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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2021/2022

COURSE NAME	:	FOUNDATION ENGINEERING
COURSE CODE	:	BFC 43103
PROGRAMME CODE	:	BFF
EXAMINATION DATE	:	JANUARY / FEBRUARY 2022
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS IN **PART A** AND **TWO (2)** QUESTIONS IN **PART B.** 2. THIS FINAL EXAMINATION IS AN **ONLINE** ASSESSMENT AND CONDUCTED VIA **CLOSE BOOK**.

THIS QUESTION PAPER CONSISTS OF **FIFTEEN (15)** PAGES

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PART A

Q1 (a) A pile is a slender structural member that is installed in the ground to transfer the structural loads to the foundation soil. Outline how piles are classified according to the type of material, cross sectional geometry, method of installation and load transfer mechanism.

(8 marks)

(b) A group pile has a section of 4 x 4 with each having a diameter of 305 mm are embedded in clay. The length of the piles are 12 m and the spacing between the piles (d) are 1.0 m. The recorded soil profile for the ground is shown in **Table 1**. Propose the allowable load bearing capacity of the pile with a factor of safety of (FS) of 3.

(17 marks)

Q2 (a) List and differentiate the type of retaining structure in terms of function, construction method and design method.

(9 marks)

(b) As a design engineer, use a suitable method to prevent slope failure for 12 m high slope with the following specification.

The soil parameters for the wall backfill
Unit weight of soil, γ, is 19.0 kN/m^3
Soil internal friction angle, ϕ', is 35°

Geotextiles properties
T_{ult} is 65 kN/m.
RF_{id} is 1.2,
RF_{cr} is 2.5,
RF_{cbd} is 1.25.

(16 marks)

PART B

Q3 (a) Soil improvement and ground modification techniques are used to improve poor/unsuitable subsurface soils and/or to improve the performance of embankments or structures. **Table 2** shows the category of the ground improvement techniques and its methods to carry it out. Elaborate **TWO (2)** function for each of category of the ground improvement techniques.

(7 marks)

(b) **Table 3** shows result of a seismic refraction field work of a proposed site for a building project.

(i) Analyse the seismic velocity and thickness of the material encountered from the survey

(10 marks)

(ii) Evaluate the advantages and disadvantages of seismic refraction technique in the site investigation works.

(8 marks)

Q4 (a) A retaining wall with a sandy soil as backfill is shown as in **FIGURE Q4(a)**. It is very important that the retaining wall is design accordingly to avoid failure.

(i) Design the size of the retaining wall.

(4 marks)

(ii) Since the consultant want to use pile as a foundation, proposed the others stability of the retaining wall.

(9 marks)

(b) A site investigation report is prepared for a construction of a high-rise building as given in **Table 4.** With that, the construction uses a 25-meter-long concrete pile with a cross section of 0.4 m x 0.4 m that is fully embedded in a non-homogeneous soil that has a combination of sand and clay layers. Design the allowable load (Q_{all}) that the pile are able to hold by considering the soil resistance in all layers in that specific soil condition. Use a factor of safety (FS) of 3. (Note: use the simpliest method for pile capacity in clay).

(12 marks)

Q5 (a) Elaborate how the the water table will decrease the bearing capacity of the soil.

(5 marks)

(b) The location of column and also the column load for construction of TNB store in new school project as shown in **FIGURE Q5(b).** As a consultant engineer you are required to design the shallow foundation for this structure. The soil properties of the dense sand given as γ = 16.5 kN/m^3, ϕ' = 20°, c' = 70 kN/m^2 and depth of the footing, D_f = 1.5 m. Evaluate if spread footings can be used.

(20 marks)

-END OF QUESTIONS-

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TABLE 1 : Soil type and soil parameter

Depth	***Soil parameter***
0.0 m to 2.0 m	Unit weight = 17.5 kN/m^3 Cohesion = 20 kN/m^2
2.0 m to 8.0 m	Unit weight = 18.5 kN/m^3 Cohesion = 60 kN/m^2
8.0 m to 15.0 m	Unit weight = 20.1 kN/m^3 Cohesion = 80 kN/m^2

TABLE 2 : Ground improvement techniques and its methods

Category	**Method**
Consolidation	prefabricated vertical drains, and surcharge
Load reduction	geofoam, foamed concrete, and lightweight fill
Densification	vibro compaction, and dynamic compaction by falling weight impact
Reinforcement	stone columns
Deep soil mixing	wet and dry mixing methods
Grouting	permeation grouting, and jet grouting
Load transfer	column supported embankment

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TABLE 3: Result of a seismic refraction field survey

Distance from the point of impact (metres)	Time of first arrival of seismic wave (milliseconds)
2.5	10
5	24
7.5	34
10	42.
15	51
20	57
25	65
30	69
35	71
40	75
50	77

TABLE 4: Site investigation soil information

Depth (m)	**Thickness of each layer (m)**	**Soil parameters given**	**Soil Description**
0 - 4	4	Cone penetration frictional resistance (f_c) = 83 (kN/m^2)	Sand
4 - 8	4	Cone penetration frictional resistance (f_c) = 143 (kN/m^2)	Sandy soil
8 - 13	5	Cone penetration frictional resistance (f_c) = 223 (kN/m^2)	Sandy gravel
13 – 17	5	c_u = 25 kN/m^2, γ = 16 kN/m^3	Silty clay
17 - 24	7	c_u = 40 kN/m^2, γ = 17 kN/m^3	Clay
24 - 28	4	c_u = 90 kN/m^2, γ = 18 kN/m^3	Hard Clay

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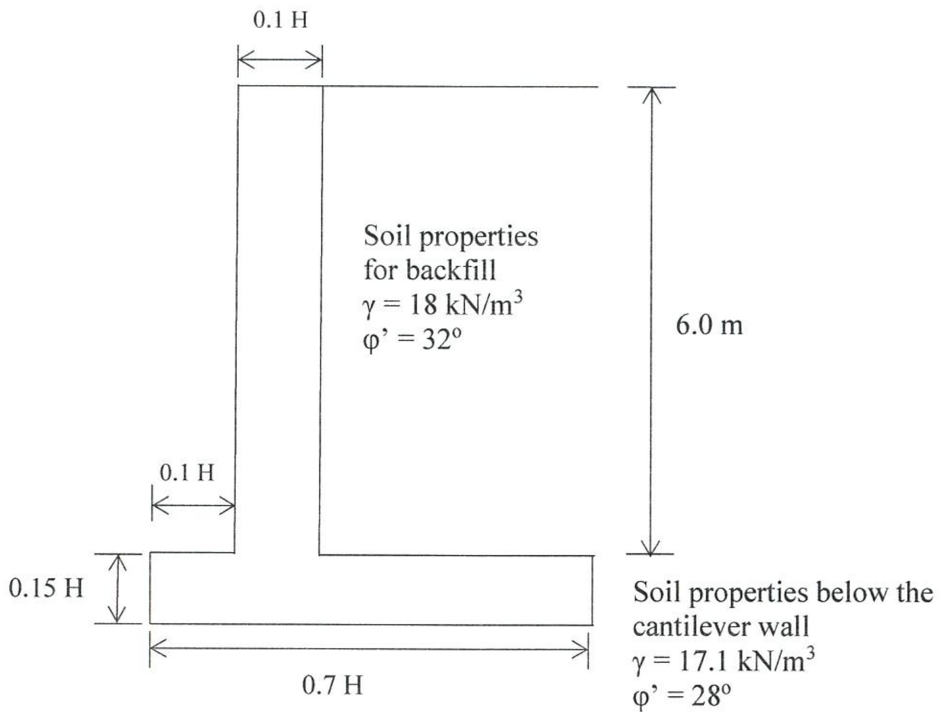

FIGURE Q4 (a) : Retaining wall

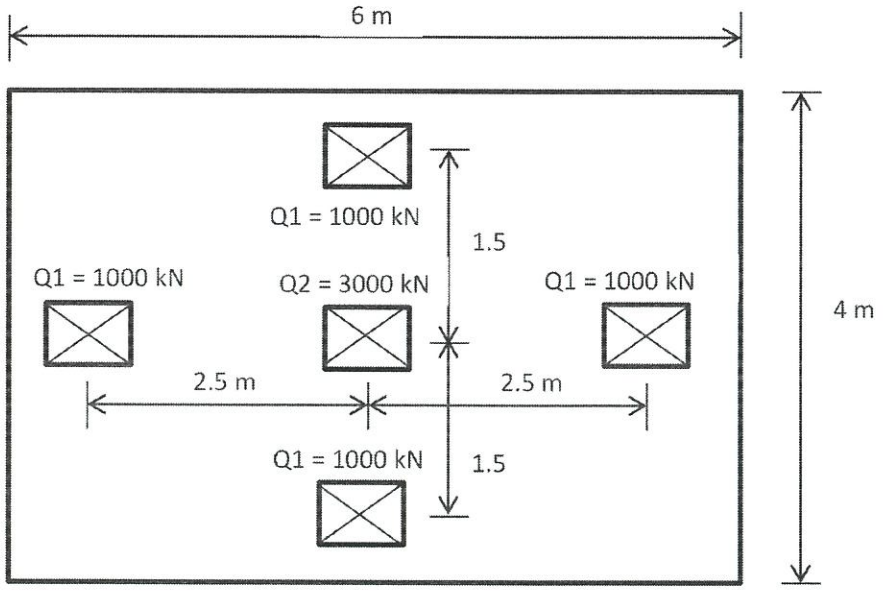

FIGURE Q5 (b) : Geometry of spread footing

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TABLE 5 : Terzaghi Bearing Capacity factor

ϕ'	N_c	N_q	N_γ^{a}	ϕ'	N_c	N_q	N_γ^{a}
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

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TABLE 6: Meyerhof's bearing capacity factor

ϕ'	N_c	N_q	N_γ	ϕ'	N_c	N_q	N_γ
0	5.14	1.00	0.00	26	22.25	11.85	12.54
1	5.38	1.09	0.07	27	23.94	13.20	14.47
2	5.63	1.20	0.15	28	25.80	14.72	16.72
3	5.90	1.31	0.24	29	27.86	16.44	19.34
4	6.19	1.43	0.34	30	30.14	18.40	22.40
5	6.49	1.57	0.45	31	32.67	20.63	25.99
6	6.81	1.72	0.57	32	35.49	23.18	30.22
7	7.16	1.88	0.71	33	38.64	26.09	35.19
8	7.53	2.06	0.86	34	42.16	29.44	41.06
9	7.92	2.25	1.03	35	46.12	33.30	48.03
10	8.35	2.47	1.22	36	50.59	37.75	56.31
11	8.80	2.71	1.44	37	55.63	42.92	66.19
12	9.28	2.97	1.69	38	61.35	48.93	78.03
13	9.81	3.26	1.97	39	67.87	55.96	92.25
14	10.37	3.59	2.29	40	75.31	64.20	109.41
15	10.98	3.94	2.65	41	83.86	73.90	130.22
16	11.63	4.34	3.06	42	93.71	85.38	155.55
17	12.34	4.77	3.53	43	105.11	99.02	186.54
18	13.10	5.26	4.07	44	118.37	115.31	224.64
19	13.93	5.80	4.68	45	133.88	134.88	271.76
20	14.83	6.40	5.39	46	152.10	158.51	330.35
21	15.82	7.07	6.20	47	173.64	187.21	403.67
22	16.88	7.82	7.13	48	199.26	222.31	496.01
23	18.05	8.66	8.20	49	229.93	265.51	613.16
24	19.32	9.60	9.44	50	266.89	319.07	762.89
25	20.72	10.66	10.88				

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TABLE 7 : Variation of α

$\frac{c_u}{p_a}$	α
≤ 0.1	1.00
0.2	0.92
0.3	0.82
0.4	0.74
0.6	0.62
0.8	0.54
1.0	0.48
1.2	0.42
1.4	0.40
1.6	0.38
1.8	0.36
2.0	0.35
2.4	0.34
2.8	0.34

Note: p_a = atmospheric pressure
≈ 100 kN/m^2 or 2000 lb/ft^2

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List of formula

SOIL IMPROVEMENT AND GROUND MODIFICATION

$$S_{c(p)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o}$$

$$S_{c(p+f)} = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \left[\Delta\sigma'_{(p)} + \Delta\sigma'_{(f)}\right]}{\sigma'_o}$$

$$U = \frac{\log\left[\frac{\sigma'_o + \Delta\sigma'_{(p)}}{\sigma'_o}\right]}{\log\left[\frac{\sigma'_o + \Delta\sigma'_{(p)} + \Delta\sigma'_{(f)}}{\sigma'_o}\right]}$$

$$T_v = \frac{c_v t}{H_c^2}$$

For U%: 0% to 60%; $T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$

For U% > 60%;

$$T_v = 1.781 - 0.931\log\left(100 - U\%\right)$$

$$U = \frac{\log\left[1 + \frac{\Delta\sigma'_{(p)}}{\sigma'_o}\right]}{\log\left[1 + \frac{\Delta\sigma'_{(p)}}{\sigma'_o}\left(1 + \frac{\Delta\sigma'_{(f)}}{\sigma'_{(p)}}\right)\right]}$$

SITE INVESTIGATION

$$A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2}(\%)$$

$$N_{corrected} = C_N * N_{field}$$

$$C_N = 0.77 \log_{10} \frac{1915}{p'_o}$$

$$N_{60} = \frac{N\eta_H\eta_B\eta_S\eta_R}{60}$$

where

N_{60} = Standard penetration number, corrected for field conditions.

η_H = Hammer Effiency (%)

η_B = Correction for borehole diameter

η_S = Sampler correction

η_R = Correction for rod length

Variation of η_B

Diameter (mm)	η_B
60 – 120	1
150	1.05
200	1.15

Variation of η_S

Rod lenght (mm)	η_B
Standard sampler	1.0
With liner for dense sand and clay	0.8
With liner for loose sand	0.9

Schmertmann's (1975) theory

$$\phi = tan^{-1}\left[\frac{N_{60}}{12.2+20.3\left(\frac{\sigma'_0}{P_a}\right)}\right]^{0.34}$$

where, σ'_0 = effective overburden pressure (kPa) = γH

P_a = atmospheric pressure

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SHALLOW FOUNDATIONS

Modification of Bearing Capacity Equations for Water Table

Case I for water within $0 \le D_1 \le D_f$; $q = D_1\gamma_{dry} + D_2(\gamma_{sat} - \gamma_w)$ $\gamma' = \gamma_{sat} - \gamma_w$	Case II for water within $0 \le d \le B$; $q = D_1\gamma_{dry}$ $\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma_{dry} - \gamma')$	Case III when the water table is located so that $d \ge B$, the water will have no effect on the ultimate bearing capacity.

$$q_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

Shape Factor

$F_{cs} = 1 + \frac{B}{L}.\frac{N_q}{N_c}$	$F_{qs} = 1 + \frac{B}{L}\tan\phi$	$F_{\gamma s} = 1 - 0.4\frac{B}{L}$

Depth Factor

$D_f/B \le 1, for\ \phi = 0$		
$F_{cd} = 1 + 0.4(^{D_f}/_B)$	$F_{qd} = 1$	$F_{\gamma d} = 1$
$^{D_f}/_B \le 1, for\ \phi > 0$		
$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\phi'}$	$F_{qd} = 1 + 2tan\phi'(1 - sin\phi')^2\frac{D_f}{B}$	$F_{\gamma d} = 1$
$D_f/B > 1, for\ \phi = 0$		
$F_{cd} = 1 + \underbrace{0.4\ tan^{-1}(^{D_f}/_B)}_{\text{radians}}$	$F_{qd} = 1$	$F_{\gamma d} = 1$
$D_f/B > 1, for\ \phi > 0$		
$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c tan\phi'}$	$F_{qd} = 1 + 2\tan\phi'(1 - sin\phi')^2 \underbrace{tan^{-1}(\frac{D_f}{B})}_{\text{radians}}$	$F_{\gamma d} = 1$

where L is the length of the foundation and L>B.

Inclination Factor

$$F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2 \qquad F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)^2$$

β is the inclination of the load on the foundation with respect to vertical

Eccentric Loading in Shallow Foundations

$q_{max} = \frac{Q}{BL} \pm \frac{6M}{B^2L}$	$e = \frac{M}{Q}$
$q_{max} = \frac{4Q}{3L(B - 2e)}$	$FS = \frac{Q_{ult}}{Q}$

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SHALLOW FOUNDATIONS

$$q'_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma'B'N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

One Way Eccentric Loading in Shallow Foundations

Method 1:

$$B' = B - 2e$$
$$L' = L$$
$$q'_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \tfrac{1}{2}\gamma'B'N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$
$$Q_{ult} = q'_uB'L'$$

Method 2:

$$Q_{ult} = B\left[c'N_{c(e)} + qN_{q(e)} + \frac{1}{2}\gamma BN_{\gamma(e)}\right]$$
$$Q_{ult} = BL\left[c'N_{c(e)}F_{cs(e)} + qN_{q(e)}F_{qs(e)} + \frac{1}{2}\gamma BN_{\gamma(e)}F_{\gamma s(e)}\right]$$
$$F_{cs(e)} = 1.2 - 0.025\frac{L}{B}$$
$$F_{qs(e)} = 1.00$$
$$F_{\gamma s(e)} = 1.0 + \left(\frac{2e}{B} - 0.68\right)\frac{B}{L} + \left[0.43 - \left(\frac{3}{2}\right)\left(\frac{e}{B}\right)\right]\left(\frac{B}{L}\right)^2$$

Method 3:

$$R_k = 1 - \frac{q_{u(eccentric)}}{q_{u(centric)}}$$
$$R_k = a\left(\frac{e}{B}\right)^k$$
$$q_{u(eccentric)} = q_{u(centric)}\left(1 - R_k\right)$$
$$q_{u(centric)} = qN_qF_{qd} + \tfrac{1}{2}\gamma BN_\gamma F_{\gamma d}$$
$$Q_{ult} = Bq_{u(eccentric)}$$

Primary Consolidation Settlement for Normally Consolidated Clays

$$S_{c(p)} = \frac{C_cH_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}, \text{ for 2:1 method } \Delta\sigma'_{(1)} = \frac{Q_g}{(L_g+z_1)(B_g+z_1)}$$

Primary Consolidation Settlement for OverConsolidated Clays

for $\sigma'_o + \Delta\sigma'_{av} < \sigma'_c$

$$S_{c(p)} = \frac{C_sH_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}$$

for $\sigma'_o < \sigma'_c < \sigma'_o + \Delta\sigma'_{av}$

$$S_{c(p)} = \frac{C_sH_c}{1+e_o}\log\frac{\sigma'_c}{\sigma'_o} + \frac{C_cH_c}{1+e_o}\log\frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_c}$$

Average Increase in Pressure

$$\Delta\sigma'_{av} = \tfrac{1}{6}\left(\Delta\sigma'_{top} + 4\Delta\sigma'_{medium} + \Delta\sigma'_{bottom}\right), \Delta\sigma'_{top/middle/bottm} = q_oI_c$$
$$m_1 = \frac{L}{B}, n_1 = \frac{z}{(B/2)}$$

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PILE FOUNDATIONS

Ultimate Capacity of Piles and Group Piles in Saturated Clay

$$Q_s = \sum f p \Delta L$$
$$f = \beta \sigma'_o$$
$$\beta = K \tan \phi'_R$$
$$K = 1 - \sin \phi'_R$$
$$K = 1 - \sin \phi'_R \sqrt{OCR}$$
$$OCR = \frac{p_c}{P_o}$$
$$Q_p = A_p q_p$$
$$Q_p = A_p q' N_q^*$$
$$Q_p \approx N_c^* c_u A_p$$
$$Q_p = 9 c_u A_p$$
$$f_{av} = \lambda(\bar{\sigma}'_o + 2c_u)$$

$$\sum Q_u = n_1 n_2 \left[9 A_p c_{u(p)} + \sum \alpha p c_u \Delta L \right]$$
$$L_g = (n_1 - 1) d + 2\left(\frac{D}{2}\right)$$
$$B_g = (n_2 - 1) d + 2\left(\frac{D}{2}\right)$$
$$\sum Q_u = L_g B_g c_{u(p)} N_c^* + \sum 2(L_g + B_g) c_u \Delta L$$
$$\Delta s_{c_i} - \left[\frac{\Delta e_i}{1 + e_{o_i}}\right] H_i$$
$$\eta = \frac{[2(n_1 + n_2 - 2)d + 4D]}{p n_1 n_2}$$

CONVENTIONAL GRAVITY AND CANTILEVER WALL

Rankine's Theory

$$P_a = \tfrac{1}{2} K_a \gamma_1 H^2$$
$$P_a = \tfrac{1}{2} K_a \gamma_1 H^2 + q K_a H$$
$$P_v = P_a \sin \alpha°$$
$$P_h = P_a \cos \alpha°$$
$$P_p = \tfrac{1}{2} K_p \gamma_2 D^2 + 2c'_2 \sqrt{K_p} D$$
$$K_a = \tan^2\left(45° - \tfrac{1}{2}\phi'_1\right)$$
$$K_p = \tan^2\left(45° + \tfrac{1}{2}\phi'_2\right)$$

$$FS_{overturning} = \frac{\sum M_R}{\sum M_O}$$
$$\sum M_O = P_h \left(\frac{H'}{3}\right)$$
$$P_h = P_a \cos \alpha$$
$$P_v = P_a \sin \alpha$$

$$FS_{sliding} = \frac{\sum F_{R'}}{\sum F_d} = \frac{(\sum V)\tan(k_1 \phi'_2) + B k_2 c'_2 + P_p}{P_a \cos \alpha}$$

$$q_u = c'^{N_c} + q N_q + \frac{1}{2} \gamma B N_\gamma$$

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LATERAL EARTH PRESSURE AND RETAINING WALLS

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

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

$$L_3 = \frac{\sigma'_2}{\gamma'(K_p - K_a)}$$

$$\sigma'_5 = (\gamma L_1 + \gamma' L_2)K_p + \gamma' L_3(K_p - K_a)$$

$$A_1 = \frac{\sigma'_5}{\gamma'(K_p - K_a)}$$

$$A_2 = \frac{8P}{\gamma'(K_p - K_a)}$$

$$A_3 = \frac{6P\left[2\bar{z}\gamma'(K_p - K_a) + \sigma'_5\right]}{\gamma'^2(K_p - K_a)^2}$$

$$A_4 = \frac{P\left[6\bar{z}\sigma'_5 + 4P\right]}{\gamma'^2(K_p - K_a)^2}$$

$$L_4^4 + A_1 L_4^3 - A_2 L_4^2 - A_3 L_4 - A_4 = 0$$

$$\sigma'_4 = \sigma'_5 + \gamma' L_4(K_p - K_a)$$

$$\sigma'_3 = L_4(K_p - K_a)\gamma'$$

$$L_5 = \frac{\sigma'_3 L_4 - 2P}{\sigma'_3 + \sigma'_4}$$

$$K_{p(design)} = \frac{K_p}{FS}$$

$$S_V = \frac{T_{all}}{\gamma_1 z K_a [FS_{(B)}]}$$

$$L = \frac{H - z}{\tan\left(45 + \frac{\phi'_1}{2}\right)} + \frac{S_V K_a [FS_{(B)}]}{2\tan\phi'_F}$$

$$l_l = \frac{S_V K_a [FS_{(P)}]}{4\tan\phi'_F}$$

$$v = \sqrt{\frac{E}{\left(\frac{\gamma}{g}\right)}\frac{(1-\mu)}{(1-2\mu)(1+\mu)}}$$

$$Z_1 = \frac{1}{2}\sqrt{\frac{v_2 - v_1}{v_2 + v_1}}x_c$$

$$z_2 = \frac{1}{2}\left[T_{i2} - 2Z_1\frac{\sqrt{v_3^2 - v_1^2}}{v_3 v_1}\right]\frac{v_3 v_2}{\sqrt{v_3^2 - v_2^2}}$$