

Université d'Ottawa  
Faculté de génie

Département de  
Génie civil



University of Ottawa  
Faculty of Engineering

Department of  
Civil Engineering

**CVG 3109  
SOIL MECHANICS - I  
FINAL EXAMINATION**

**Length of Examination: 3hrs**  
**Professor: Prof. Sai Vanapalli**

**19<sup>th</sup> Dec, 2017 (19:00 to 22:00) (FSS 2005)**  
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First Name: \_\_\_\_\_  
Last Name: \_\_\_\_\_  
Student Number: \_\_\_\_\_  
Signature \_\_\_\_\_

- i) This is a closed book exam. No textbooks are allowed
- ii) **Formula sheet** is available on last pages of this question paper
- iii) **If you do not understand a question, clearly state an assumption and proceed.**
- iv) Non programmable calculators are permitted
- v) Questions have the values shown next to the question.
- vi) **Marks will be taken out for missing units and labels.**
- vii) Answers should be succinct.

At the end of the exam, when time is up:

- Stop working and turn your exam upside down.
- Please remain silent.
- Do not move or speak until ALL exams have been picked up, and a TA or the Professor gives the go-ahead to leave.

<b><u>Question</u></b>	<b><u>Max Marks</u></b>	<b><u>Marks Awarded</u></b>
1	10 marks: Multiple choice questions	
2	15 marks: Multiple choice + Provide reason for your answer	
3	10 marks: Consolidation + Shear Strength	
4	12 marks: Stress Distribution Theory (Problem)	
5	15 marks: Consolidation (Problem)	
6	12 marks: Effective Stress + Seepage Analysis (Problem)	
7	26 marks: Shear Strength (Problem)	
<b>Total</b>	<b>100</b>	

## Formulae Sheet

### Phase relationships:

Unit weight of soil:

$$\gamma = \frac{W}{V} = \frac{(Se + G_s) \gamma_w}{1 + e}$$

Submerged unit weight:  $\gamma_{sub} = \frac{(G_s - 1)}{1 + e} \gamma_w$

Dry unit weight:

$$\gamma_d = \frac{W_s}{V} = \frac{G_s}{1 + e} \gamma_w = \frac{\gamma}{1 + w}$$

$$Se = wG_s$$

### Elastic Theory (Stress Distribution theory)

Boussinesq's equation for determining vertical stress due to a point load

$$\sigma_z = \frac{3Q}{2\pi z^2} \left\{ \frac{1}{1 + \left(\frac{r}{z}\right)^2} \right\}^{5/2}$$

Determination of vertical stress due to a rectangular loading:  $\sigma_z = q I_c$  (Charts also available)

$$I_c = \frac{1}{4\pi} \left[ \frac{2mn\sqrt{m^2 + n^2 + 1}}{m^2 + n^2 + m^2n^2 + 1} \left( \frac{m^2 + n^2 + 2}{m^2 + n^2 + 1} \right) + \tan^{-1} \frac{2mn\sqrt{m^2 + n^2 + 1}}{m^2 + n^2 + m^2n^2 + 1} \right]$$

$m = B/z$  and  $n = L/z$  (both  $m$  and  $n$  are interchangeable)

Approximate method to determine vertical stress,

$$\sigma_z = \frac{qBL}{(B+z)(L+z)}$$

Vertical stress determination using Newmarks Chart

$$\sigma_z = q I_c \text{ (No. of sectors)}$$

### Permeability & Effective Stress

Total head = Pressure head + Elevation head + Velocity head

$$h = \frac{u}{\gamma_w} + \frac{v^2}{2g} + z$$

Hydraulic gradient:  $i = \frac{\Delta h}{L}$

$$v = ki$$

Darcy's law:  $q = vA$

$$Q = kiAt = k \cdot \frac{\Delta h}{L} \cdot At$$

Equivalent hydraulic conductivity:

$$k_{H(eq)} = \frac{k_{H_1}H_1 + \dots + k_{H_n}H_n}{H_1 + \dots + H_n}$$

$$k_{V(eq)} = \frac{H_1 + \dots + H_n}{\left(\frac{H_1}{k_{V_1}}\right) + \dots + \left(\frac{H_n}{k_{V_n}}\right)}$$

Seepage in a flow net:

$$q = k \cdot h_w \cdot \frac{N_f}{N_d}$$

Pore-water pressure (kPa):

$$u_p = \gamma_w [h_p - (-z_p)] = \gamma_w (h_p + z_p)$$

Total seepage force =  $i\gamma_w V$

Seepage per unit volume =  $i\gamma_w$

Effective stress:  $\sigma' = \sigma - u_w$

Effective stress on downward seepage:

$$\sigma' = \gamma_{sub}z + jz = \gamma_{sub}z + iz\gamma_w$$

Effective stress on upwards seepage:

$$\sigma' = \gamma_{sub}z - jz = \gamma_{sub}z - iz\gamma_w$$

Critical hydraulic gradient:

$$\sigma' = 0 = \gamma_{sub}z - iz\gamma_w \Leftrightarrow i_c = \frac{\gamma_{sub}}{\gamma_w}$$

$$i_c = \frac{(G_s - 1)\gamma_w}{1 + e} \cdot \frac{1}{\gamma_w} = \frac{(G_s - 1)}{1 + e}$$

**Shear strength:**

$$\tau_f = c' + (\sigma - u_w) \tan \phi'$$

$$\sigma'_1 = \sigma'_3 \tan^2 \left( 45^\circ + \frac{\phi'}{2} \right) + 2c' \tan \left( 45^\circ + \frac{\phi'}{2} \right)$$

$$\tau_f = \frac{1}{2} (\sigma'_1 - \sigma'_3) \sin 2\theta$$

$$\sigma_f = \frac{1}{2} (\sigma'_1 + \sigma'_3) + \frac{1}{2} (\sigma'_1 - \sigma'_3) \cos 2\theta$$

$$B = \frac{\Delta u_{(Confining)}}{\Delta \sigma_3}$$

$$A = \frac{\Delta u_{(Deviator)}}{(\Delta \sigma_1 - \Delta \sigma_3)}$$

$$q' = m + p' \bullet \tan \alpha$$

$$\phi' = \sin^{-1}(\tan \alpha)$$

$$c' = \frac{m}{\cos \alpha}$$

**Consolidation:**

*Compression index*

$$C_c = \frac{e_o - e_1}{\log \left( \frac{\sigma'_1}{\sigma'_0} \right)} \quad (\sigma'_1 > \sigma'_0)$$

$$C_c = 0.009 [LL(\%) - 10] \text{ for undisturbed clay}$$

$$C_c = 0.007 [LL(\%) - 10] \text{ for disturbed clay}$$

$$OCR = \frac{\sigma'_p}{\sigma'_0}$$

*Swelling index,  $C_s$  : Slope of swelling path*

$$m_v = \frac{\Delta e}{1 + e_o} \left( \frac{1}{\Delta \sigma'} \right) = \frac{1}{1 + e_o} \left( \frac{e_o - e_1}{\sigma'_1 - \sigma'_0} \right)$$

$$s_c = \int_0^H \frac{e_o - e_1}{1 + e_o} dz = \frac{\Delta e}{1 + e_o} H$$

$$s_c = \int_0^H m_v \Delta \sigma' dz = m_v \Delta \sigma' H$$

$$s_c = \frac{C_c}{1 + e_o} H \log \left( \frac{\sigma'_0 + \Delta \sigma}{\sigma'_0} \right)$$

$$s_c = \frac{C_s}{1 + e_o} H \log \left( \frac{\sigma'_p}{\sigma'_0} \right) + \frac{C_c}{1 + e_o} H \log \left( \frac{\sigma'_p + \Delta \sigma}{\sigma'_p} \right)$$

$$T_v = \frac{c_v t}{H_{dr}^2}$$

$$U = \frac{e_1 - e}{e_1 - e_2}$$

$$U = \frac{u_i - u}{u_i} = 1 - \frac{u}{u_i}$$

$$U = \frac{\delta}{\delta_c}$$

for  $U < 60\%$ ,

$$T_v = \frac{\pi}{4} \left( \frac{U\%}{100} \right)^2$$

for  $U \geq 60\%$ ,

$$T_v = 1.781 - 0.933 \log(100 - U\%)$$