CV4110 Excavation and Retaining Walls
Semester 1 Examination 2018-2019
Suggested Solutions by Lim Kai Jian

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2018-2019

CV4110 – EXCAVATION AND RETAINING WALLS

November / December 2018 **Time Allowed: 2½ hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SEVEN (7)** pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. An **APPENDIX** of **ONE (1)** page is attached to the Question Paper.
5. This is a Closed-Book Examination.

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1. It is proposed to construct a 12 m deep, 20 m wide and 60 m long braced excavation with 3 levels of struts as shown in Figure Q1. The horizontal spacing of the struts is 3 m. There is a surcharge q = 20 kPa adjacent to the excavation. The existing groundwater level is 9.0 m below the existing ground surface. The properties of the two clay layers are: Clay1 - γ = 17 kN/m^3 and c_u = 60 kPa; Clay2 - γ = 18 kN/m^3 and c_u = 80 kPa.

(i) Determine the factor of safety against basal heave failure using the modified Terzaghi method. State the assumptions in the modified Terzaghi method.

(6 Marks)

(ii) Using Peck's apparent pressure diagram and the tributary area method, determine the magnitude of the forces acting on the three levels of the struts. Estimate the maximum wall bending moment.

(12 Marks)

(iii) An alternative design proposal is to omit the 3rd level of struts. The two levels of struts are at 2 m and 6 m below the ground surface, respectively. The horizontal spacing of the struts remains at 3 m. Explain how this omission of the 3rd level of struts would affect the horizontal wall deflection, the ground settlement, the forces in the struts and the basal heave stability. You are required to substantiate your answer with technical reasoning(s). No mathematical calculations are required.

(7 Marks)

Note: Question No. 1 continues on Page 2.

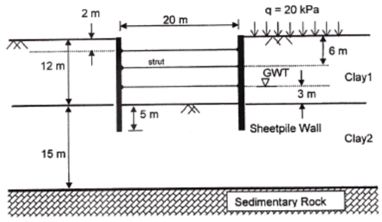


Figure Q1

2. (a) The cross-section of a 20 m wide and 50 m long reinforced concrete underground structure in a thick deposit of sand is shown in Figure Q2. The weight of the concrete structure is 1500 kN/m. The groundwater table is located 3 m below the existing ground surface. The properties of the sand are: γ = 21 kN/m^3 (above and below the water table), c′ = 0 and ϕ' = 35°. Assume plane strain conditions, and γ_w = 10 kN/m^3.

(i) Determine the net uplift force acting on the underground structure. Sketch the potential uplift failure mechanism.

(ii) Assuming the coefficient of lateral earth pressure K_0 = 0.43 and the concrete-sand interface friction δ' = 20°, determine the factor of safety against uplift failure.

(13 Marks)

Note: Question No. 2 continues on Page 3.

(b) A 10 m deep and 15 m wide excavation for a basement is to be constructed 8 m away from the existing underground reinforced concrete structure shown in Figure Q2. The design engineer has proposed to use a retaining wall system comprising of 18 m deep sheetpile walls with 3 levels of struts. Sump pumping will be used to control the groundwater seepage into the excavation.

(i) Briefly describe the main considerations in designing the excavation support system. No calculations are required.

(ii) What field monitoring instruments should be installed to check the design considerations described in part (b)(i)? Indicate with a simple sketch where these instruments should be installed and the purpose of each instrument.

(12 Marks)

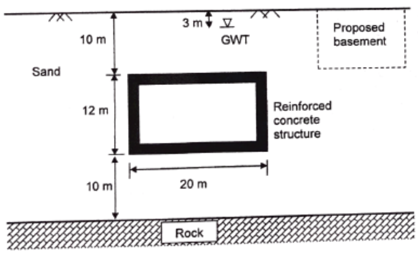


Figure Q2

3. (a) The retaining wall in Figure Q3(a) rests on an impermeable stratum. No drains are provided in the 5.6 m wall and sand backfill. During a very heavy and prolonged rainfall the water table in the backfill rises to the surface of the backfill. The front of the wall is dry. The saturated unit weight of the soil is 20 kN/m^3. The design values of the shear strength parameters for the backfill are c′ = 0 and ϕ' = 36°. The angle of friction between the concrete wall and the backfill is δ = 24°. Compute the total horizontal thrust acting on the back of the wall with the water table at the surface of the backfill. Assume the unit weight of water is 10 kN/m^3.
Note: Use the Kerisel and Absi chart in the Appendix when computing the active earth thrust component.

(7 Marks)

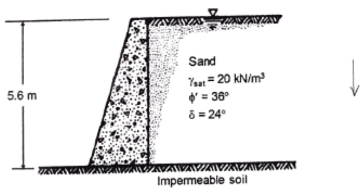


Figure Q3(a)

(b) Figure Q3(b) shows the same retaining wall as Figure Q3(a), but with a vertical gravel drain. There is steady state seepage towards the vertical gravel drain along the back of the wall during a heavy rainfall, as shown by the flow net in Figure Q3(b).

(i) Compute the pore water pressure acting on the trial failure plane at point M.

(ii) Compute the weight W of the triangular soil wedge (per m run, to be used in a force polygon for determining the wall reaction P on the trial wedge). The trial failure plane AB is inclined at 45°.

(iii) Sketch schematically the force polygon showing the directions of forces W, P, U, and R′, where P is the resultant wall reaction to the backfill, U is the total water force acting perpendicular to the trial failure plane, and R′ is the effective resultant force which is inclined at ϕ' with respect to the normal to the trial failure plane. Show the values of angles between the forces, and explain how the active thrust P_a on the wall can be determined.

(12 Marks)

Note: Question No. 3 continues on Page 5.

CV4110 Excavation and Retaining Walls
Semester 1 Examination 2018-2019
Suggested Solutions by Lim Kai Jian

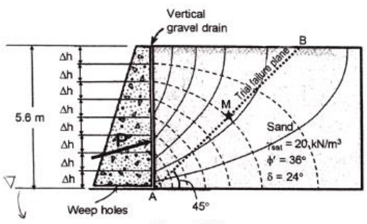


Figure Q3(b)

(c) If the front of the wall is flooded such that the water level in front of the wall is the same as the water level in the fill behind the wall, both being 5.6 m above the base of the retaining wall, calculate the horizontal thrust on the wall.

(2 Marks)

(d) Suppose the backfill in Figure Q3(a) is dry, and compacted in layers by a roller, from the bottom to the top of the backfill. During compaction the compaction-induced horizontal stress σ_h decreases with depth z below the surface of the fill. Upon removal of the roller the residual compaction-induced pressure for each layer was equal to the passive earth pressure $\sigma_p = K_p \gamma z$, but only down to a depth of 0.8 m from the top of each compacted layer. Show in a sketch, with labels "0.8 m", σ_h, σ_p and σ_a, how the compaction-induced lateral pressure changes the distribution of the active earth pressure σ_a with depth. Do not calculate σ_p and σ_a.

(4 Marks)

4. Figure Q4 shows a pile-supported retaining wall with a dry granular backfill of unit weight 18 kN/m³ and a friction angle φ' of 34°. The unit weight of the soil in front of the wall is also 18 kN/m³. The first two rows of piles (below the base of the retaining wall) are inclined at 18° with respect to vertical while the third row of piles are vertical. The horizontal spacing of the piles is 0.9 m center-to-center for the first row and 1.8 m for the second and third rows, as shown in the plan sketch below the cross section of the retaining wall. The allowable axial load on each pile is 130 kN.

(a) Compute the total horizontal active thrust on the wall and the overturning moment of the active thrust about the toe (point A).

(4 Marks)

(b) Show computations in a table for the moments contributed by the weights of the concrete and soil components lying above level AB. The unit weight of concrete is 24 kN/m³.

(6 Marks)

(c) Determine the distance of the point of action of the resultant of the forces in parts 4(a) and 4(b) from the toe of the retaining wall.

(2 Marks)

(d) What is the eccentricity of the resultant with respect to the centroid of the piles supporting the retaining wall?

(3 Marks)

(e) Compute the axial load per pile for each row. Are the loads acceptable?

(6 Marks)

(f) What are the limitations of using piles to support retaining walls?

(4 Marks)

Note: Question No. 4 continues on Page 7.

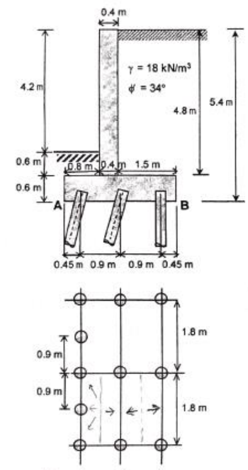


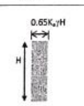
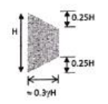
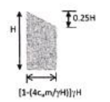
Figure Q4

END OF PAPER

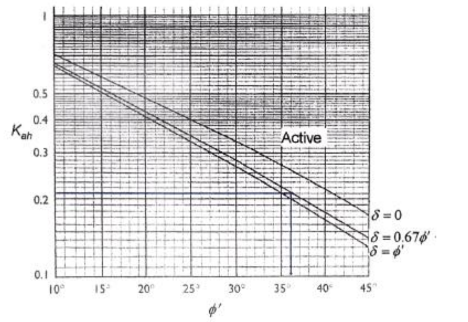
Terzaghi method

$$F_s = \frac{5.7 c_{ub} B_1}{(\gamma H B_1 + q B_1 - c_{uh} H)} \qquad B_1 = T, \text{ if } T \le 0.7B; \quad B_1 = 0.7B, \text{ if } T > 0.7B$$

Peck's apparent pressure diagram

Sand	Stiff clay $(\gamma H+q)/c_u \le 4$	Soft clay $(\gamma H+q)/c_u > 4$
		
Ground water beneath base of excavation		For deep deposit of soft clay, use m=0.4; otherwise use m=1

Kerisel and Absi chart for the coefficient of horizontal component of active pressure



CV4110 Excavation and Retaining Walls
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Q1(i)

(i) Basal Heave FS (Modified Terzaghi's Method) $= \dfrac{5.7 C_{ub} B_1 + C_{uh} H}{\gamma H B_1 + q B_1}$

$B_1 = 0.7B = 0.7(20) = 14m < T = 15m$

$= \dfrac{(5.7)(80)(14) + (60)(12)}{(17)(12)(14) + 20(14)}$ ~~= 2.27~~

Assumptions:

① Failure surface is circular and extends towards the ground surface.

② Wall is very stiff and does not affect the factor of safety

③ The depth of penetration of the embedded wall does not affect the factor of safety

Q1 (ii)

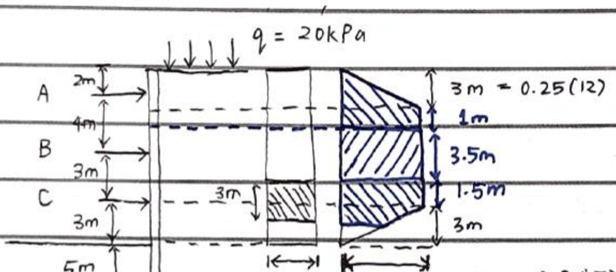
Using Peck's APD & tributary area method:

$H = 12m$

Stability Number:

$\dfrac{\gamma H + q}{C_u} = \dfrac{(17)(12) + 20}{60}$

$= 3.73 \leq 4$



$p = 0.3\gamma H = 0.3(17)(12) = 61.2 kPa$

$F_A = (3.0)(20 \times 4 + \frac{1}{2} \times (4+1) \times 61.2) = 699$ kN per strut

$F_B = (3.0)(20 \times 3.5 + 61.2 \times 3.5) = 852.6$ kN per strut

$F_C = (3.0)(20 \times 3 + 1.5 \times 61.2 + 0.5 \times 1.5 \times (61.2 + 30.6))$

$= 661.95$ kN per strut.

Estimated $M_{max} = P(d_{max})^2/10 = (20+61.2)(4)^2/10 = 129.92$ kN m/m

Q1(iii)

Alternative design → Omit Strut level C

Horizontal Wall Deflection : The lack of a strut level at the initial level will result in no support for the lateral earth pressures, causing the wall deflection to increase.

Ground settlement : Ground settlement is closely related to horizontal wall deflection and hence, larger ground settlement would also be expected.

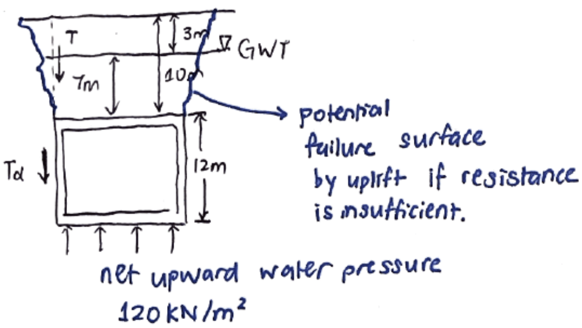
Forces in the struts : Since there are only 2 levels of struts to take the lateral loads, the forces will increase significantly, specifically for the struts at the second level.

Basal Heave stability : The FS for basal heave is expected to reduce as it is closely related to horizontal wall deflections.

Q2(a)

(i) Net uplift force on the underground structure

$= (12+7-7)(10)(20)(50)$
$= (2400\ kN/m)(50)$
$= 120\ 000\ kN$



(ii) $K_o = 0.43$

Concrete - Sand Interface Friction, $\delta' = 20^\circ$

Determine FS uplift :

For T :

At 5m, $\sigma_v' = (3 \times 21) + (21-10)(2) = 85 kPa$

$T = (85 kPa)(0.43)(\tan 35^\circ)(10m) = 255.9\ kN/m$

For Td :

At 16m, $\sigma_v' = (3 \times 21) + (21-10)(13) = 206 kPa$

$T_d = (206 kPa)(0.43)(\tan 20^\circ)(12m) = 386.9\ kN/m$

For Weight of Soil :

Weight $= (3 \times 20)(21) + (7 \times 20)(21-10) = 2800\ kN/m$

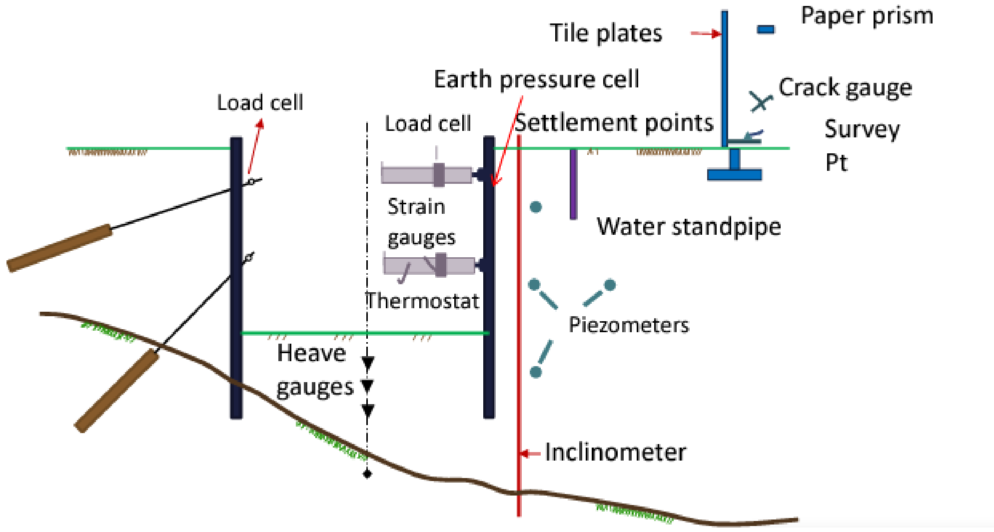
$$FS\ (uplift) = \frac{2800 + 1500 + 2(255.9) + 2(386.9)}{2400}$$

$= 2.327$ //

Q2(b)(i) (ii)

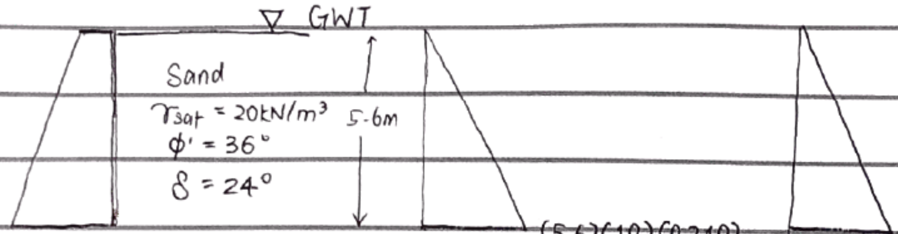
Main considerations in designing excavation support system:

- **Heave Gauge:** To check the factor of safety against basal heave, caused by failure of the soil surrounding the excavation/retaining walls
- **Piezometer:** To check if the de-watering is sufficient to prevent uplift failure caused by the upward water pressure
- **Strain Gauges, Thermostats:** To check the excavation support structural components, namely the struts and the walers, such that the fore taken by these components are within capacity
- **Inclinometers:** Check for potential settlement surrounding the basement which can be done by checking the horizontal wall movements



From CV4110 Notes: Design Codes and Instrumentation

Q3(a)



(5.6)(10)(0.210) = 11.76kPa

(10)(5.6) = 56kPa

$\delta/\phi' = 24/36 = 0.67$

From the Kerisel & Absi Chart, $K_{ah} = 0.210$

Total Horizontal Thrust $= \frac{1}{2}(11.76)(5.6) + \frac{1}{2}(56)(5.6)$

$= 32.928 + 156.8 = 189.73$ kN/m

Q3(b)(i)

$$\Delta H = \frac{h}{8} = \frac{5.6}{8} = 0.7m$$

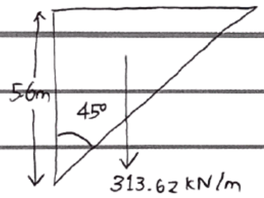
$$At\ point\ M, total\ head = 5.6 - 2(0.7) = 4.2m$$

$$Elevation\ head = \frac{5.6}{2} = 2.8m$$

$$Pressure\ head = 4.2 - 2.8 = 1.4m$$

$$Pressure = 1.4(10) = 14kPa$$

Q3(b)(ii)



$\cos 45° = \frac{5.6}{H}$

Length of hypotenuse $= 5.6/\cos 45° = 7.92\,m$

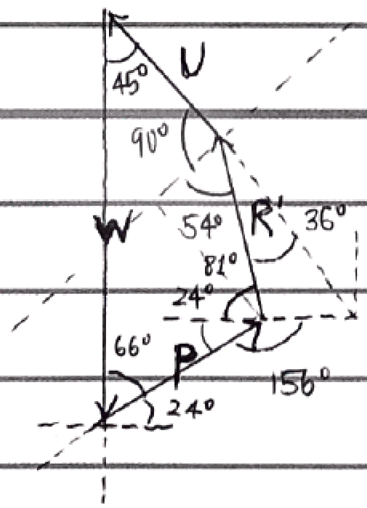
$\gamma \times$ Area of triangle = Weight of Triangular Component

$= 20 \times \frac{1}{2}(5.6)(7.92)\sin 45°$

$= 313.62\ kN/m$

Q3(b)(iii)

Force Polygon: (Enclosed ⇒ No Resultant Force)



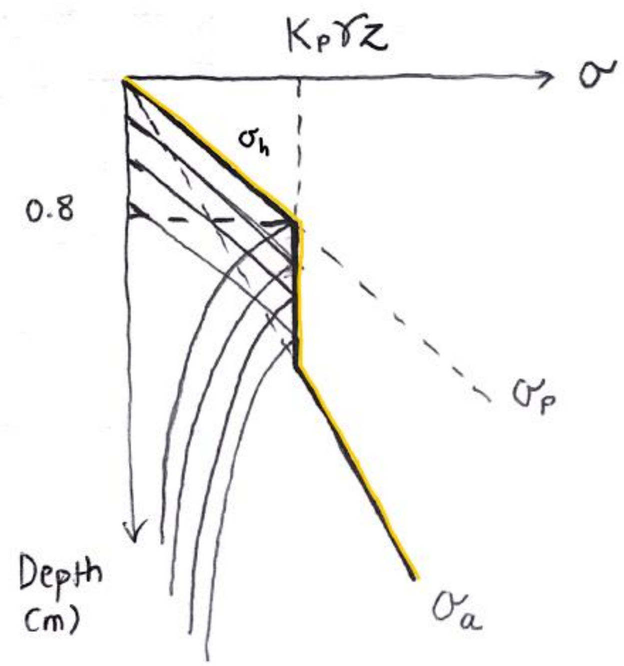
The force P_a can be solved by drawing the force polygon to scale and with accuracy such that the angles of the forces should be measured to precision. The length of the vector for P will hence give the magnitude of the force.

Q3(c)

If front and back is flooded with water, water pressure will cancel out each other

Therefore, horizontal thrust = 32.928kN/m

Q3(d) Compaction-Induced Lateral Earth Pressure



CV4110 Excavation and Retaining Walls
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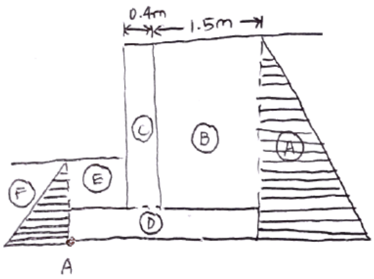
Q4) Dry Granular Backfill

$\gamma_{soil} = 18 kN/m^3$, $\phi' = 34°$

Allowable axial load on each pile = 130kN

(a) Compute total horizontal thrust & overturning moment

$$K_a = \frac{1 - \sin 34°}{1 + \sin 34°} = 0.283$$



$P_a = \frac{1}{2} H^2 \gamma K_a = \frac{1}{2}(5.4)^2(18)(0.283) = 74.27 kN/m$

Overturning Moment of Active Thrust = $(74.27)(\frac{1}{3} \times 5.4) = 133.69 kN m/m$

Q4(b)

Component	Force (kN/m)	Lever Arm (m)	Moment
A	74.27	1.8	133.69
B	(1.5)(4.8)(18) = 129.6	$0.8 + 0.4 + \frac{1.5}{2} = 1.95$	252.72
C	(0.4)(4.8)(24) = 46.08	0.8+0.2 = 1.0	46.08 //
D	(2.7)(0.6)(24) = 38.88	2.7/2 = 1.35	52.49 //
E	(0.8)(0.6)(18) = 8.64	0.8/2 = 0.4	3.456 //
F	$\frac{1}{2}(1.2)^2(0.283^{-1})(18) = 45.8$	0.4	18.32

Q4(c)

Distance of resultant active horizontal force to the toe = 1.8m

$$\frac{\Sigma M_R - \Sigma M_O}{\Sigma F_V} = 0.9904 m$$

Where Resisting Moment = 252.72 + 46.08 + 52.49 + 3.456 = 354.75 kNm/m

Overturning Moment = 133.69 kNm/m

Vertical Force = 46.08 + 38.88 + 8.64 + 129.6 = 223.2 kN/m

Q4(d)

Eccentricity = 0.134 m

Q4(e)

Row 1 = 122.6kN

Row 2 = 99.75kN

Row 3 = 73kN

Q4(f)

It could be difficult and challenging to construct as piling is required to be performed before constructing the retaining wall. This also means that it could be costly as compared to cheaper alternatives such as sheet-pile walls.

- END -