NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2010-2011

CV2301 – SOIL MECHANICS

December 2010 **Time Allowed: 2½ hours**

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **SIX (6)** pages.
2. Answer **ALL** questions.
3. An **Appendix** of **THREE (3)** pages is attached to the Question Paper.
4. This is a Closed-Book Examination.
5. All questions carry equal marks.

---

1. (a) A perfectly dry sand sample completely fills a cylinder. Determine the void ratio e and porosity n of the sand in terms of the volume of the cylinder V, the specific gravity of the soil solids G_s, the unit weight of water γ_w and the dry weight of the sand enclosed in the cylinder W_s.

(4 Marks)

(b) A compacted soil sample has a total unit weight of 16 kN/m^3 and a moisture content of 8%. Determine the degree of saturation and void ratio of the soil. What would the moisture content have been if the soil had been fully saturated? Assume the unit weight of water γ_w = 9.81 kN/m^3 and the specific gravity of the soil solids G_s = 2.70.

(8 Marks)

(c) State the physical properties considered in classifying soils using the Unified Soil Classification System. What laboratory tests are required to determine these physical properties? Briefly discuss the main characteristics of well graded and gap graded soils.

(7 Marks)

(d) A project site for a proposed dam is described as covered with glacial deposits overlain by alluvial sands. What are glacial deposits and alluvial sands? Explain how they are formed. What differences do you commonly find in the particle size distribution of glacial deposits versus alluvial deposits?

(6 Marks)

2. (a) Figure Q2 shows an excavation through a deposit of silty sand near a river to form a temporary trench. Steel sheet pile walls at the sides of the excavation ensure stability of the excavation. Pumps are used within the trench to pump water away so that construction work can proceed in the dry inside the excavated area. A standpipe inserted at point A shows a pressure head of 8 m. In all calculations assume the total unit weight of the soil above and below the groundwater table is the same and the unit weight of water $\gamma_w = 9.81$ kN/m^3. The properties of the soils are shown below:

Soil	Total unit weight (kN/m^3)	Coefficient of lateral earth pressure K
Silty sand	20	0.5
Clay	16	0.7
Sandy gravel	22	0.4

(i) Determine the total vertical stress, effective vertical stress and pore water pressure at point A.

(ii) With respect to the datum shown, determine the total head and elevation head at point A.

(iii) Determine the total horizontal stress and effective horizontal stress at point A.

(iv) With respect to the datum shown, determine the total head at point C. Calculate the hydraulic gradient for upward flow of water between the sheet piles, assuming one-dimensional steady-state flow of water in the clay layer.

(v) Determine the total vertical stress, effective vertical stress and pore water pressure at point B which is located in the middle of the clay layer.

(17 Marks)

Note: Question No.2 continues on page 3.

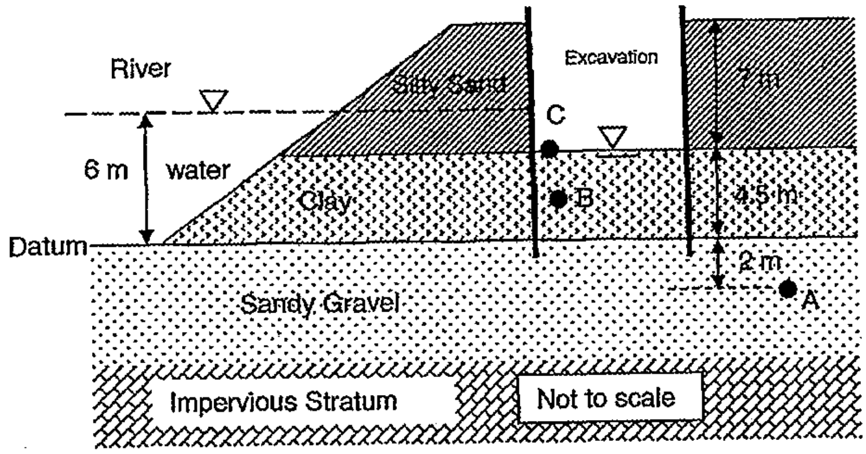


Figure Q2

(b) The rock cycle shows the inter-relationship of rock groups and geological processes. Sketch the rock cycle using appropriate names of the rock groups and geological processes.

(8 Marks)

3. Figure Q3 shows a site consisting of a 10 metre-thick clay layer, which is underlain by permeable conglomerate bedrock. A 1 m thick sand fill, which can be considered large in lateral extent, will be placed on top of the clay (not shown in the figure).

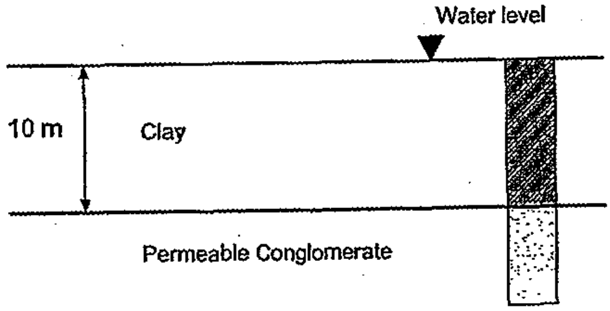


Figure Q3

Note: Question No.3 continues on page 4.

- Prior to the placement of sand fill, laboratory tests were performed on the clay and the results are listed below.

Saturated unit weight $\gamma_{sat} = 16$ kN/m^3
Initial void ratio $e_o = 1.7$
Overconsolidation ratio OCR = 1.5
Compression index $C_c = 0.38$
Swell index $C_s = 0.02$
Coefficient of consolidation $c_v = 2.7 \times 10^{-8}$ m^2/s

The elevation of the water level on the site remains the same before and after the placement of the sand fill. The sand fill will have a unit weight of 20 kN/m^3 above and below water level. In your calculation, treat the clay layer as one layer, i.e. subdivisions are not required. Refer to the Appendix where necessary during your calculation.

(a) Explain the meaning of overconsolidation ratio. (2 Marks)

(b) Explain the meaning of consolidation. What is the most commonly used laboratory test for measuring the one-dimensional consolidation behavior of a soil sample.

(4 Marks)

(c) Calculate the consolidation settlement and the time (2 decimal places in years) required for the clay layer to reach 50% average degree of consolidation due to the loading from the sand fill.

(7 Marks)

(d) If a standpipe piezometer is installed at the centre of the clay layer, what would be the height of the water column in the piezometer when the clay layer reaches 50% average degree of consolidation?

(5 Marks)

(e) Calculate the consolidation settlement and the time (2 decimal places in years) required for the centre of the clay layer to become normally consolidated again.

(7 Marks)

4. (a) Explain briefly the field loading conditions that the drained shear strength test and the undrained shear strength test are meant to simulate.

(5 Marks)

(b) Direct shear test is conducted on a dry sand sample. The shear box holding the sample has a circular cross-section with a diameter of 50 mm. The normal (compressive) load imposed is 200 N. Shear failure occurs in the sample when the shear force reaches 130 N.

(i) Determine the normal stress and shear stress on the shearing plane at failure (1 decimal place in kPa).

(ii) Determine the angle of internal friction for this soil.

(iii) Figure Q4 shows the shear strength characteristics of two sand samples **C** and **D**, which are determined from other sets of direct shear tests under the same magnitude of normal loading. Which sand sample is at an originally "dense" state and which sand sample is at an originally "loose" state? Explain your answer.

(9 Marks)

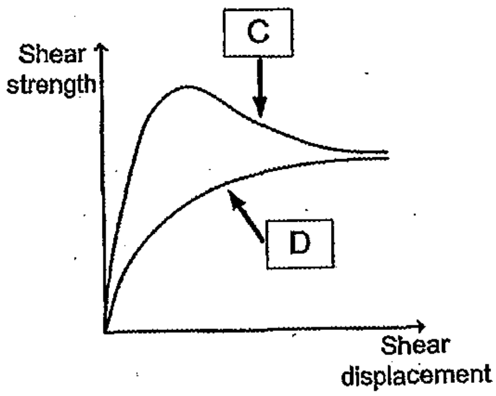


Figure Q4

Note: Question No.4 continues on page 6.

(c) From a drained triaxial test on two saturated clay specimens with identical initial diameter of 38 mm and height h_o of 76 mm, the data associated with specimen failure are obtained and shown in the following table.

Test No.	All-round cell pressure, σ_3 (kN/m^2)	Axial load (N)	Axial deformation, Δh (mm)	Volume change, ΔV (mm^3)	σ_1 (kN/m^2)
1	200	403	10.81	6.6	?
2	600	1,265	14.17	9.5	?

(i) Determine the values of σ_1 for the two tests.

<u>Note:</u> In the drained triaxial test, the fact that the average cross-sectional area A of the specimen does not remain constant throughout the test must be taken into account. Given that the original cross-sectional area of the specimen is A_o and the original volume is V_o, then, as the volume decreases during the test, A can be computed as

$$A = A_o \frac{1 - \varepsilon_v}{1 - \varepsilon_a}$$

where ε_v is the volumetric strain ($\Delta V/V_o$) and ε_a is the axial strain ($\Delta h/h_o$).

(ii) By plotting the Mohr circles of the two tests on the same graph paper, determine the values of the shear strength parameters c' and ϕ' for an assumed linear failure envelope.

(11 Marks)

END OF PAPER

Table 1: Unified Soil Classification System

Description		Group symbols	Laboratory criteria: Fines (%)	Grading	Plasticity	Notes
Coarse grained (more than 50% larger than 0.075 mm)	Gravels (more than 50% of coarse fraction of gravel size i.e. > 4.75 mm)	GW	0-5	$C_U > 4$ $1 < C_Z < 3$		Dual symbols if 5-12% fines. Dual symbols if above A-line and $4 < I_p < 7$.
		GP	0-5	Not satisfying GW requirements		
		GM	> 12		Below A-line or $I_p < 4$	
		GC	> 12		Above A-line and $I_p > 7$	
	Sands (more than 50% of coarse fraction of sand size)	SW	0-5	$C_U > 6$ $1 < C_Z < 3$		
		SP	0-5	Not satisfying SW requirements		
		SM	> 12		Below A-line or $I_p < 4$	
		SC	> 12		Above A-line and $I_p > 7$	
Fine grained (more than 50% smaller than 0.075 mm)	Silts and clays ($w_L < 50$)	ML	Use plasticity chart			
		CL	Use plasticity chart			
		OL	Use plasticity chart			
	Silts and clays ($w_L \geq 50$)	MH	Use plasticity chart			
		CH	Use plasticity chart			
		OH	Use plasticity chart			
Highly organic soils		Pt	-			

$C_U = D_{60}/D_{10}$ $\quad C_Z = (D_{30})^2/(D_{60} \times D_{10})$

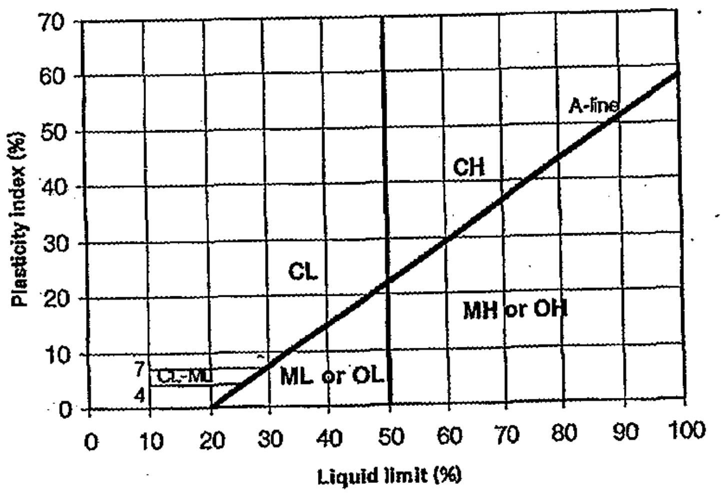


Figure 1: Plasticity Chart

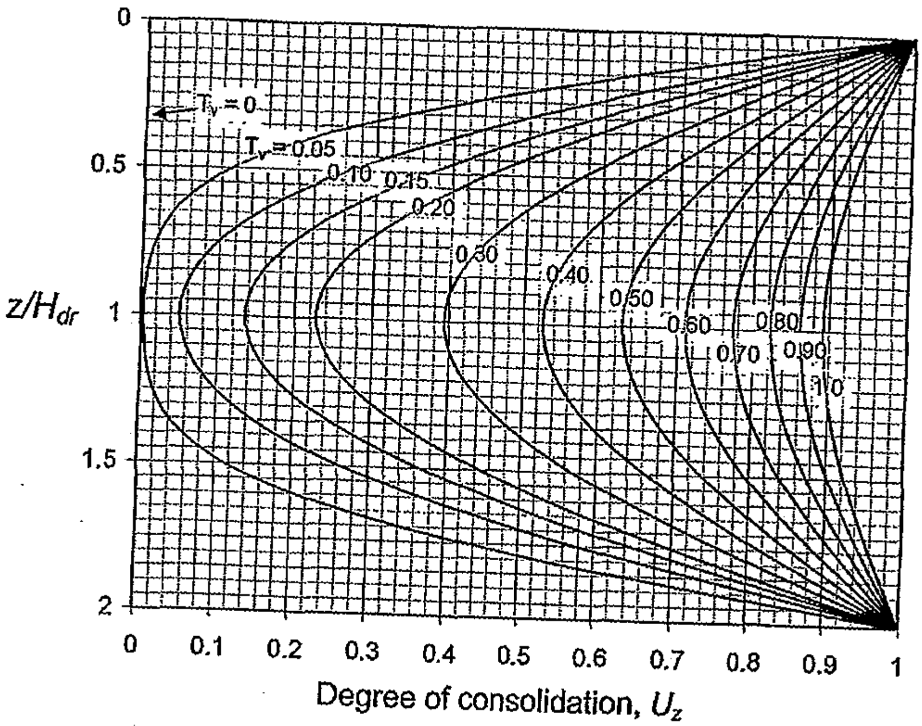


Figure 2: Degree of consolidation U_z as a function of depth and time factor

U(%)	T_v	U(%)	T_v
0	0	51	0.204
1	0.00008	52	0.212
2	0.0003	53	0.221
3	0.00071	54	0.230
4	0.00126	55	0.239
5	0.00196	56	0.248
6	0.00283	57	0.257
7	0.00385	58	0.267
8	0.00502	59	0.276
9	0.00636	60	0.286
10	0.00785	61	0.297
11	0.0095	62	0.307
12	0.0113	63	0.318
13	0.0133	64	0.329
14	0.0154	65	0.304
15	0.0177	66	0.352
16	0.0201	67	0.364
17	0.0227	68	0.377
18	0.0254	69	0.390
19	0.0283	70	0.403
20	0.0314	71	0.417
21	0.0346	72	0.431
22	0.0380	73	0.446
23	0.0415	74	0.461
24	0.0452	75	0.477
25	0.0491	76	0.493
26	0.0531	77	0.511
27	0.0572	78	0.529
28	0.0615	79	0.547
29	0.0660	80	0.567
30	0.0707	81	0.588
31	0.0754	82	0.610
32	0.0803	83	0.633
33	0.0855	84	0.658
34	0.0907	85	0.684
35	0.0962	86	0.712
36	0.102	87	0.742
37	0.107	88	0.774
38	0.113	89	0.809
39	0.119	90	0.848
40	0.126	91	0.891
41	0.132	92	0.938
42	0.138	93	0.993
43	0.145	94	1.055
44	0.152	95	1.129
45	0.159	96	1.219
46	0.166	97	1.336
47	0.173	98	1.500
48	0.181	99	1.781
49	0.188	100	∞
50	0.197		

Table 2: Variation of T_v with U

Sem 1 2010-2011

CV2301

1a $e = \frac{V_v}{V_s} = \frac{V - V_s}{V_s} = \frac{V}{V_s} - 1$

$G_s = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \cdot \gamma_w}$

$V_s = \frac{W_s}{G_s \cdot \gamma_w}$

$\therefore e = \frac{V}{\frac{W_s}{G_s \cdot \gamma_w}} - 1$

$= \frac{V \cdot G_s \cdot \gamma_w}{W_s} - 1$

$n = \frac{V_v}{V} = \frac{eV_s}{V}$

$= e\left(\frac{1}{e+1}\right)$

$= \left(\frac{V \cdot G_s \cdot \gamma_w}{W_s} - 1\right)\left(\frac{1}{\frac{V \cdot G_s \cdot \gamma_w}{W_s} - 1 + 1}\right)$

$= 1 - \frac{W_s}{V \cdot G_s \cdot \gamma_w}$

b $W = 16 kN/m^3$

$w = 8\%$

let $V = 1 m^3$

$w = \frac{W_w}{W_s} \times 100\%$

$W_w = 0.08 W_s$

$16 - W_s = 0.08 W_s$

$W_s = 14.8 kN/m^3$

$W_w = 1.2 kN/m^3 \longrightarrow V_w = \frac{1.2}{9.8} = 0.12 m^3$

$G_s = \frac{\gamma_s}{\gamma_w}$

$2.70 = \frac{W_s}{V_s} \times \frac{V_w}{W_w}$

$2.70 = \frac{V_w}{V_s \times w}$

$V_w = 2.70 \times 0.08 V_s$

$V_w = 0.216 V_s$

$V_s = 4.63 V_w$

$V_s = 4.63 V_w$

$= 4.63 \times 0.12$

$= 0.556 m^3$

$V_v = 1 - 0.556 = 0.444 m^3$

$S_r = \frac{V_w}{V_v} \times 100\%$

$= \frac{0.12}{0.444} \times 100\%$

$= 27\%$

$e \cdot S_r = w \cdot G_s$

$e = 0.08 \times 2.70$

0.27

$= 0.8$

If $S_r = 100\%$ $\rightarrow$ $w = \frac{e \cdot S_r}{G_s}$ (Void ratio, e, still remains the same. $V_w = V_v$)

$= \frac{0.8 \times 1}{2.7}$

$= 0.296$

$= 29.6\%$

c. Classification of soils: - Coarse-grained
- Fine-grained
- Organic soils
- Peat

Laboratory tests: - Sieve analysis
- Wet Sieving (To wash away fine particles of silt and clay)
- Hydrometer analysis

Well graded soil - No excess particles in any size range and if no intermediate sizes are lacking
Gap graded soil - Particles of both large and small sizes are present but relatively low proportion of intermediate size.

d. Glacial soils is type of soil that has wide range of particle size and strength due to the dramatic change in landscape while Alluvial sands is type of soil which is deposited by rivers. The particles are sorted according to stream velocity.

2a (i) $\sigma_v = 7\times20 + 4.5\times16 + 2\times22$

$= 256\ kPa$

$u = 8\times9.81 = 78.48\ kPa$

$\sigma_v' = 256 - 63.8 = 177.52\ kPa$

(ii) $h_{pA} = 8m$

$z_A = -2m$

$h_A = 6m$

(iii) $\sigma_{vA}' = 177.52\ kPa$

$K = \frac{\sigma_h'}{\sigma_v'}$

$\sigma_h' = 0.4\times177.52$

$= 71\ kPa$

$\sigma_h = 71 + 78.48 = 149.5\ kPa$

(iv) $h_{pc} = 0$ $\quad i = \frac{\Delta h}{L} = \frac{6-4.5}{4.5} = \frac{1}{3}$

$z_c = 4.5m$

$h_c = 4.5m$

(v) $\sigma_v = \frac{4.5}{2}\times16 = 36\ kPa$

$u = \gamma_w(h_w + Y_x) + \gamma_w i Y_x$ (upward flow)

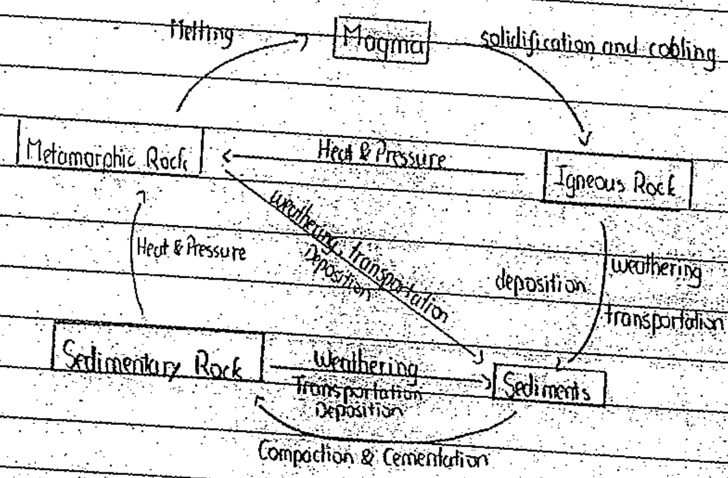
$= 9.81(\frac{4.5}{2}) + 9.81\times\frac{1}{3}\times\frac{4.5}{2}$

$= 29.43\ kPa$

$\sigma_v' = 36 - 29.43$

$= 6.57\ kPa$

b



3 a Overconsolidation ratio : The ratio of the maximum stress that the soils ever experienced to the present stress

b Consolidation is the gradual reduction in volume of a fully saturated soil due to drainage of some of the pore water

c At the mid-depth

$\sigma_v' = 5\times16 - 5\times9.81 = 30.95\,kPa$

$OCR = \frac{\sigma_c'}{\sigma_i'}$

$\sigma_c' = 1.5\times30.95$

$= 46.43\,kPa$

After putting the fill

$\sigma_2' = 30.95+20$

$= 50.95$

$S_{c\,ultimate} = \frac{H}{1+e_0} C_r \log\left(\frac{\sigma_c'}{\sigma_i'}\right) + \frac{H}{1+e_0} C_c \log\left(\frac{\sigma_2'}{\sigma_c'}\right)$

$= \frac{1.0}{1+1.7}(0.07)\log\left(\frac{46.43}{30.95}\right) + \frac{1.0}{1+1.7}\times0.38\log\left(\frac{50.95}{46.43}\right)$

$= 0.0698\,m$

$= 69.8\,mm$

$S_{c\,50\%} = U_{50}\times S_{c\,ultimate}$

$= 34.9\,mm$

$U_{avg} = 50\%$

(From the table, $T_v = 0.197$)

$T_v = \frac{c_v t}{d^2} \Rightarrow t = \frac{T_v d^2}{c_v} = \frac{0.197 \times \left(\frac{10}{2}\right)^2}{2.7 \times 10^{-8}}$ (Double drainage)

$= 5.78$ years

d. At depth 5m, $z/H_d = 1$

$T_v = 0.197$

(From the graph, $U_z = 0.22$)

$U_z = 1 - \frac{u_e}{u_i}$

$u_e = u_i(1 - U_z)$

$= 20(1 - 0.22)$

$= 15.6$ kPa

$u_z = 5 \times 9.81 + 15.6 = \gamma_w h$

$h = 6.59$ m

e. For normally consolidated soil

$S_c = \frac{H}{1+e_0} C_c \log\left(\frac{\sigma_f'}{\sigma_i'}\right)$

$= \frac{10}{1+1.7} \times 0.38 \log\left(\frac{50.95}{46.45}\right)$

$= 0.0568$ m

$= 56.8$ mm

$U = \frac{S_c}{S_{c\,ultimate}} = \frac{56.8}{69.8} = 0.814$

(From the table, $U = 81.4 \Rightarrow T_v = 0.590$)

Since the question refers to a specific depth, use U_z

$T_v = 0.590 \Rightarrow U_z = 0.7$

$S_{c\,70\%} = 0.7 \times 69.8 = 48.86$ mm

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

$t = \frac{0.7 \times 5^2}{2.7 \times 10^{-8}} \times \frac{1}{3600 \times 24 \times 365}$ years

$= 20.55$ years

4a | Drained condition is applied to simulate the case in soils of low permeability after consolidation is complete and would represent the situation a long time after the completion of construction.
Undrained condition apply for the case like embankment on clay where load is applied very fast e.g. earthquake.

b(i) $\sigma = \frac{P}{A} = \frac{200}{\frac{1}{4}\pi(0.05)^2} = 101.9 \text{ kPa}$ $\qquad \tau = \frac{V}{A} = \frac{130}{\frac{1}{4}\pi(0.05)^2} = 66.2 \text{ kPa}$

(ii) $\tau = c' + \sigma \tan \phi'$

For sand, assume $c' = 0$ (cohessionless)

$66.2 = 0 + 101.9 \tan \phi'$

$\phi' = 33°$

(iii) C is at an originally dense state because the stress needed to shear the specimen is high until it reaches the peak stress and starts to dilate due to interlocking (shear strength decreasing to ultimate stress). D is at an originally loose state because it hass less interlocking and as the stress increases, the sand is compressed until it reaches the same ultimate stress as dense sand

c $h_0 = 76\text{mm}$ $\quad A_0 = \frac{1}{4}\pi(38)^2 = 1134.11\text{mm}^2$ $\quad V_0 = \frac{1}{4}\pi(38)^2(76) = 86,192.7\text{mm}^3$

Test No.	σ_3 (kN/m²)	Δh (mm)	ε_a ($\Delta h/h_0$)	ΔV (mm³)	ε_v ($\Delta V/V_0$)	$A = A_0\frac{1-\varepsilon_v}{1-\varepsilon_A}$ (mm²)	P (N)	$\sigma_1 = \sigma_3 + \frac{P}{A}$ (kPa)
1	200	10.81	0.142	6.6	7.66×10^{-5}	1321.77	403	504.9
2	600	14.71	0.182	9.5	1.10×10^{-4}	1360.28	1265	1512.5

(ii) $c' = 0$

$\phi' = \sin\left[\frac{\frac{1}{2}(504.9-200)}{\frac{1}{2}(504.9+200)}\right] = 25.6°$