CV3013 – FOUNDATION ENGINEERING AY20/21 SOLUTION

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Q1.

(a) Pressuremeter Test (PMT), Dilatometer Test (DMT), Cone Penetration Test (CPT), Field Vane Test (FVT), Plate Load Test (PLT) can be used to determine the undrained shear strength of fine-grained soils.

For sensitive soft marine clays, I would suggest FVT. As compared to other suitable methods like PMT and CPT, the amount of soil disturbance during FVT is significantly lower. Given that soft marine clay is susceptible to large volume and strength changes under loading, the minimal soil disturbance in FVT is suitable in testing such soils.

FVT is especially suitable for saturated soft clays, and it would produce a direct measurement of the undrained shear strength at discrete points.

(b) $\sigma'_{v0} = (17)(2) + (19 - 9.81)(6) = 89.14kPa$

From the graph, $\sigma'_{h0} = 115 - (9.81)(6) = 56.14kPa$

$K_o = \frac{\sigma'_{h0}}{\sigma'_{v0}} = \frac{56.14}{89.14} = 0.63$

(c) $\sigma_{v0} = (17)(2) + (19)(6) = 148kPa$

$\sigma'_{v0} = 148 - (9.81)(6) = 89.14kPa$

$q_t = 0.8MPa = 800kPa$

$K_0 = 0.1\left(\frac{q_t - \sigma_{v0}}{\sigma'_{v0}}\right) = 0.1\left(\frac{800-148}{89.14}\right) = 0.73$

(d) The coefficient of lateral earth pressure obtained from PMT in 1(b) is more reliable as compared to the coefficient of lateral earth pressure obtained from CPTU in 1(c).

This is because PMT measures the cavity pressure (p) and cavity strain (ε_c) and by plotting them like in Figure Q1, we can directly measure the in-situ horizontal stress (σ_{h0}) and shear modulus (G). Whereas for CPTU, it is based on an empirical correlation formula which is used in the calculations in 1(c) and is not the most reliable.

Q2.

(a) DA1a:

<u>Partial Factors:</u>

$\gamma_G = 1.35, \gamma_Q = 1.5, \gamma_\gamma = 1.0, \gamma_{\tan\phi'} = 1.0, \gamma_{c'} = 1.0, \gamma_{\gamma'} = 1.0$

<u>Design Parameters:</u>

$\gamma'_d = \frac{\gamma_k - \gamma_w}{\gamma_{\gamma'}} = \frac{16-9.81}{1.0} = 6.19kN/m^3$

$\phi'_d = \tan^1\left(\frac{\tan\phi'_k}{\gamma_{\tan\phi'}}\right) = \tan^1\left(\frac{\tan 30°}{1.0}\right) = 30°$

$c'_d = \frac{c'_k}{\gamma_{c'}} = \frac{2.0}{1.0} = 2kPa$

Design Calculation Factors:

$N_q = \frac{(1+\sin\phi')}{(1-\sin\phi')} e^{\pi\tan\phi'} = \frac{(1+\sin 30°)}{(1-\sin 30°)} e^{\pi\tan 30°} = 18.4$, $N_c = \frac{N_q - 1}{\tan\phi'} = \frac{18.4-1}{\tan 30°} = 30.14$

$N_\gamma = 2(N_q - 1)\tan\phi' = 2(18.4 - 1)\tan 30° = 20.09$

$s_q = 1 + \frac{B}{L}\sin\phi' = 1 + \frac{0.8}{0.8}\sin 30° = 1.5, s_c = \frac{s_q N_q - 1}{N_q - 1} = \frac{(1.5)(18.4)-1}{(18.4)-1} = 1.53$

$s_\gamma = 1 - 0.3\frac{B}{L} = 1 - 0.3\frac{0.8}{0.8} = 0.7$

$q_f = s_c N_c c' + s_q N_q \sigma_q' + 0.5\gamma B s_\gamma N_\gamma$

$q_f = (1.53)(30.14)(2) + (1.5)(18.4)(0.5 \times 16) + 0.5(6.19)(0.8)(0.7)(20.09)$

$q_f = 347.85kPa$

$R_d = q_f A = (347.85)(0.8 \times 0.8) = 222.6kN$

DA1b:

Partial Factors:

$\gamma_G = 1.0, \gamma_Q = 1.3, \gamma_\gamma = 1.0, \gamma_{\tan\phi'} = 1.25, \gamma_{c'} = 1.25, \gamma_{\gamma'} = 1.0$

Design Parameters:

$\gamma_d' = \frac{\gamma_k - \gamma_w}{\gamma_{\gamma'}} = \frac{16-9.81}{1.0} = 6.19kN/m^3$

$\phi_d' = \tan^1\left(\frac{\tan\phi_k'}{\gamma_{\tan\phi'}}\right) = \tan^1\left(\frac{\tan 30°}{1.25}\right) = 24.791°$

$c_d' = \frac{c_k'}{\gamma_{c'}} = \frac{2.0}{1.25} = 1.6kPa$

Design Calculation Factors:

$N_q = \frac{(1+\sin\phi')}{(1-\sin\phi')} e^{\pi\tan\phi'} = \frac{(1+\sin 24.791°)}{(1-\sin 24.791°)} e^{\pi\tan 24.791°} = 10.43$

$N_c = \frac{N_q - 1}{\tan\phi'} = \frac{10.43-1}{\tan 24.791°} = 20.42$

$N_\gamma = 2(N_q - 1)\tan\phi' = 2(10.43 - 1)\tan 24.791° = 8.711$

$s_q = 1 + \frac{B}{L}\sin\phi' = 1 + \frac{0.8}{0.8}\sin 24.791° = 1.419, s_c = \frac{s_q N_q - 1}{N_q - 1} = \frac{(1.419)(10.43)-1}{(10.43)-1} = 1.46$

$s_\gamma = 1 - 0.3\frac{B}{L} = 1 - 0.3\frac{0.8}{0.8} = 0.7$

$q_f = s_c N_c c' + s_q N_q \sigma_q' + 0.5\gamma B s_\gamma N_\gamma$

$q_f = (1.46)(20.42)(1.6) + (1.419)(10.43)(0.5 \times 16) + 0.5(6.19)(0.8)(0.7)(8.711)$

$q_f = 181.20kPa$

$R_d = q_f A = (181.20)(0.8 \times 0.8) = 116.0kN$

(b) $gross\ bearing\ pressure\ at\ foundation\ depth, q = \frac{(23.5)(0.8\times0.8\times0.5)+100+20}{0.8\times0.8} = 199.25kPa$

$net\ bearing\ pressure, q_n = q - \sigma'_q = 199.25 - (16)(0.5) = 191.25kPa$

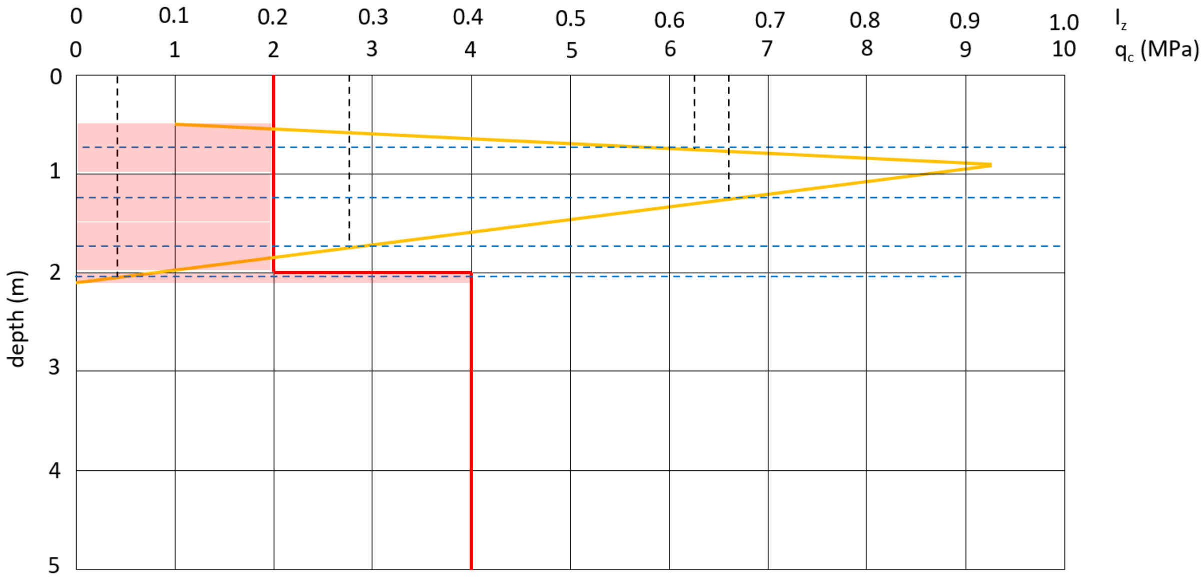
$\sigma'_p = (16)(0.9) - (9.81)(0.4) = 10.476kPa$

$\sigma'_q = (16)(0.5) = 8kPa$

$$I_{zp} = 0.5 + 0.1\left(\frac{q_n}{\sigma'_p}\right)^{0.5} = 0.5 + 0.1\left(\frac{199.25}{10.476}\right)^{0.5} = 0.927$$

$$c_1 = 1 - 0.5\left(\frac{\sigma'_q}{q_n}\right) = 1 - 0.5\left(\frac{8}{191.25}\right) = 0.980$$

$$c_2 = 1 + 0.2\log\left(\frac{t}{0.1}\right) = 1 + 0.2\log\left(\frac{30}{0.1}\right) = 1.495\ or\ 1\ (immediate)$$



Δz	q_c	E	I_z	$I_z\frac{\Delta z}{E}$
0.5	2	5	0.62	0.062
0.5	2	5	0.66	0.066
0.5	2	5	0.27	0.027
0.1	4	10	0.045	0.00045
			sum	0.15545

$$s = c_1 c_2 q_n \sum I_z \frac{\Delta z}{E}$$

$$s_{immediate} = (0.980)(1)(191.25)(0.15545) = 29.13mm$$

$$s_{30\ years} = (0.980)(1.495)(191.25)(0.15545) = 43.55mm$$

Q3.
(a) DA1b:

<u>Partial Factors:</u>

$\gamma_\gamma = 1.0, \gamma_{c_u} = 1.0, \gamma_G = 1.0$

<u>Design Parameters:</u>

$\gamma_{1;d} = \frac{\gamma_{1;k}}{\gamma_\gamma} = \frac{17.5}{1.0} = 17.5kN/m^3, \gamma_{2;d} = \frac{\gamma_{1;k}}{\gamma_\gamma} = \frac{18}{1.0} = 18kN/m^3$

$c_{u1;d} = \frac{c_{u1;k}}{\gamma_{cu}} = \frac{60}{1.0} = 60kPa, c_{u2;d} = \frac{c_{u2;k}}{\gamma_{cu}} = \frac{120}{1.0} = 120kPa$

Assuming deep foundation which terminates deep into the second clay layer, $N_c = 9.0$.

$Q_{bu} = \frac{A_p(N_c c_u + \sigma_q)}{\xi} = \frac{\pi(0.4)^2[(9.0)(120)+(17.5)(6)+(L_p-6)(18)]}{1.55} = 349.26 + 5.8373L_p$

$Q_{su} = \frac{\pi D_0 \int_0^{L_p} \tau_{int}}{\xi}, \alpha_1 = 1.16 - \frac{60}{185} = 0.83568, \alpha_2 = 1.16 - \frac{120}{185} = 0.51135$

$Q_{su} = \frac{\pi D_0[(6)(0.83568)(60)+(L_p-6)(0.51135)(120)]}{1.55} = 99.497L_p - 109.17$

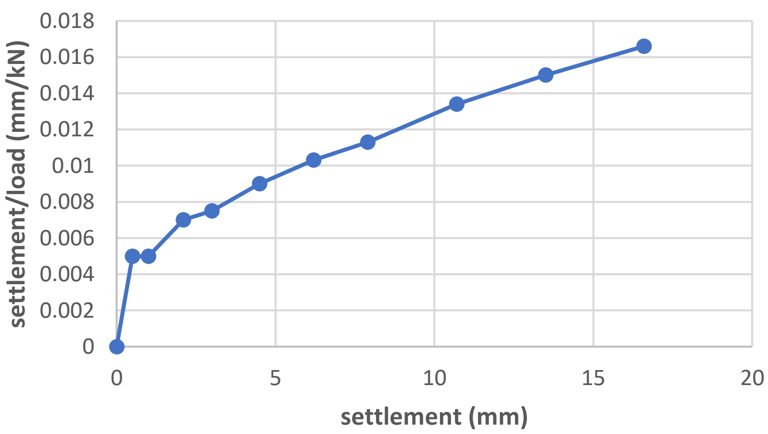
$R_d = \frac{349.26+5.8373L_p+99.497L_p-109.17}{2.0} \rightarrow R_d = 52.667L_p + 120.05$

$Q_d = \gamma_A(Q_k + \gamma_{conc}A_pL_p) = 1.0[900 + (23.5)(\pi \times 0.4^2)(L_p)] = 900 + 11.812L_p$

$R_d = Q_d \rightarrow\ 52.667L_p + 120.05 = 900 + 11.812L_p \rightarrow L_p = 19.09m$

(b)

Settlement (mm)	Settlement/Load (mm/kN)
0	0
0.5	0.005
1.0	0.005
2.1	0.007
3.0	0.0075
4.5	0.009
6.2	0.0103
7.9	0.0113
10.7	0.0134
13.5	0.015
16.6	0.0166



Taking gradient of last point and 4th last point, $gradient = \frac{0.0166-0.0113}{16.6-7.9} = 0.000609$

$\frac{1}{P_{ult}} = 0.000609 \rightarrow P_{ult} = 1642kN$

Q4.

(a) DA1b:

Partial Factors:

$\gamma_{\tan\phi'} = 1.25, \gamma_{\gamma'} = 1.0$

Design Parameters:

$\gamma'_d = \frac{\gamma_k}{\gamma_{\gamma'}} = \frac{20}{1.0} = 20kN/m^3, \phi'_d = \tan^1\left(\frac{\tan\phi'_k}{\gamma_{\tan\phi'}}\right) = \tan^1\left(\frac{\tan 32°}{1.25}\right) = 26.56°$

$K_{ah} = \frac{1-\sin\phi'_d}{1+\sin\phi'_d} = \frac{1-\sin 26.56°}{1+\sin 26.56°} = 0.382, K_{ph} = \frac{1+\sin\phi'_d}{1-\sin\phi'_d} = \frac{1+\sin 26.56°}{1-\sin 26.56°} = 2.6175$

$\gamma_{G;dst} = \gamma_{G;stb} = \gamma_{Q;dst} = 1.0$

Soil-side LEP

$\sigma'_{a1;d} = K_a\gamma'_d H_{4.5m} = (0.382)(20)(4.5) = 34.38kN/m$

$\sigma'_{a2;d} = K_a\gamma'_d H_{8m} = (0.382)(20)(4.5) + (0.382)(20-10)(3.5) = 47.75kN/m$

Excavation-side LEP

$\sigma'_{p1;d} = K_a\gamma'_d H_{3.5m} = (2.6175)(10)(3.5) = 91.613kN/m$

Design Horizontal Force (kN/m)	Lever Arm (m)	Design Moment (kNm/m)
$\frac{1}{2}(34.38)(4.5)(\gamma_{G;dst}) = 77.355$	$3-1$	154.71
$(34.38)(3.5)(\gamma_{G;dst}) = 120.33$	$1.75+4.5-1$	631.733
$\frac{1}{2}(47.75-34.38)(3.5)(\gamma_{G;dst}) = 23.398$	$\frac{2\times3.5}{3}+4.5-1$	136.488
$\frac{1}{2}(91.613)(3.5)(\gamma_{G;stb}) = 160.325$	$\frac{2\times3.5}{3}+4.5-1$	935.229

$ODF = \frac{935.229}{154.71+631.733+136.488} = 1.0133 = 1.013$

(b) $F_{anchor} = P_{a;d} - P_{p;d} = 60.758kN/m \times 3 = 182.274kN = 182.27kN$

Assuming point of zero shear is within 4.5m depth from the top,

$P_{a;d} = \frac{1}{2}K_a(20)(x)(x)(\gamma_{G;dst}) = 3.82x^2$

$3.82x^2 = 60.758 \rightarrow x = 3.988m$

Taking moment about x,

$M_{max} = (60.758)\left(\frac{2\times3.988}{3} - 1\right) = 107.78kNm/m$

(c) When the groundwater level at the retained side is much higher than the excavated side, this presents an issue due to out-of-balance groundwater levels. When the groundwater level on the retained side rises, there would be an increase in the hydrostatic pressure exerted on the wall. This would mean an increase in the design horizontal force acting on the retained side of the wall. As the groundwater level on the excavated side does not change, the forces calculated in part (b) would not change.

Together, the increase in the design horizontal force acting on the retained side of the wall and the design horizontal force staying the same on the excavated side, this would pose an issue to overall stability.

For sliding ULS $\left(ODF = \frac{resistance}{driving\ force}\right)$ and overturning ULS $\left(ODF = \frac{resisting\ moment}{overturning\ moment}\right)$, the increase in design horizontal forces on the retained side would mean an increase in driving force and overturning moment which would result in a decrease in the ODF of sliding and overturning ULS. This would mean a reduction in overall stability.

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NOTE:

Do reach out to me at KEAL0001@e.ntu.edu.sg if you have any queries regarding any of my submitted workings. Feel free to leave an email to ask any questions covered in the curriculum, will be glad to help!

DISCLAIMER:

You are advised to take my solutions as a **guide**, rather than an absolute answer to the questions.