Module 4  
Lecture 18  
Pore water pressure and shear strength -2  
Topics  

1.2 SHEARING STRENGTH OF GRANULAR SOILS  

1.2.1 Direct Shear Test  
1.2.2 Triaxial Test  

1.2 SHEARING STRENGTH OF GRANULAR SOILS  

For granular soils with $c = 0$,  

$$s = \sigma' \tan \phi$$  

(4)  

The determination of friction angle $\phi$ is commonly accomplished by one of two methods; the direct shear test or the triaxial test. The test procedures are given below.  

1.2.1 Direct Shear Test  

A schematic diagram of the direct shear test equipment is shown in Figure 4.2. Basically, the test equipment consists of a metal shear box into which the soil specimen is placed. The specimen can be square or circular in plan, about 3 to 4 $in^2$ (19.35 to 25.80 $cm^2$) in area, and about 1 in (25.4 mm) in height. The box is split horizontally into two halves. Normal force on the specimen is applied from the top of the shear box by dead weights. The normal stress on the specimens obtained by the application of dead weights can be as high as 1035 kN/m$^2$. Shear force is applied to the side of the top half of the box to cause failure in the soil specimen. (The two porous stones shown in Figure 4.2 are not required for tests on dry soil). During the test, the shear displacement of the top half of the box and the change in specimen thickness are recorded by the use of horizontal and vertical dial gauges.
Figure 4.2 Direct shear test arrangement

Figure 4.3 Shows the nature of the results of typical direct shear tests in loose, medium, and dense sands. The following observations can be drawn:

1. In dense and medium sands, shear stress increases with shear displacement to a maximum or peak value $\tau_m$ and then decreases to an approximately constant value $\tau_{cv}$ at large shear displacement. This constant stress $\tau_{cv}$ is the ultimate shear stress.
2. For loose sands, the shear stress increases with shear displacement to a maximum value and then remains constant.
3. For dense and medium sands, the volume of the specimen initially decreases and then increases with shear displacement. At large values of shear displacement, the volume of the specimen remains approximately constant.
4. For loose sands, the volume of the specimen gradually decreases to a certain value and remains approximately constant thereafter.

Figure 4.3 Direct shear test results in loose, medium and dense sands
If dry sand is used for the test, the pore water pressure \( u \) is equal to zero, and so the total normal stress \( \sigma \) is equal to the effective stress \( \sigma' \). The test may be repeated for several normal stresses. The angle of friction \( \phi \) for the sand can be determined by plotting a graph of the maximum or peak shear stresses vs. the corresponding normal stresses, as shown in Figure 4.4. The Mohr-Coulomb failure envelope can be determined by drawing a straight line through the origin and the points representing the experimental results. The slope of this line will give the peak friction angle \( \phi \) of the soil. Similarly, the ultimate friction angle \( \phi_{cv} \) can be determined by plotting the ultimate shear stresses \( \tau_{cv} \) vs. the corresponding normal stresses, as shown in Figure 4.4. The ultimate friction angle \( \phi_{cv} \) represents a condition of shearing at constant volume of the specimen.

![Figure 4.4](image)

**Figure 4.4** Determination of peak and ultimate friction angle from direct shear test

Some typical values of \( \phi \) and \( \phi_{cv} \) for granular soils are given table 1.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>( \phi ), deg</th>
<th>( \phi_{cv} ), deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand: round grains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loose</td>
<td>28 to 30</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>30 to 35</td>
<td>26 to 30</td>
</tr>
<tr>
<td>Dense</td>
<td>35 to 38</td>
<td></td>
</tr>
<tr>
<td>Sand: angular grains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loose</td>
<td>30 to 35</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>35 to 40</td>
<td>30 to 35</td>
</tr>
<tr>
<td>Dense</td>
<td>40 to 45</td>
<td></td>
</tr>
<tr>
<td>Sandy gravel</td>
<td>34 to 48</td>
<td>33 to 36</td>
</tr>
</tbody>
</table>

**1.2.2 Triaxial Test**

A schematic diagram of a triaxial test equipment is shown in Figure 4.5. In this type of test, a soil specimen about 1.5 in (38.1 mm) in diameter and 3 in (76.2 mm) in length is generally used. The specimen is enclosed inside a thin rubber membrane and placed inside a cylindrical plastic chamber. For conducting the test, the
chamber is usually filled with water or glycerin. The specimen is subjected to a confining pressure $\sigma_3$ by application of pressure to the fluid in the chamber. (Air can sometimes be used as a medium for applying the confining pressure). Connections to measure drainage into or out of the specimen or pressure in the pore water are provided. To cause shear failure in the soil, an axial stress $\Delta \sigma$ is applied through a vertical loading ram. This is also referred to as deviator stress. For determination of $\theta$ dry or fully saturated soil can be used. If saturated soil is used, the drainage connection is kept open during the application of the confining pressure and the deviator stress. Thus, during the test the excess pore water pressure in the specimen is equal to zero. The volume of the water drained from the specimen during the test provides a measure of the volume change of the specimen.

![Triaxial test equipment](image)

**Figure 4.5** Triaxial test equipment.

For drained test, the total stress is equal to the effective stress. Thus, the major effective principal stress is $\sigma'_1 = \sigma_1 = \sigma_3 + \Delta \sigma$; the minor effective principal stress is $\sigma'_3 = \sigma_3$; and the intermediate effective principal stress is $\sigma'_2 = \sigma'_3$.

At failure, the major effective principal stress is equal to $\sigma_3 + \Delta \sigma_f$, where $\Delta \sigma_f$ is the deviator stress at failure, and the minor effective principal stress is $\sigma_3$. **Figure 4.6** shows the nature of the variation of $\Delta \sigma$ with axial strain for loose and dense granular soils. Several tests with similar specimens can be conducted by the using different confining pressure $\sigma_3$. The value of the soil peak friction angle $\theta$ can be determined by plotting effective-stress Mohr’s circles for various tests and drawing a common tangent to these Mohr’s circles passing through the origin. This is shown in **Figure 4.7a**. The angle that this envelope makes with the normal stress axis is equal to $\theta$. It can be seen from **Figure 4.7b** that
\[ \sin \phi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3} = \frac{(\sigma'_1 - \sigma'_3)/2}{(\sigma'_1 + \sigma'_3)/2} \]

Or \( \phi = \sin^{-1} \left( \frac{\sigma'_1 - \sigma'_3}{\sigma'_1 + \sigma'_3} \right) \)

**Figure 4.6** Drained triaxial test in granular soils (a) application of confining pressure (b) application of deviator stress

**Figure 4.7** Drained triaxial test results
However, it must be pointed out that in Figure 4.7a the failure envelope defined by the equation $s = \sigma' \tan \phi$ is an approximation to the actual curved failure envelope. The ultimate friction angle $\phi_{uc}$ for a given test can be also be determined from the equation

$$\phi_{uc} = \sin^{-1} \left[ \frac{\sigma'_1(\sigma_{uc}) - \sigma_3}{\sigma'_1(\sigma_{uc}) + \sigma_3} \right]$$

(6)

Where $\sigma'_1(\sigma_{uc}) = \sigma'_3 + \Delta \sigma_{uc}$. For similar soils, the friction angle $\phi$ determined by triaxial tests is slightly lower (0 to 3°) than that obtained from direct shear tests.

The axial compression triaxial test described above is the conventional type. However, the loading process on the specimen in a triaxial chamber can be varied in several ways. In general, the tests can be divided into two major groups: axial compression tests and axial extension tests (Figure 4.8).

![Figure 4.8 Soil specimen with axial and radial stress](image-url)