Development of the Borehole Direct Shear Testing Apparatus

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Keywords: Direct shear test, Geotechnical engineering, Shear box.

Abstract. The physical parameters of soil is the foundation of engineering. If data is not the exact value of any geotechnical engineering, it will not get the exact design and evaluation. This paper introduces a borehole direct shear testing apparatus can accurately and quickly get soil shear strength at any depth. It overcome the in-situ shear strength test is not accurate enough, long test time defect, fully meet the requirements of the indicators of field testing.

Introduction

The direct shear test come from the Mohr-Coulomb failure criterion[1]. In geotechnical engineering, it is used to define shear strength of soil. Thus, according a maximum shear stress for each value of the applied normal stress, a linear fit can be obtained and friction angle as well as cohesion can be inferred, as shown in Expression(1) and figure 1.

\[ \tau = \sigma \tan \phi + C \]  

(1)

Figure 1. Mohr-Coulomb failure criterion

The direct shear test is one of the strength tests for geotechnical engineering in a laboratory[2]. It is used by geotechnical engineers to measure the shear strength properties of soil or rock material, or of discontinuities in soil. From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a vertical confining stress[3]. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion(C) and angle of internal friction(\( \phi \))[4].

Direct shear tests are usually applicable only to natural or artificial joints in the lab. During the transportation from In-situ to Laboratory, the specimens will have a large deformation. In the case of soft rock and sand, instead the interest may be focused on the shear behavior of the full matrix more than on the behavior of a clearly defined discontinuity plane. To face this need, an innovative controlled direct shear apparatus was designed.

Description of the Borehole Direct Shear Testing Apparatus

The entire device are 1500mm height and 96mm diameter. The dimension of the entire device, as shown in figure2. The most vital components of the apparatus are: borehole fixing system, sample shear cup, loading system, measuring system, test control system.

The apparatus allows direct shear tests to be performed under closely controlled conditions in terms of axial pressure applied to the specimen. It was designed to allow for testing soft rock materials.
The Shear Box and Borehole Fixing System

The sample shear cup is built in stainless steel, which are available to test sample cylindrical specimens of 61.8 mm diameter and 50mm height, as shown in figure 3. Thickness of test cup is 2mm, with sharp edge at the bottom. There is a ring cutter in the middle of test cup, which is 61.8mm diameter and 20mm height. Due to the mechanical set-up, the maximum shear displacement is 12 mm.

The borehole fixing system is in the head of the device, as shown in figure 4. The motor rotates and take the connector going down. Then the connector pushes the holder open. The holder will brace at wall of the hole and make the device stable. This may allow tests to be conducted on rough or filled discontinuities. According engineering data, Soil gives the Backup arm is 220Kpa, the motor can applied 230N. After calculating, the fixing system can hold the device stable.

Loading System and Measuring System

The Sample testing system includes vertical pressure applied system and horizontal pressure applied system. A servo-controlled electrical motor promote the shoe by connector and make shoe shift downwards. The horizontal load is applied by shoe connected to the ring cutter and by the servo-controlled electrical motor. A piston is moved by an electrical motor and screw. The rotation of the motor is not continuous but it can be a constant in angular increments. The both horizontal and vertical maximum loading is 1000N, with 1N precision.

The horizontal load is measured by a load cell integrated into the ring cutter. The horizontal load is measured by taking the influence of pore pressure and considering a constant contact area. The cell is 100K full scale. The vertical and horizontal displacements are measured by two different means. The measurement is given by the rotation of the driving system of the electrical motor that moves the axial loading arms (1μm). The shear displacement measurement is taken by the LVDT. The system measures the relative displacement between the ring cutter and shear test cup. The LVDT is connected to the ring cutter. The maximum displacement of LVDT is 12mm with a 1 μm precision.

Control System

The control system is based on a two level approach, as shown in figure 5. At first, the controlling and measuring system are connected to autonomous units. At the second level, different units joins together to a circuit board and then to a PC.

With this approach, the engineers can operate both in a local manner, by using the single units control panels, and in a remote way, by accessing the software on the PC. The software allows the user to strictly control the test procedure and parameters, allowing one.
Shear Test Procedure

As described above, the novel apparatus allows direct shear tests to be performed on either sand or soft rock. Total stresses may be applied to a dry specimen or one can apply a pore pressure to saturated specimen and shear it in truly effective stress conditions. The working environment is shown in Figure 6. The rest of the procedure and related device is described below step by step:

1. The engineer will drill a 5-50m deep hole at ground. Then, the device is placed in the hole. The engineers can control the device behavior and test the soils.

2. After drilling, engineers place the device into the hole. When the device at the bottom of the hole, engineer controls motor1 to open the holders. The holders can strict at wall of hole and hold the device position.

3. When the device is at the working position, the sample preparation is next step. The engineer control motor to push the sample box into the soils. It makes the sample box fill up soils.

4. After the sample box fill up soils, engineer control the motor to applied the vertical stress. The pressure sensor will transfer and record data.

Step4: After vertical stress is stable, another motor rotate and push the shoe going down, then the shoe will drive the ring cutter to shift a horizontal movement. The LVDT will record data and transfer to the computer.

Figure 6. Working environment.
Experiment

To test and verify the feasibility of direct shear test measuring, the experiments are conducted in deep hole environment. Taking around an open ground as the research area, using drilling machine drill a 110mm diameter and 5m deep. Experiments of specimen density is 1.82g/cm$^3$, the moisture content is 19.07%. Using the National Standard direct shear test of slow shear experiments as testing process. The experiments applied three different stress 25Kpa, 50Kpa and 75Kpa.

This is the kind of soil sample gravel prone broken under high pressure, but basically no effect on this trial cohesive soil. The test to 0.02mm / min shear rate cut, each sample generated 0.4mm displacement remember a number of times until the shear displacement reaches 6mm shutdown. Due to the shear surface of this device has two sides, so the shear stress is calculated as follows:

$$\tau = \frac{C \cdot R}{2A} \times 10$$

(2)

Shear Strength: $\tau$, Cohesion: $C$, Displacement: $R$, Area: $A$

Figure 7 shows the shear stress/shear displacement plot for all the test performed. Figure 8 depicts the strength line on the shear stress diagram. From the two figures, we can know cohesion, $C=33.5$KPa and frictional angle is 35.9.

![Figure 7. Shear stress versus shear displacement](image)

![Figure 8. Stresses at failure.](image)

Summary

The instability of rock and soil engineering mostly caused by shear damage, accurate determination of shear strength parameters of rock mass is of great significance in the construction of geotechnical engineering. This paper has illustrated the innovative and peculiar features of a novel borehole direct shear apparatus recently developed. This apparatus is highly integrated, portable and flexible operation, which can be widely used in direct shear test for geotechnical engineering. It is shown that the new apparatus is working properly and that the accuracy of the measurement system implemented to obtain results during testing.

References

