Module 1
Lecture 4

Soil Aggregate -4

Topics

1.6 EFFECTIVE STRESS

1.6.1 Effective Stress Concept in Saturated Soils

1.6.2 Critical Hydraulic Gradient and Boiling

1.6 EFFECTIVE STRESS

1.6.1 Effective Stress Concept in Saturated Soils

Terzaghi (1925, 1936) was the first to suggest the principle of effective stress. According to this, the *total vertical stress* σ at a point *O* in a soil mass as shown in **Figure 1.28a** can be given by

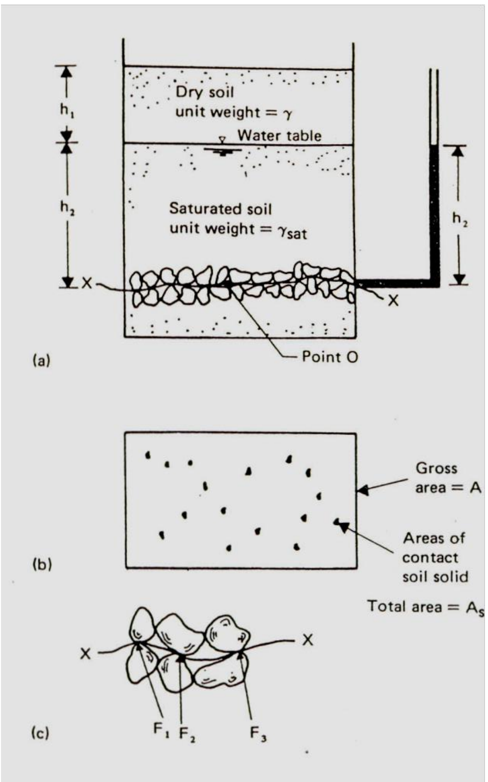

Figure 1.28 Effective-stress concepts. (a) Section. (b) Section at the level of *O*. (c) forces carried by soil solids at their place of contact

$$\sigma = h_1\gamma + h_2\gamma_{sat} \qquad (1.56)$$

The total vertical stress σ consists of two parts. One part is carried by water and is continuous and acts with equal intensity in all directions. This is the *pore water pressure or neutral stress u.* from **Figure 1.28a**,

$$u = \gamma_w h_2 \qquad (1.57)$$

The other part is the stress carried by the soil structure and is called the *effective stress* σ'. Thus

$$\sigma = \sigma' + u \qquad (1.58)$$

Combining eqs. (1.56) to (1.58).

$$\sigma' = \sigma - u = (h_1\gamma + h_2\gamma_{sat}) - h_2\gamma_w = h_1\gamma + h_2(\gamma_{sat} - \gamma_w) = h_1\gamma + h_2\gamma' \qquad (1.59)$$

Where γ' is the submerged unit weight of soil $\gamma_{sat} - \gamma_w$.

For dry soils, $u = 0, so\ \sigma = \sigma'$.

In general, if the normal total stresses at a point in a soil mass are $\sigma_1, \sigma_2, and\ \sigma_3$ as shown in **Figure 1.29**, the effective stresses can be given as follows:

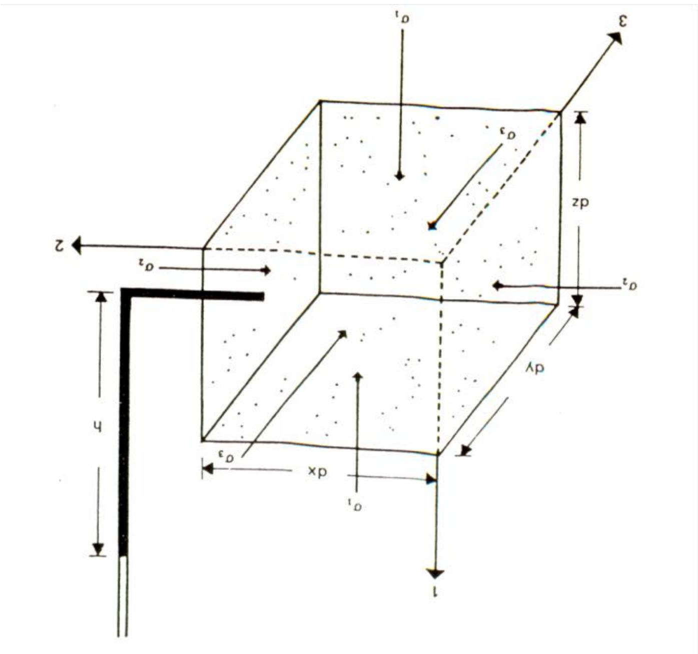

Figure 1.29 Normal total stresses in a soil mass

Where $\sigma'_1, \sigma'_2, and\ \sigma'_3$ are the effective stresses and u is the pore water pressure, $h\gamma_w$.

The principle of effective stress [eq. (1.58)] is one of the most important findings in sol mechanics. The present developments on compressibility of soils, shear strength, and lateral earth pressure on retaining structures are all based on the effective stress concept.

The term effective stress is sometimes used interchangeably with the term inter-granular stress by soils and foundation engineers. Although the terms are approximately the same, there is some difference. In order to visualize the difference, first refer to **Figure 1.28.** The total vertical force *F* at the level of *O* in **Figure 1.28a** is the sum of the following forces:

1. The force carried by soil solids at their point of contact, F_3. This can be seen by considering a wavy surface XX which passes through the point O and the points of contact of the solid particles. $F_1, F_2, F_3, \ldots$ are the resultant forces acting at the points of contact of the soil solids. So,

   $F_s = F_{1(v)} + F_{2(v)} + F_{3(v)+\cdots}$
   Where $F_{1(v)}, F_{2(v)}, F_{3(v)+\cdots}$are the vertical components of the forces $F1_{,} F_2, F_3$ ...

2. The force carried by water, $F_{w,}$
   $F_w = u(A - A_s)$
   Where $u = pore\ water\ pressure = \gamma_w h_2$
   $A = gross\ area\ of\ cross\ section\ soil\ (Figure\ 1.28b)$
   $A_s = area\ occupied\ by\ soil\ solid - to - solid\ contact\ (Figure\ 1.28b)$

3. The electrical attractive force between the solid particles at the level of O, F_A
4. The electrical repulsive force between the solid particles at the level of O, F_R.

Thus, the total vertical force is

$$F = F_s + F_w - F_A + F_R$$

Or $\sigma = \frac{F}{A} = \frac{F_s}{A} + \frac{F_w}{A} - \frac{F_A}{A} + \frac{F_R}{A}$

Where σ is the total stress at the level of *O*, and so

$$\sigma = \sigma_{ig} + u\left(1 - \frac{A_s}{A}\right) - A' + R' = \sigma_{ig} + u(1 - a) - A' + R'$$

Where

$$\sigma_{ig} = \frac{F_s}{A} = intergranularstress$$

$$a = A_s/A$$

$$A' = F_A/A = electrical\ attractive\ force\ per\ unit\ area\ of\ cross\ section\ of\ soil$$

$$R' = F_g/A = electrical\ repulsive\ \ force\ per\ unit\ area\ of\ cross\ section\ of\ soil$$

Hence

$$\sigma_{ig} = \sigma - u(1 - a) + A' - R' \qquad (1.60)$$

The value of a in the above equation is very small in the working stress range. We can thus approximate eq. (1.60) as

$$\sigma_{ig} = \sigma - u - A' + R' \qquad (1.61)$$

For granular soils, silts, and clays of low plasticity, the magnitudes of *A'* and *R'* are small; so for all practical purposes, the intergranular stress becomes

$\sigma_{ig} \approx \sigma - u$ (1.62)

For this case, eqs. (1.58) and (1.62) are similar and $\sigma' = \sigma_{ig}$. However, if *A'-R'* is large, $\sigma_{ig} \neq \sigma'$. Such situations can be encountered in highly plastic, dispersed clays.

1.6.2 Critical Hydraulic Gradient and Boiling

Consider a condition where there is an upward flow of water through a soil layer, as shown in **Figure 1.30a.** The total stress at a point *O* is

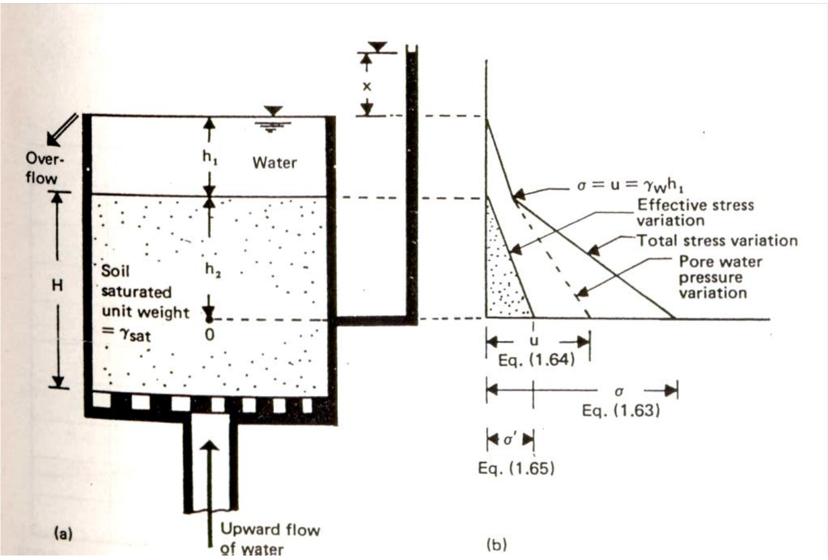

Figure 1.30 Critical hydraulic gradient and boiling

$\sigma = h_1\gamma_w + h_2\gamma_{sat}$ (1.63)

Where γ_{sat} is the saturated unit weight of soil. The pore water pressure at *O* is

$u = (h_1 + h_2 + x)\gamma_w$ (1.64)

And the effective stress at *O* is

$\sigma' = \sigma - u = h_1\gamma_w + h_2\gamma_{sat}) - (h_1 + h_2 + x)\gamma_w = h_2\gamma' - x\gamma_w$ (1.65)

If the flow rate of water through the soil is continuously increased, the value of *x* will increase and will reach a condition where $\sigma' = 0$. This condition is generally referred to as *boiling*. Since the effective stress in the soil is zero, the soil will not be stable. Thus

$\sigma' = 0h_2\gamma' - x\gamma_w$

Or $i_{cr} = \frac{x}{h_2} = \frac{\gamma'}{\gamma_w}$ (1.66)

Where i_{cr} is the critical hydraulic gradient.