DELFT UNIVERSITY OF TECHNOLOGY

Faculty of Civil Engineering and Geosciences

Soil Mechanics

CTB2310 / AESB2330

BSc EXAMINATION 2019

THIRD PERIOD

DATE: 15 APRIL 2019 TIME: 13.30 – 16.30

Answer ALL Questions
(Questions have unequal marks)

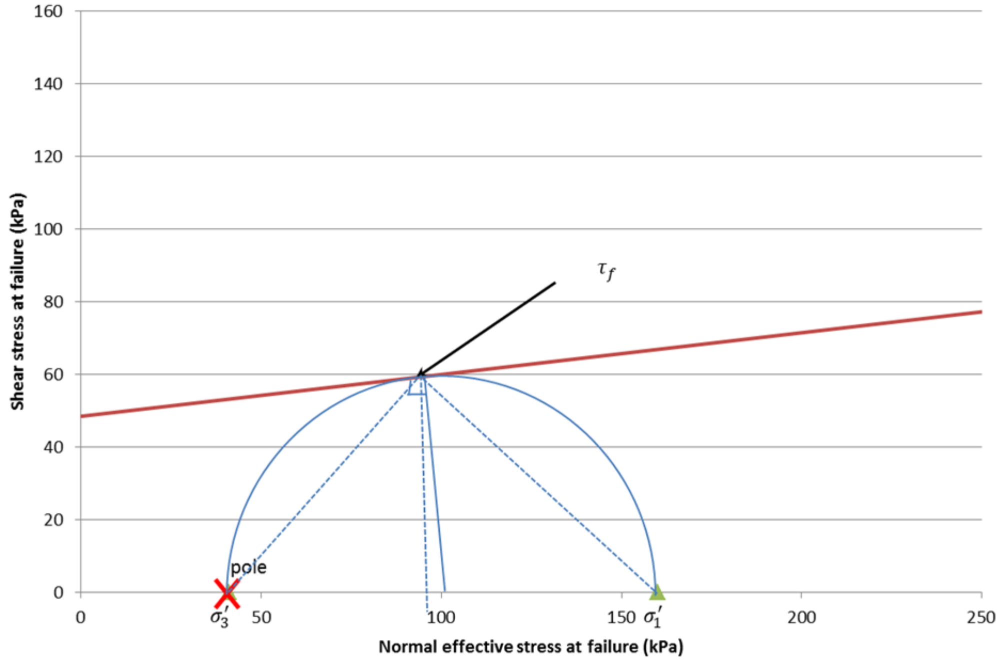
Other instructions
Write your name and student number on each sheet

Clearly identify the answer in the answer box

<table>
<tr><th>Question No.</th><th>Workings</th><th>Answer</th></tr>
<tr><td>1a</td><td>$$\Delta p = B(\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3))$$
For the initial (isotropic) consolidation phase, $(\Delta\sigma_1 - \Delta\sigma_3) = 0$, therefore we can write:
$$\Delta p = B(\Delta\sigma_3)$$
$$120 - p_0 = B(150)$$
$$410 - p_0 = B(450)$$
$B = \frac{410-120}{450-150} = 0.97$ and $p_0 = -25kPa$</td><td>$B = 0.97$
$p_0 = -25kPa$</td></tr>
<tr><td>1b</td><td>For c' and ϕ' we need to calculate σ_1' and σ_3' (effective stresses) for both tests at failure:
Test 1:
$\sigma_1' = 269 - 109 = 160$ kPa
$\sigma_3' = 150 - 109 = 41$ kPa
Test 2:
$\sigma_1' = 672 - 11 = 661$ kPa
$\sigma_3' = 450 - 11 = 439$ kPa

Can draw Mohr's circle or solve analytically:
$\sigma_1' = \sigma_3' tan^2\left(45 + {\phi'}/{2}\right) + 2c' tan\left(45 + {\phi'}/{2}\right)$
$$c' = 48.3\ kPa$$
$$\phi' = 6.6°$$

Can use a graphical method, but normally less exact. (reduce mark by 2 points)</td><td>$c' = 48.3\ kPa$
$\phi' = 6.6°$</td></tr>
</table>

<table>
<tr><td>1c</td><td colspan="2">
</td></tr>
<tr><td>1d</td><td>

$$\Delta p = B(\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3))$$

B=0.97, $\Delta\sigma_3$=0, therefore:

$$\Delta p = 0.97A(\Delta\sigma_1)$$

For test 1:

$$A = \frac{\Delta p}{0.97(\Delta\sigma_1)} = \frac{109}{0.97 \times 119} = 0.95$$

therefore normally consolidated

For test 2:

$$A = \frac{\Delta p}{0.97(\Delta\sigma_1)} = \frac{11}{0.97 \times 222} = 0.05$$

therefore (lightly) overconsoliodated</td><td>Test 1
A=0.95
NC

Test 2
A=0.05
OC</td></tr>
</table>

<table>
<tr><th>Question No.</th><th>Workings</th><th>Answer</th></tr>
<tr><td>2a</td><td>Using the Prandtl/Brinch Hansen formula:
$$q = \gamma d = 19 \times 1 = 19\ kPa$$
$$N_q = 1, N_c = 5.14$$
$$p_c = 5.14 s_u + q = 5.14 \times 110 + 19 \times 1 = 584.4\ kPa$$
Applied load
$$p_a = \frac{250}{0.5} = 500\ kPa$$
$$FoS = \frac{584.4}{500} = 1.17$$</td><td>$FoS = 1.17$</td></tr>
<tr><td>2b</td><td>Using the Brinch Hansen method:
$$p_c = c' N_c i_c s_c + q' N_q i_q s_q + \frac{1}{2}\gamma' B N_\gamma i_\gamma s_\gamma$$
No inclination factors or surcharge due to being at ground level. Therefore, only the N factors needed.
$$N_q = \frac{1 + sin\ \phi}{1 - sin\ \phi}\exp(\pi\ tan\ \phi) = \frac{1 + sin\ 15}{1 - sin\ 15}\exp(\pi\ tan\ 25) = 3.94$$
$$N_c = (N_q - 1)cot\ \phi = 10.98$$
$$N_\gamma = 2(N_q - 1)tan\ \phi = 1.58$$
As no inclination or shape factors:
$$p_c = c' N_c + q' N_q + \frac{1}{2}\gamma' B N_\gamma$$
$$q' = \gamma' d = (19 - 10) \times 1 = 9\ kPa$$
$$p_c' = c' N_c + q' N_q + \frac{1}{2}\gamma' B N_\gamma = 45 \cdot 10.98 + 9 \cdot 3.94 + \frac{1}{2} \cdot 9 \cdot 0.5 \cdot 1.58 = 533 kPa$$
$$p_a = 500\ kPa$$
In the FoS, must also account for the pore water:
$$FOS = \frac{p_c + 10}{p_a} = 1.09$$
Will also accept FoS calculated in effective capacities:
$$FOS = \frac{p_c}{p_a - 10} = 1.09$$</td><td>2.12</td></tr>
<tr><td>2c</td><td>

Split clay into 3 layers
Calculate effective stress before construction at the centre of the layers
Use Flamant's technique, either a strip or a line load answers are almost identical:

$$\sigma_{zz} = \frac{2p}{\pi}\left(\tan^{-1}\left(\frac{a}{z}\right) + \frac{az}{a^2 + z^2}\right)$$
$$\sigma_{zz} = \frac{2F}{\pi}\frac{z^3}{r^4}$$</td><td>21.5 cm</td></tr>
</table>

- Strain: $\varepsilon = \frac{1}{C_p} \ln\left(\frac{\sigma'}{\sigma'_1}\right)$ and displacement is then $disp = \sum \varepsilon d$, where d is the sub-layer thickness.

layer centre depth (m)	$\sigma_v'_1$ (kPa)	Strip (kPa)	Line (kPa)	Strain (-)	Layer thickness (m)	Deform. (m)
2.5	22.5	104.19	106.10	0.049	3	0.148
5.5	49.5	35.30	35.37	0.015	3	0.046
8.5	76.5	21.20	21.22	0.007	3	0.021
				Displacement (m)		**0.215**

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<tr><td>3a</td><td>Most likely failure is active.

Calculate the active and passive coefficients of lateral earth pressure:
$$K_a = \frac{1-\sin\phi'}{1+\sin\phi'} = 0.27$$
$$K_a = \frac{1+\sin\phi'}{1-\sin\phi'} = 3.69$$

Calculate the horizontal stresses:
$$Q_{a1} = \frac{1}{2}K_a\gamma_d' {h_{Qa1}}^2 = \frac{1}{2}\times 0.27\times 17\times 5^2 = 57.6kN/m$$
$$Q_{a2} = K_a\gamma_d' h_{Qa1}h_{Qa2} = 0.27\times 17\times 3\times(2+2) = 92.1\ kN/m$$
$$Q_{a3} = \frac{1}{2}K_a\gamma_d' {h_{Qa2}}^2 = \frac{1}{2}\times 0.27\times(19-10)\times(2+2)^2 = 19.5\ kN/m$$
$$Q_{w1} = \frac{1}{2}\gamma_w {h_{Qw1}}^2 = \frac{1}{2}\times 10\times(2+2)^2 = 80.0\ kN/m$$

$$Q_{p1} = \frac{1}{2}K_p\gamma_d' d^2 = \frac{1}{2}3.69\times 9\times 2^2 = 66.4\ kN/m$$
$$Q_{w2} = \frac{1}{2}\gamma_w {h_{Qw2}}^2 = \frac{1}{2}\times 10\times 2^2 = 20.0\ kN/m$$

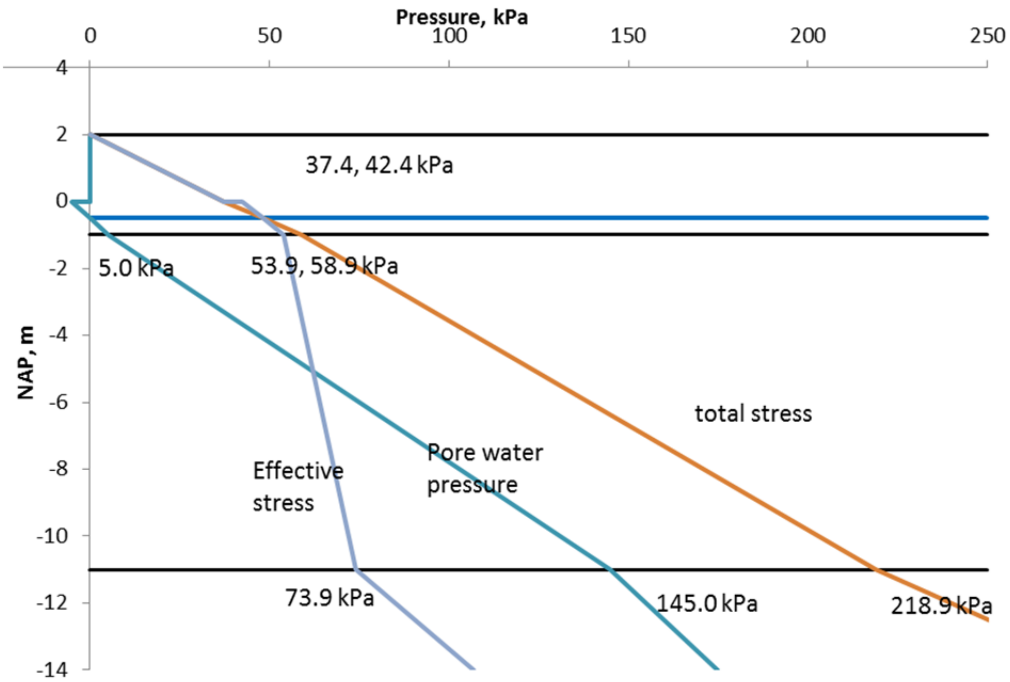
Friction from wall:
$$R = Wtan\delta = 9\times t\times\gamma_{conc}\times tan20 = 81.9\ t\ kN/m$$

$$Q_{slide} = 57.6+92.1+19.5+80 = 249.2\ kN/m$$
$$Q_{resist} = 66.4+20+R = 86.4+81.9t\ kN/m$$
$$Q_{resist} = Q_{slide}FOS$$

$$t = 3.51m$$</td><td>3.51 m</td></tr>
<tr><td>3b</td><td>Load from the train must be divided by width of the bridge:
$$train\ load = \frac{900}{10} = 90\ kN/m$$

Load can act positively or negatively, but the FoS should be against the worst case:
$$FOS = \frac{Q_{resist}}{Q_{slide} + train\ load} = 1.10$$</td><td>1.10</td></tr>
<tr><td>3c</td><td>Two reasons, for example:
• Draining water
• Increasing width
• Embedding the wall more</td><td></td></tr>
</table>

Question No.	Workings	Answer
4a	The porosity, $n = V_p/V_t$ The sample is not necessarily saturated so the volume of voids cannot be calculated from the water content. It can be calculated from the volume of solids: Mass of solids: $$M_s = 550\ g$$ Volume of solids: $$V_s = \frac{M_s}{\rho_s} = \frac{550}{1000 \times 2600} = 0.000212m^3$$ Volume total: $$l\pi r^2 = 0.150 \times \pi \times 0.025^2 = 0.000295m^3$$ Volume of voids: $$V_p = V_t - V_s = 0.000295 - 0.000212 = 0.000083m^3$$ $$n = \frac{V_p}{V_t} = \frac{0.000083}{0.000295} = 0.28$$	0.28
4b	Degree of saturation, $S_r = V_w/V_p$ Mass of water initially: $$M_w = 620 - 550 = 70g$$ Volume of water: $$V_w = \frac{70}{1000 \times 1000} = 0.00007m^3$$ Degree of saturation: $$S_r = \frac{0.00007}{0.00083} = 0.84$$	0.84
4c	Dry volumetric weight, $\gamma_d = W_d/V$ Initially: $$W = \frac{550 \times 10}{1000 \times 1000} = 0.0055kN$$ $$\gamma = 18.7\ kN/m^3$$	18.7 kN/m^3
4d	Saturated volumetric weight, $\gamma_{sat} = W_{sat}/V$ Total mass = $Ms + Mw = Ms + V_p\rho_w = 550 + 0.000083 \times 1000 \times 1000 = 633\ g$	21.5 kN/m^3

	$$W_{sat} = \frac{633 \times 10}{1000 \times 1000} = 0.00633kN$$ $$\gamma = 21.5\ kN/m^3$$	
4e	Note follow on from the volumetric unit weights above (-2 points if wrong). 	
4f	dL is 8 m dh is (0+8) – (14.5+0) = –6.5 m $$q = -k\frac{dh}{dL} = -2.7 \times 10^{-7}\frac{-6.5}{8} = 2.2 \times 10^{-7} m/s$$	$2.2 \times 10^{-7} m/s$