NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2017-2018

CV2014 - GEOTECHNICAL ENGINEERING

April / May 2018 **Time Allowed: 2½ hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer all **FOUR (4)** questions.
3. All questions carry equal marks.
4. An **APPENDIX** of **ONE (1)** page is attached to the Question Paper.
5. This is a Restricted Open-Book Examination. You may bring in **ONE (1)** piece of A4 size paper with notes written on both sides.

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1. (a) An unconsolidated undrained (UU) triaxial test was carried out on a fully saturated clay specimen under a cell pressure of 100 kPa. The specimen was 38 mm in diameter and 72 mm in height. The maximum axial load measured was 200 N when the axial deformation is 7.2 mm.

   (i) Calculate the deviator stress at failure;
   (ii) Sketch the total stress Mohr circle and determine the undrained shear strength of the clay;
   (iii) Given the residual pore water pressure in the soil specimen is 45 kPa, what would be the initial effective cell pressure applied on this soil specimen? Would the initial effective cell pressure increase, decrease or remain the same if the UU test were carried out using a cell pressure of 400 kPa?
   (iv) Explain the reasons why the undrained shear strength determined by UU test is not reliable.

   (12 marks)

   (b) An isotropically consolidated undrained (CU) triaxial test was carried out on a normally consolidated (NC) clay specimen under a consolidation stress of 150 kPa without the use of back pressure. The deviator stress at failure was 200 kPa. Given the effective friction angle of the soil is 30 degrees,

   (i) Calculate the pore water pressure at failure;
   (ii) Plot both the effective stress and total stress Mohr circles at failure;
   (iii) Determine the normal stress and shear stress on the failure plane;
   (iv) Plot schematically the deviator stress versus axial strain curve and the pore water pressure change versus axial strain curve;
   (v) The water content of the specimen before the CU test was 60%. Explain briefly whether the water content of the specimen at the end of the test would be higher or lower than 60%.

   (13 marks)

2. (a) A 8 m high retaining wall is shown in Figure Q2(a). The top 6 m of soil behind the wall is sand and the bottom 2 m is clay. The water table is at 8 m above the base of the wall. The soil properties of the sand and clay are given in Figure Q2(a). Use Rankine's theory for the following problems (you may use unit weight of water as 10 kN/m^3):

(i) Calculate the active earth pressure at 6 m and 8 m below the top of the wall respectively. Plot the active earth pressure distribution along the wall and calculate the total thrust on the wall;

(ii) Calculate the total thrust on the wall <u>when the water table is at 2 m above the base of the wall</u>;

(iii) Explain the effect of water table variation on the total thrust on the wall. Suggest a method that can be used to reduce the total thrust on the wall.

(17 marks)

(b) A vertical trench is to be cut in a layer of clay with an undrained shear strength of 20 kPa and total unit weight of 20 kN/m^3. Calculate the maximum excavation depth that the trench can stand without support using Rankine's earth pressure theory.

(3 marks)

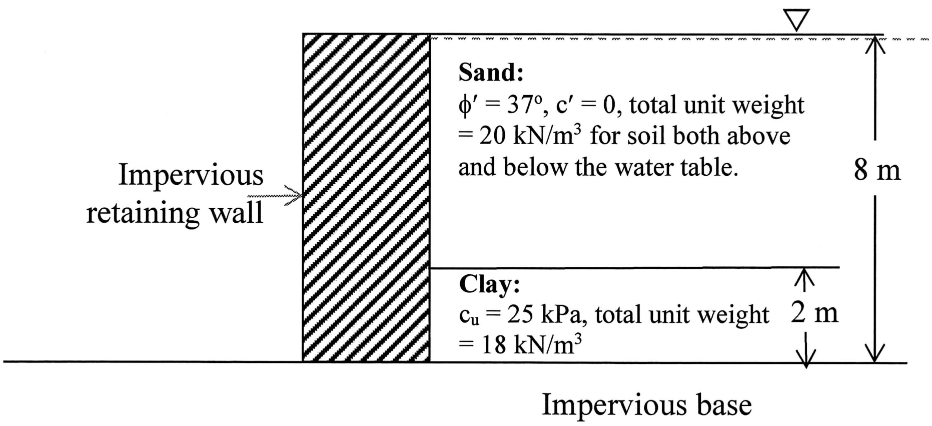


Figure Q2(a)

Note: Question No. 2 continues on page 3.

(c) The foot print of a building is made of a square of 20 m by 20 m and a rectangle of 20 m by 10 m. Uniformly distributed loads of 100 kPa and 200 kPa are applied as shown in Figure Q2(b). Calculate the increase in vertical stress at 10 m below point A.

(5 marks)

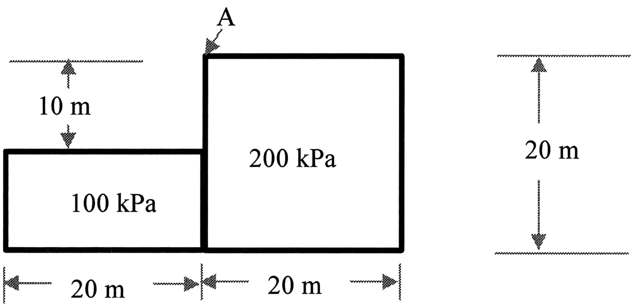


Figure Q2(b)

Note: Relevant tables and formulas are included in the APPENDIX.

3. Figure Q3 shows a long slope of a residual soil with a unit weight of 19 kN/m^3 above water table and 20 kN/m^3 below water table and shear strength parameters of c' = 0 and ϕ' = 33°. The slope is inclined at 27° to the horizontal. A potential failure surface on a plane parallel to the slope surface is located at a depth of 5 m. The water table is always parallel to the slope surface at a height of mz ($0 \le m \le 1$) above the potential failure plane. The height of the water table may vary from the potential failure plane to the slope surface. A piezometer is installed at a point on the potential failure plane.

(a) (i) Briefly explain the purpose of installing the piezometer and what is measured by the piezometer.

(ii) Derive the ratio between the height of the water table and the height of the water level in the piezometer with respect to the potential failure plane. Briefly explain the reason why there is a difference between the height of the water table and the height of the water level in the piezometer.

(iii) Under what condition will the ratio between the height of the water table and the height of the water level in the piezometer with respect to the potential failure plane become one?

(iv) Under what condition will the ratio between the height of the water table and the height of the water level in the piezometer with respect to the potential failure plane become very large?

(10 marks)

(b) Determine the height of the water level in the piezometer at failure.

(5 marks)

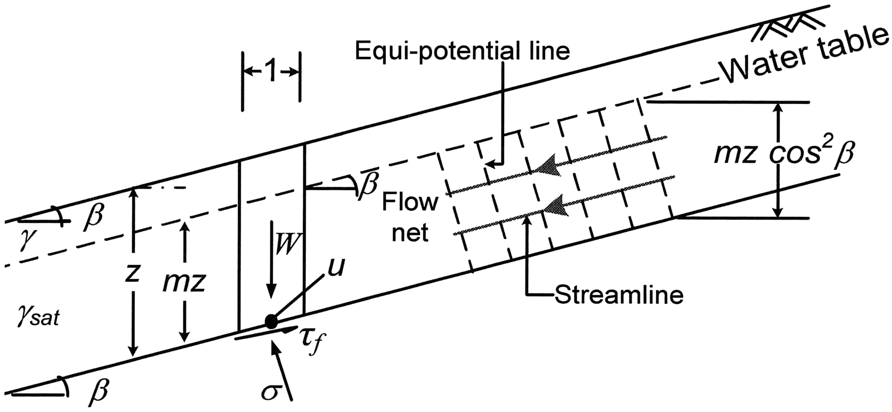
(c) The local building authority requires a minimum factor of safety of 1.5 to be maintained for every slope. Determine whether the slope meets this requirement.

(5 marks)

(d) The slope is improved by performing grouting that increases the effective cohesion of the soil. With other properties remaining the same, calculate the required minimum effective cohesion of the improved soil in order for the slope to have a minimum factor of safety of 1.5 when the water table rises to the slope surface.

(5 marks)

Note: Question No. 3 continues on page 5.



Plane Translational Slip

$$F = \frac{c' + \left[\left\{(1-m)\gamma + m\gamma_{sat}\right\} z\cos^2\beta - mz\gamma_w \cos^2\beta\right]\tan\phi'}{\left\{(1-m)\gamma + m\gamma_{sat}\right\} z\sin\beta\cos\beta}$$

Note:

	W	= total weight of the slice
	u	= pore water pressure at the centre of the base of the slice
	τ_f	= shear strength along the base of the slice
	σ	= normal stress on the base of the slice
	β	= inclination of the slope to the horizontal
	z	= depth of the failure plane
	F	= factor of safety
	γ	= unit weight of soil above water table
	γ_{sat}	= saturated unit weight of soil
	γ_w	= unit weight of water
	c'	= effective cohesion
	ϕ'	= effective friction angle of soil

Figure Q3

4. (a) A sand fill of 9 m thickness is hydraulically placed as part of a reclamation project with an average placement relative density of 40%. The sand has a maximum void ratio of 0.90 and a minimum void ratio of 0.2. An in-situ densification work is required to compact the sand fill to an average relative density of 95%. Briefly explain the working principle of an appropriate method that can be used for the densification of the sand deposit and calculate the expected settlement of the sand fill after the densification works.

(10 marks)

(b) A development site has 1 m thick loose fill below the ground surface, covering an area of approximately 200 m^2. The site needs to be improved by excavating the loose fill and compacting it back to the site with a specification that the relative compaction of the compacted fill must be at least 95% and the field moisture content must be within the range of 3% dry to 4.5% wet of optimum conditions. Briefly explain the necessary laboratory and field tests required for constructing the specified compacted fill. Explain the purpose of performing the required tests and the soil properties measured by each test.

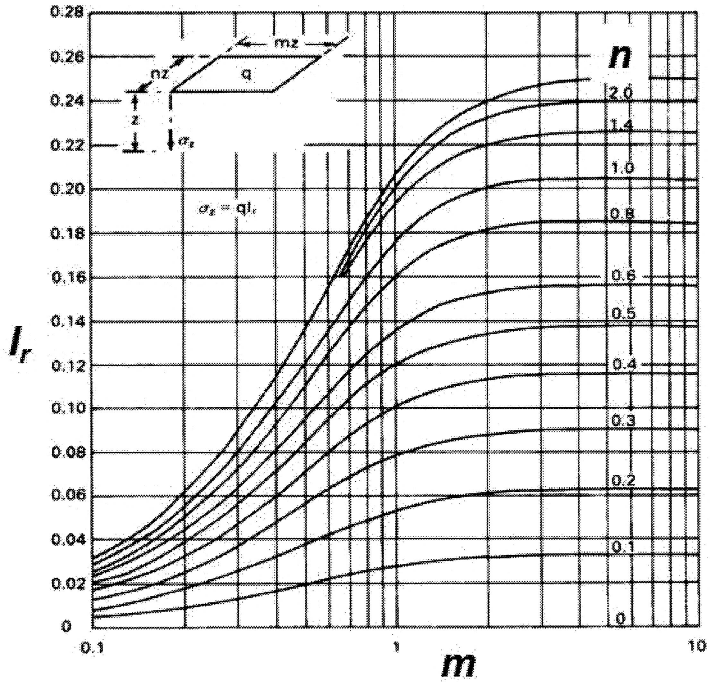
(10 marks)

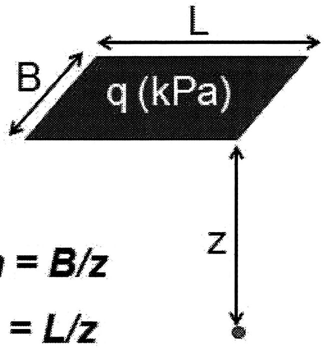
(c) Briefly discuss the objective of having a drainage system in slope stabilization using the principle of effective stress and the difference between surface drainage and subsurface drainage.

(5 marks)

END OF PAPER

Fadum's Chart





m* = *B/z

n* = *L/z

m and ***n*** are interchangeable

$$\Delta\sigma_z = q\, I_r$$

CV2014 GEOTECHNICAL ENGINEERING

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

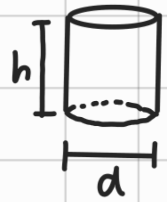
3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.

CV2014 2017/18 Sem 2

Renardi Muliawan (@pardirenardi)

1. (a) UU test

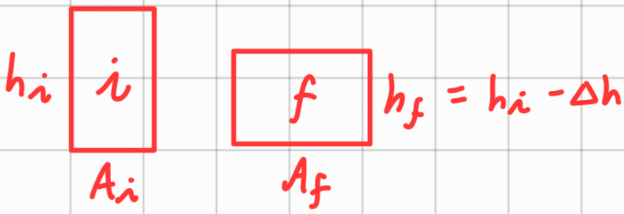


$A = \frac{\pi}{4} d^2$

$\sigma_3 = 100$ kPa $\quad F = 200$ N

$d_i = 38$ mm $\quad \Delta h = 7.2$ mm

$h_i = 72$ mm

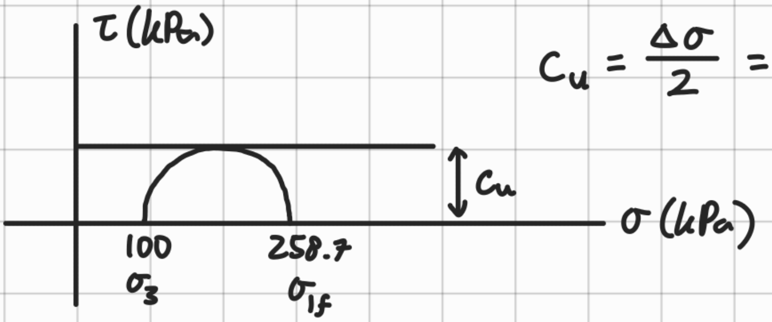


(i) $V_{initial} = V_{final} \Rightarrow A_i h_i = A_f h_f$

$$A_f = A_i\left(\frac{h_i}{h_f}\right) = \left(\frac{\pi}{4}(38)^2\right)\left(\frac{72}{72-7.2}\right) = 1260.13 \text{ mm}^2$$

$$\Delta\sigma = \frac{F}{A_f} = \frac{200 \text{ N}}{1260.13 \times 10^{-6} \text{ m}^2} \times 10^{-3} \text{ kPa} = 158.7 \text{ kPa}$$

(ii)



$$c_u = \frac{\Delta\sigma}{2} = \frac{158.7}{2} = 79.4 \text{ kPa}$$

(iii) $u = 45$ kPa $\quad \sigma_3' = 100 - 45 = 55$ kPa

Initial σ_3' would stay the same as it is independent of σ_3
(Unconsolidated → cell pressure is all carried by excess/residual u)

(iv) The test result is very sensitive to the sample's disturbance $-u_r$.

(b) (i) $\sigma_3 = 150$ kPa $\quad \Delta\sigma = 200$ kPa $\quad \phi' = 30°$

$$\frac{\sigma_{1f}'}{\sigma_{3f}'} = \frac{1 + \sin\phi'}{1 - \sin\phi'} = \frac{1 + \sin 30°}{1 - \sin 30°} = 3$$

$$\sigma_{1f}' = 3\sigma_{3f}'$$

$$\sigma_{1f}' = \sigma_{3f}' + \Delta\sigma$$

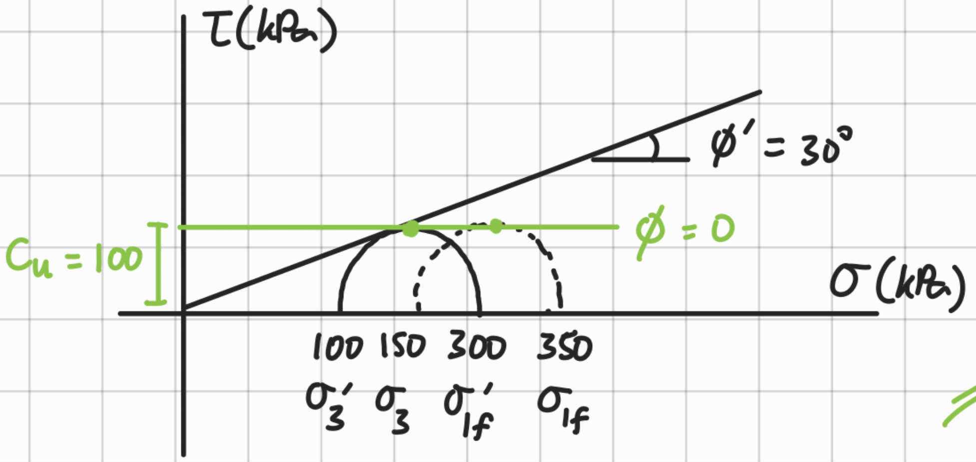
$$(\sigma_{3f}' + \Delta\sigma) = 3\sigma_{3f}'$$

$$\sigma_{3f}' = \frac{1}{2}\Delta\sigma = \frac{1}{2}(200) = 100 \text{ kPa}$$

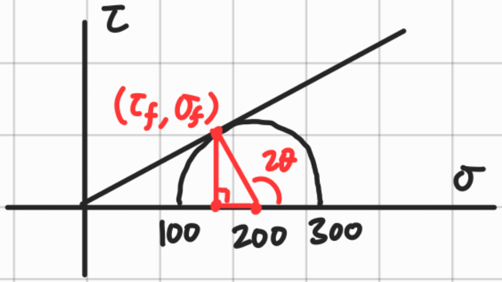
$$\sigma_3 = \sigma_3' + u_f$$

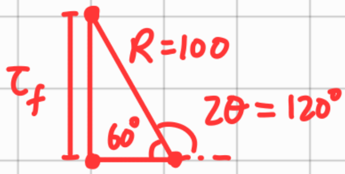
$$u_f = \sigma_3 - \sigma_3' = 150 - 100 = 50 \text{ kPa}$$

(ii) $\sigma_3 = 150\ kPa$ $\quad \sigma_3' = 100\ kPa$ $\quad \Delta\sigma = 200\ kPa$



(iii)



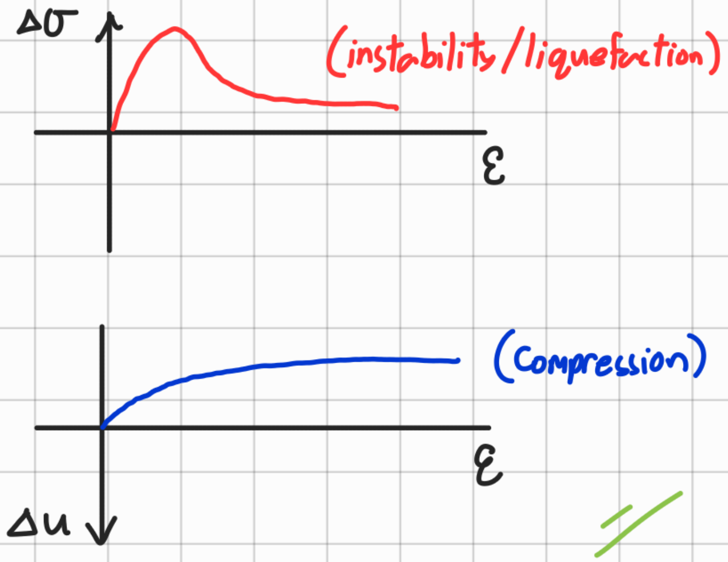


$$\theta = 45^\circ + \frac{\phi'}{2}$$
$$= 45^\circ + \frac{30^\circ}{2} = 60^\circ$$

$$\tau_f = 100 \sin 60^\circ = 86.6\ kPa$$

$$\sigma_f = 200 - 100 \cos 60^\circ = 150\ kPa$$

(iv) For CU, loose (NC) sand ...



(v) Water content would be lower as excess pore water pressure escapes due to consolidation.

Hence $V_w \downarrow \Rightarrow M_w \downarrow$

V_s stays $\Rightarrow M_s$ stays

$$w = \frac{M_w}{M_s} \downarrow$$

(2.) (a) $\gamma_w = 10\ kN/m^3$

$c' = 0$

$\gamma_s = 20\ kN/m^3$

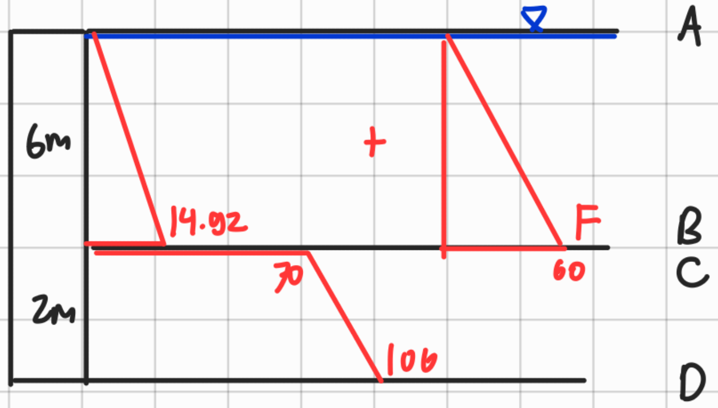
$\gamma_{sat} = 20 - 10 = 10\ kN/m^3$

$K_A = \frac{1 - \sin 37^\circ}{1 + \sin 37^\circ} = 0.2486$

$\gamma_c = 18\ kN/m^3$

$c_u = 25 kPa$

(i)



$\sigma_A' = 0$

$\sigma_B' = 0.2486(6 \times 10) = 14.92\ kPa$

(z, γ_{sat})

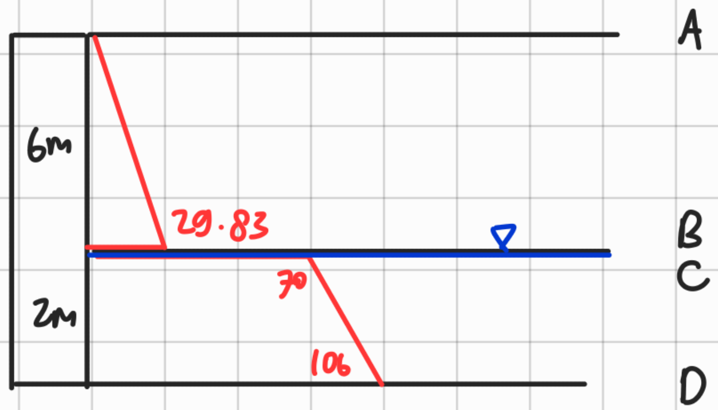
$\sigma_C = (20 \times 6) - 2(25) = 70\ kPa$

$\sigma_D = (20 \times 6 + 18 \times 2) - 2(25) = 106\ kPa$

$\sigma_F = 10 \times 6 = 60\ kPa$

$P_{thrust} = \frac{1}{2} \times 14.92 \times 6 + \frac{1}{2} \times 60 \times 6 + \frac{1}{2} \times (70 + 106) \times 2$
$= 400.76\ kN/m$

(ii)



$\sigma_B' = 0.2486(20 \times 6) = 29.83\ kPa$

$\sigma_C = (20 \times 6) - 2(25) = 70\ kPa$

$\sigma_D = (20 \times 6 + 18 \times 2) - 2(25) = 106\ kPa$

$P_{thrust} = \frac{1}{2} \times 29.83 \times 6 + \frac{1}{2} \times (70 + 106) \times 2 = 265.49\ kN/m$

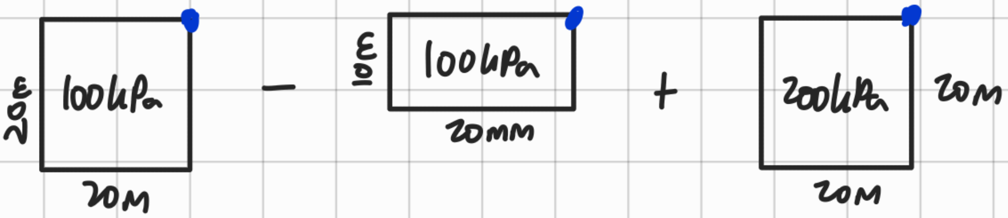
(iii) W.T. ↓ ⇒ P_{thrust} ↓, as it lowers the total vertical stress induced in the soil behind the wall.

Method to reduce P_{thrust}: Lower the water table by pumping it out. (from a well/drain)

(b) $c_u = 20$ kPa $\quad \gamma = 20$ kN/m³ $\quad \sigma_A = 0$

$$z = \frac{2c_u}{\gamma} = \frac{2 \times 20}{20} = 2m$$

(c)



$z = 10m$

$m = 1$	$m = 2$
$n = 2$	$n = 2$
$I_r = 0.1999$	$I_r \approx 0.231$

$$\Delta\sigma_z = 100(0.231) - 100(0.19999) + 200(0.231)$$
$$= 49.3 \text{ kPa}$$

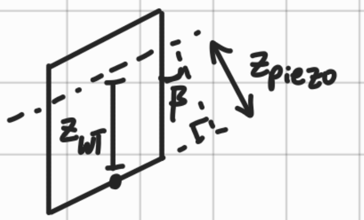
③ (a) $\gamma_{above\ H_2O} = 19$ kN/m³

$\gamma_{below\ H_2O} = 20$ kN/m³ → $\gamma_{sat} = 20 - 9.81 = 10.19$ kN/m³

$c' = 0 \quad \phi' = 33^\circ \quad \beta = 27^\circ \quad z = 5m$

(i) To measure positive pressures of groundwater (groundwater monitoring). In this case, to measure $u = \gamma_w z_{piezo}$.

(ii)



$$\frac{z_{piezo}}{z_{WT}} = \cos\beta$$

$$\frac{z_{WT}}{z_{piezo}} = \frac{1}{\cos 27^\circ} = 1.122$$

Difference as z_{WT} is measured vertically while z_{piezo} is measured as the length of the equipotential lines, which assumed to be perpendicular to the slope (as Flownets are assumed to be parallel to the slope).

(iii) $\beta = 0°$ a.k.a. horizontal slope.

(iv) Large β a.k.a. very, extremely, utterly, significantly steep slope.

(b) Failure $\rightarrow$ $F = 1$

$$1 = \frac{[(1-m)(19) + m(10.19 - 9.81)] \tan 33°}{[(1-m)(19) + m(10.19)] \tan 27°}$$

Solving for m, $m = 0.350$

$\therefore z_w = mz = 0.350 \times 5 = 1.75\ m$

(c)

$$1.5 = \frac{[(1-m)(19) + m(10.19 - 9.81)] \tan 33°}{[(1-m)(19) + m(10.19)] \tan 27°}$$

Solving, $m = -0.407$

As $m < 0$, $\therefore$ Slope does NOT meet requirements.

(d) Now $m = 1$; $c' = ?$ for $F = 1.5$?

Use full formula (see formula given in PYP)

$$1.5 = \frac{c' + [10.19 \times 5 \times \cos^2(27°) - 5 \times 9.81 \times \cos^2(27°)] \tan 33°}{10.19 \times 5 \times \sin 27° \times \cos 27°}$$

Solving, $c' = 29.9$ kPa

④ (a) $D_{r,i} = 40\%$ $e_{max} = 0.90$
$D_{r,target} = 95\%$ $e_{min} = 0.2$
$H_i = 9m$

- Giving vibrations to the sand in-situ would be preferred. Vibroflot method is a viable option. The method uses a probe with vibrator and water jet installed.
  The water jet creates a quick condition in the sand, allowing the probe to sink into the ground. The probe then is gradually raised with the vibrator that compacts the soil along the way. (Compaction effort ↑, better compaction)

- $$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$ (Lect. 4, Slide 29)

$$40\% = \frac{0.90 - e_i}{0.90 - 0.2} \Rightarrow e_i = 0.62$$

$$95\% = \frac{0.90 - e_f}{0.90 - 0.2} \Rightarrow e_f = 0.235$$

(Soil mech.) $$S_c = \frac{e_i - e_f}{1 + e_i} H = \frac{0.62 - 0.235}{1 + 0.62} \times 9 = 2.14\text{ m}$$

(b) Lab test : Proctor test, to determine the optimum water content and $(\gamma_d)_{max}$ of the soil used for the fill. Purpose is to set a reference for the "optimum" condition.

Field test : Sand cone test, to get dry density, γ, of the compacted fill and hence to find relative compaction, C_R. This is for quality control.

(c) To decrease the pore water pressure in the slope as pore water reduces the effective stress of the soil ($\sigma' = \sigma - u$).

Surface drainage : Prevents infiltration, happens on-surface
e.g. ditches, plastic sheets, culverts, ...

Subsurface drainage : Removes water in the slope, happens subsurface
e.g. perforated pipes, wells, horizontal drains, ...