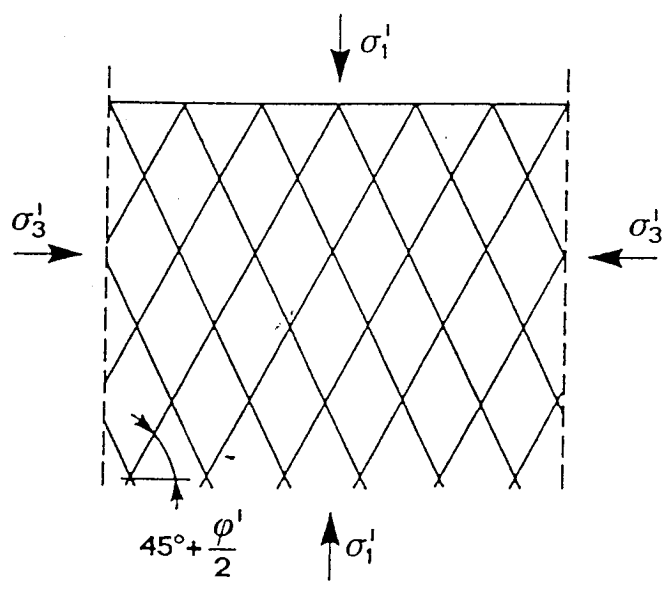
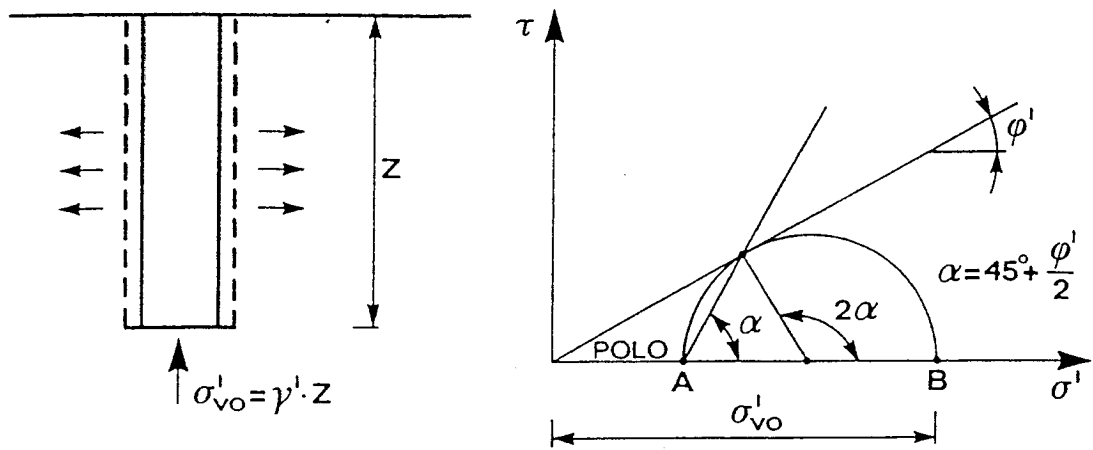
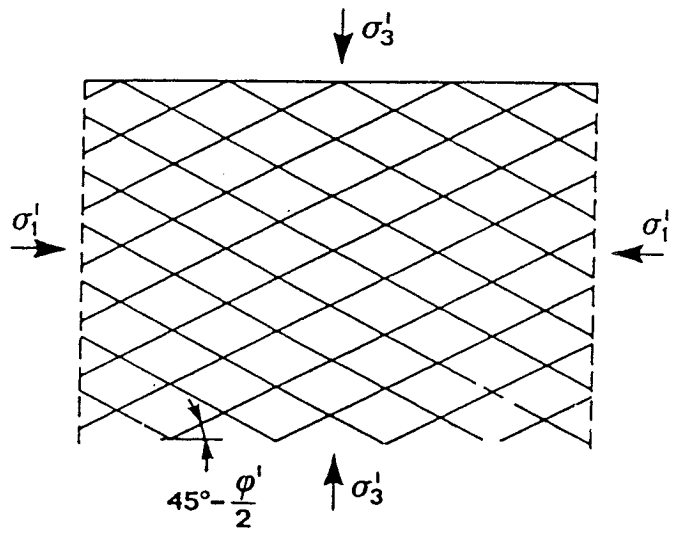
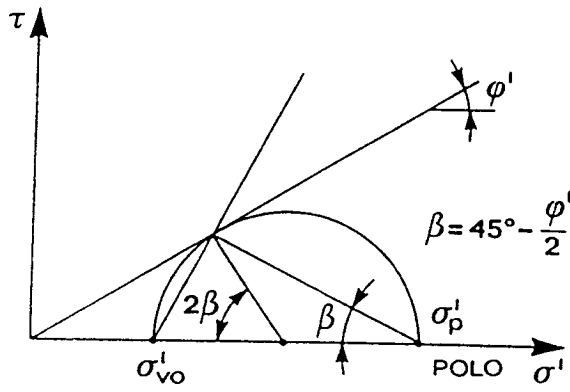
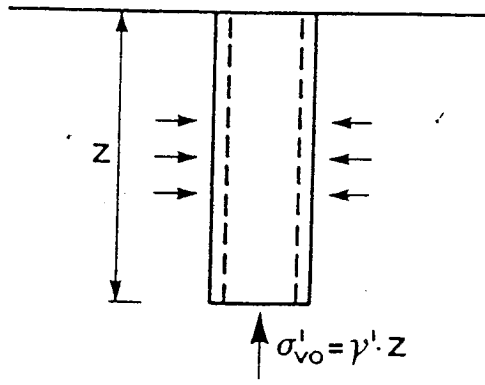


**PROBLEMI DI STABILITA':  
SPINTA DELLE TERRE ED  
OPERE DI SOSTEGNO**

# **PROBLEMI DI STABILITA'**

- 1) PROBLEMI RICORRENTI:**
  - a. Spinte sulle opere di sostegno**
  - b. Capacità portante delle fondazioni**
  - c. Stabilità dei pendii e degli scavi**
- 2) METODI DISPONIBILI**
  - a. Metodo delle tensioni (problema al contorno)**
  - b. Teoremi dell'analisi limite**
  - c. Metodo delle caratteristiche**
  - d. Metodo dell'equilibrio limite globale**
- 3) LEGAMI COSTITUTIVI RICORRENTI**
  - a. Rigido – plastico ideale**
  - b. Elastico – perfettamente plastico**





# SPINTE PER MATERIALI DOTATI DI ATRRITO E

## COESIONE

$$\left( \frac{\sigma'_a + \sigma'_{v_0}}{2} + \frac{c'}{\tan \varphi'} \right) \text{sen} \varphi' = \left( \frac{\sigma'_a - \sigma'_{v_0}}{2} \right)$$

$$\sigma'_a = \sigma'_{v_0} \frac{1 - \text{sen} \varphi'}{1 + \text{sen} \varphi'} - 2c' \frac{\cos \varphi'}{1 + \text{sen} \varphi'}$$

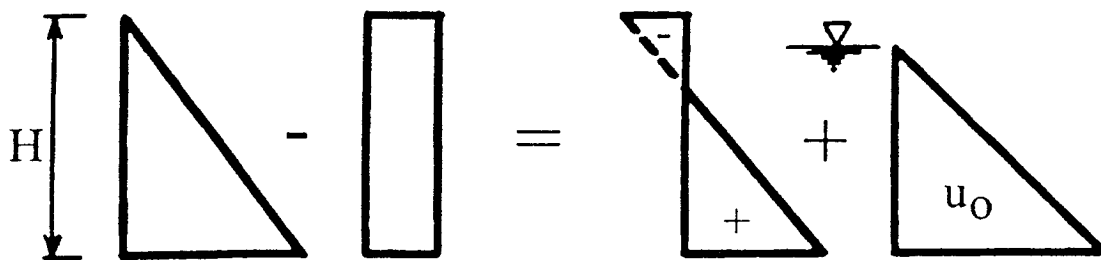
$$\sigma'_a = \sigma'_{v_0} K_a - 2c' \sqrt{K_a}$$

$$\sigma'_p = \sigma'_{v_0} K_p + 2c' \sqrt{K_p}$$

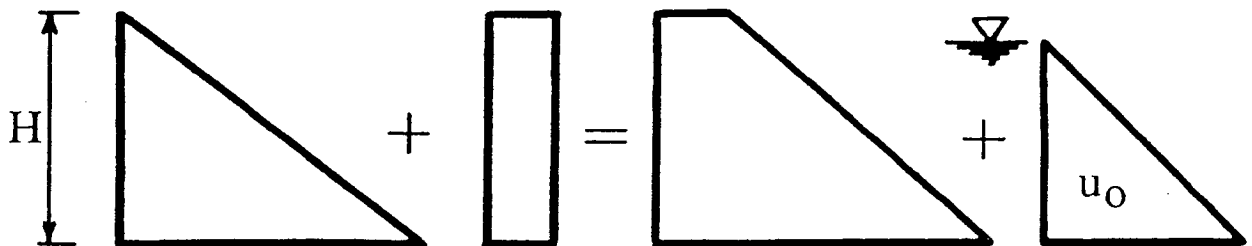
## FORMULE DI RANKINE-BELL IN CONDIZIONI DRENATE

$$\tau_{ff} = \sigma'_{ff} \tan \varphi' + c'$$

$$\sigma'_a = \sigma'_{vo} \cdot K_A - 2c' \sqrt{K_A} \quad \text{SPINTA ATTIVA}$$



$$\sigma'_p = \sigma'_{vo} \cdot K_P + 2c' \sqrt{K_P} \quad \text{SPINTA PASSIVA}$$



FORMULE RIFERITE ALLE TENSIONI EFFICACI

ALLE SPINTE DEL TERRENO VA AGGIUNTA QUELLA DELL'ACQUA.

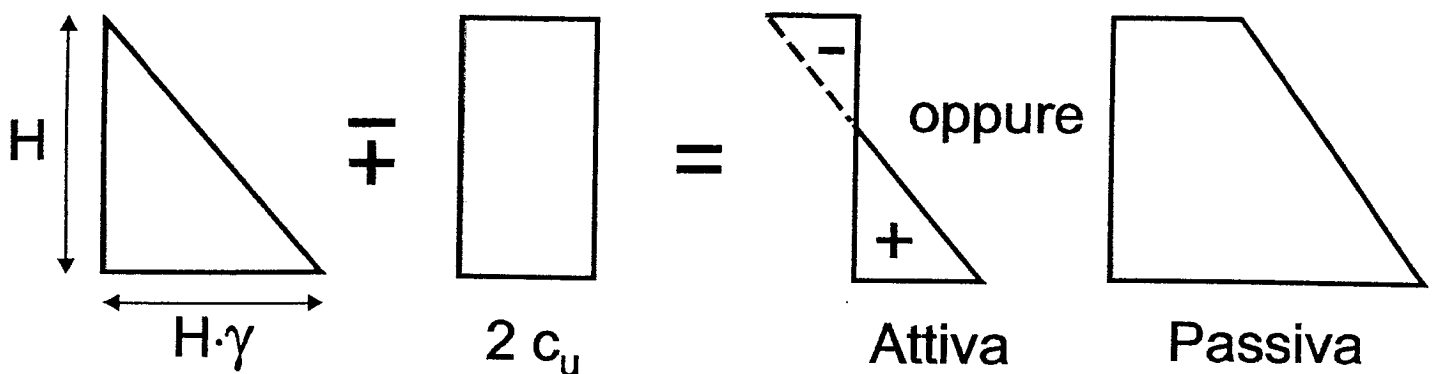
# SPINTA ATTIVA E PASSIVA IN CONDIZIONI NON DRENATE

$$\varphi_u = 0^\circ \rightarrow \tau_f = c_u$$

$$\sigma_a = \sigma_{v0} - 2c_u \quad ; \quad \text{spinta attiva}$$

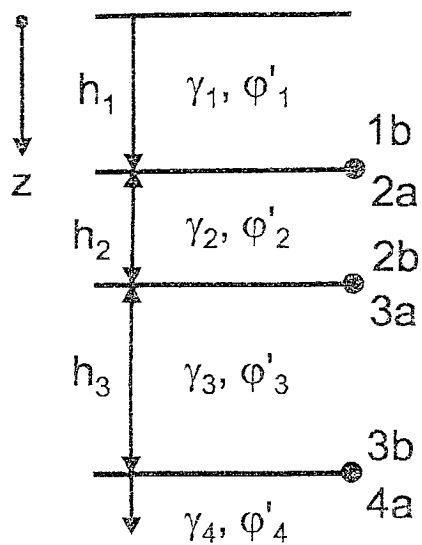
$$\sigma_p = \sigma_{v0} + 2c_u \quad ; \quad \text{spinta passiva}$$

$$\sigma_{v0} = \text{tensione verticale totale}$$



N.B. il contatto muro-terreno è privo della resistenza a trazione, trascurare nelle verifiche di stabilità la spinta attiva negativa.

# SPINTA ATTIVA IN UN TERRENO STRATIFICATO



$$1b: \sigma_a = \gamma_1 \cdot h_1 \cdot K_a(\varphi'_1)$$

$$2a: \sigma_a = \gamma_1 \cdot h_1 \cdot K_a(\varphi'_2)$$

$$2b: \sigma_a = (\gamma_1 \cdot h_1 + \gamma_2 \cdot h_2) K_a(\varphi'_2)$$

$$3a: \sigma_a = (\gamma_1 \cdot h_1 + \gamma_2 \cdot h_2) K_a(\varphi'_3)$$

$$3b: \sigma_a = (\gamma_1 \cdot h_1 + \gamma_2 \cdot h_2 + \gamma_3 \cdot h_3) K_a(\varphi'_3)$$

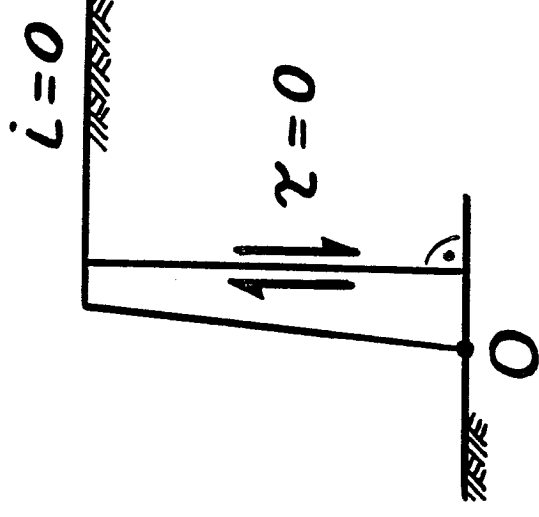
$$4a: \sigma_a = (\gamma_1 \cdot h_1 + \gamma_2 \cdot h_2 + \gamma_3 \cdot h_3) K_a(\varphi'_4)$$

Per semplificare, si considera il terreno asciutto ( $u=0$ )



# CONDIZIONI PER LA VALIDITA' DELLA TEORIA DI RANKINE

- 1) MURO LISCIO ( $\tau = 0$ )
- 2) PARAMENTO INTERNO VERTICALE ( $\beta = 0$ )
- 3) TERRAPIENO A TERGO DEL MURO ORIZZONTALE ( $i = 0$ )
- 4) MECCANISMO DI ROTTURA = ROTAZIONE ATTORNO AL PUNTO O



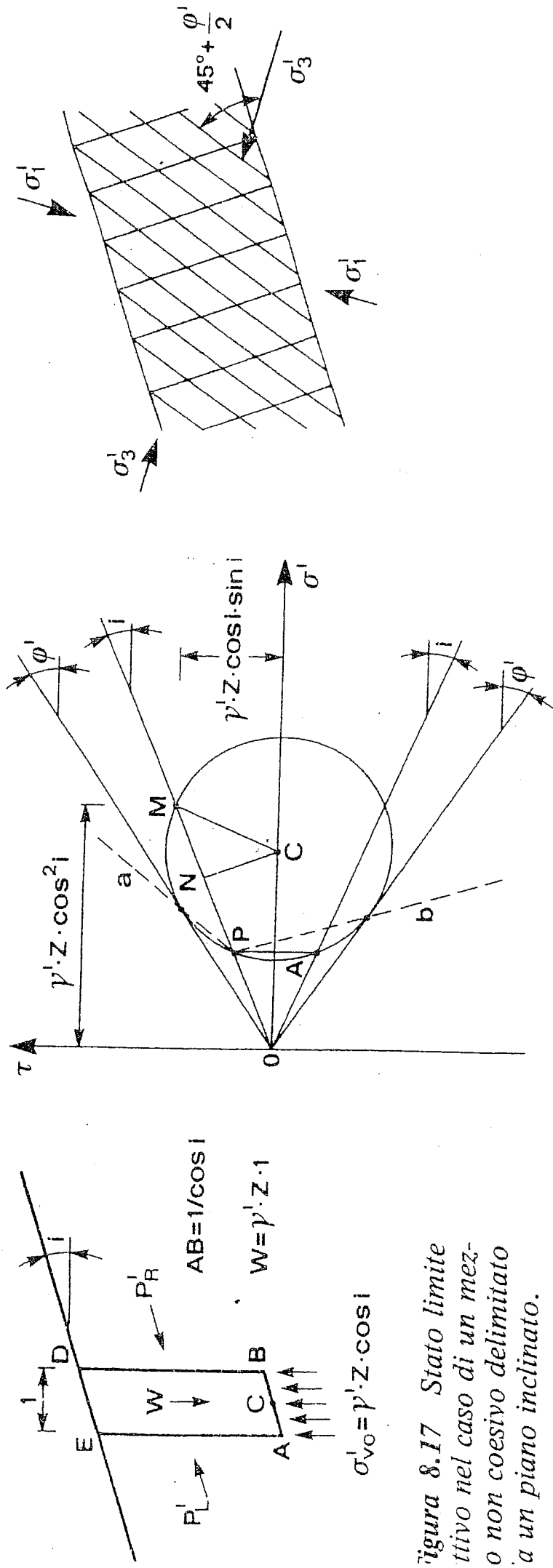


Figura 8.17 Stato limite  
 attivo nel caso di un mezz-  
 o non coesivo delimitato  
 a un piano inclinato.

# **METODO DELL'EQUILIBRIO LIMITE GLOBALE**

## **1. PROCEDIMENTO**

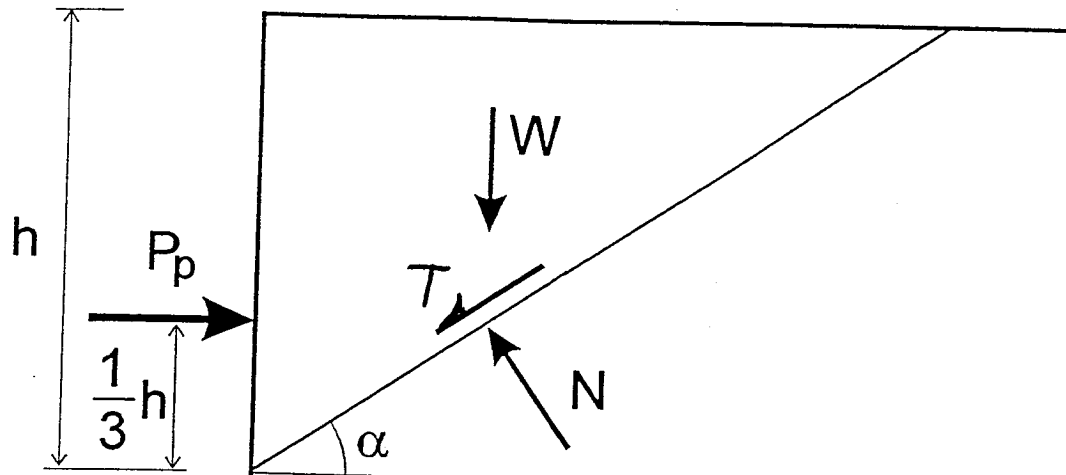
- Individuazione per tentativi della superficie di scorrimento critica.
- Assunzione delle ipotesi a proposito della distribuzione delle tensioni lungo tale superficie.
- Risoluzione del problema mediante una o più equazioni scelte fra le tre di equilibrio di un corpo, applicate al terreno all'interno della superficie di rottura.

## **2. IPOTESI SEMPLIFICATIVE**

- Problema di deformazioni piane.
- Terreno considerato materiale rigido-plastico.
- Frequentemente ipotesi di un muro liscio  
(  $\delta = 0^\circ$ ,  $c_a = 0$  )

# METODO DELL'EQUILIBRIO LIMITE GLOBALE

## Determinazione della spinta passiva



In condizioni di collasso incipiente:

$$\left. \begin{aligned} -W \sin \alpha + P_p \cos \alpha &= T \\ W \cos \alpha + P_p \sin \alpha &= N \end{aligned} \right\} \text{ Condizioni di equilibrio}$$

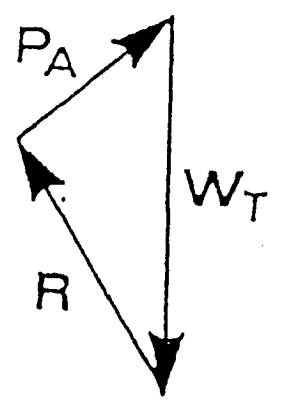
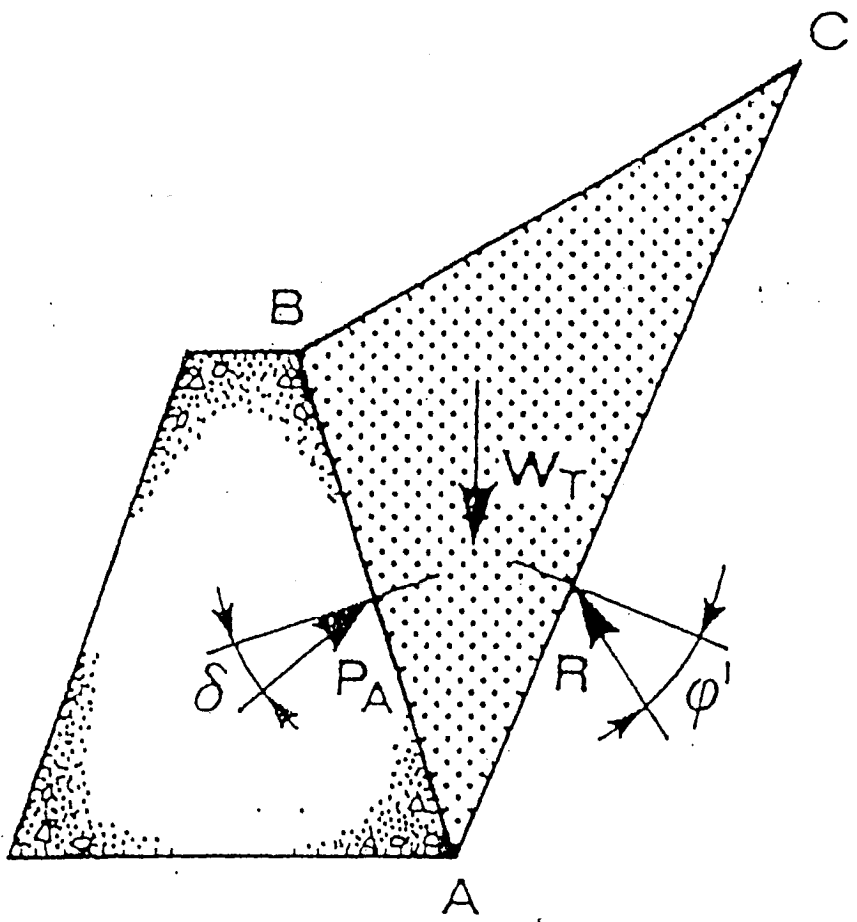
$$N \tan \varphi' = T$$

Criterio di rottura

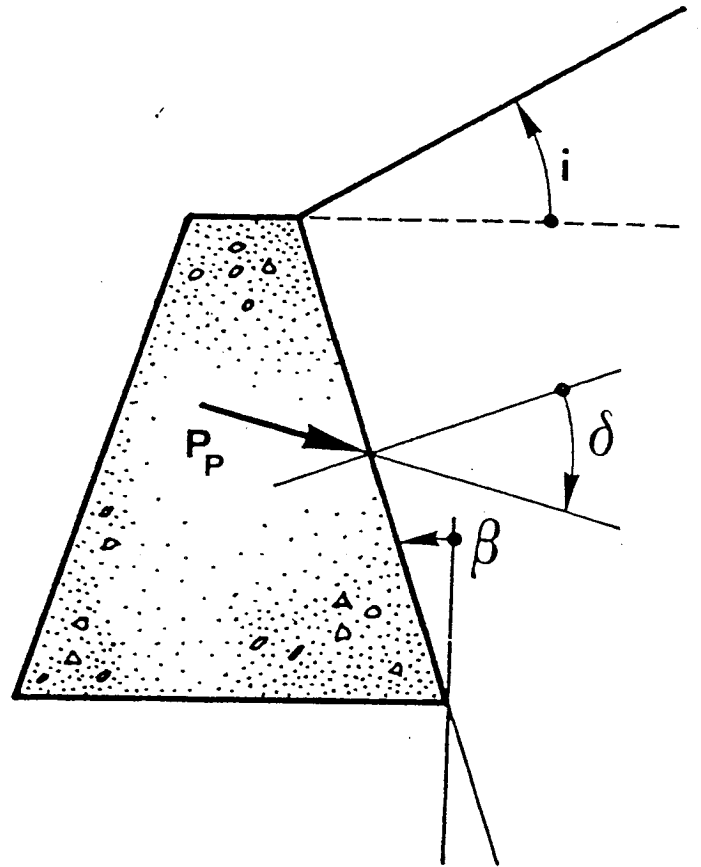
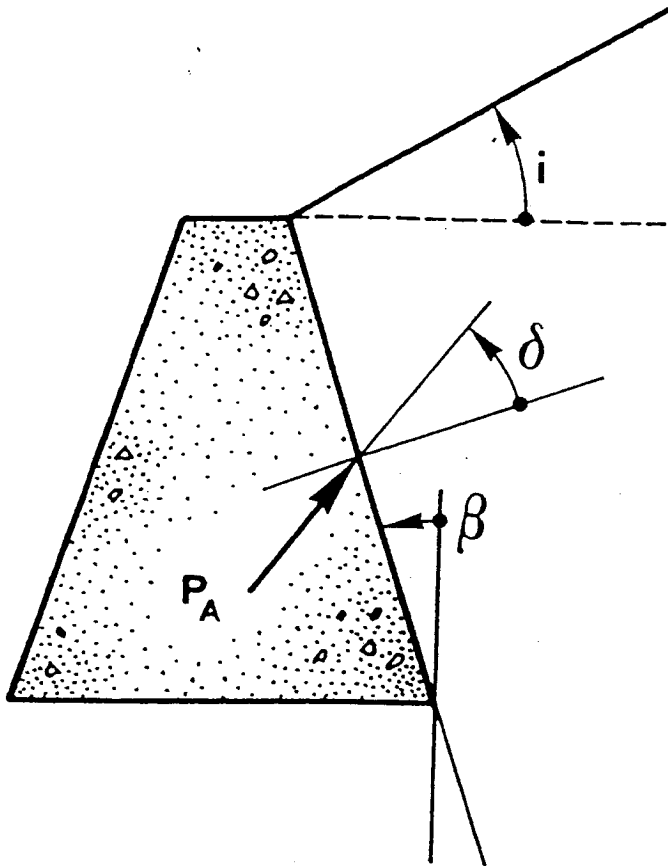
$$\text{Con; } W = \frac{1}{2} \gamma' h^2 \cot \alpha \rightarrow P_p = \frac{1}{2} \gamma' h^2 \frac{\tan(\alpha + \varphi')}{\tan \alpha}$$

$$\text{per } \frac{dP_p}{d\alpha} = 0; P_p = (P_p)_{\min} \text{ e } \alpha = \frac{\pi}{4} - \frac{\varphi'}{2}, \text{ da cui:}$$

$$P_p = \frac{1}{2} \gamma' h^2 \tan^2 \left( 45 + \frac{\varphi'}{2} \right)$$

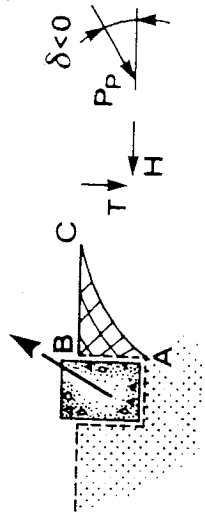


$(\phi' > 0, c' = 0)$

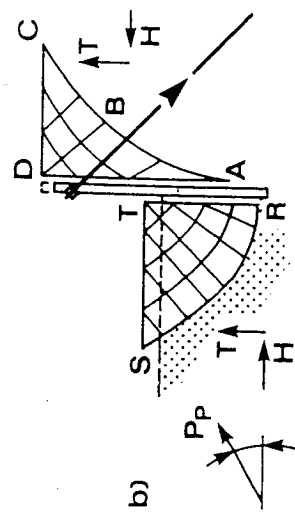
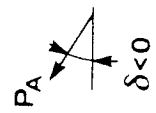


$$K_a = \frac{\cos^2(\bar{\phi} - \beta)}{\cos^2 \beta \cdot \cos(\beta + \delta) \left[ 1 + \sqrt{\frac{\sin(\delta + \bar{\phi}) \cdot \sin(\bar{\phi} - i)}{\cos(\beta + \delta) \cdot \cos(\beta - i)}} \right]^2};$$

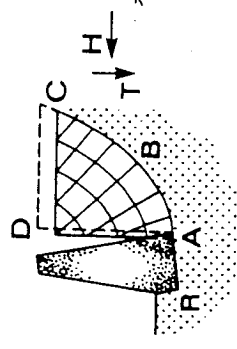
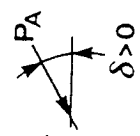
$$K_p = \frac{\cos^2(\bar{\phi} + \beta)}{\cos^2 \beta \cdot \cos(\beta - \delta) \left[ 1 - \sqrt{\frac{\sin(\delta + \bar{\phi}) \cdot \sin(\bar{\phi} + i)}{\cos(\beta - \delta) \cdot \cos(\beta - i)}} \right]^2};$$



c)

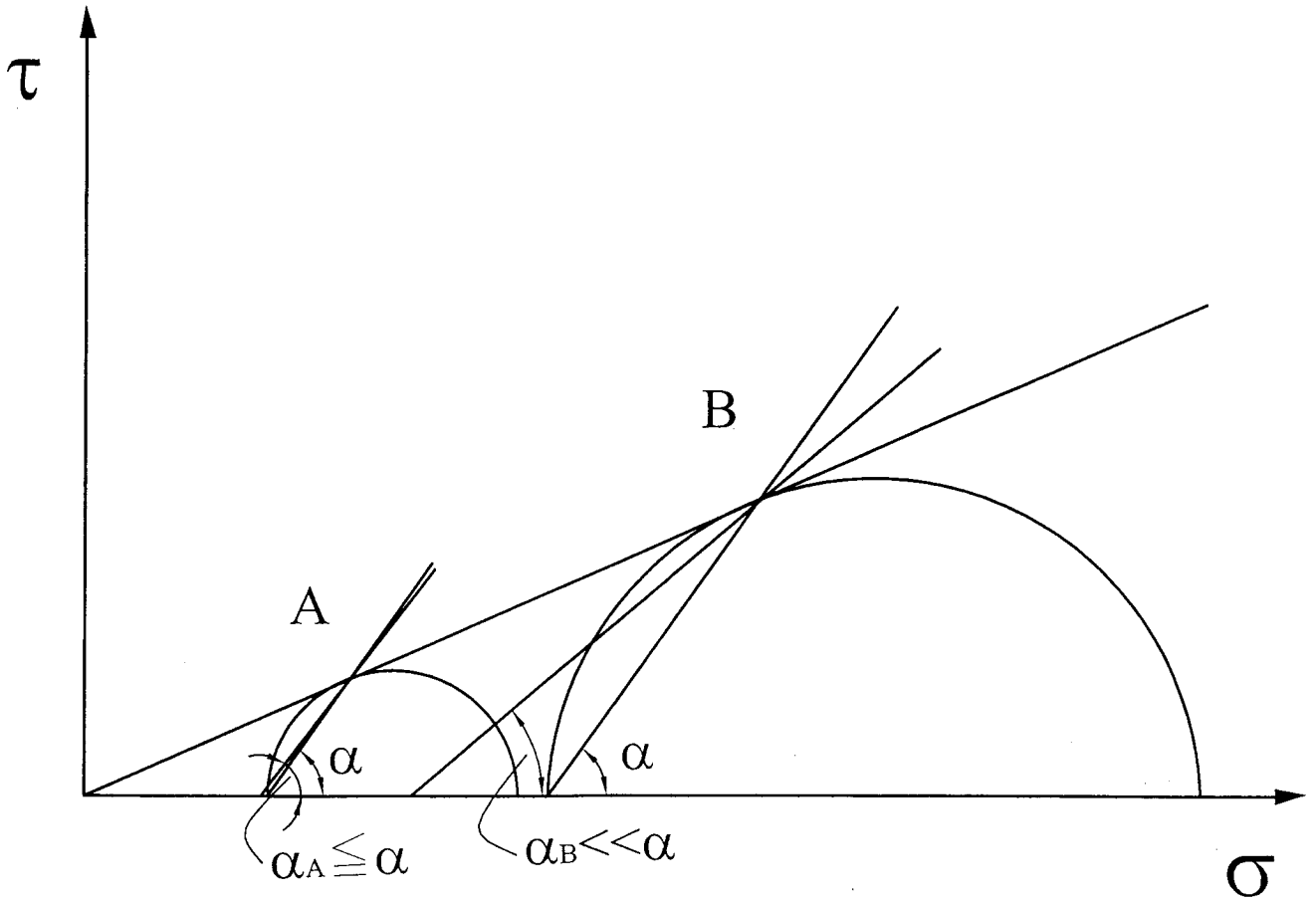
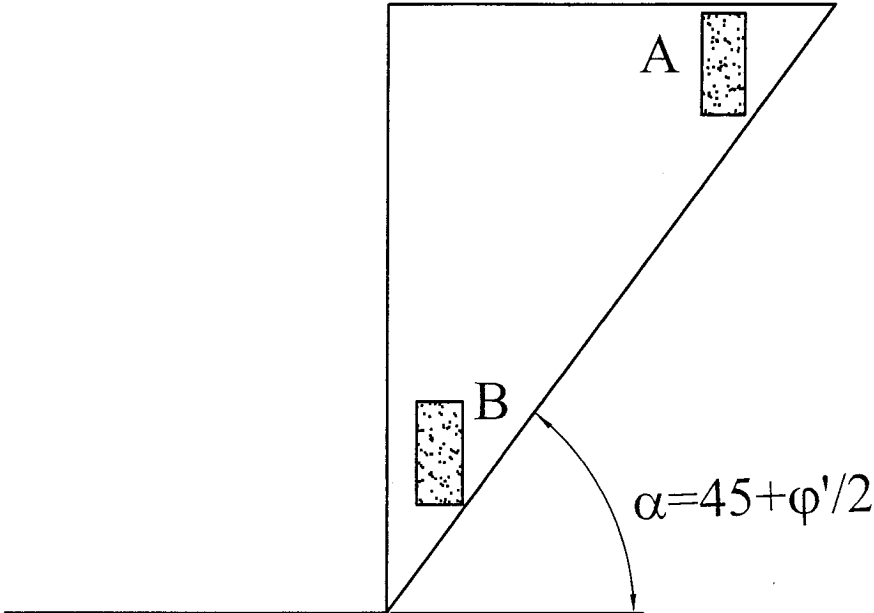


b)



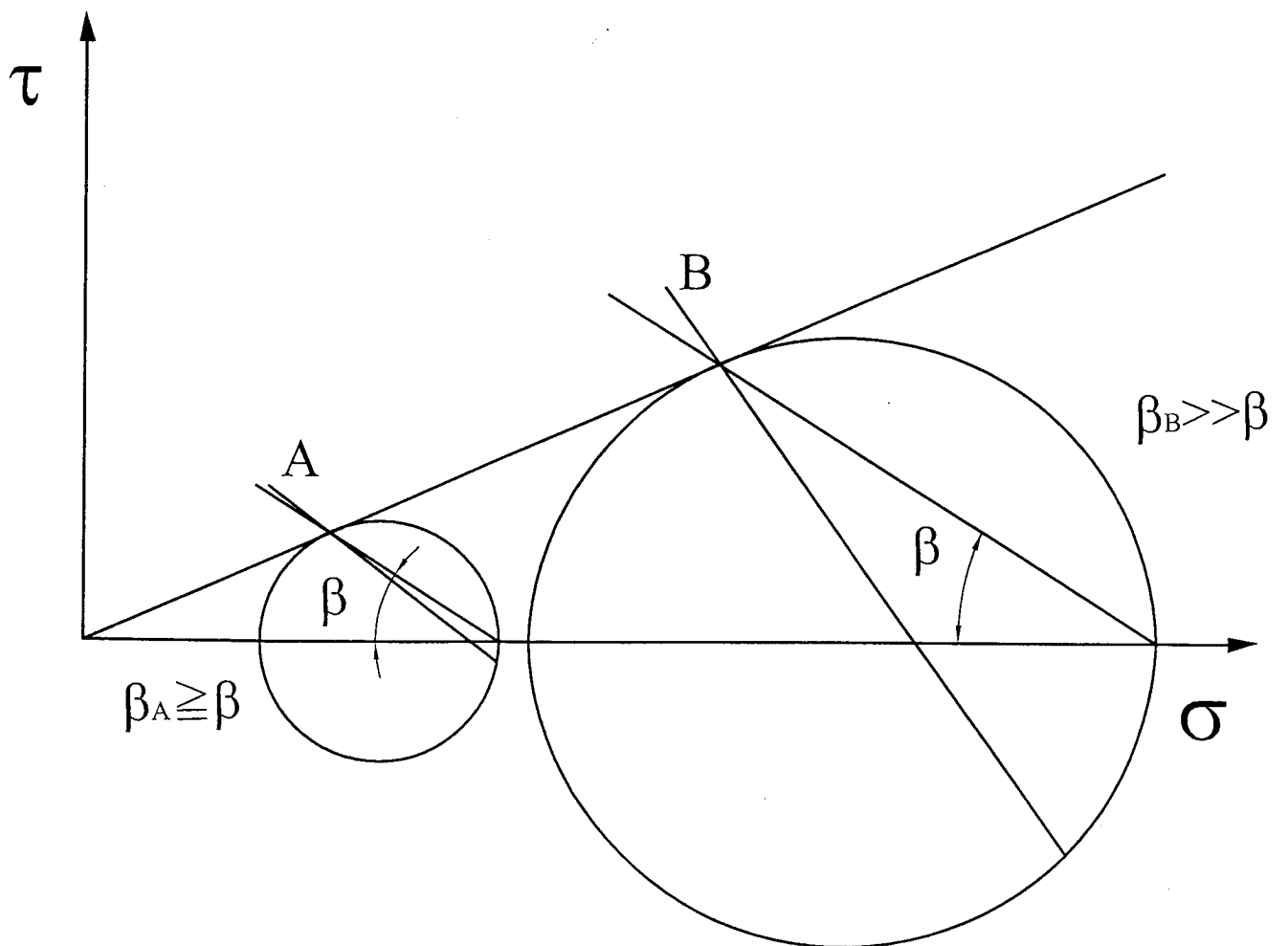
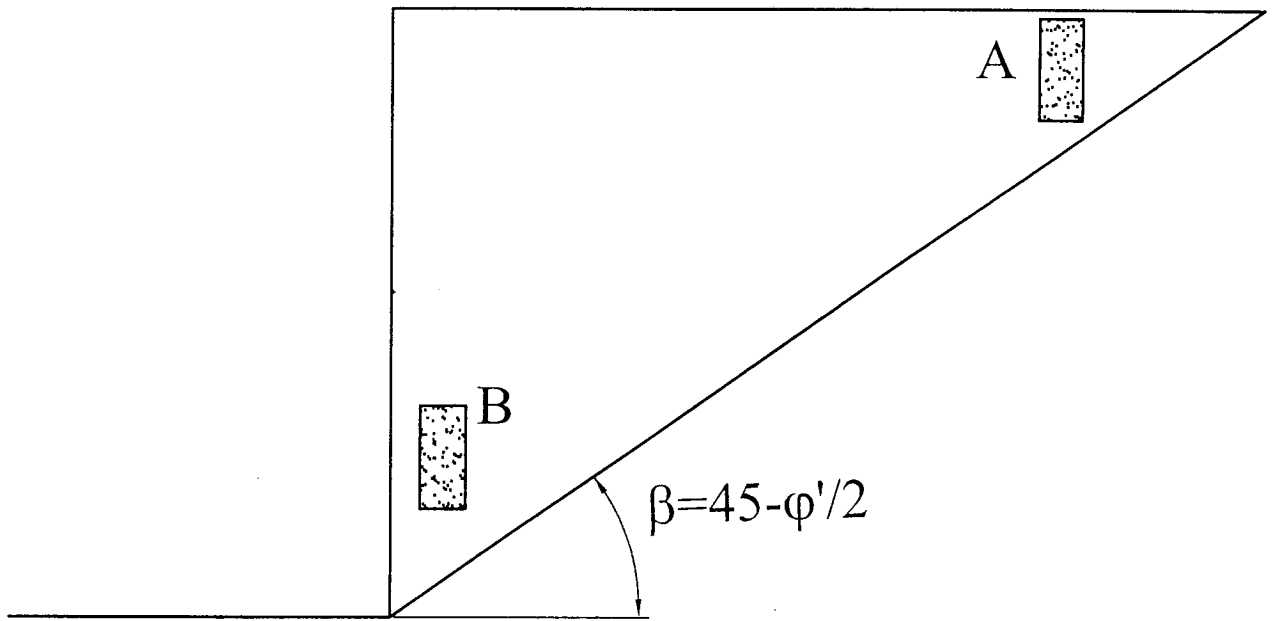
a)

# SPINTA ATTIVA

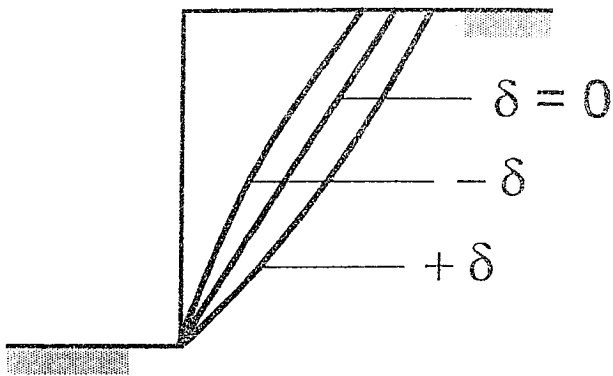
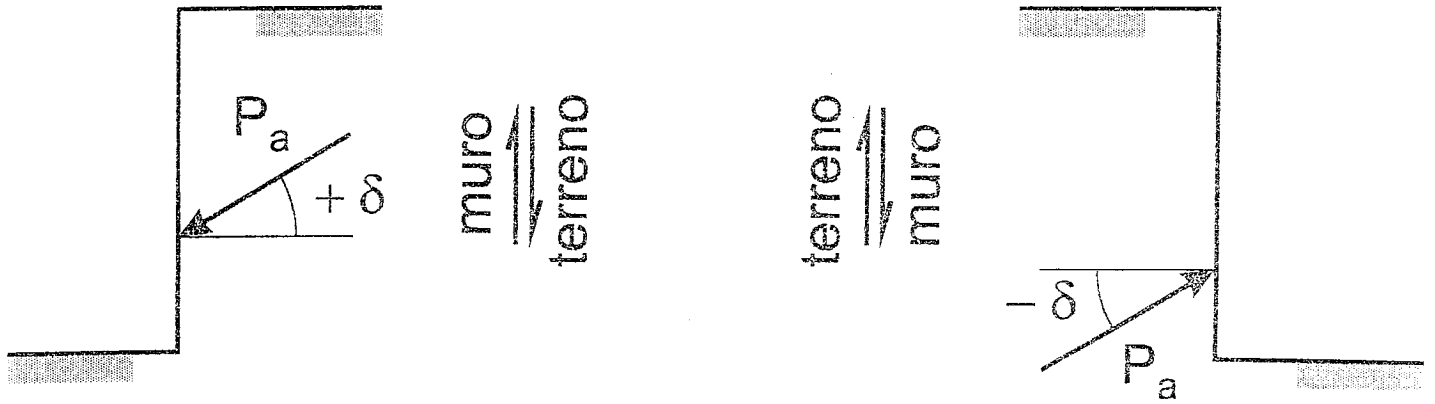




# SPINTA PASSIVA



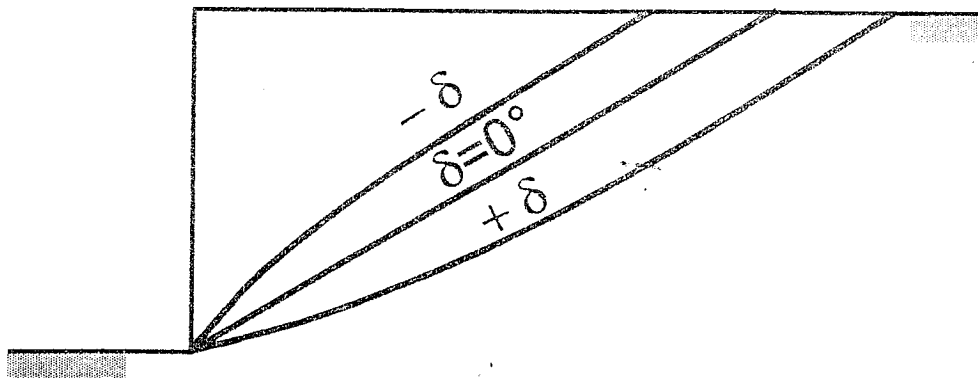
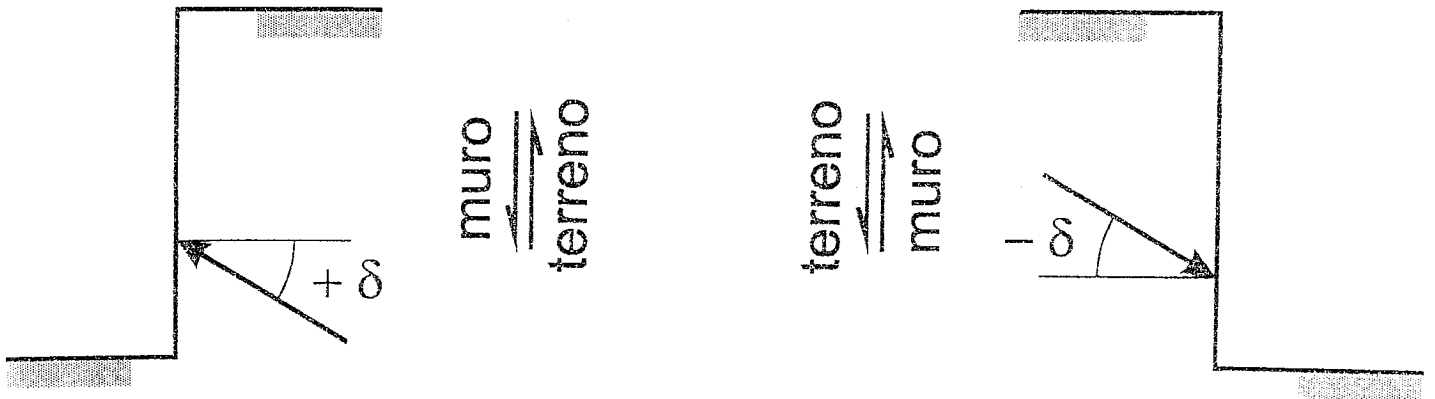
# ATTRITO MURO-TERRENO SPINTA ATTIVA



$\phi'_s = 30^\circ$ :

$\delta$	$K_a$
$0^\circ$	0.33
$+15^\circ$	0.29
$-15^\circ$	0.41

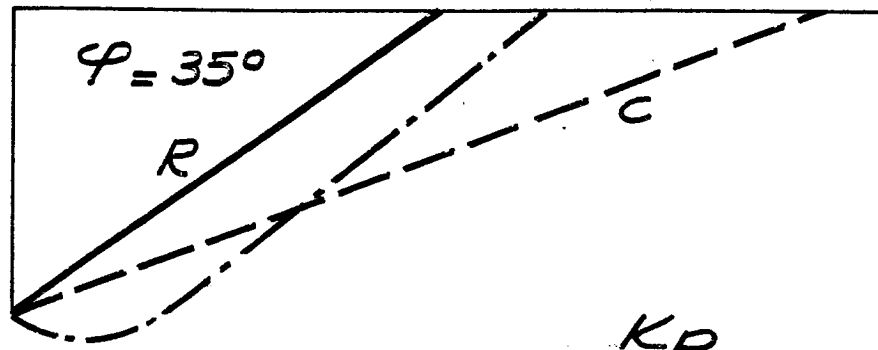
# ATTRITO MURO-TERRENO SPINTA PASSIVA



$\varphi' = 30^\circ$ :

$\delta$	$K_p$
$0^\circ$	3.0
$+20^\circ$	5.2
$-20^\circ$	1.5

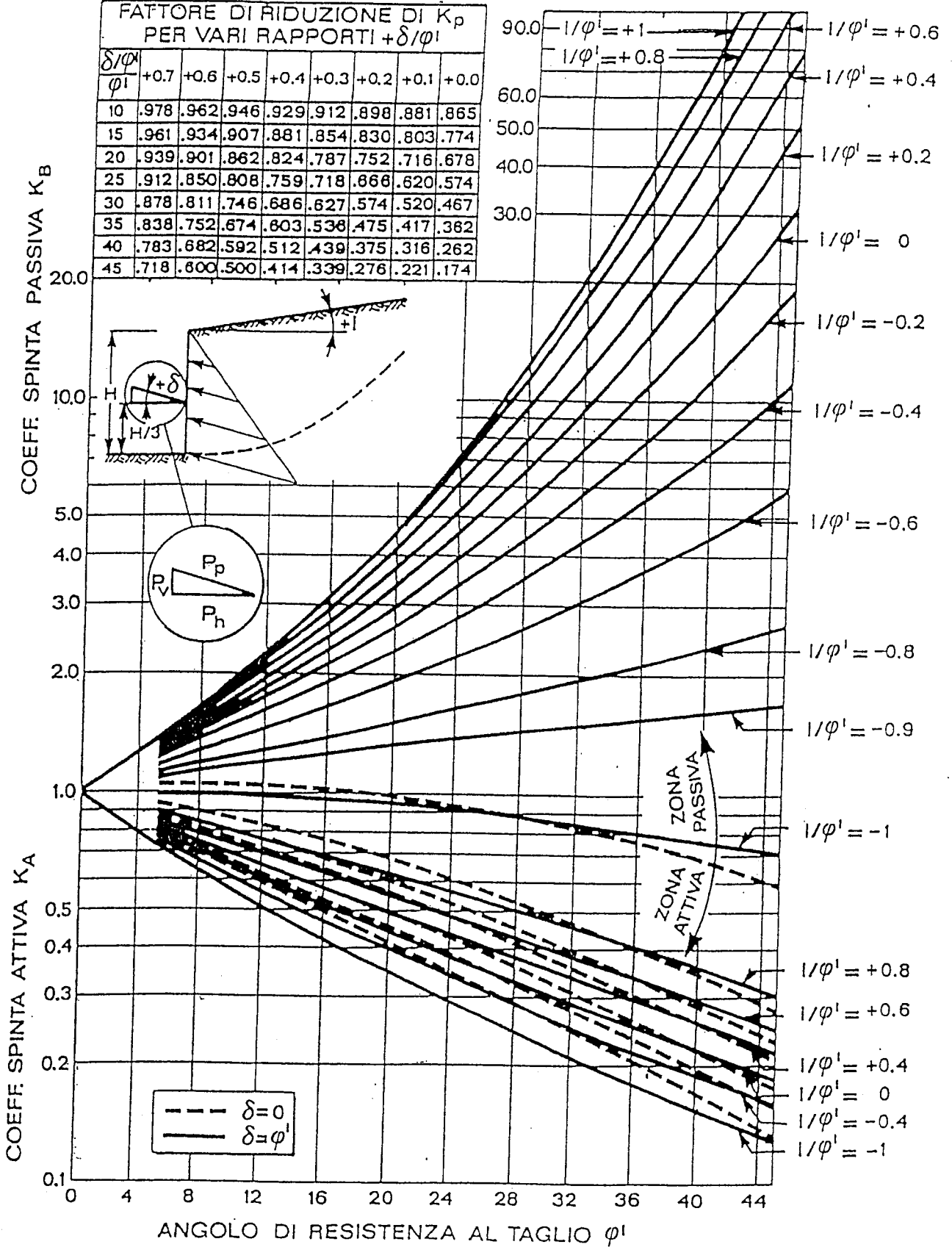
# SPINTA PASSIVA CONFRONTO TRA RANKINE, COULOMB E SUPERFICIE DI ROTTURA CURVA



	$K_p$		
	$\delta = 0$	$\delta = \frac{1}{2} \bar{\varphi}$	$\delta = \bar{\varphi}$
RANKINE	3.69	-	-
COULOMB	3.69	7.02	18.82
(SUP. CURVA)	-	6.50	10.50

FATTORE DI RIDUZIONE DI  $K_p$   
PER VARI RAPPORTI  $+\delta/\varphi'$

$\frac{\delta/\varphi'}{\varphi'}$	+0.7	+0.6	+0.5	+0.4	+0.3	+0.2	+0.1	+0.0
10	.978	.962	.946	.929	.912	.898	.881	.865
15	.961	.934	.907	.881	.854	.830	.803	.774
20	.939	.901	.862	.824	.787	.752	.716	.678
25	.912	.850	.808	.759	.718	.668	.620	.574
30	.878	.811	.746	.686	.627	.574	.520	.467
35	.838	.752	.674	.603	.536	.475	.417	.362
40	.783	.682	.592	.512	.439	.375	.316	.262
45	.718	.600	.500	.414	.339	.276	.221	.174

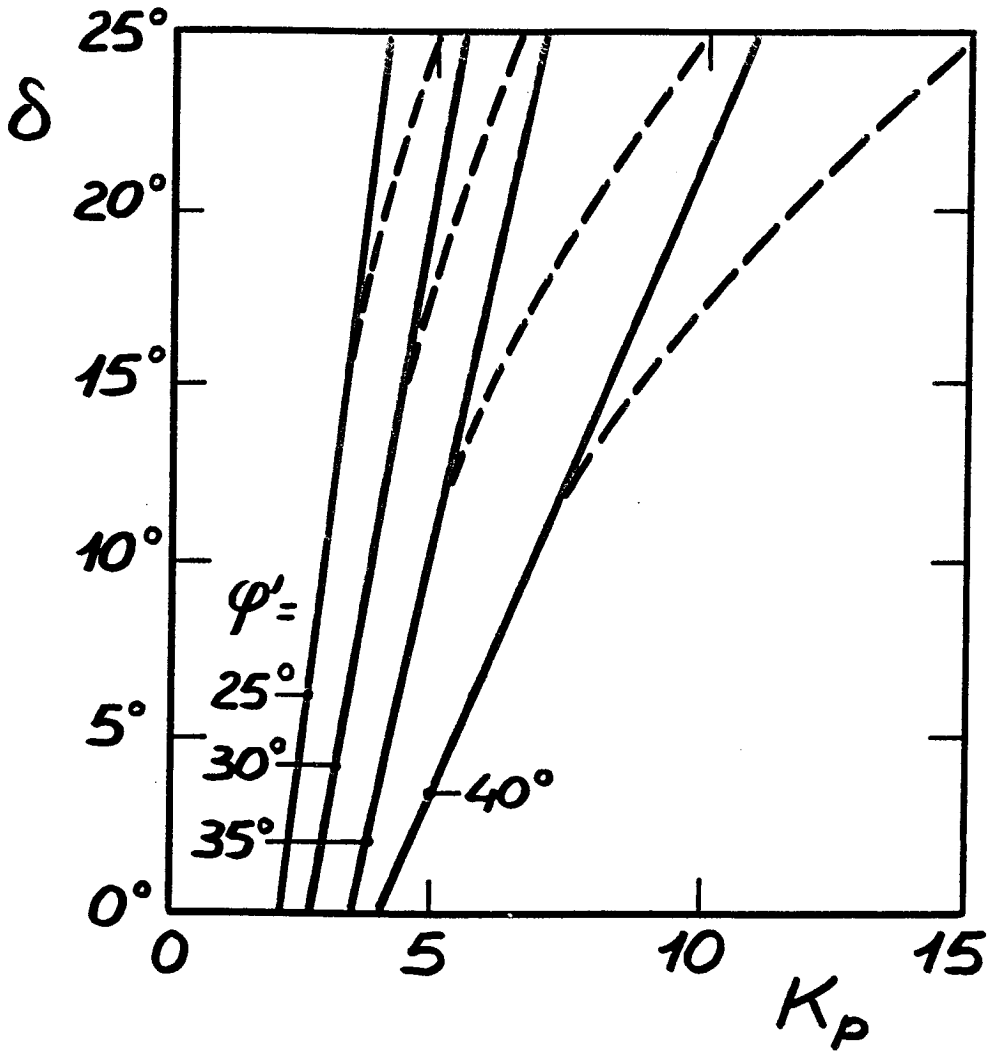


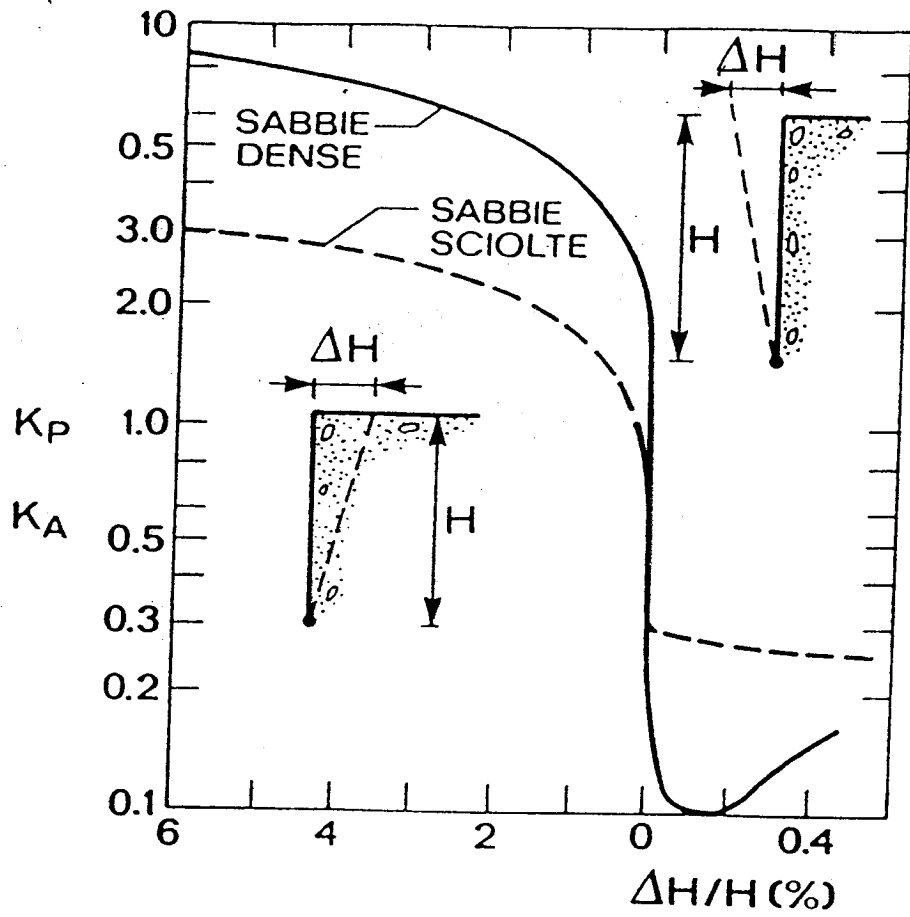
ANGOLO DI RESISTENZA AL TAGLIO  $\varphi'$

# INFLUENZA DELLA RUGOSITA' DEL MURO

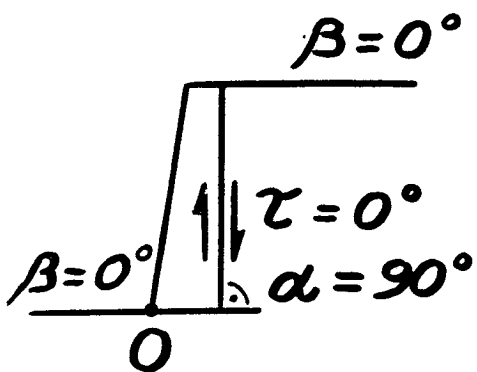
## SU $K_p$

- SUPERFICIE DI SCORRIMENTO CURVA
- SUPERFICIE DI SCORRIMENTO PIANA



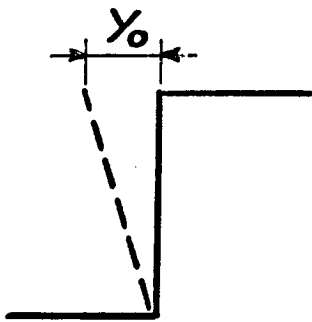


# INFLUENZA DELLA CINEMATICA DELLA OPERA DI SOSTEGNO SULLA DISTRIBUZIONE DELLA SPINTA ATTIVA

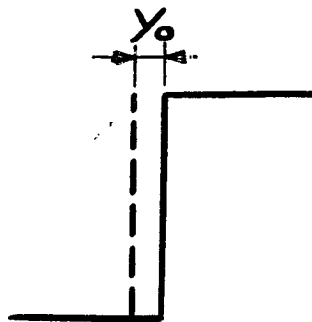


1. OPERA DI SOSTEGNO LISCIA ( $\zeta = 0$ )
2. MURO VERTICALE ( $\alpha = 90^\circ$ )
3. SUPERFICIE DI TERRENO ORIZZONTALE
4. IL MURO RUOTA ATTORNO AL PUNTO "O"

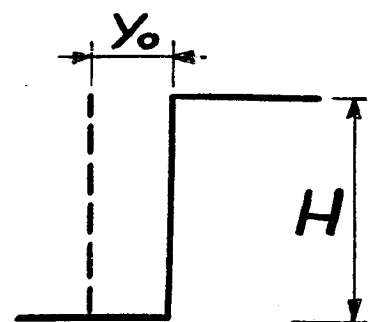
QUANDO QUEST'ULTIMA CONDIZIONE NON E' SODDISFATTA IL DIAGRAMMA DELLE SPINTE SUL PARAMENTO NON E' PIU' TRIANGOLARE



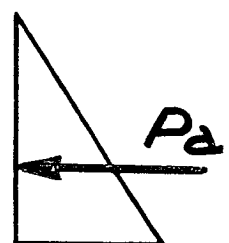
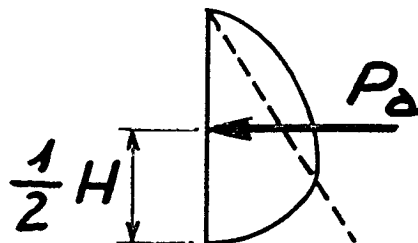
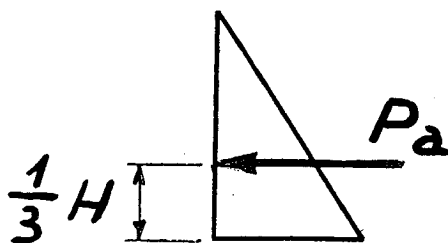
$y_0 \geq 0.002 H$



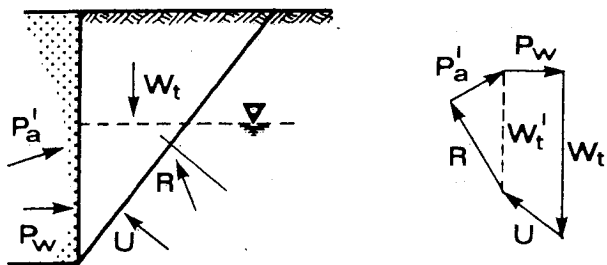
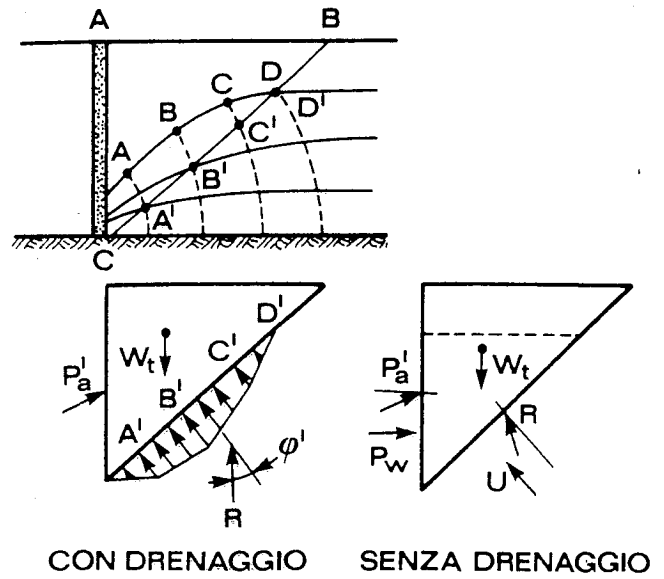
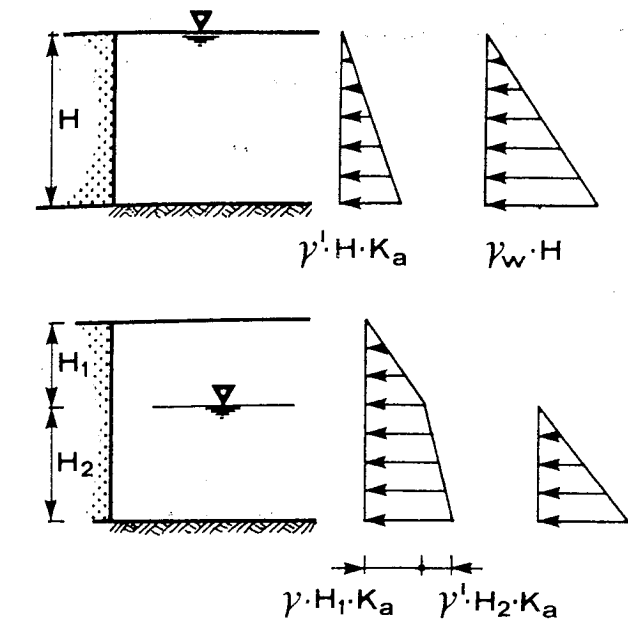
$y_0 < 0.002 H$



$y_0 \geq 0.002 H$





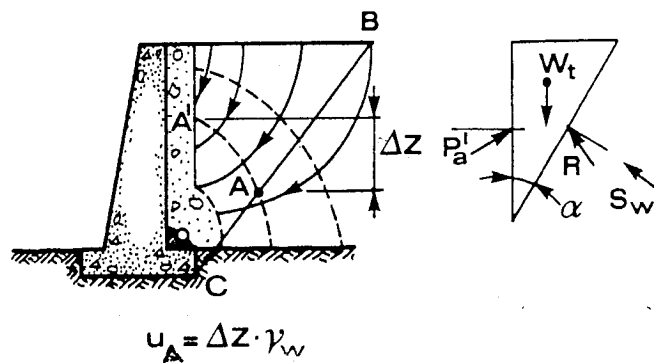
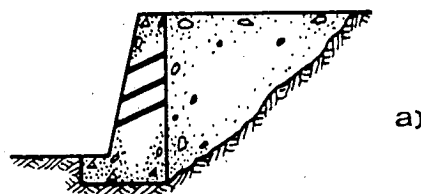


$$h_A = h_{A'}$$

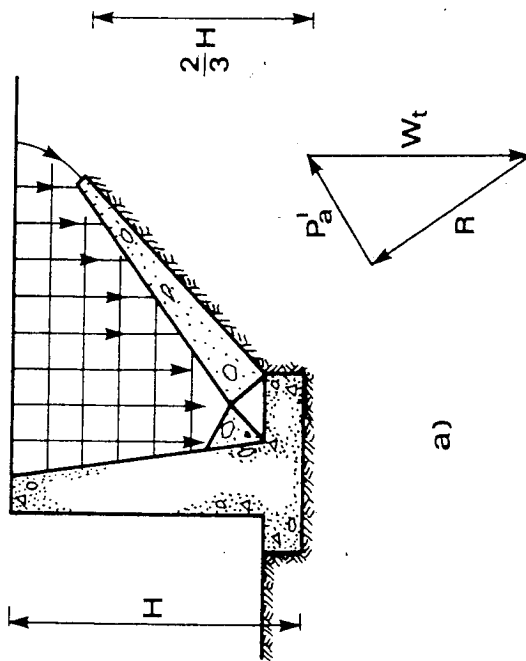
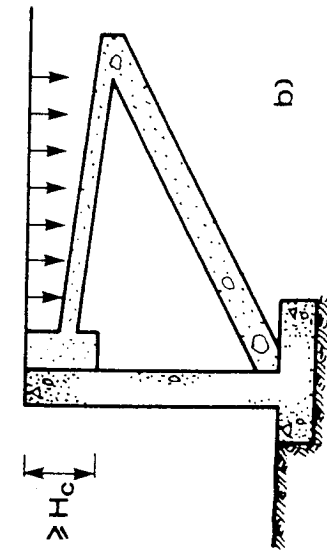
si ha pure:

$$u_{A'} = u_A + \gamma_w(z_A - z_{A'})$$

ed essendo  $u_A = 0$ , risulta  $u_{A'} = \gamma_w(z_A - z_{A'})$ .



$$u_A = \Delta Z \cdot \gamma_w$$



# SPINTE DEL TERRENO DOVUTE A SOVRACCARICHI

## 1. FORMULE DELLA TEORIA DELL'ELASTICITA'

### a. VALUTAZIONE DIRETTA DI $\Delta\sigma_h$

- Formule di Boussinesq e Mindlin
- Applicabile solo al calcolo di  $\Delta\sigma_a$
- Nel caso delle opere di sostegno rigide,  
 $\Delta\sigma_a = 2 \Delta\sigma_h$
- $\nu' = 0.2 \div 0.3$  ;  $\nu_u = 0.5$

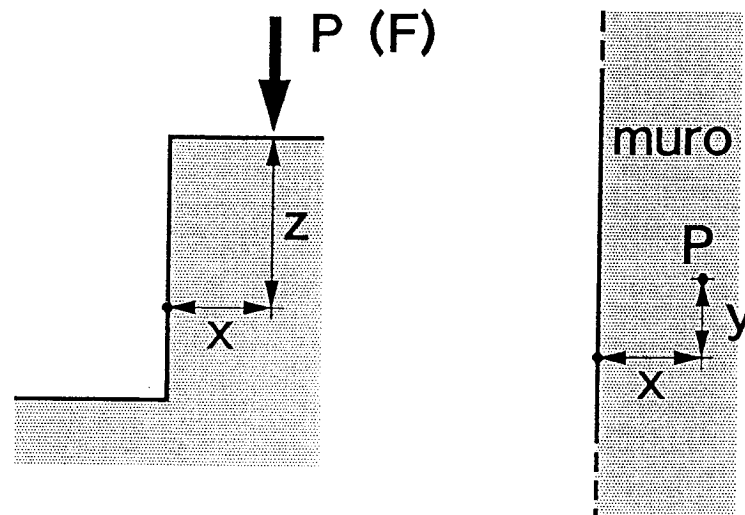
### b. VALUTAZIONE INDIRETTA DI $\Delta\sigma_h$

- Le stesse formule del caso 1a)
- $\Delta\sigma_a = K_a \Delta\sigma_v$  e  $\Delta\sigma_p = K_p \Delta\sigma_v$

## 2. FORMULE EMPIRICHE

- Da prove su modelli
- Da misure sulle opere in scala reale

## CARICO PUNTIFORME



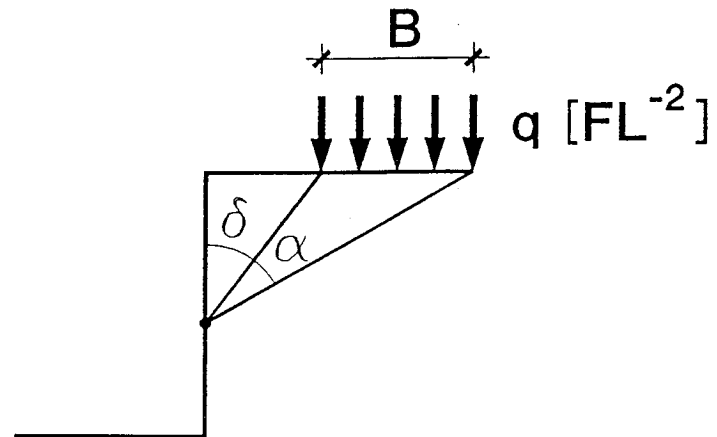
$$\Delta\sigma_h = \frac{P}{2\pi R^2} \left[ \frac{3r^2}{R^3} - \frac{(1-\nu)R}{R+z} \right]$$

$$\Delta\sigma_v = \frac{3Pz^3}{2\pi R^5}$$

$$r = (x^2 + y^2)^{0.5}$$

$$R = (x^2 + y^2 + z^2)^{0.5}$$

## CARICO NASTRIFORME PARALLELO AL MURO



$$\Delta\sigma_h = \frac{q}{\pi} [\alpha - \sin\alpha \cdot \cos(2\delta + \alpha)]$$

$$\Delta\sigma_v = \frac{q}{\pi} [\alpha + \sin\alpha \cdot \cos(2\delta + \alpha)]$$

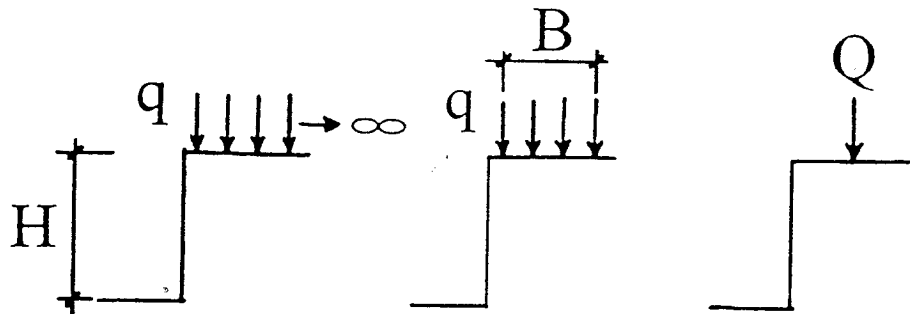
# SPINTE DEL TERRENO - FORMULE GENERALI

$$\sigma'_a = K_a \cdot \sigma'_{vo} - K_{ac} \cdot c' + K_{aq} \cdot q \quad [FL^{-2}]$$

$$\sigma'_p = K_p \cdot \sigma'_{vo} + K_{pc} \cdot c' + K_{pq} \cdot q \quad [FL^{-2}]$$

$$\left. \begin{matrix} K_a \\ K_p \end{matrix} \right\} = f(\varphi', \delta); \quad \left. \begin{matrix} K_{ac} \\ K_{pc} \end{matrix} \right\} = f(\varphi', \delta, c_w); \quad \left. \begin{matrix} K_{aq} \\ K_{pq} \end{matrix} \right\} = f(\varphi, \text{tipo di sovracc.})$$

$$\left. \begin{matrix} \varphi' = 0 \\ c = c_u \end{matrix} \right\} K_a = K_p = 1 \quad K_c = 2\sqrt{1 + c_w / c_u}$$



$$H_e = H + q / \gamma$$

TIPI DI SOVRACCARICO

# COEFFICIENTI DI SPINTA ATTIVA E PASSIVA TERRENI DOTATI DI COESIONE TENSIONI EFFICACI

		$\delta'/\phi'$	$c'_a/c$	$\phi'$		
				15°	20°	25°
$K_a$	0	NI*	0.59	0.48	0.40	
	1		0.50	0.40	0.32	
$K_{ac}$	0	0	1.54	1.40	1.29	
	0	1	2.16	1.96	1.76	
	1	0.5	1.55	1.32	1.15	
	1	1	1.85	1.59	1.41	
$K_p$	0	NI*	1.70	2.10	2.50	
	1		2.20	2.90	3.90	
$K_{pc}$	0	0	2.60	2.80	3.10	
	0	0.5	3.20	3.50	3.80	
	0	1	3.60	4.00	4.40	
	0	0.5	3.80	4.50	5.50	
	1	1	3.90	4.70	5.70	

NI = non  
influyente

$$\left. \begin{matrix} \sigma'_a \\ \sigma'_p \end{matrix} \right\} = K_p^a \cdot \sigma'_{vo} \mp K_{cp}^a \cdot c'$$

# COMMENTI DI CARATTERE PRATICO

1. Le opere di sostegno non sono mai perfettamente lisce.

## a. CALCESTRUZZO

$$\frac{1}{2} \leq \frac{\delta}{\varphi'} \leq \frac{2}{3} \quad ; \quad \frac{1}{3} \leq \frac{c_a'}{c'} \leq \frac{1}{2}$$

## b. ACCIAIO

$$\frac{1}{3} \leq \frac{\delta}{\varphi'} \leq \frac{1}{2} \quad ; \quad \frac{1}{3} \leq \frac{c_a'}{c'} \leq \frac{1}{2}$$



# COMMENTI DI CARATTERE PRATICO

2. La mobilitazione delle spinte attive e passive avviene dopo che l'opera di sostegno ha subito spostamenti e rotazioni di una certa entità.

a. **SPINTA ATTIVA:**

$$\frac{\Delta y(z = 0)}{H} \leq 0.002$$

b. **SPINTA PASSIVA:**

$$0.03 \leq \frac{\Delta y(z = 0)}{H} \leq 0.06$$

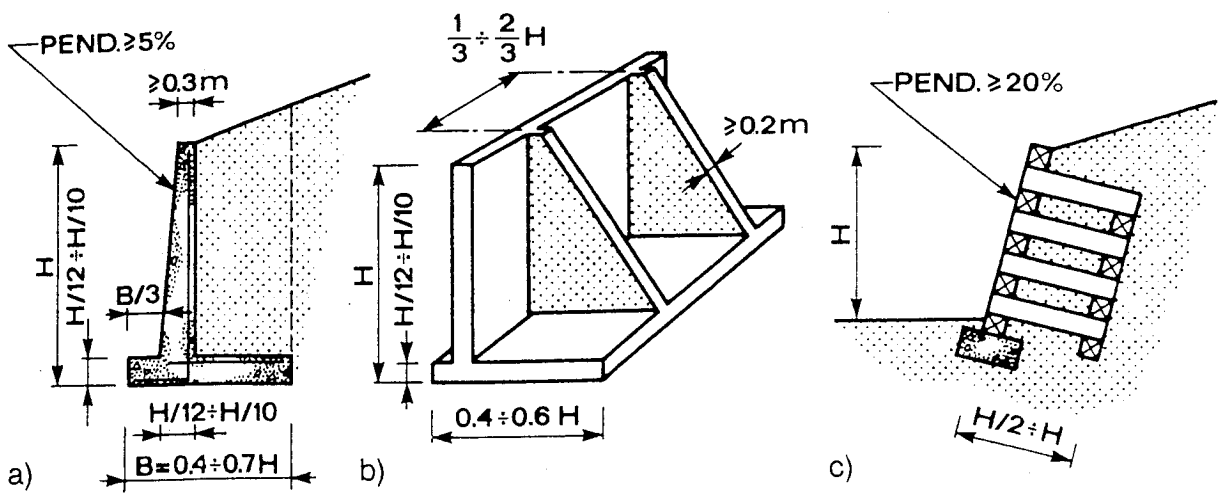
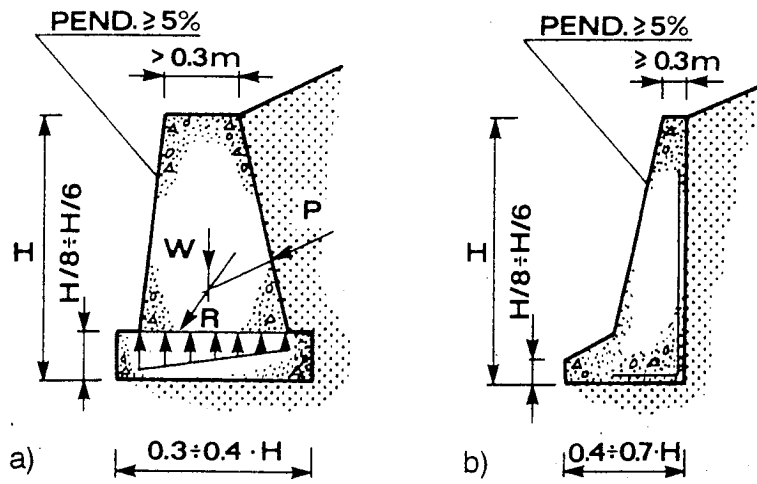
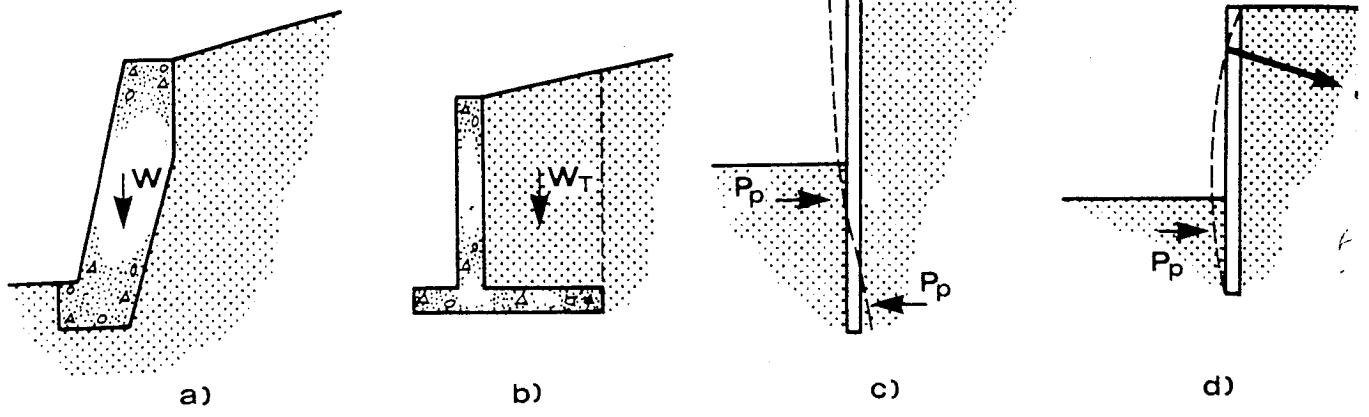
# COMMENTI DI CARATTERE PRATICO

3. La distribuzione delle spinte e il punto di applicazione della loro risultante dipende da:
  - a. Caratteristiche degli spostamenti e delle rotazioni subite dall'opera di sostegno.
  - b. Rigidezza flessionale dell'opera stessa.

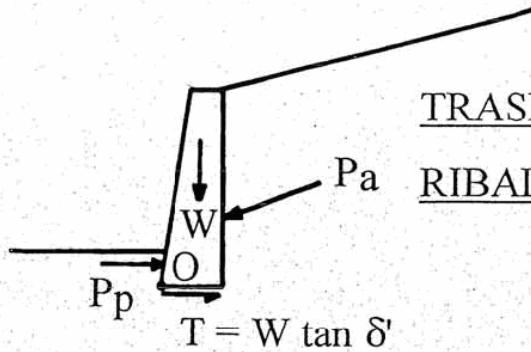
# CALCOLO DELLE SPINTE

## Conclusioni

1. Azioni: terreno + acqua + sovraccarichi + sisma
2. Spinta attiva: utilizzare le soluzioni con la superficie di scorrimento piana:
  - Rankine ( $i = 0$ ,  $\delta = 0^\circ$ ,  $c_a' = 0$ )
  - Coulomb ( $i \neq 0$ ,  $\delta \neq 0^\circ$ ,  $c_a' \neq 0$ )
3. Spinta passiva: quando  $\delta > 1/3 \varphi'$  utilizzare le soluzioni con la superficie di scorrimento curvilinea.
4. Spostamenti necessari per mobilitare la spinta:
  - attiva, molto modesti
  - passiva, rilevanti

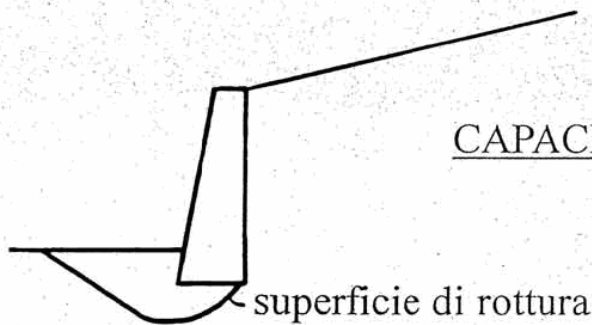


# VERIFICHE DI STABILITA'

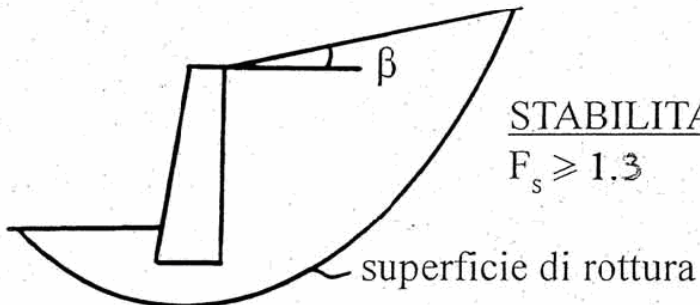


TRASLAZIONE ( $\Sigma T = 0$ ):  $F_s \geq 1.3$

RIBALTAMENTO ( $\Sigma M_o = 0$ ):  $F_s \geq 1.5$

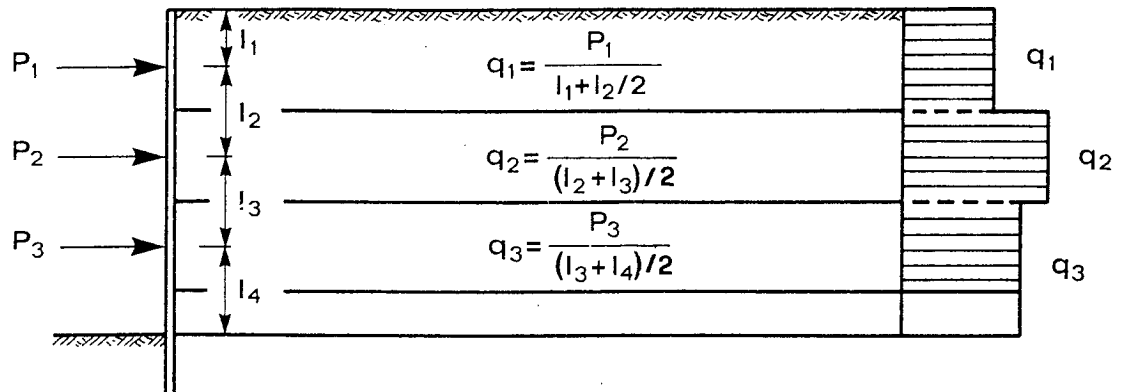


CAPACITA' PORTANTE:  $F_s \geq 2$

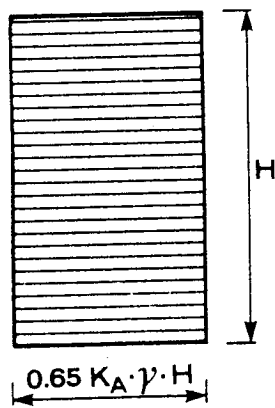


STABILITA' GLOBALE ( $\beta \geq 0$ )

$F_s \geq 1.3$

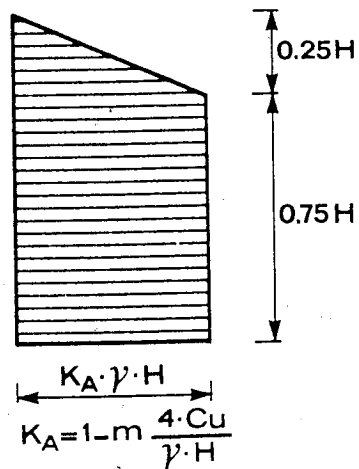


SABBIE



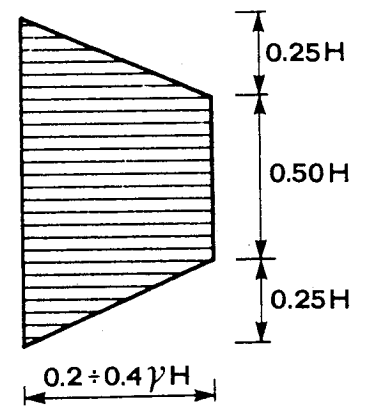
a)

ARGILLA NC



b)

ARGILLA OC



c)

$$N_o = \frac{\gamma H}{C_u}$$

$$N_o = 6 \div 8$$

$$m = 0.4$$

$$N_o = 4 \div 6$$

$$m = 1$$

$$N_o = 3 \div 4$$