Technobius, 2023, 3(3), 0043, DOI: https://doi.org/10.54355/tbus/3.3.2023.0043

Technobius

https://technobius.kz/

e-ISSN
2789-7338

Article

Research on clay shear strength anisotropy at Šenkovec clay pit

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Abstract. The paper deals with influence anisotropy to shear strength of clay and differences in test results of shear strength parameters, cohesion (*c*) and internal friction angle (*φ*) considering the direction of testing. Clay is very often the foundation soil of many buildings. There were performed three series of direct shear experiments for each of two different directions in relation to the horizontal, 0° and 90° (18 direct shear experiments in total). The results showed significant differences in the values of the shear strength parameters and to shear strength ultimately with considering to the test direction. Angle of internal friction (*φ*) is higher by 3.0° or 11.81% in the test at an angle of 0° in relation to the horizontal. A much more significant difference is visible in cohesion (*c*). The results showed that the cohesion (*c*) in the 90° test was higher by 14.92 kN/m² or 106.04%.
Keywords: anisotropy, cohesion, direct shear experiment, internal friction angle, shear strength.

1. Introduction

In recent times, the rapid development of cities, industry and transport, and an increasingly common occurrence redevelopment leads to a lack of land suitable for construction leading to situations of not choosing a place to build large and demanding buildings. That is why it is becoming more common such buildings are built in extremely complex geological conditions. Clay soil belongs to the complex engineering geological conditions of construction in the construction of various facilities in construction such as underground structures, underground garages, underground railways and the foundation of all buildings, especially indented buildings of irregular form.

When designing buildings and dimensioning load-bearing structures, using Mohr-Coulomb, is required determine the parameters of shear strength of the soil from which according to known methods and accordingly prescribed norms can calculate the bearing capacity of the foundation soil, active pressure, passive resistance, slope stability and more.

Most calculation models state that the soil is homogeneous and isotropic. Natural soil is in most cases very heterogeneous and anisotropic. In work of Shkola [1], based on calculation and analysis, it is stated that the anisotropic properties must be taken into account in differences in the shear strength properties of the soil with directions of at least 5% in the angle of internal friction and 10% in cohesion. Actually, number of soil properties involved in the formation of its discrete model, determines the number of isotropies, i.e., anisotropies in its qualitative and quantitative characteristics being studied.

Zaretsky [2] stated in his paper that the influence of the orientation of structural elements on the shear strength of clay soils and grain orientation in non-cohesive soils is qualitatively similar. This theme was also considered by many scientists such as Ž.E. Rogatkina [3], A.K. Loh – R.T. Holt [4], Z. Ewertowska-Madej [5], K.Y. Lo – V. Milligan [6] and A.V. Shkola – A. Kheydar [7], A. Aniskin and others [8]. Many of them confirmed the influence of clay anisotropy on shear strength parameters.

According to some papers, there are two basic types of soil anisotropy. The first refers to the layering of textural elements consisting of soil layers with different granulometric composition, structure and physical-mechanical properties Ornatskyi [9], and Harr [10]. The deviation of the soil from the isotropy in this case is defined by natural or artificial stratification. The process of sedimentation of rocks that form natural heterogeneous soil deposits are characterized by natural stratification while artificial stratification is realized in newly formed massifs through the technological specifics of construction. The second type of anisotropy is determined to be predominant by the orientation of anisometric particles in space. Soil particles are considered to be asymmetric and yes are oriented sedimentation and fit into layers under the action of gravitational forces predominantly horizontally with a larger area Ornatskyi [9]; Geniev [11] and Kandaurov [12].

The works of the Shkola [13] and Voitenko [14] provide a detailed review of the literature on experimental and theoretical investigations of shear strength anisotropy of natural and artificial soils.

An analysis of many papers concludes that the anisotropy of the shear strength of clay has not been sufficiently studied. Through this work it is wanted by laboratory testing of a series of undisturbed clay samples and by processing and analyzing the obtained results, investigate the difference in the shear strength parameters given the direction of the test in relation to the orientation of the samples in nature.

2. Methods

2.1 Materials

In this study, 18 clay test samples were investigated. The samples were taken from a clay pit to ensure they were as homogeneous as possible. The location of the clay pit is in Šenkovec (46.410704N, 16.407906E), in the northern region of Croatia (Figure 1). From this clay pit, clay is extracted to produce bricks.

Figure 1 – Šenkovec clay pit

Upon choosing the site within the clay pit, we removed the visibly disturbed surface layer of soil, which was 10.0 to 15.0 cm thick due to atmospheric influences. Subsequently, we excavated a rectangular ditch, 40.0 cm deep, enabling the extraction of a clay sample (Figure 2). To maintain the integrity of the sample, it was carefully wrapped in plastic to prevent moisture fluctuations. Emphasizing the study's objective, we took special care to preserve the natural orientation of the sample in space during both extraction and transport.

Figure 2 – Sample prepared for extraction (left) and sample with top mark (right)

2.2 Investigating physical characteristics of clay

A series of laboratory tests were performed to determine the physical characteristics of clay. Physical characteristics are essential to determine the uniformity of test samples. All experiments were performed in accordance with the prescribed standards for laboratory tests. The physical characteristics for each tested sample of clay (Table 1 and 2) and the particle-size distribution of clay (Figure 3) obtained by soil hydrometry are given below.

Table 1 – The physical characteristics of clay samples

Mark	Moisture w [%]	Density ρ $[g/cm^3]$	Dry density ρ_d $[g/cm^3]$	Particle density ρ_s $[g/cm^3]$	Porosity n [%]	Void ratio e [1]	Saturation S_r [%]
1a 0°	24.3	1.83	1.47	2.747	46.48	0.8683	76.88
1b 0°	23.3	1.85	1.50		45.25	0.8264	77.45
1c 0°	22.6	1.87	1.52		44.58	0.8043	77.19
2a 0°	22.7	1.88	1.53		44.18	0.7915	78.78
2b 0°	21.8	1.89	1.55		43.49	0.7695	77.82
2c 0°	25.4	1.93	1.54		43.90	0.7825	89.16
3a 0°	25.2	1.88	1.50		45.36	0.8300	83.40
3b 0°	24.9	1.92	1.54		43.95	0.7841	87.23
3c 0°	25.3	1.84	1.47		46.59	0.8722	79.68
1a 90°	24.2	1.89	1.52		44.66	0.8070	82.38
1b 90°	26.7	1.88	1.48		46.06	0.8539	85.89
1c 90°	24.7	1.88	1.51		45.12	0.8220	82.54
2a 90°	25.6	1.86	1.48		46.13	0.8564	82.11
2b 90°	26.3	1.91	1.52		44.84	0.8130	88.86
2c 90°	25.4	1.87	1.49		45.66	0.8402	83.05
3a 90°	226	1.87	1.52		44.54	0.8030	77.32
3b 90°	24.7	1.90	1.53		44.41	0.7989	84.93
3c 90°	26.6	1.93	1.52		44.59	0.8046	90.81

Table 2 – The mean values of physical characteristics for samples in 0° and 90°

Test direction	Moisture w [%]	Density ρ $[g/cm^3]$	Dry density ρ_d $[g/cm^3]$	Particle density ρ_s $[g/cm^3]$	Porosity n [%]	Void ratio e [1]	Saturation S_r [%]
0°	23.9	1.88	1.51	2.747	44.86	0.8129	80.84
90°	25.2	1.89	1.51	2.747	45.11	0.8221	84.21
Differences	1.30	0.01	0	0	0.25	0.0092	3.37

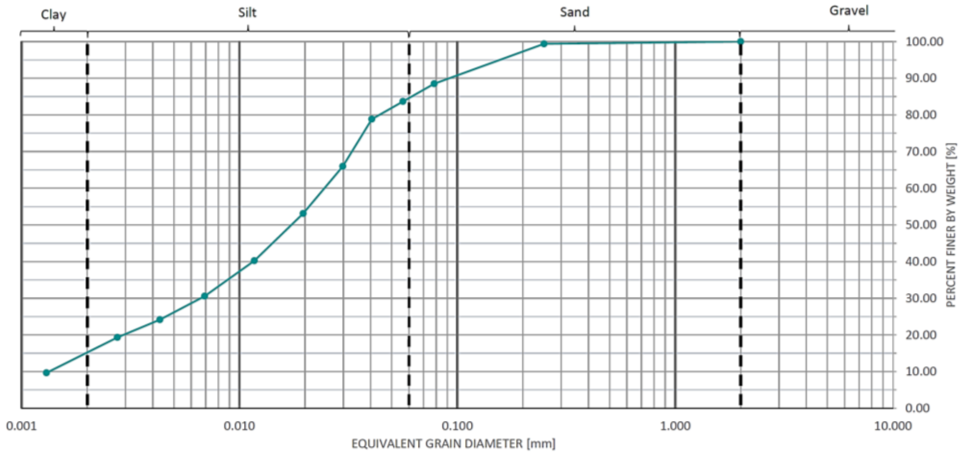

Figure 3 – Particle-size distribution of the clay

From the obtained results of the physical characteristics of the clay samples, we can conclude that the samples are enough uniform and they are suitable for direct shear testing. Considering on the long-time duration of the experiments, the moisture did not change significantly.

2.3 Methodology of experimental research

A commonly used device for laboratory determination of shear strength parameters is the device for direct shear.

In this case, for determination of the shear strength parameters it was used an automatic direct shear apparatus "27-WF21E80 Shearmatic EmS" manufactured by Controls Group and Wykeham Farrance (Figure 4).

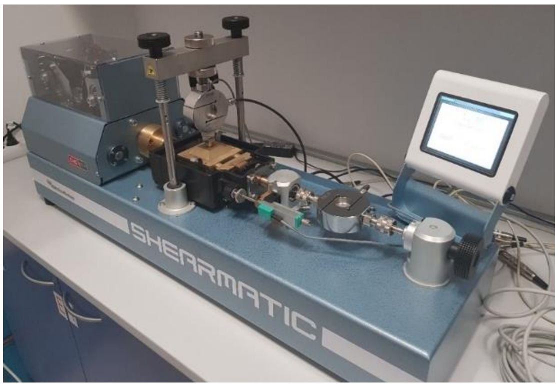

Figure 4 – Direct shear apparatus "Shearmatic" during testing

Shearmatic is a standalone automatic apparatus with electro mechanic servo actuation for direct/residual shear testing. It incorporates two high resolution stepper motors with high precision transmissions for applying and retaining forces. It also contains horizontal and vertical displacement transducers for displacement measurement. We control the device using software via a touch screen that allows us to adjust the test settings. We use the screen to run, pause and stop the experiment, and numerically and graphically monitor the readings during experiments execution. The big advantage of this device is that, depending on the settings, it starts automatically direct shear experiment after completed consolidation. The device saves all read data to a external memory in TXT format.

There were performed three series of direct shear experiments for each of two different directions in relation to the horizontal, 0° and 90° (Figure 6). Each series included three direct shear tests at different normal stress – 50.0 kPa, 100.0 kPa and 200.0 kPa at shear rate velocity of 0.01 mm/min. In total it is 18 direct shear tests (2 directions×3 series×3 tests). All tests were performed in accordance to British Standard BS 1377-7:1990 clause 4 [15].

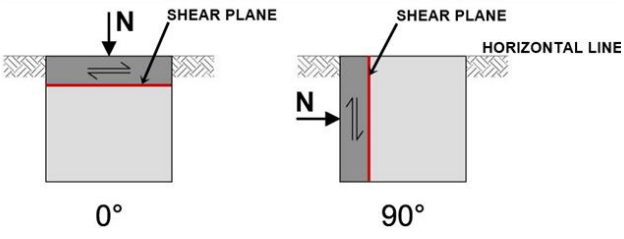

Figure 5 – Direction of sampling and shear (N- normal stress)

The samples are shaped with a mold to dimension 6.0×6.0×2.0 cm with special attention to the natural orientation of the samples in space (Figure 6).

a) Shear direction 0° b) Shear direction 90°

Figure 6 – Sample shaping

These experiments will allow an assessment of the shear direction influence on the values of the shear strength parameters, angle of internal friction (φ) and cohesion (c).

3. Results and Discussion

All experimental data were obtained from Shearmatic in TXT format. Data were processed in Microsoft Excel and interpretated in figures (Figures 7-12).

Peak value of tangential stress was determined in curve maximum according to standard method [15]. In each series of tests, the result is three peak values of τ for each vertical stress σ. Shear strength parameters were calculated with linear regression.

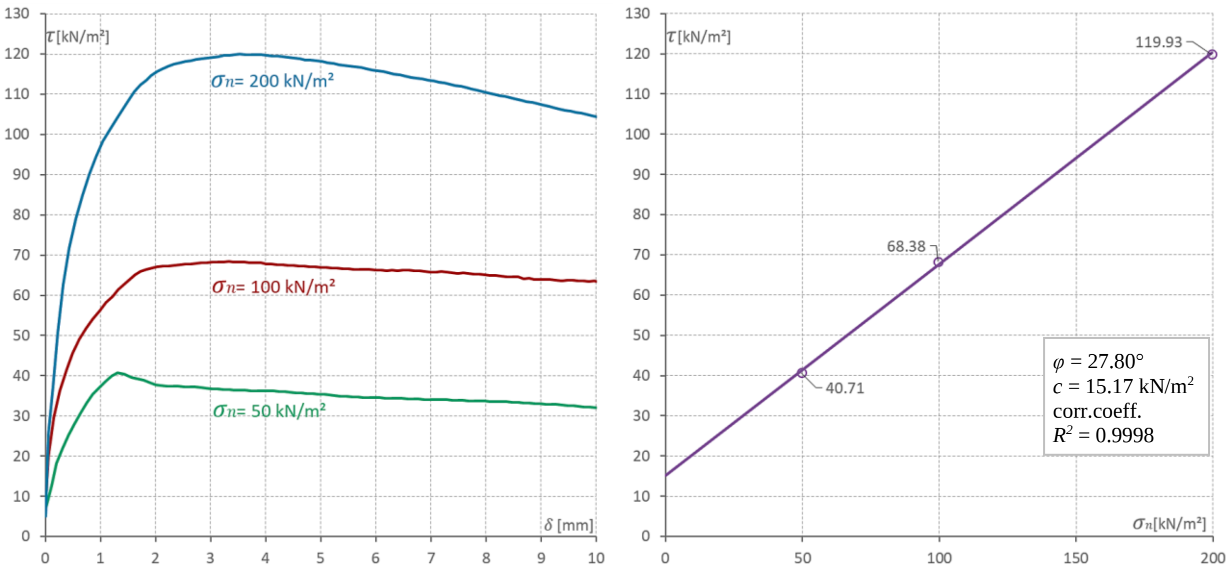

Figure 7 – Analysis of 1 test direct shear data for direction 0°

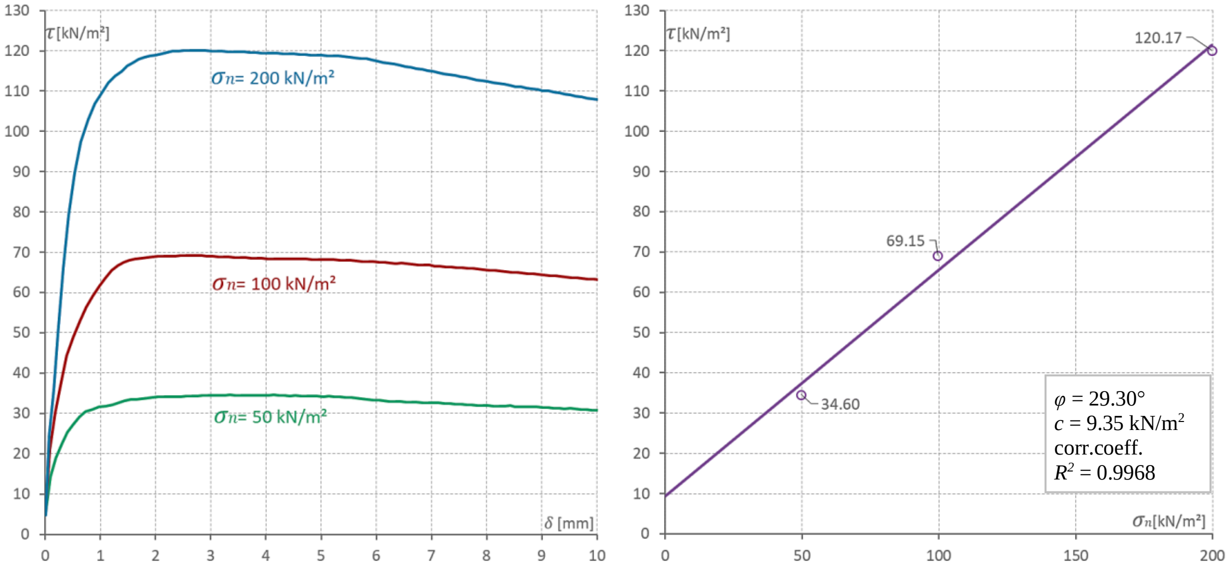

Figure 8 – Analysis of 2 test direct shear data for direction 0°

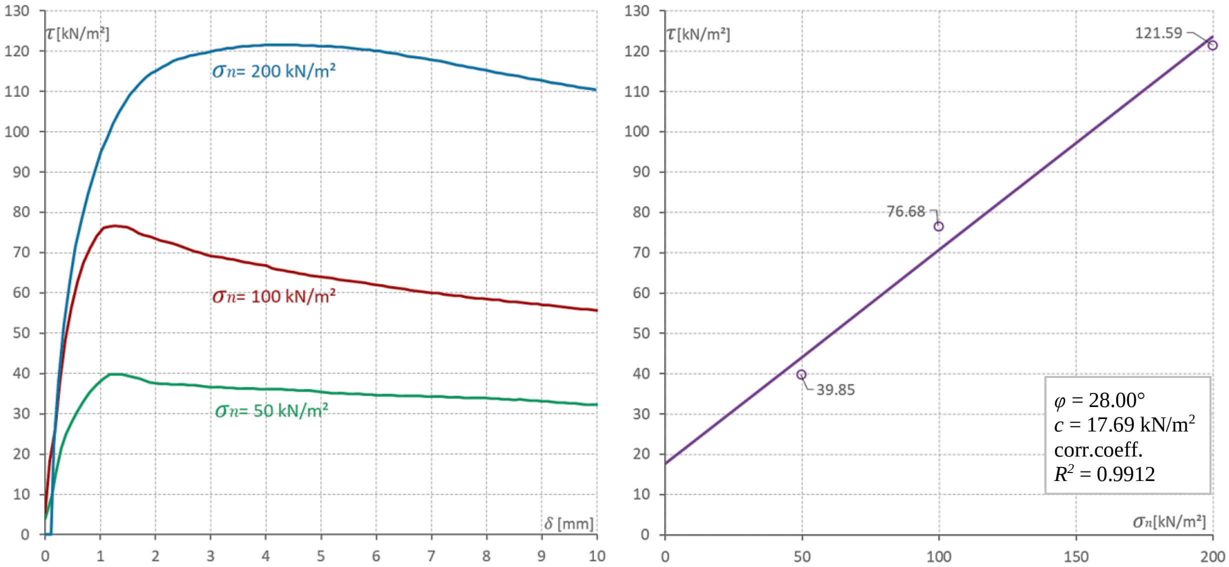

Figure 9 – Analysis of 3 test direct shear data for direction 0°

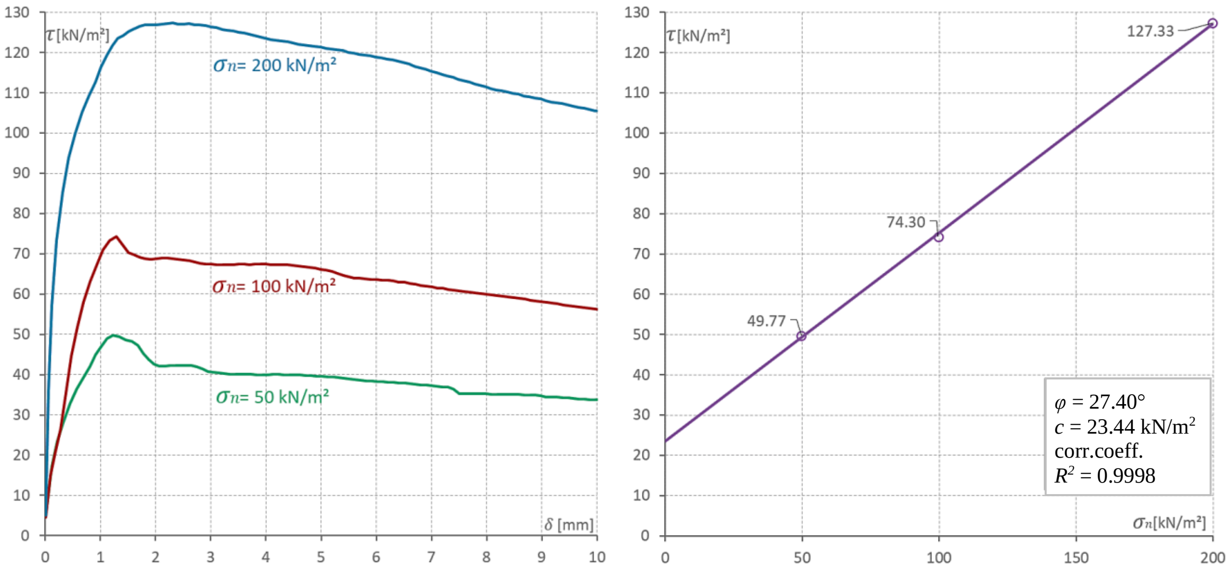

Figure 10 – Analysis of 1 test direct shear data for direction 90°

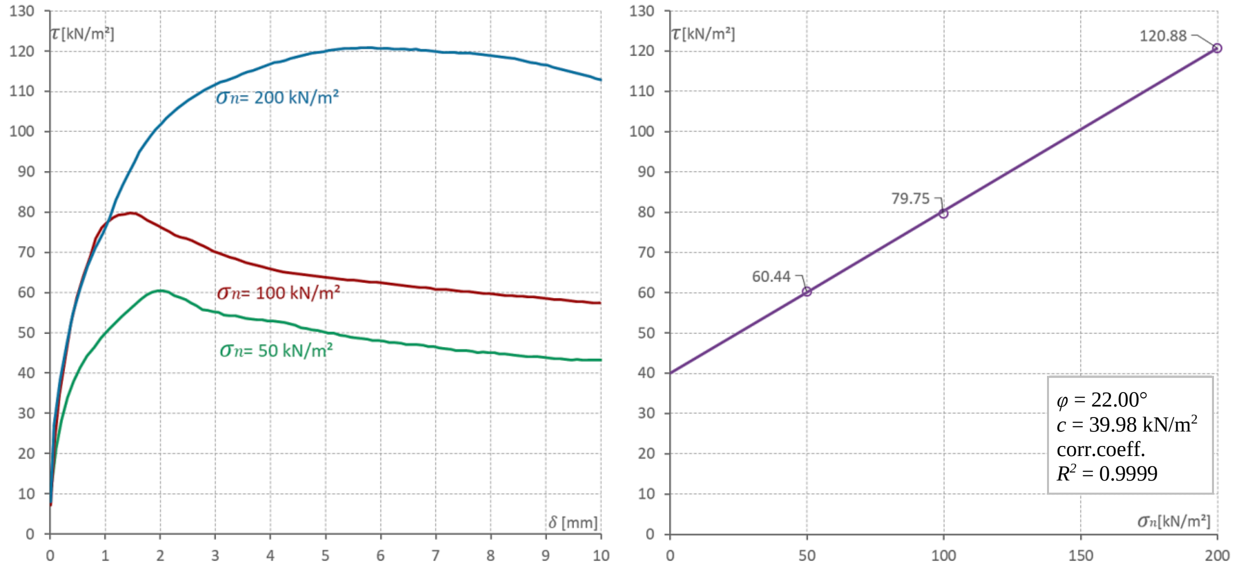

Figure 11 – Analysis of 2 test direct shear data for direction 90°

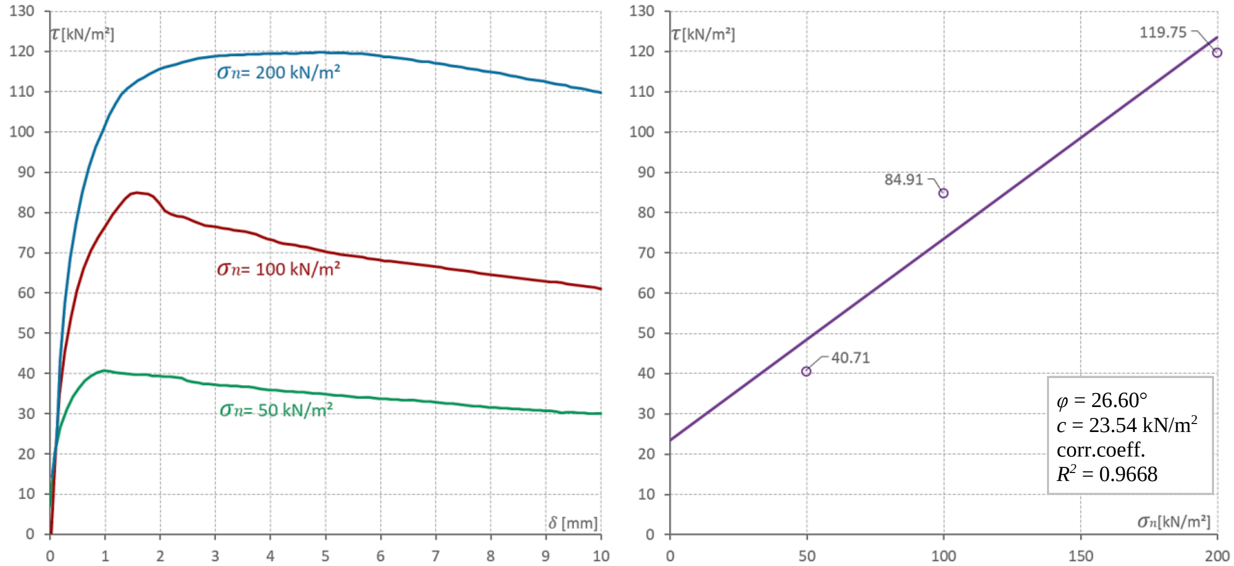

Figure 12 – Analysis of 3 test direct shear data for direction 90°

Considering that three series of direct shear experiments were performed for each of two different directions in relation to the horizontal (0° and 90°), the mean value of the measured data for each of the directions was calculated and the obtained values of shear strength parameters were analyzed (Table 3 and 4).

Table 3 – Mean value of direct shear data for direction 0°

Measured			Linear regression			
σ $[kN/m^2]$	τ $[kN/m^2]$	$\tau_{regres.}$ $[kN/m^2]$	c $[kN/m^2]$	*tg φ* [1]	*φ* [°]	*correl. coeff.* [1]
0.00	0.00	14.07	14.07	0.5397	28.4	0.9970
49.54	38.39	40.80				
99.52	71.40	67.78				
199.56	120.56	121.77				

Table 4 – Mean value of direct shear data for direction 90°

Measured			Linear regression			
σ $[kN/m^2]$	τ $[kN/m^2]$	$\tau_{regres.}$ $[kN/m^2]$	c $[kN/m^2]$	*tg φ* [1]	*φ* [°]	*correl. coeff.* [1]

0.00 49.63 99.56 199.58	0.00 50.31 79.66 122.65	28.99 52.56 76.28 123.78	28.99	0.4750	25.4	0.9966

The analysis of the obtained results of the direct shear test showed significant differences in the values of the shear strength parameters with considering to the test direction. The angle of internal friction (*φ*) is higher by 3.0° or 11.81% in the test at an angle of 0° in relation to the horizontal. A much more significant difference is visible in cohesion (c). The results showed that the cohesion (*c*) in the 90° test was higher by 14.92 kN/m² or 106.04%. Significant difference can be explained by particle orientation. The similar result with a less pronounced difference was obtained by authors: Ž.E. Rogatkina [3], A.K. Loh – R.T. Holt [4], Z. Ewertowska-Madej [5], K.Y. Lo – V. Milligan [6] and A.V. Shkola – A. Kheydar [7].

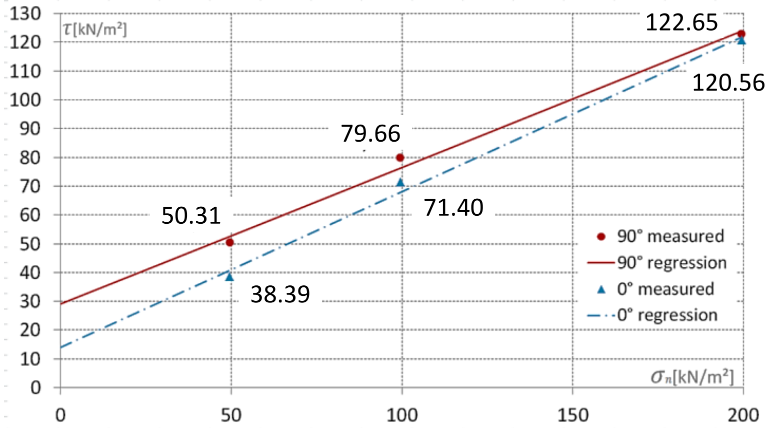

Figure 13 – Analysis of mean values direct shear data for direction 0° and 90°

Table 5 – Analysis of shear strength parameters for direction 0° and 90°

Parameter	0°	90°	Difference	
			[1]	[%]
c [kN/m^2]	14.07	28.99	14.92	106.04
φ [°]	28.4	25.40	3.00	11.81

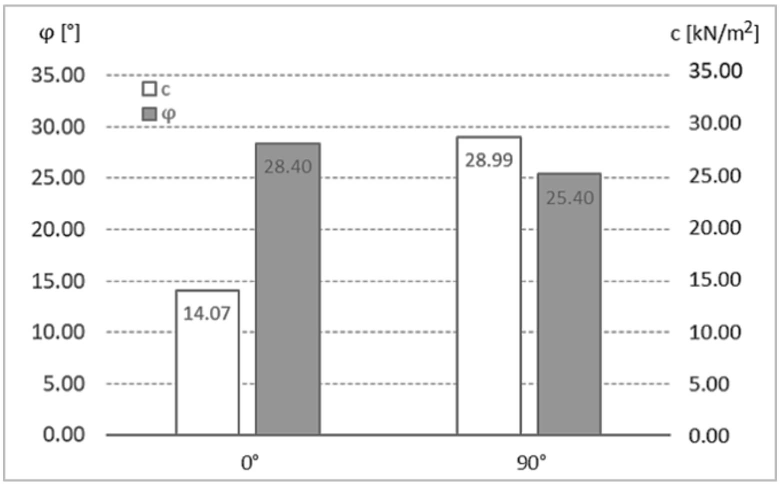

Figure 15 – Shear strength parameters for direction 0° and 90°

It can be concluded that anisotropy of shear strength of clay is not negligible and according Shkola [1], should be considered in practical calculations, designing and dimensioning of structures.

Also, when conducting investigation works on anisotropic soils, the natural orientation of the test specimens and the direction of the tests should be considered as it proposed Shkola in [1].

4. Conclusions

1. Three series of direct shear experiments of clay were performed for each of two different directions, 0° and 90° in relation to the horizontal (18 direct shear experiments). The shear strength parameters (cohesion and internal friction angle) of 0° and 90° were obtained.

2. The results showed that anisotropy in shear strength parameters of clay is significant. Angle of internal friction (φ) is 11.81% higher in the test at an angle of 0° and cohesion (c) is more than twice the value (106.04%) at an angle of 90°. Shear strength anisotropy of clay is significant and should be considered in practical calculations, design and dimensioning of structures.

3. Also, when conducting investigation works on anisotropic soils, the natural orientation of the test specimens and the direction of the tests should be considered.

References

1. Diagnostika portovykh sooruzheniy / A.V. Shkola. — Odessa, Ukraine: Astroprint, 2010. — 592 p.
2. Viazkoplastichnost' gruntov i raschety sooruzhenii / Ju.K. Zareckii. — Moscow, Russia: Stroiizdat, 2988. — 352 p.
3. Influence of anisotropy of clay soils on physical and mechanical properties / Ž.E. Rogatkina // Grounds, foundations and mechanics of soils. — 1967. — No. 1. — P. 14–15.
4. Directional Variation in Undrained Shear Strength and Fabric of Winnipeg Upper Brown Clay / A.K. Loh, R.T. Holt // Canadian Geotechnical Journal. — 1974. — Vol. 11, No. 3. — P. 430–437. https://doi.org/10.1139/t74-044
5. Anizotropia wytrzimalosci kaolinu sedleckiedo w aparacie bezposrednieno scinania / Z. Ewertowska-Madej // IBW, Polskiej AN. Gdansk rozpraawy hydrotechniczne. — 1972. — No. 30. — P. 121–124.
6. Shear Strength Properties of Two Stratified Clays / K.Y. Lo, V. Milligan // Journal of the Soil Mechanics and Foundations Division. — 1967. — Vol. 93, No. 1. — P. 1–15. https://doi.org/10.1061/JSFEAQ.0000928
7. Anizotropiya prochnostnykh svoystv lessovykh gruntov i raschet nesushchey sposobnosti osnovaniy s yeye uchetom / A.V. Shkola, A. Kheydar // Lessovyye prosadochnyye grunty kak osnovaniya zdaniy i sooruzheniy: tez. Vsesoyuzn. nauch. pr. konf: Vol. 2: 2. — Barnaul: 1990. — P. 212–217.
8. Experimental study of shear strength anisotropy of granula medium considering technology factors / A. Aniskin, A. Shkola, V. Premur // Academic Journal Industrial Machine Building, Civil Engineering. — 2015. — Vol. 3, No. 45. — P. 144–151.
9. Mekhanika gruntov / N.V. Ornatskiy. — Moscow, Russia: Izd-vo MGU, 1962. — 447 p.
10. Osnovy teoreticheskoi mehaniki gruntov / M.E. Harr. — Moscow, Russia: 1971. — 317 p.
11. Ploskaia deformaciia anizotropnoi sypuchei sredy / G.A. Geniev // Structural Mechanics and Analysis of Constructions. — 1986. — No. 5. — P. 33–35.
12. Mehanika zernistyh sred i ee primenenie v stroitel'stve / I.I. Kandaurov. — Moscow, Russia: Stroiizdat, 1966. — 319 p.
13. Bokovoe davlenie anizotropnyh gruntov na sooruzhenia / A.V. Shkola. — Odessa, Ukraine: MAG VT, 2012. — 219 c.
14. Bokovoe davlenie anizotropnogo grunta na raspornye sooruzheniia v slozhnyh geotehnicheskih usloviah: dis. na soiskanie uchenoi stepeni kandidata tehnicheskih nauk. / Voitenko I.V. — Odessa, Ukraine, 2011. — 227 p.
15. BS1377 - Methods of Test for Soils for Civil Engineering Purposes / British Standards Institution. — 1990.

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Damir Štuhec – data collection, testing, drafting.
Khrystyna Moskalova – visualization, interpretation, editing.

Received: 14.07.2023
Revised: 18.08.2023
Accepted: 19.09.2023
Published: 30.09.2023