left[\frac{z^2}{2}\right]_0^L\right]$$

$$+ \frac{\alpha\overline{\Delta T}}{h}\left\{\left[\frac{z^2}{2}\right]_0^L - L\left[z\right]_0^L\right\} =$$

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$$= \frac{1}{EI}\underbrace{\left\{-\frac{qL^4}{6}+\frac{qL^4}{8}\right\}}_{\frac{-4+3}{24}} + \frac{X_1}{EI}\underbrace{\left[\frac{L^3}{3}+\frac{L^3}{3}+\cancel{L^3}-\cancel{L^3}\right]}_{\frac{2}{3}L^3} + \underbrace{\frac{\alpha\Delta T}{h}}_{=\frac{qL^2}{EI}}\underbrace{\left\{\frac{L^2}{2}-L^2\right\}}_{-\frac{L^2}{2}} =$$

$\frac{\alpha\Delta T}{h} = \frac{qL^2}{EI}$ tenendo conto delle posizioni iniziali!

$$= -\frac{qL^4}{24EI} + \frac{2X_1L^3}{3EI} - \frac{qL^4}{2EI}$$

In definitiva $L_{ve}=L_{vi}$ fornisce:

$$\frac{5}{6}\frac{qL^4}{EI} - \frac{L^3}{3EI}X_1 = -\frac{qL^4}{24EI} + \frac{2X_1L^3}{3EI} - \frac{qL^4}{2EI}$$

$$X_1\underbrace{\left[\frac{2}{3}\frac{L^3}{\cancel{EI}}+\frac{L^3}{EI}\right]}_{\frac{\cancel{L^3}}{\cancel{EI}}} = \frac{q\cancel{L^4}}{\cancel{EI}}\underbrace{\left[\frac{5}{6}+\frac{1}{24}+\frac{1}{2}\right]}_{\frac{20+1+12}{24}=\frac{\cancel{33}^{\,11}}{\cancel{24}_{\,8}}}$$

$$X_1 = \frac{11}{8}qL$$

positiva ⇒ verso ipotizzato corretto!

- cfr. RV di pag. VII!
- valgono le considerazioni di pag. VIII!