



**NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**FACULTY OF INDUSTRIAL TECHNOLOGY**

**DEPARTMENT OF CIVIL AND WATER ENGINEERING**

**DESIGN OF STRUCTURES III**

**TCW 5105**

**Supplementary Examinations paper**

**August 2024**

**This examination paper consists of 8 pages**

**Time Allowed: 3 hours**

**Total Marks: 100**

**Special requirements: Graph paper**

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**INSTRUCTIONS**

1. Answer any four questions
2. Each question carries 25 marks
3. Clearly state any assumptions made

**MARK ALLOCATION**

QUESTION	MARKS
1	25
2	25
3	25
4	25
5	25
<b>TOTAL</b>	<b>100</b>

## Question 1

Figure 1 shows a cantilever retaining wall

- Determine the factors of safety against overturning, sliding and bearing capacity failure (10 marks)
- Design the wall and base reinforcement for  $f_{cu} = 30\text{N/mm}^2$ ,  $f_y = 460\text{N/mm}^2$ , cover = 40mm and sketch the reinforcement layout. The soil parameters are as follows:  $\sigma = 30^\circ$ ,  $\gamma = 20\text{kN/m}^3$ ,  $\phi = 40^\circ$ ,  $q_{ult} = 450\text{kN/m}^3$  (15 marks)

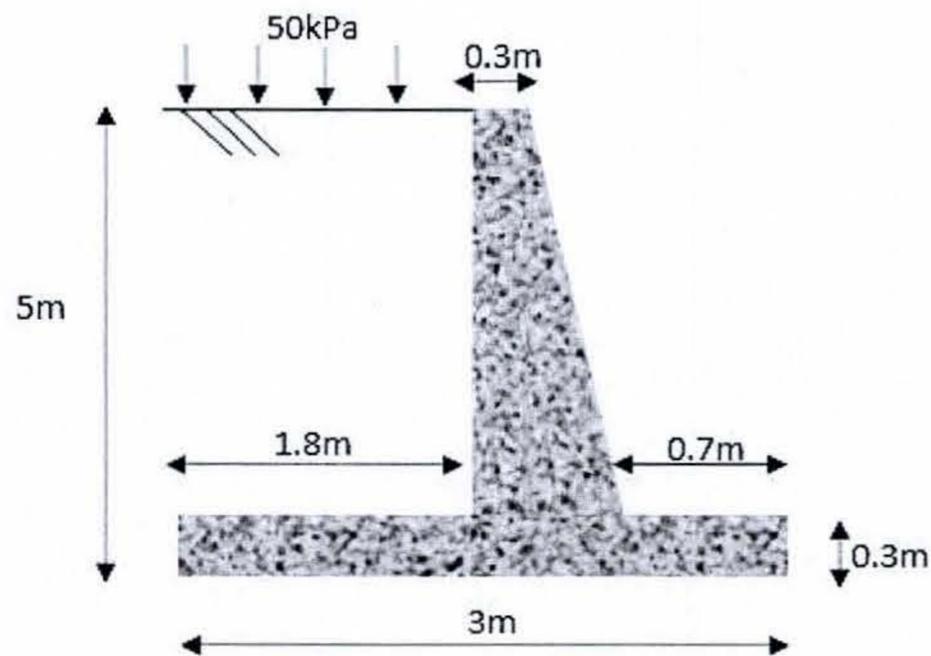


Figure 1

## Question 2

- A sand sample with relative density 40% and critical state friction angle of  $18^\circ$  is subjected to a consolidated drained triaxial test with a confining pressure of 150kPa. Determine the peak friction angle of the sand sample. (13 marks)
- Two tri-axial tests were performed on specimens of the same clay with the following results at failure:  
Test 1:  $\sigma_1 = 108\text{kPa}$ ,  $\sigma_3 = 41\text{kPa}$   
Test 2:  $\sigma_1 = 83\text{kPa}$ ,  $\sigma_3 = 27\text{kPa}$ 
  - Determine the cohesion and internal friction angle
  - Find the shear and normal stresses at failure for the two specimens and the orientation of the failure planes
  - Compute the maximum shear stress and the values of the normal stress on this plane (12 marks)

### Question 3

- c. Using the Brinch Hansen method determine if a 2.0m long x 1.5m wide rectangular footing which is 0.8m deep can adequately support a vertical load  $V_{ult} = 2000\text{kN}$ , a horizontal load  $H_L = 500\text{kN}$  and  $H_B = 0\text{kN}$ . The soil parameters are  $\phi = 30^\circ$ ,  $C = 15\text{kPa}$ ,  $\gamma = 20\text{kN/m}^3$ , the inclination constants are  $\alpha_1 = 1.5$  and  $\alpha_2 = 2.0$ . The required safety factor is 2.5  
(15marks)
- d. Determine the bearing capacity of a circular footing 3.2m in diameter at a depth of 1m. The soil properties are  $\phi = 25^\circ$ ,  $C = 10\text{kPa}$ ,  $\gamma = 15\text{kN/m}^3$ . The water table is 1.5m below the ground level.  
(10 marks)

### Question 4

- a. A single 600mm diameter reinforced concrete pile is required to carry a maximum compression load of 900kN. The soil profile comprises of a 8.0m thick top layer of silt with  $\gamma = 10\text{kN/m}^3$ ,  $\phi = 17^\circ$  and a 9.6m thick bottom layer of dense clay with  $\gamma = 13\text{kN/m}^3$ ,  $\phi = 38^\circ$ . Determine the depth of penetration  
(5 marks)
- b. Compute the number of driven piles 0.5m in diameter and 12m long that are required to support a building given that the characteristic permanent load is 9MN while the characteristic variable load is 4MN. Static pile load test results that were performed on five piles are listed in Table 2.  
(15 marks)

**Table 2**

Pile Number	Resistance R (MN)
1	2.51
2	2.87
3	1.96
4	2.17
5	2.62

- c. A group of 6No. piles supports a structure with a load of 2200kN. The piles are spaced at 2m c/c, each pile is 600mm in diameter and 9m long. The soil  $c_u = 80\text{kN/m}^2$  at the surface and  $110\text{kN/m}^2$  at a depth of 9m. Assess the group efficiency  
(5 marks)

### Question 5

A 7m thick clay deposit underlain by a sand layer was preconsolidated with a 60kPa surcharge prior to the construction of a building with a surface loading of 80kPa. The in-situ pressure was 75kPa and the water table was at the ground surface. The soil parameters are  $c_c = 0.51$ ,  $c_s = 0.15c_c$ , the natural water content  $w_n = 62\%$ ,  $G_s = 2.65$  and  $c_v = 2.5\text{m}^2/\text{yr}$ .

- a. Calculate the settlement that was induced by the surcharge load of 60kPa  
b. How long should the surcharge load be kept for 95% consolidation to take place

- c. If prefabricated vertical drains 0.8m diameter are used in a triangular pattern at 2m c/c, how long should the surcharge be kept for the same U of 95%,  $c_h = 11\text{m}^2/\text{yr}$  and  $m_v = 0.4\text{m}^2/\text{mN}$
- d. Determine the settlement that occurred after the surcharge was removed
- e. Calculate the settlement that occurred after the final construction

(25 marks)

### FORMULAE

$$e = wG_s \quad \gamma = \left( \frac{G_s \pm e_o}{1 + e_o} \right) \gamma_w \quad T_v = \frac{c_v t}{Hd^2} \quad T_v = -0.933 \log_{10}(1 - U) - 0.085$$

$$S_{oc} = \frac{-c_s}{1 + e_o} H_o \log_{10} \left( \frac{\sigma_{vp}}{\sigma_{vinsitu}} \right) \quad S_{nc} = \frac{-c_c}{1 + e_p} H_p \log_{10} \left( \frac{\sigma_{vinsitu \pm q}}{\sigma_{vp}} \right) \quad H_p = H_b - S_{oc}$$

$$e_p = e_o - \frac{C_s}{s} \log_{10} \left( \frac{\sigma_{vp}}{\sigma_{vinstu}} \right) \quad U_v = \sqrt{\frac{4T_v}{\pi}} \quad U = 1 - 10^{-1.0718(T+0.085)}$$

$$S_{rebound} = \frac{-c_s}{1 + e_{p1}} H_{p1} \log_{10} \left( \frac{\sigma_{vinsitu}}{\sigma_{vinsitu + q}} \right) \quad e_{p1} = e_p - C_c \log_{10} \left( \frac{\sigma_{vinsitu \pm q}}{\sigma_{vp}} \right)$$

$$S = S_{oc} + S_{nc}$$

$$S = C_1 C_2 (q - \gamma D) \sum_{0.5}^z \frac{I_z}{E_s} \Delta z \quad C_1 = 1 - 0.5 \frac{\sigma_n}{q_n} \quad C_2 = 1 + 0.2 \log \left( \frac{\text{time in years}}{0.1} \right)$$

$$I_{zp} = 0.5 + 0.1 \left( \frac{q_n}{\sigma_p} \right)^{0.5} \quad I_z = \frac{I_{zp} - 0.1}{0.5B} z + 0.1 \quad I_z = \left( \frac{-I_{zp}}{2B - 0.5B} \right) (z - 0.5B) + I_{zp}$$

$$H = 0.5B \tan \left( 45 + \frac{\phi}{2} \right) \quad e_y = \frac{M_x}{V} \quad e_x = \frac{M_y}{V} \quad B_{min} = 4 + e_y + B_c$$

$$L_{min} = 4 + e_x + L_c$$

$$B' = B - 2e_y$$

$$L' = L - e_x$$

$$N_q = e^{\pi \tan \phi} \tan^2 \left( 45 + \frac{\phi}{2} \right)$$

$$N_c = (N_q - 1) \cot \phi$$

$$N_\gamma = 2(N_q + 1) \tan \phi$$

$$q_{ult} = c N_c s_c d_c i_c g_c b_c + \gamma D N_q s_q d_q i_q g_q b_q + 0.5 \gamma B N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$$

$$Q' = Q_x SRF$$

$$N = Q' x A x B x C$$

$$h = \frac{w \tan \alpha \tan \beta}{\tan \alpha + \tan \beta}$$

$$N = \frac{0.5 \rho g h w l}{FS}$$

$$N_p = \frac{1 + \sin \phi_p}{1 - \sin \phi_p}$$

$$\sigma_{1p} = N_p \sigma_3$$

$$\sigma_{mp} = \frac{\sigma_{1p} + 2\sigma_3}{3}$$

$$\phi_p = \phi + A I_R$$

$$I_R = \frac{D_R}{100} \left[ Q - \ln \left( \frac{100 \sigma_{mp}}{P_A} \right) \right]$$

$$T_r = \frac{c_h t}{d_e^2}$$

$$U_T = 1 - (1 - U_v)(1 - U_r)$$

$$U_r = 1 - e^{-\frac{8T_r}{Fn}}$$

$$F_n = \left(\frac{n^2}{n^2-1}\right) \ln n - \left(\frac{3n^2-1}{4n^2}\right)$$

$$S_{ult} = m_v H_o \Delta \sigma$$

$$P = \frac{ES^2}{NMH}$$

$$D = n\sqrt{mh}$$

$$k_a = \tan^2\left(45 - \frac{\phi}{2}\right)$$

$$Q_u = \left(\frac{1+\sin\phi_c}{1-\sin\phi_c}\right) \gamma H + 4C$$

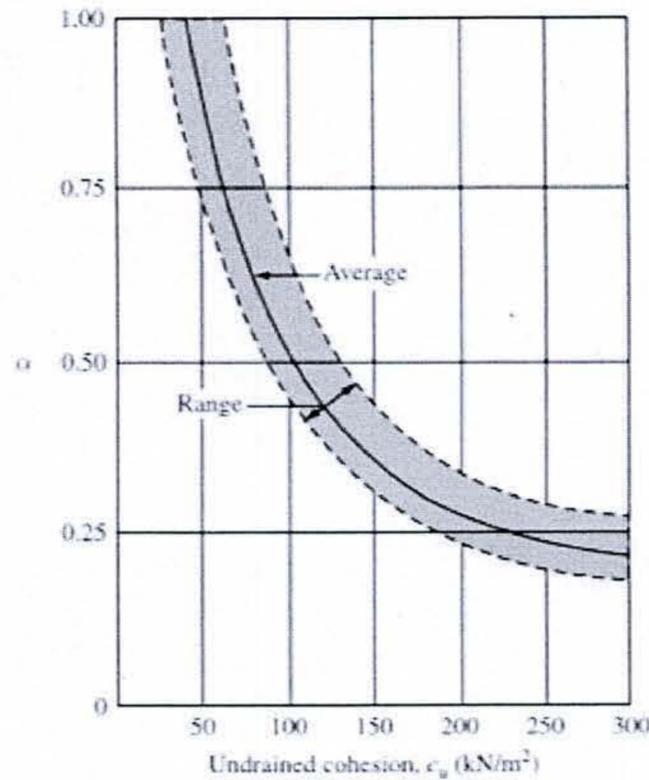
$$Q_u = Q_b + Q_s$$

Approximate induced settlement as % of treatment depth

Soil type	% depth
Natural clays	1-3
Clay fills	3-5
Natural sands	3-10
Granular fills	5-15
Refuse and peat	7-20

Range of n values for various soil types

Soil type	Degree of saturation	Recommended n value
Pervious soil deposits - Granular soils	High	0.5
	low	0.5 - 0.6
Semipervious soil deposits - Primarily silts with plasticity index of < 8	High	0.35 - 0.40
	low	0.4 - 0.5
Impervious deposits - Primarily clayey soils with plasticity index of > 8	High	Not recommended
	Low	0.35 - 0.40 Soils should be at water content less than the plastic limit



**TABLE 4-5a**  
Shape and depth factors for use in either the Hansen (1970) or Vesic (1973, 1975b) bearing-capacity equations of Table 4-1. Use  $s'_c, d'_c$  when  $\phi = 0$  only for Hansen equations. Subscripts  $H, V$  for Hansen, Vesic, respectively.

Shape factors	Depth factors
$s'_{c(H)} = 0.2 \frac{B'}{L'} \quad (\phi = 0^\circ)$	$d'_c = 0.4k \quad (\phi = 0^\circ)$
$s_{c(H)} = 1.0 + \frac{N_q}{N_c} \cdot \frac{B'}{L'}$	$d_c = 1.0 + 0.4k$
$s_{c(V)} = 1.0 + \frac{N_q}{N_c} \cdot \frac{B}{L}$	$k = D/B \text{ for } D/B \leq 1$
$s_r = 1.0 \text{ for strip}$	$k = \tan^{-1}(D/B) \text{ for } D/B > 1$
	$k \text{ in radians}$
$s_{q(H)} = 1.0 + \frac{B'}{L'} \sin \phi$	$d_q = 1 + 2 \tan \phi (1 - \sin \phi)^2 k$
$s_{q(V)} = 1.0 + \frac{B}{L} \tan \phi$	$k \text{ defined above}$
for all $\phi$	
$s_{\gamma(H)} = 1.0 - 0.4 \frac{B'}{L'} \geq 0.6$	$d_\gamma = 1.00 \text{ for all } \phi$
$s_{\gamma(V)} = 1.0 - 0.4 \frac{B}{L} \geq 0.6$	

**Notes:**

- Note use of "effective" base dimensions  $B', L'$  by Hansen but not by Vesic.
- The values above are consistent with either a vertical load or a vertical load accompanied by a horizontal load  $H_B$ .
- With a vertical load and a load  $H_L$  (and either  $H_B = 0$  or  $H_B > 0$ ) you may have to compute two sets of shape  $s_i$  and  $d_i$  as  $s_{i,B}, s_{i,L}$  and  $d_{i,B}, d_{i,L}$ . For  $i, L$  subscripts of Eq. (4-2), presented in Sec. 4-6, use ratio  $L'/B'$  or  $D/L'$ .

**TABLE 4-5b**  
Table of inclination, ground, and base factors for the Hansen (1970) equations. See Table 4-5c for equivalent Vesic equations.

Inclination factors	Ground factors (base on slope)
$i'_c = 0.5 - \sqrt{1 - \frac{H_i}{A_f c_a}}$	$g'_c = \frac{\beta^2}{147^\circ}$
$i_c = i_q - \frac{1 - i_q}{N_q - 1}$	$g_c = 1.0 - \frac{\beta^2}{147^\circ}$
$i_q = \left[ 1 - \frac{0.5H_i}{V + A_f c_a \cot \phi} \right]^{0.2}$	$g_x = g_y = (1 - 0.5 \tan \beta)^5$
$2 \leq \alpha_1 \leq 5$	
	<b>Base factors (tilted base)</b>
$i_\gamma = \left[ 1 - \frac{0.7H_i}{V + A_f c_a \cot \phi} \right]^{0.2}$	$b'_c = \frac{\eta^2}{147^\circ} \quad (\phi = 0)$
$i_\gamma = \left[ 1 - \frac{(0.7 - \eta^2/450^\circ)H_i}{V + A_f c_a \cot \phi} \right]^{0.2}$	$b_c = 1 - \frac{\eta^2}{147^\circ} \quad (\phi > 0)$
$2 \leq \alpha_2 \leq 5$	$b_q = \exp(-2\eta \tan \phi)$
	$b_\gamma = \exp(-2.7\eta \tan \phi)$
	$\eta \text{ in radians}$

**Notes:**

- Use  $H_i$  as either  $H_B$  or  $H_L$ , or both if  $H_L > 0$ .
- Hansen (1970) did not give an  $i_c$  for  $\phi > 0$ . The value above is from Hansen (1961) and also used by Vesic.
- Variable  $c_a$  = base adhesion, on the order of 0.6 to 1.0  $\times$  base cohesion.
- Refer to sketch for identification of angles  $\eta$  and  $\beta$ , footing depth  $D$ , location of  $H_i$  (parallel and at top of base slab; usually also produces eccentricity). Especially note  $V$  = force normal to base and is not the resultant  $R$  from combining  $V$  and  $H_i$ .

Action	Symbol	Set	
		A1	A2
		DA1.C1, DA2 DA3 (structural actions)	DA1.C2 DA3 (geotech.actions)
Permanent	Unfavourable	1,35	1,0
	Favourable	1,0	1,0
Variable	Unfavourable	1,5	1,3
	Favourable	0	0

**8.4.1 Recommended correlation factors  $\xi_1$  and  $\xi_2$  to determine characteristic resistance from pile load test results**

n	1	2	3	4	$\geq 5$
$\xi_1$	1,4	1,3	1,2	1,1	1,0
$\xi_2$	1,4	1,2	1,05	1,0	1,0

**Recommended partial resistance factors for driven, bored and CFA piles**

Resistance	Symbol	Set			
		R1	R2	R3	R4
<b>Partial resistance factors for driven piles</b>					
Base	$\gamma_b$	1,0	1,1	1,0	1,3
Shaft (compression)	$\gamma_s$	1,0	1,1	1,0	1,3
Total/combined (compression)	$\gamma_t$	1,0	1,1	1,0	1,3
Shaft in tension	$\gamma_{s,t}$	1,25	1,15	1,1	1,6
<b>Partial resistance factors for bored piles</b>					
Base	$\gamma_b$	1,25	1,1	1,0	1,6
Shaft (compression)	$\gamma_s$	1,0	1,1	1,0	1,3
Total/combined (compression)	$\gamma_t$	1,15	1,1	1,0	1,5
Shaft in tension	$\gamma_{s,t}$	1,25	1,15	1,1	1,6
<b>Partial resistance factors for continuous flight auger (CFA) piles</b>					
Base	$\gamma_b$	1,1	1,1	1,0	1,45
Shaft (compression)	$\gamma_s$	1,0	1,1	1,0	1,3
Total/combined (compression)	$\gamma_t$	1,1	1,1	1,0	1,4
Shaft in tension	$\gamma_{s,t}$	1,25	1,15	1,1	1,6

Bar size (mm)	50	75	100	125	150	175	200	250	300
6	566	377	283	226	189	162	142	113	94.3
8	1010	671	503	402	335	287	252	201	168
10	1570	1050	785	628	523	449	393	314	262
12	2260	1510	1130	905	754	646	566	452	377
16	4020	2680	2010	1610	1340	1150	1010	804	670
20	6280	4190	3140	2510	2090	1800	1570	1260	1050
25	9820	6550	4910	3930	3270	2810	2450	1960	1640
32	16100	10700	8040	6430	5360	4600	4020	3220	2680
40	25100	16800	12600	10100	8380	7180	6280	5030	4190