THE UNIVERSITY OF IOWA
Department of Civil & Environmental Engineering
53:030 Soil Mechanics, Lab Experiment No. 7:
"Seepage Forces and Liquefaction of a Sandy Soil"

Fall Semester, 2003 **Instructor: C.C. Swan**

Equipment: Reverse seepage tank, load ring, mass on a string.

A. Objective

In class and through reading the text, you have been exposed to the notions of effective stress and seepage forces. In this lab experiment, you will have the opportunity to see quite tangibly how upward flow through a soil causes a reduction in vertical effective stresses, and how this can ultimately cause a soil to lose all of its strength and to behave like a liquid. A schematic of the reverse seepage tank to be used in this experiment is shown in Figure 1.

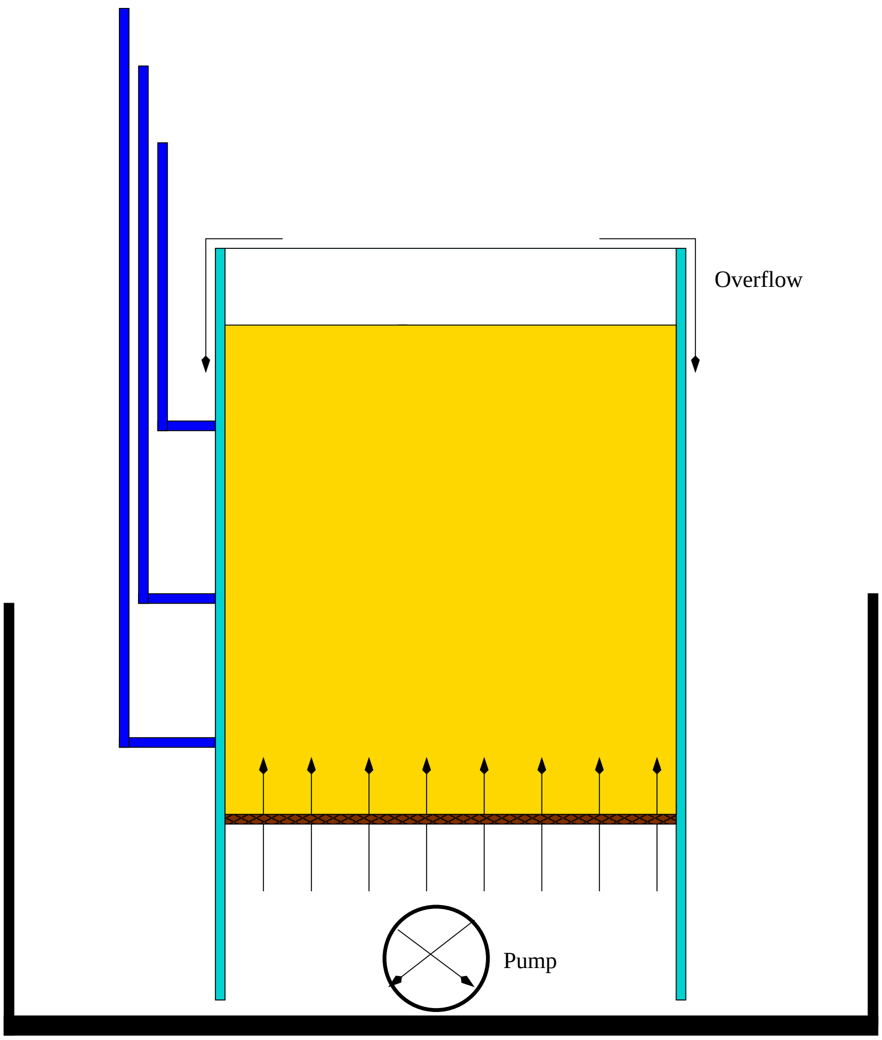

Figure 1. Reverse seepage tank with upward flow through a uniform saturated sandy soil.

B. Background

The normal stresses on an arbitrarily oriented plane through a soil deposit can be expressed as the sum of effective stresses and pore-fluid pressure:

$$\sigma = \sigma' + p_w.$$

For a static saturated soil deposit subjected only to gravitational loading with no seepage occuring, the total vertical stress and pore pressure on a given horizontal plane at depth z are written:

$$\sigma_v(z) = \gamma_w H + \gamma_{sat} z; \qquad p_w(z) = \gamma_w (H + z).$$

Thus, the vertical effective stress at depth z in a uniform soil deposit is written

$$\begin{aligned} \sigma'_v(z) &= \sigma_v - p_w \\ &= \gamma_b z, \end{aligned}$$

where $\gamma_b = (\gamma_{sat} - \gamma_w)$.

If we now consider the case in which fluid seeps upward through the soil we will observe that the seepage forces exerted by the fluid on the soil skeleton reduce the vertical effective stresses in the soil. To demonstrate, assume a uniform hydraulic gradient i in the soil that is driving the upward flow. The piezometric head distribution in the soil is simply

$$h(z) = H + iz,$$

where the reference datum was taken at z=0. Knowing the piezometric head distribution in the soil, it is then quite simple to compute the pore pressure distribution in the soil as:

$$\begin{aligned} p_w(z) &= [h(z) - h_z(z)] \cdot \gamma_w \\ &= [H + iz + z] \cdot \gamma_w. \end{aligned}$$

Since during upward flow, the total vertical stress is still given by

$$\sigma_v(z) = \gamma_w H + \gamma_{sat} z,$$

the vertical effective stress distribution in the soil during upflow is simply

$$\sigma'_v(z) = (\gamma_b - i\gamma_w) z.$$

Thus upward flow **diminishes** the effective stresses in the soil. The critical hydraulic gradient $i = i_{cr}$ at which the effective stresses vanish throughout the depth of the deposit occurs when

$$i = i_{cr} = \frac{\gamma_b}{\gamma_w} = \frac{G_s - 1}{1 + e}.$$

As we have discussed in class, when a soil entirely loses its inter-particle “contact” stresses, it ceases to behave like a solid. In this experiment, we will see how as the effective stresses in a soil are progressively decreased due to increasing i, the soil gets progressively weaker until it behaves like a fluid.

A semi-empirical expression for ultimate bearing capacity of a circular foundation resting on a sandy soil is given by:

$$q_u = 0.3B(\gamma_b - i\gamma_w)N_\gamma,$$

where: q_u is the bearing stress between the foundation and the soil; B is the diameter of the foundation; and N_γ is a soil constant. In this laboratory experiment, the bearing capacity of the sand in the seepage tank is measured for a number of upward seepage hydraulic gradients i in the soil. For a sufficiently large upward hydraulic gradient, liquefaction or boiling is observed in the soil, at which point the bearing capacity vanishes.

C. Experimental Procedure

1. Fill the reservoir of the seepage tank with water.
2. Calibrate the bearing capacity load ring as demonstrated by the lab instructor.
3. Measure the diameter B of the circular footing used in the bearing capacity measurements.
4. Turn on the pump in the seepage tank until water flows over the spillway and back into the reservoir. Smooth the top surface of the sand, and wet any floating sand so that it sinks.
5. At hydraulic gradients of 0.0, 0.33, 0.67, and 1.0:
   a: Measure the bearing capacity of the sand in the vicinity of the top surface using the load ring apparatus. (Note: The measured bearing capacity of the soil, is the force value in the load ring at which large penetration of the load ring's "foot" occurs with minimal incremental force.)
   b: At each incremental hydraulic gradient, take and record **five** bearing capacity measurements at various locations throughout the tank.
   c: Before taking measurements at i = 1.0, drop a mass on the end of a string onto the top of the soil surface. If the sand cannot support the mass, the bearing capacity is nil and the measurement can be omitted.
6. By adjusting the hydraulic gradient through the sand bed, identify or measure the critical hydraulic gradient i_{cr} at which boiling first occurs in the deposit.

D. Data Collection

1. Collect the data for each different hydraulic gradient in Table 2.
2. Pertinent data for the sand in the tank is given in Table 1. Assume in all computations that the sand is "loose" and thus $e = e_{max}$.
3. The vertical distance L between the highest and lowest manometer tubes extending from the side of the tank is 15.2 cm.

E. Computations

1. Assuming that the sand in the tank is "loose" and thus has $e = e_{max}$, compute the theoretical critical hydraulic gradient for the soil and compare this value to the measured i_{cr} in step C.6
2. For all of the tests performed, plot bearing capacity q_u versus the effective unit weight of the soil $\gamma_b - i\gamma_w$. From this plot, estimate the constant N_γ for the soil.

Table 1. Miscellaneous data for fine sand FI-14.

Sieve No.	size (mm)	% finer	Other Data
10	2.000	100	G_s = 2.66
20	0.850	99	e_{min} = 0.51
40	0.425	3	e_{max} = 0.80
60	0.250	0	D_{10} = 0.45mm

Table 2. Data collection for bearing capacity vs. effective stress.

Test 1 ($i \simeq 0.00$)						
	1	2	3	4	5	Mean
Δh(cm)						
$i = \Delta h/L$						
Load dial reading						
q_u						
Test 2 ($i \simeq 0.33$)						
	1	2	3	4	5	Mean
Δh(cm)						
$i = \Delta h/L$						
Load dial reading						
q_u						
Test 3 ($i \simeq 0.67$)						
	1	2	3	4	5	Mean
Δh(cm)						
$i = \Delta h/L$						
Load dial reading						
q_u						
Test 4 ($i \simeq 1.00$)						
	1	2	3	4	5	Mean
Δh(cm)						
$i = \Delta h/L$						
Load dial reading						
q_u						