

## Experimental Tests of the Shear Strength of the Cohesive Soils and Their Use in the Geotechnical Calculations

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**Abstract:** The paper deals with experimental determination of shear strength of cohesive soils in the laboratory conditions. Peak and residual shear strength characteristics (angle of internal friction and cohesion) are analyzed in detail. Determination of representative shear strength characteristics of cohesive soil (clays and silts) are necessary for reliable design of the geotechnical structures from the 1<sup>st</sup> group of limit states (bearing capacity) point of view.

**Keywords:** Experimental, Shear Test, Shear Strength, Internal Friction, Cohesion

### 1. Introduction

For the solution of the geomechanical stability problems it is necessary to know the value of the shear strength of natural rock environment. The most frequent stability tasks in engineering practice are solved by following calculations:

- bearing capacity of foundation [1], [2], [3] and [4],
- slope stability [1], [2],
- earth pressure on the retaining wall and underground structures [1] and [4].

Building structures are most often founded in cohesionless or cohesive soils, i.e. non-strengthened (mechanically and chemically failed) rocks. For laboratory assessment of shear strength in the engineering practice the following equipment is usually used:

- a) direct shear box device (used for cohesionless soil – sands and cohesive soils – clay and loam) in accordance with STN 72 1030 [5],
- b) triaxial device (used for cohesive soil – clay and loam) in accordance with STN 721023 [6].

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Shear strength of soils according to Coulomb's theory [8] is defined as a shear stress on the failure limit as follows:

$$\tau = \sigma \cdot \operatorname{tg} \varphi + c \quad (1)$$

where:  $\tau$  is the shear strength of soil,  $\varphi$  – the angle of internal friction of soil,  $c$  – the cohesion of soil.

In cohesionless soils (gravels, sands),  $c=0$  and  $\varphi>0$ ; in cohesive soils (clay, loam)  $c>0$  and  $\varphi>0$ ; for ideally cohesive (extremely plastic clay) soils  $c>0$  and  $\varphi=0$ . From relation (1) it is obvious that the value of the shear strength is functionally dependent on the intensity of the normal stress. Parameters of shear strength ( $\varphi$ ,  $c$ ) are dependent on the boundary conditions for realized shear tests. With respect to various choices of boundary conditions for the shear test, the following types of tests can be classified [8]:

- a) consolidated drained tests (label "CD"); the effective parameters of shear strength ( $\varphi_{ef}$ ,  $c_{ef}$ ) are obtained,
- b) consolidated non-drained tests (label "CU"); the total parameters of shear strength ( $\varphi_u$ ,  $c_u$ ) and the effective parameters of shear strength ( $\varphi_{ef}$ ,  $c_{ef}$ ) are obtained,
- c) non-consolidated non-drained tests (label "UU"); the total parameters of shear strength ( $\varphi_u$ ,  $c_u$ ) are obtained.

The correct choice of the type of shear test for shear strength assessment depends on the type of solved geotechnical problem, i.e. on boundary conditions of the solved problem.

## 2. Direct box shear test

Methodology, boundary conditions and interpretation of direct box shear test results are defined in detail in STN 72 1030 [5]. Boundary conditions of direct box shear test are schematically showed in Fig. 1.

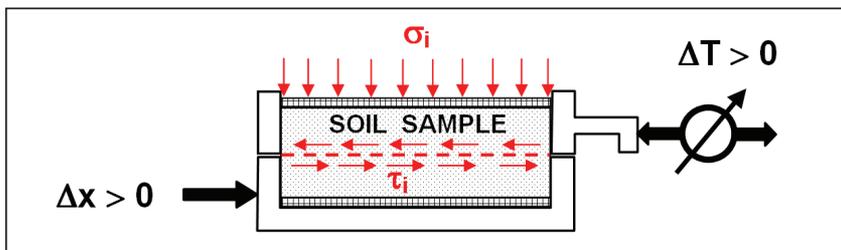


Fig. 1. Boundary conditions of direct box shear test.

The predetermined shear plane (failed area) and type of test "CD" (consolidated drainage test) are the basic boundary conditions. The test is performed in a way that, that the drained tested sample is loaded with constant

normal stress ( $\sigma_i$ ). After the consolidation of the sample the shear displacement is applied until the failure of sample due to the shear stress (i.e. achieving the shear strength). Time "t" required to achieve the consolidation of the sample can be calculated from the formula

$$t = \frac{2.H^2}{c_v} \quad (2)$$

where: H is maximal drainage path (in bidirectional drainage it is half of sample height),  $c_v$  – soil consolidation coefficient.

Shear device can be a box of square (the most usual case) or circular cross section with a ratio of height to length (or diameter) 1:3 to 1:5. From the viewpoint of the method of horizontal displacement coating, the device can operate with controlled displacement rate (constant displacement and variable shear stress) or with controlled shear stress (shear stress is constant and rate displacement is variable). Rate of shear displacement depends on the soil type.

In the direct shear box test the effective parameters of peak and residual shear strength are assessed. Shear test is realized using at least four different normal stresses (for determination of peak parameters) or at least three different normal stresses (for determination of residual parameters), respectively. The values of the normal stresses are chosen with respect to the designed (supposed) stress change due to additional loading from the building structure. Shear stress (or shear resistance) “ $\tau$ ” on the predetermined sliding surface is calculated according to relation

$$\tau = \frac{T}{A} \quad (3)$$

where: T is shear force, A is sample area.

The advantage of the direct shear box test is its simplicity and the fact that the 3D state of stress ( $\sigma_1 > \sigma_2 > \sigma_3$ ) corresponds well to real conditions of soil failure. On the other hand, the disadvantage of the test is the fact that the failure area is predetermined by position of the box walls.

The practical example of direct shear box test evaluation for cohesive soil (clay with low plasticity) is given in [7]. Stress-strain diagram of shear test is given in Fig. 2. The curve of shear strength with evaluation of effective residual and peak parameters (angle of internal friction and cohesion) is shown in Fig. 3. The parameters of shear strength belong to the most important input data required for analysis of stability problems in geomechanics.

### 3. Triaxial shear test

Methodology, boundary conditions and interpretation of triaxial shear test of soils are defined in detail in STN 72 1023 [6]. Boundary conditions of triaxial shear test are schematically showed in Fig. 4. In the triaxial device we can choose boundary conditions for different types of shear tests (CD, CU, UU) in which we determine

effective and total parameters of soil shear strength (angle of internal friction and cohesion). In the triaxial test the 3D state of stress acts on the cylindrical sample of cohesive soil (height: diameter = 2:1). Shear strength of soil is evaluated in sense of Mohr's theory of failure [8].

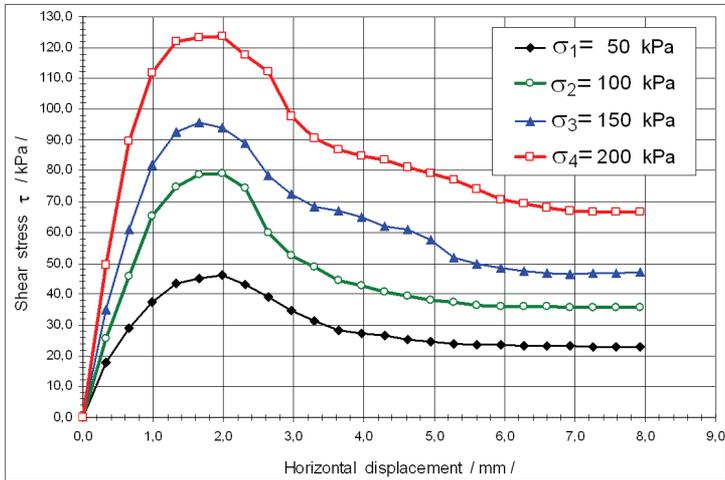


Fig. 2. Stress-strain diagram of direct shear box test (for clay with low plasticity) [7].

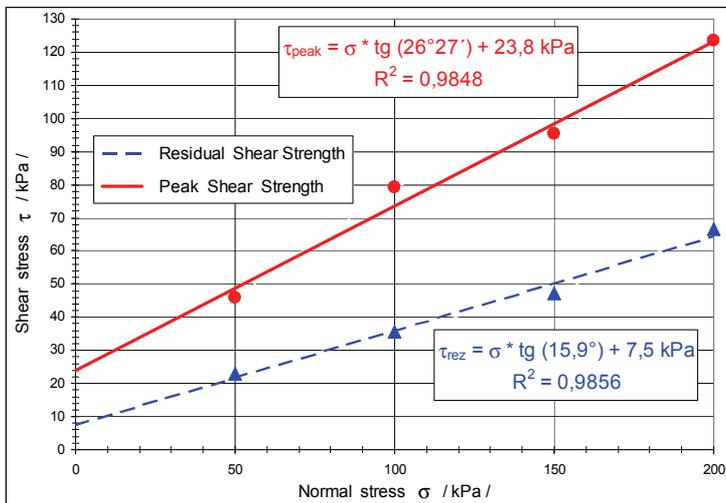


Fig. 3. Evaluation of direct shear box test – curve of shear strength with peaks and residual parameters (for clay with low plasticity) [7].

Advantages of test:

- more accurate regarding of stress and strain states of changes in subsoil,
- provides information about neutral stresses in subsoil,
- soil failure in location with smallest shear strength.

Disadvantages of test:

- complicated preparation of samples and device (methodology of test),
- complicated determination of real path of stresses,
- state of stress of the sample is axis-symmetrical ( $\sigma_1 > \sigma_2 = \sigma_3$ ) which does not correspond to the real state of stress in subsoil ( $\sigma_1 > \sigma_2 > \sigma_3$ ).

The triaxial device is usually used for assessment of the shear strength in more complicated building structures.

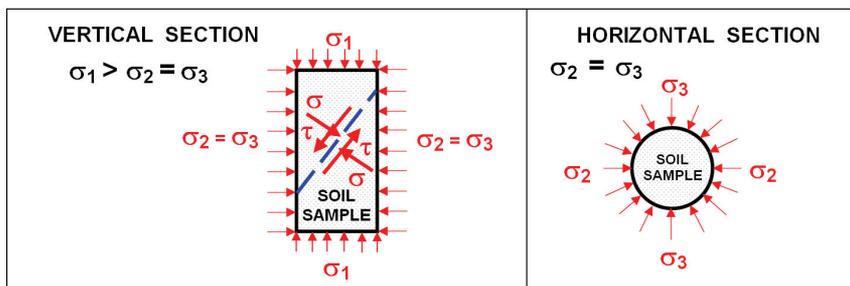


Fig. 4. Boundary conditions of triaxial test.

#### 4. Conclusion

Assessment of soil strength parameters (angle of internal friction and cohesion) is important for solution of large number of stability problems (e.g. bearing capacity of foundation, slope stability, earth pressure calculation, etc.). Due to this fact it is important to pay large attention to correct choice of methods for determining the shear strength as well as and to the choice of the boundary conditions of tests (CD, CU, UU). The use of different parameters of shear strength (total or effective parameters, peak or residual parameters) depends on the real boundary conditions in subsoil. Boundary conditions are usually changing during the lifetime of building structures. This fact has affects significantly the assessment of the reliability of structures. Geotechnical design of structures is detail.

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## References

- [1] EN 1997-1:2004: *EUROCODE 7 - Geotechnical design – Part 1: General rules* (in Slovak).
- [2] EN 1997-2:2004: *EUROCODE 7 - Geotechnical design – Part 2: Ground investigation and testing* (in Slovak).
- [3] STN 73 1001: *Foundation of structures* (in Slovak).
- [4] STN 73 0037: *Earth pressure* (in Slovak).
- [5] STN 72 1030: *Laboratory direct shear box drained test of soils* (in Slovak).
- [6] STN 72 1023: *Laboratory triaxial shear test of soils* (in Slovak).
- [7] Kuzma J. et. al., *Geotechnical investigation. Reconstruction of JE V-1 in Jaslovské Bohunice, TVD 1<sup>st</sup> and 2<sup>nd</sup> Block* (in Slovak) (SvF STU, Bratislava, 2000), 126 pp.
- [8] Jesenák J., *Soil mechanics* (in Slovak) (STU, Bratislava, 1994). ISBN 80-227-0642-6.