The University of Iowa
Dept. of Civil & Environmental Engineering
53:030 SOIL MECHANICS
Makeup Midterm Exam #2, Fall Semester 2005

<u>Question #1</u>: (33.33 points)

A soil deposit with a groundwater table located 2m beneath the ground surface is as shown in Fig. 1a. It is anticipated that due to excavations on an adjacent parcel of land the water-table will drop by 4m over a time span of one-month, and then remain at the lower level permanently. The owner of the parcel of land shown in Fig. 1a is concerned that the drop in water table could cause settlements on her land. As her consultant, using the information provided, calculate for her:

a. the ultimate settlements that might be expected due to the dropping of the water table;
b. how much settlement would be expected at:
   - t=1 year?
   - t=5 years?
   - t=20 years?

Note the non-dimensional time constants for varying degrees of average consolidation are given on page 4 of this exam.

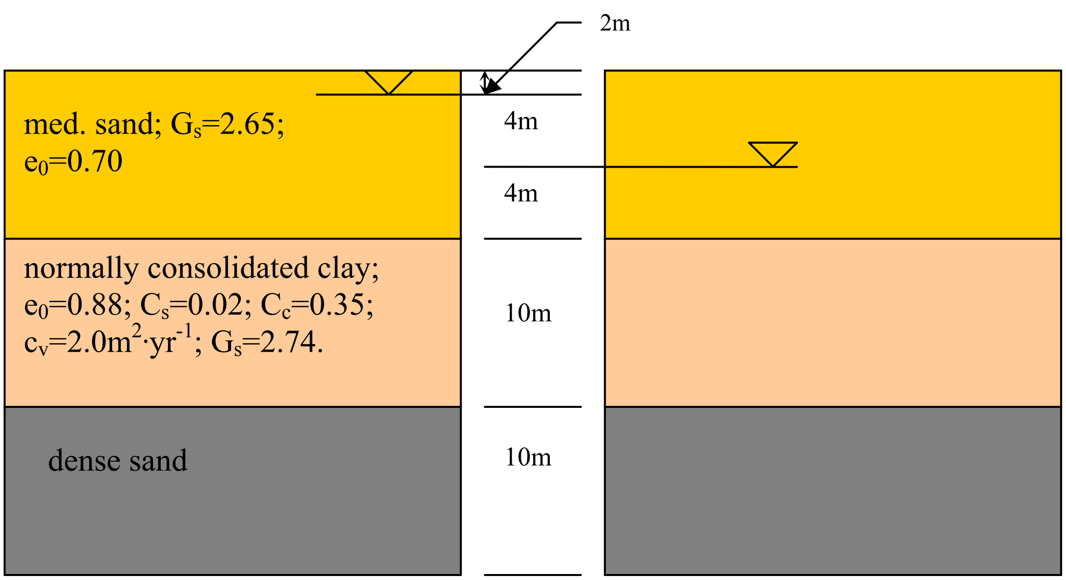


Fig. 1a. Existing location of water table;

Fig. 1b. Anticipated lower level of water table.

<u>Question #2</u>: (33.33 points)

Figure 2 shows a homogeneous, sandy soil deposit with a horizontal ground surface. Before the strip load is applied, the stresses at point A are as follows: vertical stress σ_v=90 kPa; horizontal stress σ_h=45kPa.

a. Compute the maximum shear stress at point A **<u>before</u>** the surface pressure is applied.
b. Using the information provided in Figure 1, compute the major and minor principal stresses at point A **<u>after</u>** the uniform strip load is applied.
c. What are the respective orientations of the principal planes at point A after the surface pressure is applied?

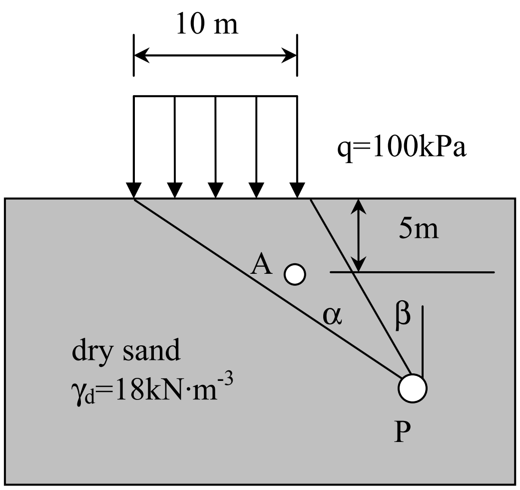


Fig. 1.

Stress increases at a general point P making angles α and β with respect to the strip load are given by the following formulae:

$$\Delta\sigma_{zz} = \frac{q}{\pi}\left[\alpha + sin(\alpha)cos(\alpha + 2\beta)\right]$$

$$\Delta\sigma_{xx} = \frac{q}{\pi}\left[\alpha - sin(\alpha)cos(\alpha + 2\beta)\right]$$

$$\Delta\tau_{xz} = \frac{q}{\pi}\left[sin(\alpha)sin(\alpha + 2\beta)\right]$$

<u>Question #3:</u> (33.33 points)

A sheetpile retaining wall is shown in Figure 3a, and the state of total stresses in the silty-sandy soil at point A are as shown. As part of a construction operation, a bracing force is pushing on the sheetpile wall as shown in Figure 3b, and this force leads to an increase in lateral stress in soil behind the retaining wall, while the vertical stress in the soil remains essentially constant.

a. For the conditions shown in Figure 3b, how large would the lateral stress need to become at point A to cause shear failure?
b. At shear failure at point A, what would be the orientation of the plane(s) on which shear failure occurs? (Use the pole method.)
c. What are the effective shear and normal stresses on the failure plane passing through point A?

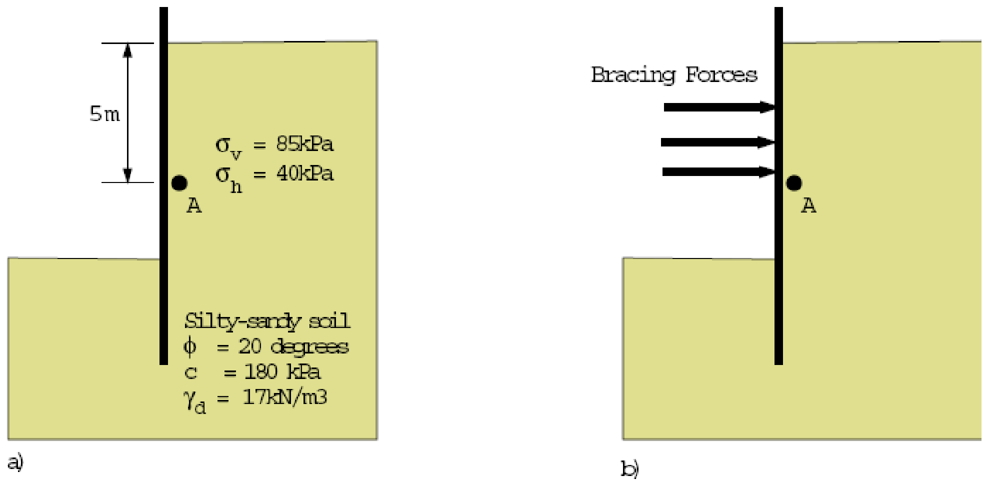


Figure 3.

Bonus Question (10 points!!)

Explain in detail how one can go about estimating the permeability of a fine-grained soil from a 1-dimensional consolidation test.

Tabulated values of degree of consolidation U(%) versus non-dimensional time factor T_v in the one-dimensional consolidation model.

U(%)	T_v	U(%)	T_v	U(%)	T_v
0	0	34	.0907	68	.377
1	.00008	35	.0962	69	.390
2	.00030	36	.102	70	.403
3	.00071	37	.107	71	.417
4	.00126	38	.113	72	.431
5	.00196	39	.119	73	.446
6	.00283	40	.126	74	.461
7	.00385	41	.132	75	.477
8	.00502	42	.138	76	.493
9	.00636	43	.145	77	.511
10	.00785	44	.152	78	.529
11	.00950	45	.159	79	.547
12	.01130	46	.166	80	.567
13	.0133	47	.173	81	.588
14	.0154	48	.181	82	.610
15	.0177	49	.188	83	.633
16	.0201	50	.197	84	.658
17	.0227	51	.204	85	.684
18	.0254	52	.212	86	.712
19	.0283	53	.221	87	.742
20	.0314	54	.230	88	.774
21	.0346	55	.239	89	.809
22	.0380	56	.248	90	.848
23	.0415	57	.257	91	.891
24	.0452	58	.267	92	.938
25	.0491	59	.276	93	.993
26	.0531	60	.286	94	1.055
27	.0572	61	.297	95	1.129
28	.0615	62	.307	96	1.219
29	.0660	63	.318	97	1.336
30	.0707	64	.329	98	1.500
31	.0754	65	.340	99	1.781
32	.0803	66	.352	100	∞
33	.0855	67	.364		

Solution of Makeup 53:030 Soil Mechanics Midterm Exam #2, Fall Semester, 2005.

Question #1: (33.33 points)

a) 24 points

For the sand layer:

$$(\gamma_d)_{sand} = \frac{G_s \gamma_w}{1+e} = \frac{2.65 * 9.81 kN \cdot m^{-3}}{1+0.70} = 15.29 kN \cdot m^{-3}$$

$$(\gamma_{sat})_{sand} = \frac{\gamma_w (G_s + e)}{1+e} = \frac{9.81 kN \cdot m^{-3} * (2.65+0.70)}{1+0.70} = 19.33 kN \cdot m^{-3}$$

For the clay layer:

$$(\gamma_{sat})_{clay} = \frac{\gamma_w (G_s + e)}{1+e} = \frac{9.81 kN \cdot m^{-3} * (2.74+0.88)}{1+0.88} = 18.89 kN \cdot m^{-3}$$

The current effective stress level at the center of the clay layerl is:

$$\begin{aligned}(\sigma_v)_o' &= 2m * (\gamma_d)_{sand} + 8m * (\gamma_b)_{sand} + 5m * (\gamma_b)_{clay} \\ &= 2\text{m} * 15.29 \text{kN} \cdot \text{m}^{-3} + 8m * (19.33 - 9.81) \text{kN} \cdot \text{m}^{-3} + 5m * (18.89 - 9.81) \text{kN} \cdot \text{m}^{-3} \\ &= 152.15 \text{kPa}\end{aligned}$$

The effective stress level at the center of the clay layer after the water level drops by 4m and the clay layer consolidates under the associated increase in stress will be:

$$\begin{aligned}(\sigma_v)_f' &= 6m * (\gamma_d)_{sand} + 4m * (\gamma_b)_{sand} + 5m * (\gamma_b)_{clay} \\ &= 6\text{m} * 15.29 \text{kN} \cdot \text{m}^{-3} + 4m * (19.33 - 9.81) \text{kN} \cdot \text{m}^{-3} + 5m * (18.89 - 9.81) \text{kN} \cdot \text{m}^{-3} \\ &= 175.33 \text{kPa}\end{aligned}$$

The resulting consolidation settlements due to compression of the clay layer will be:

$$\begin{aligned}S_c &= \frac{H_o}{1+e_o} \Delta e = \frac{H_o}{1+e_o} C_c \log\left(\frac{(\sigma_v)_f'}{(\sigma_v)_o'}\right) \\ &= \frac{10m}{1+0.88} * 0.35 * \log\left(\frac{175.33}{152.15}\right) \\ &= 0.115 \text{m}\end{aligned}$$

b) 9 points

At t=1yr:

$$T_V = \frac{t * c_v}{(H_{dr})^2} = \frac{1yr * 2m^2 yr^{-1}}{(5m)^2} = 0.08 \Rightarrow \text{U} = 0.32 \Rightarrow \text{S}_\text{c} = 0.32 * 0.115m = .037m$$

At t=5yr:

$$T_V = \frac{5yr * 2m^2 yr^{-1}}{(5m)^2} = 0.40 \Rightarrow \mathrm{U} = 0.70 \Rightarrow \mathrm{S_c} = 0.70 * 0.115m = .080m$$

At t=20yr:

$$T_V = \frac{20yr * 2m^2 yr^{-1}}{(5m)^2} = 1.60 \Rightarrow \mathrm{U} = 0.985 \Rightarrow \mathrm{S_c} = 0.985 * 0.115m = .0112m$$

Question #2: (33.33 points)

a) 11 points

$$\sigma_1' = \sigma_v' = 90kPa$$
$$\sigma_3' = \sigma_h' = 45kPa$$

The resulting effective stress Mohr's Circle has a center at
$\sigma_c = \frac{1}{2}(90+45) = 67.5kPa$, and a radius of $r = \frac{1}{2}(\sigma_1' - \sigma_3') = 22.5kPa$
$\tau_{\max} = r = 22.5kPa.$

b) 11 points

At the point of interest A: $\alpha = \tan^{-1}\left(\frac{10m}{5m}\right) = 1.107rad; \beta = \tan^{-1}\left(\frac{0m}{5m}\right) = 0rad$

Thus:

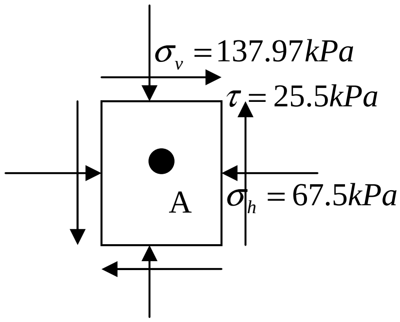
$$\Delta\sigma_{zz} = \Delta\sigma_v = \frac{100kPa}{\pi}\left[1.107 + \sin(1.107)\cos(1.107)\right] = 47.97kPa$$
$$\Delta\sigma_{xx} = \Delta\sigma_h = \frac{100kPa}{\pi}\left[1.107 - \sin(1.107)\cos(1.107)\right] = 22.51kPa$$
$$\Delta\tau_{xz} = \frac{100kPa}{\pi}\left[\sin(1.107)\cos(1.107)\right] = 25.46kPa$$

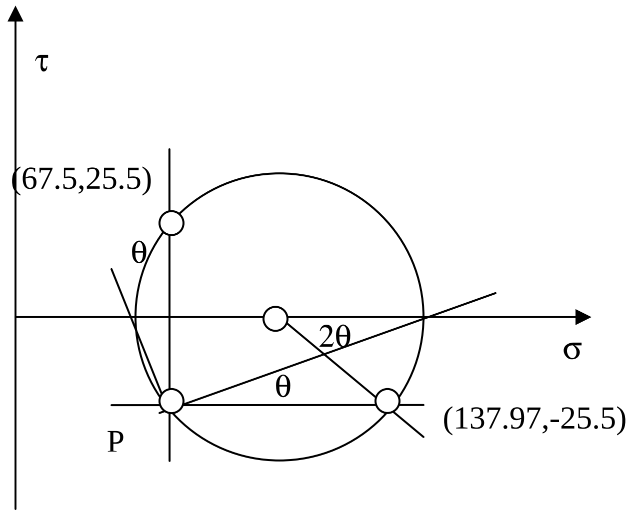
Adding these stresses to the originals gives:

$$\sigma_{zz} = \sigma_v = 90kPa + 47.97kPa = 137.97kPa$$
$$\sigma_{xx} = \sigma_h = 45kPa + 22.51kPa = 67.51kPa$$
$$\tau_{xz} = 0 + 25.46kPa = 25.46kPa$$

$$\sigma_c = \tfrac{1}{2}(\sigma_{xx} + \sigma_{zz}) = 102.74kPa$$
$$r = \left[\left(\tfrac{1}{2}(\sigma_{xx} - \sigma_{zz})\right)^2 + \tau_{xz}^2\right]^{1/2} = 43.47kPa$$
$$\sigma_1 = \sigma_c + r = 146.21kPa$$
$$\sigma_3 = \sigma_c - r = 59.27kPa$$

c) 11 points





$$2\theta = \tan^{-1}\left(\frac{\sigma_v - \sigma_c}{\tau}\right)$$

$$= \tan^{-1}\left(\frac{137.97 - 102.74}{25.46}\right) = 35.85^\circ$$

$$\theta = 17.93^\circ$$

Accordingly, the major principal plane passing through point A makes an angle of 17.93 degrees counter-clockwise with respect to the horizontal.

The minor principal plane makes an angle of 17.93 degrees counter-clockwise with respect to the vertical.

Question #3: (33.33 points)

a) 11 points:

σ_v =85kPa; σ_h =40kPa.
While the vertical stress remains constant, the horizontal stress increases until shear failure occurs. At failure, the horizontal stress will be the major principal stress, and the vertical stress will be the minor principal stress. Also at failure, the relation between the major and minor principal stresses is:

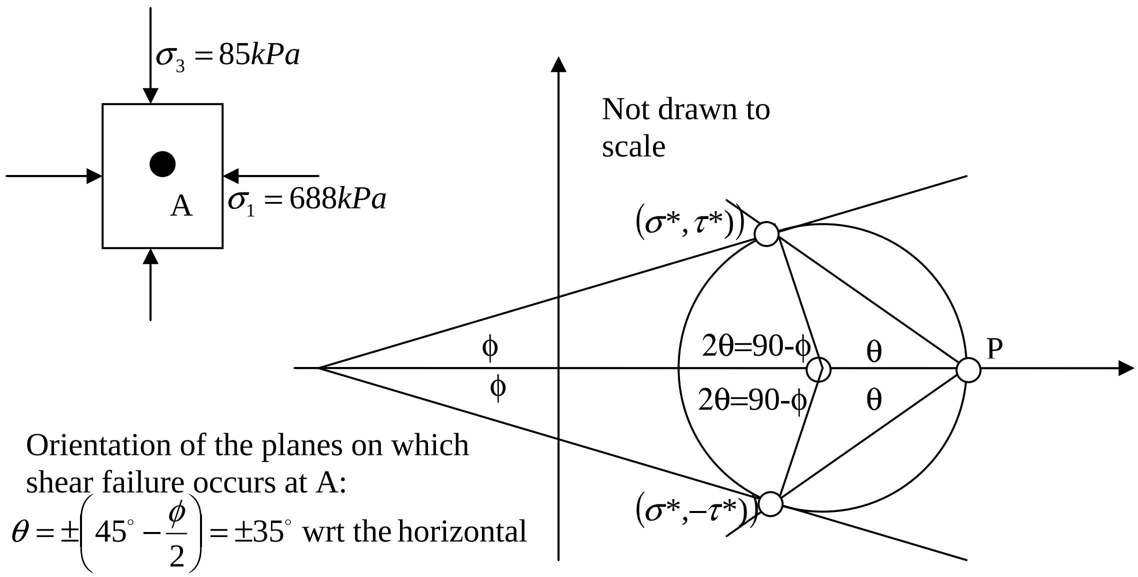
$$\sigma_1 = \sigma_3 \tan^2\left(45^\circ + \frac{\phi}{2}\right) + 2c * \tan\left(45^\circ + \frac{\phi}{2}\right)$$

$$= 85\text{kPa} * \tan^2(55^\circ) + 2 * 180 kPa * \tan(55^\circ)$$

$$= 688\text{kPa}$$

b) 11 points:

Using Mohr's circle and the Pole Method, the orientation of the planes passing through the point of interest, and on which shear failure occurs can be computed as follows:



Orientation of the planes on which shear failure occurs at A:

$$\theta = \pm\left(45^\circ - \frac{\phi}{2}\right) = \pm 35^\circ \text{ wrt the horizontal}$$

c) 11 points:

The normal and shear stresses acting on the failure planes can be computed as follows:

$$\sigma^* = \sigma_c - r\cos(2\theta) = \tfrac{1}{2}(688+85) - \tfrac{1}{2}(688-85)\cos(70^\circ)$$
$$= 283.2\text{kPa}$$
$$\tau^* = r\sin(2\theta) = \tfrac{1}{2}(688-85)\sin(70^\circ)$$
$$= 283.1\text{kPa}$$
$$\text{Check: Is } \tau^* = \text{c} + \sigma^* \tan(\phi)\ ?$$
$$283.1\text{kPa} = 180\text{kPa} + 283.2\text{kPa} * \tan(20^\circ)$$
$$= 180\text{kPa} + 103.1\text{kPa}$$
$$= 283.1\text{kPa}$$

Bonus Question (10 points)

How to measure the permeability from the 1-D consolidation test?

This can be done following the same procedure used in processing of the Lab 9 experimental data:

1) From the displacement versus time curve, note the time t_{50} required for 50% consolidation to occur.
2) Using the known drainage distance, estimate the coefficient of consolidation over the interval as:

$$c_v = \frac{0.196(H_{dr})^2}{t_{50}}$$

3) From consolidation theory, $c_v = \frac{k(1+e_o)}{\gamma_w a_v}$, so re-arranging gives an expression for the soil permeability k. The soil compressibility coefficient a_v over the interval needs to be estimated as $a_v = \Delta e / \Delta\sigma_v'$.