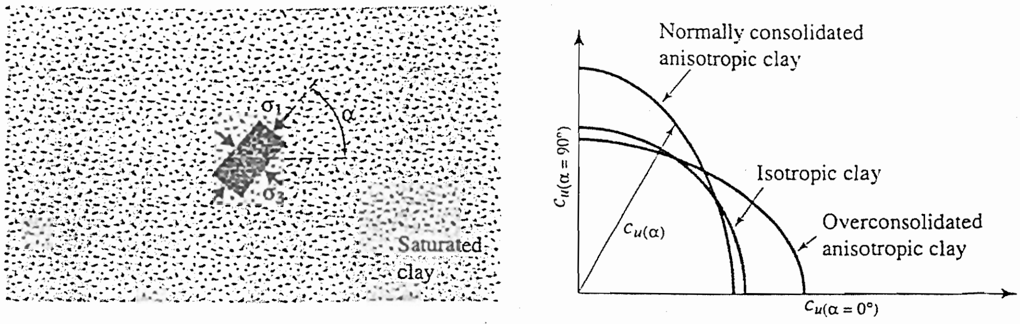

(a) (b)

Figure 11.44 Strength anisotropy in clay

An excellent example of this is the stability of slopes of earth dams after rapid drawdown. The unconsolidated-undrained shear strength of clays can be used to evaluate the end-of-construction stability of saturated cohesive soils with the assumption that the load caused by construction has been applied rapidly and there has been little time for drainage to take place. The bearing capacity of foundations on soft saturated clays and the stability of the base of embankments on soft clays are examples of this condition.

The unconsolidated-undrained shear strength of some saturated clays can vary depending on the direction of load application; this is referred to as *anisotropy with respect to strength.* Anisotropy is primarily caused by the nature of the deposition of the cohesive soils, and subsequent consolidation makes the clay particles orient perpendicular to the direction of the major principal stress. Parallel orientation of the clay particles can cause the strength of clay to vary with direction. Figure 11.44a shows an element of saturated clay in a deposit with the major principal stress making an angle α with respect to the horizontal. For anisotropic clays, the magnitude of c_u will be a function of α. For normally consolidated clays, $c_{u(\alpha=90°)} > c_{u(\alpha=0°)}$; for overconsolidated clays, $c_{u(\alpha=90°)} < c_{u(\alpha=0°)}$. Figure 11.44b shows the directional variation for $c_{u(\alpha)}$. The anisotropy with respect to strength for clays can have an important effect on the load-bearing capacity of foundations and the stability of earth embankments because the direction of the major principal stress along the potential failure surfaces changes.

The sensitivity of clays was discussed in Section 11.15. It is imperative that sensitive clay deposits are properly identified. For instance, when machine foundations (which are subjected to vibratory loading) are constructed over sensitive clays, the clay may substantially lose its load-bearing capacity, and failure may occur.

Problems

11.1 A direct shear test was conducted on a specimen of dry sand with a normal stress of 200 kN/m^2. Failure occurred at a shear stress of 175 kN/m^2. The size of the specimen tested was 75 mm × 75 mm × 30 mm (height). Determine the angle of friction, ϕ'. For a normal stress of 150 kN/m^2, what shear force would be required to cause failure in the specimen?

11.2 The size of a sand specimen in a direct shear test was 50 mm × 50 mm × 30 mm (height). It is known that, for the sand, $\tan \phi' = 0.65/e$ (where e = void ratio) and the specific gravity of solids, $G_s = 2.68$. During the test a normal stress of 150 kN/m^2 was applied. Failure occurred at a shear stress of 110 kN/m^2. What was the mass of the sand specimen?

11.3 Following are the results of four drained direct shear tests on a normally consolidated clay:

Size of specimen = 60 mm × 60 mm
Height of specimen = 30 mm

Test no.	Normal force (N)	Shear force at failure (N)
1	200	155
2	300	230
3	400	310
4	500	385

Draw a graph for the shear stress at failure against the normal stress and determine the drained angle of friction (ϕ') from the graph.

11.4 Following are the results of four drained direct shear tests on a normally consolidated clay:

Specimen size: diameter of specimen = 2 in.
height of specimen = 1 in.

Test no.	Normal force (lb)	Shear force at failure (lb)
1	60	37.5
2	90	55
3	110	70
4	125	80

Draw a graph for shear stress at failure against the normal stress and determine the drained angle of friction (ϕ') from the graph.

11.5 The equation of the effective stress failure envelope for a loose sandy soil was obtained from a direct shear test as $\tau_f = \sigma' \tan 30°$. A drained triaxial test was conducted with the same soil at a chamber confining pressure of 10 $lb/in.^2$

a. Calculate the deviator stress at failure.

b. Estimate the angle that the failure plane makes with the major principal plane.

c. Determine the normal stress and shear stress (when the specimen failed) on a plane that makes an angle of 30° with the major principal plane. Also, explain why the specimen did not fail along the plane during the test.

11.6 The relationship between the relative density D_r and the angle of friction, ϕ', of a sand can be given as $\phi'° = 28 + 0.18\, D_r$ (D_r is in %). A drained triaxial test on the same sand was conducted with a chamber confining pressure of 120 kN/m^2. The relative density of compaction was 65%. Calculate the major principal stress at failure.

11.7 For a normally consolidated clay, the results of a drained triaxial test are as follows:

Chamber confining pressure = 15 lb/in.^{2}
Deviator stress at failure = 34 lb/in.^{2}

Determine the soil friction angle, ϕ'.

11.8 For a normally consolidated clay, it is given that $\phi' = 24°$. In a drained triaxial test, the specimen failed at a deviator stress of 175 kN/m^2. What was the chamber confining pressure, σ_3'?

11.9 For a normally consolidated clay, it is given that $\phi' = 28°$. In a drained triaxial test, the specimen failed at a deviator stress at 30 lb/in.^{2} What was the chamber confining pressure, σ_3'?

11.10 A consolidated-drained triaxial test was conducted on a normally consolidated clay. The results were as follows:

$\sigma_3 = 250$ kN/m^2
$(\Delta\sigma_d)_f = 275$ kN/m^2

Determine the following:

a. Angle of friction, ϕ'
b. Angle θ that the failure plane makes with the major principal plane
c. Normal stress, σ', and shear stress, τ_f, on the failure plane

11.11 The results of two drained triaxial tests on a saturated clay are as follows:

Specimen I: chamber confining pressure = 70 kN/m^2
deviator stress at failure = 215 kN/m^2
Specimen II: chamber confining pressure = 120 kN/m^2
deviator stress at failure = 260 kN/m^2

Calculate the shear strength parameters of the soil.

11.12 If a specimen of clay described in Problem 11.11 is tested in a triaxial apparatus with a chamber confining pressure of 200 kN/m^2, what will be the major principal stress at failure? Assume full drained condition during the test.

11.13 A sandy soil has a drained angle of friction of 35°. In a drained triaxial test on the same soil, the deviator stress at failure is 2.69 ton/ft^2. What is the chamber confining pressure?

11.14 A deposit of sand is shown in Figure 11.45. Find the maximum shear resistance in kN/m^2 along a horizontal plane located 10 m below the ground surface.

11.15 A consolidated-undrained test on a normally consolidated clay yielded the following results:

$\sigma_3 = 15$ lb/in.^{2}
Deviator stress, $(\Delta\sigma_d)_f = 11$ lb/in.^{2}
Pore pressure, $(\Delta u_d)_f = 7.2$ lb/in.^{2}

Calculate the consolidated-undrained friction angle and the drained friction angle.

11.16 Repeat Problem 11.15, using the following values:

$\sigma_3 = 140$ kN/m^2
$(\Delta\sigma_d)_f = 125$ kN/m^2
$(\Delta u_d)_f = 75$ kN/m^2

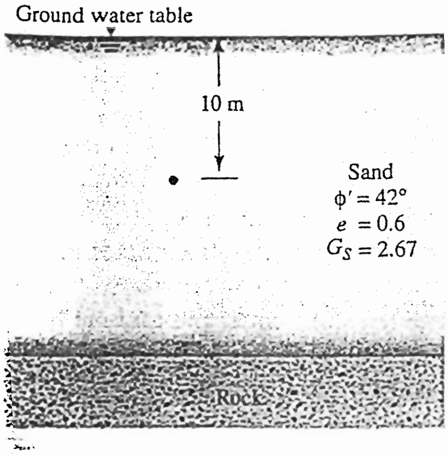

Figure 11.45

11.17 The shear strength of a normally consolidated clay can be given by the equation $\tau_f = \sigma' \tan 31°$. A consolidated-undrained test was conducted on the clay. Following are the results of the test:

Chamber confining pressure = 112 kN/m^2
Deviator stress at failure = 100 kN/m^2

Determine

a. The consolidated-undrained friction angle, ϕ

b. The pore water pressure developed in the clay specimen at failure

11.18 For the clay specimen described in Problem 11.17, what would have been the deviator stress at failure if a drained test would have been conducted with the same chamber confining pressure (i.e., $\sigma_3 = 112$ kN/m^2)?

11.19 A silty sand has a consolidated-undrained friction angle of 22° and a drained friction angle of 32° ($c' = 0$). If a consolidated-undrained test on such a soil is conducted at a chamber confining pressure of 1.2 ton/ft^2, what will be the major principal stress (total) at failure? Also, calculate the pore pressure that will be generated in the soil specimen at failure.

11.20 Repeat Problem 11.19, using the following values:

$\phi = 19°$
$\phi' = 28°$
$\sigma_3 = 85$ kN/m^2

11.21 The following are the results of a consolidated-undrained triaxial test in a clay:

Specimen no.	σ_3 (kN/m^2)	σ_1 at failure (kN/m^2)
I	192	375
II	384	636

Draw the total stress Mohr's circles and determine the shear strength parameters for consolidated undrained conditions (i.e., ϕ and c).

11.22 The consolidated-undrained test results of a saturated clay specimen are as follows:

$\sigma_3 = 97\ \text{kN/m}^2$

σ_1 at failure $= 197\ \text{kN/m}^2$

What will be the axial stress at failure if a similar specimen is subjected to an unconfined compression test?

11.23 The friction angle, ϕ', of a normally consolidated clay specimen collected during field exploration was determined from drained triaxial tests to be 25°. The unconfined compression strength, q_u, of a similar specimen was found to be $100\ \text{kN/m}^2$. Determine the pore water pressure at failure for the unconfined compression test.

11.24 Repeat Problem 11.23 using the following values:

$\phi' = 23°$

$q_u = 120\ \text{kN/m}^2$

11.25 The results of two consolidated-drained triaxial tests on a clayey soil are as follows:

Test no.	σ'_3 (lb/in.^{2})	$\sigma'_{1(\text{failure})}$ (lb/in.^{2})
1	27	73
2	12	48

Use the failure envelope equation given in Example 11.7 — that is, $q' = m + p' \tan \alpha$. (Do not plot the graph.)

a. Find m and α.

b. Find c' and ϕ'.

11.26 A 15-m-thick normally consolidated clay layer is shown in Figure 11.46. The plasticity index of the clay is 18. Estimate the undrained cohesion as would be determined from a vane shear test at a depth of 6 m below the ground surface. Use Skempton's equation in Table 11.6.

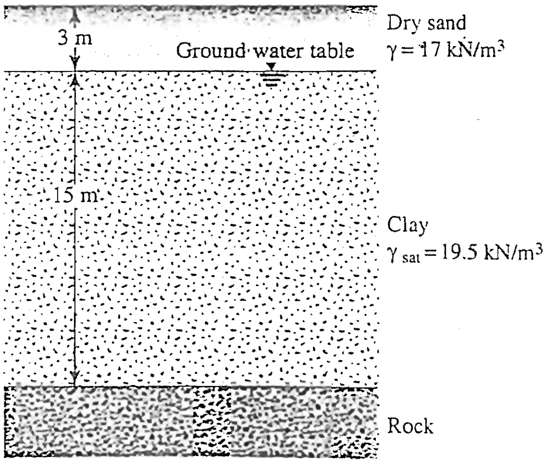

Figure 11.46