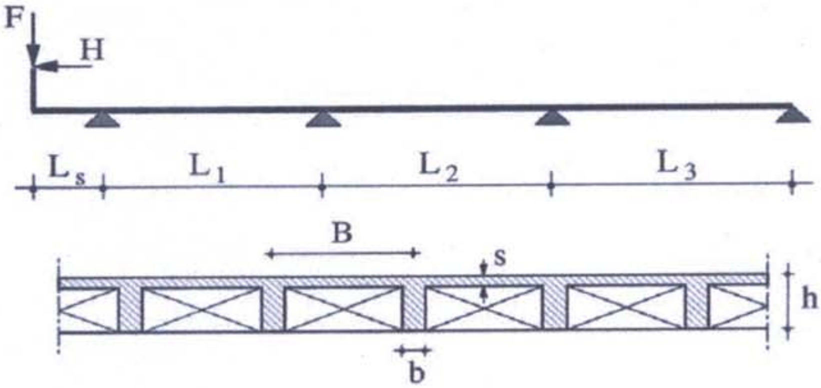
UNIVERSITÀ DEGLI STUDI DI SALERNO
DIPARTIMENTO DI INGEGNERIA CIVILE
CORSO DI TECNICA DELLE COSTRUZIONI I
Anno Accademico 2004-2005

(Allievi con matricola dispari)

Prof. Ciro Faella
Ing. Gianvittorio Rizzano – Ing. Enzo Martinelli

Allievo: CARMINE LIMA Matricola: ____ __________

SOLAIO LATERO-CEMENTIZIO GETTATO IN OPERA



$L_1 = 4.50 + 0.15\,N - 0.10\,C$ [m]
$L_2 = 5.00 + 0.15\,N - 0.10\,C$ [m]
$L_3 = 4.00 + 0.10\,N - 0.10\,C$ [m]
$L_s = 1.05 + 0.05\,M$ [m]

N = numero di lettere del nome;
C = numero di lettere del cognome
M = ultima cifra del numero di matricola

B = 50 cm; b = 10 cm; s = 4 cm; $h \geq L_{max}/25$

Carichi:

- *F (peso del parapetto);*
- *H = 1.00 kN/m;*
- *Sovraccarichi accidentali per uffici aperti al pubblico.*

Caratteristiche geometriche

$\mathbf{L_1}$ = 4.50 + 0.15 N – 0.10 C = **5.15 m**

$\mathbf{L_2}$ = 5.00 + 0.15 N – 0.10 C = **5.65 m**

$\mathbf{L_3}$ = 4.00 + 0.10 N – 0.10 C = **4.30 m**

$\mathbf{L_s}$ = 1.05 + 0.05 M = **1.2 m**

B = 50 cm ; b = 10 cm ; s = 4 cm ; h = $\mathbf{L_{max}}$ **/25**

Caratteristiche meccaniche

Calcestruzzo : R_{ck} = 25.0 MPa

Acciaio : FeB38K

Schema

Analisi dei carichi

$h = L_{max} / 25 = \frac{5.65}{25} = 0.226\ m = 22.6\ cm$

Campata centrale (h = 24 cm ; s = 4 cm ; h_1 = 20 cm)

- travetti	(0.20 x 0.10 x 1) x 2 = 0.04 x 25 =	1.00 kN/m^2
- soletta	(0.04 x 1 x1) = 0.04 x 25 =	1.00 kN/m^2
- laterizi	(0.20 x 0.40 x 1) x 2 = 0.16 x 8 =	1.28 kN/m^2
	peso proprio	**g_k = 3.28 kN/m^2**
- 3 cm massetto	(0.03 x 1 x 1) = 0.03 x 18 =	0.54 kN/m^2
- 2 cm pavimento	(0.02 x 1 x 1) = 0.02 x 20 =	0.40 kN/m^2
- 1.5 cm intonaco	(0.015 x 1 x 1) = 0.015 x 20 =	0.30 kN/m^2
- incidenza tramezzi		1.00 kN/m^2
	sovraccarichi permanenti	**g'_k = 2.24 kN/m^2**
	sovraccarichi accidentali	**q_k = 3.00 kN/m^2**

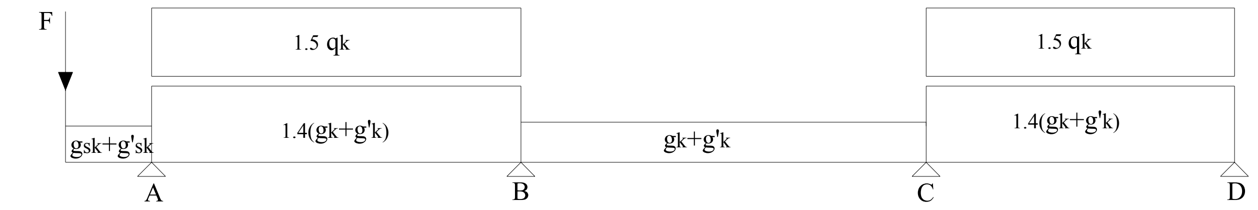
Sbalzo (h_{sb} = 20 cm ; s = 4 cm ; h_1 = 16 cm)

- travetti	(0.16 x 0.10 x 1) x 2 = 0.032 x 25 =	0.80 kN/m^2
- soletta	(0.04 x 1 x 1) = 0.04 x 25 =	1.00 kN/m^2
- laterizi	(0.16 x 0.4 x 1) x 2 = 0.128 x 8 =	1.02 kN/m^2
	peso proprio	**g_{sk} = 2.82 kN/m^2**
- 3 cm massetto	(0.03 x 1 x 1) = 0.03 x 18 =	0.54 kN/m^2
- 2 cm pavimento	(0.02 x 1 x 1) = 0.02 x 20 =	0.40 kN/m^2
- 1.5 cm intonaco	(0.015 x 1 x 1) = 0.015 x 20 =	0.30 kN/m^2
	sovraccarichi permanenti	**g'_{sk} = 1.24 kN/m^2**
- ringhiera		**F = 0.50 kN/m**
	sovraccarichi accidentali	**q_{sk} = 4 kN/m^2**
		H = 1.00 kN/m

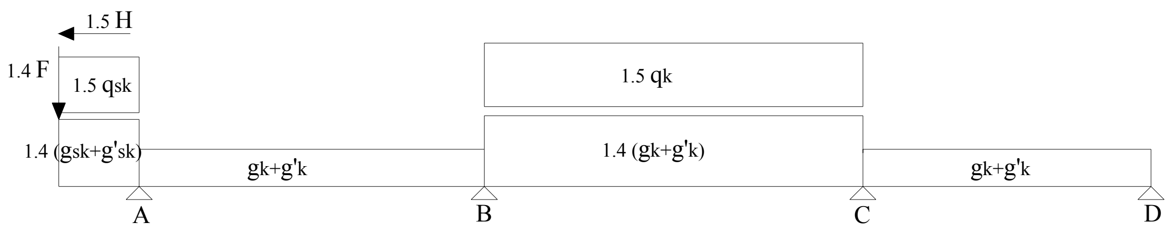
Fattori di amplificazione dei carichi

γ_g = 1.4 **γ_q = 1.5**

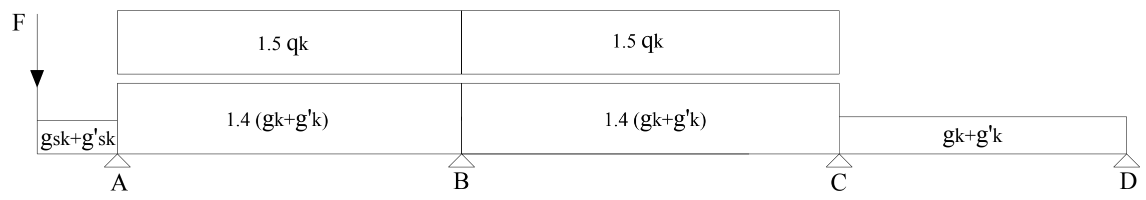
combinazione S.L.U. 1



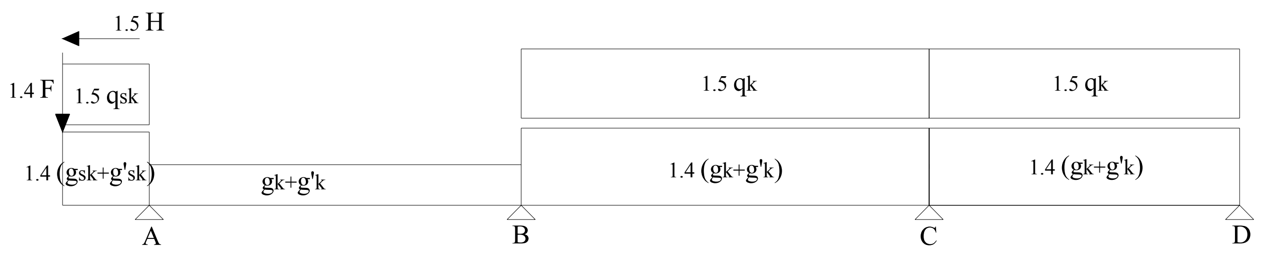
combinazione S.L.U. 2



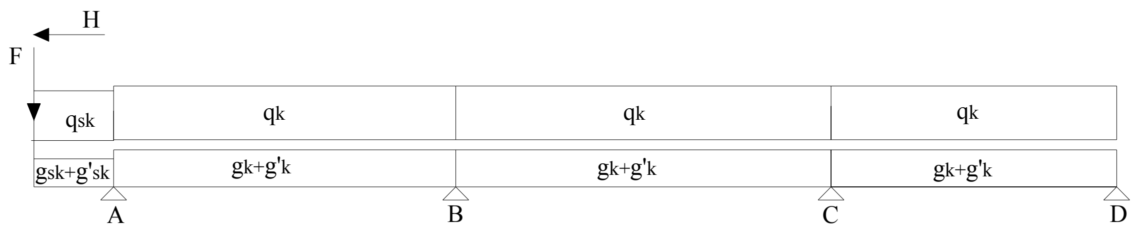
combinazione S.L.U. 3



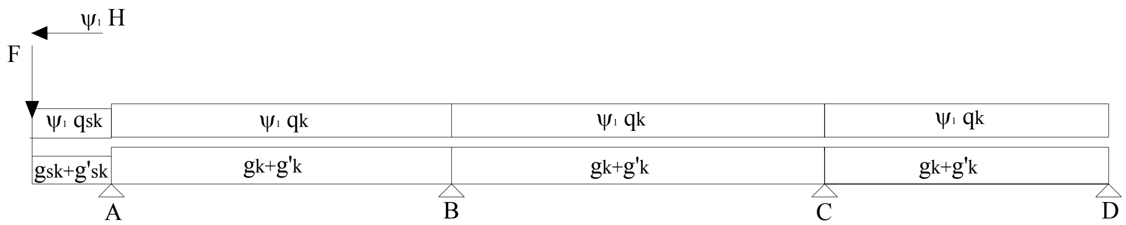
combinazione S.L.U. 4



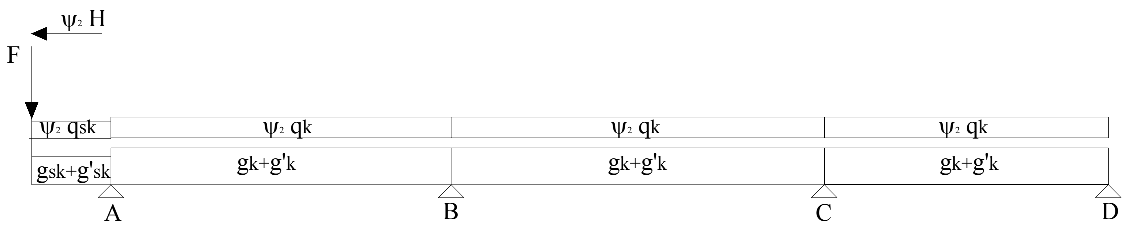
combinazione S.L.S. 1 (rara)



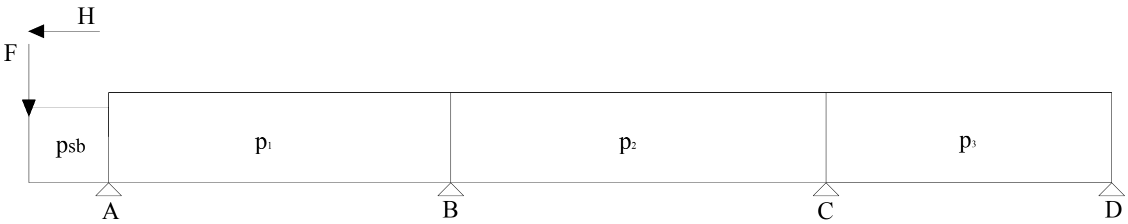
combinazione S.L.S. 2 (frequente) $\psi_1 = 0.6$

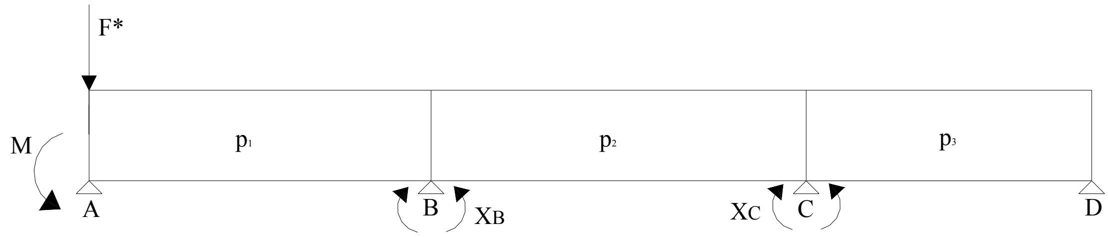


combinazione S.L.S. 3 (quasi permanente) $\psi_2 = 0.3$



<u>Risoluzione con il metodo delle forze</u>





$F^* = F + p_{sb} \bullet L_{sb}$

$M = F \bullet L_{sb} + p_{sb} \bullet \dfrac{L_{sb}^2}{2} + H \bullet h$

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI}$$

$$\varphi_{CB} = \frac{X_B L_2}{6EI} - \frac{p_2 L_2^3}{24EI} + \frac{X_C L_2}{3EI}$$

$$\varphi_{CD} = \frac{p_3 L_3^3}{24EI} - \frac{X_C L_3}{3EI}$$

$$\varphi_{BA} - \varphi_{BC} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3Ei} - \frac{p_2 L_2^3}{24EI} + \frac{X_B L_2}{3EI} + \frac{X_C L_2}{6EI} = 0$$

$$\varphi_{CB} - \varphi_{CD} = \frac{X_B L_2}{6EI} - \frac{p_2 L_2^3}{24EI} + \frac{X_C L_2}{3EI} - \frac{p_3 L_3^3}{24EI} + \frac{X_C L_3}{3EI} = 0$$

$$\frac{X_B L_1}{3Ei} + \frac{X_B L_2}{3EI} + \frac{X_C L_2}{6EI} = \frac{p_1 L_1^3}{24EI} + \frac{p_2 L_2^3}{24EI} - \frac{M\,L_1}{6EI}$$

$$\frac{X_B L_2}{6EI} + \frac{X_C L_2}{3EI} + \frac{X_C L_3}{3EI} = \frac{p_2 L_2^3}{24EI} + \frac{p_3 L_3^3}{24EI}$$

portando in forma matriciale e semplificando EI :

$$\begin{bmatrix} \frac{L_1}{3}+\frac{L_2}{3} & \frac{L_2}{6} \\ \frac{L_2}{6} & \frac{L_2}{3}+\frac{L_3}{3} \end{bmatrix} \text{x} \begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} \frac{p_1 L_1^3}{24}+\frac{p_2 L_2^3}{24}-\frac{M\,L_1}{6} \\ \frac{p_2 L_2^3}{24}+\frac{p_3 L_3^3}{24} \end{bmatrix}$$

$$\mathbf{D} \text{ x } \mathbf{X}^{\mathbf{comb}} = \boldsymbol{\delta}^{\mathbf{comb}} \quad \Rightarrow \quad \mathbf{X}^{\mathbf{comb}} = \mathbf{D}^{-1} \text{x } \boldsymbol{\delta}^{\mathbf{comb}}$$

$$\mathbf{D} = \begin{bmatrix} 3.6000 & 0.9417 \\ 0.9417 & 3.3167 \end{bmatrix}$$

$$\mathbf{D}^{-1} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix}$$

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} \text{x} \begin{bmatrix} \frac{p_1 L_1^3}{24}+\frac{p_2 L_2^3}{24}-\frac{M\,L_1}{6} \\ \frac{p_2 L_2^3}{24}+\frac{p_3 L_3^3}{24} \end{bmatrix}$$

Luci delle varie campate

L_{SB}= 1.20 m

L_1= 5.15 m

L_2= 5.65 m

L_3= 4.30 m

Carichi

g_{sk}+g'_{sk}= 4.06 kN/m g_k+g'_k= 5.52 kN/m

q_{sk} = 4.00 kN/m q_k = 3.00 kN/m

F = 0.50 kN

H = 1.00 kN

Combinazione S.L.U. 1

p_{sb}= 4.06 kN/m M = 3.52 kNm

F* = 5.37 kN p_1 = 12.23 kN/m

p_2 = 5.52 kN/m

p_3 = 12.23 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 108.0664 \\ 81.9987 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(1)} = 25.44 kNm \\ X_C^{(1)} = 17.50 kNm \end{bmatrix}$$

Combinazione S.L.U. 2

p_{sb} = 11.68 kN/m — M =10.75 kNm

F* = 14.72 kN — p_1 = 5.52 kN/m

p_2 =12.23 kN/m

p_3 = 5.52 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 114.0898 \\ 110.1961 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(2)} = 24.85 kNm \\ X_C^{(2)} = 26.17 kNm \end{bmatrix}$$

Combinazione S.L.U. 3

p_{sb} = 4.06 kN/m — M = 3.52 kNm

F* = 5.37 kN — p_1 = 12.23 kN/m

p_2 = 12.23 kN/m

p_3 = 5.52 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 158.4926 \\ 110.1961 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(3)} = 38.17 kNm \\ X_C^{(3)} = 22.39 kNm \end{bmatrix}$$

Combinazione S.L.U. 4

p_{sb} = 11.68 kN/m — M =10.75 kNm

F* = 14.72 kN — p_1 = 5.52 kN/m

p_2 = 12.23 kN/m

p_3 = 12.23 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 114.0984 \\ 133.4250 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(4)} = 22.96 kNm \\ X_C^{(4)} = 33.41 kNm \end{bmatrix}$$

Combinazione S.L.S. 1 (rara)

p_{sb} = 8.06 kN/m M = 7.40 kNm

F* = 10.17 kN p_1 = 8.52 kN/m

p_2 = 8.52 kN/m

p_3 = 8.52 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 106.1666 \\ 92.2535 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(R)} = 24.00 kNm \\ X_C^{(R)} = 21.00 kNm \end{bmatrix}$$

Combinazione S.L.S. 2 (frequente)

p_{sb} = 6.46 kN/m M = 5.85 kNm

F* = 8.25 kN p_1 = 7.32 kN/m

p_2 = 7.32 kN/m

p_3 = 7.32 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 91.6494 \\ 79.2601 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(F)} = 20.75 kNm \\ X_C^{(F)} = 18.01 kNm \end{bmatrix}$$

Combinazione S.L.S. 3 (quasi permanente)

p_{sb} = 5.26 kN/m M = 4.69 kNm

F* = 6.81 kN p_1 = 6.42 kN/m

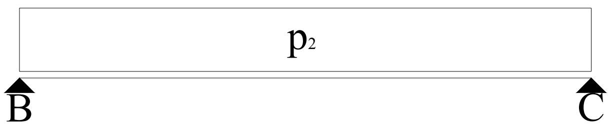
p_2 = 6.42 kN/m

p_3 = 6.42 kN/m

$$\begin{bmatrix} X_B \\ X_C \end{bmatrix} = \begin{bmatrix} 0.3001 & -0.0852 \\ -0.0852 & 0.3257 \end{bmatrix} * \begin{bmatrix} 80.7593 \\ 69.5150 \end{bmatrix} \quad => \quad \begin{bmatrix} X_B^{(Q,P)} = 18.31 kNm \\ X_C^{(Q,P)} = 15.76 kNm \end{bmatrix}$$

Risoluzione con il metodo di Hardy – Cross

Campata intermedia BC

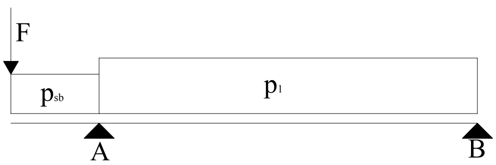


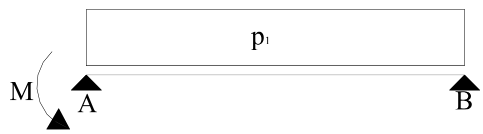
$\mu_{BC} = -\dfrac{p_2 L_2^2}{12}$ $\qquad$ $\mu_{CB} = \dfrac{p_2 L_2^2}{12}$ $\qquad$ *momenti di incastro perfetto*

$$\left.\begin{matrix}\varphi_B = 1 \\ \varphi_C = 0\end{matrix}\right] \Rightarrow \left[\begin{matrix}\dfrac{W_{BC} L_2}{3EI} - \dfrac{V_{CB} L_2}{6EI} = 1 \\ -\dfrac{W_{BC} L_2}{6EI} + \dfrac{V_{CB} L_2}{3EI} = 0\end{matrix}\right. \quad \Rightarrow \quad \left[\begin{matrix}W_{BC} = \dfrac{4EI}{L_2} \\ V_{CB} = \dfrac{2EI}{L_2}\end{matrix}\right.$$ *coefficienti di rigidezza*

$$\left.\begin{matrix}\varphi_B = 0 \\ \varphi_C = 1\end{matrix}\right] \Rightarrow \left[\begin{matrix}\dfrac{V_{BC} L_2}{3EI} - \dfrac{W_{CB} L_2}{6EI} = 0 \\ -\dfrac{V_{BC} L_2}{6EI} + \dfrac{W_{CB} L_2}{3EI} = 1\end{matrix}\right. \quad \Rightarrow \quad \left[\begin{matrix}V_{BC} = \dfrac{2EI}{L_2} \\ W_{CB} = \dfrac{4EI}{L_2}\end{matrix}\right.$$ *coefficienti di rigidezza*

Campata di riva AB

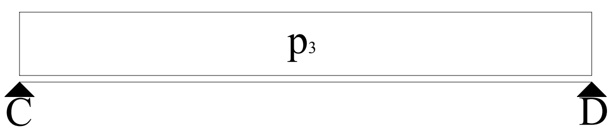




$\mu_{BA} = \dfrac{p_1 L_1^2}{8} - \dfrac{M}{2}$ $\qquad$ *momento di incastro perfetto*

$$\varphi_B = 1 \Big] \Rightarrow \left[\dfrac{W_{BA} L_1}{3EI} = 1 \right. \quad \Rightarrow \quad \left[W_{BA} = \dfrac{3EI}{L_1} \right.$$ *coefficiente di rigidezza*

Campata di riva CD



$\mu_{CD} = -\dfrac{p_3 L_3^2}{8}$ *momento di incastro perfetto*

$\varphi_C = 1] => \left[\dfrac{W_{CD} L_3}{3EI} = 1\right.$ => $\left[W_{CD} = \dfrac{3EI}{L_3}\right.$ *coefficiente di rigidezza*

Essendo $\boldsymbol{\tau_{ij}} = \dfrac{W_{ij}}{W_{ij} + W_{ik}}$ ***coefficiente di ripartizione***

$\mathbf{t_{ji}} = \dfrac{V_{ji}}{W_{ij}}$ ***coefficiente di trasporto***

risulta la tabella

nodo	***asta***	***coeff. di rigidezza (W_{ij})***	***coeff. di ripartizione (τ_{ij})***	***coeff. di trasporto (t_{ij})***
B	AB	$\dfrac{3EI}{L_1}$	0.451	0
B	BC	$\dfrac{4EI}{L_2}$	0.549	0.5
C	BC	$\dfrac{4EI}{L_2}$	0.504	0.5
C	CD	$\dfrac{3EI}{L_3}$	0.496	0

Combinazione S.L.U. 1

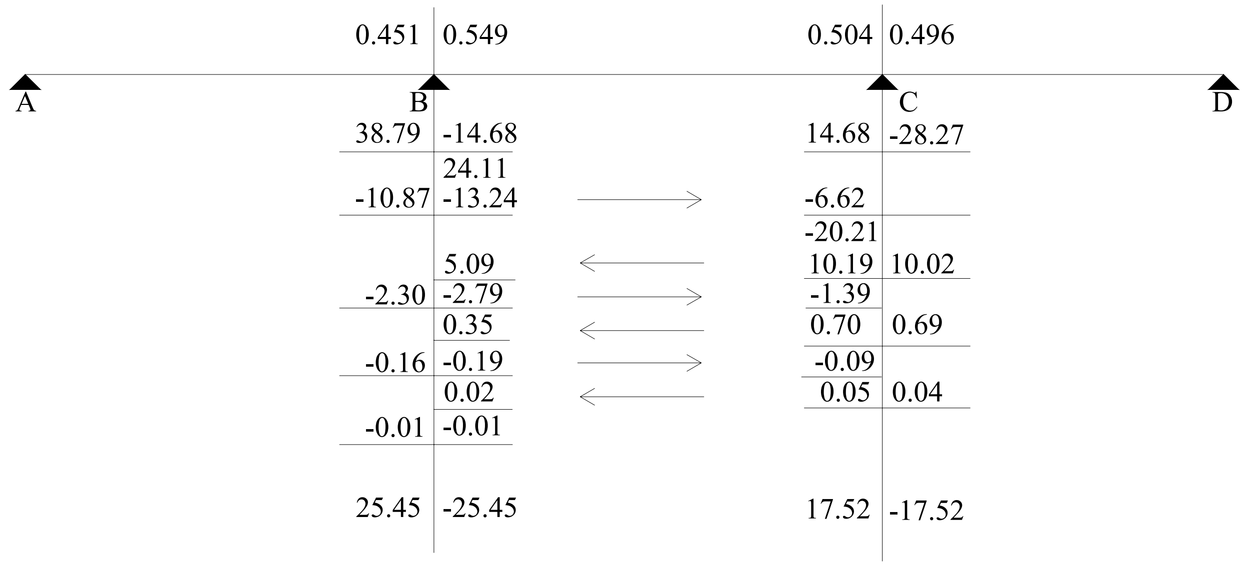
p_{sb} = 4.06 kN/m M = 3.52 kNm p_2 = 5.52 kN/m

F* = 5.37 kN p_1 = 12.23 kN/m p_3 = 12.23 kN/m

μ_{BA} = 38.79 kNm

μ_{BC} = -14.68 kNm μ_{CB} = 14.68 kNm

μ_{CD} = - 28.27 kNm



$X_B^{(1)}$ = 25.45 kNm

$X_C^{(1)}$ = 17.52 kNm

Verifica di congruenza

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{3.0213}{EI} - \frac{69.6044}{EI} + \frac{43.6892}{EI} = -\frac{22.8939}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{41.4833}{EI} - \frac{47.9308}{EI} - \frac{16.4980}{EI} = -\frac{22.9455}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = -\frac{22.9197}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 2.25 \times 10^{-3}$$

Combinazione S.L.U. 2

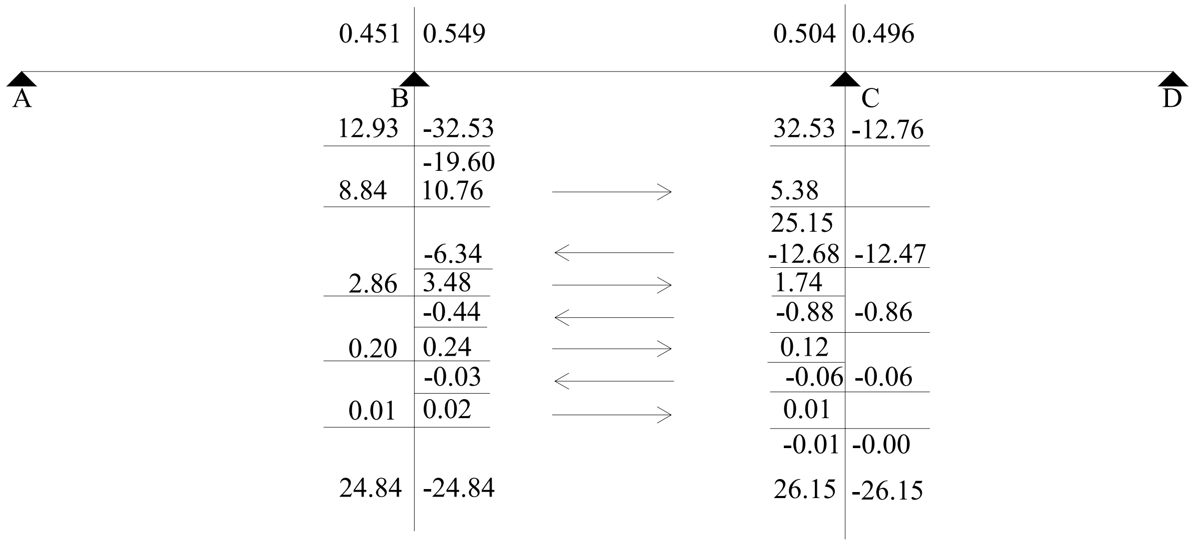
p_{sb} = 11.68 kN/m M =10.75 kNm p_2 =12.23 kN/m

F* = 14.72 kN p_1 = 5.52 kN/m p_3 = 5.52 kN/m

μ_{BA} = 12.93 kNm

μ_{BC} = -32.53 kNm μ_{CB} = 32.53 kNm

μ_{CD} = -12.76 kNm



$X_B^{(2)}$ = 24.84 kNm

$X_C^{(2)}$ = 26.15 kNm

Verifica di congruenza

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{9.2271}{EI} - \frac{31.4159}{EI} + \frac{42.6420}{EI} = +\frac{20.4532}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{91.9095}{EI} - \frac{46.482}{EI} - \frac{24.6246}{EI} = +\frac{20.8029}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = +\frac{20.6281}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 1.69 \times 10^{-2}$$

Combinazione S.L.U. 3

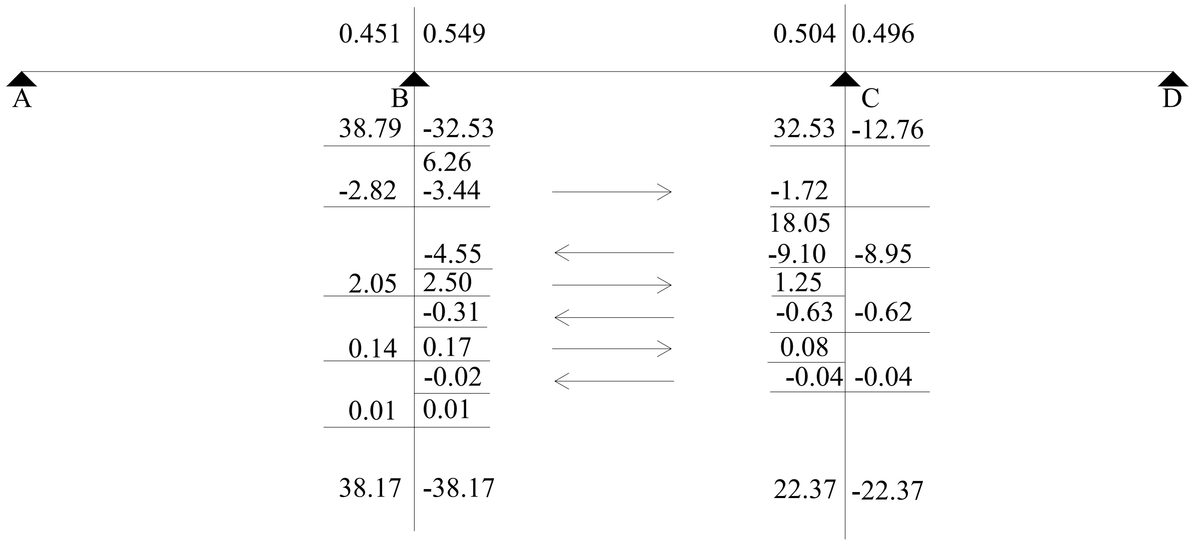
p_{sb} = 4.06 kN/m M = 3.52 kNm p_2 = 12.23 kN/m

F* = 5.37 kN p_1 = 12.23 kN/m p_3 = 5.52 kN/m

μ_{BA} = 38.79 kNm

μ_{BC} = -32.53 kNm μ_{CB} = 32.53 kNm

μ_{CD} = -12.76 kNm



$X_B^{(3)}$ = 38.17 kNm

$X_C^{(3)}$ = 22.37 kNm

Verifica di congruenza

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{3.0213}{EI} - \frac{69.6044}{EI} + \frac{65.5252}{EI} = -\frac{1.0579}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{91.9095}{EI} - \frac{71.8868}{EI} - \frac{21.0651}{EI} = -\frac{1.0424}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = -\frac{1.0502}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 1.47 \times 10^{-2}$$

Combinazione S.L.U. 4

p_{sb} = 11.68 kN/m M =10.75 kNm p_2 = 12.23 kN/m

F* = 14.72 kN p_1 = 5.52 kN/m p_3 = 12.23 kN/m

μ_{BA} = 12.93 kNm

μ_{BC} = -32.53 kNm μ_{CB} = 32.53 kNm

μ_{CD} = -28.27 kNm

A	B (BA)	B (BC)	C (CB)	C (CD)	D
	0.451	0.549	0.504	0.496	
	12.93	-32.53	32.53	-28.27	
		-19.60			
	8.84	10.76	5.38		
			9.64		
		-2.43	-4.86	-4.78	
	1.10	1.33	0.66		
		-0.16	-0.33	-0.33	
	0.07	0.09	0.04		
		-0.01	-0.02	-0.02	
	0.00	0.01			
	22.94	-22.94	33.40	-33.40	

$X_B^{(4)} = 22.94$ kNm

$X_C^{(4)} = 33.40$ kNm

Verifica di congruenza

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{9.2271}{EI} - \frac{31.4159}{EI} + \frac{39.3803}{EI} = +\frac{17.1915}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{91.9095}{EI} - \frac{43.2037}{EI} - \frac{31.4517}{EI} = +\frac{17.2541}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = +\frac{17.2228}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 3.63 \times 10^{-3}$$

Combinazione S.L.S. 1 (rara)

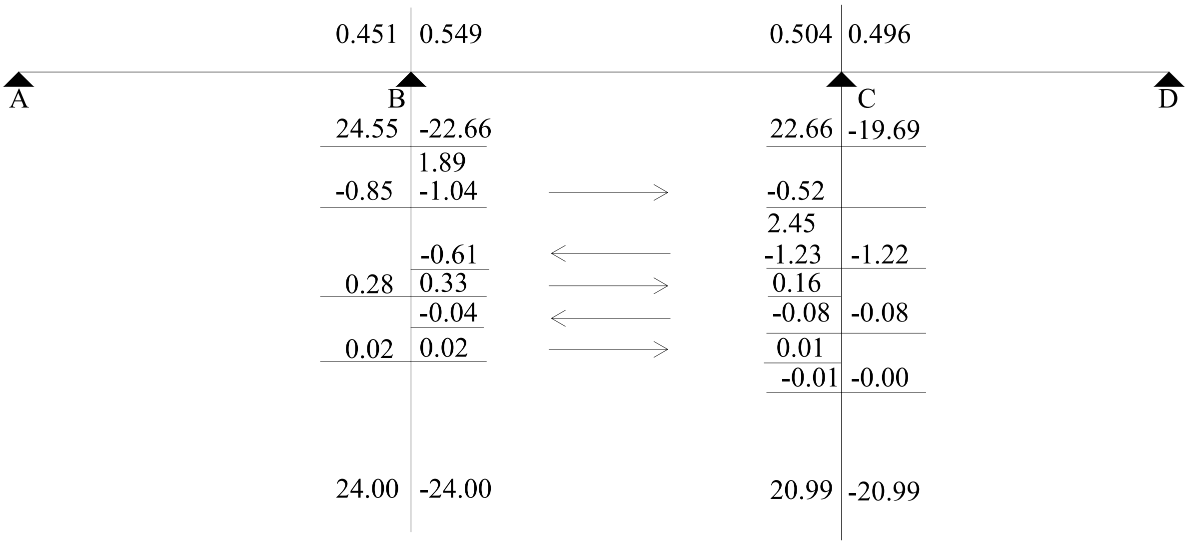
p_{sb} = 8.06 kN/m M = 7.40 kNm p_2 = 8.52 kN/m

F* = 10.17 kN p_1 = 8.52 kN/m p_3 = 8.52 kN/m

μ_{BA} = 24.55 kNm

μ_{BC} = -22.66 kNm μ_{CB} = 22.66 kNm

μ_{CD} = -19.69 kNm



$X_B^{(R)}$ = 24.00 kNm

$X_C^{(R)}$ = 20.99 kNm

Verifica di congruenza

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{6.3517}{EI} - \frac{48.4898}{EI} + \frac{41.2000}{EI} = -\frac{0.9381}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{64.0285}{EI} - \frac{45.2000}{EI} - \frac{19.7656}{EI} = -\frac{0.9371}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = -\frac{0.9376}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 1.06 \times 10^{-3}$$

Combinazione S.L.S. 2 (frequente)

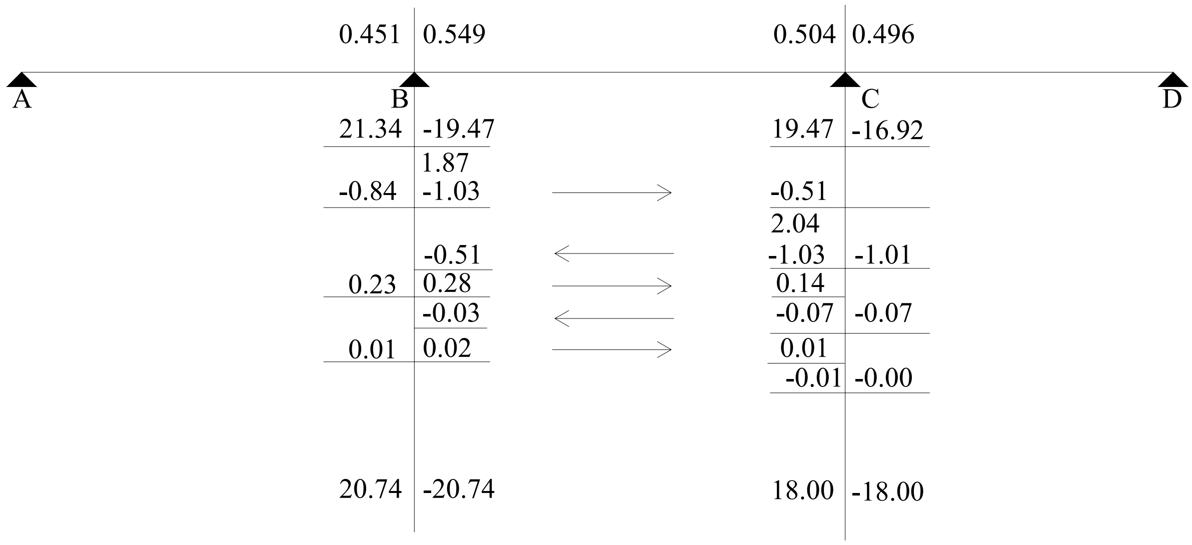
p_{sb} = 6.46 kN/m   M = 5.85 kNm p_2 = 7.32 kN/m

F* = 8.25 kN p_1 = 7.32 kN/m p_3 = 7.32 kN/m

μ_{BA} = 21.34 kNm

μ_{BC} = -19.47 kNm μ_{CB} = 19.47 kNm

μ_{CD} = -16.92 kNm



$X_B^{(F)}$ = 20.74 kNm

$X_C^{(F)}$ = 18.00 kNm

<u>*Verifica di congruenza*</u>

$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{5.0212}{EI} - \frac{41.6602}{EI} + \frac{35.6037}{EI} = -\frac{1.0353}{EI}$$

$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{55.0104}{EI} - \frac{39.0603}{EI} - \frac{16.9500}{EI} = -\frac{0.9999}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = -\frac{1.0176}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 3.48 \times 10^{-2}$$

Combinazione S.L.S. 3 (quasi permanente)

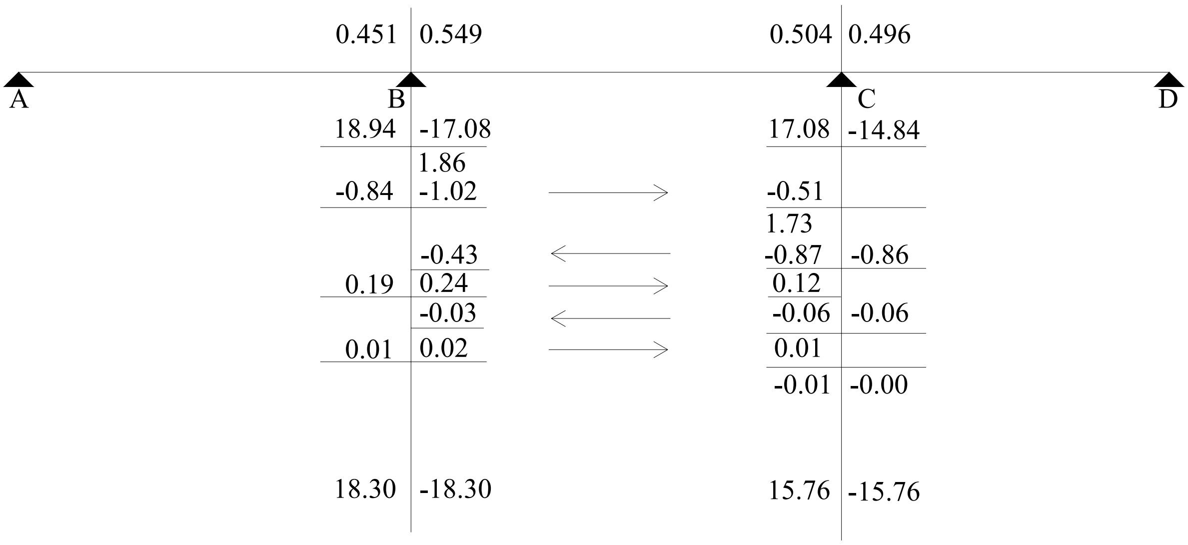
$p_{sb} = 5.26$ kN/m $\quad$ $M = 4.69$ kNm $\quad$ $p_2 = 6.42$ kN/m

$F^* = 6.81$ kN $\quad$ $p_1 = 6.42$ kN/m $\quad$ $p_3 = 6.42$ kN/m

$\mu_{BA} = 18.94$ kNm

$\mu_{BC} = -17.08$ kNm $\quad$ $\mu_{CB} = 17.08$ kNm

$\mu_{CD} = -14.84$ kNm



$X_B^{(Q,P)} = 18.30$ kNm

$X_C^{(Q,P)} = 15.76$ kNm

Verifica di congruenza

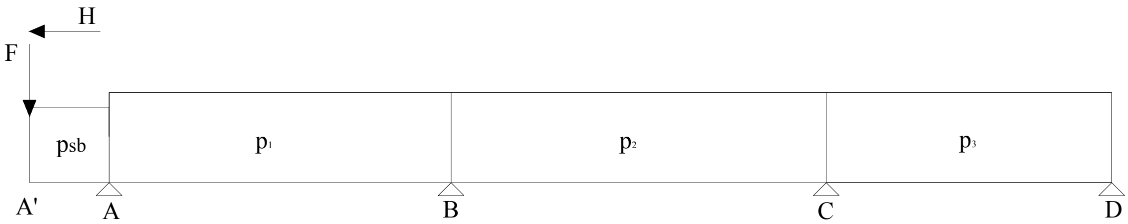
$$\varphi_{BA} = \frac{M\,L_1}{6EI} - \frac{p_1 L_1^3}{24EI} + \frac{X_B L_1}{3EI} = \frac{4.0256}{EI} - \frac{36.5380}{EI} + \frac{31.4150}{EI} = -\frac{1.0974}{EI}$$

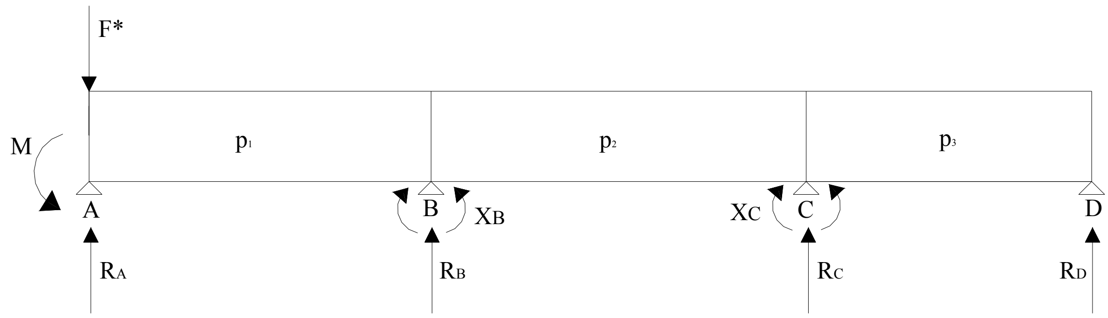
$$\varphi_{BC} = \frac{p_2 L_2^3}{24EI} - \frac{X_B L_2}{3EI} - \frac{X_C L_2}{6EI} = \frac{48.2469}{EI} - \frac{34.4650}{EI} - \frac{14.8407}{EI} = -\frac{1.0588}{EI}$$

$$\varphi^* = \frac{\varphi_{BA} + \varphi_{BC}}{2} = -\frac{1.0781}{EI}$$

$$\varepsilon = \frac{|\varphi_{BC} - \varphi_{BA}|}{|\varphi^*|} = 3.58 \times 10^{-2}$$

Diagrammi di Taglio e Momento





Reazioni vincolari

$$\mathbf{R_A} = \frac{M}{L_1} + \frac{p_1 L_1}{2} - \frac{X_B}{L_1} + F^*$$

$$\mathbf{R_B} = -\frac{M}{L_1} + \frac{p_1 L_1}{2} + \frac{X_B}{L_1} + \frac{X_B}{L_2} + \frac{p_2 L_2}{2} - \frac{X_C}{L_2}$$

$$\mathbf{R_C} = \frac{X_C}{L_2} + \frac{p_2 L_2}{2} - \frac{X_B}{L_2} + \frac{X_C}{L_3} + \frac{p_3 L_3}{2}$$

$$\mathbf{R_D} = \frac{p_3 L_3}{2} - \frac{X_C}{L_3}$$

Sollecitazioni di taglio

$\mathbf{T_A^{(s)}} = -F^*$

$\mathbf{T_A^{(D)}} = T_A^{(s)} + R_A$

$\mathbf{T_B^{(S)}} = T_A^{(D)} - p_1 L_1$

$\mathbf{T_B^{(D)}} = T_B^{(S)} + R_B$

$\mathbf{T_C^{(S)}} = T_B^{(D)} - p_2 L_2$

$\mathbf{T_C^{(D)}} = T_C^{(S)} + R_C$

$\mathbf{T_D^{(S)}} = T_C^{(D)} - p_3 L_3 = -R_D$

Sollecitazioni di momento

$\mathbf{M_{A'}} = -H \times 1.00$ m

$\mathbf{M_A} = -M$

$\mathbf{M_B} = -X_B$

$\mathbf{M_C} = -X_C$

$\mathbf{M_D} = 0$

Combinazione S.L.U. 1

p_{sb}= 4.06 kN/m

F^* = 5.37 kN

$X_B^{(1)}$ = 25.44 kNm

$X_C^{(1)}$ = 17.50 kNm

M = 3.52 kNm

p_1 = 12.23 kN/m

p_2 = 5.52 kN/m

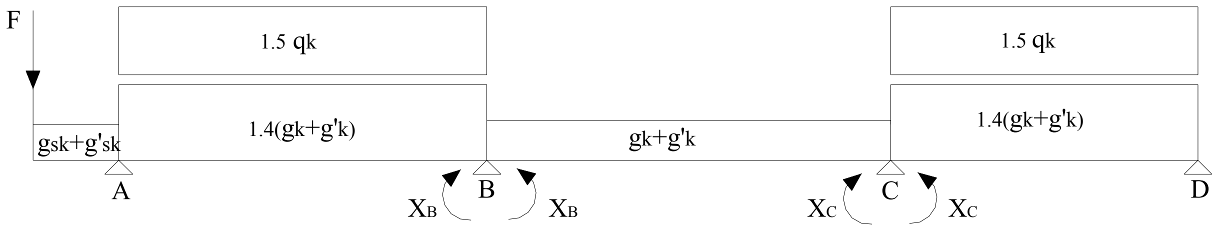
p_3 = 12.23 kN/m

L_{SB}= 1.20 m

L_1= 5.15 m

L_2= 5.65 m

L_3= 4.30 m



R_A = 32.61 kN

R_B = 52.75 kN

R_C = 44.55 kN

R_D = 22.22 kN

$T_A^{(s)}$ = -5.37 kN

$T_A^{(D)}$ = 27.24 kN

$T_B^{(S)}$ = -35.75 kN

$T_B^{(D)}$ = 17.00 kN

$T_C^{(S)}$ = -14.19 kN

$T_C^{(D)}$ = 30.36 kN

$T_D^{(S)}$ = -22.22 kN

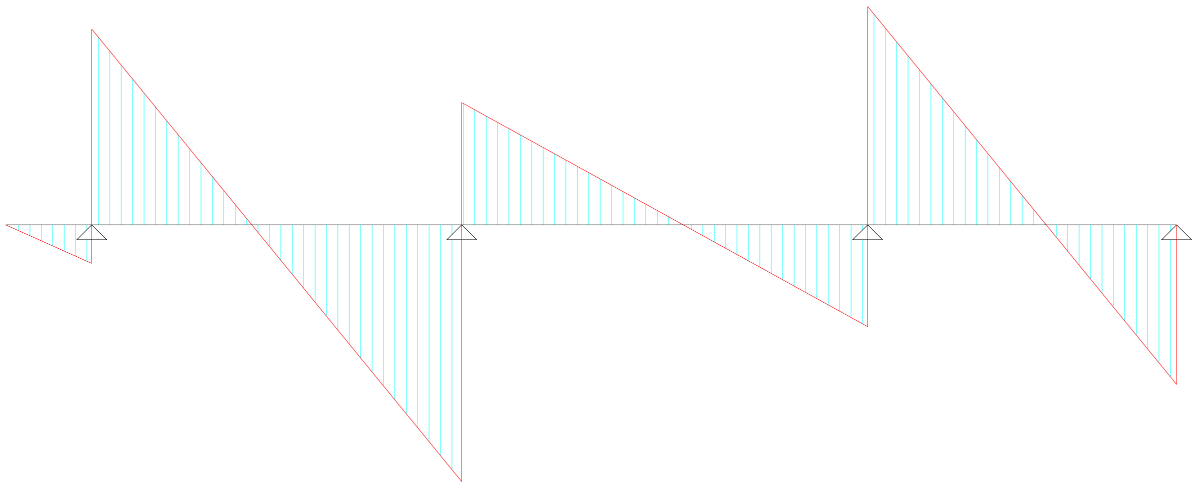
M_A'= 0

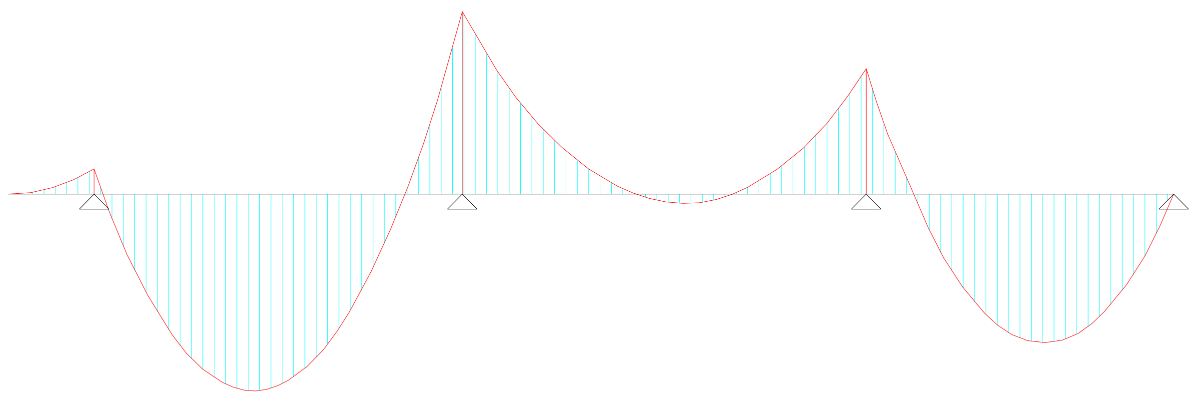
M_A = - 3.52 kNm

M_B = - 25.44 kNm

M_C = -17.50 kNm

M_D = 0





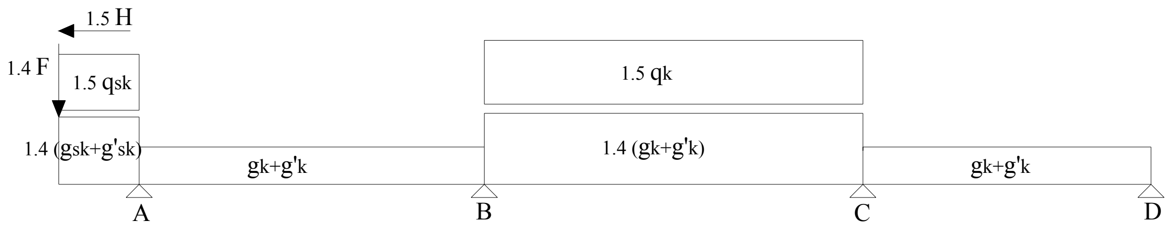
Combinazione S.L.U. 2

p_{sb}= 11.68 kN/m   M = 10.75 kNm   H* =1.5 kN L_{SB}= 1.20 m

F* = 14.72 kN p_1 = 5.52 kN/m L_1= 5.15 m

$X_B^{(2)}$ = 24.85 kNm p_2 = 12.23 kN/m L_2= 5.65 m

$X_C^{(2)}$ = 26.17 kNm p_3 = 5.52 kN/m L_3= 4.30 m



R_A = 26.20 kN $T_A^{(s)}$ = -14.72 kN M_A'= - 1.5 kNm

R_B = 51.27 kN $T_A^{(D)}$ = 11.48 kN M_A = - 10.75 kNm

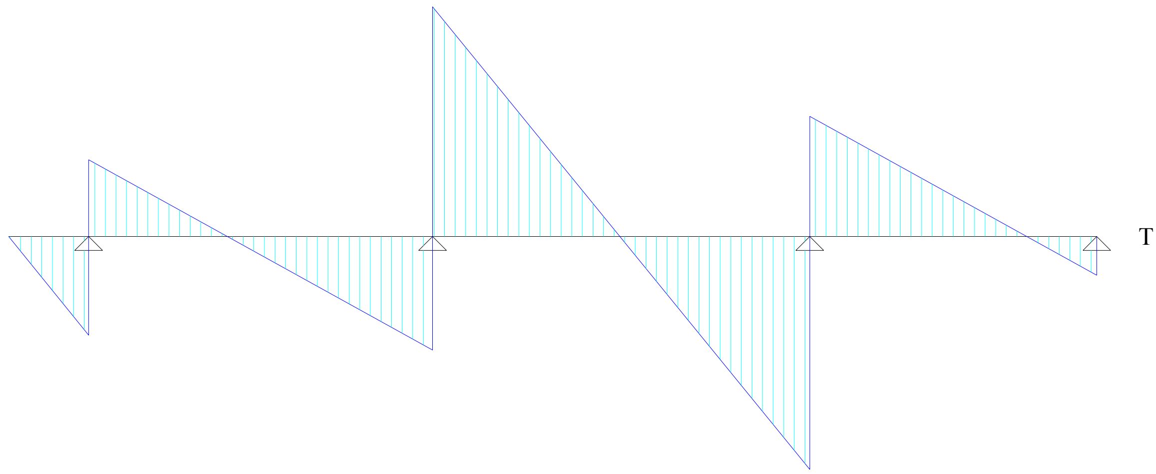
R_C = 52.74 kN $T_B^{(S)}$ = -16.95 kN M_B = - 24.85 kNm

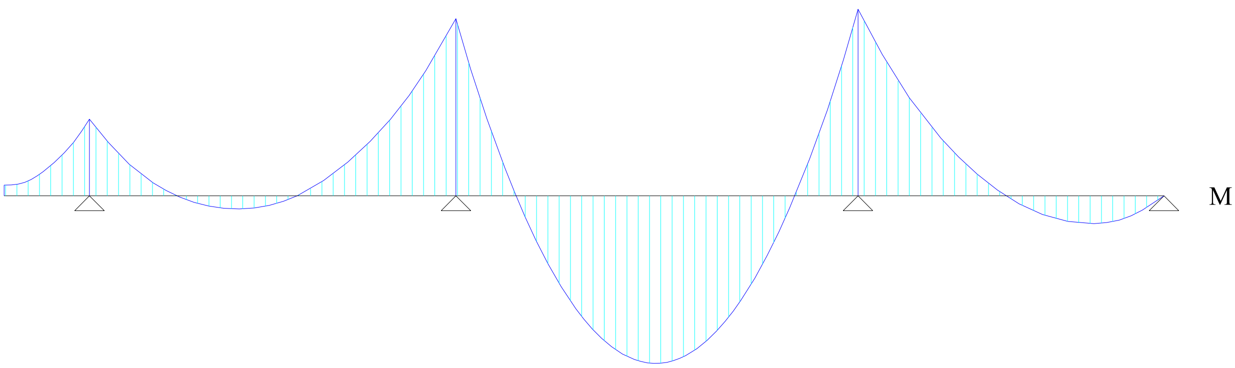
R_D = 5.78 kN $T_B^{(D)}$ = 34.32 kN M_C = - 26.17 kNm

$T_C^{(S)}$ = -34.78 kN M_D = 0

$T_C^{(D)}$ = 17.96 kN

$T_D^{(S)}$ = -5.78 kN



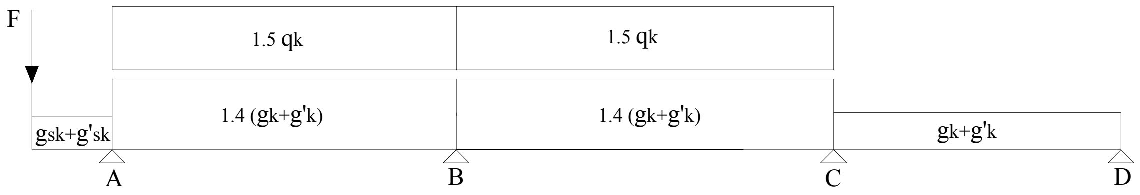


Combinazione S.L.U. 3

p_{sb}= 4.06 kN/m
F^* = 5.37 kN
$X_B^{(3)}$ = 38.17 kNm
$X_C^{(3)}$ = 22.39 kNm

M = 3.52 kNm
p_1 = 12.23 kN/m
p_2 = 12.23 kN/m
p_3 = 5.52 kN/m

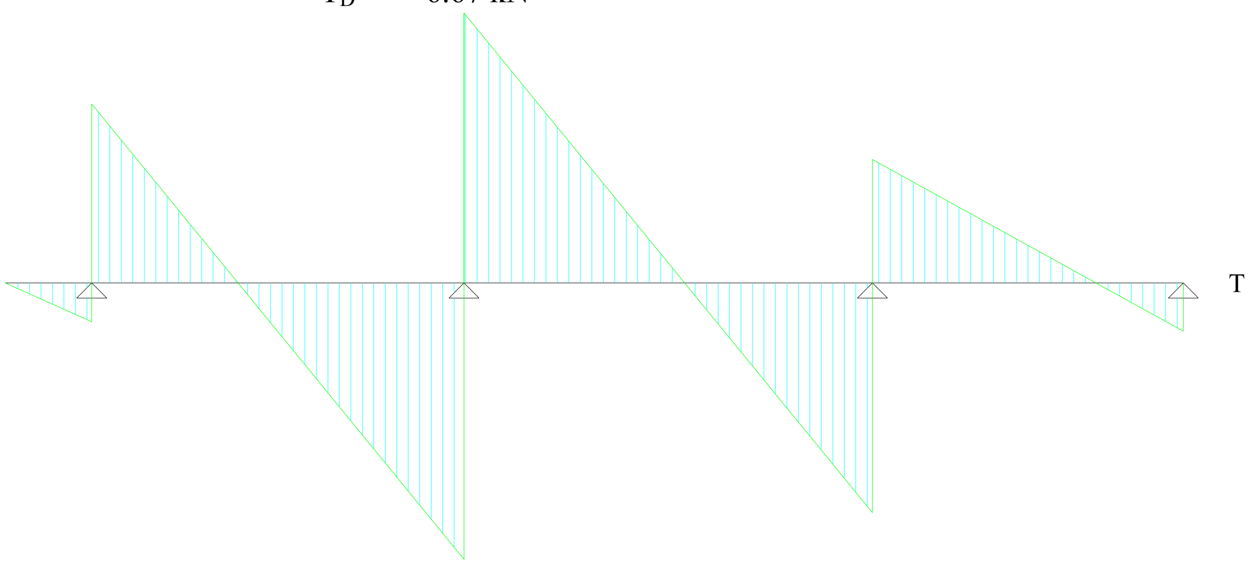
L_{SB}= 1.20 m
L_1= 5.15 m
L_2= 5.65 m
L_3= 4.30 m

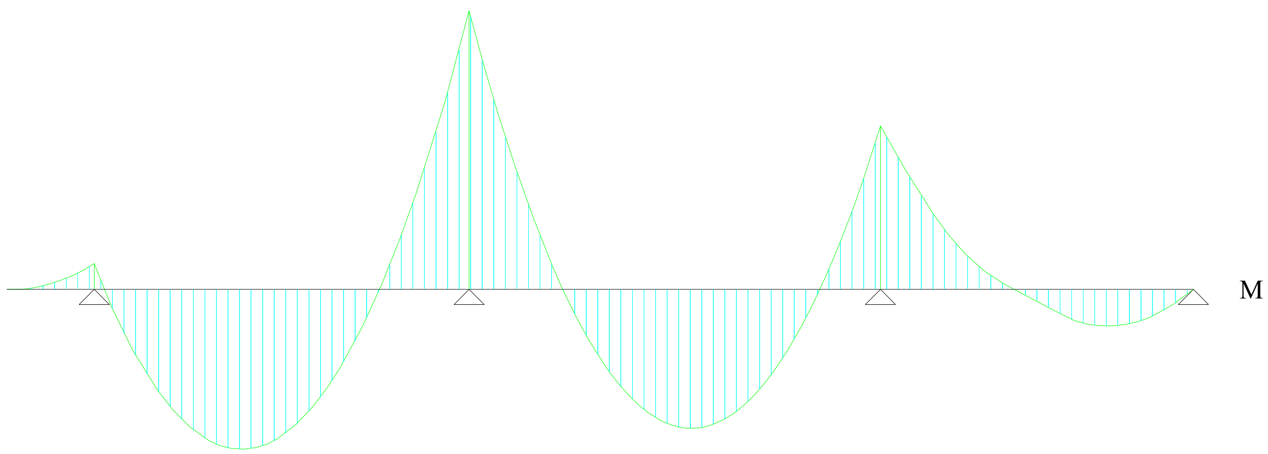


R_A = 30.13 kN
R_B = 75.56 kN
R_C = 48.83 kN
R_D = 6.66 kN

$T_A^{(s)}$ = -5.37 kN
$T_A^{(D)}$ = 24.76 kN
$T_B^{(S)}$ = -38.22 kN
$T_B^{(D)}$ = 37.34 kN
$T_C^{(S)}$ = -31.76 kN
$T_C^{(D)}$ = 17.07 kN
$T_D^{(S)}$ = -6.67 kN

M_A'= 0
M_A = - 3.52 kNm
M_B = - 38.17 kNm
M_C = - 22.39 kNm
M_D = 0





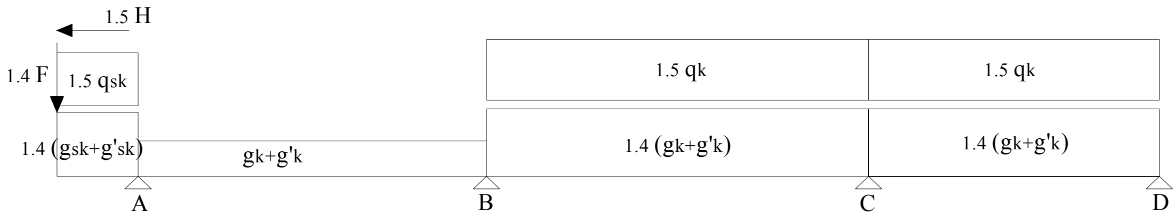
Combinazione S.L.U. 4

p_{sb}= 11.68 kN/m M = 10.75 kNm H* =1.5 kN L_{SB}= 1.20 m

F* = 14.72 kN p_1 = 5.52 kN/m L_1= 5.15 m

$X_B^{(4)}$ = 22.96 kNm p_2 = 12.23 kN/m L_2= 5.65 m

$X_C^{(4)}$ = 33.41 kNm p_3 = 12.23 kN/m L_3= 4.30 m



R_A = 26.56 kN $T_A^{(s)}$ = -14.72 kN M_A'= - 1.5 kNm

R_B = 49.28 kN $T_A^{(D)}$ = 11.84 kN M_A = - 10.75 kNm

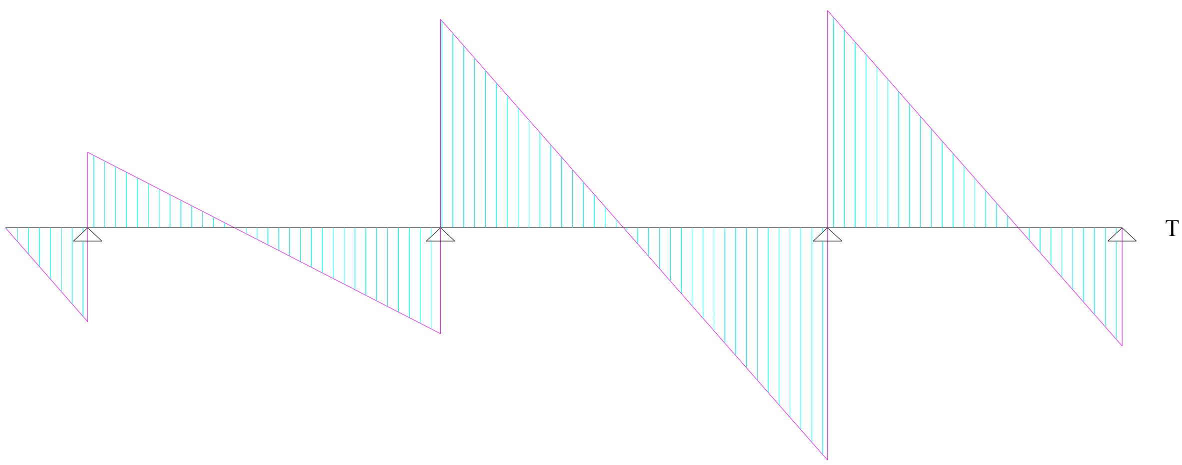
R_C = 70.46 kN $T_B^{(S)}$ = -16.59 kN M_B = - 22.96 kNm

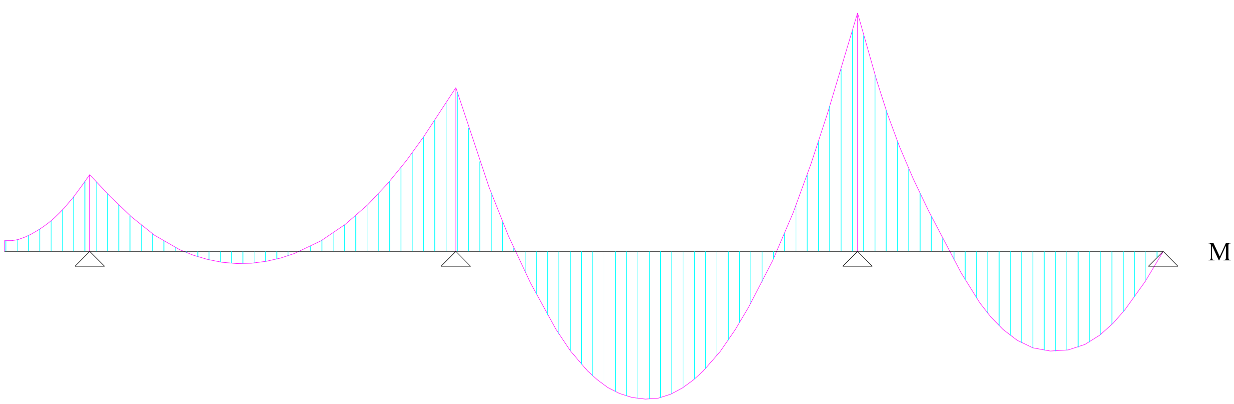
R_D = 18.52 kN $T_B^{(D)}$ = 32.69 kN M_C = - 33.41 kNm

$T_C^{(S)}$ = -36.41 kN M_D = 0

$T_C^{(D)}$ = 34.05 kN

$T_D^{(S)}$ = -18.54 kN





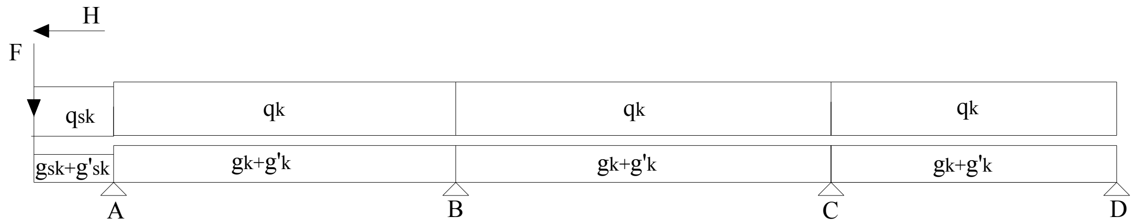
Combinazione S.L.S. 1 (rara)

p_{sb}= 8.06 kN/m M = 7.40 kNm H =1.00 kN L_{SB}= 1.20 m

F* = 10.17 kN p_1 = 8.52 kN/m L_1= 5.15 m

$X_B^{(R)}$ = 24.00 kNm p_2 = 8.52 kN/m L_2= 5.65 m

$X_C^{(R)}$ = 21.00 kNm p_3 = 8.52 kN/m L_3= 4.30 m



R_A = 28.88 kN $T_A^{(s)}$ = -10.17 kN M_A'= - 1.00 kNm

R_B = 49.76 kN $T_A^{(D)}$ = 18.71 kN M_A = - 7.40 kNm

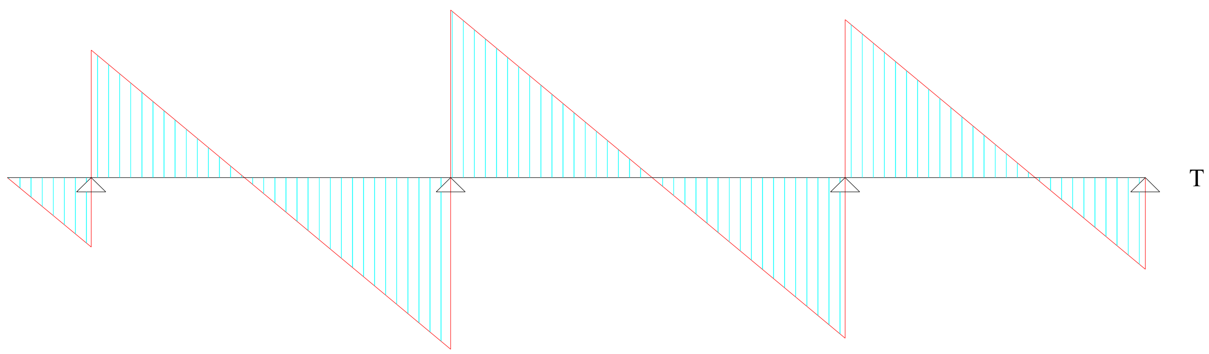
R_C = 46.74 kN $T_B^{(S)}$ = -25.17 kN M_B = - 24.00 kNm

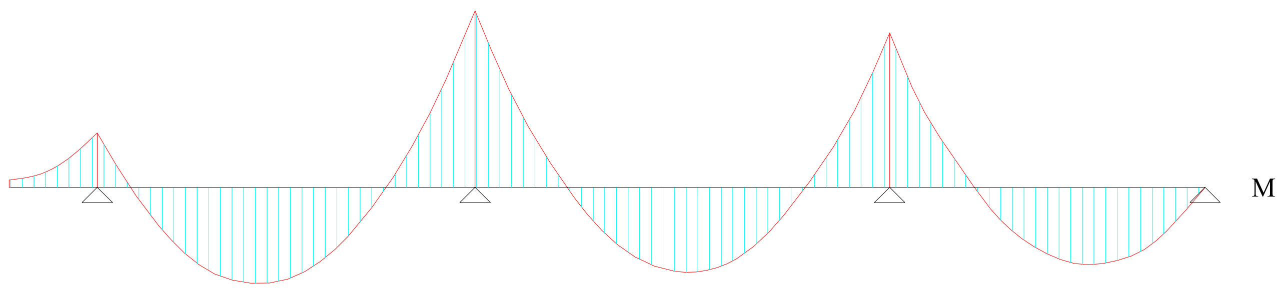
R_D = 13.43 kN $T_B^{(D)}$ = 24.59 kN M_C = - 21.00 kNm

$T_C^{(S)}$ = -23.55 kN M_D = 0

$T_C^{(D)}$ = 23.19 kN

$T_D^{(S)}$ = -13.44 kN





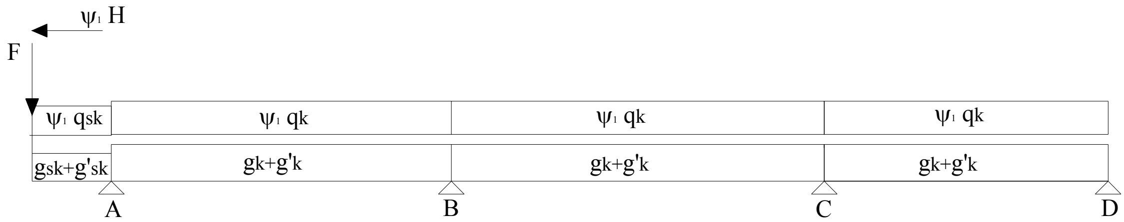
Combinazione S.L.S. 2 (frequente)

p_{sb}= 6.46 kN/m | M = 5.85 kNm | H* =0.60 kN | L_{SB}= 1.20 m

F* = 8.25 kN | p_1 = 7.32 kN/m | L_1= 5.15 m

$X_B^{(F)}$ = 20.75 kNm | p_2 = 7.32 kN/m | L_2= 5.65 m

$X_C^{(F)}$ = 18.01 kNm | p_3 = 7.32 kN/m | L_3= 4.30 m



R_A = 24.21 kN | $T_A^{(s)}$ = -8.25 kN | M_A'= - 0.60 kNm

R_B = 42.91 kN | $T_A^{(D)}$ = 15.96 kN | M_A = - 5.85 kNm

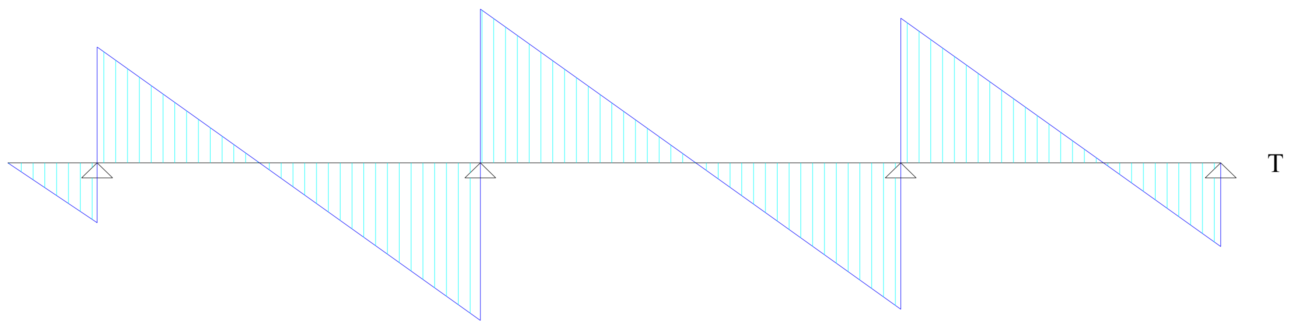
R_C = 40.12 kN | $T_B^{(S)}$ = -21.74 kN | M_B = - 20.75 kNm

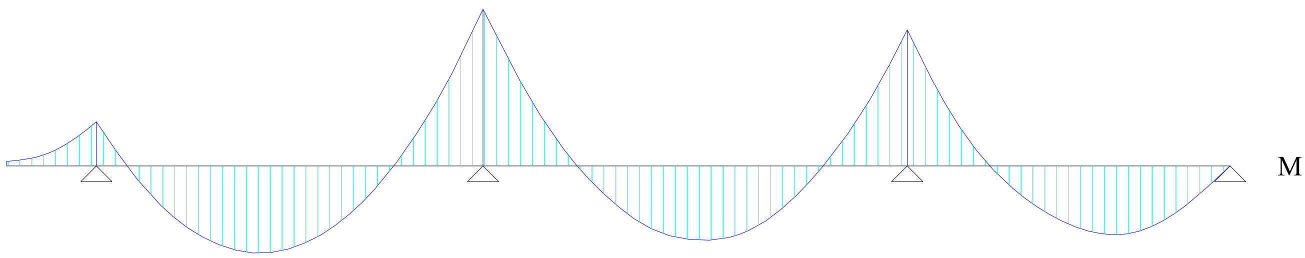
R_D = 11.55 kN | $T_B^{(D)}$ = 21.17 kN | M_C = - 18.01 kNm

$T_C^{(S)}$ = -20.19 kN | M_D = 0

$T_C^{(D)}$ = 19.93 kN

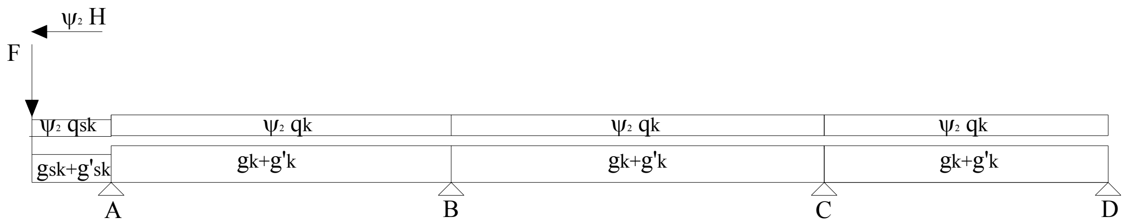
$T_D^{(S)}$ = -11.55 kN



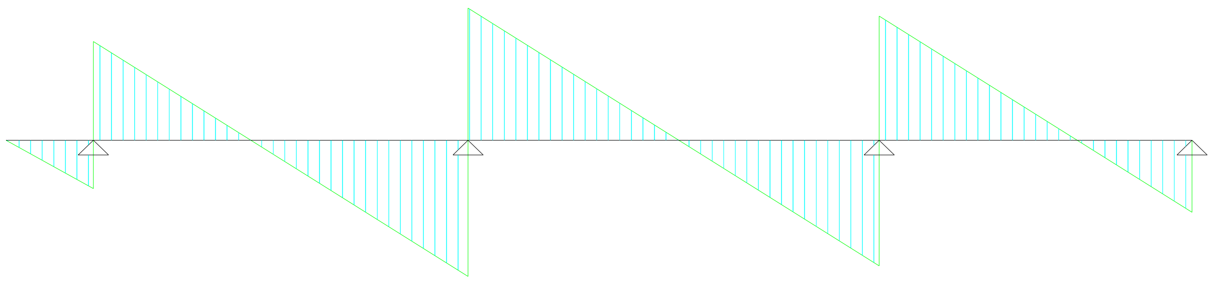


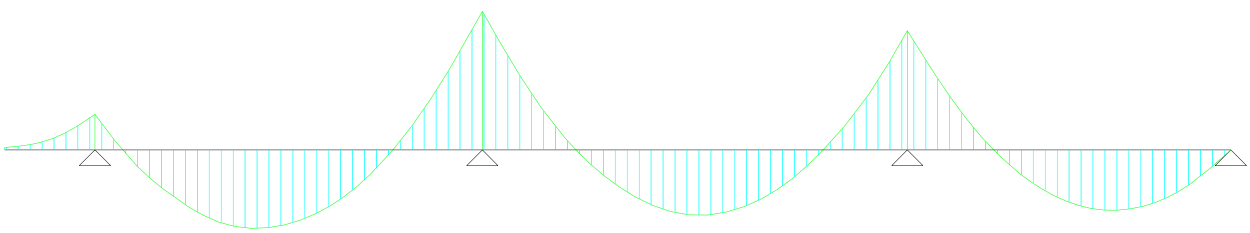
Combinazione S.L.S. 3 (quasi permanente)

p_{sb}= 5.26 kN/m	M = 4.69 kNm	H* =0.30 kN	L_{SB}= 1.20 m
F* = 6.81 kN	p_1 = 6.42 kN/m		L_1= 5.15 m
$X_B^{(Q,P)}$ = 18.31 kNm	p_2 = 6.42 kN/m		L_2= 5.65 m
$X_C^{(Q.P)}$ = 15.76 kNm	p_3 = 6.42 kN/m		L_3= 4.30 m

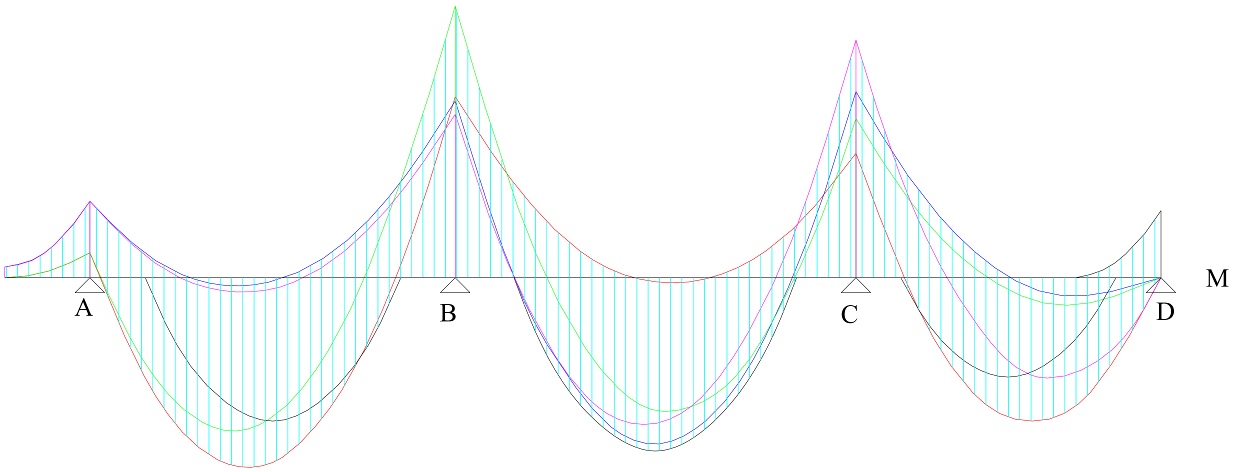


R_A = 20.70 kN	$T_A^{(s)}$ = -6.81 kN	M_A'= - 0.30 kNm
R_B = 37.76 kN	$T_A^{(D)}$ = 13.89 kN	M_A = - 4.69 kNm
R_C = 35.15 kN	$T_B^{(S)}$ = -19.17 kN	M_B = - 18.31 kNm
R_D = 10.14 kN	$T_B^{(D)}$ = 18.59 kN	M_C = - 15.76 kNm
	$T_C^{(S)}$ = -17.68 kN	M_D = 0
	$T_C^{(D)}$ = 17.47 kN	
	$T_D^{(S)}$ = -10.14 kN	





Inviluppo delle sollecitazioni allo stato limite ultimo



Momenti massimi agli appoggi

$\boldsymbol{M_A^{(max)}} = -M_A^{(4)} =$ ***- 10.75 kNm***

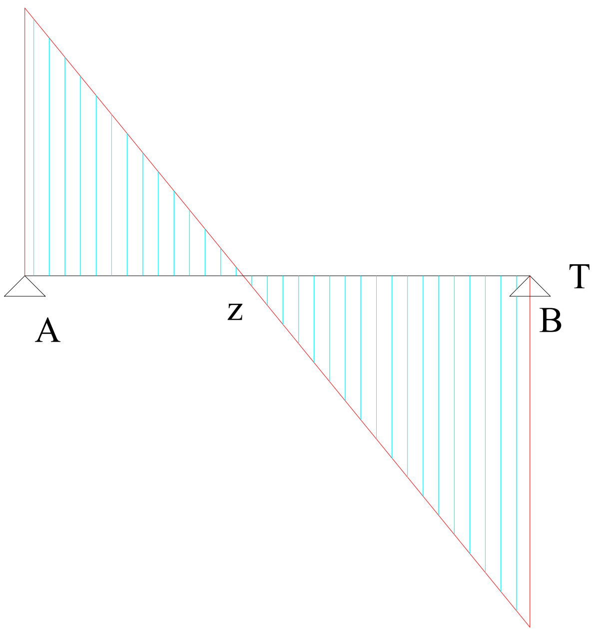
$\boldsymbol{M_B^{(max)}} = -X_B^{(3)} =$ ***- 38.17 kNm***

$\boldsymbol{M_C^{(max)}} = -X_C^{(4)} =$ ***- 33.41 kNm***

$\boldsymbol{M_D^{(max)}} = -\frac{p_3^{(d)} L_3^2}{24} =$ ***- 9.42 kNm***

Momenti massimi in campata

$\boldsymbol{M_{AB}^{(max)}}$ è dato dalla soluzione di carico S.L.U. 1 in corrispondenza del punto in cui il taglio è nullo.

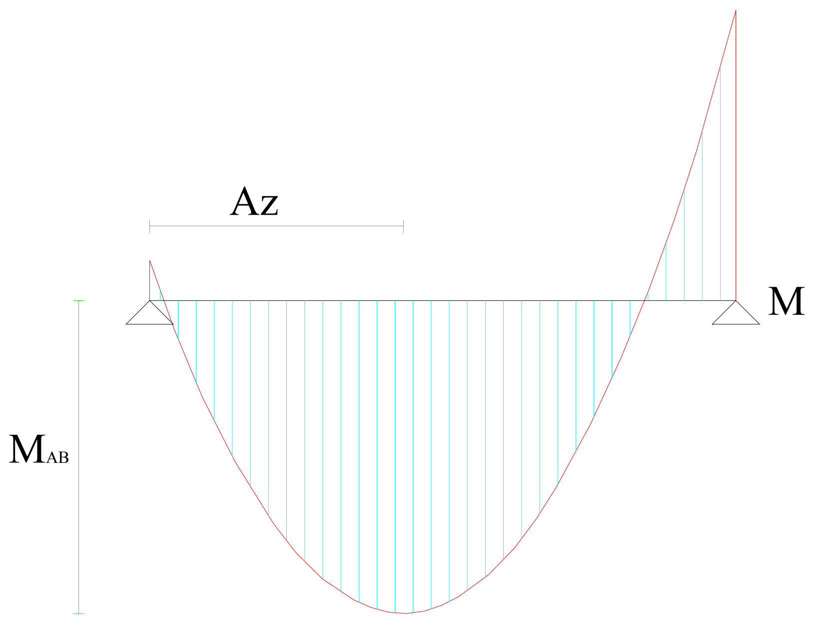


$T_A^{(D)} = 27.24$ kN $\qquad T_B^{(S)} = -35.75$ kN l'equazione del taglio è : T = Ax + C

$$\begin{cases} x = 0 \Rightarrow C = 27.24 \\ x = 5.15 \Rightarrow A \bullet 5.15 + 27.24 = -35.75 \Rightarrow A = -12.23 \end{cases}$$

-12.23 Az + 27.24 = 0

$$\boldsymbol{Az} = \frac{27.24}{12.23} = \boldsymbol{2.23\ m}$$



M_A = - 3.52 kNm M_B = - 25.44 kNm

$$M_{(x)} = \int T dx = \int (-12.23x + 27.24) dx = -12.23 \frac{x^2}{2} + 27.24\,x + \text{Cost}$$

x = 0 => Cost = -3.52

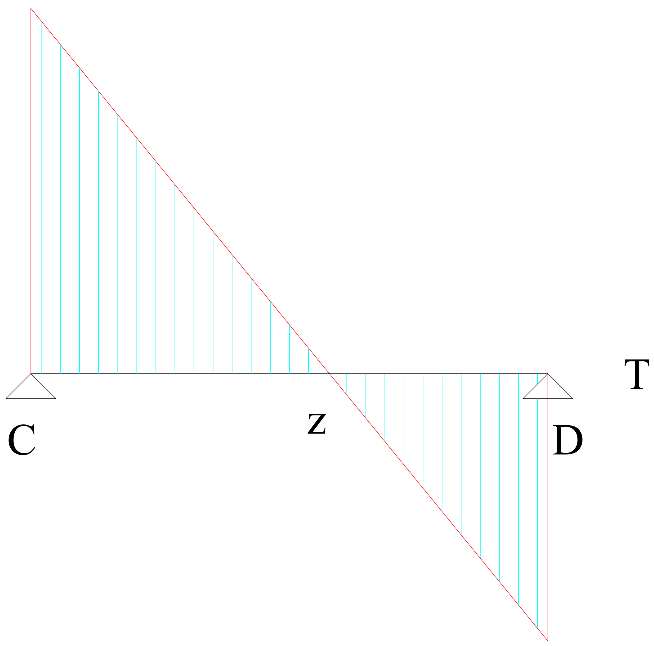
$$-12.23 \frac{x^2}{2} + 27.24\,x - 3.52 = 0$$

$$\boldsymbol{M_{AB}^{(max)}} = -12.23\ \frac{2.23^2}{2} + 27.24 \bullet 2.23 - 3.52 = \boldsymbol{26.82\ kNm}$$

$\boldsymbol{M_{BC}^{(max)}}$ è dato dall'aumento del momento in campata dovuto al semincastro

$$\boldsymbol{M_{BC}^{(max)}} = \frac{p_2^{(max)} L_2^2}{16} = \boldsymbol{24.40\ kNm}$$

$\boldsymbol{M_{CD}^{(max)}}$ è dato dalla soluzione di carico S.L.U. 1 in corrispondenza del punto in cui il taglio è nullo.



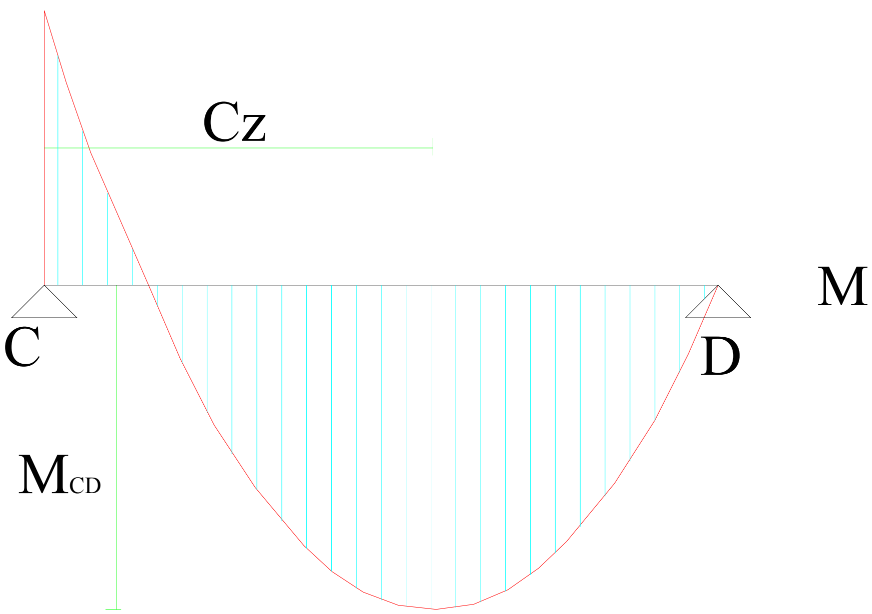
$T_C^{(D)} = 30.36$ kN $\qquad$ $T_D^{(S)} = -22.22$ kN

l'equazione del taglio è : T = Ax + C

$$\begin{cases} x = 0 \Rightarrow C = 30.36 \\ x = 4.30 \Rightarrow A \bullet 4.30 + 30.36 = -22.22 \Rightarrow A = -12.23 \end{cases}$$

-12.23 Cz + 30.36 = 0

$$\boldsymbol{Cz = \frac{30.36}{12.23} = 2.48\ m}$$



$M_C = -\ 17.50$ kNm $\qquad$ $M_D = 0$ kNm

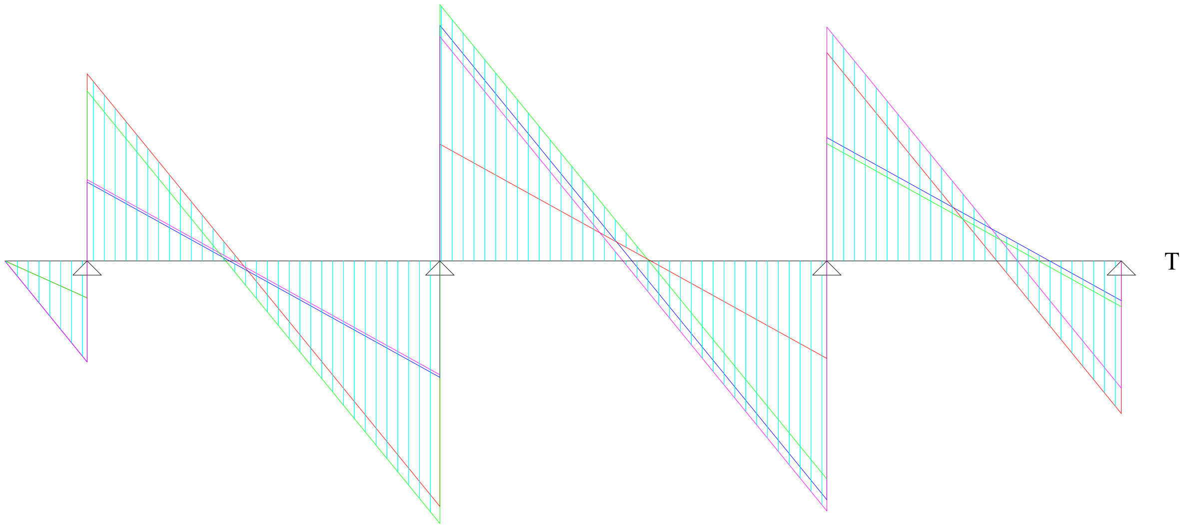
$M_{(x)} = \int T dx = \int (-12.23x + 30.36) dx = -\ 12.23 \frac{x^2}{2} + 30.36\ x + Cost$

x = 0 => Cost = -17.50

$-12.23 \frac{x^2}{2} + 30.36\ x - 17.50 = 0$

$M_{CD}^{(max)} = -12.23\ \frac{2.48^2}{2} + 30.36 \bullet 2.48 - 17.50 = \mathbf{20.18\ kNm}$

Inviluppo del taglio allo stato limite ultimo



$T_A = \begin{bmatrix} -14.72 kNm \\ 27.24 kNm \end{bmatrix}$

$T_B = \begin{bmatrix} -38.22 kNm \\ 37.34 kNm \end{bmatrix}$

$T_C = \begin{bmatrix} -36.41 kNm \\ 34.05 kNm \end{bmatrix}$

$T_D = 22.22\ kNm$

Progetto armatura

FeB38K => $\mathbf{f_{sk} = 375\ MPa}$

$f_{sd} = \frac{f_{sk}}{\gamma_s} = \frac{375}{1.15} = \mathbf{326.09\ MPa}$

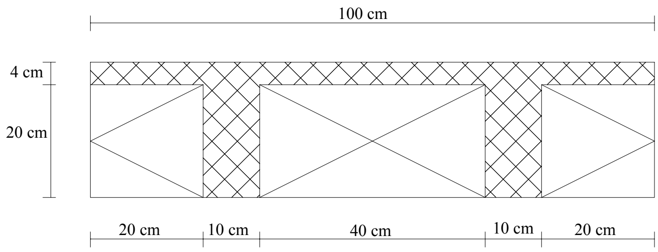
Rck = 25 Mpa $\quad f_{ck} = 0.83\ R_{ck} = 20{,}75$MPa => $\quad f_{ctm} = 0.27\ R_{ck}^{(2/3)} = 2.31$ MPa

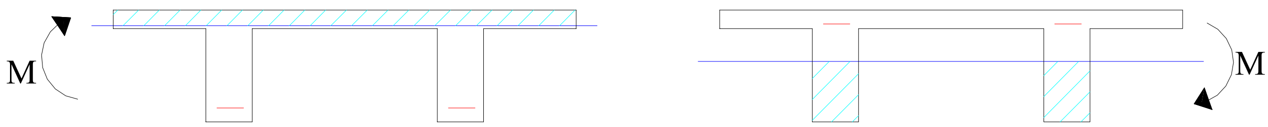
$f'_{cd} = \frac{0.83 \bullet 0.85 \bullet R_{ck}}{\gamma_c} = \mathbf{11\ MPa}$

$f_{ctk} = 0.7\ f_{ctm} = 1.62$ MPa

$f_{ctd} = \frac{f_{ctk}}{\gamma_c} = \frac{1.62}{1.6} = \mathbf{1.01\ MPa}$

Si progetta un solaio a semplice armatura quindi $\boldsymbol{\rho} = \frac{As^{I}}{As} = \mathbf{0}$





Campate centrali — **h = 24 cm** **d' = 3 cm**

Sbalzo — **h = 20 cm** **d' = 3 cm**

Utilizzando le formule di progetto

$\mathbf{r_u} = \frac{h}{\sqrt{\frac{Mu}{b}}}$ $\mathbf{As} = \frac{Mu}{\zeta f_{sd} h}$

e leggendo i valori corrispondenti di ζ e ξ si ottiene la seguente tabella

sezioni	M [kNm]	b [cm]	r_u	ζ	ξ	As [cm^2]	As,tr [cm^2]	Armature	**As [cm^2]**
A	-10.75	20	0.327	0.843	0.150	1.63	0.82	*2 Φ12*	**2.26**
AB	26.82	100	0.463	0.900	0.100	3.81	1.91	*2 Φ12*	**2.26**
	-	20	-	-	-	-	-	-	**-**
B	-38.17	60	0.301	0.835	0.169	5.84	2.92	*3 Φ12*	**3.39**
BC	24.40	100	0.486	0.900	0.100	3.47	1.74	*2 Φ12*	**2.26**
	-	20	-	-	-	-	-	-	**-**
C	-33.41	20	0.186	0.712	0.450	6.00	3.00	*3 Φ12*	**3.39**
CD	20.18	100	0.534	0.900	0.100	2.87	1.44	*2 Φ12*	**2.26**
	-	20	-	-	-	-	-	-	**-**
D	-9.42	20	0.350	0.849	0.138	1.42	0.71	*1 Φ12*	**1.13**

Nell'appoggio in B si considera una base di 60 cm al fine di ottenere un armatura di 3Φ12; ciò è possibile in quanto in realtà la base è 100 cm perché è presente la trave.

Considerando il taglio si ha:

$\mathbf{V_{Rd1}} = 0.25\ b_w\ d\ f_{ctd}\ r\ (\ 1 + 50\ \rho_l\ )\ \delta > T$

$\boldsymbol{\delta} = \mathbf{1}$ *(elemento inflesso)*

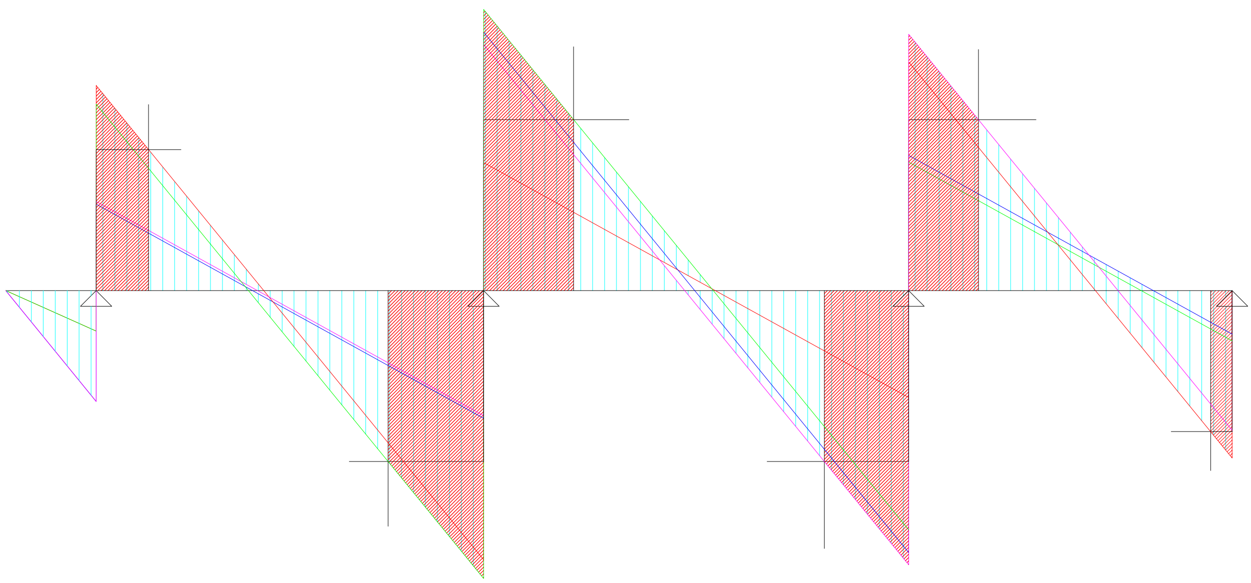
$\mathbf{r} = 1.6 - d > 1.00$

$\boldsymbol{\rho_l} = \dfrac{As}{bd}$

sezioni	T [kN]	b [cm]	As_l [cm^2]	ρ_l	V_{Rdi} [KN]	z_f [m]
A	-14.72	20	2.26	0.0066	16.33	0.00
	27.24	20		0.0054	18.72	0.70
B	-38.22	20	4.52	0.0108	22.70	1.27
	37.34	20				1.20
C	-36.41	20	4.52	0.0108	22.70	1.12
	34.05	20				0.93
D	22.22	20	2.26	0.0054	18.72	0.29

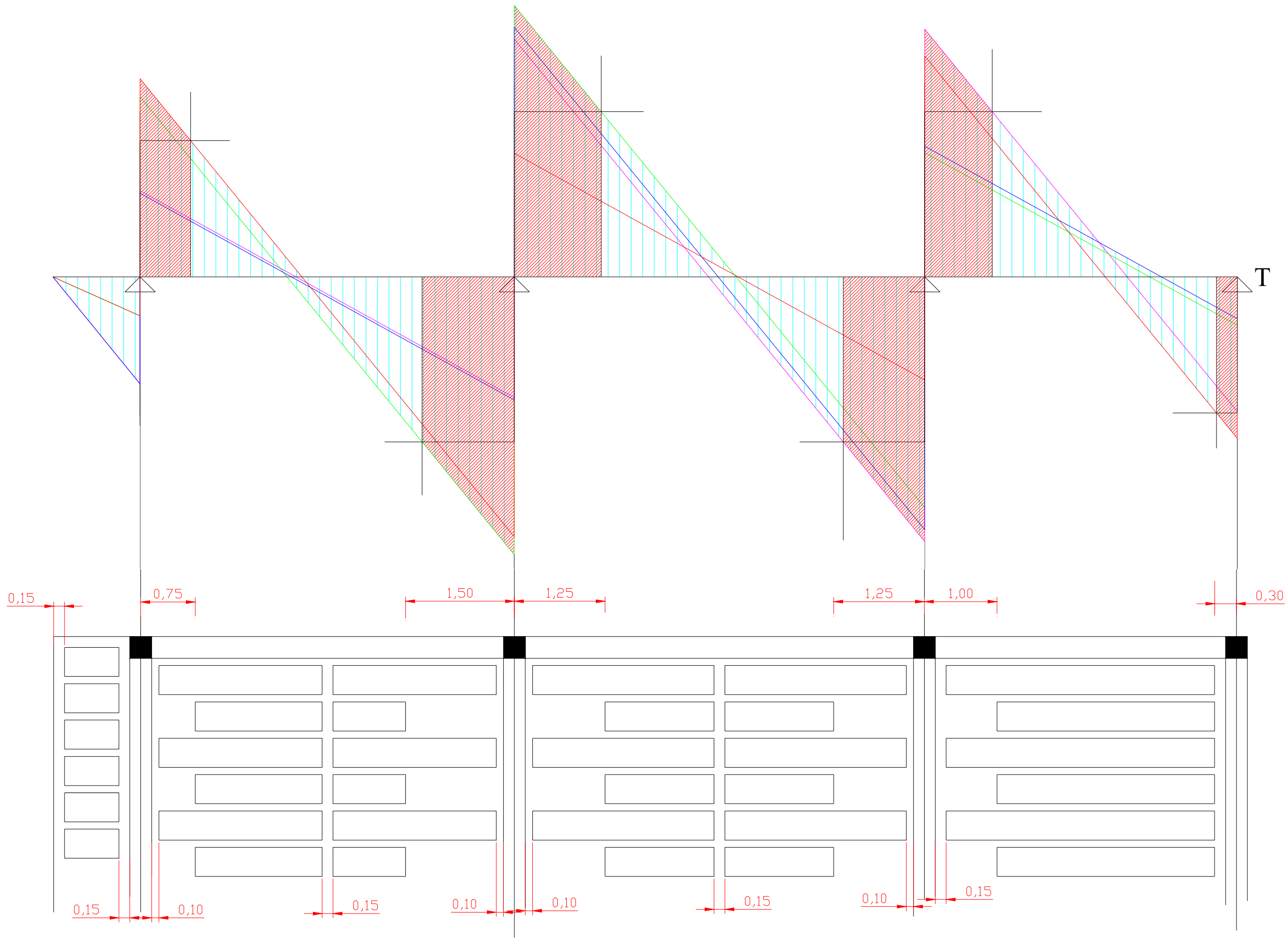
Nelle sezioni B e C si considera un As tesa data da due Φ12 per evitare di avere una fascia semipiena eccessivamente grande, ricordando di predisporre un ferro in più a trazione se ne è presente solo uno.

Nei casi in cui $V_{Rdi} < T$ la distanza z_f in cui si ha questa condizione è: $\mathbf{z_f} = \dfrac{|T_i| - V_{Rdi}}{p_d}$



Tratteggiato in rosso vi sono le zone in cui non è soddisfatta la verifica a taglio.

Si vanno quindi a definire delle fascie piene e semipiene allo scopo di aumentare la base per una maggiore resistenza a taglio di tali sezioni.



Determinazione dell'armatura

Considerando le armature inserite in ogni campata, si determina il momento resistente considerando **ζ =0.85**

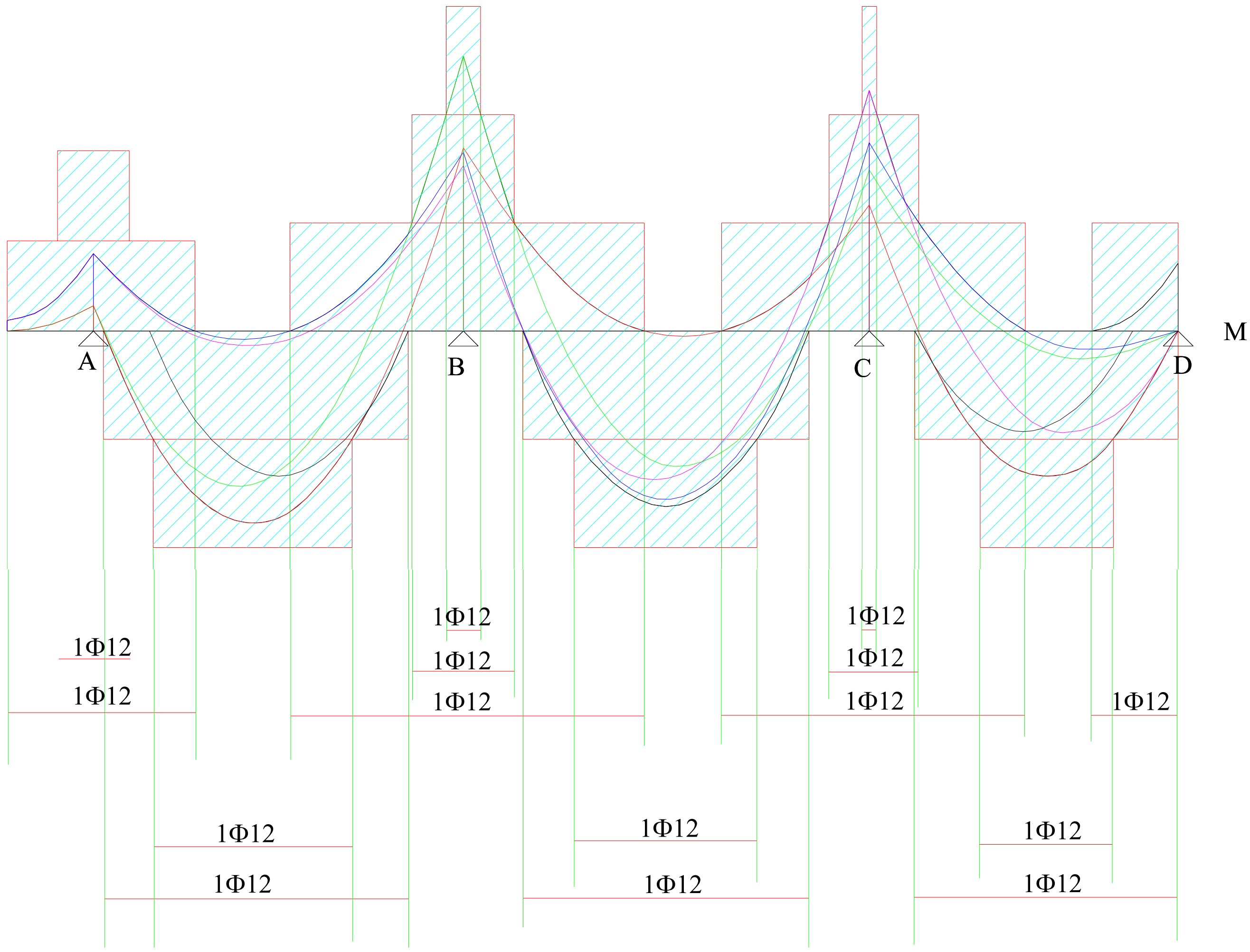
$\mathbf{M_{Rd} = 0.85\ h\ f_{sd}\ As}$

Tale momento dovra essere maggiore in ogni punto al momento sollecitante M_{sd}, quindi il diagramma del momento sollecitante dovrà risultare interno al diagramma del momento resistente.

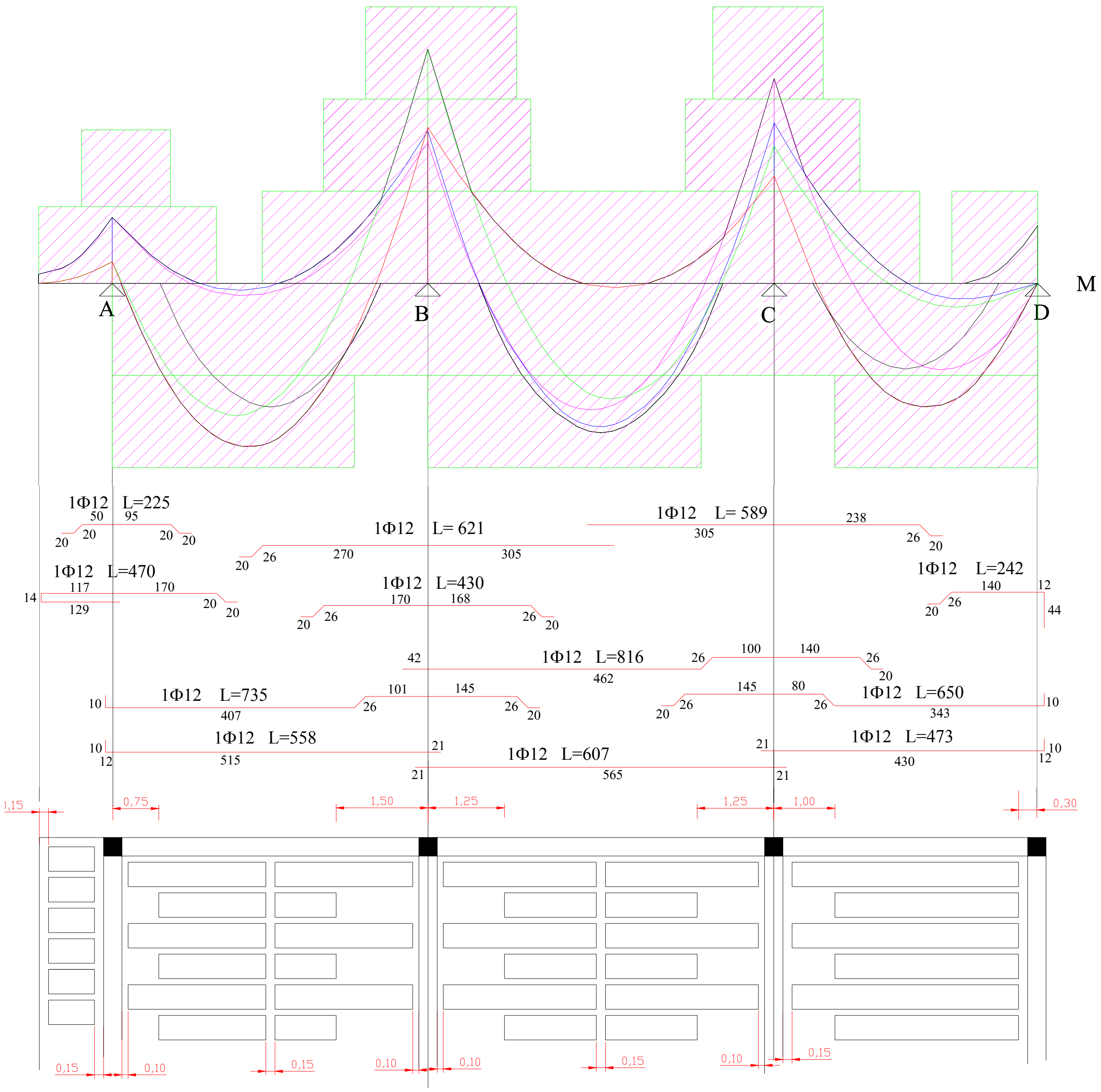
Φ12 => $M_{Rd} = 0.85 \times 200 \times 326 \times 113 \times 2 = 12524920\ Nmm$ = ***12.52 kNm*** sbalzo

Φ12 => $M_{Rd} = 0.85 \times 240 \times 326 \times 113 \times 2 = 15029904\ Nmm$ = ***15.03 kNm***

Primaria disposizione delle armature per travetto



Si va quindi a definire la distinta delle armature



Si va a verificare che in appoggio risulti $As_{min} \geq \frac{V_{sd}}{f_{sd}}$

e per l'armatura inferiore si abbia As > 0.07 h

Tali verifiche risultano soddisfatte per ogni punto del solaio.

Verifica allo stato limite ultimo

Tale verifica consiste nel determinare il momento resistente M_{Rd} e il taglio resistente V_{Rd} in ogni sezione significativa e confrontarli rispettivamente con il momento e il taglio sollecitante M_{sd} e V_{sd}, verificando che sussistano le seguenti condizioni:

$$|M_{Rd}| \geq |M_{sd}|$$

$$|V_{Rd}| \geq |V_{sd}|$$

con Ψ = 0.8 λ 0.4

Per basi di 60 e 100 cm si considera a semplice armatura a vantaggio di sicurezza

$$\mathbf{y_c} = \frac{As\, f_{sd}}{\Psi b\, f'_{cd}}$$

$$\mathbf{M_{Rd}} = \Psi b\, y_c\, f'_{cd}\,(h - d' - \lambda\, y_c)$$

Per base di 20 cm si fa la verifica a doppia armatura

$$\mathbf{y_c} = \frac{As\, f_{sd} - A's\, f_{sd}}{\Psi b\, f'_{cd}}$$

$$\mathbf{y_{2'2''}} = d' + \frac{\frac{f_{sd}}{E_s}}{0.01 + \frac{f_{sd}}{E_s}} \bullet (d - d') \qquad \mathbf{y_{3.4}} = \frac{0.0035}{\frac{f_{sd}}{E_s} + 0.0035} \bullet d$$

Se $y_{2'2''} < y_c < y_{3.4}$

$$\mathbf{M_{Rd}} = \Psi b\, y_c\, f'_{cd}\,(\frac{h}{2} - \lambda\, y_c) + A's\, f_{sd}\,(\frac{h}{2} - d') + As\, f_{sd}\,(\frac{h}{2} - d')$$

Se $y_c < y_{2'2''}$

y_c si ricava dalla risoluzione della seguente equazione di secondo grado

$$0.8b\, f'_{cd}\, y_c\, d - 0.8b\, f'_{cd}\, y_c^2 + (A's\, E_s\, 0.01)\, y_c - (A's\, E_s\, 0.01)d' - As\, f_{sd}\, d + As\, f_{sd}\, y_c = 0$$

$$\mathbf{M_{Rd}} = 0.8b\, f'_{cd}\, y_c\,(\frac{h}{2} - \lambda\, y_c) + A's\, E_s \frac{0.01(y_c - d')}{d - y_c}(\frac{h}{2} - d') + As\, f_{sd}\,(\frac{h}{2} - d')$$

Se $y_c > y_{3.4}$

y_c si ricava dalla risoluzione della seguente equazione di secondo grado

$$0.8b\, f'_{cd}\, y_c^2 + (A's\, f_{sd} + As\, E_s\, 0.0035)\, y_c - A's\, E_s\, 0.0035 d = 0$$

$$\mathbf{M_{Rd}} = 0.8b\, f'_{cd}\, y_c\,(\frac{h}{2} - \lambda\, y_c) + A's\, f_{sd}\,(\frac{h}{2} - d') + As\, E_s \frac{0.0035}{y_c}(d - y_c)(\frac{h}{2} - d')$$

Per il taglio

$$V_{Rd1} = 0.25\, b\, d\, f_{ctd}\, r\, (1 + 50\, \rho_l)\, \delta \qquad \rho_l = \frac{As}{bd}$$

Verifica allo stato limite di servizio

Tale verifica va condotta determinando l'entità delle tensioni nel calcestruzzo e nell'acciaio; in particolare dovrà risultare:

$$\left.\begin{array}{l}\sigma_c \le 0.60\, f_{ck} \\ \sigma_S \le 0.70\, f_{Sk}\end{array}\right\}$$ ***per la combinazione rara***

$$\left.\begin{array}{l}\sigma_c \le 0.45\, f_{sk} \\ \sigma_s \le 0.70\, f_{sk}\end{array}\right\}$$ ***per la combinazione quasi permanente***

Ciò equivale a verificare che in entrambe le combinazioni i momenti resistenti del cls e dell'acciaio M_{rc} e M_{rs} relativi alle tensioni limite devono risultare maggiori del momento sollecitante.

Combinazione rara

$$\begin{cases} y_{c,r} = \dfrac{n(A_S + A'_S)}{b}\left[-1+\sqrt{1+\dfrac{2b(A_S d + A'_S d')}{n(A_S + A'_S)^2}}\right] \\ M_{rc,r} = \dfrac{I_n}{y_c} 0.60\, f_{ck} \\ M_{rs,r} = \dfrac{I_n}{n(d - y_c)} 0.70\, f_{sk} \end{cases}$$

Combinazione quasi permanente

$$\begin{cases} y_{c,qp} = \dfrac{n(A_S + A'_S)}{b}\left[-1+\sqrt{1+\dfrac{2b(A_S d + A'_S d')}{n(A_S + A'_S)^2}}\right] \\ M_{rc,qp} = \dfrac{I_n}{y_c} 0.45\, f_{ck} \\ M_{rs,qp} = \dfrac{I_n}{n(d - y_c)} 0.70\, f_{sk} \end{cases}$$

$$\boldsymbol{I_n} = \frac{b\, y_c^3}{3} + n\, A'_S (y_c - d')^2 + n\, A_S (d - y_c)^2$$

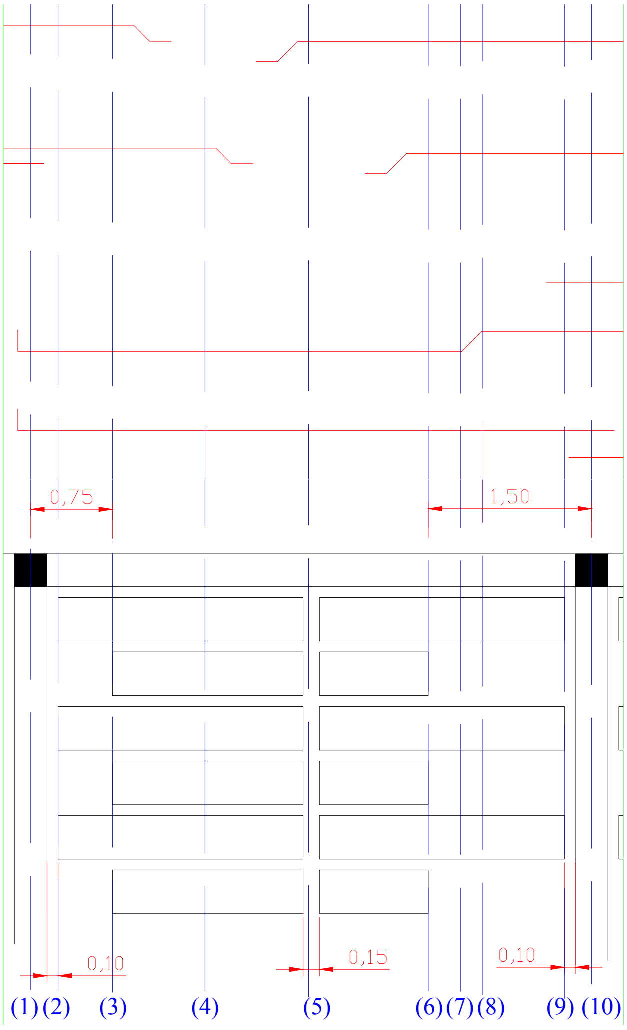
n = 15 per normativa

Nel caso del momento positivo se y_c > 40 mm la sezione non è più rettangolare ma a T ; in questo caso nei calcoli si trascura il contribbuto dell'anima a compressione in quanto di piccole dimensioni, il tutto a vantaggio di sicurezza.

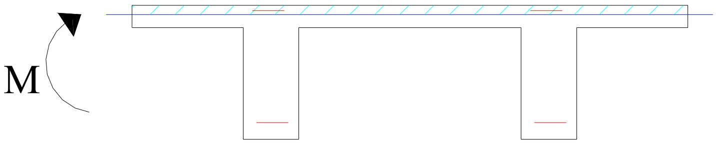
In momento positivo se y_c > 40 mm

$$\begin{cases} y_c = \dfrac{\dfrac{b\, s^2}{2} + n\, A'_S d' + n\, A_S d}{bs + n\, A'_S + n\, A_S} \\ I_n = \dfrac{b\, y_c^3}{3} - \dfrac{b\,(y_C - s)^3}{3} + n\, A'_S (y_C - d')^2 + n\, A_S (d - y_C)^2 \end{cases}$$

Campata AB

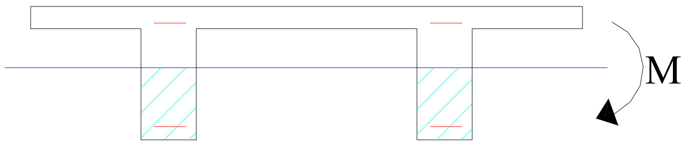


Momento positivo (b = 100)



sez	z [m]	b [mm]	h [mm]	A's [mm²]	As [mm²]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm⁴]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	452	452	16,74	29,95	50,38	$2,176*10^8$	53.77	23.86	40.33	23,86
2	0,25	1000	240	452	452	16.74	29.95	50.38	$2,176*10^8$	53.77	23.86	40.33	23,86
3	0,75	1000	240	226	452	16,74	29,95	49.05	$2,162*10^8$	54.88	23,51	41.16	23,51
4	1,60	1000	240	0	452	16,74	29,95	47.54	$2,146*10^8$	56,20	23.31	42,15	23.31
5	2,55	1000	240	226	452	16,74	29,95	46,35	$2,156*10^8$	57,91	23,05	43,43	23,05
6	3.65	1000	240	452	452	16.74	29.95	45.32	$2,164*10^8$	59.45	23.00	44.59	23.00
7	3.95	1000	240	452	226	8,37	15,23	33.80	$1,182*10^8$	43,54	11,74	32,65	11,74
8	4,14	1000	240	678	226	8,37	15,23	33,53	$1,183*10^8$	43,93	11,73	32,94	11,73
9	4.9	1000	240	678	226	8.37	15.23	33.53	$1,183*10^8$	43,93	11,73	32,94	11,73

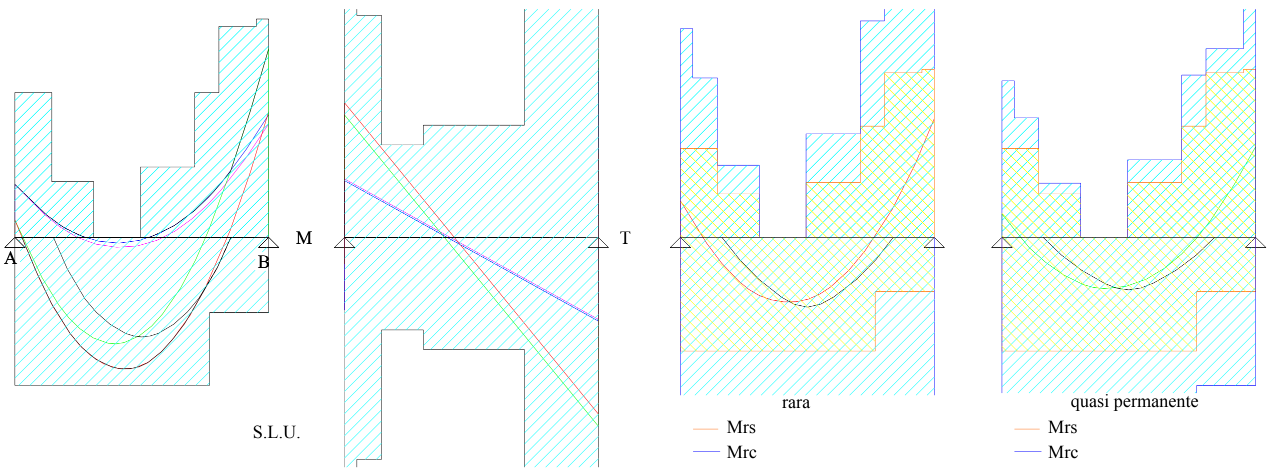
Momento negativo (b variabile)



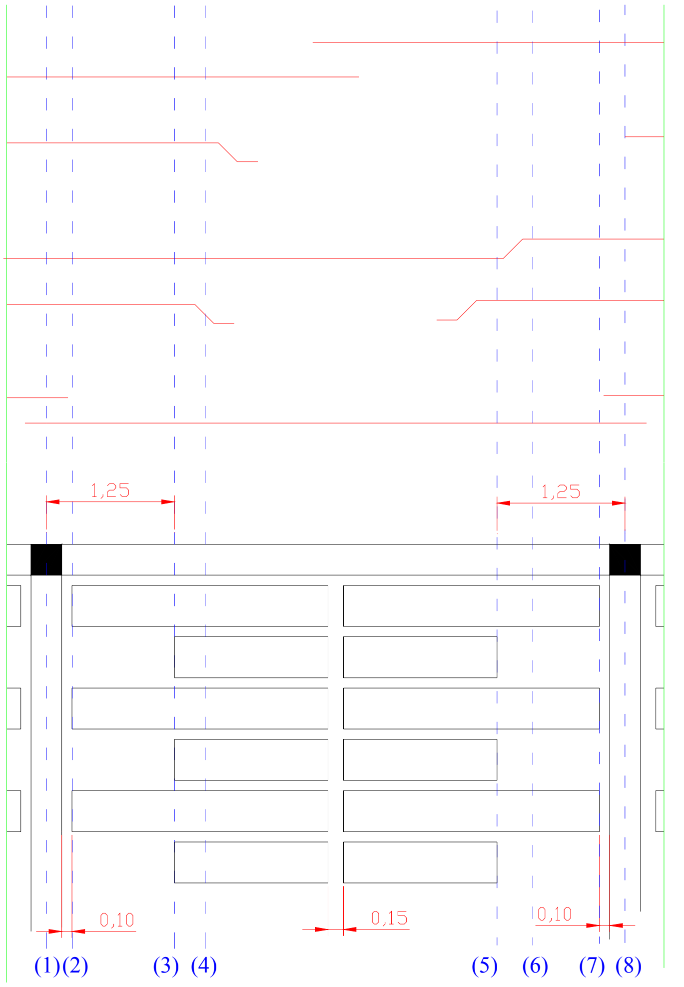
sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	452	452	16.74	29.95	40.25	$1.366*10^8$	42.25	18.42	31.69	18.42
2	0,25	600	240	452	452	27.91	29.30	48.33	$1.252*10^8$	32.25	18.01	24.19	18.01
3	0,75	200	240	452	226	32.41	11.28	51.05	$5.984*10^7$	14.59	8.80	10.95	8.80
4	1,60	200	240	452	0	----	-----	-----	-------	-----	------	-----	------
5	2,55	200	240	452	226	32.93	14.24	57,49	$9,664*10^7$	20,93	11,09	15,70	11,09
6	3.65	600	240	452	452	27.91	29.30	54.44	$2.004*10^8$	45.83	22.54	34.37	22.54
7	3.95	600	240	226	452	27.91	29.30	56.35	$1.982*10^8$	43.79	22.57	32.84	22.57
8	4,14	600	240	226	678	41.86	42.71	66.67	$2.727*10^8$	50.92	33.29	38.19	33.29
9	4.9	1000	240	226	678	25.12	44.19	54.69	$3.019*10^8$	68.73	34.02	51.54	34.02

Taglio

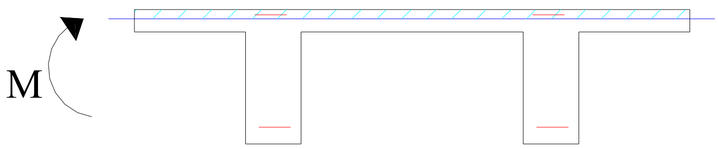
sezioni	z [m]	b [mm]	h [mm]	As_t [mm^2]	ρl	V_{Rd1} [kN]	V_{Sd} [kN]
1	0	1000	240	452	0,0027	69,67	27.24
2	0,25	600	240	452	0,0044	44,93	24.18
3	0,75	200	240	226	0,0054	18.72	18,07
4	1,60	200	240	452	0,0108	22,70	7,67
5	2,55	200	240	452	0,0108	22,70	6,42
6	3.65	600	240	452	0,0036	52,18	19,88
7	3.95	600	240	226	0.0018	48,20	23.54
8	4,14	600	240	678	0,0054	56,16	25.87
9	4.9	1000	240	678	0,0032	85,50	35.16



Campata BC

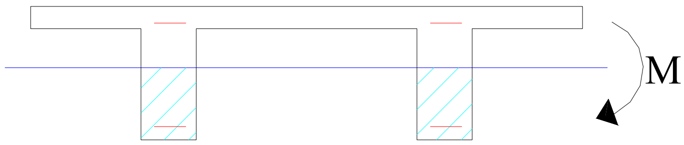


Momento positivo (b = 100 cm)



sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	678	452	16,74	29,95	44,25	$2{,}172*10^8$	61,11	22,93	45,83	22,93
2	0.25	1000	240	678	452	16,74	29,95	44,25	$2{,}172*10^8$	61,11	22,93	45,83	22,93
3	1,25	1000	240	452	452	16.74	29.95	45.32	$2{,}164*10^8$	59.45	23.00	44.59	23.00
4	1,55	1000	240	226	452	16,74	29,95	46,35	$2{,}156*10^8$	57,91	23,05	43,43	23,05
5	4,40	1000	240	452	226	8,37	15,23	33.80	$1{,}182*10^8$	43,54	11,74	32,65	11,74
6	4,75	1000	240	678	226	8,37	15,23	33,53	$1{,}183*10^8$	43,93	11,73	32,94	11,73
7	5,40	1000	240	678	226	8,37	15,23	33,53	$1{,}183*10^8$	43,93	11,73	32,94	11,73

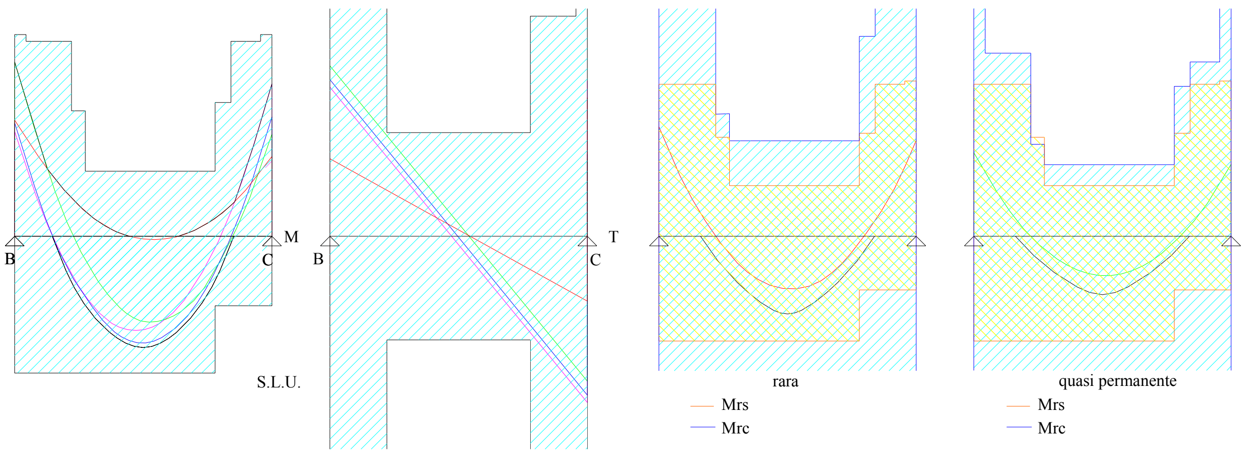
Momento negativo (b variabile)



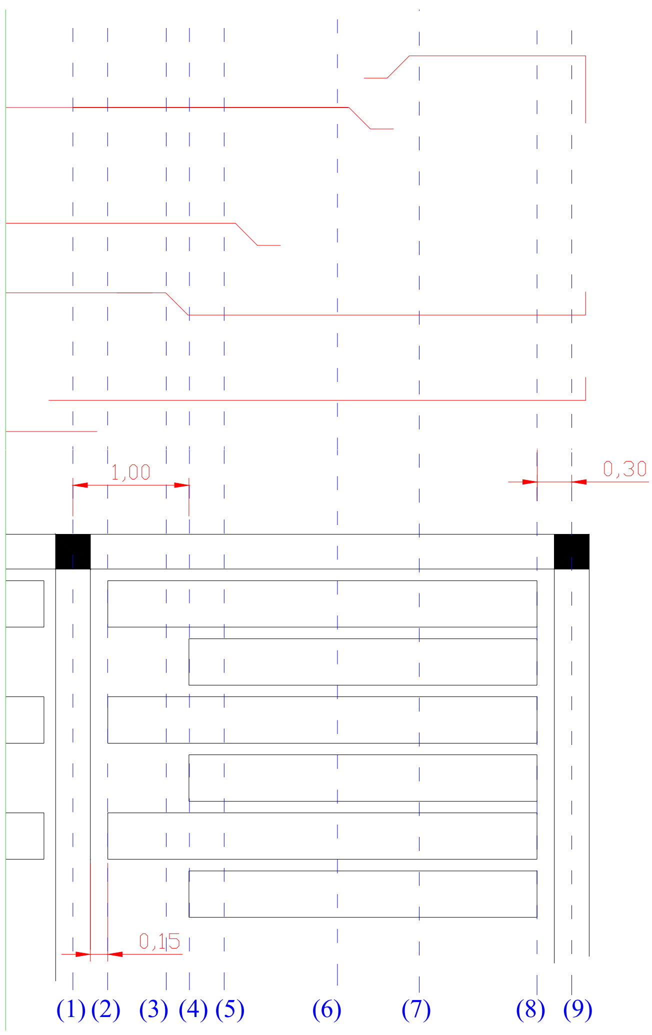
sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	452	678	25,12	44,20	53,52	3,039*10^8	70,69	33,99	53,02	33,99
2	0.25	600	240	452	678	41,86	42,71	64,46	2,770*10^8	53,50	33,31	40,12	33,31
3	1,25	200	240	452	452	42,71	27,49	76,66	1,653*10^8	26,84	21,69	20,13	21,69
4	1,55	200	240	452	226	32.93	14.24	57,49	9,664*10^7	20,93	11,09	15,70	11,09
5	4,40	600	240	226	452	27.91	29.30	56.35	1.982*10^8	43.79	22.57	32.84	22.57
6	4,75	600	240	226	678	41.86	42.71	66.67	2.727*10^8	50.92	33.29	38.19	33.29
7	5,40	1000	240	226	678	25.12	44.19	54.69	3.019*10^8	68.73	34.02	51.54	34.02

Taglio

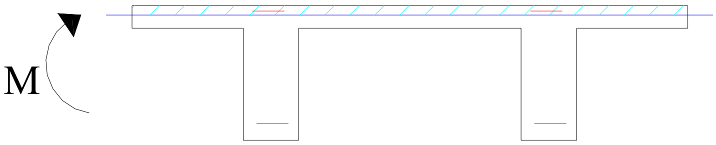
sezioni	z [m]	b [mm]	h [mm]	As_t [mm^2]	ρl	V_{Rd} [kN]	V_{Sd} [kN]
1	0	1000	240	678	0,0032	85,50	37,34
2	0.25	600	240	678	0,0054	56,16	34,28
3	1,25	200	240	452	0,0108	22,70	22,05
4	1,55	200	240	452	0,0108	22,70	18,38
5	4,40	600	240	226	0.0018	48,20	21,12
6	4,75	600	240	226	0.0018	48,20	25,40
7	5,40	1000	240	678	0,0032	85,50	33,35



Campata CD

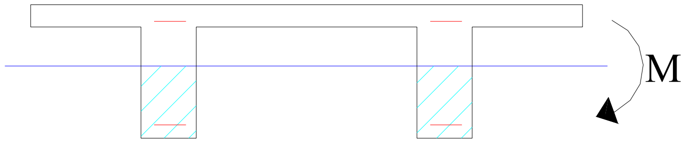


Momento positivo (b = 100 cm)



sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	678	226	8,37	15,23	33,53	$1{,}183 \cdot 10^8$	43,93	11,73	32,94	11,73
2	0.30	1000	240	678	226	8,37	15,23	33,53	$1{,}183 \cdot 10^8$	43,93	11,73	32,94	11,73
3	0.80	1000	240	452	226	8,37	15,23	33.80	$1{,}182 \cdot 10^8$	43,54	11,74	32,65	11,74
4	1,00	1000	240	452	452	16.74	29.95	45.32	$2{,}164 \cdot 10^8$	59.45	23.00	44.59	23.00
5	1,30	1000	240	226	452	16,74	29,95	46,35	$2{,}156 \cdot 10^8$	57,91	23,05	43,43	23,05
6	2,30	1000	240	0	452	16,74	29,95	47.54	$2{,}146 \cdot 10^8$	56,20	23.31	42,15	23.31
7	3,00	1000	240	226	452	16,74	29,95	46,35	$2{,}156 \cdot 10^8$	57,91	23,05	43,43	23,05
8	4,00	1000	240	226	452	16,74	29,95	46,35	$2{,}156 \cdot 10^8$	57,91	23,05	43,43	23,05

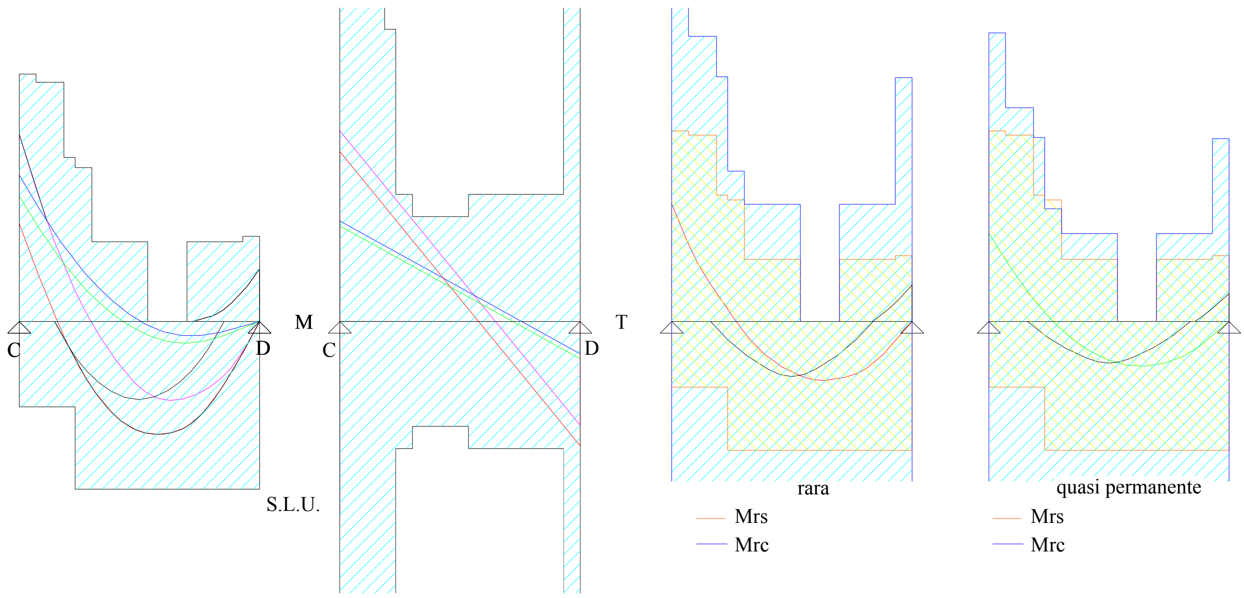
Momento negativo (b variabile)



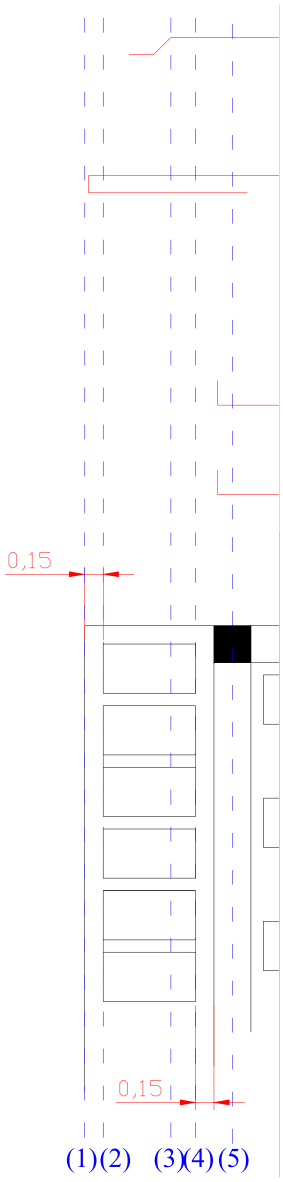
sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	240	226	678	25.12	44.19	54.69	$3.019*10^8$	68.73	34.02	51.54	34.02
2	0.30	600	240	226	678	41.86	42.71	66.67	$2.727*10^8$	50.92	33.29	38.19	33.29
3	0.80	600	240	226	452	27.91	29.30	56.35	$1.982*10^8$	43.79	22.57	32.84	22.57
4	1,00	200	240	452	452	42,71	27,49	76,66	$1,653*10^8$	26,84	21,69	20,13	21,69
5	1,30	200	240	452	226	32.93	14.24	57,49	$9,664*10^7$	20,93	11,09	15,70	11,09
6	2,30	200	240	452	0	-----	------	------	--------	----	----	-----	-----
7	3,00	200	240	452	226	32.93	14.24	57,49	$9,664*10^7$	20,93	11,09	15,70	11,09
8	4,00	1000	240	452	226	8,37	15,23	33.80	$1,182*10^8$	43,54	11,74	32,65	11,74

Taglio

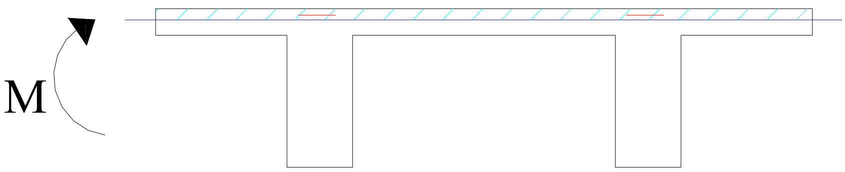
sezioni	z [m]	b [mm]	h [mm]	As_t [mm^2]	ρl	V_{Rd} [kN]	V_{Sd} [kN]
1	0	1000	240	678	0,0032	85,50	34,05
2	0.30	600	240	678	0,0054	56,16	30,38
3	0.80	600	240	452	0,0036	52,18	24,27
4	1,00	200	240	452	0.0108	22,70	21,82
5	1,30	200	240	226	0,0054	18,72	18,15
6	2,30	200	240	452	0,0108	22,70	5,92
7	3,00	200	240	452	0,0108	22,70	6,32
8	4,00	1000	240	226	0,0011	77,76	18,55



Sbalzo

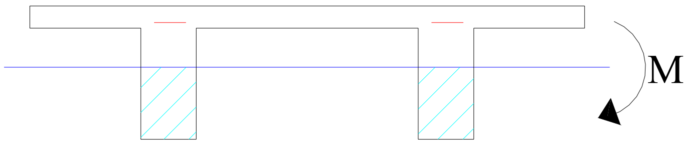


Momento positivo (b = 100 cm)



sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
1	0	1000	200	226	0	-----	------	-----	--------	-----	-----	----	----
2	0.15	1000	200	226	0	-----	------	-----	--------	-----	-----	----	----
3	0.70	1000	200	452	0	-----	------	-----	--------	-----	-----	----	----
4	0,90	1000	200	452	0	-----	------	-----	--------	-----	-----	----	----

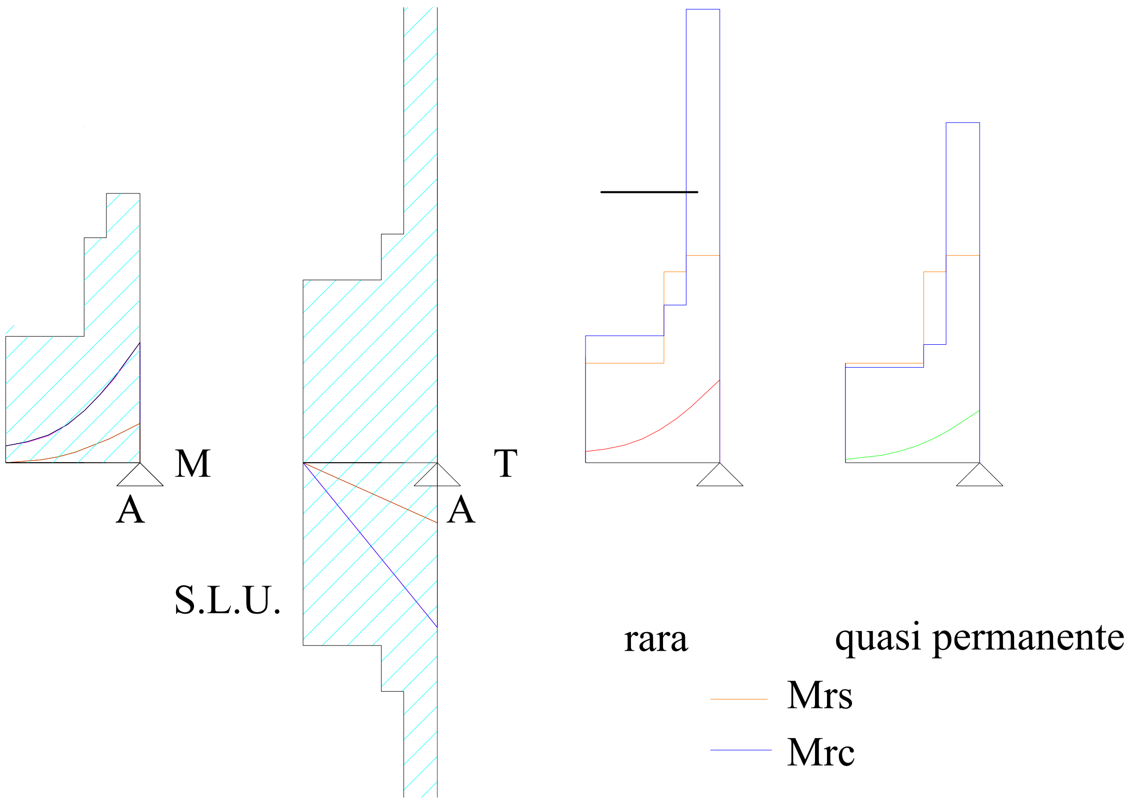
Momento negativo (b variabile)

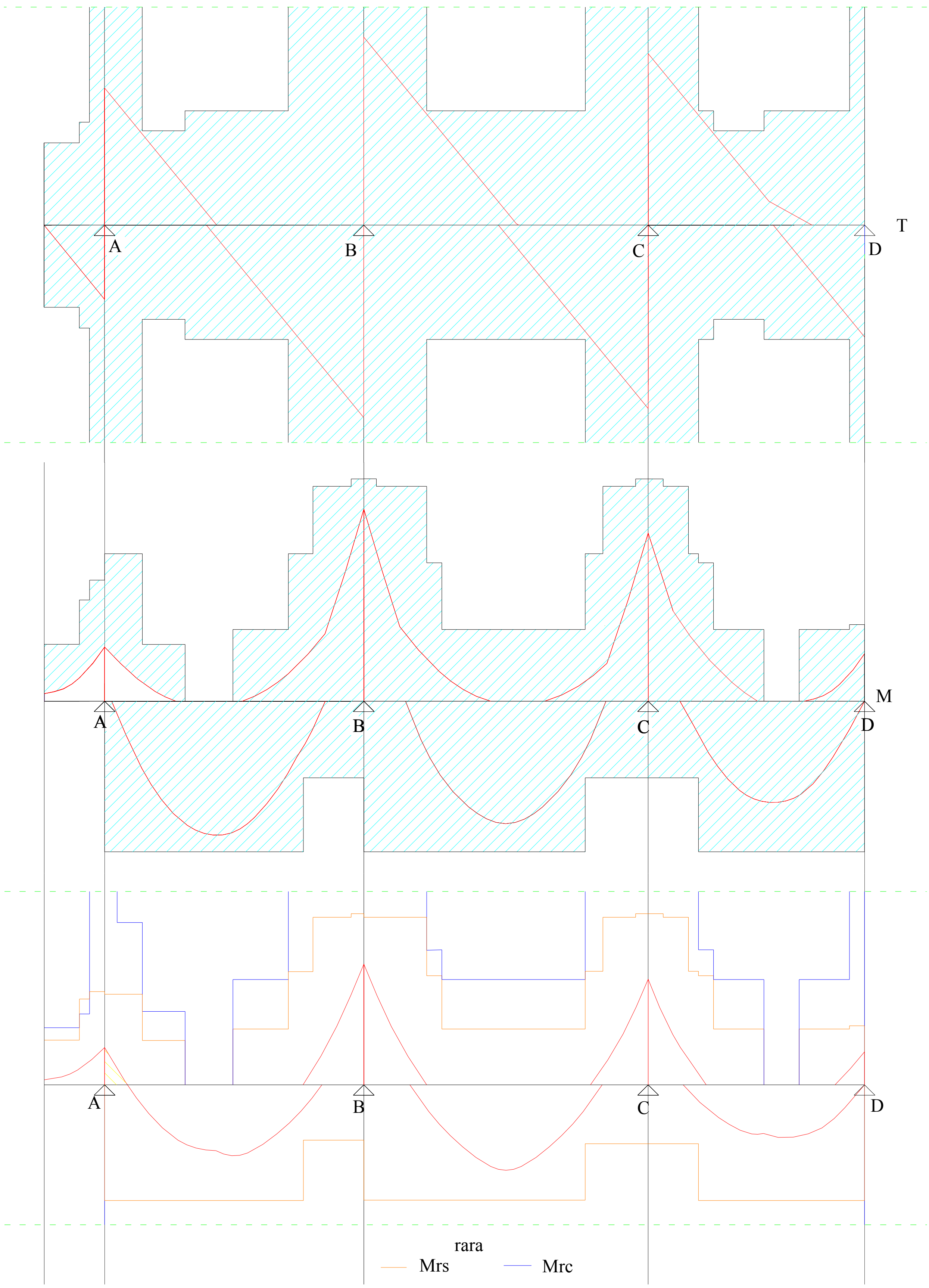


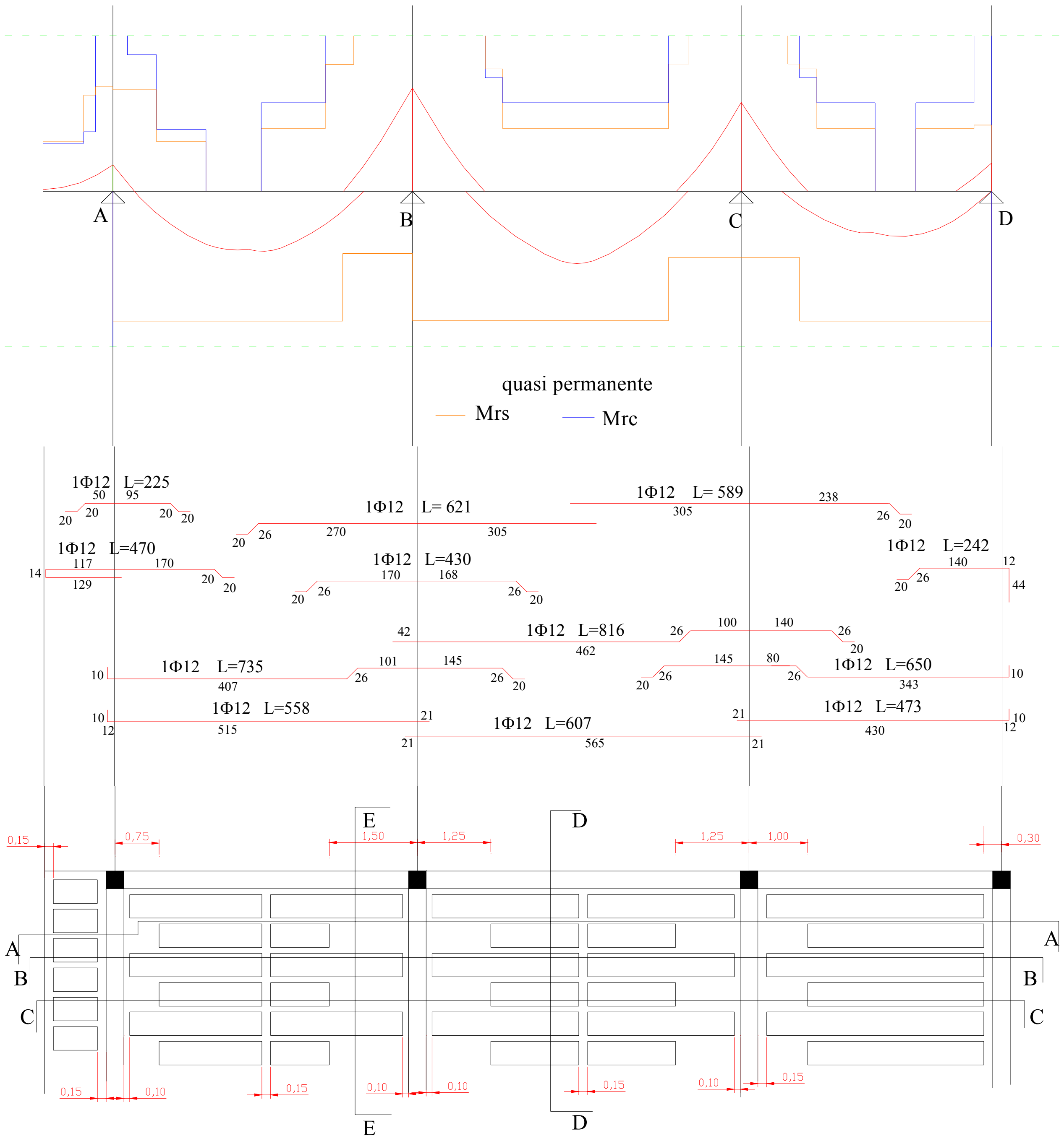
sez	z [m]	b [mm]	h [mm]	A's [mm^2]	As [mm^2]	y_c [mm]	M_{Rd} [kNm]	y_c [mm]	I_n [mm^4]	$M_{rc,r}$ [kNm]	$M_{rs,r}$ [kNm]	$M_{rc,qp}$ [kNm]	$M_{rs,qp}$ [kNm]
2	0,15	200	200	0	226	41.86	11,29	60,83	$5{,}541 \cdot 10^7$	11,34	8,88	8,51	8,88
3	0.7	200	200	0	452	83.72	20.11	78,68	$8{,}901 \cdot 10^7$	14,08	17,06	10,56	17,06
4	0.90	1000	200	0	452	16.74	24.06	41,71	$1{,}358 \cdot 10^8$	40,53	18,52	30,40	18,52

Taglio

sezioni	z [m]	b [mm]	h [mm]	As_{tot} [mm^2]	ρl	V_{Rd} [kN]	V_{Sd} [kN]
2	0,15	200	200	226	0.0066	16,33	1,84
3	0.7	200	200	452	0.0133	20,44	8,59
4	0.9	1000	200	452	0.0027	69,67	11,04

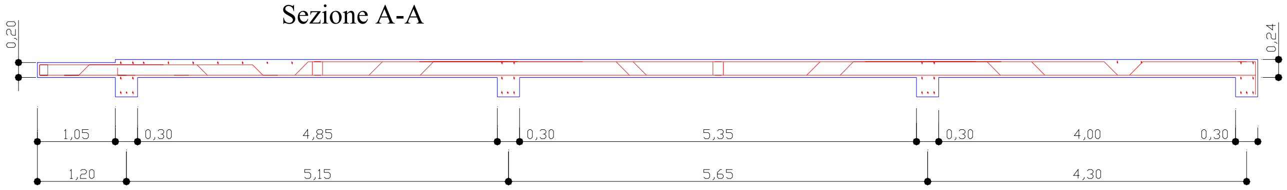



T
A
B
C
D
M
A
B
C
D
A
B
C
D
rara
Mrs
Mrc

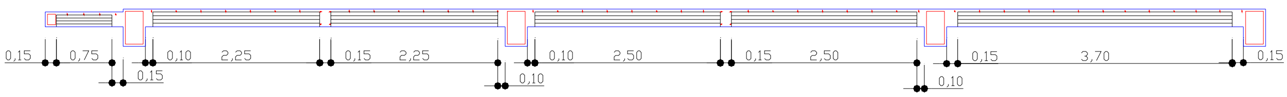

A
B
C
D
quasi permanente
Mrs
Mrc
1Φ12 L=225
1Φ12 L= 621
1Φ12 L= 589
1Φ12 L=470
1Φ12 L=430
1Φ12 L=242
1Φ12 L=816
1Φ12 L=735
1Φ12 L=650
1Φ12 L=558
1Φ12 L=607
1Φ12 L=473
E
D
0,15
0,75
1,50
1,25
1,25
1,00
0,30
0,15
0,10
0,15
0,10
0,10
0,15
0,10
0,15

Sezioni

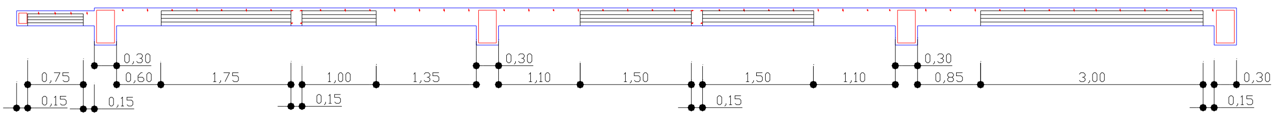
Sezione A-A



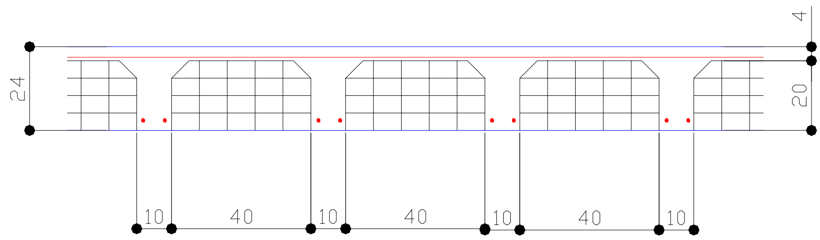
Sezione B-B



Sezione C-C



Sezione D-D



Sezione E-E