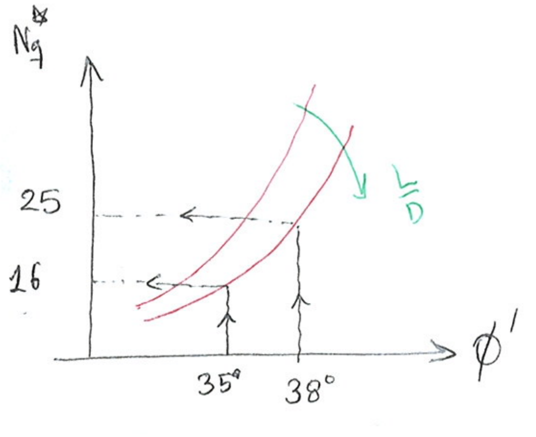
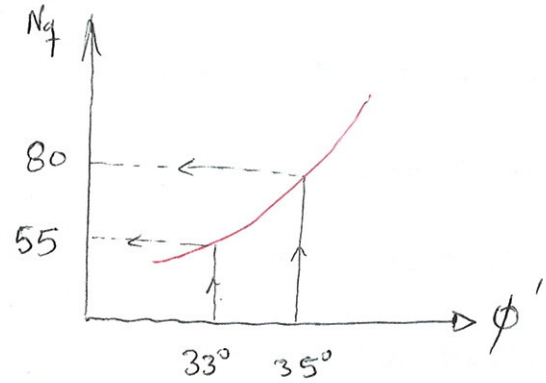


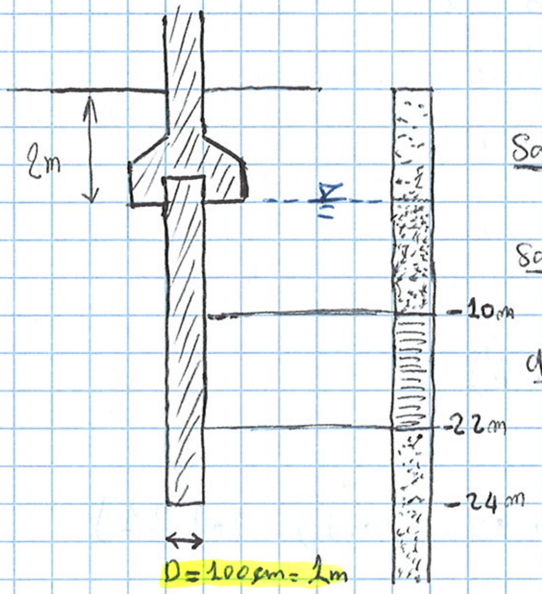
N_q^*
25
16
L/D
35°
38°
ϕ'



N_q
80
55
33°
35°
ϕ'

ESERCIZI SUI PALI TRIVELLATI

ES 1 "PALO TRIVELLATO CON PUNTA IN SABBIA"



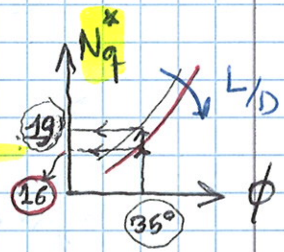
Sabbia : $\gamma = 15\ KN/m^3$

Sabbia : $\gamma = 18\ KN/m^3$, $\phi' = 30°$

Argilla : $\gamma = 17\ KN/m^3$, $c_u = 30\ kPa$

Sabbia : $\gamma = 20\ KN/m^3$, $\phi' = 35°$

↳ Siccome $\underbrace{D \geq 80cm}_{\text{cioe' palo di grande diametro!}}$ ⇒ Berezantzev



i) Resistenza di Base : (in sabbia ⇒ sempre L.T)!

$$R_B = A_B \cdot q_B = \frac{\pi \cdot D^2}{4}\left(N_q^* \cdot \sigma'_{v0}\right)$$

$$\sigma'_{v0} = \left[15.2 + 18.8 + 17.12 + 20.2\right] - \overset{10}{\gamma_w}\left[+8+12+2\right] = 198\ kPa.$$

$$N_q^*\Big|_{\phi=35°} = 16$$

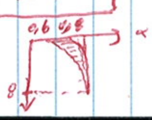
sarebbe un po' altino in quanto il palo non e' ben immorsato

Infine : $R_B = 2488\ KN$

$\boxed{L_{imm} \approx 8D}$ per pali triv.

$\boxed{L_{imm} \approx 10D}$ per pali infissi

⇒ Quindi dovrebbe essere diminuito di un certo coef. α



ii) Resistenza laterale in Sabbia : (sempre a L.T.) vicino alla punta.

$$R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz$$

$$= \pi \cdot D \cdot K \cdot \bar{\sigma}_{v0}' \cdot tg(\delta) \cdot 2$$

δ = ϕ' perché pali costruiti in opera. Inoltre la sup. del palo e' molto irregolare!

K → AGI : $K = (0{,}4 \div 0{,}5)$

scelgo ⇒ 0,5 → perché c'e' stato un rilascio tensionale.

$$= \pi \cdot D \cdot 0{,}5 \cdot \bar{\sigma}_{v0}' \cdot tg(\phi') \cdot 2$$

$$\bar{\sigma}_{v0}' = [15 \cdot 2 + 18 \cdot 8 + 17 \cdot 12 + 20 \cdot 1] - 10\,[21]$$

$$= 288 \text{ KPa}$$

Infine $R_L|_{sabbia} = 413{,}56$ KN.

iii) Resistenza laterale in argilla : da $(10 \div 22)$m.

$$R_L = \pi \cdot D \int_0^z \tau_{Lim}\, dz \; : \begin{cases} \text{metodo } \alpha & \text{I} \checkmark \\ \text{metodo } \beta & \text{II} \times \end{cases}$$

I $= \pi \cdot D \cdot \alpha \cdot cu \cdot 12$

α → AGI : $\begin{cases} \alpha = 0{,}9 & \text{se } cu \leq 25 \text{ KPa} \\ \alpha = 0{,}4 & \text{se } cu \geq 70 \text{ KPa} \end{cases}$ ← per pali trivellati

per i valori intermedi di α ⇒ interpolazione Lineare!

e.g. $\alpha = 30$

α	cu
0,9	25
α	30
0,4	70

$$\Rightarrow \frac{70-25}{0{,}4-0{,}9} = \frac{30-25}{x-0{,}9}$$

$\alpha \cong 0{,}85$

$$R_L \cong 942 \text{ KN}$$

iv) Resistenza laterale in sabbia da (2 ÷ 10) m:

$$R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim}\, dz$$

$$= \pi \cdot D \cdot \underset{\uparrow 0{,}5}{K} \cdot \bar{\sigma}_{v0}' \cdot tg\underset{\uparrow \phi'}{\delta} \cdot 8$$

$$= \pi \cdot D \cdot 0{,}5\, \bar{\sigma}_{v0}' \cdot tg(\phi') \cdot 8$$

$$\bar{\sigma}_{v0}' = [25 \cdot 2 + 28 \cdot 4] - 10[4] = 62 \text{ KPa}$$

infine:

$$R_L\Big|_{sabbia} = 450 \text{ KN}$$

Infine carico Limite:

$$R_{Lim} = 2488 + (413 + 942 + 450) = 4293 \text{ KN}$$

- verifica: DM'88:

NB!

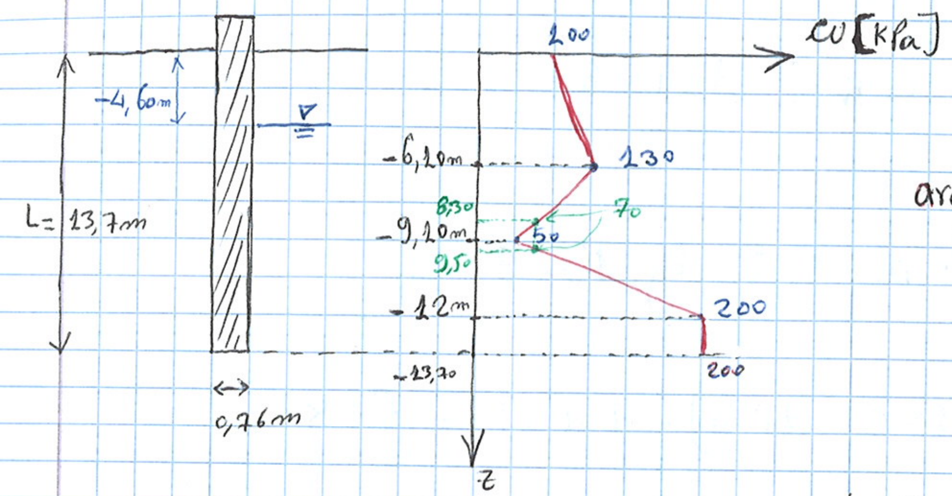
$$R_{amm} = \frac{R_{Lim}}{F_{S=2,5}} = 1717 \text{ KN} < R_{L_{Tot}} \Rightarrow$$

⇒ siccome R_{amm} e' unpo' piu' piccolo della resistenza laterale tot. del palo ⇒ il palo ha piccoli cedimenti. perche' ~~R_L~~ si mobilita' per grandi spostamenti!

$\uparrow R_B$?

—

ES. 2 PALO TRIVELLATO IN ARGILLA:



argilla con $\gamma_a = 19\ kN/m^3$

- Dalle raccomandazioni AGI: $\alpha \begin{cases} 0,9 & \text{se } c_u \leq 25\ kPa \\ 0,4 & \text{se } c_u \geq 70\ kPa \end{cases}$

$$\Rightarrow \begin{cases} 0 \div 6,10 \longrightarrow \alpha = 0,4 \\ 6,10 \div 8,30 \longrightarrow \alpha = 0,4 \\ 8,30 \div 9,50 \longrightarrow \alpha = 0,60 \\ 9,50 \div 13,7 \longrightarrow \alpha = 0,4 \end{cases}$$

: interpolato Linearmente con ($c_u = 60\ kPa = \frac{70+50}{2}$)

(i) Resistenza laterale R_L con il metodo α:

$$R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz$$

$$= \pi \cdot D \cdot \alpha \cdot c_u \cdot \int_0^z dz$$

$$= \pi \cdot D \cdot \left[0,4 \cdot \frac{130+200}{2} \cdot 6,10 + 0,4 \cdot \frac{70+130}{2} \cdot 2,20 + 0,60 \cdot \frac{50+70}{2} \cdot 1,20 + \right.$$

$$\left. + 0,4 \cdot \frac{200+70}{2} \cdot 2,50 + 0,4 \cdot \frac{200+200}{2} \cdot 1,70 \right]$$

$$= 1630\ kN$$

(iii) Resistenza di base : R_B (sempre in condizioni non drenate B.T) $\rightarrow \sigma_{v_0}$

$$R_B = A_B \cdot q_B = A_B (c_U \cdot N_c + \sigma_{v_0})$$

$\sigma_{v_0} \rightarrow \gamma_a \cdot 13{,}70 = 260{,}3$ kPa

$N_c \rightarrow 9$ se $L_{imm} \geq (3 \div 4\,D)$

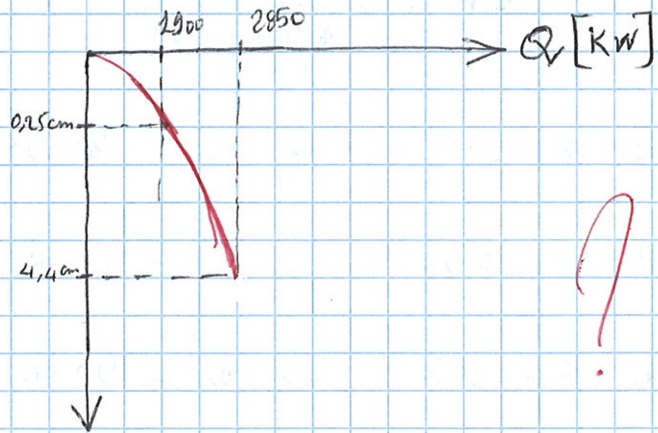
$$= \frac{\pi \cdot D^2}{4} (200 \cdot 9 + 260{,}3) = 934{,}64 \text{ KN.}$$

infine

$$R_{Lim} = R_L + R_B = 1630 + 935 = 2565 \text{ KN}$$

- La curva carico – cedimento misurata :

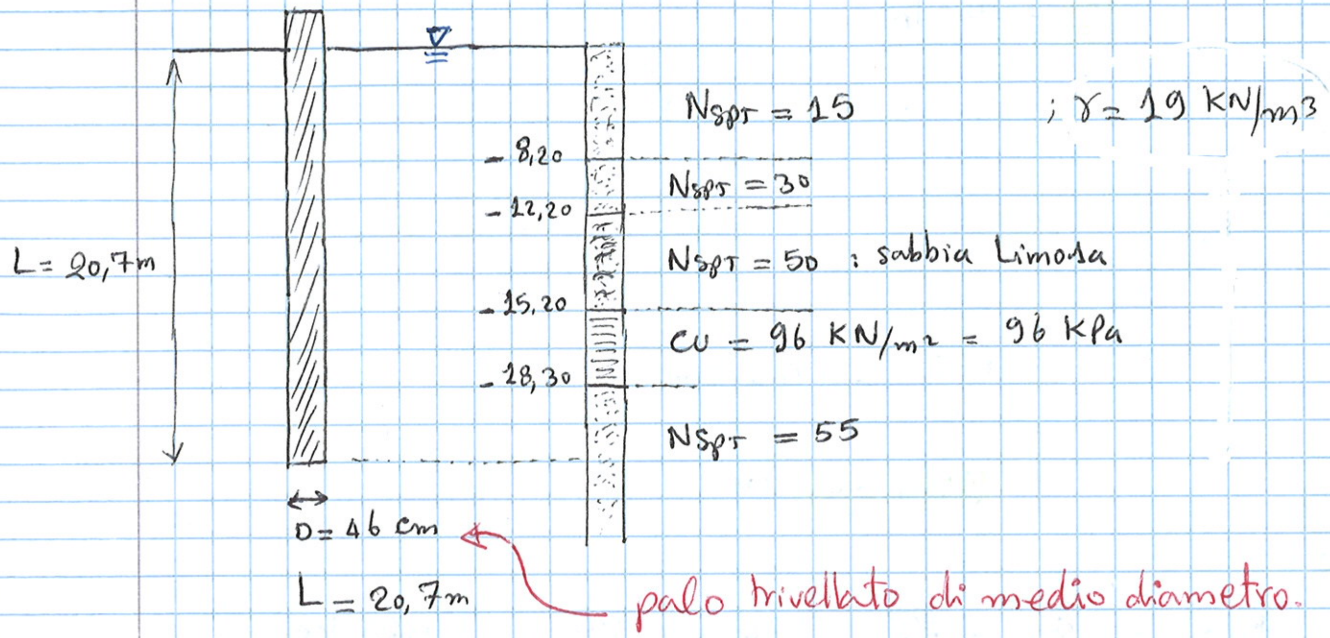
misurata : $\begin{cases} R_L = 1594 \text{ KN} \\ R_B = 1253 \text{ KN} \end{cases}$



?

—

ES. 3 PALO TRIVELLATO IN SABBIA



(i) Resistenza di base R_B : $R_B = A_B \cdot q_B = A_B\,(N_q \cdot \sigma'_{v_0})$

$$- \quad D_r = \sqrt{\frac{N_{SPT}}{0{,}25\,\sigma'_{v_0} + 16}}$$

Gibbs & Holtz

per $z = 20,7\,m \rightarrow \sigma'_{v_0} = (19-10)\,20,7 = 186,3\ kPa \Rightarrow D_r = 0,94$

da $0 \div 8,20 \rightarrow \sigma'_{v_0} = (4 \cdot 8) = 32\ kPa \Rightarrow D_r = 0,8$

da $8,20 \div 12,20 \rightarrow \sigma'_{v_0} = 90\ kPa \Rightarrow D_r = 0,9$

?

- per ricavare la ϕ' uso la procedura iterativa :

$- \text{hp. } \phi' \rightarrow \text{trovo } N_q^* \rightarrow \bar{p}' = \sigma'_{v_0} \cdot \sqrt{N_q^*} \rightarrow$

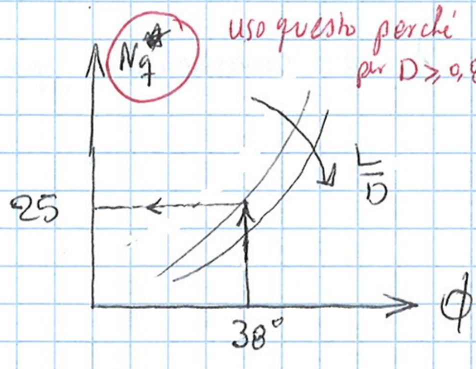
$\rightarrow \phi' = \phi'_{cv} + 3\left[D_r\,(10 - \ln \bar{p}') - 1\right]$

e.g.

$- \text{con } \phi' = 38° \rightarrow N_q^* = 25 \rightarrow \bar{p}' = 186,3\sqrt{25} = 931\ KPa$

$\rightarrow \phi' = 38° \rightarrow$ OK! mi fermo!

Quindi una volta che ho $\phi' = 38°$ $\Rightarrow$ riccavo N_q^* dal grafico di Berezantzev. (I)[a]



uso questo perché Dr grande!!
per $D \geq 0,8$ m
?

NB) attenzione a pali trivellati in sabbia $\rightarrow$
$\rightarrow$ per scarico tensionale in punta ho come avere gomma piuma in punta.

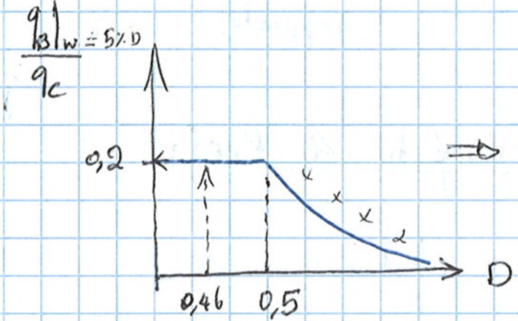
Infino:

$$R_B = \frac{\pi \cdot D^2}{4} \cdot (25 \cdot 186,3) = 774 \text{ KN}$$

- usando altri metodi $\rightarrow$ correlazione prove in sito:

(I)[b] Jamiolkowski & Lancellotta:

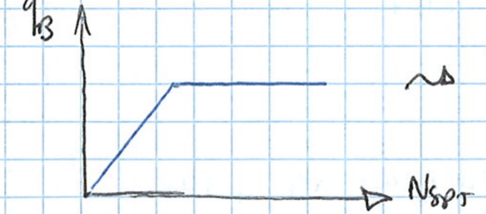
$$q_c \simeq 0,4 \cdot N_{SPT} = 22 \text{ MPa}$$



$\Rightarrow$ nostro $q_B = 0,2\, q_c = 4,4$ MPa

$\Rightarrow R_B = A_B \cdot q_B = 580$ kN

(II) Right & Reese:



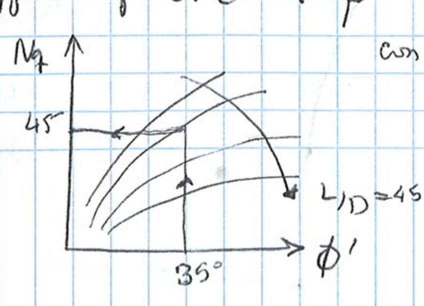
$\rightsquigarrow$ nel nostro caso $q_B = 3,7$ MPa $\Rightarrow$

$R_B = 615$ KN

NB) Queste stime sono fatte per pali di grande diametro in cui $w = 5\% D = 2,3$ cm. cioè troppo cautalative!

se si accetta $\frac{w}{D}$ maggiori perché il palo è di medio diametro. $\rightarrow$

(III) Poulos & Davis.



con $\phi' = \phi'_{misurato} - 3 = 35°$
$\phi'_{misurato} = 38°$

$N_q = 45 \rightarrow q_B = 45 \cdot 186,3 = 8,4$ MPa

$\Rightarrow R_B = 1390$ KN

– Resistenza laterale: R_L

Si e' considerato per la sabbia $\rightarrow \begin{cases} \phi' = 39° \\ K = 0{,}5 \end{cases}$

sabbia limosa $\rightarrow \begin{cases} \phi' = 34° \\ K = 0{,}4 \end{cases}$

argilla $\rightarrow \{ \alpha = 0{,}4$

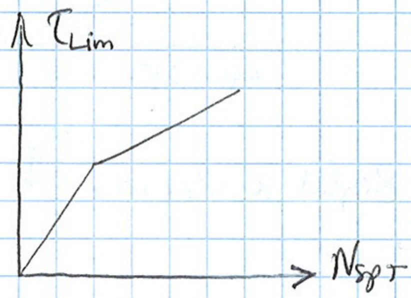
$$R_L = \pi \cdot D \left[\underset{K}{0{,}5} \cdot \tan(39°) \cdot \underbrace{(\overset{\gamma'}{9} \cdot 1{,}10)}_{\sigma'_{v0}} \cdot 12{,}20 + \underset{K}{0{,}4} \cdot \tan(34°) \cdot \overbrace{\frac{12{,}20 + 15{,}30}{2}}^{\sigma'_{v0}} \cdot 9.3 + \right.$$

$$\left. + \underset{K}{0{,}5} \tan(39°)\, 9 \cdot \underbrace{\left(\frac{18{,}30 + 20{,}70}{2}\right)}_{\sigma'_{v0}} \cdot 2{,}40 + 0{,}4 \cdot 96 \cdot 3{,}10 \right] =$$

$= 954$ KN $\leftarrow$ controllare i conti non gli ho fatti io! coppiato!

– usando la correlazione di **Wright & Rees**:

$$\tau_{Lim} < \underbrace{0{,}7 \tan\phi'}_{0{,}57} \cdot \sigma'_{v0}$$

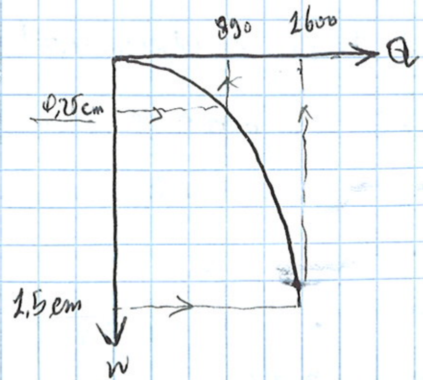


$$R_L \simeq \frac{(638 + 144)}{0{,}5} \cdot 0{,}7 + 172$$

$\simeq$ **1260 KN**

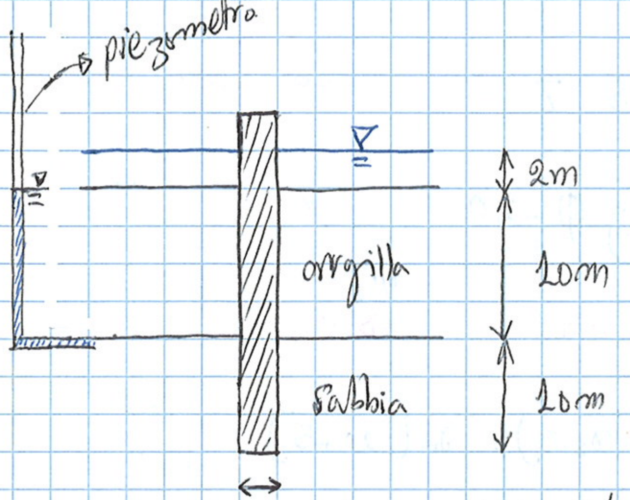
– misurato

prova di carico! su pali pilota



$\Rightarrow \begin{cases} R_L = 1477 \text{ KN} \\ R_B = 125 \text{ KN} \end{cases}$ $\rightarrow$ piccolissimo perché cedimenti imposti nel grafico sono piccoli!

ES4 "PALO TRIVELLATO DI GRANDE DIAMETRO"



$D = 0,8m$ ciò palo triv. di grande diametro.

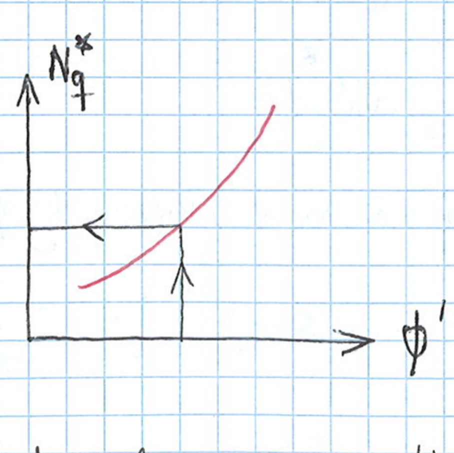
Ben immorsato!

(i) Resistenza di base: (in sabbia) sempre a (B.T.) NB!

$$R_B = \frac{\pi \cdot D^2}{4} \cdot \left(N_q^* \cdot \sigma'_{v0}\right)$$

$$\sigma'_{v0} = \left[\underset{\gamma_w}{10} \cdot 2 + 10 \cdot \gamma_a + 10\,\gamma_s\right] - \gamma_w\left[\overset{10+10}{20}\right]$$

N_q^* da berezantzev:



(ii) Resistenza laterale R_L in sabbia

$$R_L = \pi \cdot D \int_0^z \tau_{Lim}\, dz$$

$$R_L\Big|_{sabbia} = \pi \cdot D \cdot \int_0^z \tau_{lim}\, dz$$

ϕ' perché pali costruiti opera con sup. molto ruvida!

$$\overset{!}{=} \pi \cdot D \cdot \bar{\sigma}_h' \cdot tg\,\delta \cdot z$$

$$\overset{!}{=} \pi \cdot D \cdot K \cdot \bar{\sigma}_{v_0}' \cdot tg\,\phi \cdot 10$$

AGI: $K = 0{,}4 \div 0{,}5 \rightsquigarrow K = 0{,}5$

$$\bar{\sigma}_{v_0}' = [\gamma_w \cdot 2 + \gamma_a \cdot 10 + \gamma_s \cdot 5] - \gamma_w [10 + 5]$$

(iii) Resistenza laterale in argilla: R_L (sempre a L.T.)!

$$R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz \quad \begin{cases} \text{metodo } \alpha & (\mathrm{I}) \\ \text{metodo } \beta & (\mathrm{II}) \end{cases}$$

(I) $\overset{!}{=} \pi \cdot D \cdot \alpha \cdot c_u \cdot z^{=10}$

AGI: $\alpha \begin{cases} 0{,}9 & \text{se} \quad c_u \leq 25 \text{ kPa} \\ 0{,}4 & \text{se} \quad c_u \geq 70 \text{ kPa} \end{cases}$

(II) $$R_L = \pi \cdot D \int_0^z \tau_{lim}\, dz$$

$$\overset{!}{=} \pi \cdot D \cdot \beta \cdot \bar{\sigma}_{v_0}' \int_0^z dz$$

$$\overset{!}{=} \pi \cdot D \cdot (1 - \sin\phi')\,(OCR)^{0,5} \cdot tg\,\phi' \cdot \bar{\sigma}_{v_0}' \cdot 10$$

$$\bar{\sigma}_{v_0}' = [2 \cdot \gamma_w + 5\gamma_a] - \left[\frac{\gamma_w \cdot 2 + \gamma_w \cdot 10}{2}\right]$$

_Infine $$R_{Lim} = R_L\Big|_{sabbia} + R_L\Big|_{argilla} + R_B\Big|_{sabbia}$$

_Verifica DM'88: $$R_{amm} = \frac{R_{Lim}}{F_s} = \frac{R_{Lim}}{2{,}5}\ !$$

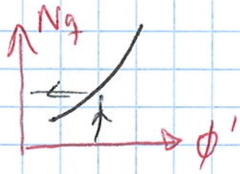
— o —

FORMULARIO PALI TRIVELLATI

(i) $R_B \Big|_{sabbia} = A_B \cdot q_B$: Sempre a L.T.

$= \frac{\pi \cdot D^2}{4} \cdot N_q \cdot \sigma_{v0}'$

N_q ⟶ Berezantzev.



(ii) $R_L \Big|_{sabbia} = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz$

$= \pi \cdot D \cdot \bar{\sigma}_{h0}' \cdot tg\,\delta \cdot \int_0^z dz$

$= \pi \cdot D \cdot K \cdot \bar{\sigma}_{v0}' \cdot tg\,\phi' \cdot z$

$\delta = \phi'$ perchè pali costruiti ~~[illegible]~~ in opera e in sup. molto ruvidi.

K: 0,5 (AGI) ⟶ ($K = 0{,}4 \div 0{,}5$)

(iii) $R_B \Big|_{argilla} = A_B \cdot q_B$

$= \frac{\pi \cdot D^2}{4} \cdot (c_u \cdot N_c + \bar{\sigma}_{v0})$

NB! Sempre a B.T!

N_c: 9 se $L_{imm} \simeq (3 \div 4)\,D$

(iv) $R_L \Big|_{argilla} = \pi \cdot D \cdot \int_0^z \tau_{lim}\, dz$ $\begin{cases} \text{metodo } \alpha & \text{(I)} \\ \text{metodo } \beta & \text{(II)} \end{cases}$

(I) $= \pi \cdot D \cdot \int_0^z \alpha\, c_u\, dz$

$= \pi \cdot D \cdot \alpha \cdot c_u \cdot z$

⟶ AGI: $\begin{cases} \alpha = 0{,}9 & \text{se } c_u \leq 25 \text{ kPa} \\ \alpha = 0{,}4 & \text{se } c_u \geq 70 \text{ kPa.} \end{cases}$

(II) $R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz$

$= \pi \cdot D \cdot \beta \cdot \bar{\sigma}_{v0}' \cdot z$

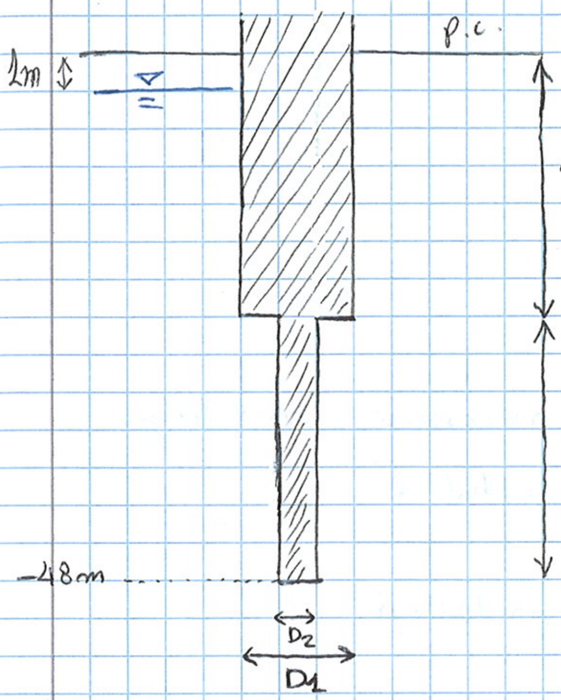
$= \pi \cdot D \cdot (1 - \sin\phi') \cdot (OCR)^{0,5} \cdot tg(\phi') \cdot \bar{\sigma}_{v0}' \cdot z$

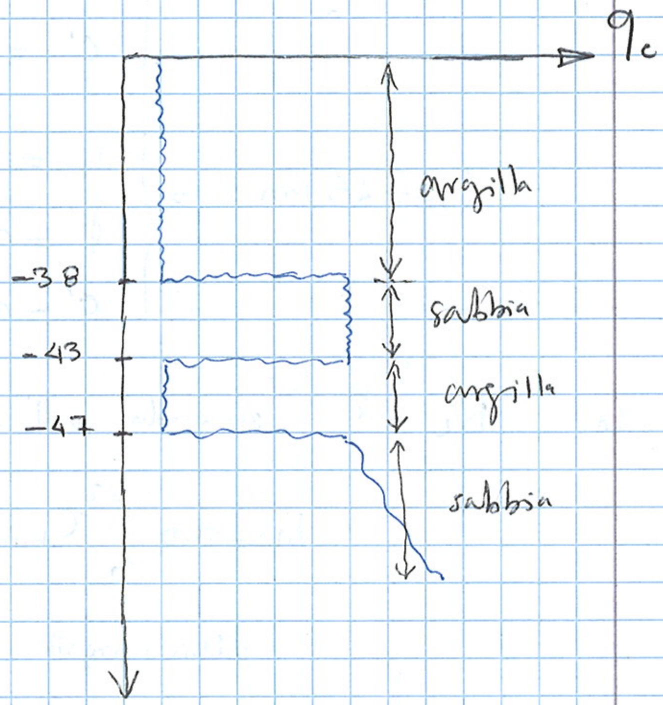
— o —

E8.5

PALO INFISSO

$D_1 = 40,6\,cm$ e $D_2 = 35,6\,cm$; $\gamma = 17,5\ kN/m^3$





- per trovare c_u sapendo q_c :

$$\boxed{c_u = \frac{q_c - \sigma_{v0}}{20}}$$

NB!

- Dividiamo in tratti in cui q_c e' circa costante ⟹ si e' ottenuto l'andamento di c_u : AGI. $\begin{cases} \alpha = 1 & \text{se } c_u \leq 25\ kPa \\ \alpha = 0,5 & \text{se } c_u \geq 70\ kPa \end{cases}$

$0 \div 2,5$	⟿	$c_u = 100\ kPa$	⟿	$\alpha = 0,5$
$2,5 \div 6$	⟿	$c_u = 50\ kPa$	⟿	$\alpha = 0,70$
$6 \div 16$	⟿	$c_u = 150\ kPa$	⟿	$\alpha = 0,5$
$16 \div 30$	⟿	$c_u = 100\ kPa$	⟿	$\alpha = 0,5$
$30 \div 39$	⟿	$c_u = 120\ kPa$	⟿	$\alpha = 0,5$
$39 \div 42$	⟿	sabbia		
$42 \div 47$	⟿	$c_u = 110\ kPa$	⟿	$\alpha = 0,5$

- oltre prove di Laboratorio hanno indicato che fino a $z=32m$

$$(0 \div 32)m \rightarrow \begin{cases} I_p = 40 \div 50 \\ \phi' = 26° \\ c' = 0 \end{cases}$$

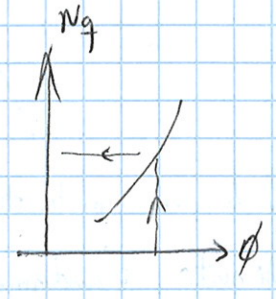
$$(32 \div 45)m \rightarrow \begin{cases} I_p = 25 \div 30 \\ \phi' = 30° \\ c' = 0 \end{cases}$$

(i) $R_L = ?$ avendo tutti i valori necessari posso trovare:

$$R_L \Big|_{\text{sabbia + argilla}} = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz \quad \begin{cases} \text{metodo } \alpha \\ \text{metodo } \beta \end{cases}$$

(ii) $R_B \Big|_{\text{sabbia}} = A_B \cdot q_B = \frac{\pi \cdot D^2}{4} \cdot (N_q \cdot \sigma'_{v0})$

↳ Berezantzev!



NB! Siccome il palo non e' ben immorsato nell'argilla:

$$1m \sim 3D \leq 10D$$

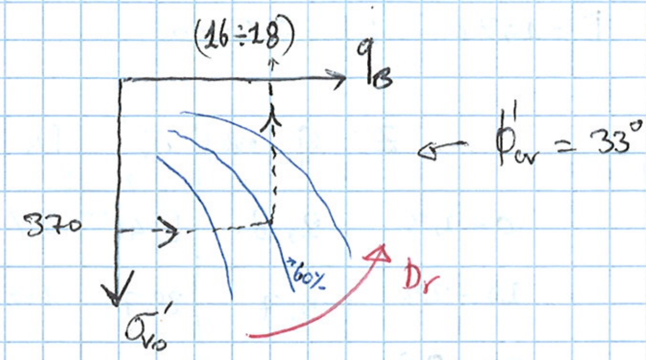
⇒ dovro' abbattere il valore di q_B:

facciamolo variare linearmente:

$$\boxed{q_B^* \simeq \frac{3D}{10D} \cdot q_B} \simeq \frac{3}{10} \cdot q_B \qquad (A)$$

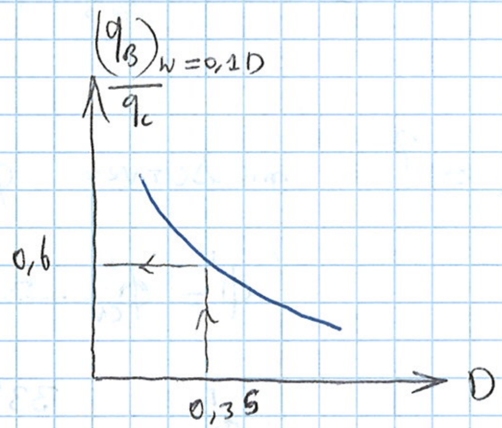
Altri metodi per calcolare R_B:

- FLEMMING:



anche qui però dobbiamo applicare 1 riduzione perché se in sabbia l'infissione non sarà adeguato!

- Jardine & Chow



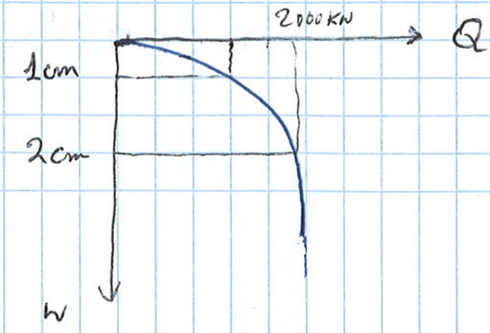
La "q_c" nella sabbia è molto variabile e la consideriamo compresa tra (20 ÷ 30) MPa → prendo 25 MPa

$$q_B\Big|_{W=0,1D} = 0,6 \cdot q_c \simeq 15\,MPa.$$

Infine scelgo (A) ⇒ $R_B = 600\,kN$

- infine $\quad R_{Lim} = R_L\Big|_{TOT} + R_B$.

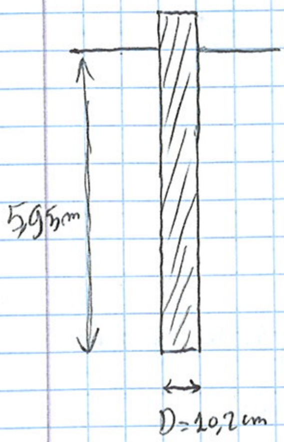
- verifica $\quad R_{amm} = \frac{3600}{2,5} = 1500\,kN$ → dà 1 cedimento di 1cm.



— o —

ES. 6 "Palo infisso per presso-infissione" in sabbia

$D = 10{,}2\ cm$; $L = 5{,}95\ m$



Z	q_c [MPa]	σ_v'	D_r	τ_{Lim}	L
0 ÷ 1,3	2,8	8,45	50%	18,7	1,3
1,3 ÷ 2,2	5,7	28,7	60%	38	0,9
2,2 ÷ 2,8	3	42,3	40%	2	0,6
2,8 ÷ 3,8	1,4	55,4	20%	9,3	1
3,8 ÷ 6	4,2	69,9	40%	28	2,2
6 ÷ 6,2	5,3	81,1	40%		

(i) $R_L = ?$ mi server ϕ': uso l'espressione di BOLTON:

$$\phi' = \phi'_{cv} + 3\left[\frac{D_r}{100}(10 - \ln p') - 1\right]$$

$$\phi'_{cv} = \begin{cases} 33° & \text{se sabbia media grossa} \checkmark \\ 30 & \text{se sabbia fine e limosa} \\ 27° & \text{se limo} \end{cases}$$

$$p' = \frac{1 + 2\overset{=1}{K}}{3} \cdot \overline{\sigma_{v0}'}$$

↑ NB! calcolato a metà dello strato!

Ip.: $K = 1$ (**)

ottengo $\phi' = 38°$

$$R_L = \pi \cdot D \cdot \int_0^z \tau_{Lim} \cdot dz$$

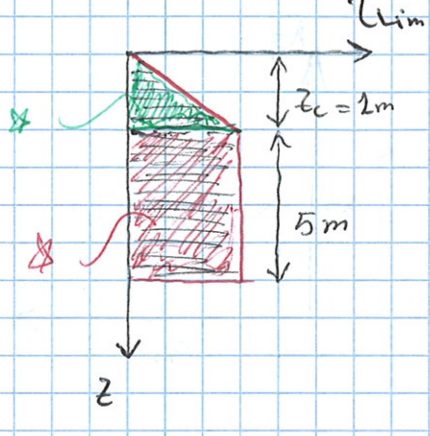
$$= \pi \cdot D \cdot K \cdot \overline{\sigma_v'} \cdot tg(\delta) \cdot z$$

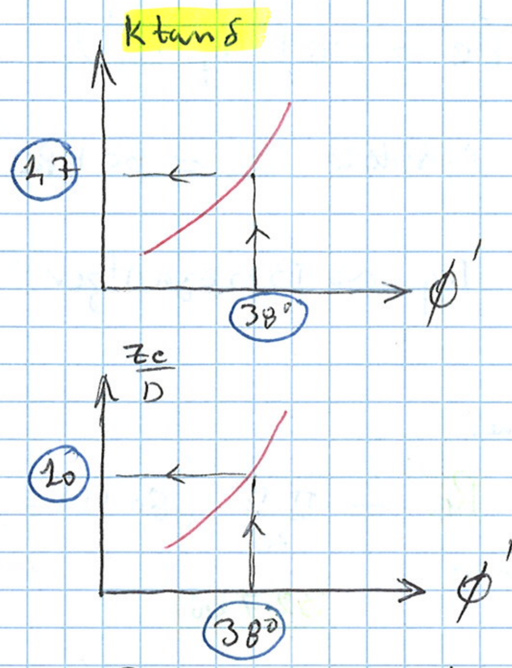
$\frac{3}{4}\phi'$: per pali costruiti fuori opera.

1 AGI (1 ÷ 2).

- Altro metodo: POULOS & Davis per Q_L:

propongono invece:





Hp: $\gamma_{sabbia} = 15\ kN/m^3 \rightarrow \tau_{Lim} = K\tan\delta \cdot \sigma_v'$

$\overset{!}{=} 1,7\,(15 \cdot 1m) = 25\ kPa$

$\Rightarrow R_L = \pi \cdot D \cdot \left[\frac{25 \cdot 1}{2} + 25 \cdot 5 \right]$

$\overset{!}{=} 44\ kN.$

N.B.! $K\tan\delta = 1,7$ con $\delta = \frac{3}{4}\phi'$ mi da' $K = 3 >>$ di quello ipotizzato prima (☆☆).

- CORRELAZIONI CON PROVE IN SITO:

$$\tau_{Lim} = \frac{q_c}{150} \quad se \quad q_c < 10\ MPa \rightarrow \text{scritto}$$

nella tabella iniziale in rosso (τ_{Lim} e L).

$R_L = (18,7 \cdot 1,3 + 38 \cdot 0,9 + 2 \cdot 0,6 + 9,3 \cdot 1 + 28 \cdot 2,2)\,\pi \cdot D$

$\overset{!}{=} 45\ kN.$

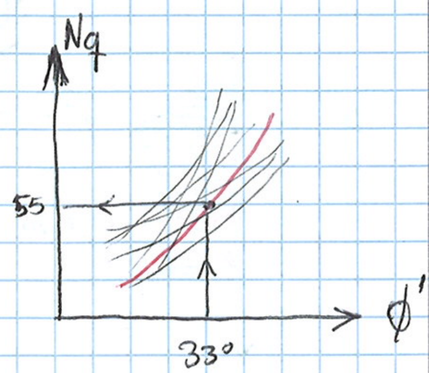
e' stato misurato $R_L = 60\ kN \Rightarrow$ valori trovati quasi accettabili!

(ii) calcoliamo la resistenza alla base R_B:

① - $R_B = A_B \left(N_q \cdot \sigma'_{v0} \right)$

considero $\sigma'_{v0} \simeq 80$ KPa

N_q ⇝ Berezantzev ⇝



infine:

$R_B = \frac{\pi \cdot D^2}{4} \cdot (\underbrace{80 \cdot 55}_{q_B = 4 MPa}) =$

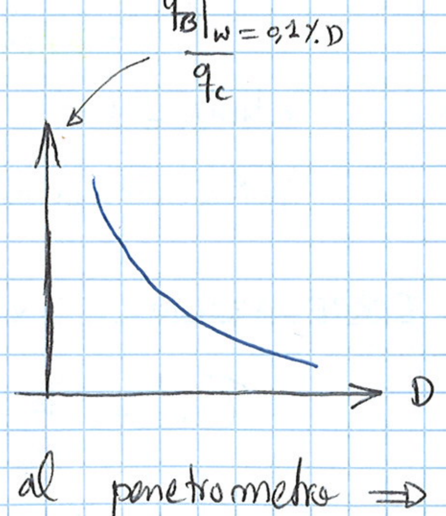
$= 32,7$ kN

② - correlazione con prove in sito:

alcuni q_B → $\simeq q_c$

→ $\simeq \frac{q_c}{2}$

oppure Jardine



Questo palo e' circa uguale al penetrometro ⇒

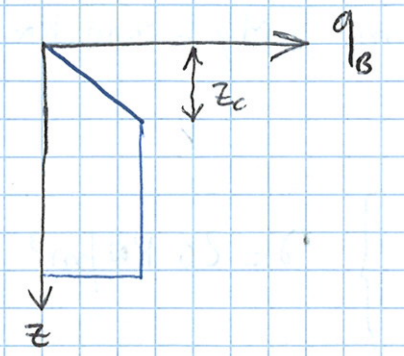
$\boxed{q_B \simeq q_c}$

Dai dati in tabella all'inizio:

$4,2 < q_c < 5,3$ → prendendo $\boxed{q_c = 4,5 \text{ MPa}}$

si ottiene $R_B = 36,8$ kN $\rightsquigarrow$ poco $\neq$ dal primo calcolato.

③ VESIC



$$Z_c \begin{cases} \to 8D \\ \to 20D \end{cases} \rightsquigarrow Z_c = 15\,D = 1,5\,m$$

$$\sigma_{v_0}' = 30\ kPa$$

$$R_B = \frac{\pi \cdot D^2}{4} \cdot \left(N_q \cdot \sigma_{v_0}'\right) = \frac{\pi \cdot D^2}{4} \underbrace{(30 \cdot 55)}_{q_B = 1,5\ MPa} = 12,3\ kN.$$

④ FLEMMING :

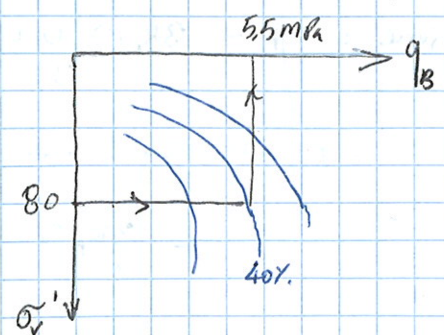
Hp $\phi' \to N_q \longrightarrow$ ricavo $\bar{p}' = \sigma_v' \sqrt{N_q} \rightsquigarrow$

$\phi' = \phi_{cv}' + 3\left[D_r\left(10 - \ln \bar{p}'\right) - 1\right] \to$ confronto con Hp!
se ok stop!

usando $\phi' = 33,4° \longrightarrow N_q = 55 \longrightarrow R_B = 36$ kN

⑤ Flemming ha poi proposto metodo grafico.

$R_B = 45$ kN



$\phi_{cv}' = 33°$

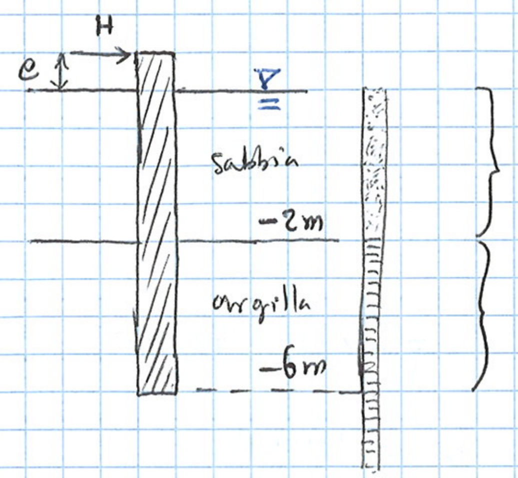
Quello misurato e' $R_B = 37$ kN corrispondente a $q_B = 4,5$ MPa

— o — fine.

"ESERCIZI SU PALI CARICATI ORIZZONTALMENTE"

es 1 PALO LIBERO DI RUOTARE IN TESTA CARICATO ORIZZONTALMENTE:

$D = 0{,}5\,m \quad , \quad M_y = 300\ KN \cdot m \quad , \quad e = 1m$

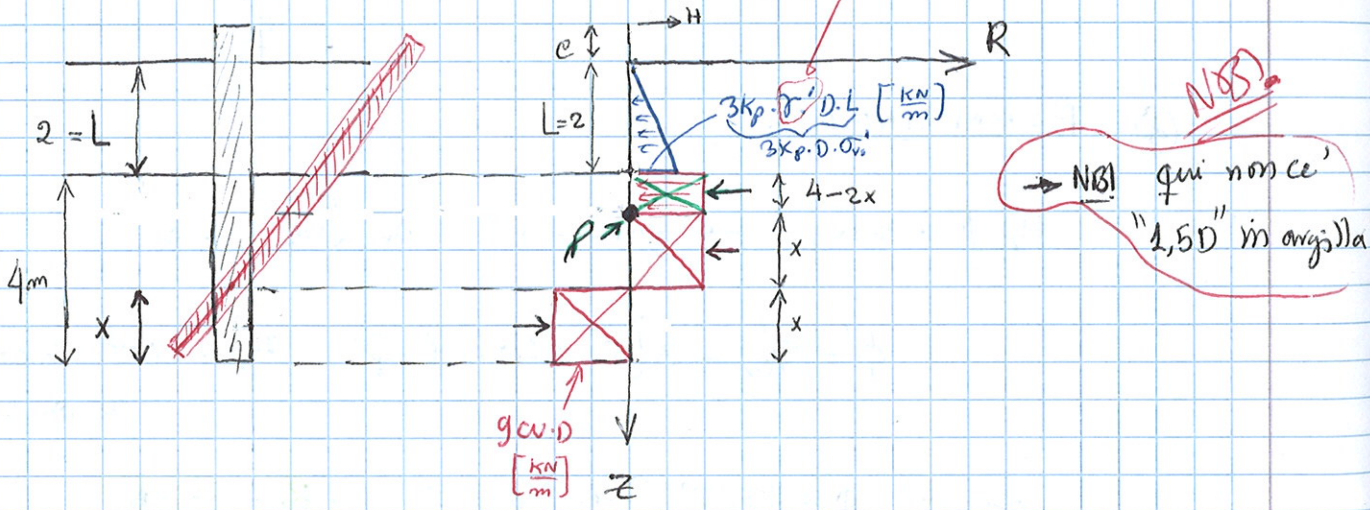


$\gamma = 20\ KN/m^3 \quad , \quad \phi' = 38° \Rightarrow K_p = 4{,}2$

$\gamma = 18\ KN/m^3 \quad , \quad c_u = 30\ Kpa$

(i) situazione palo corto:

NB! condizioni a L.T! sempre! in sabbia



- L'incognite sono "H" e "il punto di rotazione" x:

Eq. traslazione: $H = \dfrac{3K_p \cdot \gamma' \cdot D \cdot L \cdot L}{2} + 9c_u \cdot D\,(4-2x)$

Eq. rotazione in P: $H\,(2+1+4-2x) - (9c_u \cdot D) \cdot \dfrac{(4-2x)^2}{2} +$

$- \dfrac{3}{2}K_p \cdot \gamma' \cdot D \cdot L^2 \cdot \left[(4-2x) + \dfrac{2}{3}\right] - 9c_uD \cdot x^2 = 0$

sistema:

$$\begin{cases} H = \overbrace{\frac{3}{2}\cdot(4,2)(10)\cdot 0,5\cdot 2^2}^{126\ kN} + \overbrace{9\cdot(30)(0,5)}^{135\ [kN/m]}(4-2x) \\ H(7-2x) - \frac{135}{2}(4-2x)^2 - 126\left[(4-2x)+\frac{2}{3}\right] = 135x^2 \end{cases} \Rightarrow$$

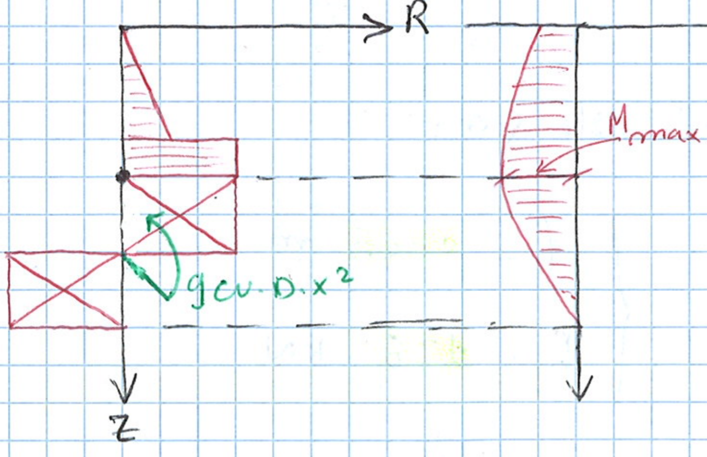
$$\Rightarrow \begin{cases} H = 126 + 135(4-2x) \\ H(7-2x) - \frac{135}{2}(4-2x)^2 - 126\left[\frac{14}{3}-2x\right] = 135x^2 \end{cases}$$

risolvendo il sistema ottengo

non accettabile; giustamente!

$$\begin{cases} x = 1,82\ m \ ✓ \\ H = 174,33\ kN \ ✓ \end{cases} \quad e \quad \begin{cases} x = 12,17\ m \\ H = -2622,33\ kN \end{cases}$$

- Inoltre devo verificare che $M_{max} < M_y$:



$$\boxed{M_{max} = 9\cdot c_u\cdot D\cdot x^2}$$

↓

ove $T(z) = 0$!!!

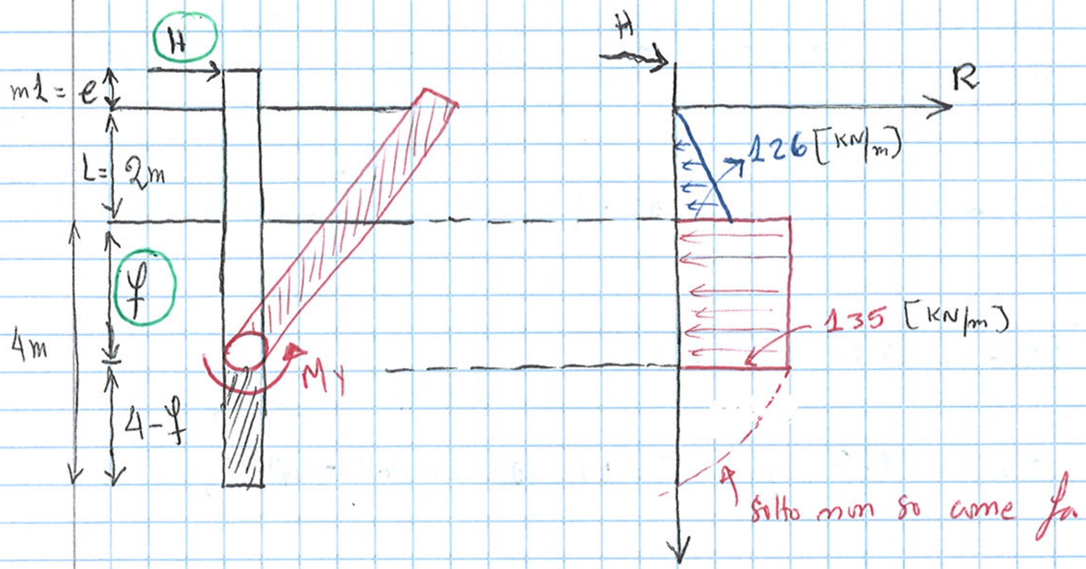
$$M_{max} = 9\cdot c_u\cdot D\cdot x^2 = 135\cdot x^2 = 447,17\ kN\cdot m$$

siccome $M_{max} > M_y = 300\ kNm \Rightarrow$ si forma una cerniera plastica! $\Longrightarrow$ palo Lungo!

↑

cioè ha un comportamento del

(ii) situazione del palo lungo:



- incognite H e ψ

- sistema di equazione:

$$\begin{cases} \text{Eq. T: } & H = 135 \cdot \psi + \frac{126 \cdot 2}{2} \quad [kN] \\ \text{Eq. R: } & \underset{\underset{300}{\parallel}}{M_y} = H \cdot (\psi + 3) - 135 \frac{\psi^2}{2} - 126 \cdot (\psi + \frac{2}{3}) \end{cases}$$

risolvo il sistema ed ottengo:

$$\begin{cases} \psi = -6{,}01 \\ h = -685{,}99 \end{cases} \qquad \begin{cases} \psi = 0{,}015 \text{ m.} \\ h = 128 \text{ kN} \end{cases}$$

non ha senso fisico! OK!

NB! - Quale è la lunghezza limite (L_{Lim}) che mi faceva passare da palo lungo a palo corto?

$$(M_{max})_{palo\ corto} = M_y^{=300} \quad \longleftarrow L_{transizione}$$

$$135\, x^2 = 300$$

$$x = \pm\sqrt{\frac{300}{135}} = +1,49\ m.$$

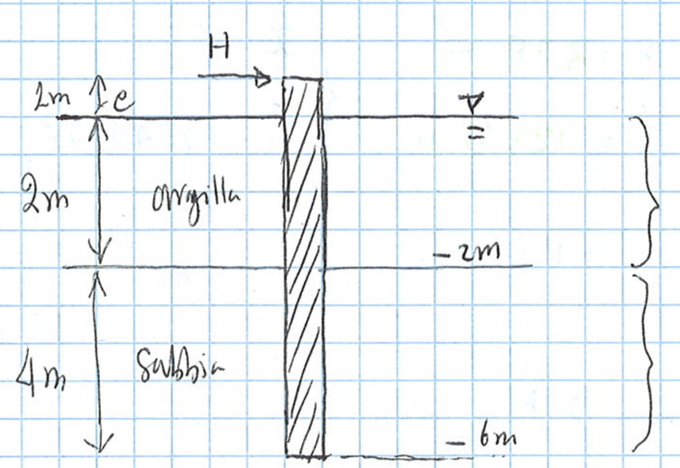
$$\Rightarrow \boxed{L_{lim}} = 2 + 0,015 + 2\cdot(1,49) \simeq 5m$$

- Faccio lo stesso esercizio con i terreni scambiati: argilla sopra e sabbia sotto!

fine!

es 2

$D = 0,5m$, $M_y = 300\ kN\cdot m$.

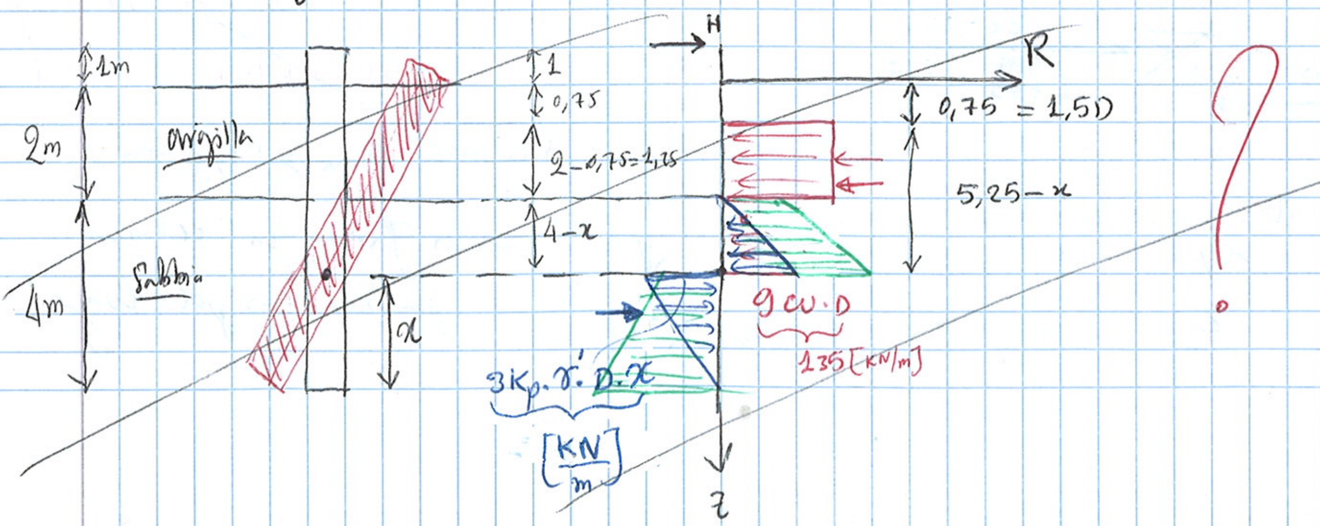


$c_u = 30\ kPa$; $\gamma = 18\ kN/m^3$

$\gamma = 20\ kN/m^3$; $\phi' = 38° \Rightarrow K_p = 4,2$

$$K_p = \frac{1+\sin\phi'}{1-\sin\phi'} = 4,207$$

(i) La situazione del palo corto:



H

- Incognite h e x

- sistema di eq. a disposizione:

$$\text{Eq. T}: \begin{cases} H = 9c_u \cdot D\left[1{,}25 + 4 - x\right] - 3K_p \cdot \gamma' \cdot D \cdot \dfrac{x^2}{2} \\ \text{Eq. R}: \; H \cdot (5{,}25 - x + 1{,}75) - 9\dfrac{c_u \cdot D}{2} \cdot (5{,}25 - x)^2 + \\ \qquad - \dfrac{3K_p \cdot \gamma' \cdot D \cdot x^2}{2} \cdot \dfrac{x}{3} = 0 \end{cases}$$

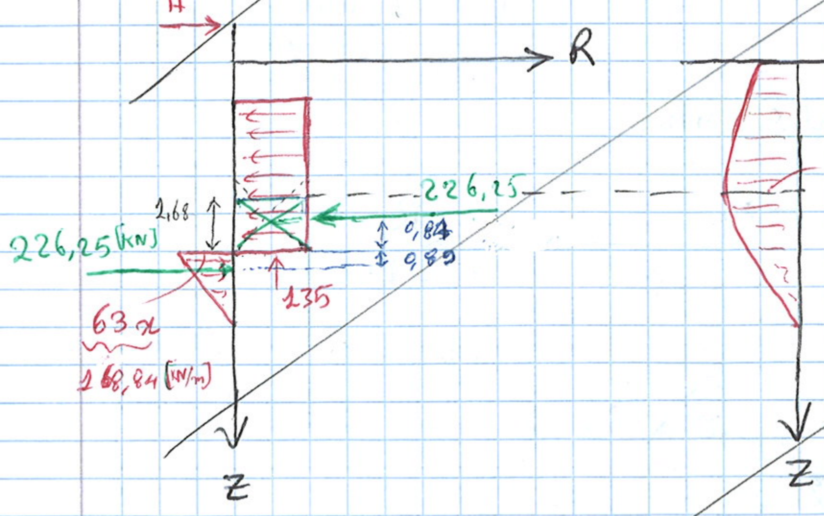
$$\begin{cases} H = 135\left[5{,}25 - x\right] - \dfrac{63}{2} \cdot x^2 \\ H(7 - x) - \dfrac{135}{2}(5{,}25 - x)^2 - \dfrac{63}{6} \cdot x^3 = 0 \end{cases}$$

- risolvo il sistema e trovo:

$$\begin{cases} x = -4{,}93 \\ h = 608 \end{cases} \qquad \begin{cases} x = 2{,}68 \text{ m} \\ h = 120{,}65 \text{ kN} \end{cases} \qquad \begin{cases} x = 7{,}44 \to \text{m} \\ h = -2041{,}78 \to \text{kN} \end{cases}$$

No! OK! No!

- devo verificare che $M_{max} > M_y$:

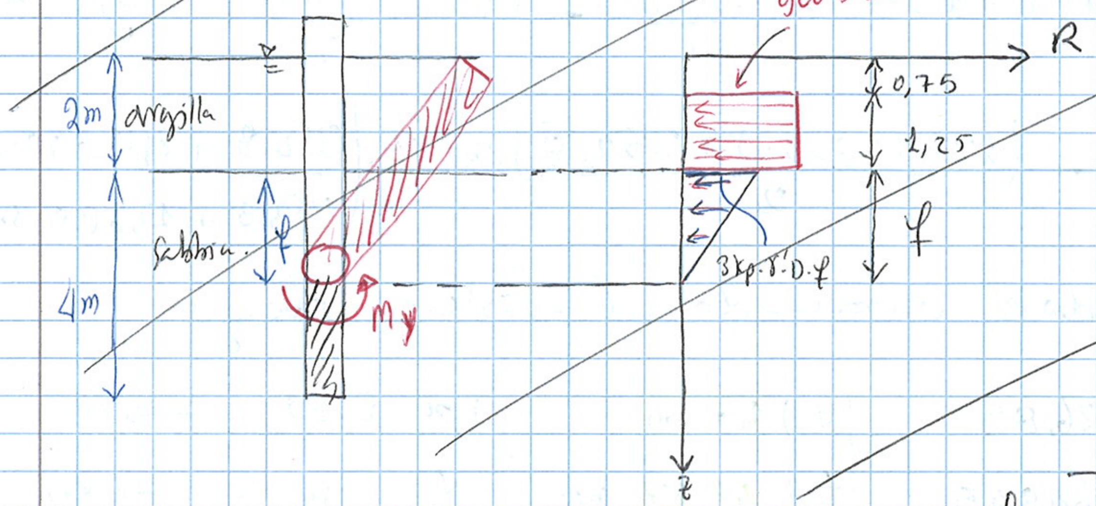


$M_{max} = 226{,}25\,(0{,}84 + 0{,}89) = 391{,}40$ kN·m

Siccome $M_{max} > M_y = 300$

⇒ si forma una cerniera plastica ⇒ palo lungo!

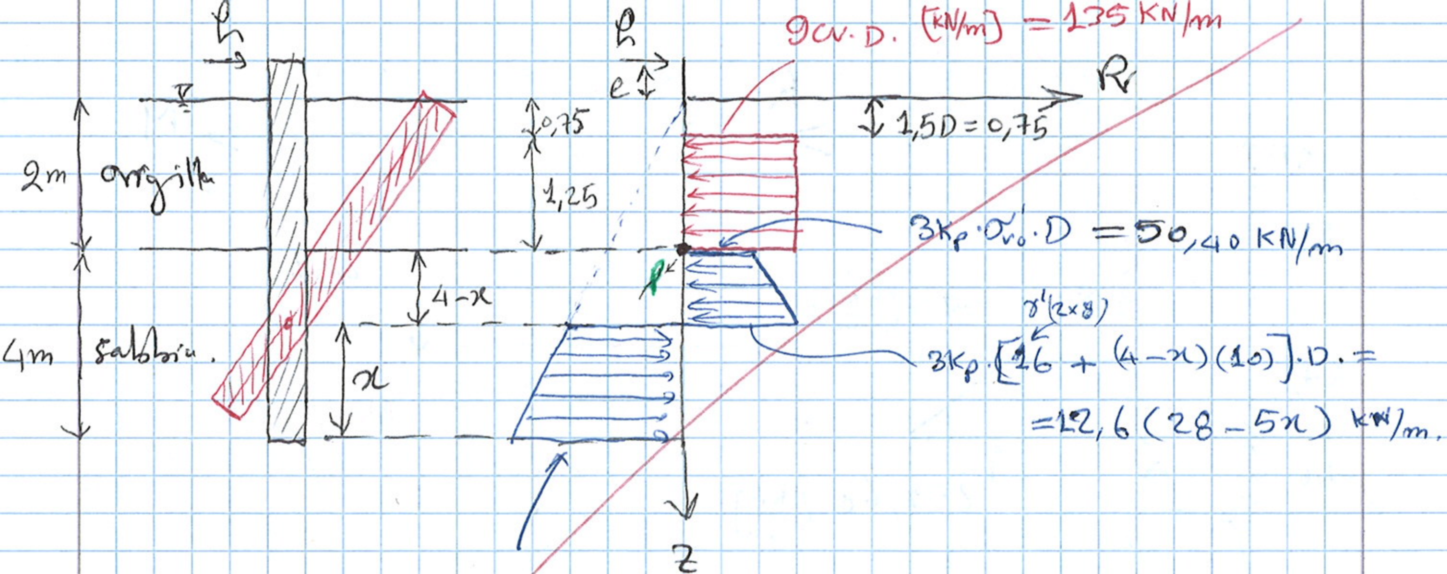
~~(ii) Quand ⇒ la situazione e' di palo lungo :~~



——— o ——— fine

Ricominciamo da capo:

(i) Quando la situazione e' del palo corto :



$$3k_p \cdot \sigma'_{v0} \cdot D = 3k_p \cdot [2 \cdot 8 + 4 \cdot 10] \cdot D = 352,8 \text{ kN/m}.$$

incognite x e h

$$Eq.T \Rightarrow H = 135(1,25) + \left[\frac{12,6(28-5x) + 50,40}{2}\right] \cdot (4-x) - \left[\frac{12,6(28-5x) + 352,8}{2}\right] \cdot x$$

$$\left[\frac{4-x}{3}\right]\left[\frac{12,6(28-5x)+2(50,4)}{12,6(28-5x)+50,40}\right]$$

Eq. Rotazione:

$$\rightarrow H(2+1)-135\cdot\frac{(1,25)^2}{2}+\left[\frac{50,4+12,6(28-5x)}{2}\right](4-x)\cdot(*)+$$

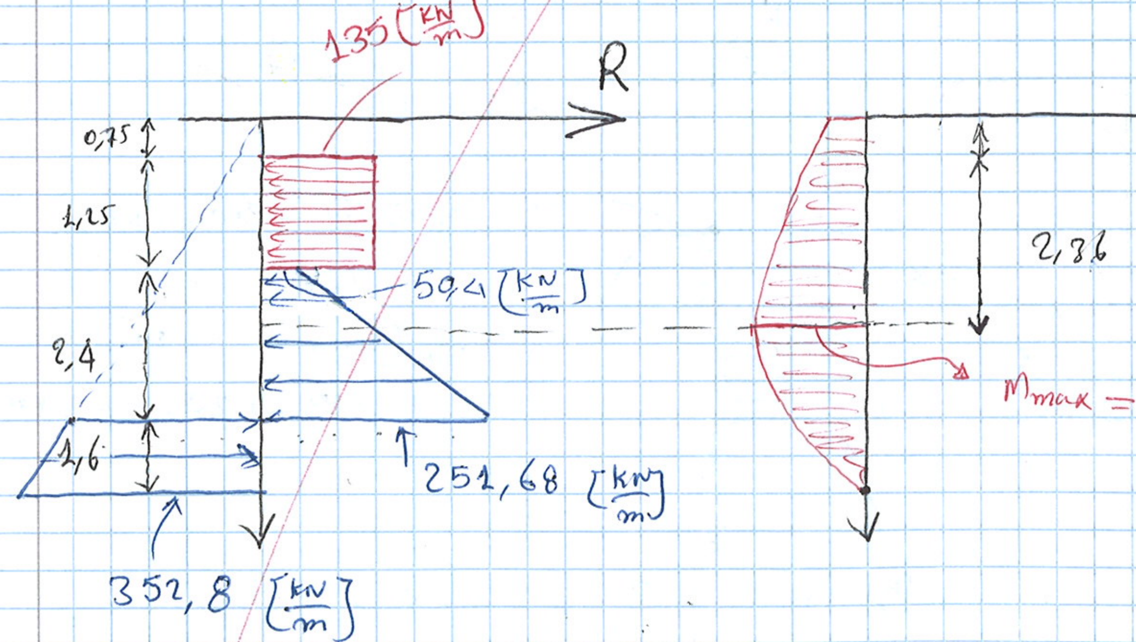
$$-\left[\frac{12,6(28-5x)+352,8}{2}\right]\cdot x\cdot\frac{x}{3}\cdot\left[\frac{352,8+2[12,6(28-5x)]}{352,8+12,6(28-5x)}\right]=0$$

riscrivendo e risolvendo il sistema ottengo.

$\begin{cases} x=-26,89 \\ h=64845 \end{cases}$ ← no!

$\begin{cases} x=1,6\ m \\ h=45,37\ kN \end{cases}$ ← OK!

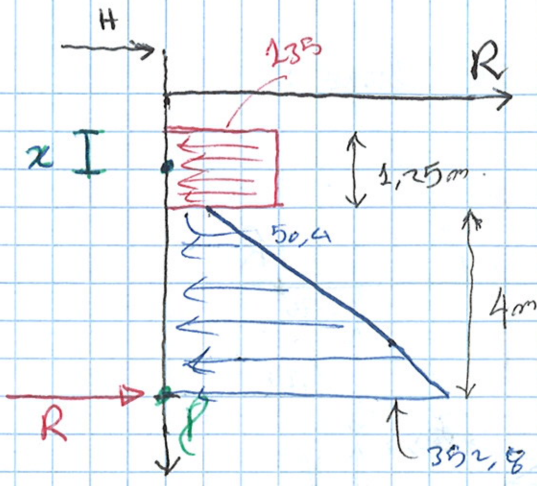
$\begin{cases} x=8,89 \rightarrow m \\ h=-94,55 \rightarrow kN \end{cases}$ ← no!



Ip. Broms: punto di rotazione e' vicino alla base ⇒ la risultante di [diagramma] concentrate sulla punta!

Questo: Non va bene inquanto quando ho la punta del palo in sabbia bisogna usare Ip. di BROMS !!!

e' con unica equazione a rotazione si trova l'unica incognita H !!!



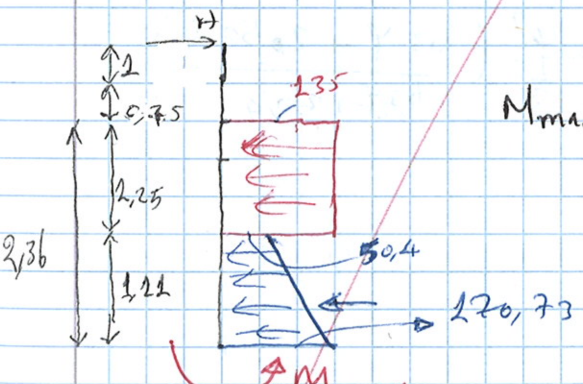
Eq. rotazione in P :

$$H\cdot(5{,}25+1) - 9\,\omega\cdot D\cdot(1{,}25)\left(4+\frac{1{,}25}{2}\right) - \left(\frac{352{,}8+50{,}4}{2}\right)\frac{4^2}{3}\cdot\left[\frac{352{,}8+2\cdot50{,}4}{352{,}8+50{,}4}\right] = 0$$

$H = 318{,}41\ \mathrm{kN}$

$M_{max} = 0$ dove $T = 0$

$\boxed{H = 135\cdot x} \rightsquigarrow x = 2{,}36\,m$

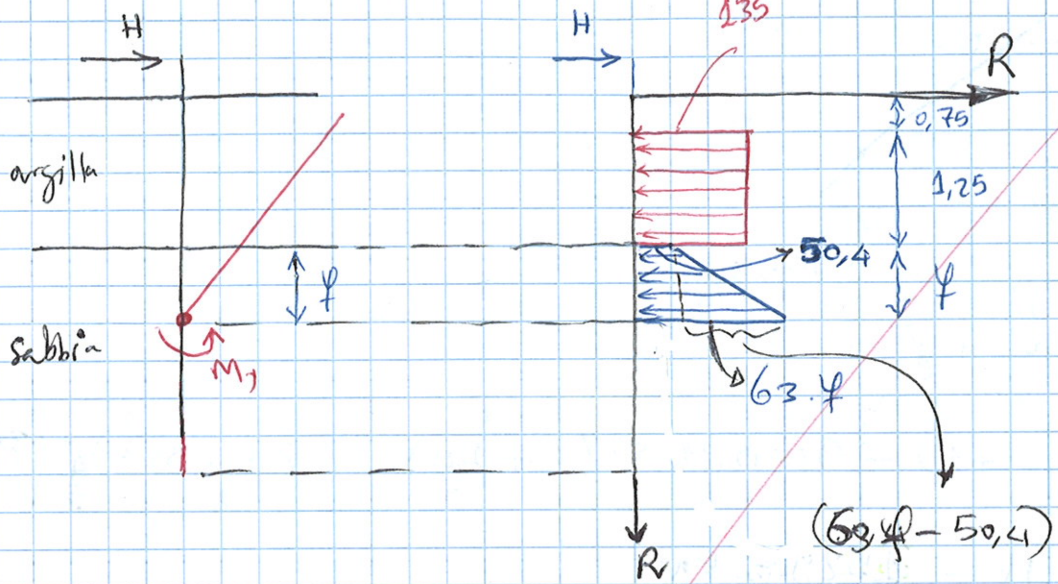


$$M_{max} = \overset{318{,}41}{H}\cdot(1{,}11+1{,}25+0{,}75+1) +$$
$$-\ 135\,(1{,}25)\cdot\left(1{,}11+\frac{1{,}25}{2}\right) +$$
$$-\left(\frac{50{,}4+170{,}73}{2}\right)\frac{1{,}11^2}{3}\cdot\left[\frac{170{,}73+2\cdot50{,}4}{170{,}73+50{,}4}\right]$$
$$= 960{,}125\ \mathrm{kN\cdot m}$$

$M_{max} > M_y \Rightarrow$ palo lungo!

— o — fine.

(ii) Quando la situazione è del palo lungo:



- incognite: "h" e "φ"

$$\text{Eq. T:}\quad H = 135\cdot 1{,}25 + \left(\frac{50{,}4 + 63\cdot\varphi}{2}\right)\cdot\varphi$$

$$\text{Eq. R:}\quad M_y = H\cdot(\varphi + 2 + 1) - 135\cdot 1{,}25\left(\varphi + \frac{1{,}25}{2}\right) + $$

$$- \left(\frac{50{,}4 + 63\cdot\varphi}{2}\right)\cdot\frac{\varphi^2}{3}\cdot\left(\frac{63\cdot\varphi + 2\cdot 50{,}4}{63\varphi + 50{,}4}\right)$$

risolvo il sistema e ottengo:

$$\begin{cases} \varphi = -4{,}32 \text{ m} \\ h = 648{,}77 \text{ kN.} \end{cases}$$

?

verifica

$$\text{Scomp.:}\quad M = (50{,}4)\frac{\varphi^2}{2} + (63\varphi - 50{,}4)\cdot\frac{\varphi}{2}\cdot\frac{\varphi}{3}$$

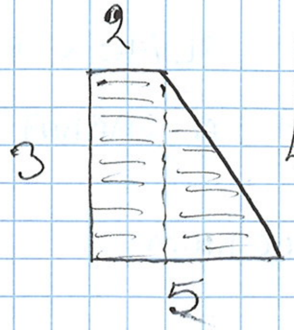
OK! Verificato

$$\text{formula:}\quad M = \left(\frac{50{,}4 + 63\cdot\varphi}{2}\right)\frac{\varphi^2}{3}\left(\frac{63\varphi + 2\cdot 50{,}4}{63\varphi + 50{,}4}\right)$$

$$\frac{21\cdot\varphi^2(\varphi + 1{,}6)}{2} = \frac{21\cdot\varphi^2(\varphi + 1{,}6)}{2}$$

OK!

e.g.

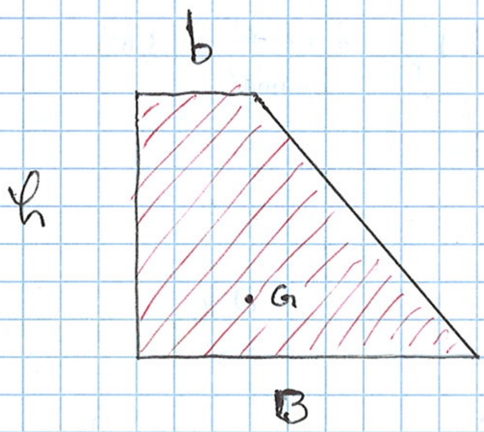


formula: $A = \left(\frac{5+2}{2}\right)3 = \frac{21}{2}$

scomp.: $A = 6 + \frac{3 \cdot 3}{2} = 6 + \frac{9}{2} = \frac{12+9}{2} \overset{!}{=} \frac{21}{2}$ OK!

OK! verificato!

—o— fine.



OK!

$$\begin{cases} \text{area} = \left(\frac{B+b}{2}\right) \cdot h & \text{(RISULTANTE)} \\ G = \left(\frac{B+2b}{B+b}\right)\frac{h}{3} & \end{cases}$$

(BARICENTO DOVE E' APPLICATO LA RISULTANTE)!

—o— fine.

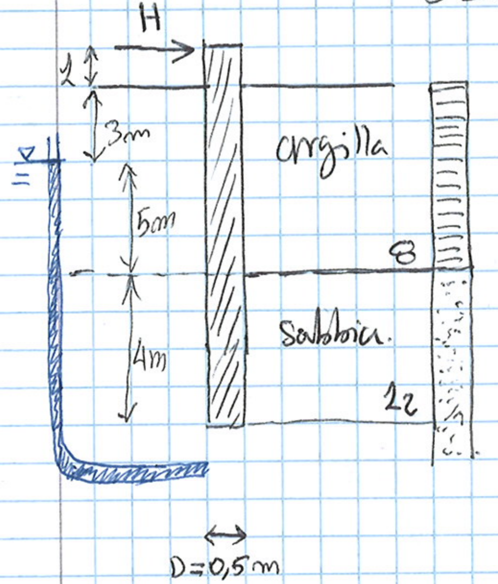
es 3

LIBERO DI RUOTARE IN TESTA

"PALO CARICATO ORIZZONTALMENTE"

IN ARGILLA CON PUNTA IN SABBIA

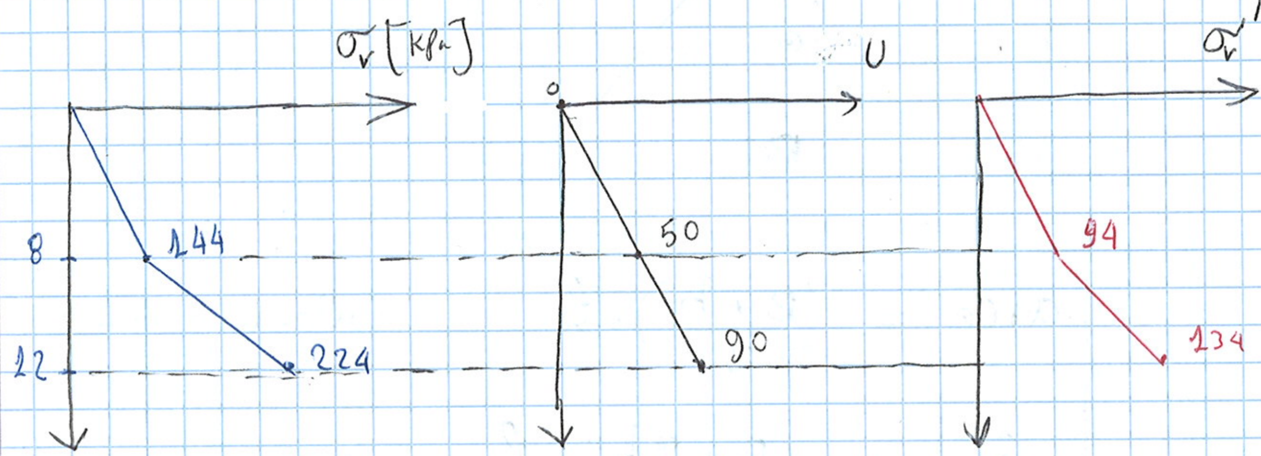
$D = 0{,}5\,m \;;\; M_y = 300\,kN\cdot m$



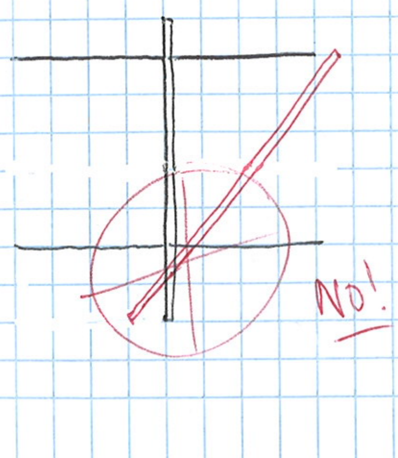
$c_u = 30\,kPa \;;\; \gamma = 18\,kN/m^3$

$\phi' = 35° \;;\; c' = 10 \;;\; \gamma = 20\,kN/m^3$

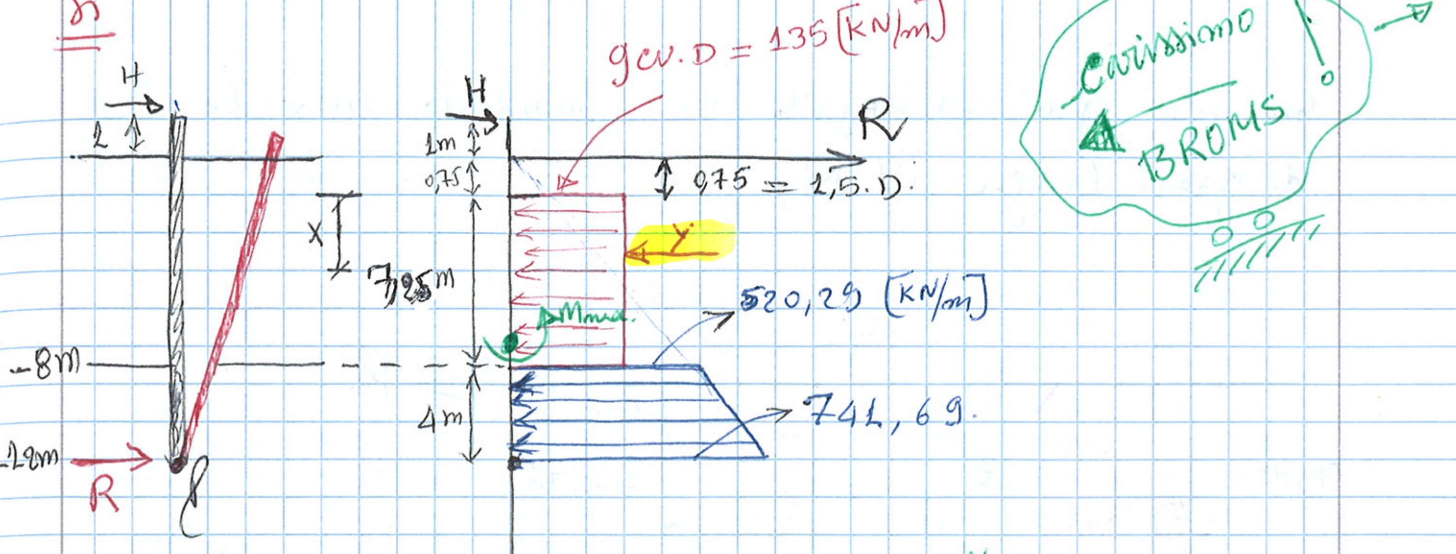
$K_p = \frac{1+\sin\phi'}{1-\sin\phi'} = 3{,}69$



(i). Hp. PALO CORTO: siccome la punta è nella sabbia il caso Broms ha fatto l'hp. che il palo ruota vicino alla punta. e li metto la risultante delle forze distribuite all'estremo del palo.



Si



Con l'unica incognita H si trova con l'eq. Rotazione:

- Eq. alla ROTAZIONE: con polo in P.

$$H \cdot 13 = 135\,(7,25) \cdot \left[4 + \frac{7,25}{2}\right] + \left(\frac{520,29 + 741,69}{2}\right) \cdot 4 \cdot \frac{4}{3} \cdot \left(\frac{741,69 + 2(520,29)}{741,69 + 520,29}\right)$$

$$= 12215.68875$$

$H = 939,67$ KN.

- adesso cerco dove il taglio e' nullo ($T=0$) nell'argilla per trovare il M_{max}.

$$H = 9\,c_u \cdot D \cdot x = 135 \cdot x$$

$$x = \frac{H}{135} = 6,961 \text{ m.} \Rightarrow z^* = 6,961 + 0,75 = 7,71 \text{ m}$$

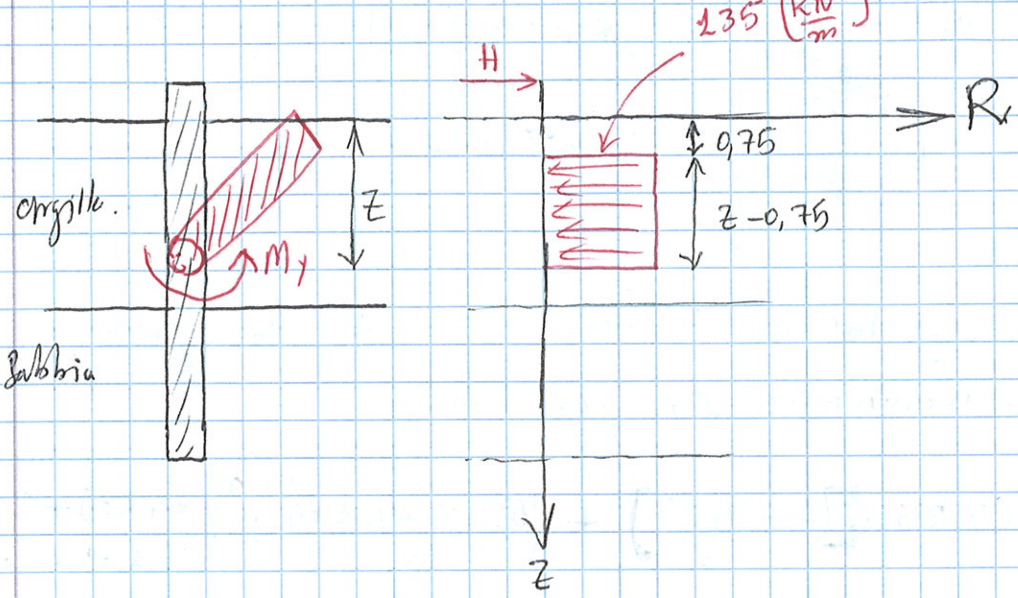
e' la posizione per la quale il taglio e' nullo!!!

$$M_{max}\Big|_{z^*=7,71} = H(z^*+1) - 9\,c_u D \frac{(\overbrace{z^*-0,75}^{Y})^2}{2}$$

$$= 4914,7 \text{ KN} \cdot \text{m} \gg M_y \Rightarrow$$

il palo e' lungo!

siccome già nell'argilla ha un momento max che supera di gran lunga il M_y $\Rightarrow$



- incognite sono "H" e "Z"
- Le equazioni:

$$\begin{cases} \text{Eq.T}: & H = 135\,(Z - 0{,}75) \\ \text{Eq.R}: & M_y = H \cdot (Z + 1) - \dfrac{135\,(Z - 0{,}75)^2}{2} \end{cases}$$

Risolvo il sistema e trovo:

$$\cancel{\begin{cases} Z = -3{,}74 \text{ m} \\ H = -606{,}23 \text{ kN} \end{cases}} \qquad \begin{cases} Z = 1{,}74 \text{ m} \\ H = 133{,}63 \text{ kN} \end{cases}$$

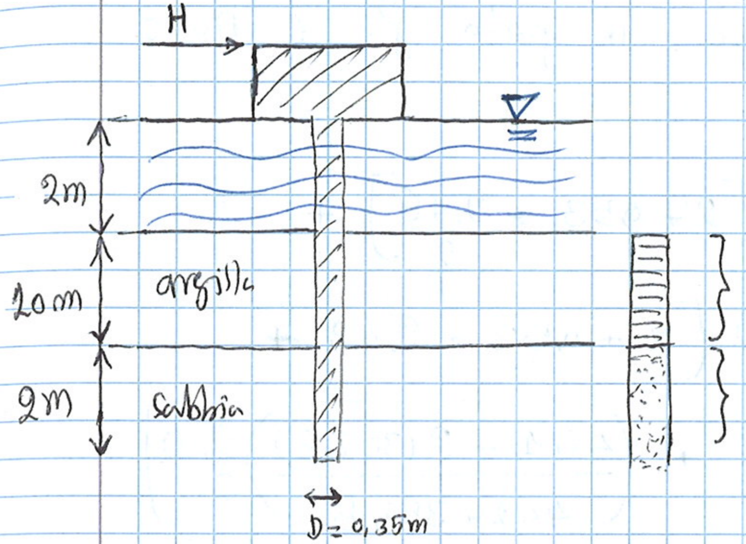
non ha senso fisico!

OK!

— o —

Fine!

es. 4 "PALO IMPEDITO DI RUOTARE IN TESTA CARICATO ORIZZONTALMENTE":

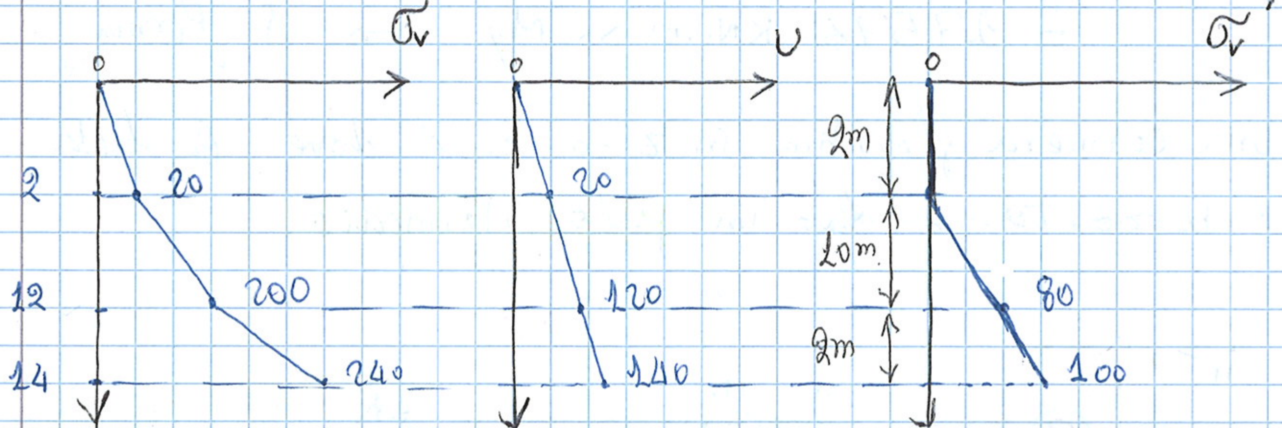


$D = 0{,}35\,m$; $M_y = 300\ KN \cdot m$

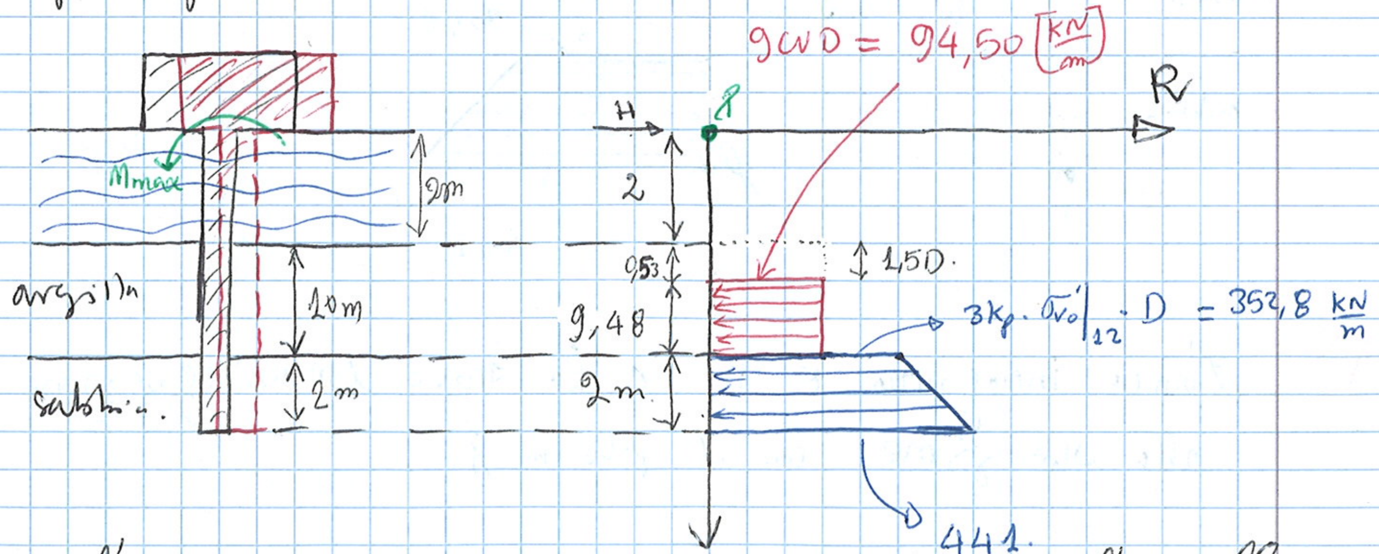
$c_u = 30\,KPa$; $\gamma = 18\ KN/m^3$

$\phi' = 38°$; $\gamma = 20\ KN/m^3$

$$K_p = \frac{1+\sin\phi'}{1-\sin\phi'} = 4{,}2$$



(i) hp. : palo corto



- L'unica incognita qua e' H e si trova con l'eq. alla traslazione!

Eq. T: $H = 94,5\,(9,48) + \left(\frac{441 + 352,8}{\cancel{2}}\right)\cdot\cancel{2}$

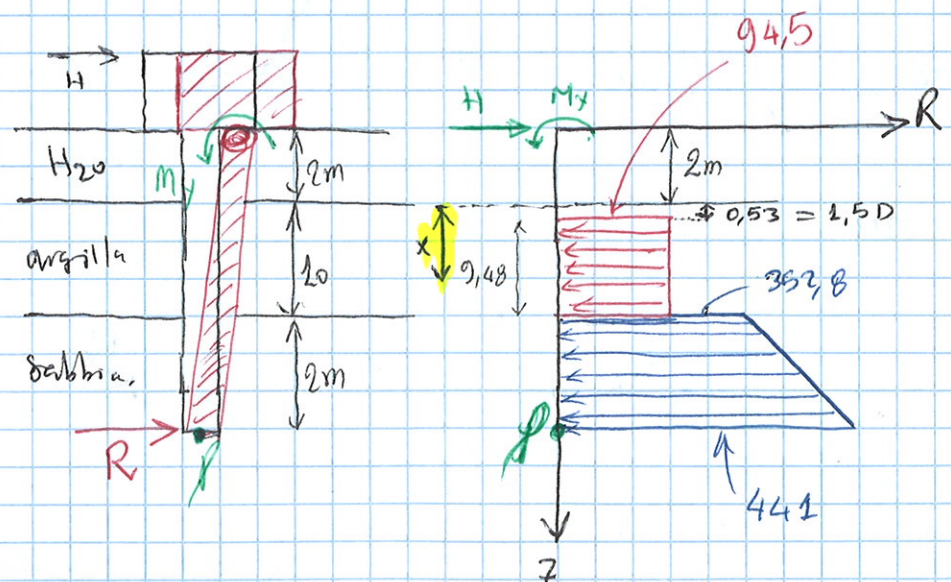
$= 1689,66$ KN.

- faccio l'eq. alla rotazione in polo P. e trovo Mmax :

$$M_{max} = 94,5\,(9,48)\cdot\left[2 + 0,53 + \frac{9,48}{2}\right] + (441 + 352,8)\cdot\left[2 + 0,53 + 9,48 + \left(\frac{441 + 2\,(352,8)}{441 + 352,8}\right)\frac{2}{3}\cdot 2\right]$$

$= 17575$ KN.m $\gg M_y$ $\Rightarrow$ si forma

(ii) • una cerniera plastica in $z=0$ cioè dove la testa è bloccato. e ho un palo intermedio:



NB - L'unica incognita è "H" e la trovo con un'equazione alla rotazione con il polo in P.

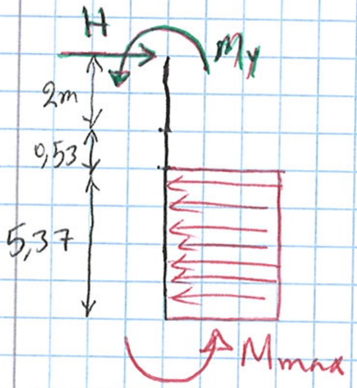
$$H \cdot (2+10+2) = M_y + 94{,}5\,(9{,}48)\cdot\left[2+\frac{9{,}48}{2}\right] +$$

$$+ (441+352{,}8)\left[\frac{441+2(352{,}8)}{441+352{,}8}\right]\cdot\frac{2}{3}$$

$\rightsquigarrow$ $H = 507{,}32$ KN.

Hp.: che Taglio si annulla in argilla $\Rightarrow$ il M_{max} è in argilla.

$H = 94{,}5\,x \quad \rightsquigarrow \quad x = 5{,}37$ m

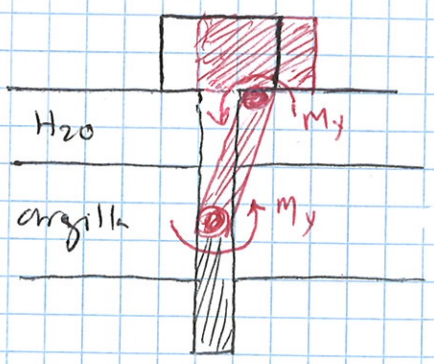


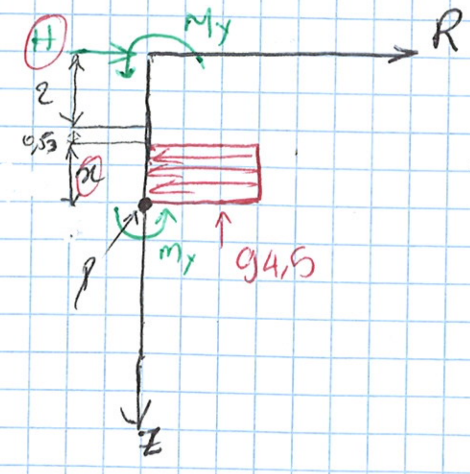
$$M_{max} = -M_y - 94{,}5\,\frac{(5{,}37)^2}{2} + H(2+0{,}53+5{,}37)$$

$$= 2345{,}28 \text{ KN}\cdot\text{m} \gg M_y$$

$\Rightarrow$ qui si forma un'altra cerniera plastica.

(iii). Hp. PALO LUNGO:





– Incognite sono "H" e "x"

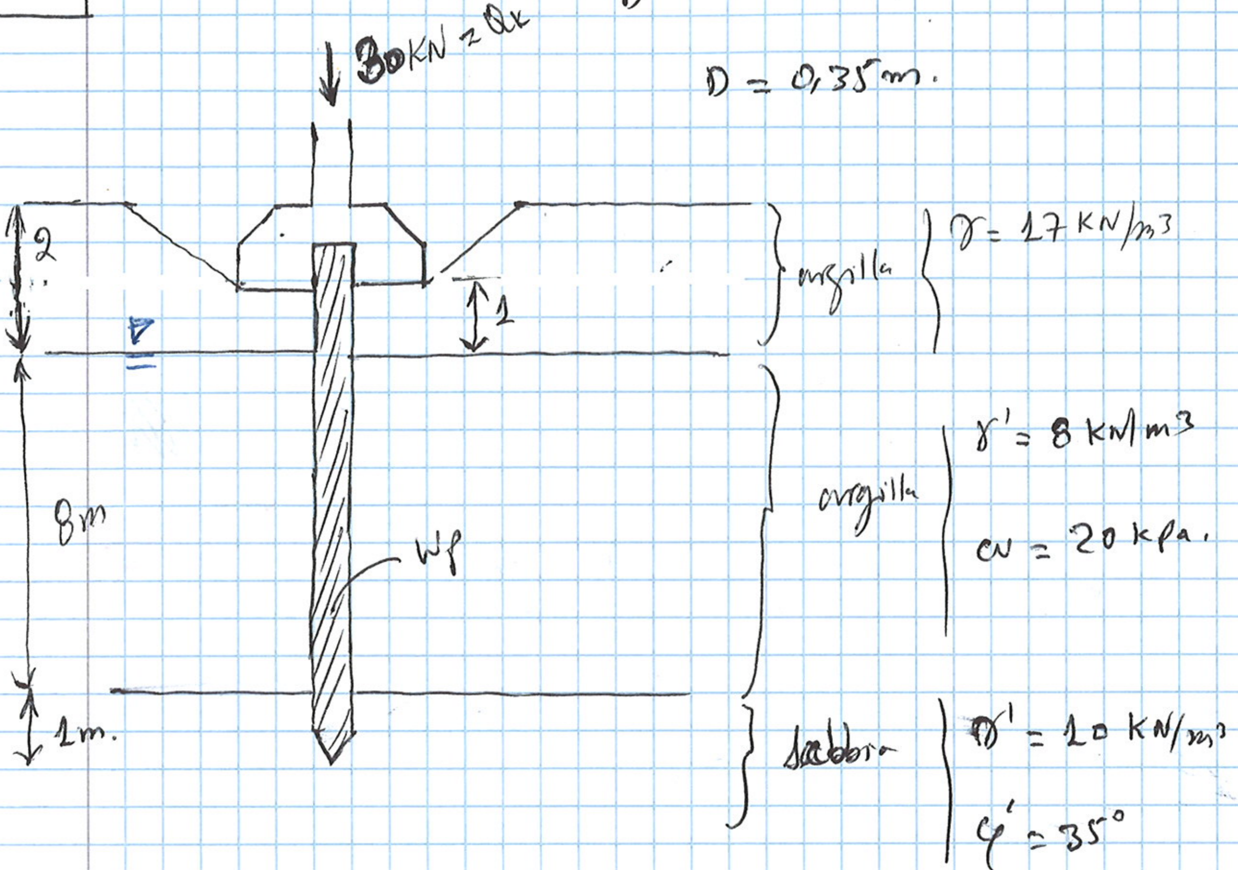
– 2 equazioni:

$$\begin{cases} H = 94{,}5\,x \\ H(x+0{,}53+2) = 2M_y + 94{,}5\,\dfrac{(x)^2}{2} \end{cases} \Rightarrow \begin{cases} x = 1{,}84 \\ H = 173{,}90 \end{cases}$$

ok!

— o — fine

es.1 "Palo infisso in argilla con punta in sabbia."



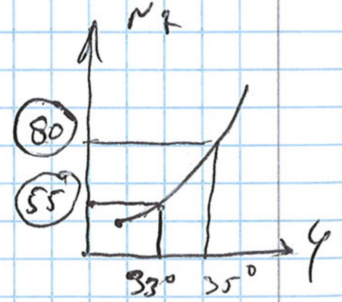
(i) $R_B = \frac{\pi \cdot D^2}{4} \cdot (N_q \cdot \sigma'_{v0})$.

$\underline{\underline{!}}$ 831,266 KN

$\sigma'_{v0} = 17 \cdot 2 + 8 \cdot 8 + 10 \cdot 1$

$\underline{\underline{!}}$ 108 kPa

$R_L|_{sabb} =$ trascurabile.



ii) $R_L = \pi \cdot D \int_0^z \tau_{lim} \, dz$

$\underline{\underline{!}}\ \pi \cdot D \cdot \alpha \cdot c_u \cdot z$

$\underline{\underline{!}}\ \pi \cdot D \cdot 20 \cdot 1 \cdot 8 = 175,929$ KN.

$$R_{Lim} = R_B + R_L$$

$$= 1007{,}195 \text{ KN}$$

Verifica R.I. 2008: DA1 (comb. 1)

$$\begin{cases} Q_K = 30 \text{ KN} \\ W_p = \frac{\pi D^2}{4} \cdot 11 \cdot 25 = 26{,}458 \text{ KN} \end{cases}$$

$$\begin{cases} Ed = 1{,}3(26{,}458) + 1{,}5(30) \\ \quad = 79{,}395 \\ Rd = \frac{R_{Lim}}{\gamma_R \cdot \xi_1} = 592{,}467 \text{ KN} \end{cases}$$

$Rd \geq Ed$ OK verificato!

— o —

ed) palo triv.

$$R_L|_{arg} = \pi \cdot D \cdot \alpha \cdot c_u \cdot z$$

$$= \pi \cdot (0{,}6)(0{,}4) \cdot 200 \cdot 10 = 753{,}982 \text{ KN}$$

$$R_L|_s = \pi \cdot D \cdot \int_0^z \tau_{lim} \, dz$$

$$= \pi \cdot D \cdot K \cdot \bar{\sigma}'_{v0} \cdot tg(\delta) \cdot z$$

$$= \pi \cdot D \cdot 0{,}5 \cdot \bar{\sigma}'_{v0} \cdot tg(\varphi') \cdot 10 \quad (\varphi' = 35)$$

$$= 1121{,}881 \text{ KN}$$

$$\bar{\sigma}'_{v0} = (200 + 90) - 120 = 170 \text{ kPa}$$

$$R_B\Big|_s = \frac{\pi \cdot D^2}{4} \cdot N_q \cdot \sigma_0'$$

$$= 4750{,}088 \text{ KN}$$

$$R_{L1m} = 6625{,}951 \text{ kN}$$