Determination of the interface parameters on the contact of concrete and soil by different methods

A Z Ter-Martirosyan, V Sidorov*, A Almakaeva
National Research Moscow State University of Civil Engineering, 26, Yaroslavskoye highway, Moscow, 129337, Russia

E-mail: vitsid@mail.ru

Abstract. The article presents a comparison of tests carried out on torsional and direct shear devices, in order to determine the strength reduction factor on its contact arising between the soil massif and the underground structure. It is necessary to understand which device makes it possible to determine the strength characteristics that are closest to real cases. For the experiments, soft clay and concrete samples were used. The tests were carried out at a vertical pressure of 100 kPa with speeds of 0.005 mm/min and 0.01196 °/min. According to the obtained results, it was concluded that the values of the shear stresses on the torsional shear device are higher than on the direct shear device. This is due to the fact that the contact area is not constant during the test, respectively, the shear resistance decreases. In a number of other works, the differences in the results are attributed to the fact that the mechanisms of collapse differs depending on the type of device. Therefore, it is necessary to study more detailed the conditions of shear and the process of specimen collapse in all devices, which allow one to determine the strength parameters in order to understand which of them gives more correct results.

Introduction
For correct modeling of the interaction between structures and soil massif in geotechnical software complexes, special contact elements called “interfaces” are used. Modeling of these elements makes it possible to separate the common nodal points on the contact of the underground structures and adjacent soils, as a result of which the structure can move and deform separately from the soil. In addition, the interface element has two main parameters: strength reduction factor ($R_{\text{inter}}$) and real interface thickness ($\delta_{\text{inter}}$). The first parameter reduces the strength characteristics on the “soil-structure” contact and varies from 0 to 1, which corresponds to an absolutely smooth contact and the roughest, i.e. with a decrease in the strength reduction ratio, the structure will be able to move more, slip and separate from the soil adjacent to it. The second parameter describes the thickness of the soil layer at the contact involved in the work during shear and displacement of the structure. The greater the thickness of the soil will interact with the underground structure, the higher the shear resistance, and hence the strength characteristics at the contact of the soil massif and the structure.

Literature References
Zhao C., Wu Y., Zhao C., Tao G. (2018) [1] carried out large-scale tests on the direct shear device between a clay of low-plasticity consistency and concrete plates. The shift occurred at a constant speed and the vertical load applied by steps, varying from 50 kPa to 400 kPa. The peak values of the shear resistance were on average 150 ... 200 kPa, the residual strength continuously increased due to an increase of the vertical load.

When testing for a torsional shear of soft clay and concrete, Hammoud F. and Boumekik A. (2006) [2] obtained the coefficients of the reduction strength equal to 0.88 with weakly rough contact ($R_{\text{max}} = 50.2 \mu m$) and 0.94 with strongly rough ($R_{\text{max}} = 136.4 \mu m$).

Comparing the tests carried out in the simple shear device and in the direct shear device, Hanzawa at all (2007) [3] came to the conclusion that in the second case, the strength characteristics are higher than in devices that implement a simple shear. This is explained by a different mechanism of destruction: with a direct shear, the soil is cut off along a fixed horizontal plane, and with a simple shear, the collapsing occurs along several shear planes. Tsubakihara Y. and Kishida H. (1993) [4] came to the same conclusions when testing marine clays with steel plates in similar devices.

Materials and methods

The strength of soils is estimated by their resistance to shear stresses. During testing the soil samples in devices, the shear begins to achieve a certain amount of shear stresses. Further growth leads to vertical and horizontal deformations. Vertical deformation can be positive (compression) and negative (expansion). Well-compact clay soils, as well as sands, under normal compaction, dilate during shear, i.e. increase in height, otherwise, there will be a compression of the soil - reducing the height of the sample. When dilatancy occurs, a brittle failure takes place, which is characterized by peak and residual strength. The presence of a peak in the resistance to shear versus the horizontal displacement plots indicates the appearance of the dilatancy effect, which can be suppressed by increasing the normal stresses. When compressing soil samples, plastic failure occurs, characterized by critical strength.

To study the strength characteristics of the soil, as well as the strength characteristics arising at the contact of the soil with various materials, such as steel, wood, geomembranes and other materials, direct shear, simple shear, as well as a torsional shear device are used [5].

In the device of a direct shear, a vertical load is applied to a sample placed in a cage consisting of two parts. The cut occurs due to the shear load at the movable part of the shroud. Upper part of the device is fixed. The gap formed between two parts, fixes the horizontal plane of the cut. The size of the gap can have a significant impact on the strength characteristics. This is due to the fact that during shear process the layers of soil particles are involved in the work and create additional resistance to shear [6].

During testing in simple shear device, the soil sample is placed in a rubber membrane, to which thin metal rings are then put on, and during the experiment with the current normal pressure shear force is transferred to them, and the load will evenly increase for each subsequent ring. Thus, a multi-plane shear occurs, in which the sample volume does not change, the sample changes only its shape. The main difference between simple shear and direct shear is the constant shear area, which allows to obtain more correct values of strength characteristics, moreover, because the soil is placed in a rubber membrane, it is possible to carry out tests without any drainage, and also to measure pore pressure. However, the values of the strength parameters in the simple shear device are lower than in the direct shear device, where they are often obtained too high.

To determine the parameters of residual strength required for solving problems related to the stability of slopes, as well as when calculating retaining walls, a torsional shear device is used. This apparatus provides large shear deformations due to the continuous rotation of the movable part of the sample relatively fixed part around its axis. Torsional shear tests corresponds to the cases when the slope is activated and sheared along the already formed slip surface. The soil sample in the device is placed in a metal holder, and compressive and shear loads are applied to it. Usually, a peak is passed
at a turning angle of 10°...30°, tests are carried out until the device reaches the residual strength, or until it reaches 15-20 counts every 1°...2°. In devices for direct shear or simple shear, the values of residual cohesion $c_r$ and the angle of internal friction $\phi_r$ can be overestimated, since in these apparatus, shear deformation is limited to 15–20%, and if the dependence curve $\tau = f(\delta)$ has not reached constant values of residual strength, it is necessary to retest the soil sample. However, in the case of reciprocating carriage movement, particles are re-installed in the shear plane, as a result of which the angle of internal friction increases and some small amount of cohesion is acquired. As a torsional shear device, it can make a full circle in one direction until constant values of residual strength are obtained. Another advantage of the torsional shear is the constant shear area, but in almost all types of constructions of this device it’s impossible to test undrained soils.

In order to compare the strength parameters at the contact of the soil with solid materials in this article, laboratory experiments were conducted on devices with a direct shear and torsional shear. For tests, soft clays with the following physical characteristics were used: natural moisture content $W = 38\%$, plastic limit $W_p = 45\%$ and liquid limit $W_l = 90\%$, and also concrete samples were used. Before each test, the clay was precompacted for 8 hours with a vertical load of 100 kPa. The tests were carried out according to GOST 12248-2010 «Soils. Laboratory methods for determining the characteristics of strength and deformability», in accordance with which the shear was carried out with a constant vertical load $\sigma_v = 100$ kPa and with a constant speed: 0.005 mm/min for a direct shear, and for torsional speed it was calculated by the formula through the relationship of linear and angle speed:

$$V = \omega \cdot R$$  \hspace{1cm} (1)

where $\omega$ – angle speed, [rad/min];

$R$ - specimen radius equal to 35.7 mm in these structural conditions.

According to the formula (1), the angle speed $\omega = 0.00014$ rad/min or 0.008 °/min. Due to the fact that in the torsional shear device the speed is set using a gearbox with only 9 modes, the tests were carried out at a speed close to the calculated one and equal to 0.01919 °/min. Such a difference is permissible, since when the shear rate is up to 1 mm/min, it does not have a significant effect on strength [7].

The shear in the direct shear device was carried out until shear deformations did not reach 15%, that is, the value of 10,71 mm. The angle of rotation corresponding to this linear displacement is equal to 19° and was determined by the formula:

$$\alpha = \omega \cdot t$$  \hspace{1cm} (2)

where $\omega$ – angle speed equal to 0.01196 °/min;

$t$ - time, [min], determined by the formula when equating to the linear speed:

$$t = \frac{d}{\omega \cdot R}$$  \hspace{1cm} (3)

where $d$ - is the magnitude of the linear displacement equal to 10,71 mm.

The time it takes for the sample to be rotated with a torsional shear, corresponding to a linear offset of 10,71 mm, when tested on a direct shear is 1596 min.

**Results**

According to the test results, the dependence of shear stresses to the angle of rotation $\tau = f(\alpha)$ plots were constructed. To superimpose curves on one graph, linear displacements were calculated by formulas (2) and (3), corresponding to the values of the angles at which the readings were taken. Tests for torsional shear are marked as RS, and for direct shear - DS.

Figure 1 shows the curves obtained during the shear tests of «clay by clay» scheme. By the form of these curves it is clear that the nature and behaviour of both shares is similar. Most of the curves reach peak values at a linear displacement of approximately 2-3 mm or at a rotation angle of about 4°. The curves did not reach the residual strength, which indicates the need for retesting for a direct shear of...
soil samples to obtain the residual values of the strength characteristics. On the torsional shear device, the residual strength value turned out to be equal to $\tau_{\text{rest}} = 55.8$ kPa. In general, in figure 1, one can see that there is a good convergence of the test curves, with the exception of the curve DS2, which has two peaks and does not reach the residual strength. Maybe it take place due to the cracks system inside the sample. The shear occurred along the plane that provides the least resistance, i.e. along the crack. The very form of the slip plane has a deepening and rounded peak, so dilatancy began to occur during the shear, and consequently, shear resistance increased, hence the appearance of a second peak on the graph. It is also worth noting that the values obtained when testing for torsional shear were slightly higher, which is explained by the constant contact area during the experiment. However, the curve RS1 turned out to be lower than the others, the possible reason for this could be a loss of alignment when transferring the vertical load on the stamp, which caused a decrease in shear stresses.

![Figure 1. Curves of shear stresses versus rotation angle $\tau = f(\alpha)$](image)

The results of all tests carried out between clay and concrete are presented in Figure 2. The brittle nature of the destruction is more pronounced, because the graphs clearly show the peak with a subsequent decrease in strength to a constant value. Peak values are reached faster than when testing by «soil-soil» scheme: with a displacement of 1-2 mm or with a turning angle of 2°, moreover, the values of the peak strength values are slightly lower than when testing the soil over the soil. So we can conclude that the strength at the contact of the soil massif and underground structures will decrease. The residual strength obtained during the experiments on a direct shear is equal to $\tau_{\text{rest}} = 42.4$ kPa, and for testing for torsional shear - $\tau_{\text{rest}} = 46.5$ kPa and $65.1$ kPa. The values of peak torsional strength with a torsional shear are also higher than the peak values obtained with a direct shear. In general, the convergence of the curves is slightly worse than in previous tests. This could be influenced by many factors, such as the magnitude of the vertical load or the roughness of the concrete surface. Therefore, for more specific conclusions, it is necessary to conduct a greater number of experiments.
Figure 2. Curves of shear stresses versus rotation angle $\tau = f(\alpha)$

Figure 3 shows the characteristic curves of the tests carried out according by “soil – soil” and “soil – solid” schemes. This graph clearly shows that in all two schemes, the strength determined using a torsional device was higher. It also shows that strength peak is achieved earlier when testing clay by concrete.

Figure 3. Curves of shear stresses versus rotation angle $\tau = f(\alpha)$

Table 1 presents the values of the peak strength, as well as the factors reducing the strength, defined as the ratio of the peak shear strength of clay in concrete to the peak strength obtained in clay by clay test scheme. Due to the large dispersion of the obtained peak values, the coefficient for reducing the strength of $R_{inter}$ varies from 0.56 ... 0.93. In [2], the average $R_{inter}$ value for clay with similar physical characteristics, tested on a torsional shear device, is 0.88. The nearest value, similar to him, is 0.93.

Table 1. The reduction factors of strength

| №  | Clay-clay $\tau_{max}$ [kPa] | Clay-concrete $\tau_{max}$ [kPa] | $R_{inter}$ |
|----|-------------------------------|---------------------------------|-------------|
| 1  | 95,3                          | 88,3                            | 0,93        |
### Summary

1. The results of the tests showed that the shear strength measured in the torsional shear device was higher than that obtained in direct shear device. This is due to the fact that when conducting the experiment in direct shear devices, the contact area does not remain constant, but decreases, hence the tangential stresses in the shear plane will be less.

2. «Clay-concrete» interaction test curves showed that the peak strength is reached earlier than when testing the corresponding soil, and the strength values were lower, i.e. this corresponds to the real picture of the fact that at the contact between the soil massif and the structure the strength decreases.

3. The tests for clays showed that the curves character depends on cracks in soil samples, since the shear can pass both along a predetermined surface and along a crack.

4. The convergence of the curves of two experiments when testing by «clay-concrete» scheme was lower than the tests according by the «soil-soil» scheme. In order to use the $R_{lower}$ strength reduction factor in engineering practice, 6 tests for a building site should be performed, and to determine a synthesis factor depending on the type of soil and material with which it interacts, a large number of tests should be processed.

5. Further research on this topic is necessary since the mechanism of collapse and the conditions of testing in different devices will differ from each other. Therefore, it is important to determine in which of them the obtained results most closely corresponds to the real picture of shear for further correct modeling in geotechnical software packages.

### References

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|       | 2 (RS2) | 3 (DS1) | 4 (DS2) |
|-------|---------|---------|---------|
| Value | 127.8   | 118.66  | 122.94  |
| Value | 72.0    | 78.56   | 55.22   |
| Value | 0.56    | 0.66    | 0.45    |