CV4110 Excavation and Retaining Walls
Semester 1 Examination 2022-2023
Suggested Solutions by Lim Kai Jian

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2022-2023

CV4110 – EXCAVATION AND RETAINING WALLS

November / December 2022 **Time Allowed: 2 hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer **ALL** questions.
3. All questions carry equal marks.
4. An **APPENDIX** of **TWO (2)** pages is attached to the Question Paper.
5. This is a Closed-Book Examination.
6. All answers must be written in the Answer Book provided. Answer each question beginning on a **FRESH** page of the Answer Book.

---

1. Figure Q1 shows a mechanically stabilized earth (MSE) wall. The groundwater table is far below the base of the wall. The soil behind the wall has an effective cohesion (c') of 0 kPa, effective friction angle (ϕ') of 33°, and unit weight (γ) of 17 kN/m³. The fill in the MSE wall has a unit weight of 18 kN/m³. The interface friction angle between the natural ground and the base of the retaining wall (δ) is 31°. A surcharge of 30 kPa is applied on the ground surface behind the wall as shown in Figure Q1. Answer the following questions.

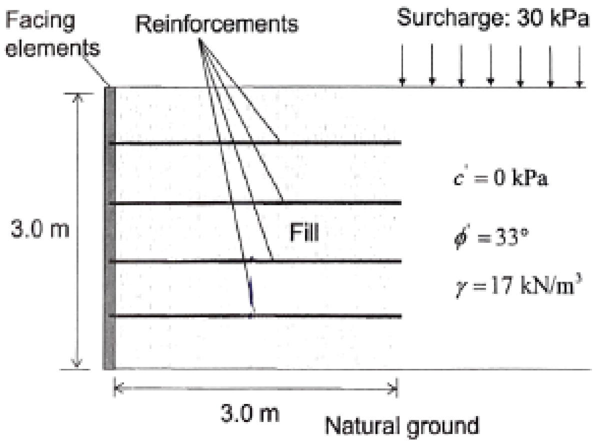


Figure Q1 (not to scale)

Note: Question No.1 continues on Page 2.

(a) Briefly describe the requirements for fill material used in MSE wall.

(3 Marks)

(b) Apply Rankine's earth pressure theory and use traditional design approach to:

(i) Calculate the factor of safety of the MSE wall with respect to sliding failure. Sketch the forces and pressures used for the analysis.

(8 Marks)

(ii) Calculate the factor of safety of the MSE wall with respect to overturning failure.

(6 Marks)

(iii) Check whether the eccentricity of the resultant force acting on the MSE wall is less than $B/6$ (B is the width of the wall).

(3 Marks)

(iv) Calculate the average bearing pressure of the MSE wall using Meyerhof's simplified pressure distribution method (i.e. equivalent wall width $B'=B-2e$).

(3 Marks)

(c) What are the internal failure modes of MSE wall?

(2 Marks)

2. Figure Q2 shows a thin retaining wall inserted in an impermeable clay to a depth of 2.2 m. On the left side of the wall, there is a sand layer with a thickness of 5.4 m. The water table levels are different on the two sides of the wall, as shown in Figure Q2. The characteristic effective cohesion, effective friction angle, and total unit weight of the sand are 0 kPa, 35°, and 21 kN/m³, respectively. The characteristic total unit weight and undrained shear strength of the clay are 19 kN/m³ and 60 kPa, respectively. The horizontal spacing of the anchors is 2.2 m. The unit weight of water is 10 kN/m³.

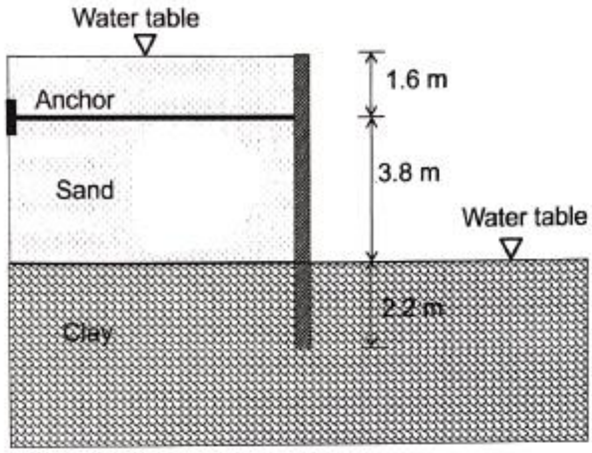


Figure Q2 (not to scale)

(a) Briefly describe the Single Source Principle.

(4 Marks)

(b) Applying the Free Earth Support method and Single Source Principle, sketch the net soil/water pressures and forces acting on the wall.

(5 Marks)

(c) Applying the Free Earth Support method, the Rankine's earth pressure theory and the EC7 Design Approach 1, Combination 2 (see Appendix), calculate:

(i) The over design factor of the wall with respect to kicking out failure.

(8 Marks)

(ii) The force in each anchor.

(4 Marks)

(iii) The maximum bending moment of the wall.

(4 Marks)

3. Figure Q3 shows the cross-section of a 5 m deep, 3 m wide and 20 m long excavation. The excavation is supported by sheetpiles with two levels of struts. The ground comprises a 1 m thick fill layer overlying a deep layer of clay. The groundwater table is 1 m below the original ground surface. A surcharge q acts on the original ground surface. The fill has a total unit weight γ of 18 kN/m³ and an undrained shear strength c_u of 30 kPa. The clay has a total unit weight of 16 kN/m³ and an undrained shear strength $c_u = 25 + 1.3z$ (kPa) as shown in Figure Q3. The average wall-soil adhesion c_A is 32 kPa.

(a) Determine the basal heave factor of safety using the Bjerrum and Eide method and the Eide et al. method.

(15 Marks)

(b) Using the CIRIA distributed prop load (DPL) distribution for Class BF soils as shown in the Appendix and the tributary area method, determine the magnitude of the force acting on each strut, assuming the horizontal strut spacing is 4 m. Indicate whether the forces on the struts are compressive or tensile. Estimate the maximum wall bending moment.

(10 Marks)

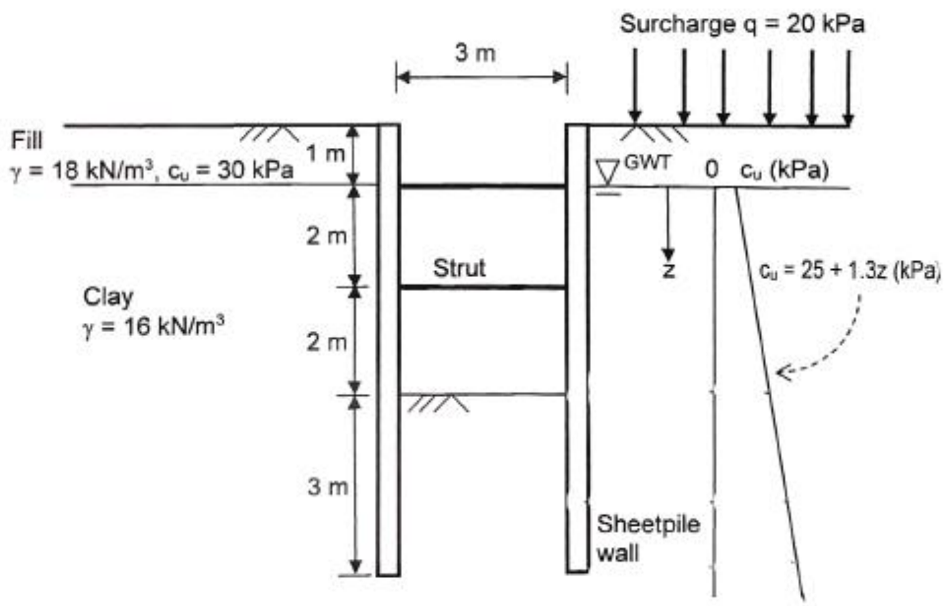


Figure Q3

4. (a) Figure Q4 shows a 12 m deep, 15 m wide and 60 m long excavation in a deposit of clay underlain by a dense sand layer. The existing groundwater table is 3 m below the ground surface. The excavation is supported by sheetpiles and three levels of internal struts. The properties of the clay are: γ = 17 kN/m^3, c_u = 50 kPa, ϕ_u = 0 and E_u = 300c_u.

(i) An inclinometer is to be installed prior to the excavation to monitor the lateral wall displacement during soil excavation and strut installation. Indicate whether an in-wall or in-soil inclinometer is to be used. With the aid of a sketch, indicate the recommended location of the inclinometer and the depth of the inclinometer.

(3 Marks)

(ii) Sketch the expected lateral wall displacement profile following the excavation of 3 m of soil before the installation of the 1st level of struts. No mathematical calculations are required.

(3 Marks)

(iii) Sketch the expected lateral wall displacement profile following the excavation to the final excavation level after the installation of the final level of struts. Estimate the maximum wall deflection using the Wong and Broms method. Assume the failure ratio R_f is 0.7.

(11 Marks)

(b) It is proposed to construct a 3 m thick jet grout layer prior to the commencement of excavation. Sketch the location where the jet grout should be placed. Without carrying out any calculations, briefly explain how the jet grout layer would affect the wall lateral deflection, the ground settlement and the strut forces compared to the case when there is no jet grout layer.

(8 Marks)

Note: Question No. 4 continues on Page 6.

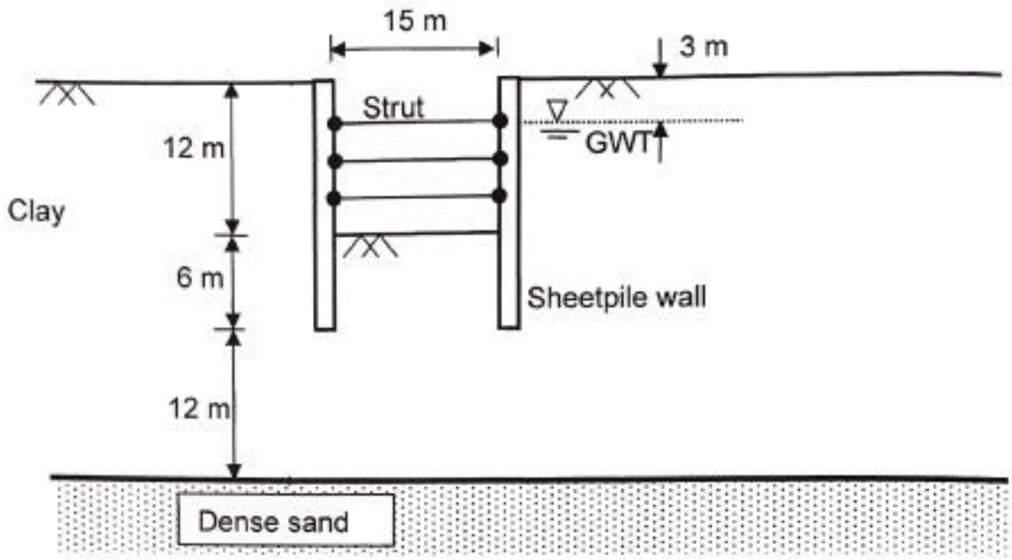


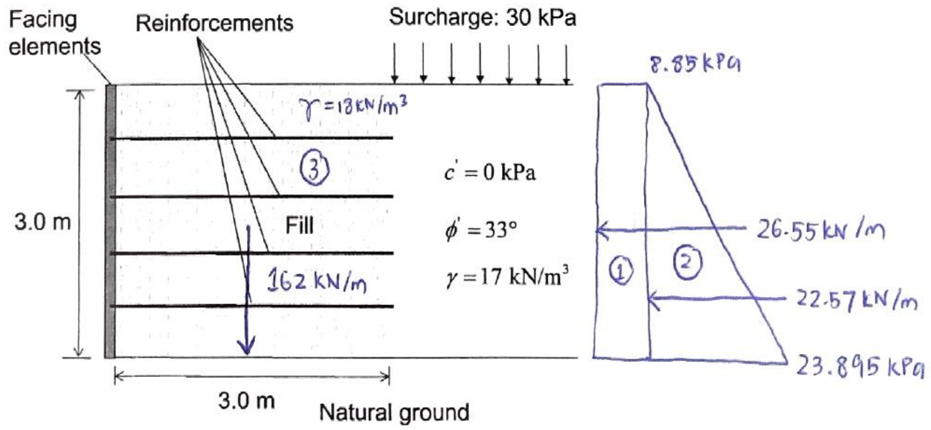
Figure Q4

END OF PAPER

Q1 (a)

MSE walls should be filled using granular material such as sand such that it ensures high friction between reinforcement and soil to prevent slippage failure. Granular material also ensures that the fill is permeable and prevents build-up of pore pressure. For durability of the reinforcements, the soil should have a pH of around 5-10.

(b)(i)



Component	Force (kN/m)	Lever Arm to Toe (m)	Moment (kNm/m)
①	$30(0.295)(3.0) = 26.55$	1.5	39.825
②	$\frac{1}{2} \times 17 \times 3^2 \times 0.295 = 22.57$	$\frac{1}{3}(3) = 1.0$	22.57
③	$(3.0 \times 3.0)(18.0) = 162$	1.5	243

(b)(i) $FS_{sliding} = (162 \times \tan 31°) / (26.55 + 22.57) = 1.98 > 1.5 \Rightarrow$ OK!

(b)(ii) $FS_{overturning} = 243 / (39.825 + 22.57) = 3.89 > 2.0 \Rightarrow$ OK!

(b)(iii) $e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_O}{\Sigma F_V} = 1.5 - \frac{243 - (39.825 + 22.57)}{162}$

$= 0.385 < \frac{B}{6} = 0.5 \Rightarrow$ OK!

(b)(iv) Average Bearing Pressure $= (162)/(3 - 2 \times 0.385)$

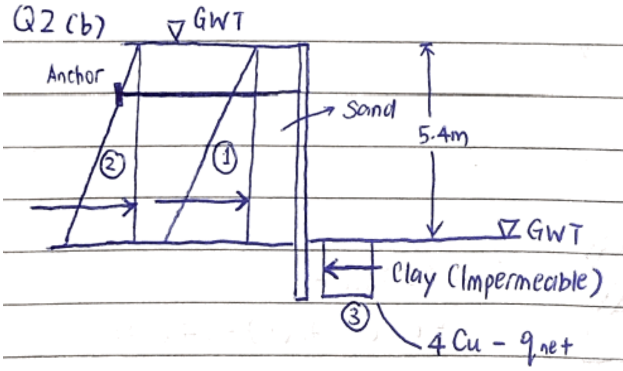
$= 72.6$ kPa //

(c) Slippage Failure and Rupture of Reinforcement.

Q2 (a)

Single source principle states that unfavourable and favourable permanent actions may in some situations be considered as coming from a single source. If they are considered so, a single partial factor may be applied to the sum of these actions or to the sum of their effects.

(b)



Sand:

$\phi'_d = \tan^{-1}\left(\frac{\tan 35°}{1.25}\right) = 29.26°$

$K_a = 0.343$

Clay:

$C_{ud} = 60/1.4 = 42.86\ kPa$

(c) (i)

Component	Force (kN/m)	Lever arm to Anchor (m)	Moment (kNm/m)
①	$\frac{1}{2}(0.343)(5.4)^2(11) = 55.01$	$5.4(\frac{2}{3}) - 1.6 = 2.0$	110.02
②	$\frac{1}{2}(5.4)^2(10) = 145.8$	2.0	291.60
③	$[4(42.86) - (21 \times 5.4)](2.2) = 127.7$	$3.8 + \frac{2.2}{2} = 4.9$	625.73

ODF for kicking out failure = 625.73 / (110.02 + 291.60) = 1.56 > 1

⇒ OK!

(c)(ii) Force per metre run of anchor

= 55.01 + 145.8 − 127.7

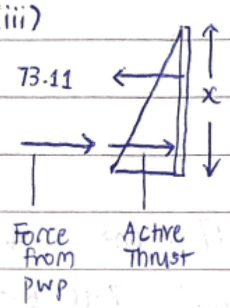
= 73.11 kN/m

Force in each anchor = 73.11 (2.2)

= 160.8 kN

Q2(c)(iii)

(iii)



$\frac{1}{2}(x)^2(0.343)(11) + \frac{1}{2}(x^2)(10) = 73.11$

$6.89x^2 = 73.11$

$x = 3.26m$

Force from pwp $= \frac{1}{2}(3.26)^2(10) = 53.14$

Force from active earth pressure

$= \frac{1}{2}(3.26)^2(0.343)(11) = 20.05$

Maximum B.M =

$73.11(3.26 - 1.6) - (53.14 + 20.05)(\frac{1}{3} \times 3.26)$

$= 41.8$ kNm/m

Q3

Q3 (a) Bjerrum & Eide Method:

$H = 5m, \; B = 3m, \; L = 20m$

$B_1 = 0.7B = 0.7(3) = 2.1\,m \quad (T > 0.7B)$

$H/B = 5/3 = 1.67 < 2.5$

$N_c = 5(1 + 0.2 \times 1.67)(1 + 0.2 \times 3/20) = 6.87$

$C_{ub} = \frac{30.2 + 32.93}{2} = 31.565\,kPa$ (avg C_u from formation level to B_1 depth below)

$F_s = \frac{31.565(6.87)}{16.4(5) + 20} = 2.13$ //

$\gamma_{avg} = \frac{18 \times 1 + 16 \times 4}{5} = 16.4\,kN/m^3$

Eide Method: $H = 5m, \; B = 3m, \; D = 3m, \; L = 20m$

$C_{ub} = \frac{1}{2}(34.1 + 36.83) = 35.465\,kPa$

$C_A = 32\,kPa$

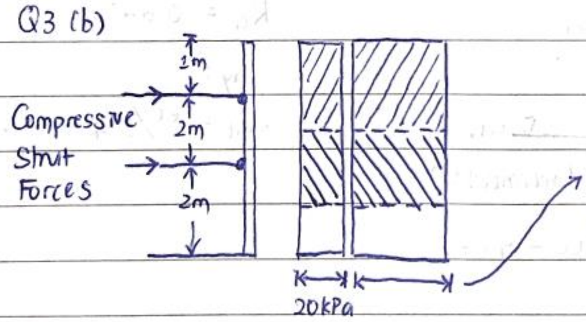
$\frac{H + D}{B} = \frac{5 + 3}{3} = 2.67 > 2.5$

$N_c = 7.5\left(1 + 0.2 \times \frac{3}{20}\right) = 7.725$

$F_s = \frac{35.465 \times 7.725 + 32(2 \times 3 \times 3 + 2 \times 3 \times 20)\left(\frac{1}{3 \times 20}\right)}{16.4(5) + 20}$

$= 3.41$ //

Q3 (b)



$0.3\,\gamma_{ave} H = 0.3(16.4)(5) = 24.6\,kPa$

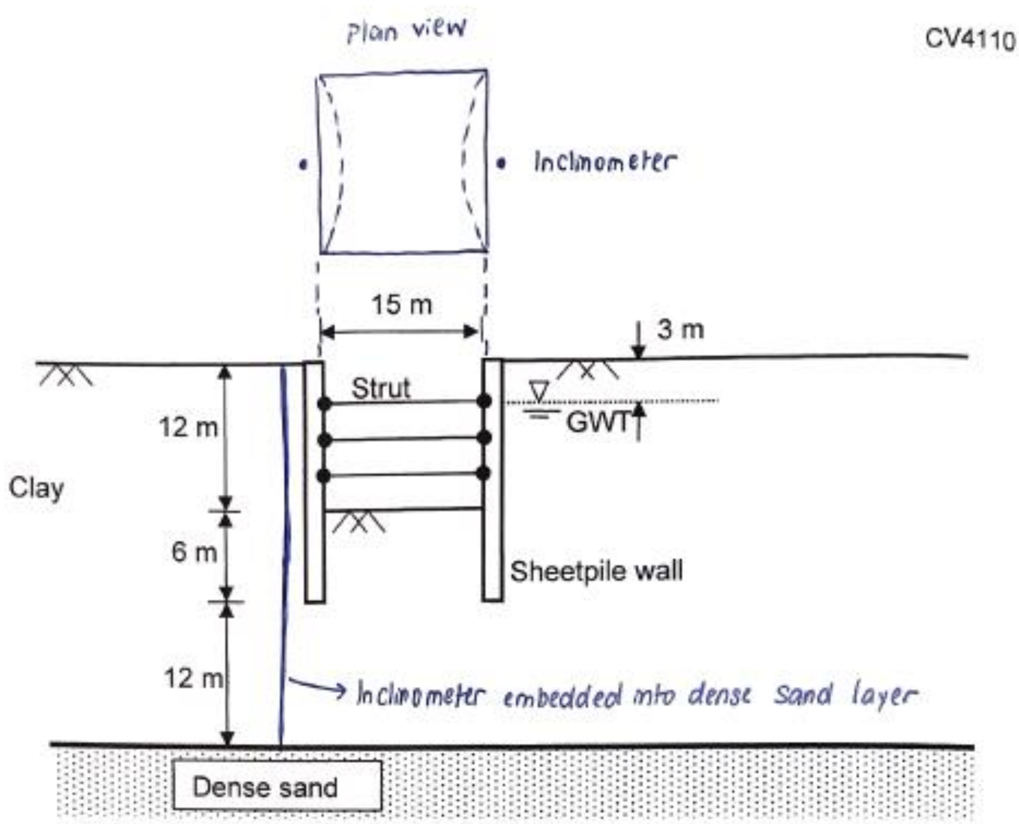
(per m) Strut Level A Force $= (20 \times 2) + (24.6 \times 2) = 89.2\,kN/m$

(per m) Strut Level B Force $= (20 \times 2) + (24.6 \times 2) = 89.2\,kN/m$

Force in each strut $= 89.2(4) = 356.8\,kN$

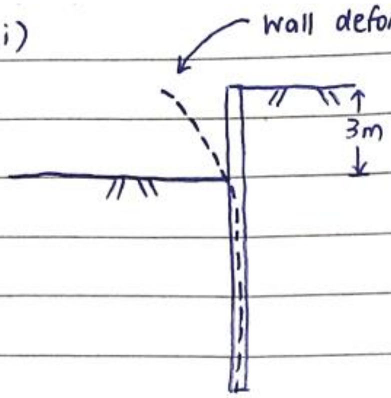
Est. Max B.M $= (2^2)(20 + 24.6)(1/10) = 17.84\,kNm/m$

Q4 (a)(i)

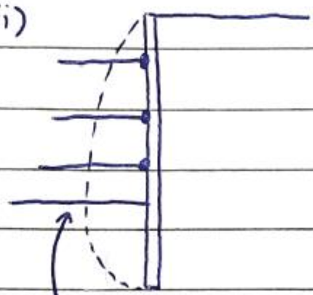


In-soil inclinometer should be used since the retaining wall is a sheet pile wall. It should be placed closely to the sheet pile walls and should be placed at the centre location where deflection is expected to be the greatest.

Q4 (a) (ii)



(a)(iii)



$R_f = 0.7$

$S_L = \frac{\gamma H + q}{C_u N_c} = \frac{(17)(12)}{(6.09)(50)} = 0.67$

$H/B = 12/15 = 0.8 < 2.5$

$N_c = 5(1 + 0.2 \times \frac{15}{60})(1 + 0.2 \times 0.8) = 6.09$

$E_s = (1 - 0.67 \times 0.7)(300 \times 50) = 7965 \text{ kPa}$

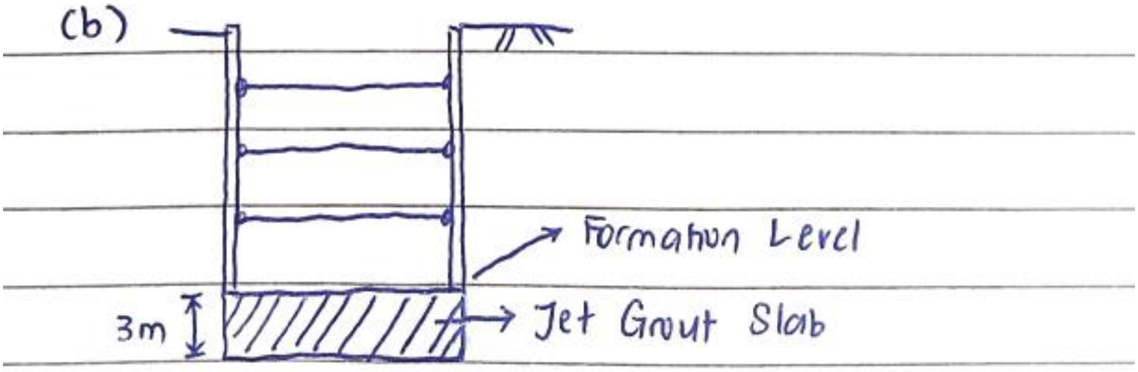
$T = 6 + 12 = 18 \text{ m} > B/2 = 15/2 = 7.5 \text{ m}$

$(\delta_h)_{max} = (0.35 \gamma H \frac{B}{2}) / E_s$

$= (0.35 \times 17 \times 12 \times \frac{15}{2}) / 7965$

$= 0.0672 \text{ m} = 67.2 \text{ mm}$ //

Q4(b)



- Th jet grout should be placed at somewhere near where the formation level is expected to be, before excavation commences.
- The jet grout slab layer helps to increase the modulus and shear strength of the clay layer near the formation level and helps to reduce lateral wall deflection.
- It also helps to reduce the strut forces, more significantly for the strut level closer to the grout slab since the slab can help to take some load.
- Furthermore, it also helps to reduce the ground settlement as basal heave is restricted due to the grout slab layer hence.

- END -