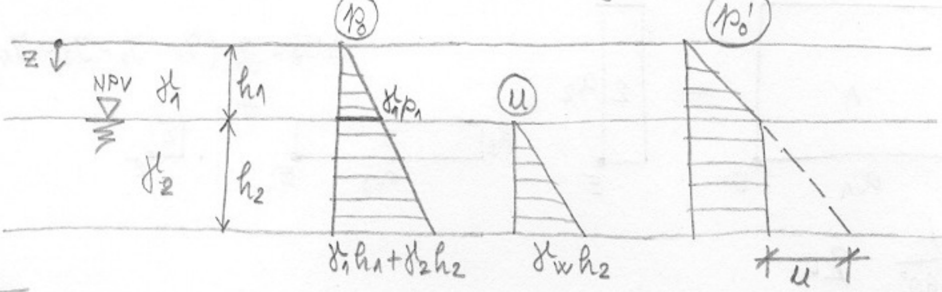
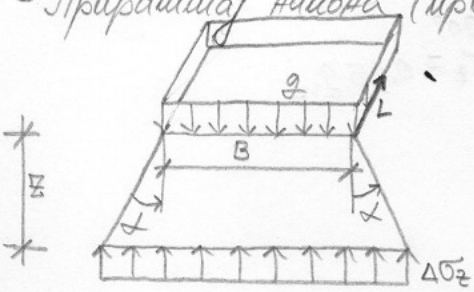
Расподела напона и прорачун слегања у ситнозрном тлу

- Прва фаза је прорачун напона у тлу, затим прорачун деформација у тлу. Интеграцијом тих деформација по дубини добијамо слегање.
- Геостатички (почетни) напон у тлу – јавља се само услед сопствене тежине тла



$$p_0' = p_0 - u$$

- Прираштај напона (приближни поступак)



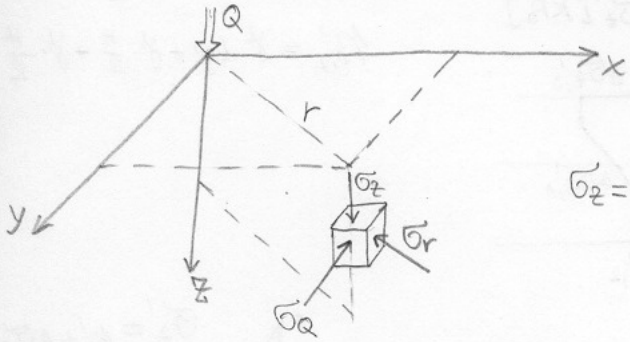
$$\Delta\sigma_z = q \cdot \frac{B \cdot L}{(B + 2z\,tg\alpha)(L + 2z\,tg\alpha)}$$

$tg\alpha = 0,5 \quad (\alpha \approx 30°)$

$$\Delta\sigma_z = q \cdot \frac{B \cdot L}{(B+z)(L+z)}$$

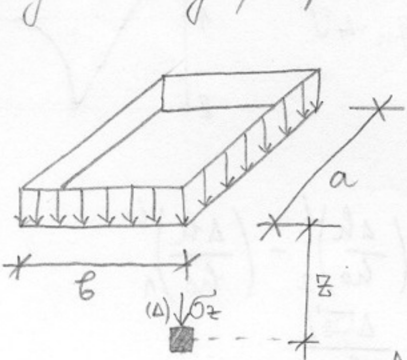
тракасти темељ: $\Delta\sigma_z = q \cdot \frac{B}{B+z} \quad L \gg B$

- Бусинесково решење (тло нема тежину, сви напони добијени на овај начин представљају прираштаје вертикалних напона по дубини, тло је идеално еластично хомогено и изотропно)



$$\sigma_z = \frac{3Qz^3}{2\pi(r^2+z^2)^{5/2}}$$

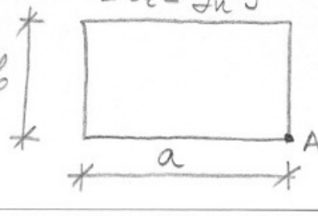
- Метода Штајнбренера (правоугаони темељ)



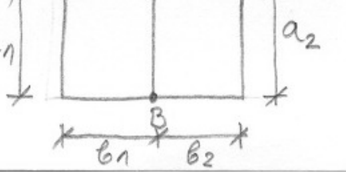
$\Delta\sigma_z = q \cdot I$ → утицајни коефицијент, зависи само од димензије темеља и дубине z

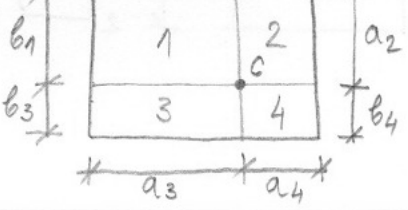
$I = I(a/b;\, z/b)$

$\Delta\sigma_z = q_n \cdot I$

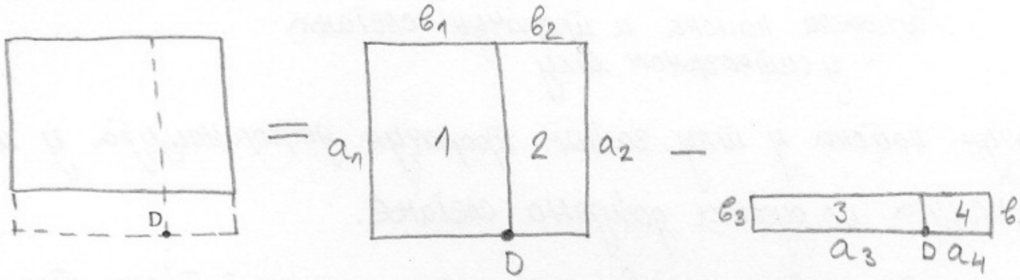


$\Delta\sigma_z = q_n(I_1 + I_2)$

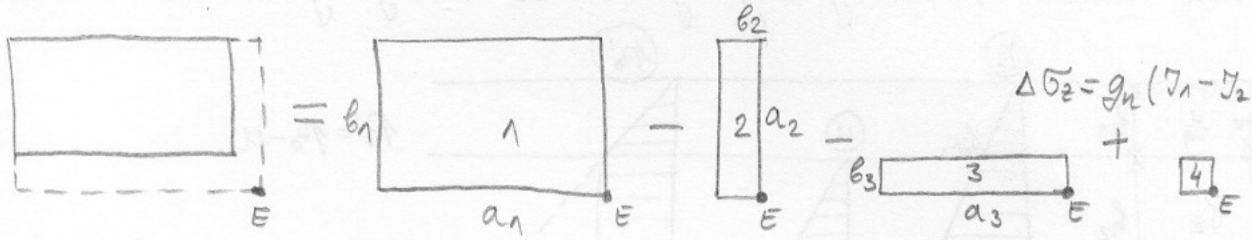




$\Delta\sigma_z = q_n(I_1 + I_2 + I_3 + I_4)$

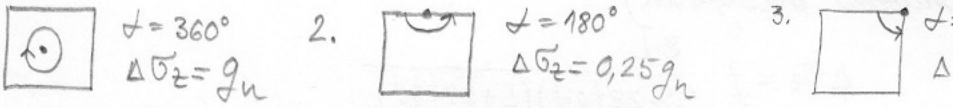


$$\Delta\sigma_z = q_n (I_1 + I_2 - I_3 - I_4)$$



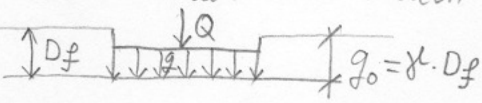
$$\Delta\sigma_z = q_n (I_1 - I_2 - I_3 + I_4)$$

$z=0$: $I = 0{,}25$ $\quad \Delta\sigma_z = \dfrac{\alpha}{360^\circ} \cdot q_n$



1. $\alpha = 360^\circ$, $\Delta\sigma_z = q_n$
2. $\alpha = 180^\circ$, $\Delta\sigma_z = 0{,}25 q_n$
3. $\alpha = 90^\circ$, $\Delta\sigma_z = 0{,}25 q_n$

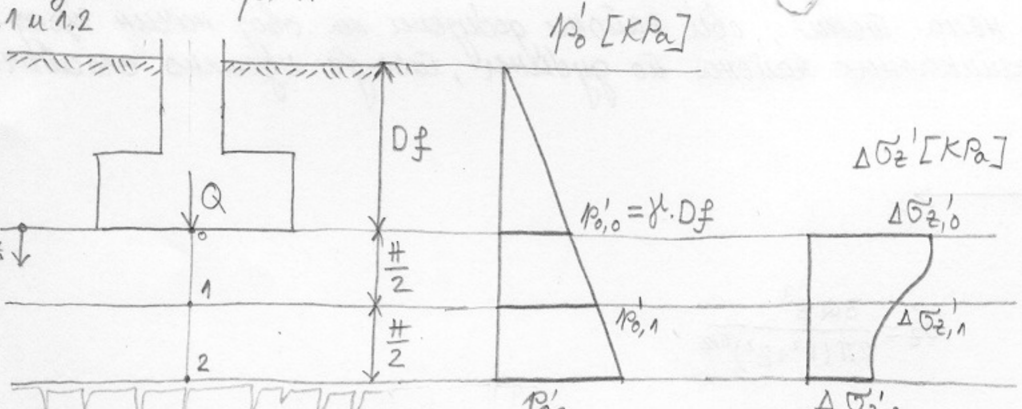
- нето контактни напон



$q_0 = \gamma \cdot D_f$ $\qquad q_n = q - q_0 = \dfrac{Q}{BL} - \gamma \cdot D_f$

- задатак стр. 1.

1.1 и 1.2



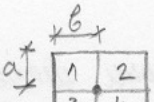
$$p'_{0,1} = \gamma \cdot D_f + \gamma \cdot \frac{H}{2}$$

$$p'_{0,2} = \gamma \cdot D_f + \gamma \cdot \frac{H}{2} + \gamma \cdot \frac{H}{2}$$

1.3. прорачун напонског стања

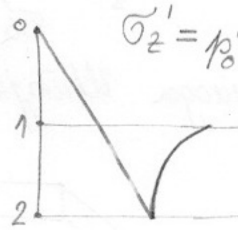
T	p_0'	$\Delta\sigma_z'$	σ_z'
0			
1			
2			

$z = \dfrac{H}{2}$



$I_1 = I_2 = I_3 = I_4 = I$

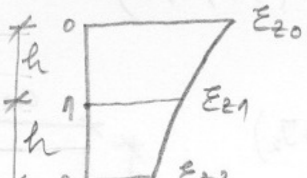
$\Delta\sigma_z = q_n \cdot 4I$



$\sigma_z' = p_0' + \Delta\sigma_z'$

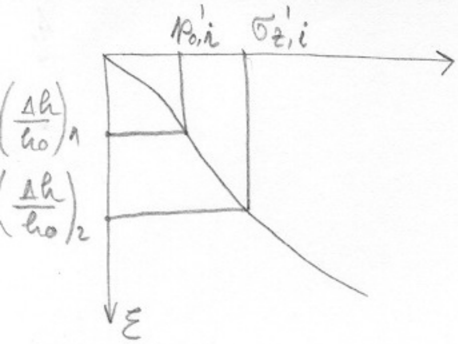
1.4. прорачун специфичних деформација

T	$\left(\frac{\Delta h}{h_0}\right)_2$	$\left(\frac{\Delta h}{h_0}\right)_1$	$\Delta\varepsilon_z$	$\Delta\sigma_z'$	M_v
0					
1					
2					



$$\varepsilon_{zi} = \left(\frac{\Delta h}{h_0}\right)_2^i - \left(\frac{\Delta h}{h_0}\right)_1^i$$

$$M_{v,i} = \frac{\Delta\sigma'_{z i}}{\varepsilon_{z,i}}$$



$$\varepsilon_z = \frac{\Delta e}{1+e_0} = \frac{e_{0,i}-e_{1,i}}{1+e_{0,i}}$$

e_0 – са дијаграма
↓
почетни коеф. порозности који је владао у тлу пре наношења вертикалног оптерећења.

T	e_0	e_1	ε_z
0			
1			
2			

1.5. $S=\int_0^z \varepsilon_z dz$ (површина дијаграма ε_z)

$$S = \frac{h}{2}\left(\varepsilon_{z,0}+\varepsilon_{z,1}\right) + \frac{h}{2}\left(\varepsilon_{z,1}+\varepsilon_{z,2}\right) = \frac{h}{2}\left(\varepsilon_{z,0}+2\varepsilon_{z,1}+\varepsilon_{z,2}\right)$$

1.6. посматра се само напонско стање за т-у 1

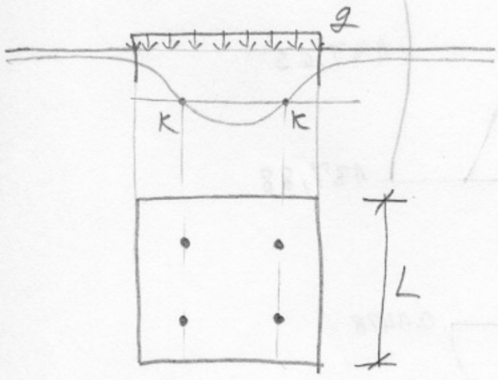
$$C = \frac{1}{\Delta\varepsilon_z}\ln\left(\frac{p'_0+\Delta\sigma'_z}{p'_0}\right) \qquad C = \frac{1-\left(\frac{\Delta h}{h_0}\right)_1}{\left(\frac{\Delta h}{h_0}\right)_2-\left(\frac{\Delta h}{h_0}\right)_1}\ln\frac{\sigma'_z}{p'_0}$$

1.7. $\varepsilon_{z,i} = \frac{1}{C}\ln\frac{\sigma'_{z,i}}{p'_0}$ $\quad C=const$

1.8. $C_c = \frac{(-)\,\Delta e}{\log\left(\frac{p'_0+\Delta\sigma'_z}{p'_0}\right)}$ $\qquad C_c = \frac{e_0-e_1}{\log\left(\frac{p'_0+\Delta\sigma'_z}{p'_0}\right)}$

1.9. $\varepsilon_{z,i} = \frac{C_c}{1+e_{0,i}}\log\frac{p'_{0,i}+\Delta\sigma'_{z,i}}{p'_{0,i}}$

– Канијев дијаграм (ради се са укупним димензијама темеља



$\Delta\sigma'_{z,i}=?$ $\quad \sigma'_{z,0}$ (као у зад. 1)

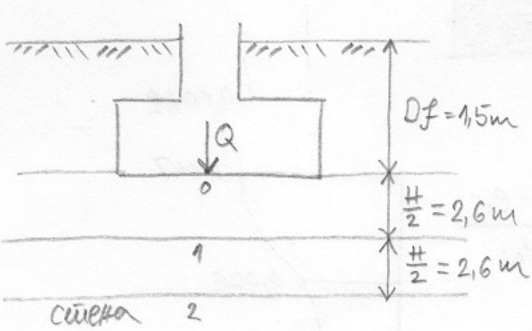
Нађемо дубину z, очитамо J $\qquad \Delta\sigma'_{z,i} = q_n \cdot J_z$

$$\sigma'_{z,i} = p'_{0,i} + \Delta\sigma'_{z,i}$$

$$\varepsilon_{z,i} = \frac{1}{C}\ln\frac{\sigma'_{z,i}}{p'_{0,i}}$$

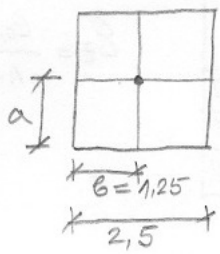
– ЗАДАЦИ:

1.1. $B=2{,}5m$
$L=3{,}75m$
$Q=1800\,KN$
$\gamma=17\,KN/m^3$
$D_f=1{,}5m$



$$q_n = \frac{Q}{B\cdot L} - \gamma\cdot D_f = \frac{1800}{2{,}5\cdot 3{,}75} - 17\cdot 1{,}5$$

$q_n = 166{,}5\,KN$



- точка 1. $z = 2{,}6\,m$ $\quad \frac{z}{b} = 2{,}08$ $\quad \frac{a}{b} = 1{,}5$ $\quad J_z = 0{,}102$

$\Delta\sigma_z' = 4 q_n \cdot J_1 = 67{,}932$

- точка 2. $z = 5{,}2\,m$ $\quad \frac{z}{b} = 4{,}16$ $\quad \frac{a}{b} = 1{,}5 \Rightarrow J_2 = 0{,}036$

$\Delta\sigma_z' = 4 q_n \cdot J_2 = 4 \cdot 166{,}5 \cdot 0{,}036 = 23{,}976$

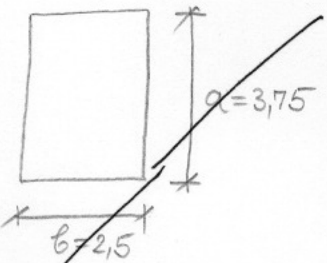
1.2.

T	p_0'	$\Delta\sigma_z'$	σ_z'
0	25,5	166,5	192,0
1	69,7	67,932	137,63
2	113,9	23,98	137,88

$p_0' = \gamma \cdot h$

$q_n = \frac{Q}{BL} - \gamma D_f = \frac{1800}{2{,}5 \cdot 3{,}75} - 17 \cdot 1{,}5 = 166{,}5\ \frac{kN}{m^2}$

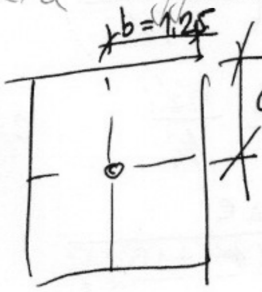
$\Delta\sigma_z = q_n \Rightarrow \Delta\sigma_z = 166{,}5\,KPa$ на длабочина $z = 0 \Rightarrow \Delta\sigma_{z,0}' = 166{,}5\,KPa$



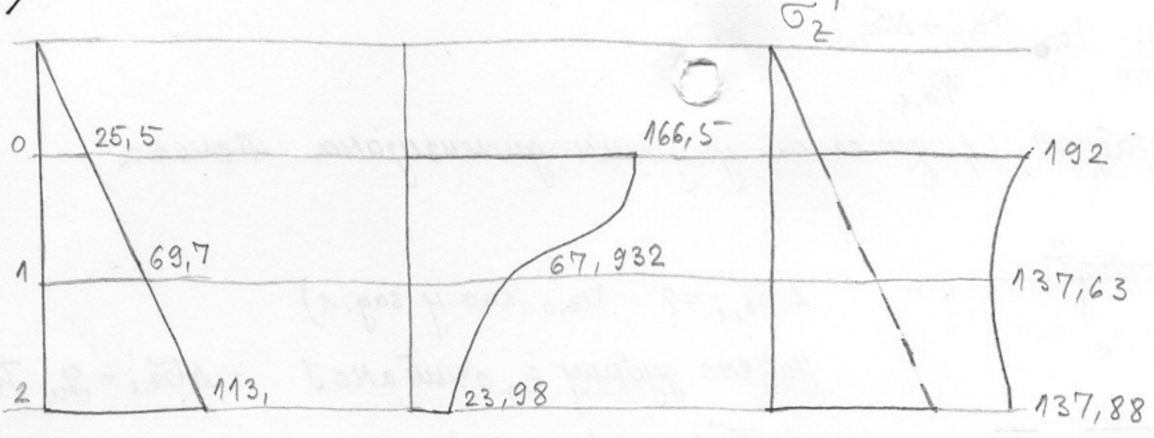
$\frac{a}{b} = 1{,}5$

$\frac{z}{b} = 1{,}04$ (за точку 1)

$\frac{z}{b} = 2{,}08$ (за точку 2)



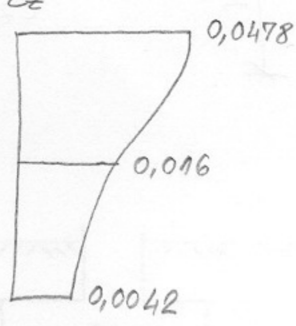
1.3.



1.4.

a)

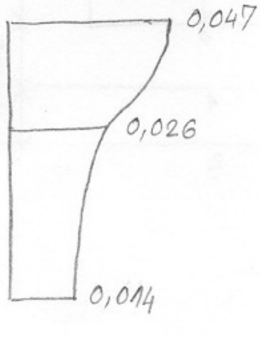
T	$\left(\frac{\Delta h}{h_0}\right)_2$	$\left(\frac{\Delta h}{h_0}\right)_1$	ε_z	$\Delta\sigma_z'$	Mv
0	0,0540	0,0062	0,0478	166,5	3483,26
1	0,0460	0,032	0,016	67,93	4245,62
2	0,0462	0,042	0,0042	23,98	5709,52



b)

t	e_0	e_1	ε_z
0	0,946	0,848	0,047
1	0,894	0,864	0,015
2	0,872	0,863	0,0042

$\varepsilon_z = \frac{e_{0,i} - e_{1,i}}{1 + e_{0,i}}$



1.5. величине слегања

Из табеле а)

добија се: $S = \frac{H}{4}\left(\varepsilon_{z,0} + 2\varepsilon_{z,1} + \varepsilon_{z,2}\right) = \frac{5,2}{4}\left(0,0478 + 2 \cdot 0,016 + 0,0042\right) = 0,109\,m$

Из табеле в)

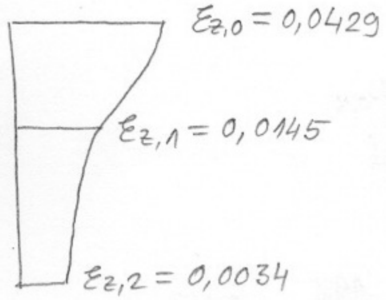
$$S = \frac{H}{4}\left(\varepsilon_{z,0} + 2\varepsilon_{z,1} + \varepsilon_{z,2}\right) = \frac{5,2}{4}\left(0,047 + 2 \cdot 0,015 + 0,0042\right) = 0,105\,m$$

1.6. Константа стишљивости C за интервал промене напона одређен за тачку 1 (1.1 и 1.2) темељне стопе:

$$C = \frac{1 - \left(\frac{\Delta h}{h_0}\right)_1}{\left(\frac{\Delta h}{h_0}\right)_2 - \left(\frac{\Delta h}{h_0}\right)_1} \cdot \ln \frac{\sigma_z'}{p_0} \quad \text{(за тачку 1)}$$

$$C = \frac{1 - 0,032}{0,0460 - 0,032} \cdot \ln \frac{137,63}{69,7} = 47,04$$

1.7. $\varepsilon_{z,i} = \frac{1}{C} \ln \frac{\sigma'_{z,i}}{p'_{0,i}}$



$$\varepsilon_{z,0} = \frac{1}{47,04} \ln \frac{192}{25,5} = 0,0429$$

$$\varepsilon_{z,1} = \frac{1}{47,04} \ln \frac{137,63}{69,7} = 0,0145$$

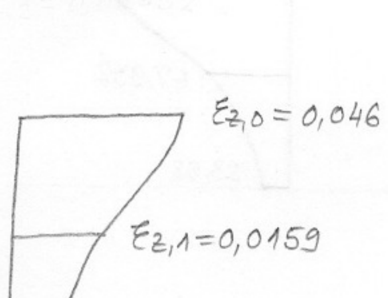
$$\varepsilon_{z,2} = \frac{1}{47,04} \ln \frac{137,88}{113,9} = 0,0034$$

$$S = \frac{H}{4}\left(\varepsilon_{z,0} + 2\varepsilon_{z,1} + \varepsilon_{z,2}\right) = \frac{5,2}{4}\left(0,0429 + 2 \cdot 0,0145 + 0,0034\right) = 0,0979\,m$$

1.8. $C_c = \frac{e_0 - e_1}{\log\left(\frac{\sigma_z'}{p_0'}\right)}$ за тачку 1

$$C_c = \frac{0,894 - 0,864}{\log\left(\frac{137,63}{69,7}\right)} = 0,102$$

1.9. $\varepsilon_{z,i} = \frac{C_c}{1 + e_{0,i}} \cdot \log \frac{\sigma'_{z,i}}{p'_{0,i}}$



$$\varepsilon_{z,0} = \frac{0,102}{1 + 0,946} \log \frac{192}{25,5} = 0,046$$

$$\varepsilon_{z,1} = \frac{0,102}{1 + 0,894} \log \frac{137,63}{69,7} = 0,0159$$

$$\varepsilon_{z,2} = \frac{0,102}{1 + 0,872} \log \frac{137,88}{113,9} = 0,00452$$

$$S = \frac{H}{4}\left(\varepsilon_{z,0} + 2\varepsilon_{z,1} + \varepsilon_{z,2}\right) = 0,107\,m$$

2. из 1.7

$\Delta\sigma_{z,i} = q_n \cdot I$ — срачунато у т-и 1.1

T	$\Delta\sigma_{z,i}$	$p'_{0,i}$	$\sigma'_{z,i}$	$\varepsilon_{z,i}$
0	166,5	25,5	192	0,0478
1	67,932	69,7	137,63	0,016
2	23,98	113,9	137,88	0,0042

$\Delta\sigma_z = q_n \cdot I$

$I = I\left(\frac{L}{B}, \frac{z}{B}\right)$

$L = 3{,}75\,m$

$B = 2{,}5\,m$

$\frac{L}{B} = 1{,}5$

$q_n = \frac{Q}{BL} - \gamma D_f = 166{,}5\,kPa$

$\sigma'_{z,i} = \Delta\sigma'_{z,i} + p'_{o,i}$

$\varepsilon_{z,i} = \frac{1}{C} \ln \frac{\sigma'_{z,i}}{p'_{o,i}}$

$C = 47{,}04$

$\varepsilon_{z,1} = \frac{1}{47{,}04} \ln \frac{192}{25{,}5} = 0{,}043$

$\varepsilon_{z,2} = \frac{1}{47{,}04} \ln \frac{137{,}63}{69{,}7} = 0{,}014\,m$

$\varepsilon_{z,3} = \frac{1}{47{,}04} \ln \frac{137{,}88}{113{,}8} = 0{,}00406\,m$

тачка 0

за $z = 0$

$\frac{z}{B} = 0 \Rightarrow \frac{\Delta\sigma_z}{q_n} = 1 \Rightarrow \Delta\sigma_z = q_n = 166{,}5\,kPa$

тачка 1

за $\frac{z}{B} = \frac{2{,}6}{2{,}5} = 1{,}04 \Rightarrow \frac{\Delta\sigma_z}{q_n} = 0{,}27 \Rightarrow \Delta\sigma_z = 0{,}27\,q_n$

$\Delta\sigma_z = 67{,}932\,kPa$

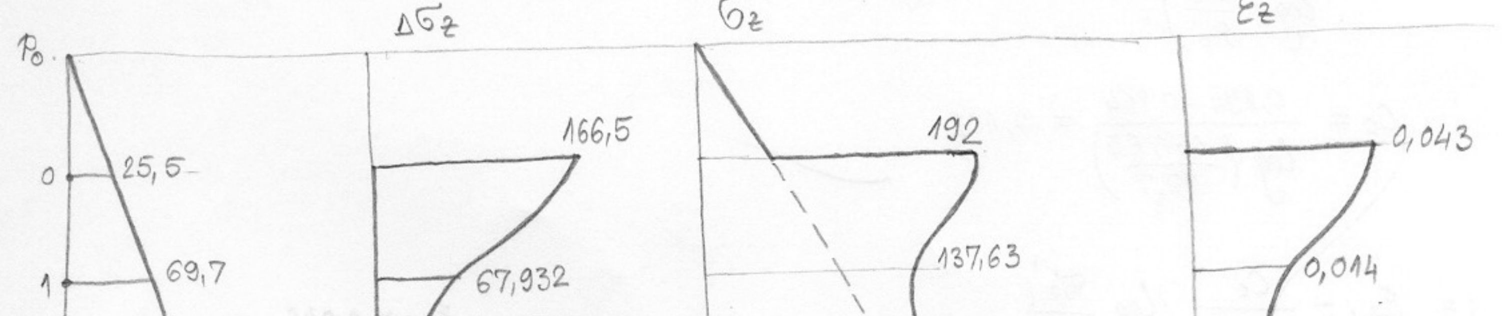
тачка 2

за $\frac{z}{B} = \frac{5{,}2}{2{,}5} = 2{,}08 \Rightarrow \frac{\Delta\sigma_z}{q_n} = 0{,}13 \Rightarrow \Delta\sigma_z = 0{,}13\,q_n$

$\Delta\sigma_z = 0{,}13 \cdot 166{,}5 = 23{,}98\,kPa$

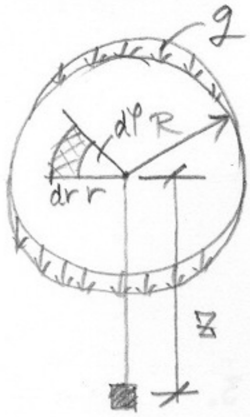
$S = \frac{5{,}2}{4}\left(0{,}043 + 2 \cdot 0{,}014 + 0{,}00406\right) = ~~0{,}076\,m~~$?

0,097 m



- ситнозрно тло

Њумарков дијаграм за прорачун напона



$dQ = q \cdot dA$

$dA = r \cdot d\psi\, dr$

$\psi = 0 \div 2\pi$

$r = 0 \div R$

$$\sigma_z = q \cdot \left[1 - \frac{1}{\left(R^2/z^2 + 1\right)^{3/2}}\right]$$

$\sigma_z = q \cdot N_z$ → утицајни коеф. (зависи од димензије темеља и од z)

$N_z = f(z/R)$

$$\Delta\sigma_z = \frac{1}{10} - \frac{1}{20}\, q = 0{,}005\, q$$

$\Delta\sigma_z = 0{,}005\, n\, q$

$R = 1 : \frac{z}{AB}$ (слегање централне т-е)

n → број површина који заузима оптерећена површина на Њумарковом дијаграму

* прорачун деформација за крупнозрно тло

Метода BUISMAN DE BEER-a

$$C = 1{,}5 \cdot \frac{q_c}{p_0'} \; ; \quad \varepsilon_z = \frac{1}{C} \ln \frac{p_0' + \Delta\sigma_z'}{p_0'}$$

q_c → отпор врха статичког пенетрометра

$$S = \sum \frac{1}{C_i} \ln \frac{p'_{0,i} + \Delta\sigma'_{z,i}}{p'_{0,i}} \cdot \Delta z_i$$

- ситнозрно тло (деформације)

1. $p_0' + \Delta\sigma_z' > p_c'$ → напон преконсол.

$$\varepsilon_z = \frac{C_r}{1+e_0} \log \frac{p_c'}{p_0'} + \frac{C_c}{1+e_0} \log \frac{p_0' + \Delta\sigma_z'}{p_c'}$$

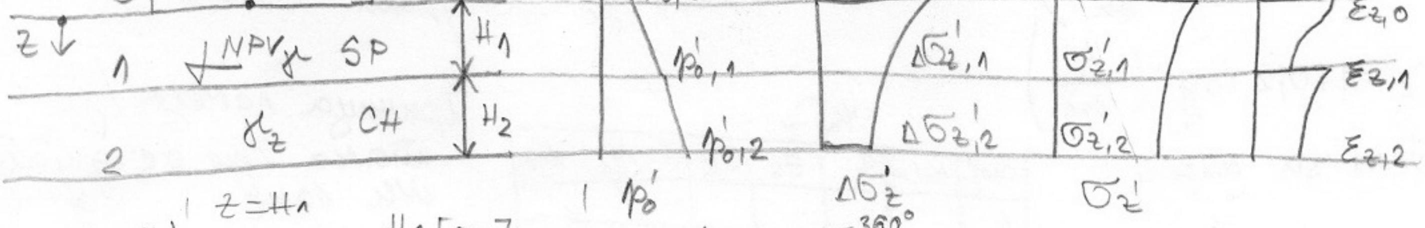
2. $p_0' + \Delta\sigma_z' < p_c'$

$$\varepsilon_z = \frac{C_r}{1+e_0} \log \frac{p_0' + \Delta\sigma_z'}{p_0'}$$

} 1 и 2 OC-тло

3. NC-тло $\quad \varepsilon_z = \frac{C_c}{1+e_0} \log \frac{p_0' + \Delta\sigma_z'}{p_0'}$

*задатак



$z=0$: („0") | $z=H_1$ | $R_1 = 1 : \frac{H_1\,[cm]}{AB\,[cm]} \Rightarrow n \quad \Delta\sigma'_{z,0} = \frac{\alpha}{360°} \cdot q_n$ ($\alpha = 360°$) („0") $\quad q_n = q - \gamma D_f$

$z = H_1 + H_2$ („2") $R_2 = 1 : \frac{H_1 + H_2}{AB} \Rightarrow n \Rightarrow \Delta\sigma_{z,2} = 0{,}005 \cdot n \cdot q_n$

„1" $\Delta\sigma_{z,1} = 0{,}005 \cdot n \cdot q_n$

2. прорачун слегања

— слој 1: SP $z=0$ $C^0 = 1{,}5 \frac{q_c^0}{p'_{0,0}}$ (дато у задатку) $\varepsilon_z^0 = \frac{1}{C^0} \ln \frac{\sigma'_{z,0}}{p'_{0,0}}$ након очитавано из претходне т-е

$z=1$ на граници SP и CH:

т. „1" у SP $C^1 = 1{,}5 \cdot \frac{q_c^1}{p'_{0,1}}$ $\varepsilon_z^{1g} = \frac{1}{C^1} \ln \frac{\sigma'_{z,1}}{p'_{0,1}}$

т. „1" у CH $C_c = 0{,}009\,(w_L - 10\%)$ (дато) $C_r = \frac{C_c}{5}$

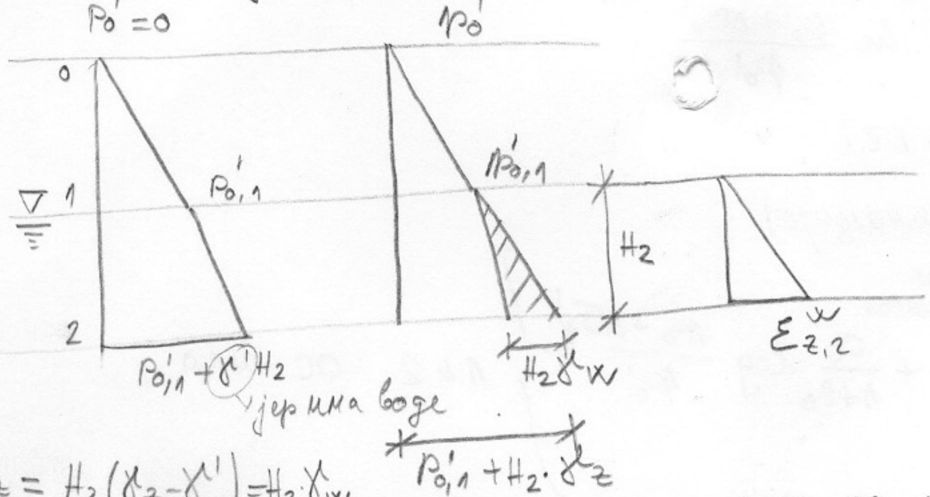
$\gamma_z = \frac{G_s + e_0}{1 + e_0} \cdot \gamma_w \Rightarrow e_0$ (G_s дато, γ_w „9,807")

$p'_{c,1} = p'_{0,1} + \gamma_n h_n$ ε_z^{1d} у зависности од 1. 2. и 3.

$p'_{c,2} = p'_{0,2} + \gamma_n \cdot h_n$

$$S = \frac{H_1}{2}\left(\varepsilon_{z,0} + \varepsilon_{z,1g}\right) + \frac{H_2}{2}\left(\varepsilon_{z,1d} + \varepsilon_{z,2}\right)$$

3.



$\Delta\sigma_z = H_2(\gamma_z - \gamma') = H_2 \gamma_w$

$\sigma_z^w = p'_0 + H_2 \cdot \gamma_w \rightarrow S = \frac{H_2}{2} \cdot \varepsilon_{z,2}^w$ → рачуна се или 1. или 2. случај

Метода

слегање темеља на песку

$S = C_1 C_2 q_n \sum_0^{2B} \frac{I_z}{E_s} \Delta z$ E_s модул деф

$C_1 = 1 - 0{,}5\left(\frac{\gamma \cdot D_f}{q_n}\right)$ $E_s = 3{,}5 \cdot q_c$ трака

$C_2 = 1 + 0{,}2 \log\left(\frac{t}{0{,}1}\right)$ $E_s = 2{,}5 \cdot q_c$ квадрат

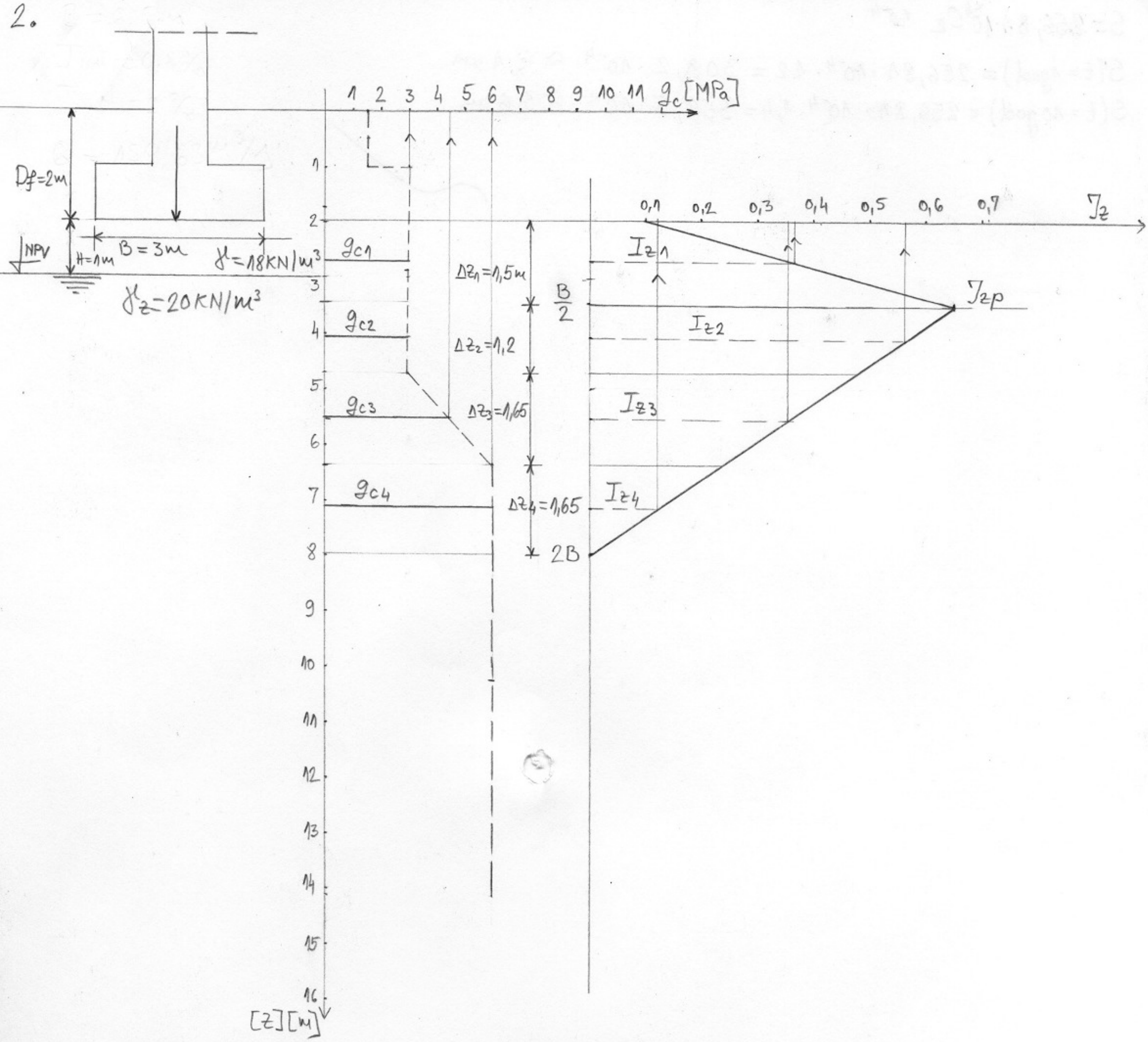
табела за стр. 4

слој	Δz[m]	q_c [kN/m²]	E_s	I_z	$(I_z/E_s)\cdot\Delta z$
1					
2					
⋮					

граница ламела је тамо где се дијаграм ломи

Σ последњу колону

2.



слој.	Δz [m]	q_c	E_s	I_z	$\frac{I_z}{E_s}\Delta z$
1.	1,5	$3\cdot10^3$	$7,5\cdot10^3$	0,37	$0,74\cdot10^{-4}$
2.	1,2	$3\cdot10^3$	$7,5\cdot10^3$	0,56	$0,9\cdot10^{-4}$
3.	1,65	$4,5\cdot10^3$	$11,25\cdot10^3$	0,35	$0,51\cdot10^{-4}$
4.	1,65	$6\cdot10^3$	$15\cdot10^3$	0,12	$0,13\cdot10^{-4}$

$\Sigma = 2,28\cdot10^{-4}$

слегање: $S = C_1 C_2\, q_n \sum_0^{2B} \frac{I_z}{E_s}\Delta z$

$q_n = q - \gamma D_f$

E_s – модул деформације

за □ темељ: $E_s = 2,5\, q_c$

$C_1 = 1 - 0,5\left(\frac{\gamma \cdot D_f}{q_n}\right)$

$C_2 = 1 + 0,2 \log(t/0,1)$ t [god] (1god и 10god)

$$I_{zp} = 0,5 + 0,1\sqrt{\frac{q_n}{\sigma'_{vp}}} = 0,5 + 0,1\cdot\sqrt{\frac{130,667}{59,0965}} = 0,65$$

σ'_{vp} → почетни геостатички напон на дубини где се јавља max def $(D_f + \frac{B}{2})$

$$q_n = \frac{V}{B\cdot L} - \gamma D_f = \frac{1500}{3\cdot3} - 18\cdot2 = 130,667\ \frac{kN}{m^2}$$

$$\sigma'_{vp} = 2\cdot18 + 1\cdot18 + (20-9,807)\cdot0,5 = 59,0965\ kPa$$

$$C_1 = 1 - 0,5\left(\frac{\gamma\cdot D_f}{q_n}\right) = 1 - 0,5\left(\frac{18\cdot2}{130,667}\right) = 0,862$$

$$C_2 = 1 + 0,2\log\left(\frac{t}{0,1}\right)$$

$$C_2(t = 1god) = 1 + 0,2\log\left(\frac{1}{0,1}\right) = 1,2$$

$$C_2(t = 10god) = 1 + 0,2\log\left(\frac{10}{0,1}\right) = 1,4$$

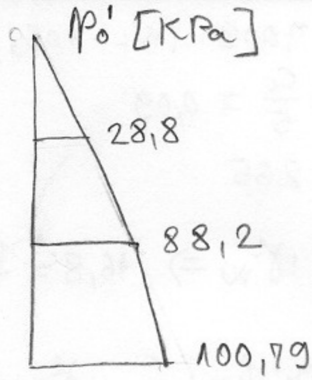
$$S = C_1 C_2\, q_n \sum_0^{2B}\frac{I_z}{E_s}\cdot\Delta z = 0,862\cdot C_2\cdot130,667\cdot2,28\cdot10^{-4}$$

$S = 256,81 \cdot 10^{-4} C_2 \cdot 10^{-4}$

$S(t = 1 god) = 256,81 \cdot 10^{-4} \cdot 1,2 = 308,2 \cdot 10^{-4} \approx 3,1$ cm

$S(t = 10 god) = 256,81 \cdot 10^{-4} \cdot 1,4 = 359,5 \cdot 10^{-4} \approx 3,6$ cm

ЗАДАТАК 1:



$p_0' = \sum h_i \gamma_i$

$p'_{0,0} = D_f \cdot \gamma_1 = 28{,}8$ KPa

$p'_{0,1} = (D_f + H_1)\cdot \gamma_1 = 88{,}2$ KPa

$p'_{0,2} = (D_f + H_1)\cdot \gamma_1 + H_2 \cdot \gamma_2' = 100{,}79$ KPa

$\gamma_2' = \gamma_2 - \gamma_w = 6{,}993$ kN/m^3

$z = 0$: („0") $\quad \Delta\sigma'_{z,0} = \frac{\alpha}{360°} \cdot q_n \quad (\alpha = 360°) \qquad q_n = q - \gamma \cdot D_f = 150 - 18 \cdot 1{,}6 = 121{,}2$ KPa

$\Delta\sigma'_{z,0} = q_n = 121{,}2$ KPa

$z = H_1$ („1") $\quad R_1 = 1 : \frac{330}{3{,}85} = 1 : 85{,}71 \quad (400 : 85{,}71 = 4{,}67)$

$R = 4$ m $\quad (4{,}67) \quad \Rightarrow n_1 = 149$

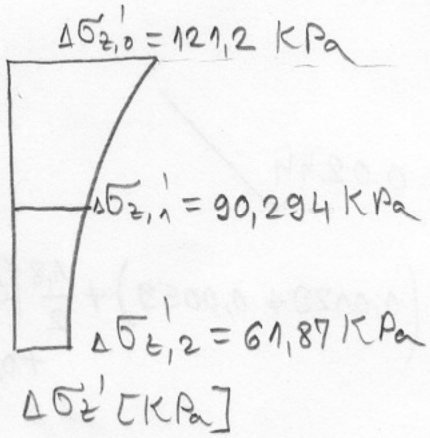
$\Delta\sigma'_{z,1} = 0{,}005 \cdot n \cdot q_n = 0{,}005 \cdot 149 \cdot 121{,}2 = 90{,}294$ KPa

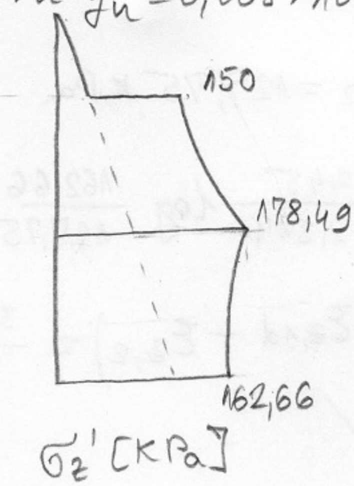
$z = H_2$ („2") $\quad R_2 = 1 : \frac{H_1 + H_2}{AB} = 1 : \frac{510}{3{,}85} = 1 : 132{,}47 \quad (400 : 132{,}47 = 3{,}02)$

$\Downarrow$

$n_2 = 102{,}1$

$\Delta\sigma'_{z,2} = 0{,}005 \cdot n \cdot q_n = 0{,}005 \cdot 102{,}1 \cdot 121{,}2 = 61{,}87$ KPa





$\sigma_z' = \Delta\sigma_z' + p_0'$

2. прорачун слегања $\qquad q_c^{\circ} = 4000$ KPa

– слој 1: SP $\quad z = 0 \quad C^{\circ} = 1{,}5 \cdot \frac{q_c^{\circ}}{p'_{0,0}} = 1{,}5 \cdot \frac{4000}{28{,}8} = 208{,}3\dot{3}$

$\varepsilon_z^{\circ} = \frac{1}{C^{\circ}} \ln \frac{\sigma_{z,0}}{p'_{0,0}} = \frac{1}{208{,}3} \ln \frac{150}{28{,}8} = 0{,}0079$

– тачка „1" на граници SP и CH:

ако је у SP: $C^{1g} = 1{,}5 \frac{q_c^{1g}}{p'_{0,1}} = 1{,}5 \cdot \frac{7000}{88{,}2} = 119{,}0476$

$\varepsilon_z^{1g} = \frac{1}{C^{1g}} \ln \frac{\sigma_{z,1}}{p'_{0,1}} = \frac{1}{119{,}0476} \ln \frac{178{,}49}{88{,}2} = 0{,}0059$

"1" y CH $\quad C_c = 0{,}009 \cdot (w_L - 10\%) = 0{,}009\,(60-10) = 0{,}45$

$$C_r = \frac{C_c}{5} = 0{,}09$$

$$G_s = 2{,}65$$

$$\gamma_z = \frac{G_s + e_0}{1+e_0} \cdot \gamma_w \Rightarrow 16{,}8 = \frac{2{,}65+e_0}{1+e_0} \cdot 9{,}807 \Rightarrow 16{,}8 + 16{,}8\,e_0 = 25{,}98855 + 9{,}807\,e_0$$

$$e_0 = 1{,}314$$

$$p'_{c,1} = p'_{0,1} + \gamma_n h_n \qquad \gamma_n = 18\ kN/m^3$$

$$h_n = 1{,}5\ m$$

$$p'_{c,1} = 88{,}2 + 18 \cdot 1{,}5$$

$$p'_{c,1} = 115{,}2\ kPa$$

$$p'_{c,2} = p'_{0,2} + \gamma_n h_n = 100{,}79 + 18 \cdot 1{,}5 = 127{,}75\ kPa$$

$$p'_{0,1} + \Delta\sigma'_{z,1} = 88{,}2 + 90{,}294 = 178{,}49 > p'_{c,1} = 115{,}2\ kPa$$

$$\varepsilon_z = \frac{C_r}{1+e_0} \log \frac{p'_{c,1}}{p'_{0,1}} + \frac{C_c}{1+e_0} \log \frac{p'_{0,1}+\Delta\sigma'_{z,1}}{p'_{c,1}}$$

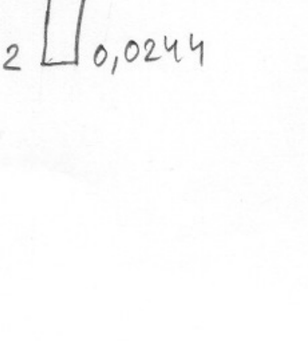
$$\varepsilon_{z,1d} = \frac{0{,}09}{1+1{,}314} \log \frac{115{,}2}{88{,}2} + \frac{0{,}45}{1+1{,}314} \log \frac{178{,}49}{115{,}2} = 0{,}0415$$

$$p'_{0,2} + \Delta\sigma'_{z,2} = 162{,}66 > p'_{c,2} = 127{,}75\ kPa$$

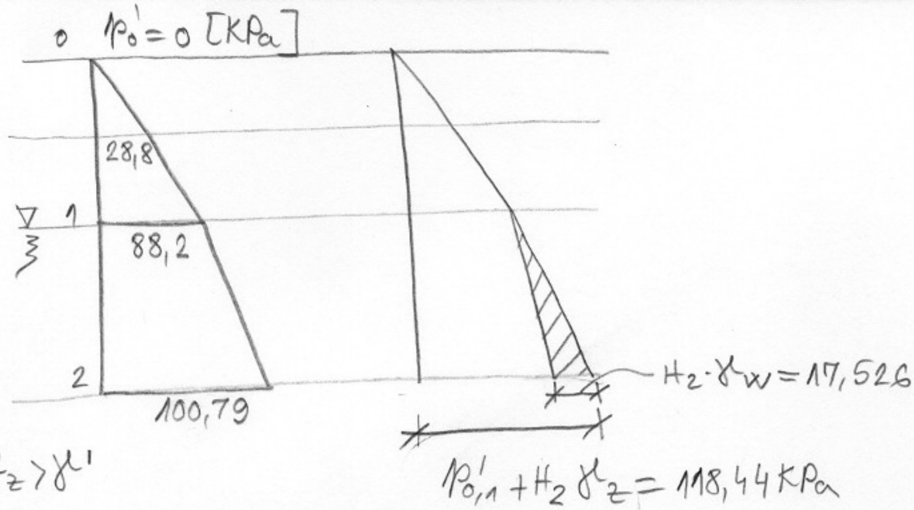
$$\varepsilon_{z,2} = \frac{0{,}09}{1+1{,}314} \log \frac{127{,}75}{100{,}79} + \frac{0{,}45}{2{,}314} \log \frac{162{,}66}{127{,}75} = 0{,}0244$$

$$S = \frac{H_1}{2}\left(\varepsilon_{z,0} + \varepsilon_{z,1g}\right) + \frac{H_2}{2}\left(\varepsilon_{z,1d} + \varepsilon_{z,2}\right) = \frac{3{,}3}{2}\left(0{,}0079 + 0{,}0059\right) + \frac{1{,}8}{2}\left(0{,}0415 + 0{,}0244\right)$$

$$S = 0{,}082\ m = 8{,}2\ cm$$



3.



$\gamma_z > \gamma'$

$\gamma' = \gamma - \gamma_w$

$\Delta\sigma_z = H_2(\gamma_z - \gamma') = H_2 \cdot \gamma_w = 17,526$ KPa

$\sigma_z^w = p_{0,2}' + H_2 \gamma_w = 100,79 + 1,8 \cdot 9,807 = 118,316$ KPa

$S = \frac{H_2}{2} \cdot \varepsilon_{z,2}^w$

$p_{c,2}' = 127,75$

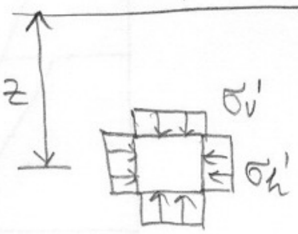
$118,316 \text{ KPa} < 127,75$

$\varepsilon_z^w = \frac{c_r}{1+e_0} \log \frac{\sigma_z^w}{p_{0,2}'} = \frac{0,09}{1+1,314} \log \frac{118,316}{100,79} = 0,0027$

$S = \frac{1,8}{2} \cdot 0,0027 = 0,0024 \text{ m} = 0,24 \text{ cm}$

Земљани притисци

Притисак тла у стању мировања



$\sigma_v' = \gamma' \cdot z$

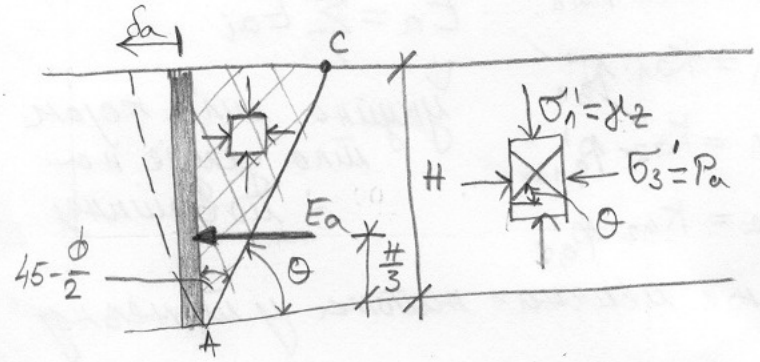
$\sigma_h' = K_0 \cdot \sigma_v' = K_0 \cdot \gamma' \cdot z$

$(\varepsilon_r = 0) \Rightarrow K_0 = \frac{\nu}{1-\nu}$ (у стању мировања)

Јаку: $K_{0,NC} \cong 1 - \sin\phi'$

$K_{0,OC} \cong K_{0,NC} \cdot \sqrt{OCR}$

Активни притисци тла (када се зид помера од тла)



$\sigma_3' = P_a = \sigma_1 \left(\frac{1-\sin\phi'}{1+\sin\phi'} \right) - 2c \left(\frac{1-\sin\phi'}{1+\sin\phi'} \right)^{1/2}$

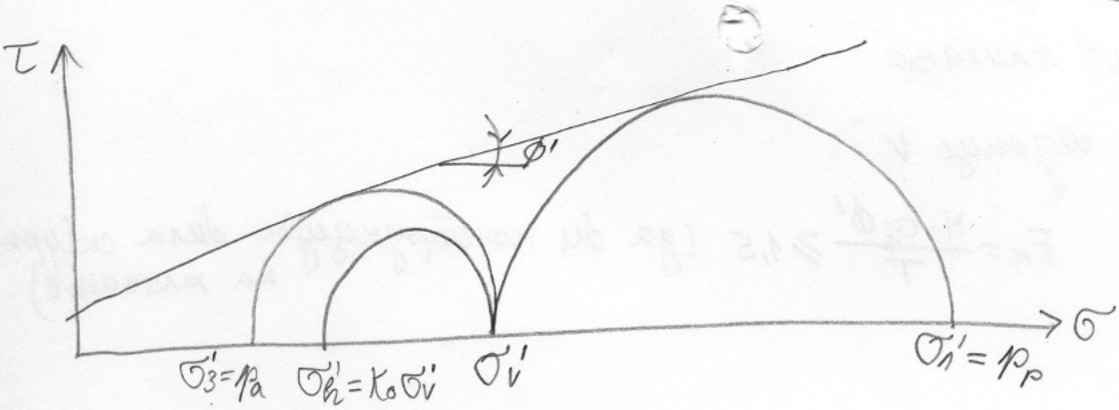
$K_a = \frac{1-\sin\phi'}{1+\sin\phi'} = \tan^2 \left(45 - \frac{\phi'}{2} \right)$

K_a → коеф. активног притиска тла

$\sigma_v = \sigma_1 = \gamma' \cdot z$

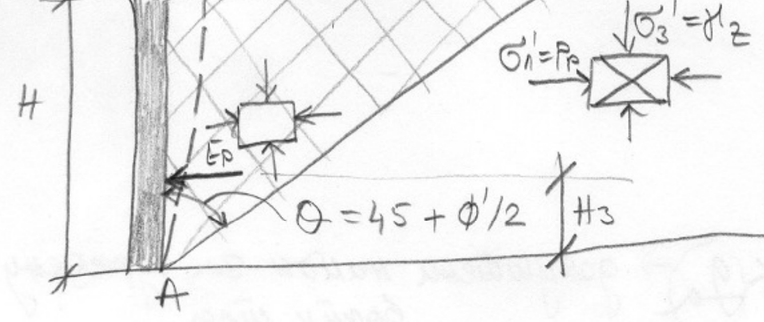
$P_a = K_a \cdot \gamma' \cdot z - 2c\sqrt{K_a}$

$2c\sqrt{K_a}$ → обично не постоји јер је $c = 0$



$(\sigma_1' - \sigma_3') = (\sigma_1' + \sigma_3') \sin\phi' + 2c' \cos\phi'$

Пасивни отпор тла

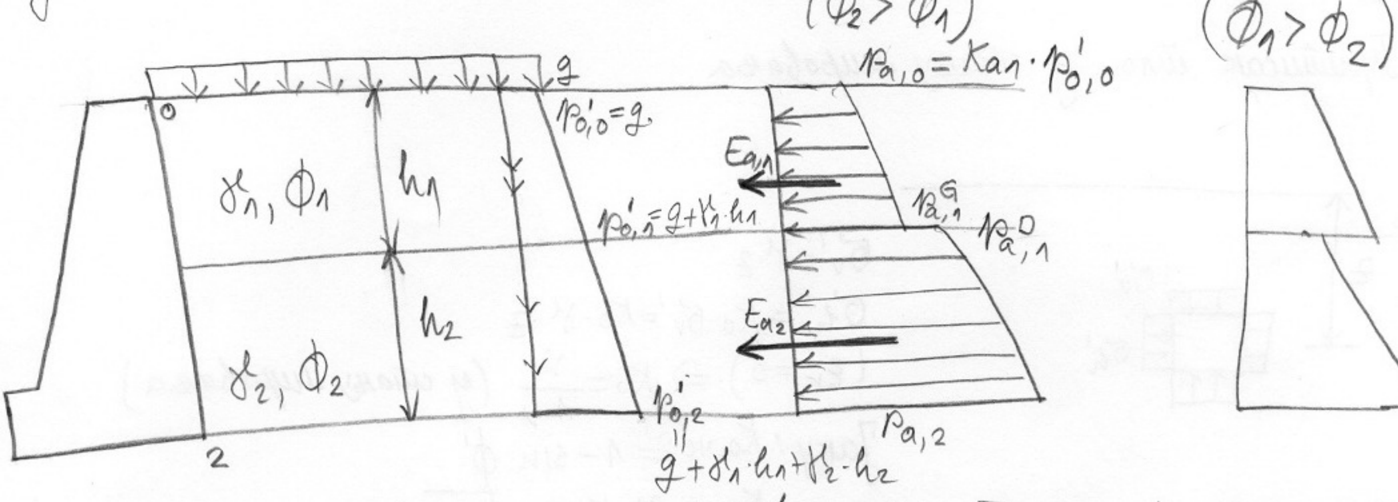


$\sigma_1' = P_p = \sigma_3' \left(\frac{1+\sin\phi'}{1-\sin\phi'} \right) + 2c \left(\frac{1+\sin\phi'}{1-\sin\phi'} \right)^{1/2}$

$K_p = \frac{1+\sin\phi'}{1-\sin\phi'} = \tan^2 \left(45 + \frac{\phi'}{2} \right)$

$P_p = K_p \cdot \gamma' \cdot z + 2c\sqrt{K_p}$

Метода Ранкина



тј. зид је гладак и вертикалан, а површина терена је хоризонтална

$K_{a1} = tg^2\left(45 - \frac{\Phi_1}{2}\right)$

$K_{a2} = tg^2\left(45 - \frac{\Phi_2}{2}\right)$

$p_{a,0} = K_{a1} \cdot p'_{0,0}$

$p_{a,1}^{g} = K_{a1} \cdot p'_{0,1}$

$p_{a,1}^{d} = K_{a2} \cdot p'_{0,1}$

$p_{a,2} = K_{a2} \cdot p'_{0,2}$

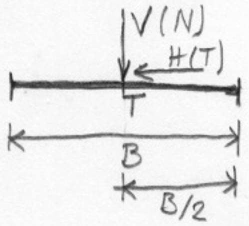
$E_a = \sum_i E_{ai}$

↓ укупна сила којом тло делује на површину

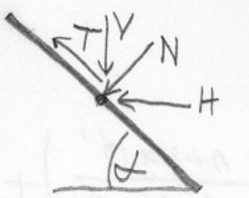
* Анализа стабилности и одређивање ивичних напона у темељној стопици

1. Сигурност против клизања

ширина темељне стопице V



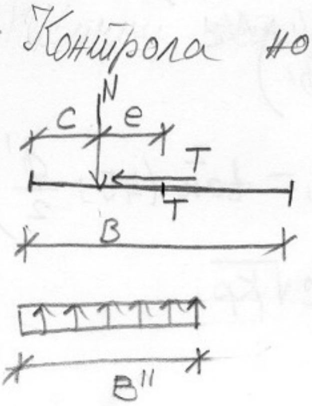
$F_K = \frac{N \cdot tg\Phi'}{T} \geq 1{,}5$ (да би конструкција била сигурна на клизање)



$N = V\cos\alpha + H\sin\alpha$

$T = -V\sin\alpha + H\cos\alpha$

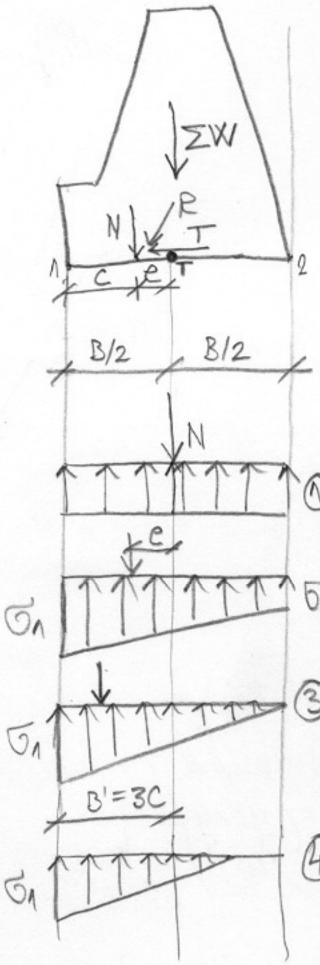
- Контрола носивости

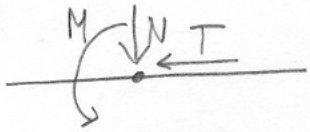


$\sigma = \frac{N}{B''} = \frac{N}{2c} \leq q_a$ → допуштени напон за одређену врсту тла

$B'' = 2c$

– Ивични напони у темељној спојници





$$\sigma_{1,2} = \frac{N}{F} \pm \frac{M}{W}$$

$$F = B \cdot 1{,}0 \qquad W = \frac{B^2 \cdot 1{,}0}{6} \qquad e = \frac{M}{N}$$

① $e=0 \quad \sigma_1=\sigma_2=\frac{N}{B}$

② $e<\frac{B}{6}$ (у језгру пресека)

③ $e=\frac{B}{6} \quad \sigma_1=\frac{2N}{B} \quad \sigma_2=0$ (на граници језгра)

④ $\frac{B}{6}<e<\frac{B}{2} \quad c=\frac{B}{2}-e$ (N није у језгру пресека)

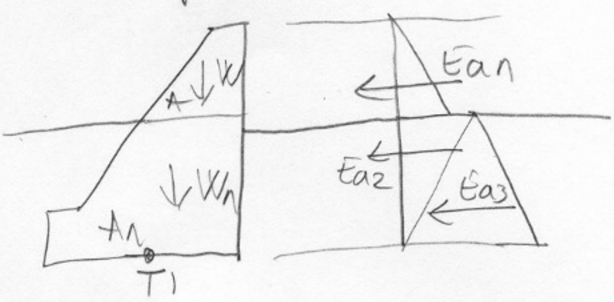
$B'=3c \quad \sigma_1=\frac{2N}{B'} \quad \sigma_2=0$

4.2. $W=\gamma_B \cdot S$ S – површина потпорне конст.

$\gamma_B = 24\ kN/m^3$ W – делује у тежишту

– делимо зид на 2 дела испод и изнад воде W тежина зида изнад воде, а тежина зида испод воде $\gamma_b = \gamma_b' - \gamma_w$

– када добијемо све силе врши се анализа стабилности



$$F_k = \frac{N\,tg\varphi}{T}$$

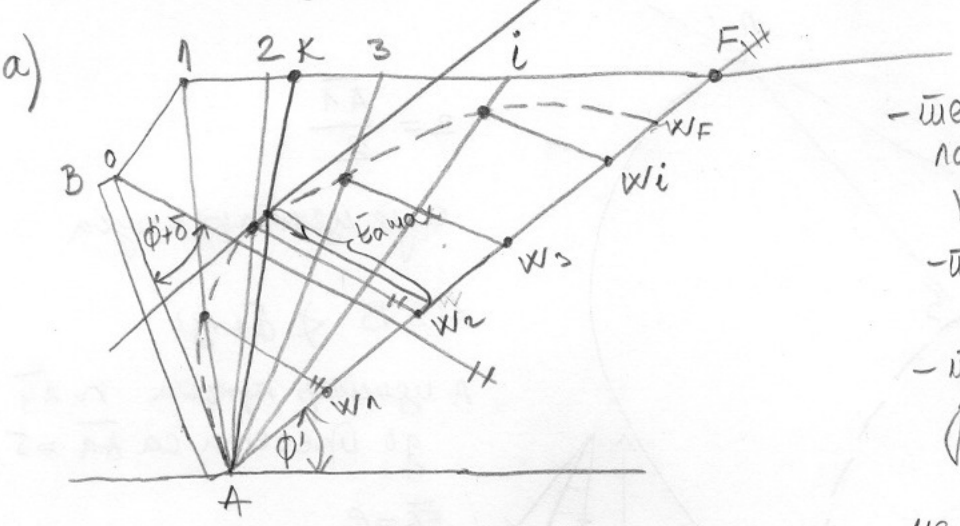
редукујемо на тежиште тем. сп.
нађемо момент у односу на T
нађемо e и видимо који случај имамо и на крају налазимо напон

Земљани притисци
Графичке методе

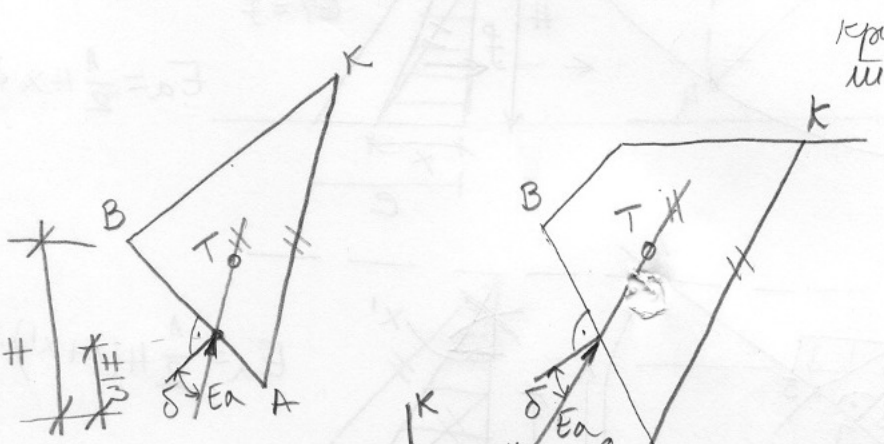
Кулманов поступак

$\delta = \frac{2}{3}\phi'$

a)

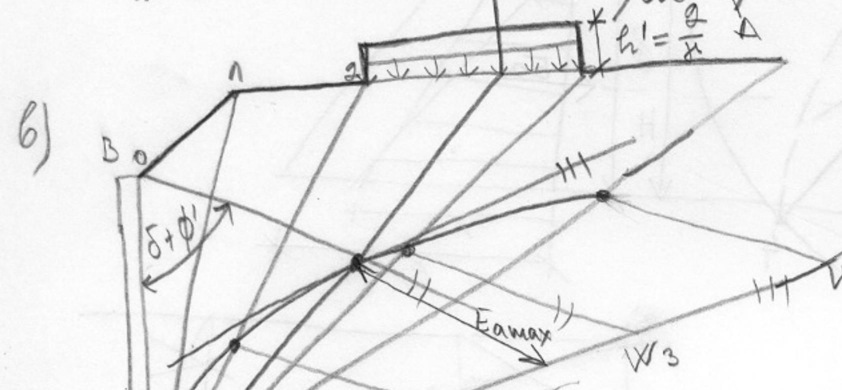


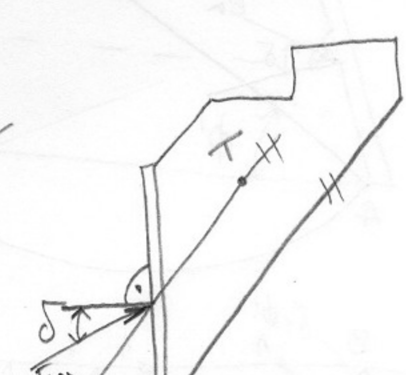
- тежина ламеле је површина ламеле x запр. тежина тла $W_i = A_i\gamma$
- тежина прве ламеле наноси се на AF, затим друге...
- тангента на Кулман. линију је паралелна са правом пошиб. правом AF, очитано E_{amax} из A кроз т-у где танг. тангира криву, у пресеку са тереном т-а K, клизна раван



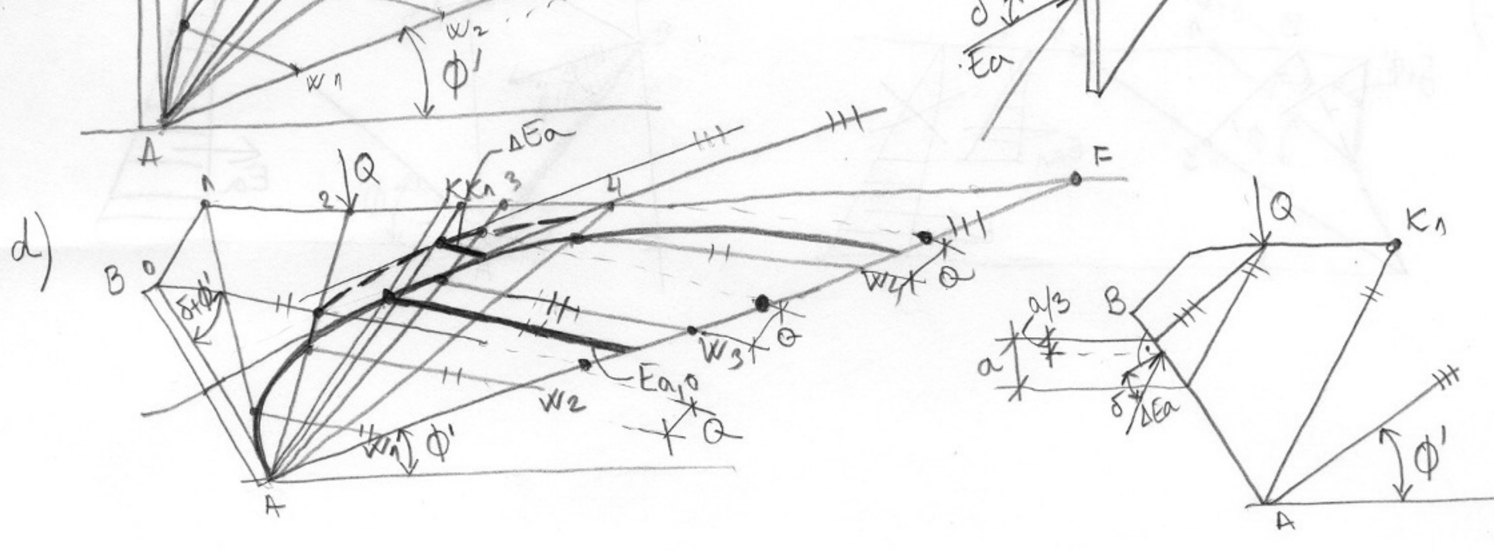
- д мењано слојем тла дебљине h'

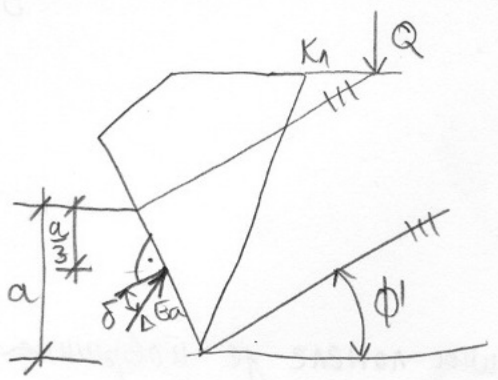
b)



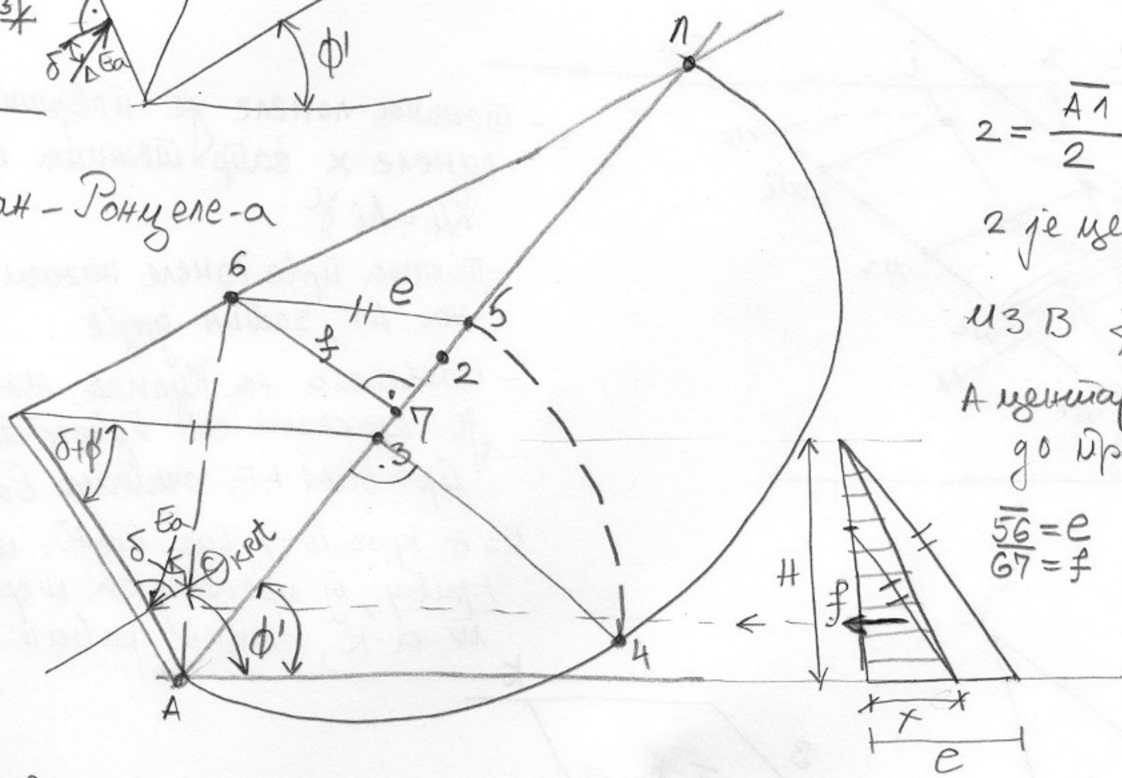


d)





* Ребан - Ронцеле-а



$2 = \frac{\overline{A1}}{2}$

2 је центар круга

из B ∡ δ+φ'

A центар круга $r = \overline{A4}$

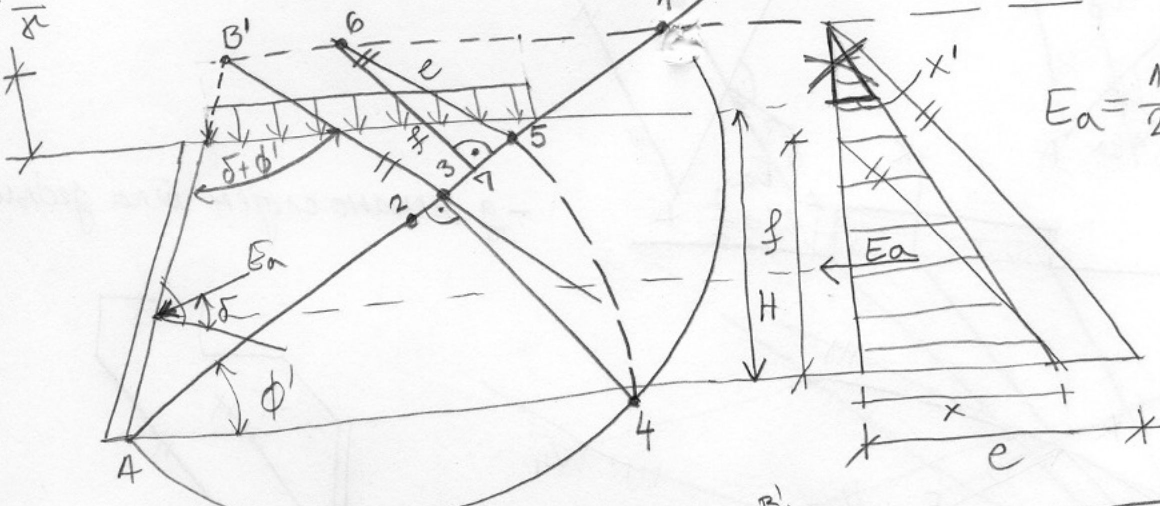
до пресека са $\overline{Aa} = 5$

$\overline{56} = e$

$\overline{67} = f$

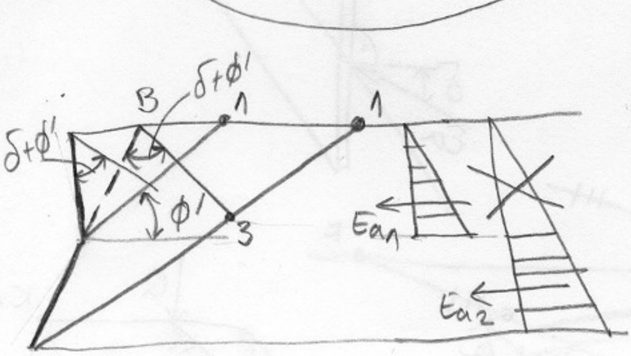
$E_a = \frac{1}{2} H x \gamma$

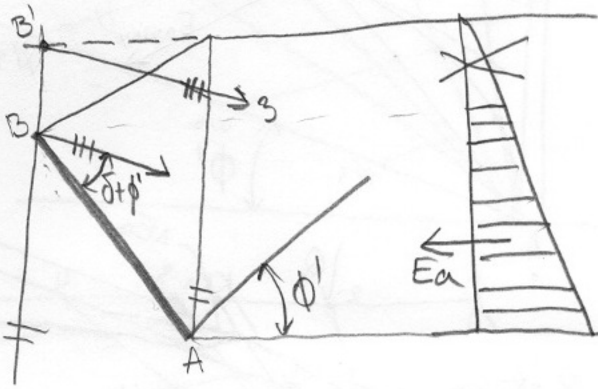
$h' = \frac{q}{\gamma}$



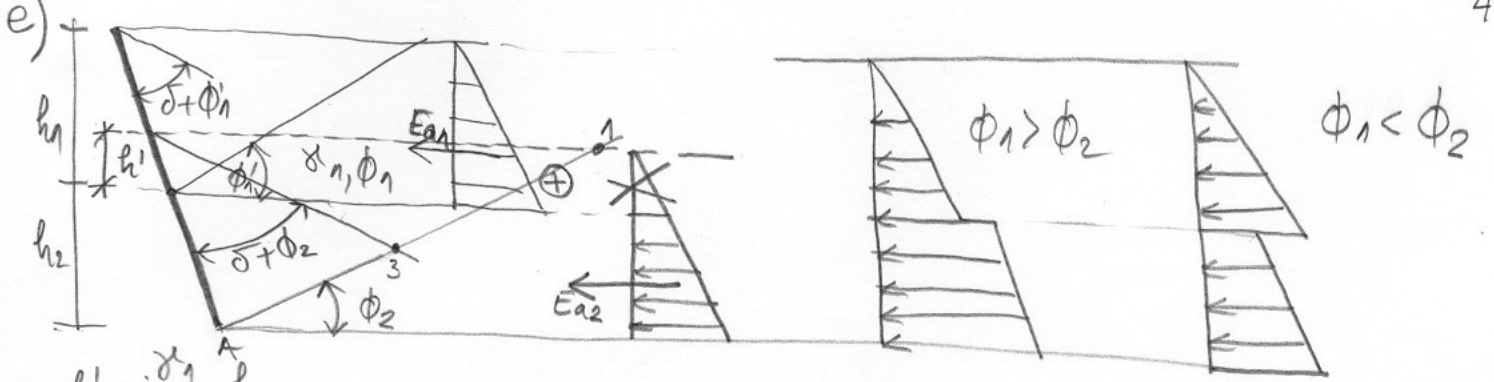
$E_a = \frac{1}{2} H (x + x') \cdot \gamma$

c)



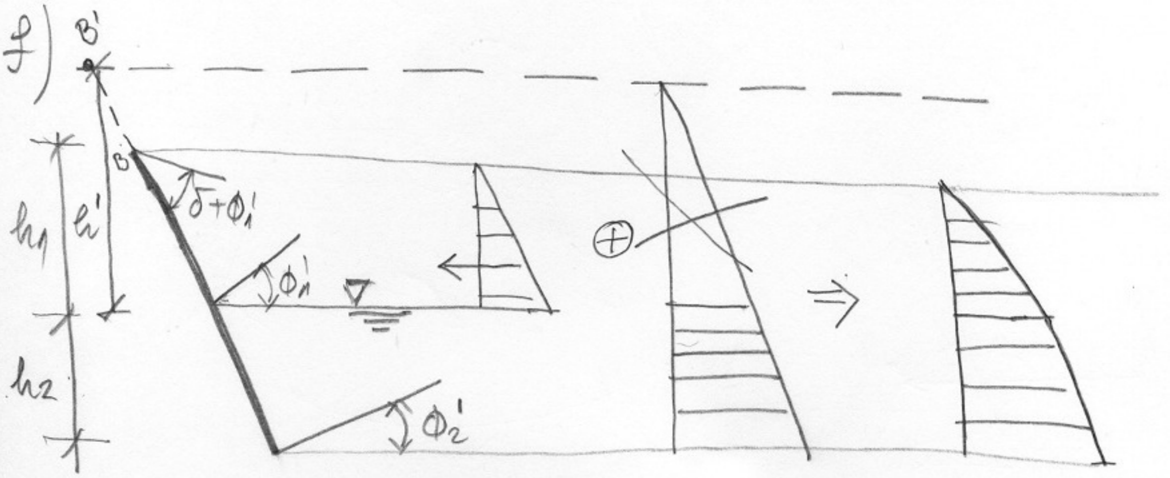


e)



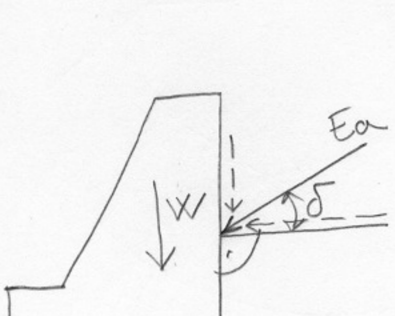
$$h' = \frac{\gamma_1}{\gamma_2} \cdot h_1$$

f)



$$h' = \frac{\gamma_1}{\gamma'} h_1$$

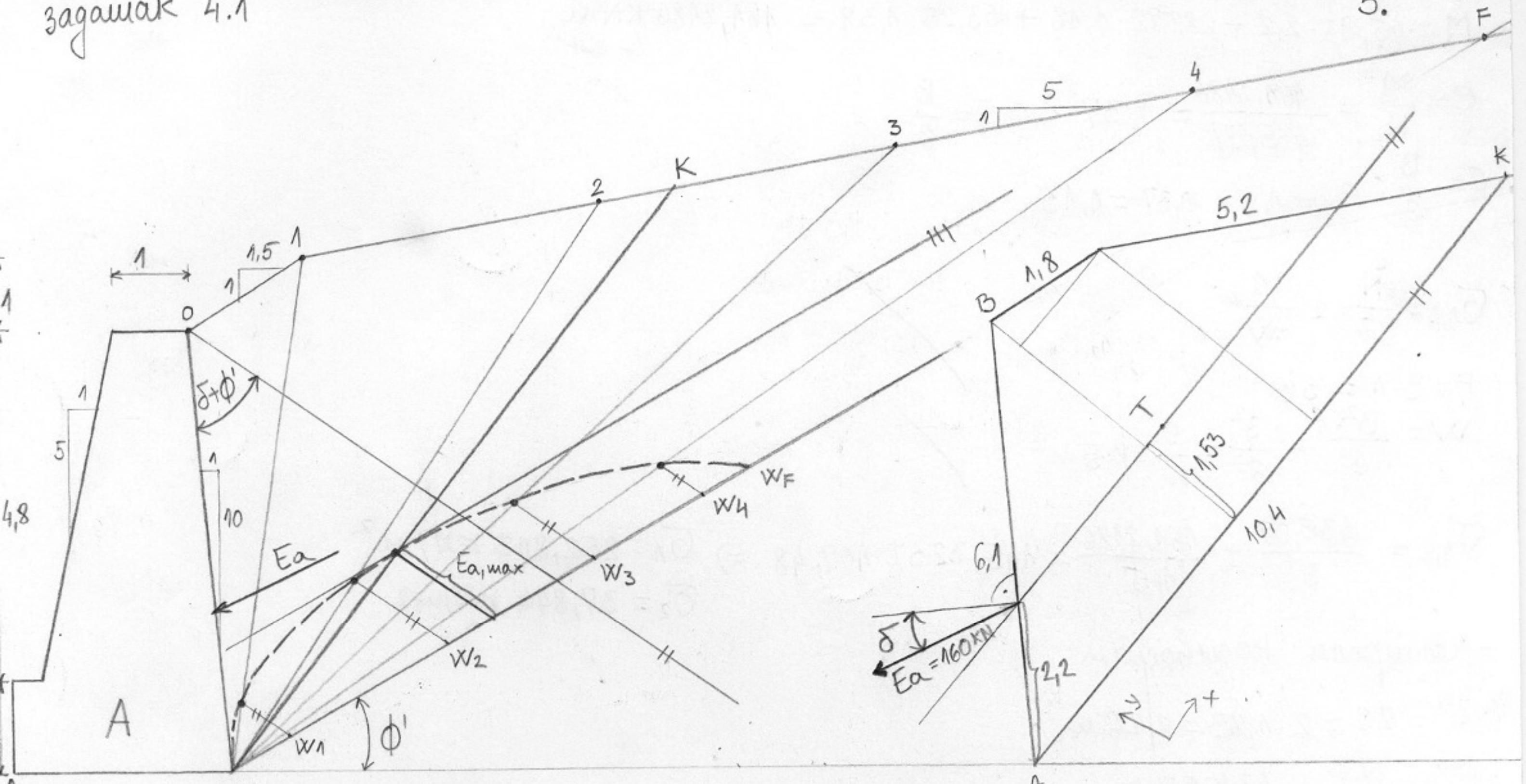
$$\gamma' = \gamma_z - \gamma_w$$



$N = W + E_{a,V}$

$T = E_{a,H}$

задатак 4.1



$\phi' = 32°$

$\gamma = 18 \, kN/m^3$

$\delta = \frac{2}{3}\phi' = \frac{2}{3} \cdot 32 = \frac{64}{3} = 21,3°$

$W_i = A_i \cdot \gamma$

$W_1 = A_1 \cdot \gamma = 4,89 \cdot 18 = 88,07 \, kN/m$

$A_1 = \sqrt{7,5 \cdot (7,5-7,1) \cdot (7,5-6,1) \cdot (7,5-1,8)} = 4,89 \, m^2$

$S_1 = \frac{6,1+7,1+1,8}{2} = 7,5$

$W_2 = A_2 \cdot \gamma = 13,73 \cdot 18 = 247,22 \, kN/m$

$A_2 = \sqrt{(10,25-4,1)(10,25-7,1)(10,25-9,3) \cdot 10,25} = 13,73$

$S_2 = \frac{4,1+7,1+9,3}{2} = 10,25$

$W_3 = A_3 \cdot \gamma = 235,54 \, kN/m$

$A_3 = 13,08 \, m^2$

$S_3 = \frac{4,1+9,3+12,6}{2} = 13$

$W_4 = 117,09 \, kN/m$

$A_4 = 6,5 \, m^2$

$S_4 = \frac{12,6+4,1+16,6}{2} = 16,65$

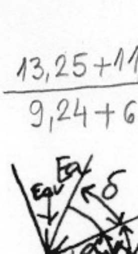
– анализа стабилности зида:

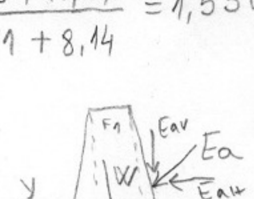
$$y_T = \frac{\frac{4,3^2}{2} \cdot \frac{4,3}{3} + \frac{1,7 \cdot 3,7^2}{2} + \frac{0,6 \cdot 1,7}{2} \cdot \left(\frac{0,6}{3} + 3,7\right) + \frac{4,4 \cdot 3,7}{2} \cdot \frac{3,7}{3}}{\frac{4,3^2}{2} + 1,7 \cdot 3,7 + \frac{0,6 \cdot 1,7}{2} + \frac{4,4 \cdot 3,7}{2}} = \frac{13,25 + 11,64 + 1,99 + 10,04}{9,24 + 6,29 + 0,51 + 8,14} = 1,53 \, m$$

$E_a = 160 \, kN/m \Rightarrow$ $E_{aH} = 160 \cdot \cos(73,3°) = $ ~~149,04 kN~~ 45,98 kN/m

$E_{av} = 160 \cdot \sin(73,3°) = $ ~~58,21 kN~~ 153,25

? $(\alpha + \delta)$! D





$\delta = 21,3°$

$\alpha = 5,7°$

– сигурност на клизање

$N = W + E_{av}$ $\quad T = E_{aH}$ $\quad F_K = \frac{N \cdot tg\phi'}{T} \geq 1,5$

$F_1 = 1 \cdot 6 = 6 \, m^2$ $\quad T_1(1,9; 3)$

$F_2 = \frac{1}{2} \cdot 4,8 \cdot 0,96 = 2,304 \, m^2$ $\quad T_2(1,08; 2,8)$

$F_3 = \frac{1}{2} \cdot 0,6 \cdot 6 = 1,8 \, m^2$ $\quad T_3(2,6; 2)$

$F_4 = 1,4 \cdot 1,2 = 1,68 \, m^2$ $\quad T_4(0,7; 0,6)$

$\Sigma F = 11,78 \, m^2$

$X_T = \frac{1,9 \cdot 6 + 2,304 \cdot 1,08 + 1,8 \cdot 2,6 + 0,7 \cdot 1,68}{11,78} = 1,68 \, m$

$Y_T = \frac{6 \cdot 3 + 2,304 \cdot 2,8 + 1,8 \cdot 2 + 1,68 \cdot 0,6}{11,78} = 2,47 \, m$

$W = \gamma_b \cdot \Sigma F_i = 24 \cdot 11,78 = 282,72 \, kN$

$N = 282,72 + 153,25 = 435,97 \, kN/m$

$T = E_{aH} = 45,98 \, kN/m$

$F_K = \frac{435,97 \, tg 32°}{45,98} = 5,92 \geq 1,5$

$$M = -45,98 \cdot 2,2 + 282,72 \cdot 0,18 + 153,25 \cdot 1,38 = 161,2186 \text{ kNm}$$

$$e = \frac{M}{N} = \frac{161,2186}{435,97} = 0,37 < 0,5 = \frac{B}{6}$$

$$C = \frac{B}{2} - e = 1,5 - 0,37 = 1,13$$

$$\sigma_{1,2} = \frac{N}{F} \pm \frac{M}{W}$$

$$F = B \cdot 1 = 3 \text{ m}^2$$

$$W = \frac{B^2 \cdot 1}{6} = \frac{3^2}{6} = \frac{9}{6} = 1,5 \text{ m}^2$$

$$\sigma_{1,2} = \frac{435,97}{3} \pm \frac{161,2186}{1,5} = 145,323 \pm 107,48 \Rightarrow \sigma_1 = 252,803 \text{ kN/m}^2$$

$$\sigma_2 = 37,844 \text{ kN/m}^2$$

- контрола носивости

$$B'' = 2C = 2 \cdot 1,13 = 2,26 \text{ m}$$

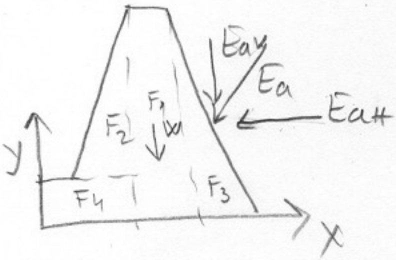
$$\sigma = \frac{N}{B''} = \frac{435,97}{2,26} = 192,91 \text{ kPa}$$

ЗАДАТАК 4.1.

$E_a = 160$ kN/m

$E_{aH} = 160 \cdot \cos 27° = 142,56$ kN/m

$E_{aV} = 160 \cdot \sin 27° = 72,64$ kN/m



$T = E_{aH} = 142,56$ kN/m

$N = W + E_{aV} = 282,72 + 72,64 = 355,36$

$W = \gamma_b \cdot \Sigma F_i = 287,72$

$$F_K = \frac{N \cdot tg\phi'}{T} = \frac{355,36 \cdot tg\,32°}{142,56} = 1,56 > 1,5$$

$$M = +142,56 \cdot 2,2 - 282,72 \cdot 0,18 - 72,64 \cdot 1,38 = 162,5 \text{ kNm}$$

$$e = \frac{M}{N} = \frac{162,5}{355,36} = 0,46 < 0,5 = \frac{B}{6}$$

$$c = \frac{B}{2} - e = 1,5 - 0,46 = 1,04$$

$$\sigma_{1,2} = \frac{N}{F} \pm \frac{M}{W}$$

$$F = B \cdot 1 = 3 \text{ m}^2$$

$$W = \frac{B^2 \cdot 1}{6} = \frac{3^2}{6} = 1,5 \text{ m}^2$$

$$\sigma_{1,2} = \frac{355,36}{3} \pm \frac{162,5}{1,5} = 118,45 \pm 108,33 \Rightarrow$$

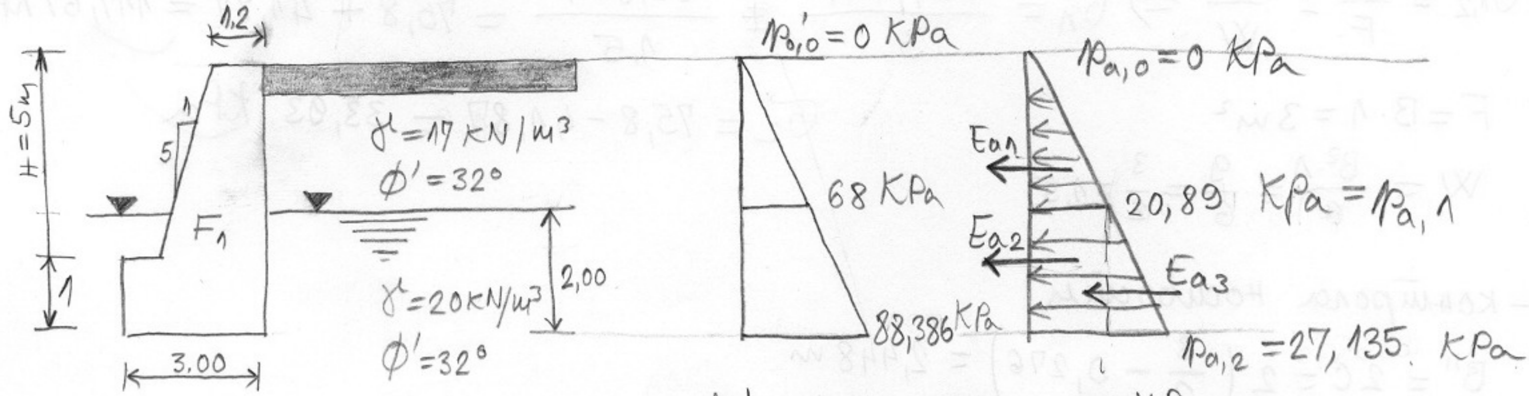
$\sigma_1 = 226,78$ kN/m²

$\sigma_2 = 10,12$ kN/m²

-контрола носивости

$$B'' = 2c = 2 \cdot 1,04 = 2,08 \text{ m}$$

$$\sigma = \frac{N}{B''} = \frac{355,36}{2,08} = 170,85 \text{ kPa}$$



$\gamma_2' = \gamma_2 - \gamma_w$ $\quad p_{o,1}' = \gamma_1 \cdot h_1 = 17 \cdot 4 = 68 \text{ KPa}$

$\gamma_2' = 10{,}193 \frac{kN}{m^3}$ $\quad p_{o,2}' = \gamma_2' \cdot h_2 + p_{o1}' = 88{,}386 \text{ KPa}$

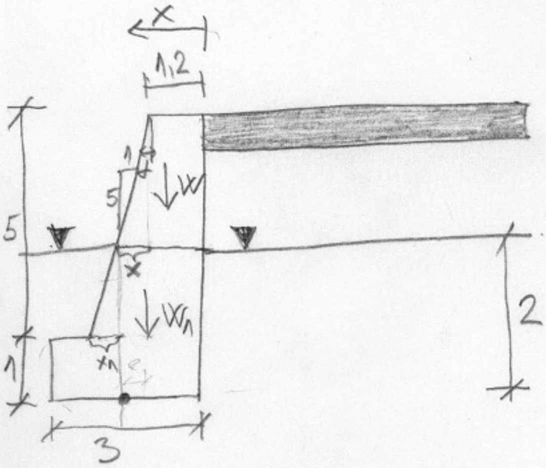
$$K_{a1} = tg^2\left(45 - \frac{\phi_1}{2}\right) = tg^2\left(45^\circ - \frac{32^\circ}{2}\right) = 0{,}307$$

$E_{a1} = \frac{1}{2} \cdot 20{,}89 \cdot 4 = 41{,}78 \text{ KN/m}$ $\qquad z_{T1} = 2 + \frac{1}{3} 4 = 3{,}3\dot{3} \text{ m}$

$E_{a2} = 2 \cdot 20{,}89 = 41{,}78 \text{ KN/m}$ $\qquad z_{T2} = \frac{1}{2} 2 = 1 \text{ m}$

$E_{a3} = \frac{1}{2} 2 \cdot (27{,}135 - 20{,}89) = 6{,}24 \text{ KN/m}$ $\qquad z_{T3} = \frac{1}{3} 2 = 0{,}67 \text{ m}$

$$E_a = \sum E_{ai} = E_{a1} + E_{a2} + E_{a3} = 89{,}8 \text{ KN/m}$$



$W = \gamma_B \cdot A = 24 \cdot \frac{1{,}2 + 2}{2} \cdot 4 = 153{,}6 \text{ KN/m}$

$W_1 = (\gamma_B - \gamma_w) \cdot A = (24 - 9{,}807)\left[2 \cdot 2 + 1 \cdot 1 + 0{,}2 \cdot 1\right]$

$W_1 = 73{,}804 \text{ KN/m}$

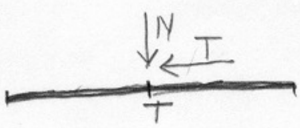
$$x_T = \frac{1{,}2 \cdot 4 \cdot 0{,}6 + \frac{1}{2} \cdot 4 \cdot 0{,}8 \cdot \left(\frac{0{,}8}{3} + 1{,}2\right)}{1{,}2 \cdot 4 + \frac{1}{2} 4 \cdot 0{,}8} = \frac{5{,}227}{6{,}4} = 0{,}8 \text{ m}$$

$$x_{T1} = \frac{2 \cdot 2 \cdot 1 + 1 \cdot 1 \cdot 2{,}5 + 0{,}2 \cdot 0{,}5 \cdot 1 \cdot \left(\frac{0{,}2}{3} + 2\right)}{4 + 1 + 0{,}2 \cdot 0{,}5 \cdot 1} = \frac{6{,}707}{5{,}1}$$

$tg\alpha = \frac{1}{5} \Rightarrow \frac{x}{4} = \frac{1}{5} \Rightarrow x = \frac{4}{5} = 0{,}8 \text{ m}$ $\qquad x_{T1} = 1{,}3 \text{ m}$

$\frac{x_1}{1} = \frac{1}{5} \Rightarrow x_1 = \frac{1}{5} = 0{,}2 \text{ m}$ $\qquad e = 1{,}5 - 0{,}8 = 0{,}7 \text{ m}$

$e_1 = 1{,}5 - 1{,}3 = 0{,}2 \text{ m}$



$N = W + W_1 = 227{,}404 \text{ KN/m}$

$T = E_a = 89{,}8 \text{ KN/m}$

$$F_K = \frac{N \cdot tg\phi'}{T} = \frac{227{,}404 \cdot tg 32^\circ}{89{,}8} = 1{,}58 > 1{,}5$$ $\Rightarrow$ испуњен услов сигурности против клизања

$$M = -153{,}6 \cdot 0{,}7 - 73{,}804 \cdot 0{,}2 + 41{,}78 \cdot 3{,}\dot{3} + 41{,}78 \cdot 1 + 6{,}24 \cdot 0{,}67 = 62{,}807 \text{ KNm}$$

$$e = \frac{M}{N} = \frac{62{,}807}{227{,}404} = 0{,}276 < \frac{B}{6} = 0{,}5$$

$$\sigma_{1,2} = \frac{N}{F} \pm \frac{M}{W} \Rightarrow \sigma_1 = \frac{227{,}404}{3} + \frac{62{,}807}{1{,}5} = 75{,}8 + 41{,}87 = 117{,}67\ KPa$$

$$F = B \cdot 1 = 3\,m^2$$

$$\sigma_2 = 75{,}8 - 41{,}87 = 33{,}93\ KPa$$

$$W = \frac{B^2 \cdot 1}{6} = \frac{9}{6} = \frac{3}{2} = 1{,}5$$

- контрола носивости

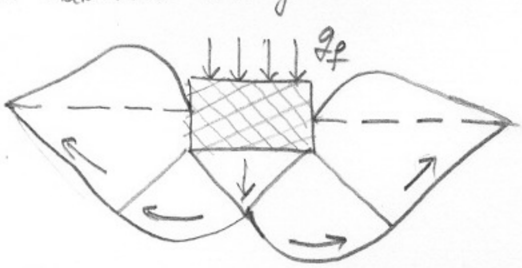
$$B'' = 2C = 2\left(\frac{3}{2} - 0{,}276\right) = 2{,}448\ m$$

$$\sigma = \frac{N}{B''} = \frac{227{,}404}{2{,}448} = 92{,}8\ KPa$$

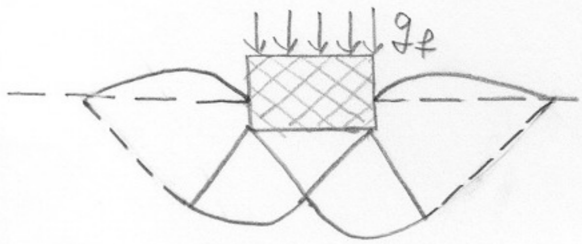
Носивост тла

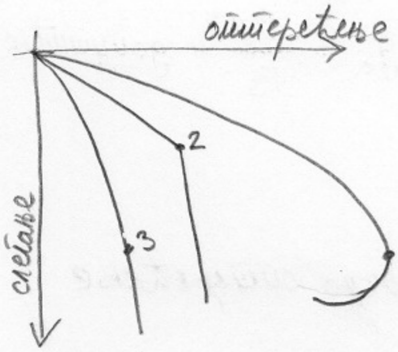
- најмање оптерећење које изазива лом тла - гранична носивост тла

1. општи смичући лом (карактеристичан за збијене пескове)

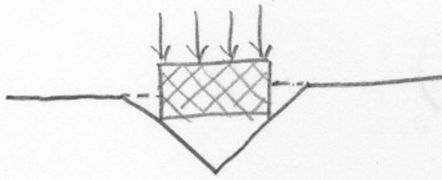


2. Локални лом (средње збијени пескови)



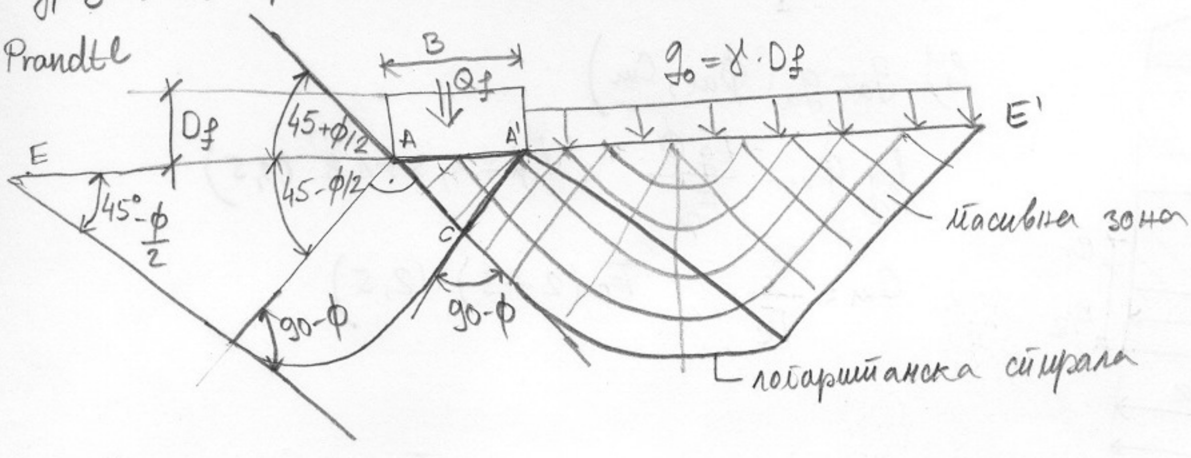


3. пробојно смицање



Одређивање граничне носивости

Prandtl



$$q_f = c \cdot N_c + q_0 \cdot N_q$$

$$N_q = \tan^2(45+\phi/2)\, e^{\pi \tan\phi}$$

$$N_c = (N_q - 1)\, ctg\,\phi$$

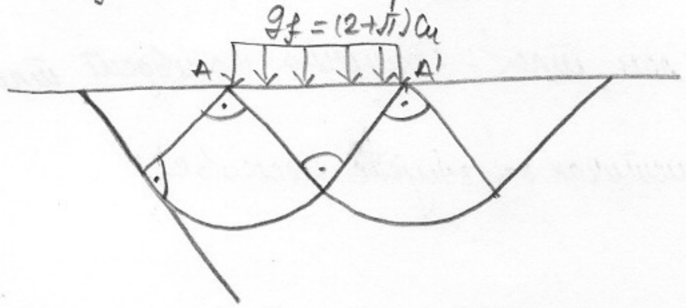
Hansen $N_\gamma = 1{,}8(N_q - 1)\, tg\,\phi$

Tercagi: $q_f = \frac{1}{2}\gamma B N_\gamma + c N_c + \gamma D_f \cdot N_q$

$c_0 = 0 \quad q_0 = 0 \rightarrow q_f = 0$

$$q_f = \frac{1}{2}\gamma B \cdot N_\gamma$$

$\phi_u = 0$ $\tau_f = c_u \rightarrow$ тачно решење



$45 + \frac{\phi}{2}$, $45 - \frac{\phi}{2}$ $\} \rightarrow 45°$

$N_c = 2 + \pi$

$q_f = (2+\pi) \cdot c_u = 5,14\, c_u$

$c_u = \frac{q_u}{2} \Rightarrow q_f = 2,57\, q_u$

$F_S = 2,57 \Rightarrow q_u \approx q_a = \frac{q_f}{F_S}$ – допуштено оптерећење

Skempton

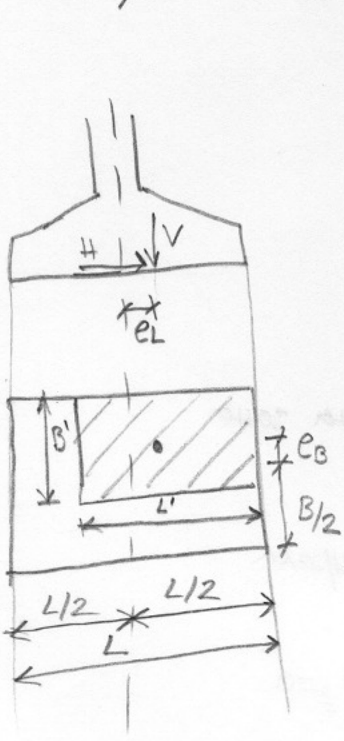
$q_f = c_u N_c + \gamma D_f$

Косо и ексцентрично оптерећење

Hansen:

$q_f = 0,5 \gamma \cdot B\, N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma + c \cdot N_c \cdot s_c \cdot d_c \cdot i_c + \gamma D_f N_q\, s_q\, d_q\, i_q$

$i_{c,\gamma,q} = i(\phi, \delta)$ $\quad s_{c,\gamma,q} = s(B/L)$ $\quad d_{c,\gamma,q} = d(D_f/B, \phi)$



– дозвољена носивост

a) $q_a = \frac{q_f}{F_S}$ (гранична равнотежа) $F_S = 2 \div 3$

b) $q_a = q_a(\phi_m, c_m)$

$tg\, \phi_m = \frac{tg\, \phi}{F_\phi}$ $\quad F_\phi = 1,3 \div 1,8$ (1,5)

$c_m = \frac{c}{F_c}$ $\quad F_c\, (2 \div 3)$ (2,5)

Задатак.

$B = ?$ слика 1. (стр 2.)

$H=0;\ X=0,\ i_c = i_\gamma = 1$

a) $tg\,\Phi_m = \frac{tg\phi}{F_\phi} \Rightarrow \Phi_m \Rightarrow N_c, N_\gamma$ (очитавано са дијаграма)

$c_m = \frac{c}{(F_c)_{1,6}}$, S_c, S_γ (стр 1.) $(L' = L,\ B' = B)$ $\quad g_o' = \gamma' \cdot D_f$

b) пп. $B_I = 1m$

$d_c = 1 + 0{,}35 \frac{D_f}{B} \leq 1{,}35$ (ако добијено већу вредност усвојано 1,35)

$g_{aI} = \ldots$

c) $A_{II} = \frac{V}{g_{aI}} \Rightarrow B_{II} = \sqrt{\frac{A_{II}}{(L/B)}}$

$|B_{II} - B_I| < 0{,}05$ — не (← назад на b)

⇓ да $(B = B_{II})$ B се заокружује на dm

L

слика 2. (стр.2)

дато R, δ, e_B, e_L

$V = R\cos\delta$

$H = R\sin\delta$

$g_o' = \gamma' D_f$

$\gamma' = \gamma_z - \gamma_w$

$X = \frac{H}{A' c_m + V\,tg\,\Phi_m} \rightarrow i_c, i_\gamma$ (дијаг. стр.3)

$d_c = 1 + 0{,}35 \frac{D_f}{B'} < 1{,}35$

$N_c, N_\gamma, S_c, S_\gamma$ остаје исто

пп. $B_I' = 1m\ (2m)$

$A_I' = B_I'^2 \left(\frac{L}{B}\right)'$ $\qquad \left(\frac{L}{B}\right)' = \frac{L}{B}$

рачунано

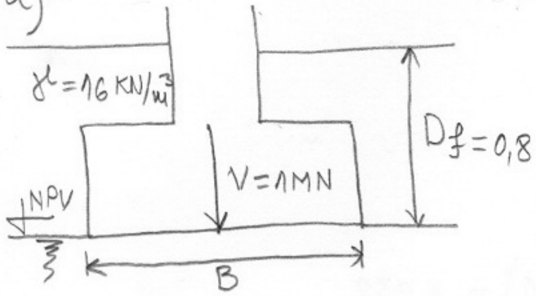
$d_c, X, i_c, i_\gamma, g_{aI} \Rightarrow A_{II}' = \frac{V}{g_{aI}}$ $\quad B_{II}' = \sqrt{\frac{A_{II}'}{(L/B)'}}$ $\quad |B_{II} - B_I| < 0{,}05$

коначне димензије темеља

$A' = L' \cdot B' = (L - 2e_L)\cdot(B - 2e_B) = \left(\frac{L}{B}\cdot B - 2e_L\right)(B - 2e_B) \Rightarrow B\ (\text{и } L)$

ЗАДАТАК 4.1:

a)



$\gamma_z = 17\,kN/m^3$

$\phi' = 30°$

$c' = 4\,kN/m^2$

$\frac{L}{B} = 2$

$N_c = 16,15$ } (са дијаграма)

$N_\gamma = 4,25$

a) $tg\,\phi_m = \frac{tg\,\phi}{F_\phi} = \frac{tg\,30°}{1,5} \Rightarrow \phi_m = 21,05°$

$c_m = \frac{c}{F_c} = \frac{4}{2,5} = 1,6$

$s_c = 1 + 0,2\,\frac{B'}{L'} = 1 + 0,2 \cdot \frac{1}{2} = 1,1$ $\quad L' = L$

$s_\gamma = 1 - 0,4\,\frac{B'}{L'} = 1 - 0,4\,\frac{1}{2} = 0,8$ $\quad B' = B$

$q_0' = \gamma \cdot D_f = 16 \cdot 0,8 = 12,8\,kN/m^2$

в) пп. $B_I = 1m$

$d_c = 1 + 0,35\,\frac{D_f}{B} = 1 + 0,35 \cdot \frac{0,8}{1} = 1,28 < 1,35$ $\quad \gamma' = \gamma_z - \gamma_w = 17 - 9,807 = 7,193\,kN/m^3$

$q_{aI} = \frac{\gamma'}{2} B' N_\gamma s_\gamma i_\gamma + (c_m + q_0\,tg\,\phi_m) N_c s_c i_c d_c + q_0$ (with $i_\gamma = 1$, $i_c = 1$)

$q_{aI} = \frac{7,193}{2} \cdot 1 \cdot 4,25 \cdot 0,8 + (1,6 + 12,8 \cdot 0,385) \cdot 16,15 \cdot 1,1 \cdot 1,28 + 12,8 = 191,19\,kN/m^2$

$A_{II} = \frac{V}{q_{aI}} = \frac{1 \cdot 10^3}{191,19} = 5,23$ $\quad B_{II} = \sqrt{\frac{A_{II}}{(L/B)}} = \sqrt{\frac{5,23}{2}} = 1,617$ $\quad |B_{II} - B_I| = 0,617 > 0,05$

$d_{cII} = 1 + 0,35\,\frac{0,8}{1,617} = 1,173$

$q_{aII} = \frac{7,193}{2} \cdot 1,617 \cdot 4,25 \cdot 0,8 + (1,6 + 12,8 \cdot 0,385) \cdot 16,15 \cdot 1,1 \cdot 1,173 + 12,8 = 168,606\,kN/m^2$

$A_{III} = \frac{1 \cdot 10^3}{168,606} = 5,931$ $\quad B_{III} = \sqrt{\frac{5,931}{2}} = 1,722$ $\quad |B_{III} - B_{II}| = 0,105 > 0,05$

$d_{cIII} = 1 + 0,35\,\frac{0,8}{1,722} = 1,163$

$q_{aIII} = \frac{7,193}{2} \cdot 1,722 \cdot 4,25 \cdot 0,8 + (1,6 + 12,8 \cdot 0,385) \cdot 16,15 \cdot 1,1 \cdot 1,163 + 12,8 = 168,73\,kN/m^2$

$A_{IV} = \frac{1 \cdot 10^3}{168,73} = 5,927$ $\quad B_{IV} = \sqrt{\frac{5,927}{2}} = 1,721$ $\quad |B_{IV} - B_{III}| = 0,001 < 0,05$

$\Downarrow$

$L = 2B = 2 \cdot 1,8 = 3,6\,m$ $\quad B = B_{IV} = 1,8\,m$

$q = \frac{1 \cdot 10^3}{3,6 \cdot 1,8} = 154,321\,kN/m^2$

$q_a(E_c) = 0,5\gamma' B \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma + c' \cdot N_c s_c i_c + q' \cdot N_q \cdot s_q \cdot i_q$

$c' = c_m = \frac{c}{F_c} = \frac{4}{1,6} = 2,5$

$F_\phi = 1,25$

$F_c = 1,6$

$tg\,\phi_m = \frac{tg\,30^\circ}{1,25} = 0,462 \Rightarrow \phi_m = 24,79^\circ$

$S_\gamma = 1 - 0,3\,\frac{B'}{L'} = 1 - 0,3 \cdot \frac{1}{2} = 0,85$ $\qquad S_c = (S_q \cdot N_q - 1)/(N_q - 1) = 1,232$

$S_q = 1 + \frac{1}{2}\sin 24,79^\circ = 1,21$

$N_q = tg^2\left(45 + \frac{24,79}{2}\right) \cdot e^{\pi\,tg\,24,79} = 10,44$

$N_c = (N_q - 1)\,ctg\,\phi = 20,433$

$N_\gamma = 2 \cdot (N_q - 1)\,tg\,\phi = 8,722$

$q_a(E_c) = 0,5 \cdot 7,193 \cdot 1,8 \cdot 8,722 \cdot 0,85 + 2,5 \cdot 20,433 \cdot 1,232 + 12,8 \cdot 10,44 \cdot 1,21 = 272,622\ KPa$

4.2. $q_0' = \gamma' \cdot D_f = (\gamma_z - \gamma_w) \cdot D_f = 7,193 \cdot 0,8 = 5,754\ kN/m^2$

$R = 1MN$

$V = R\cos\delta = 0,98 \cdot 10^3\ KN$

$H = R\sin\delta = 0,17 \cdot 10^3\ KN$

$\gamma_z = 17\ KN/m^2$

$\phi' = 30^\circ$

$C' = 4\ KN/m^2$

$\frac{L}{B} = 2$

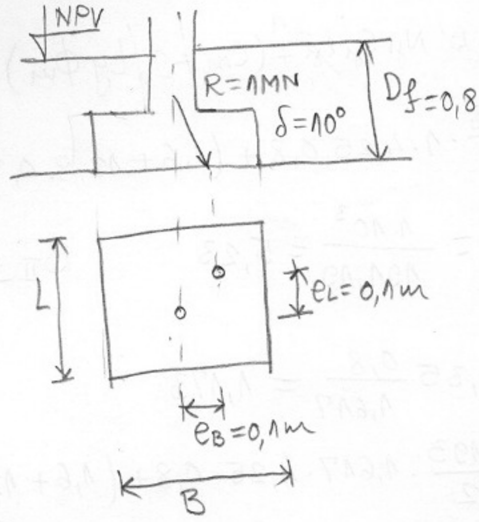
$N_\gamma = 4,25$

$N_c = 16,15$

$S_c = 1,1$

$S_\gamma = 0,8$

$c_m = 1,6$



$X = \frac{H}{A' c_m + V\,tg\,\phi_m}$

пп. $B' = 2m$

$A_I' = B_I'^2 \cdot \left(\frac{L}{B}\right)' = 4 \cdot 2 = 8$ $\qquad X = \frac{0,17 \cdot 10^3}{8 \cdot 1,6 + 0,98 \cdot 10^3 \cdot 0,385} = 0,456$

$d_{cI} = 1 + 0,35\,\frac{0,8}{2} = 1,14$

$i_c = 0,9 \qquad i_\gamma = 0,82$ (са дијаграма)

$q_{aI} = \frac{7,193}{2} \cdot 2 \cdot 4,25 \cdot 0,8 \cdot 0,82 + (1,6 + 5,754 \cdot 0,385) \cdot 16,15 \cdot 1,1 \cdot 0,9 \cdot 1,14 = 89,595$

$A_{II}' = \frac{1 \cdot 10^3}{89,595} = 11,161 \Rightarrow B_{II}' = \sqrt{\frac{11,161}{2}} = 2,362 \qquad |B_{II}' - B_I'| = 0,362 > 0,05$

$A_{III}' = 2,362^2 \cdot 2 = 11,158 \qquad d_{cII} = 1 + 0,35\,\frac{0,8}{2,362} = 1,119 \qquad X = \frac{0,17 \cdot 10^3}{11,158 \cdot 1,6 + 0,98 \cdot 10^3 \cdot 0,385} = 0,43$

$i_c = 0{,}73 \qquad i_\gamma = 0{,}57$

$q_{a\,II} = \frac{7{,}193}{2} \cdot 2{,}362 \cdot 4{,}25 \cdot 0{,}8 \cdot 0{,}57 + (1{,}6 + 5{,}754 \cdot 0{,}385) \cdot 16{,}15 \cdot 1{,}1 \cdot 0{,}73 \cdot 1{,}119 = 71{,}83 \ \text{kN/m}^2$

$A'_{III} = \frac{10^3}{71{,}83} = 13{,}92 \Rightarrow B'_{III} = \sqrt{\frac{13{,}92}{2}} = 2{,}638 \qquad |B'_{III} - B'_{II}| = 0{,}276 > 0{,}05$

$A'_{IV} = 2{,}638^2 \cdot 2 = 13{,}918 \qquad d_{c\,III} = 1 + 0{,}35 \frac{0{,}8}{2{,}638} = 1{,}106 \qquad x = \frac{0{,}17 \cdot 10^3}{13{,}918 \cdot 1{,}6 + 0{,}98 \cdot 10^3 \cdot 0{,}385} = 0{,}425$

$i_c = 0{,}74 \qquad i_\gamma = 0{,}58$

$q_{a\,III} = \frac{7{,}193}{2} \cdot 2{,}638 \cdot 4{,}25 \cdot 0{,}8 \cdot 0{,}58 + (1{,}6 + 5{,}754 \cdot 0{,}385) \cdot 16{,}15 \cdot 1{,}1 \cdot 0{,}74 \cdot 1{,}106 = 74{,}182 \ \text{kN/m}^2$

$A'_{IV} = \frac{10^3}{74{,}182} = 13{,}48 \Rightarrow B'_{IV} = \sqrt{\frac{13{,}48}{2}} = 2{,}596 \qquad |B_{IV} - B_{III}| = 0{,}04 < 0{,}05 \Rightarrow B' = B_{IV}$

$B' = 2{,}596$

$13{,}48 = (B - 2e_B)\left(\frac{L}{B} \cdot B - e_L\right)$

$13{,}48 = (B - 2 \cdot 0{,}1)(2 \cdot B - 0{,}3)$

$13{,}48 = (B - 0{,}2)(2B - 0{,}3) = 2B^2 - 0{,}3B - 0{,}4B + 0{,}06 = 2B^2 - 0{,}7B + 0{,}06 = 13{,}48$

$2B^2 - 0{,}7B - 13{,}42 = 0$

$B_{1,2} = \frac{0{,}7 \pm \sqrt{0{,}49 + 107{,}36}}{4} = \frac{0{,}7 \pm 10{,}385}{4} \Rightarrow$ **$B = 2{,}8\ m$, $L = 2B = 5{,}6\ m$**

EC: $N_q = 10{,}44 \qquad s_c = 1{,}232$

$N_c = 20{,}433 \qquad s_\gamma = 0{,}85$

$N_\gamma = 8{,}722 \qquad s_q = 1{,}21$

$m = m_B = (2 + B'/L') / (1 + \frac{B'}{L'}) = (2 + 0{,}5) / (1 + 0{,}5) = 1{,}6\dot{6}$

$i_\gamma = [1 - H/(V + A'c' \,\text{ctg}\,\phi')]^{m+1} = \left[1 - \frac{0{,}17 \cdot 10^3}{0{,}98 \cdot 10^3 + 13{,}48 \cdot 2{,}5\ \text{ctg}\ 24{,}79°}\right]^{2{,}6\dot{6}} = 0{,}625$

$i_q = [1 - H/(V + A'c' \,\text{ctg}\,\phi')]^{m} = \left[1 - \frac{0{,}17 \cdot 10^3}{0{,}98 \cdot 10^3 + 13{,}48 \cdot 2{,}5 \cdot \text{ctg}\ 24{,}79°}\right]^{1{,}6\dot{6}} = 0{,}746$

$i_c = i_q - (1 - i_q)/N_c \,\text{tg}\,\phi' = 0{,}746 - \frac{1 - 0{,}746}{20{,}433 \cdot \text{tg}\ 24{,}79°} = 0{,}719$

$\sigma_0' = \delta' \cdot D_f$

$q_a(E_c) = 0{,}5 \cdot 7{,}193 \cdot 2{,}8 \cdot 8{,}722 \cdot 0{,}85 \cdot 0{,}625 + 2{,}5 \cdot 20{,}433 \cdot 1{,}232 \cdot 0{,}719 + 12{,}8 \cdot 10{,}44 \cdot 1{,}21 \cdot 0{,}746$ (B' written above the circled 2,8)

$q_a(E_c) = 212{,}535\ \text{KPa}$

Tabela 1. **Opšti podaci**

PODACI		LAMELE 1	2	3	4	5	6	7	8	SUMA
1	b	2	1,95	0,65	1,7	1,7	2	1,5		
2	h_1	3	3	2,5	1,5	0,5				
3	h_2		0,3	1,2	2,1	2,5	2	1,3		
4	h_3									
5	γ_1	18	18	18	18	18				
6	γ_2		9,193	9,193	9,193	9,193	9,193	9,193		
7	γ_3									
8	u									
9	sin α	0,819	0,669	0,53	0,326	0,139	-0,061	-0,25		
10	c'	10	10	10	10	10	10	10		
11	tanφ'	0,488	0,466	0,466	0,466	0,466	0,466	0,466		
12	$h_1 \gamma_1 b$	108	105,3	29,25	45,9	15,3				
13	$h_2 \gamma_2 b$		5,378	7,171	32,819	39,07	36,772	17,926		
14	$h_3 \gamma_3 b$									
15	$W=\sum_{i=1}^{n} h_i \gamma_i b$	108	110,678	36,421	78,719	54,37	36,772	17,926		
16	W sin α	88,452	74,044	19,303	25,662	7,557	-2,243	-4,482		208,293

Tabela 2. **Proračun po Fellenius-u**

PODACI		LAMELE 1	2	3	4	5	6	7	8	SUMA	F_s
1	cos α	0,574	0,743	0,848	0,946	0,99	0,998	0,968			
2	W cos α	61,992	82,234	[illegible]385	74,468	53,83	36,698	17,352			
3	l = b/cos α	3,484	2,624	0,766	1,797	1,717	2,004	1,55			
4	ul										
5	W cos α - ul	61,992	82,234	30,885	74,468	53,83	36,698	17,359			
6	(W cos α - ul) tanφ'	30,252	38,321	14,392	34,702	25,085	17,101	8,089			
7	c'l	34,84	26,24	7,66	17,97	17,17	20,04	15,5			
8	c'l + (W cos α - ul) tanφ'	65,092	64,561	22,052	52,672	42,255	37,141	23,589		307,362	1,476

$$F_s = \frac{\sum c'l + (W\cos\alpha - ul)\tan\phi'}{\sum W\sin\alpha}$$

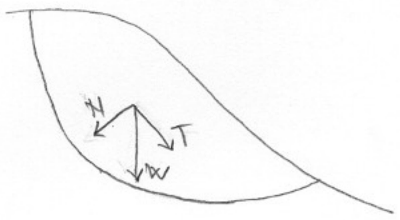
Tabela 3. **Proračun po Bishop-u**

PODACI		LAMELE 1	2	3	4	5	6	7	8	SUMA	F_s
1	c'b	20	19,5	6,5	17	17	20	15			
2	ub										
3	W-ub	108	110,678	36,421	78,719	54,37	36,772	17,926			
4	(W-ub)tanφ'	52,704	51,576	16,972	36,683	25,336	17,136	8,353			
5	c'b+(W-ub)tanφ'	72,704	71,076	23,472	53,683	42,336	37,136	23,353			
6	cos α + tanφ' sin α / F_s	0,845	0,954	1,015	1,049	1,034	0,97	0,889			
7	5/6	86,04	74,503	23,125	51,175	40,944	38,285	26,269		340,34	1,634
8	cos α + tanφ' sin α / F_s	0,819	0,934	0,999	1,039	1,03	0,981	0,897			
9	5/8	88,772	76,099	23,495	51,668	41,103	37,855	26,035		345,027	1,656
10	cos α + tanφ' sin α / F_s	0,815	0,931	0,997	1,038	1,029	0,981	0,898			
11	5/10	89,207	76,344	23,543	51,718	41,143	37,855	26,006		345,816	1,66

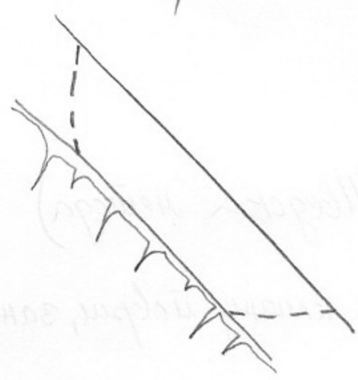
$F_s = 1,7$

$$F_s = \frac{1}{\sum W\sin\alpha} \sum (c'b + (W-ub)\tan\phi') \frac{1}{\cos\alpha + \tan\phi'\sin\alpha / F_s}$$

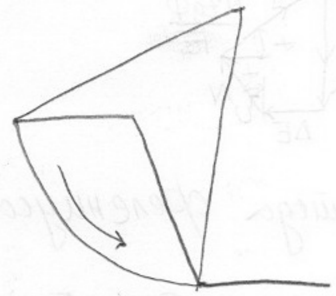
Стабилност косина



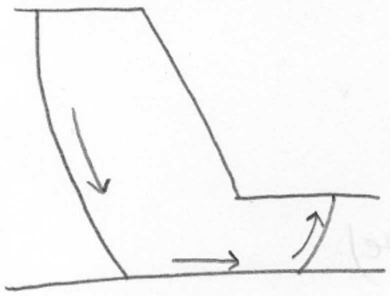
1. Планарне клизне површи

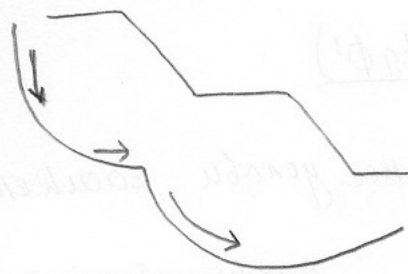


2. Кружно-цилиндричне клизне површи



3. Сложене клизне површи



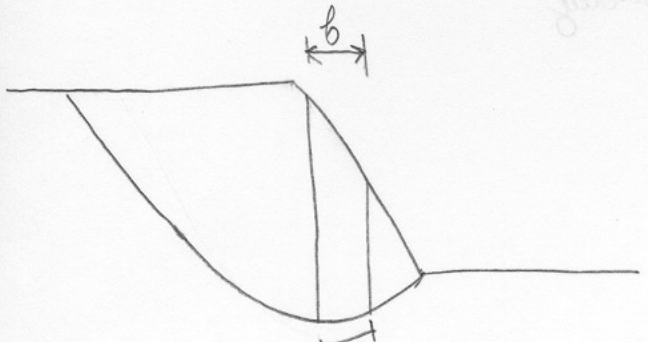


* Методе прорачуна стабилности косина

$F_S = \frac{\tau_f}{\tau_m}$ → мобилисана чврстоћа

↓ фактор стабилности

- разликујемо тачне и приближне методе



l → дужина ламеле мерена у правцу клизне површи

$$F_S = \frac{\tau_f \,(l\cdot 1)}{\tau_m \,(l\cdot 1)}$$

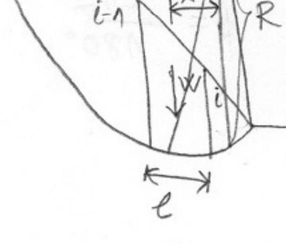
$F_S = \frac{S}{T}$ → S укупна расположива сила, T → смичуће силе у основи

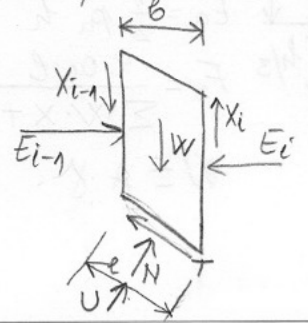
$$S = \tau_f \cdot l = (\sigma_n' \cdot tg\,\phi' + c')\cdot l$$

$$S = N'\,tg\,\phi' + c'l$$

$$\boxed{F_S = \frac{N'\,tg\,\phi' + c'l}{T}}$$ - општи израз за фактор сигурности

* Кружно-цилиндричне клизне површи





$$\tau_m = \frac{\tau_f}{F_S} = \frac{c' + (\sigma_n - u)\,tg\,\phi'}{F_S}$$

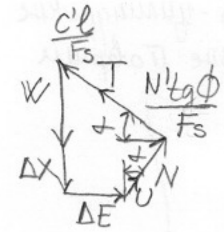
$$T = \tau_m \cdot 1 \cdot l = \frac{1}{F_S}\left(c'l + (N - ul)\,tg\,\phi'\right)$$

$$\Sigma M_O = 0$$

$$\Sigma W \cdot x = \Sigma T \cdot R = \frac{R}{F_S}\Sigma\left(c'l + (N - ul)\,tg\,\phi'\right)$$

$$F_S = \frac{R\,\Sigma\,(c'l + (N-ul)\,tg\,\phi')}{\Sigma W \cdot x} = \frac{\Sigma\,(c'l + (N-ul)\,tg\,\phi')}{\Sigma W \cdot \sin\alpha}$$

$x \rightarrow R\sin\alpha$



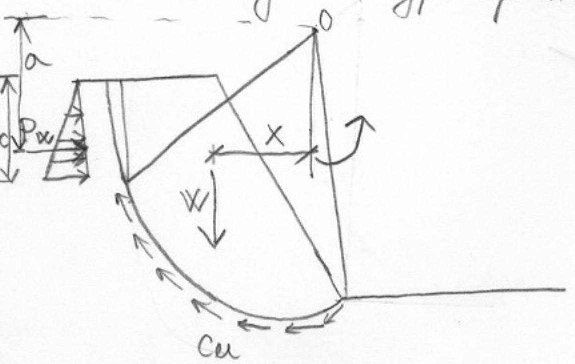
1. Метода Фелениуса (Шведска метода)

Све силе се пројектују на клизну површ, занемаре се међуламелне силе

$\Rightarrow N = W \cdot \cos\alpha$

$$F_S = \frac{\Sigma\,(c'l + (W\cos\alpha - ul)\,tg\,\phi')}{\Sigma W \sin\alpha}$$

2. „$\Phi_u = 0$" метода (недренирани услови, засићене глине)



фактор сигурности = повољни услови / неповољни (моменат)

$$F_S = \frac{R\,\Sigma c_u \cdot l\,(\cdot 1)}{\Sigma W \cdot x}$$

$$F_S = \frac{R \cdot \Sigma c_u \cdot l}{\Sigma W \cdot x + P_W \cdot a} = \left(\frac{M_{PS}}{M_{HS}}\right)$$

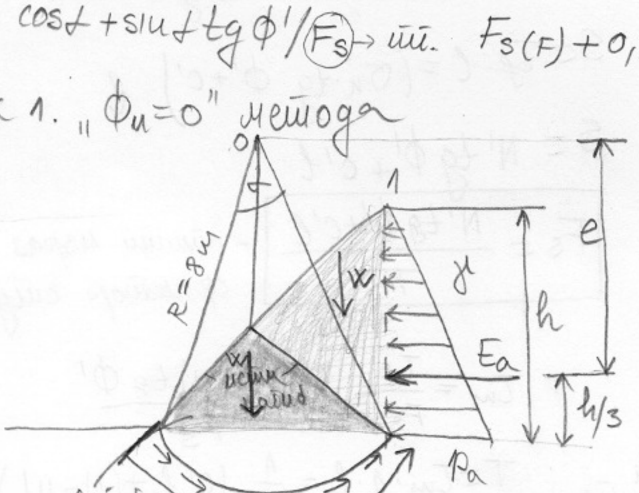
3. Метода Бишопа

Ако се силе пројектују на вертикални правац

$$F_S = \frac{\Sigma\, c'b + (W - ub)\,tg\,\phi')\cdot m_\alpha}{\Sigma W \sin\alpha}$$

$$m_\alpha = \frac{1}{\cos\alpha + \sin\alpha\, tg\,\phi' / F_S}$$ $\rightarrow$ пт. $F_S(F) + 0{,}2$

Задатак 1. „$\Phi_u = 0$" метода



$p_a = \gamma \cdot h \cdot K_a$

$K_a = tg^2\left(45° - \frac{\phi'}{2}\right)$

$E_a = \frac{1}{2}\, p_a \cdot h$

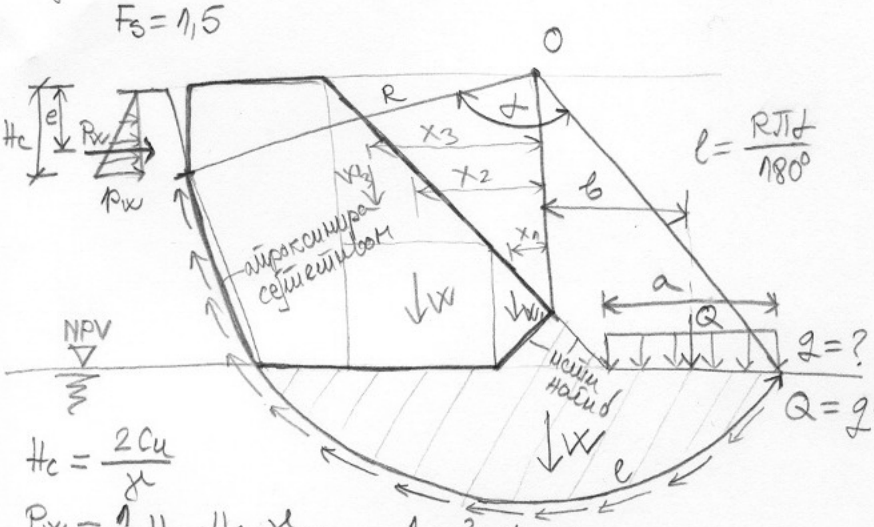
$$F_S = \frac{R \cdot c_u \cdot l}{\Sigma W \cdot x + E_a \cdot e}$$

$W = A \cdot \gamma$

$$l = \frac{R\pi\alpha}{180°}$$

овај блок може да се занемари јер не даје момент око центра ротације задатак 2.

$F_S = 1,5$



$$F_S = \frac{C_u \cdot l \cdot R}{\Sigma W \cdot x + P_w \cdot e - Q \cdot b}$$

$$l = \frac{R \pi \alpha}{180^\circ}$$

$\Downarrow$

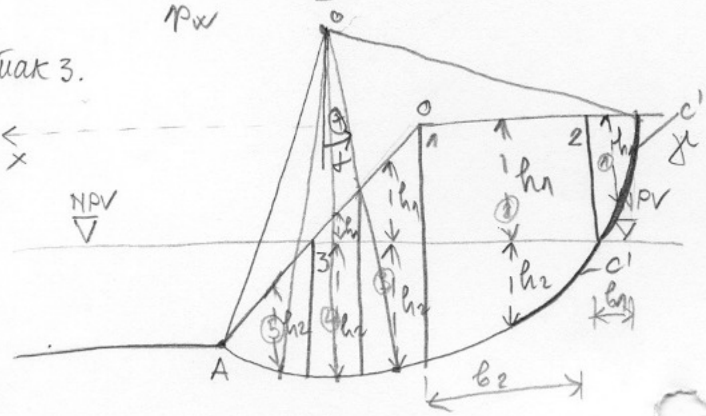
$Q \Rightarrow q$

$$H_c = \frac{2 C_u}{\gamma}$$

$$P_w = \frac{1}{2} H_c \cdot \underbrace{H_c \cdot \gamma_w}_{p_w} = \frac{1}{2} H_c^2 \cdot \gamma_w$$

задатак 3.

а) ← x



– ламеле ширине не више од 2÷2,5 m
– граница ламела на границама слојева
– једна граница на почетку косине
– на месту промене запреминске тежине (појаве воде

поделимо тело на ламеле па онда попуњавамо табеле

одредимо ширину сваке ламеле и пот. 1. врсту (у хоризонт. правцу b_i)

h_1 – висина (мери се у средини сваке ламеле) изнад воде

h_2 – висина испод воде до клизне површи (у средини ширине)

h_3 – случај (A) нема h_3

$\gamma_1 \rightarrow$ одговара h_1 запреминска тежина изнад вод ($\gamma_1 = \gamma$)

$\gamma_2 \rightarrow$ одговара h_2 $\gamma_2 = \gamma' = \gamma_z - \gamma_w$

$\gamma_3 \rightarrow$ нема под (A)

$u \rightarrow$ нема под (A)

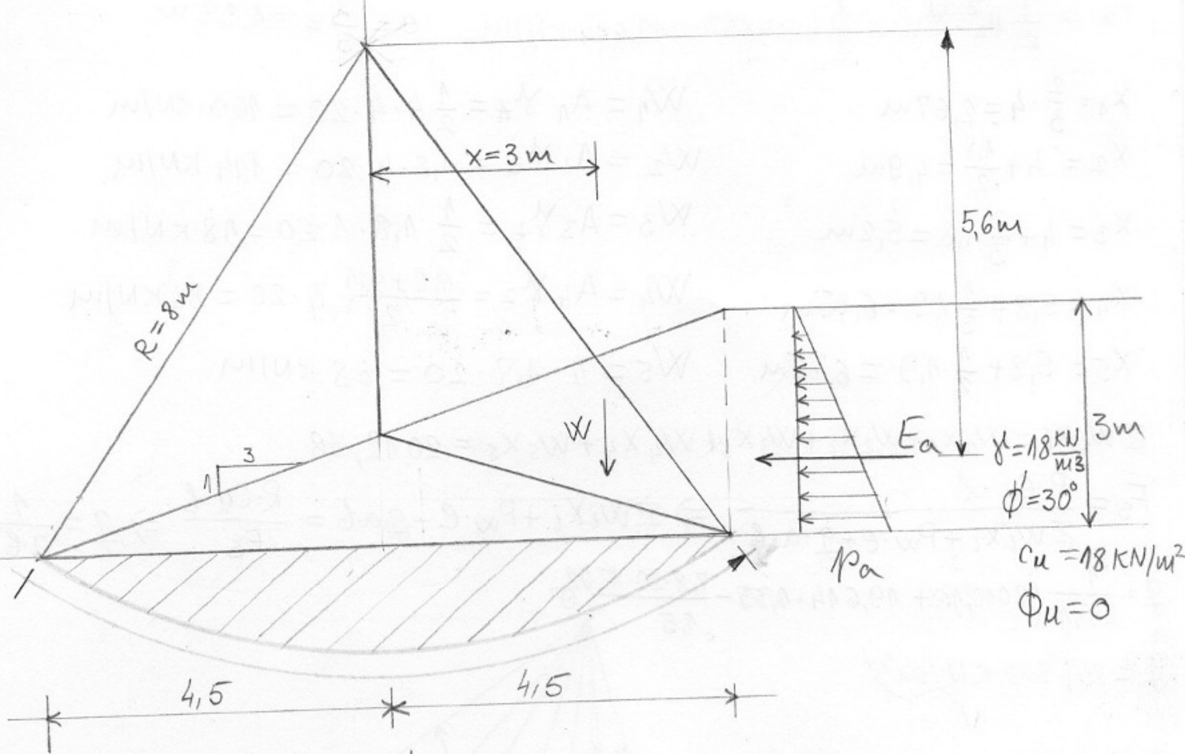
– средину сваке ламеле спојимо са центром ротације; α меримо од вертикале из центра ротације; α (+) ако окреће супротно од казаљке.

– c' гледамо где се налази основа ламеле и уписујемо φ' тог слоја

– tg φ' где се налази основа ламеле

ЗАДАТАК 1.

$\gamma = 18 KN$
$\phi' = 30^\circ$
$C_u = 18 KN/m^2$
$\phi_u = 0$
$h = 3m$



$a^2 = b^2 + c^2 - 2bc\cos\alpha$

$2bc\cos\alpha = b^2 + c^2 - a^2$

$\cos\alpha = \frac{b^2 + c^2 - a^2}{2bc}$

$\alpha = \arccos\left(\frac{8^2 + 8^2 - 9^2}{2 \cdot 8 \cdot 8}\right)$

$\alpha = 68^\circ 27' 27,84''$

$l = R\cos\frac{\alpha}{2} - 1$

$l = 8\cos\frac{68^\circ 27' 27,84''}{2} - 1 = 5,61 m$

$p_a = \gamma \cdot h \cdot tg^2(45^\circ - \frac{\phi}{2}) = 18 \cdot 3 \cdot tg^2(45^\circ - \frac{30^\circ}{2})$

$p_a = 18 \frac{KN}{m^2}$

$E_a = \frac{1}{2} p_a \cdot h = \frac{1}{2} 18 \cdot 3 = 27 \; KN/m^2$

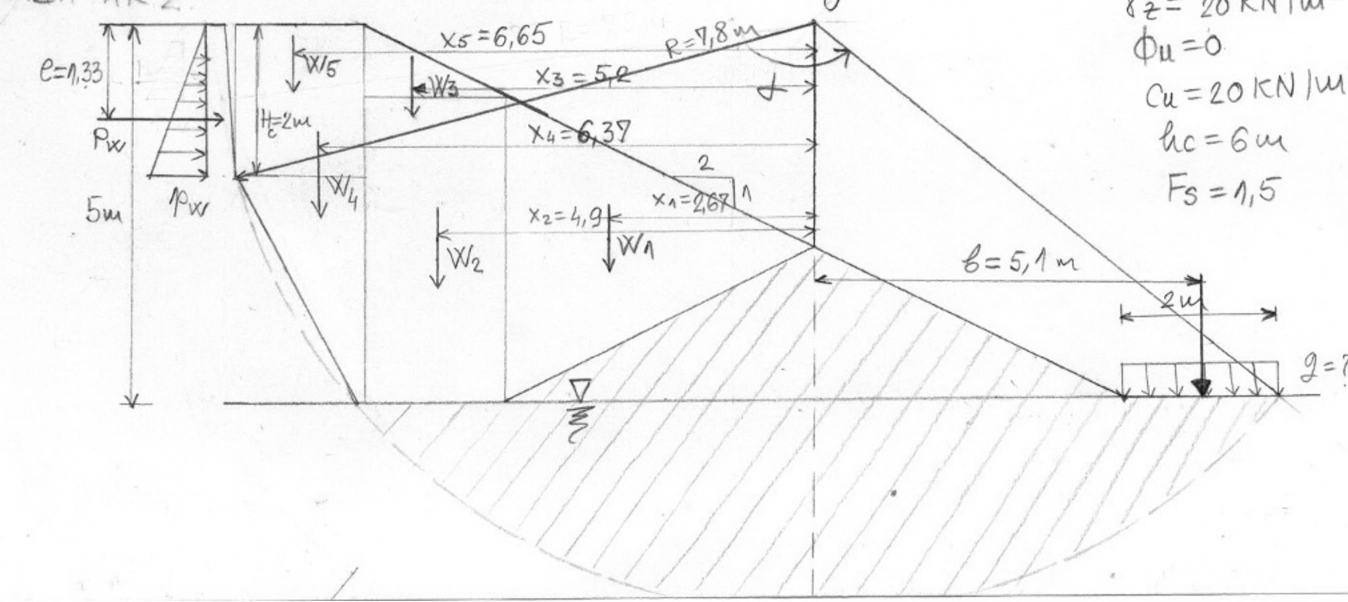
$W = A \cdot \gamma = \frac{3 \cdot 4,5}{2} \cdot 18 = 121,5 \frac{kN}{m}$

$l = \frac{R\pi\alpha}{180^\circ} = \frac{8 \cdot 3,14 \cdot 68^\circ 27' 27,84''}{180} = 9,56 m$

$F_s = \frac{R \cdot c_u \cdot l}{W x + E_a \cdot b} = \frac{8 \cdot 18 \cdot 9,56}{121,5 \cdot 3 + 27 \cdot 5,61} = 2,668$

$F_s = 2,668$

ЗАДАТАК 2



$\gamma_z = 20 \; KN/m^3$
$\phi_u = 0$
$C_u = 20 \; KN/m^2$
$h_c = 6 m$
$F_s = 1,5$

$H_c = 2C_u / \gamma_z = 2 \cdot 20/20 = 2\,m$

$P_w = \frac{1}{2} H_c^2 \cdot \gamma_w = \frac{1}{2} 4 \cdot 9{,}807 = 19{,}614\ kN/m \qquad e = \frac{2}{3} 2 = 1{,}33\,m$

$\alpha = 125^\circ$

$l = \frac{R\pi\alpha}{180^\circ} = \frac{7{,}8 \cdot 3{,}14 \cdot 125^\circ}{180}$

$l = 17{,}02\,m$

$x_1 = \frac{2}{3} \cdot 4 = 2{,}67\,m \qquad W_1 = A_1 \gamma_z = \frac{1}{2} 4 \cdot 4 \cdot 20 = 160\ kN/m$

$x_2 = 4 + \frac{1{,}8}{2} = 4{,}9\,m \qquad W_2 = A_2 \gamma_z = 1{,}8 \cdot 4 \cdot 20 = 144\ kN/m$

$x_3 = 4 + \frac{2}{3} 1{,}8 = 5{,}2\,m \qquad W_3 = A_3 \gamma_z = \frac{1}{2}\ 1{,}8 \cdot 1 \cdot 20 = 18\ kN/m$

$x_4 = 5{,}8 + \frac{1}{3} 1{,}7 = 6{,}37\,m \qquad W_4 = A_4 \gamma_z = \frac{1{,}7 + 0{,}1}{2} \cdot 3 \cdot 20 = 54\ kN/m$

$x_5 = 5{,}8 + \frac{1}{2} \cdot 1{,}7 = 6{,}65\,m \qquad W_5 = 2 \cdot 1{,}7 \cdot 20 = 68\ kN/m$

$\Sigma W_i x_i = W_1 x_1 + W_2 x_2 + W_3 x_3 + W_4 x_4 + W_5 x_5 = 2022{,}58$

$F_S = \frac{R \cdot C_u \cdot l}{\Sigma W_i x_i + P_w \cdot e - q \cdot a \cdot b} \Rightarrow \Sigma W_i x_i + P_w \cdot e - q \cdot a \cdot b = \frac{R \cdot C_u \cdot l}{F_S} \Rightarrow q = \frac{1}{a \cdot b}\left(\Sigma W_i x_i + P_w e - \frac{R C_u \cdot l}{F_S}\right)$

$q = \frac{1}{2 \cdot 5{,}1}\left(2022{,}58 + 19{,}614 \cdot 1{,}33 - \frac{7{,}8 \cdot 20 \cdot 17{,}02}{1{,}5}\right)$

$q = 27{,}312\ kN/m^2$

ЗАДАТАК.3.