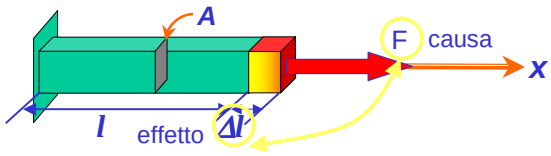
Relazione tensione-deformazione

Relazione tensione-deformazione

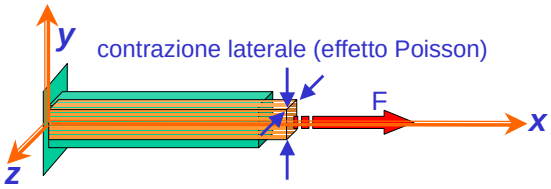
Relazioni costitutive in campo elastico



$F = K\,\Delta l$ dove $K = \frac{A\,E}{l}$

quindi $\Delta l = \frac{F\,l}{A\,E} = \frac{\sigma_x\,l}{E}$

$\frac{\Delta l}{l} = \frac{\sigma_x}{E}$ $\qquad \varepsilon_x = \frac{\sigma_x}{E}$



$\varepsilon_y = \frac{\sigma_y}{E}$ $\qquad \varepsilon_z = \frac{\sigma_z}{E}$

$\varepsilon_y = -\nu\frac{\sigma_x}{E}$ $\qquad \varepsilon_z = -\nu\frac{\sigma_x}{E}$

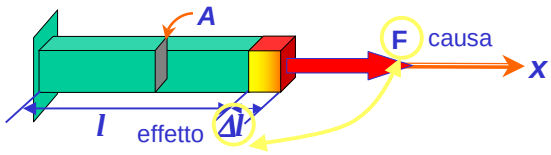
nel caso più generale di stato di tensione triassiale la deformazione ε_x è data da:

$$\varepsilon_x = 1/E\,[\sigma_x - \nu(\sigma_y + \sigma_z)]$$

4-8

Relazione tensione-deformazione

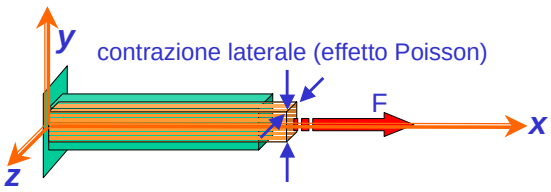
Relazioni costitutive in campo elastico



$F = K\,\Delta l$ dove $K = \frac{A\,E}{l}$

quindi $\Delta l = \frac{F\,l}{A\,E} = \frac{\sigma_x\,l}{E}$

$\frac{\Delta l}{l} = \frac{\sigma_x}{E}$ $\quad \varepsilon_x = \frac{\sigma_x}{E}$



$\varepsilon_y = \frac{\sigma_y}{E}$ $\quad \varepsilon_z = \frac{\sigma_z}{E}$

In modo analogo si possono ottenere le ε_y ed ε_z :

$\varepsilon_y = -\nu \frac{\sigma_x}{E}$ $\quad \varepsilon_z = -\nu \frac{\sigma_x}{E}$

$\varepsilon_y = 1/E\,[\sigma_y - \nu(\sigma_x + \sigma_z)]$

$\varepsilon_z = 1/E\,[\sigma_z - \nu(\sigma_x + \sigma_y)]$

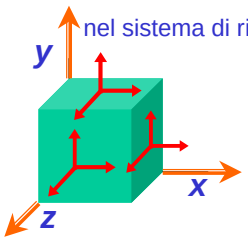
Relazione tensione-deformazione

Relazioni costitutive in campo elastico

stato di tensione triassiale

relazione costitutiva in campo elastico tra deformazione ε e la tensione σ:

nel sistema di riferimento xyz

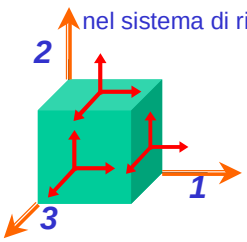


$\varepsilon_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)]$

$\varepsilon_y = \frac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)]$

$\varepsilon_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)]$

nel sistema di riferimento principale



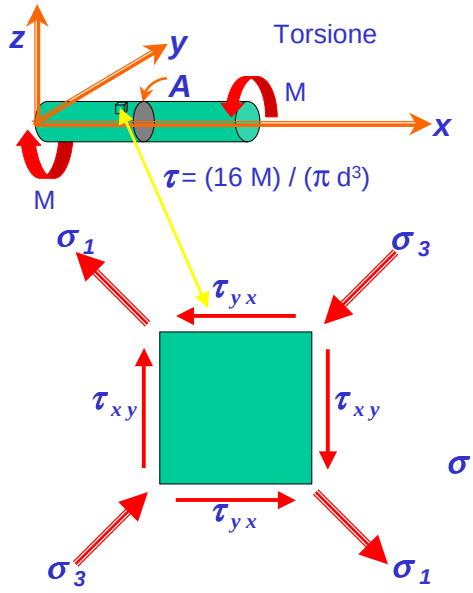
$\varepsilon_1 = \frac{1}{E}[\sigma_1 - \nu(\sigma_2 + \sigma_3)]$

$\varepsilon_2 = \frac{1}{E}[\sigma_2 - \nu(\sigma_1 + \sigma_3)]$

$\varepsilon_3 = \frac{1}{E}[\sigma_3 - \nu(\sigma_1 + \sigma_y)]$

Relazione tensione-deformazione

Relazioni costitutive in campo elastico



Nel caso di torsione pura, con la disposizione degli assi scelta, si ha:

$$\sigma_x = \sigma_y = \sigma_z = \tau_{xz} = \tau_{yz} = 0$$

$$\tau_{xy} \neq 0$$

L'equazione cubica dello stato di tensione assume quindi la seguente forma:

(si veda anche il cerchio di Mohr nel caso di torsione pura)

$$\sigma^3 - \sigma \tau_{xy}^2 = 0$$

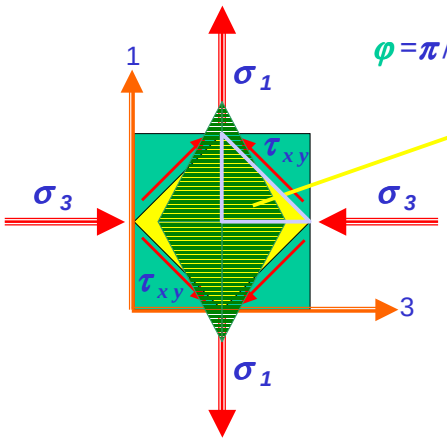
da cui si ottiene:

$$\sigma_3 = -\sigma_1$$

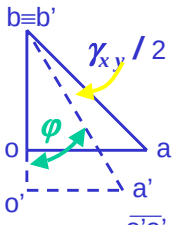
$$\sigma_1 = \tau_{xy}$$
$$\sigma_2 = 0$$
$$\sigma_3 = -\tau_{xy}$$

Relazione tensione-deformazione

Relazioni costitutive in campo elastico



$$\varphi = \pi/4 - \gamma_{xy}/2$$



$$tg(\pi/4 - \gamma_{xy}/2) = \frac{\overline{o'a'}}{o'b'}$$

$$\frac{\overline{o'a'}}{o'b'} = \frac{\overline{oa}\,(1+\varepsilon_3)}{\overline{oa}\,(1+\varepsilon_1)} \qquad \frac{\overline{oa}}{ob} = 1$$

$$tg(\pi/4 - \gamma_{xy}/2) = \frac{(1+\varepsilon_3)}{(1+\varepsilon_1)}$$

$$tg(\alpha - \beta) = \frac{tg\alpha - tg\beta}{(1 + tg\alpha\, tg\beta)} \Rightarrow tg(\pi/4 - \gamma_{xy}/2) = \frac{tg\,\pi/4 - tg\,\gamma_{xy}/2}{(1 + tg\,\pi/4\ tg\,\gamma_{xy}/2)}$$

Relazione tensione-deformazione

Relazioni costitutive in campo elastico

$$tg\left(\frac{\pi}{4} - \frac{\gamma_{xy}}{2}\right) = \frac{tg\,\frac{\pi}{4} - tg\,\frac{\gamma_{xy}}{2}}{1 + tg\,\frac{\pi}{4}\; tg\,\frac{\gamma_{xy}}{2}} = \frac{1 - \frac{\gamma_{xy}}{2}}{1 + \frac{\gamma_{xy}}{2}} = \frac{(1+\varepsilon_3)}{(1+\varepsilon_1)}$$

($tg\,\frac{\pi}{4} = 1$; $tg\,\frac{\gamma_{xy}}{2} \cong \frac{\gamma_{xy}}{2}$)

$$\sigma_3 = -\sigma_1 \Rightarrow \varepsilon_3 = -\varepsilon_1 \Rightarrow \frac{1 - \frac{\gamma_{xy}}{2}}{1 + \frac{\gamma_{xy}}{2}} = \frac{(1-\varepsilon_1)}{(1+\varepsilon_1)}$$

essendo:

$$\varepsilon_1 = 1/E\,[\sigma_1 - \nu(\sigma_2 + \sigma_3)] \Leftarrow \gamma_{xy} = 2\varepsilon_1$$

si ottiene:

$$\gamma_{xy} = 2/E\,[\sigma_1 - \nu(\sigma_2 + \sigma_3)]$$

nel caso della torsione pura $\sigma_1 = \tau_{xy}$ e $\sigma_3 = -\tau_{xy}$ e quindi:

$$\gamma_{xy} = 2(1+\nu)/E\;\sigma_1 = 2(1+\nu)/E\;\tau_{xy} = 1/G\;\tau_{xy} \rightarrow G = E/[2(1+\nu)]$$

Relazione tensione-deformazione

Relazioni costitutive in campo elastico

Sollecitazione di taglio:

$$\gamma_{xy} = \frac{\tau_{xy}}{G} \qquad \gamma_1 = \frac{\tau_1}{G} \qquad \gamma_1 = \frac{\sigma_2 - \sigma_3}{2G} \qquad \gamma_1 = \varepsilon_2 - \varepsilon_3$$

$$\gamma_{xz} = \frac{\tau_{xz}}{G} \qquad \gamma_2 = \frac{\tau_2}{G} \qquad \gamma_2 = \frac{\sigma_1 - \sigma_3}{2G} \qquad \gamma_2 = \varepsilon_1 - \varepsilon_3$$

$$\gamma_{yz} = \frac{\tau_{yz}}{G} \qquad \gamma_3 = \frac{\tau_3}{G} \qquad \gamma_3 = \frac{\sigma_1 - \sigma_2}{2G} \qquad \gamma_3 = \varepsilon_1 - \varepsilon_2$$

Relazione tensione-deformazione

Relazioni costitutive in campo elastico

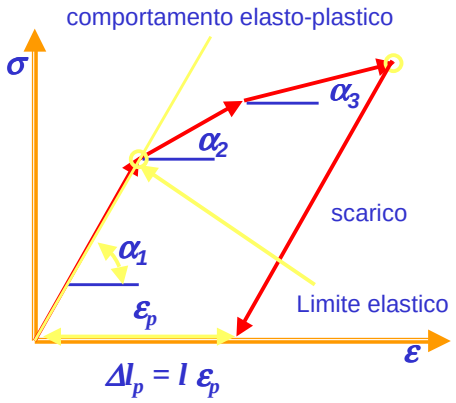
valida in campo elastico (per i materiali isotropi)

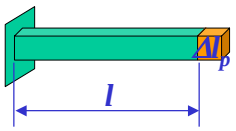
$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{xz} \\ \gamma_{yz} \end{Bmatrix} = \left[\begin{array}{ccc|ccc} 1/E & -\nu/E & -\nu/E & 0 & 0 & 0 \\ -\nu/E & 1/E & -\nu/E & 0 & 0 & 0 \\ -\nu/E & -\nu/E & 1/E & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 1/G & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G \end{array}\right] \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{xz} \\ \tau_{yz} \end{Bmatrix}$$

Le sottomatrici nulle indicano che non c'è accoppiamento tra componenti normali della tensione e distorsione

Relazione tensione-deformazione

Come si comporta il materiale oltre il limite elastico?



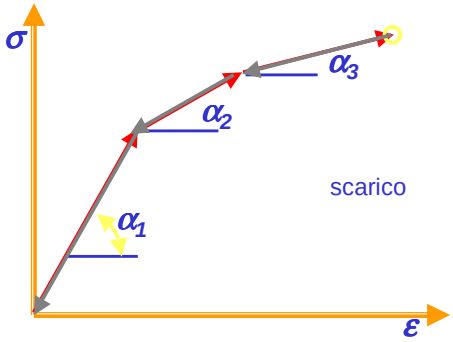


Rimuovendo la forza applicata rimane un allungamento residuo permanente

Relazione tensione-deformazione

Come si comporta il materiale oltre il limite elastico?

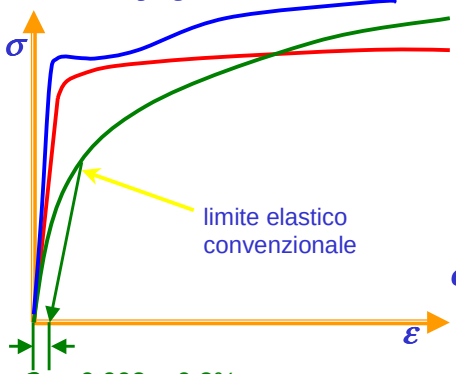
comportamento elastico non lineare



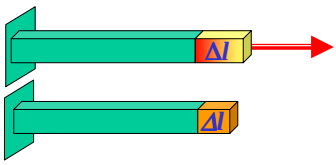
Al termine del ciclo di carico non rimane alcuna deformazione permanente

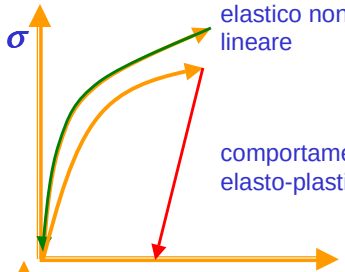
Relazione tensione-deformazione

La curva σ-ε del materiale



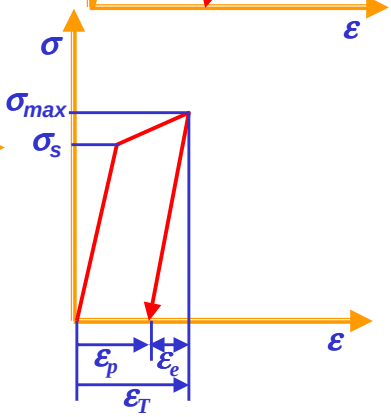
ε_r =0.002 = 0.2%





comportamento elastico non lineare

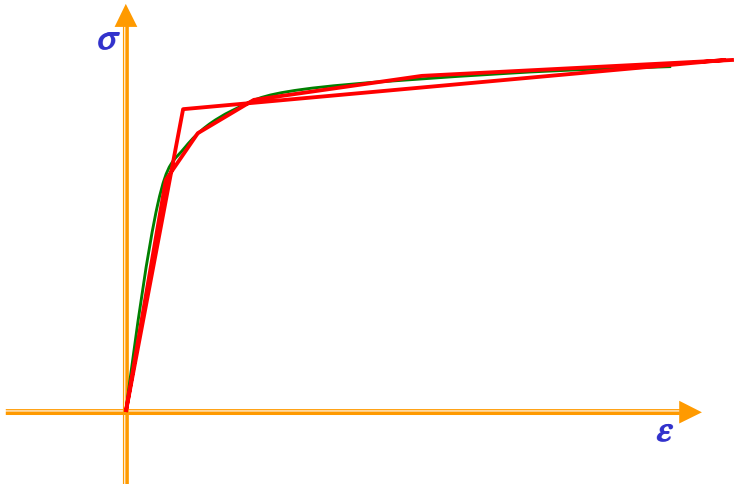
comportamento elasto-plastico



Relazione tensione-deformazione

La curva σ - ε

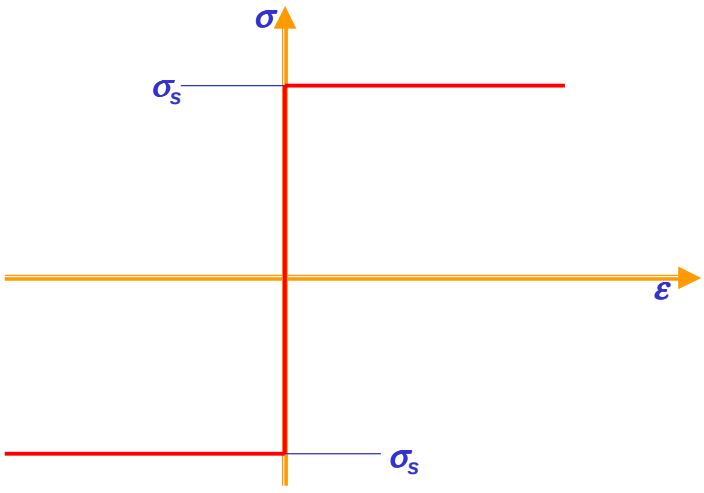
Modelli semplificati



Relazione tensione-deformazione

La curva σ - ε

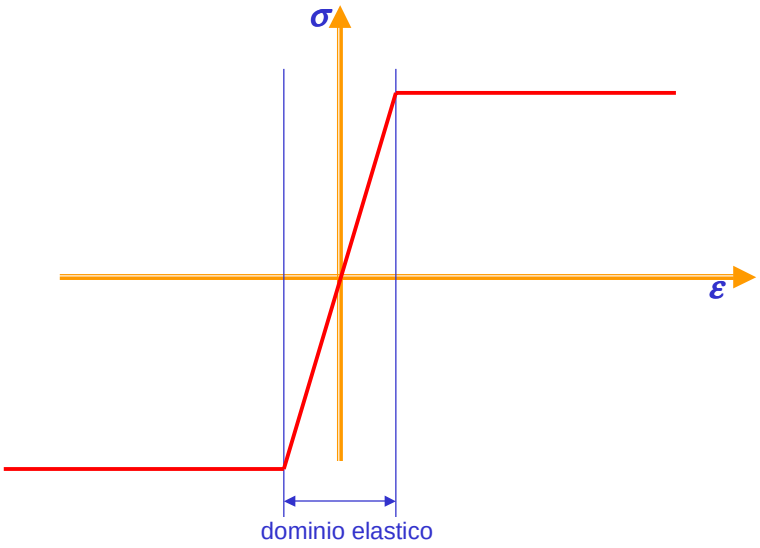
Modello bilineare: rigido-plastico



Relazione tensione-deformazione

La curva σ - ε

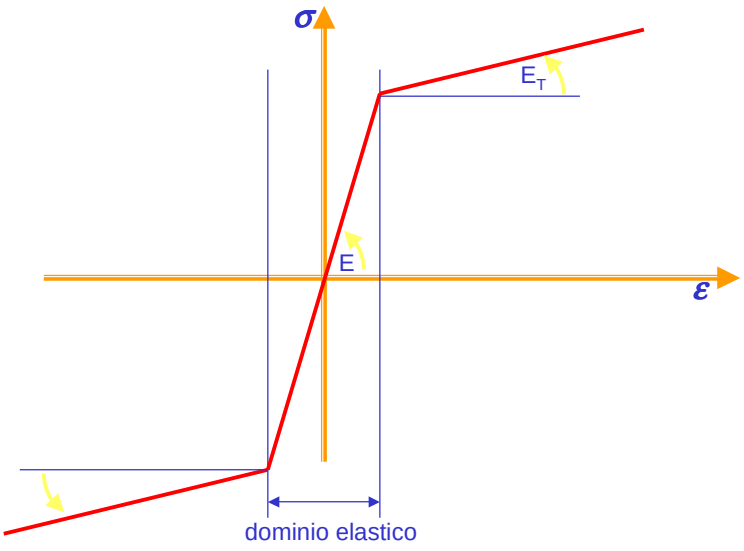
Modello bilineare: elasto-plastico perfetto



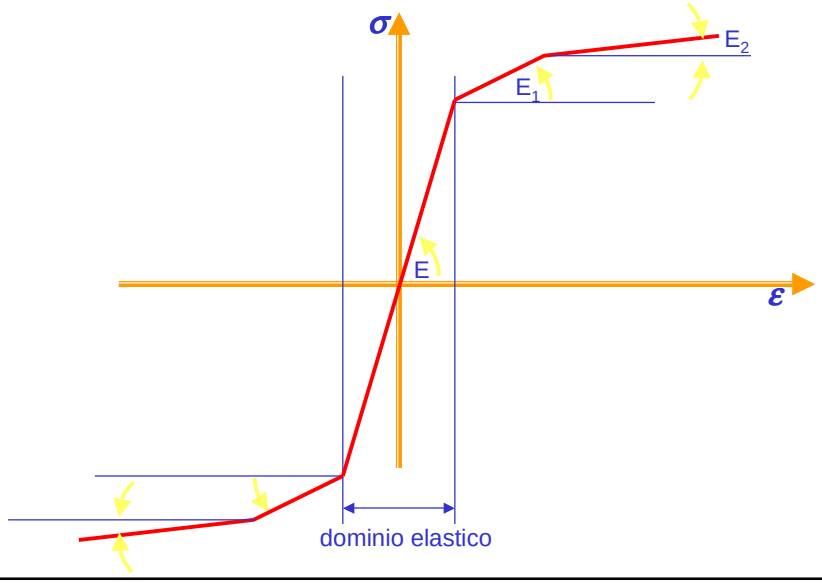
Relazione tensione-deformazione

La curva σ - ε

Modello bilineare: elasto-plastico con incrudimento



Relazione tensione-deformazione

La curva σ - ε

Modello multilineare: elasto-plastico con incrudimento