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LARGE SCALE SHEAR BOX TESTING OF INTERFACE BETWEEN CONSTRUCTION MATERIALS AND SOILS

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Abstract

The interaction between soil and building structures of various materials is defined on the basis of certain assumptions, but these are shown in many cases to be not accurate from the point of view of safe, reliable and economic design of engineering structures. Therefore, as part of our research activities, we decided to better understand the transfer of shear forces and the interaction between soil and other materials. We focused on testing materials in a shear box apparatus, where 3 types of tests were carried out: in the first stage, we tested the shear parameters of the soil in a 900 mm^2 box apparatus; in the second stage, the properties of the interaction between soil and concrete were tested, and in the third stage, soil was in contact with the steel plate. The results of the tests are within the expected range of the interface friction angle between the structures and the soils.

Keywords:

Soil interface;
Large scale direct shear test;
Soil shear strength;
Shear parameters;
Adhesion.

1 Introduction

Concrete and steel materials are mainly used for the foundation of buildings and in general when designing geotechnical constructions. The designed structures include spread foundations, deep foundations, reinforced earth structures, retaining walls and elements to ensure the stability. In the design of the mentioned structures, a certain degree of interaction between the soil and the proposed structure is considered according to analytical calculations. Similarly, in numerical calculations, changes in the shear parameters of the soils around the structure are considered using the application of the so-called "interface" elements that can have a positive effect on the given parameters and improve the given properties or can be negative and thus worsen the strength characteristics. The basic geotechnical parameters of shear strength include the angle of internal friction φ and cohesion c, from which the earth pressures acting on the proposed structures are calculated. The friction between the soil and the back of the structure affects the magnitude of earth pressures and thus the load on the structure. The level of the earth pressure depends not only on the selected method of calculation, but also on the friction between the soil and the structure or on the adhesion of the soil. These friction properties are described in [1, 2]. If the angle δ = 0, the earth pressure acts perpendicularly to the back of the structure and the resultant force of the earth pressure is also perpendicular to the back of the structure.

If we consider the effect of friction between the soil and the back of the structure when calculating earth pressures, the earth pressure and its resultant force act at an angle δ on the back of the structure. When using the angle δ, it is important to pay attention to the orientation from the perpendicular to the back of the structure. As the value of the angle δ increases, the earth pressure decreases, that is, the resulting force of the active earth pressure deviates from the vertical as shown in Fig. 1. Many authors calculate with the angle δ, which ranges from δ ≤ 1/3φ to δ = 2/3φ. The smoother the surface of the structure is, it is assumed to be closer to 1/3φ, as for rough structures of irregular shape, this value can

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reach up to 2/3φ [3, 4]. The consideration of the real angle δ is a significant measure for determining the economic impact of the evaluation of construction projects, which is the subject of the study [5].

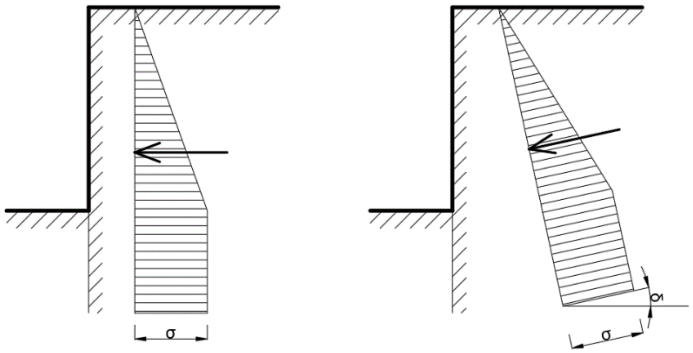


Fig. 1: Effect of earth pressure on the structure at an angle δ.

To investigate and analyse the relationship between cohesion and adhesion in clayey soils, a series of tests was carried out in an experimental study [1]. The internal shear stress and the external shear stress of the soil follow a linear dependence according to the Coulomb Equation 1. Shear stress measurements combined with normal stress measurements σ are used to describe this linear relationship 1 and 2 which can be used to determine the internal shear strength (cohesion) c, the internal friction angle φ, the external shear strength (adhesion) a, and the angle of external friction δ of the soil, as shown in Fig. 2.

$$\tau_c = c + \sigma.tan\varphi \tag{1}$$

$$\tau_a = a + \sigma.tan\delta \tag{2}$$

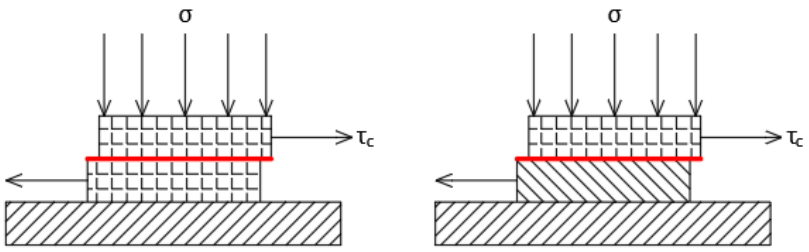


Fig. 2: The position of the shear surface and the difference in the effect of shear stress on the soil.

2 Experimental programme

Analysing the shear characteristics of the soil-structure interface was the subject to performing tests on a shear box apparatus, which was the most important part of the experimental analysis. Before performing the shear box tests, a granulometric analysis was carried out on the tested soil, which defined the boundary conditions for further testing of the materials. The results of the granulometric analysis are characterized by the grain size curve, which is shown in Fig. 3. Tests were carried out in accordance with the studies [6 – 8].

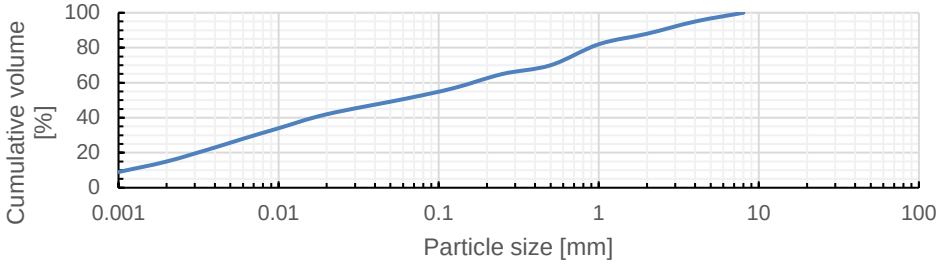


Fig. 3: Particle size distribution.

For a comprehensive understanding of the grain size curve, it was necessary to perform sieve analysis tests, and due to the presence of more than 15% of fine-grained material, it was also necessary to perform hydrometer tests and define the liquid and plasticity limits using Atterberg limit tests. To ensure optimal compaction of the material into the shear box, a Proctor Standard test was performed to ensure constant boundary conditions for achieving the maximum bulk density in the shear box test [9]. The results of the proctor standard exam are shown in Table 1 and in Fig. 4.

Table 1: Results of the Proctor Standard tests.

Number of sample	(%)	1	2	3	4	5
Moisture content	(%)	8.16	12.20	13.58	15.53	17.33
Dry density	($kg.m^{-3}$)	1820	1855	1866	1816	1757

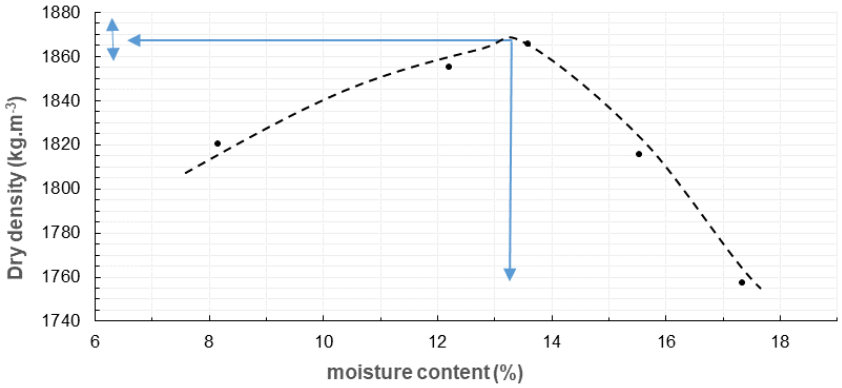


Fig. 4: Soil compactibility.

Throughout direct shear tests on four types of contact materials, vertical pressure was applied using a hydraulic device. The vertical pressures of the same group of tests were 50 kPa, 100 kPa, 200 kPa and 300 kPa. The shear rate during testing was 0.05 mm/min. The experiment was carried out in accordance with the requirements of the relevant technical standard for performing shear box tests. The soil material was tested in interface where predefined shear plane was located, and then tests were carried out where the soil was in contact with concrete or with smooth steel on the shear surface. The course of the test and its recording was carried out automatically on the shear box apparatus SHEARMATIC 300, on which force and deformation sensors are installed, similarly to the studies. [10 – 15]. The same testing procedure was applied for all tests:

(1) Soil drying and mixing with water to achieve optimal soil moisture to achieve maximum soil compaction.

(2) Placing a material in the direct shear test box so that the upper edge is max. 2 mm below the level of the device joint.

(3) Preparation of the soil sample, compaction to the required level.

(4) Application of normal stress of 50 kPa, 100 kPa, 200 kPa and 300 kPa in a vertical direction perpendicular to the shear surface.

(5) After the required consolidation time has passed, the shear shift is started [16 – 18].

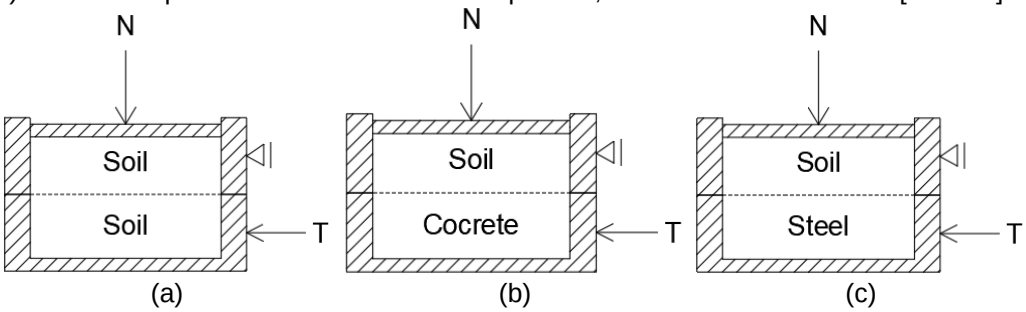


Fig. 5: Scheme of shear tests apparatus with different structure materials in the box.

3 Result and discussion

Determination of parameters on the shear surface was carried out by two approaches:

1) the friction of individual particulate particles of soil grains was evaluated,
2) friction on the shear surface between soil and concrete and between soil and steel plate was evaluated.

Regression analysis of shear strength τ_p (peak shear stress τ-s interface curve) and residual shear strength τ_r (stable value of shear stress on τ-s interface curve) on the contact surface between the soil surface and another material at different normal stresses was performed. To analyse the shear strength parameters such as the angle of internal friction, cohesion (adhesion) and coefficient of sliding, regression relations according to Equation 3 for shear stress and according to Equation 4 coefficient of sliding friction are constructed [19 – 22].

$$\tau_p = \sigma . tan\varphi + c \tag{3}$$

$$\mu = \frac{\tau_r}{\sigma} \tag{4}$$

The peak shear strength τ_p and the residual shear strength τ_r of the contact between soil and other materials are given in the Table 2, and the regression equations of the peak shear strength τ_p and the residual shear strength τ_r are given in Table 3.

Table 2: Results of the shear tests.

Type of test						
	soil - soil		concrete - soil		steel - soil	
σ [kPa]	τ_p [kPa]	τ_r [kPa]	τ_p [kPa]	τ_r [kPa]	τ_p [kPa]	τ_r [kPa]
50	71.1	59.0	56.6	54.2	31.3	28.3
100	107.0	104.2	89.4	72.1	52.6	45.6
200	151.0	133.0	134.7	117.0	91.9	71.6
300	207.2	189.6	181.1	159.0	110.4	95.1
φ	**27.8**	**25.9**	**26.0**	**23.0**	**17.8**	**14.8**
c	**48.3**	**42.5**	**36.1**	**31.6**	**19.5**	**17.2**

Table 3: Results of the shear tests (regression equation and variance).

Type of test	Regression equation	Variance R^2
soil - soil	τ_p = 0.5279 σ + 48.29	0.969
	τ_r = 0.4856 σ	0.969
concrete - soil	τ_p = 0.4881 σ + 36.14	0.996
	τ_r = 0.4242 σ	0.999
steel - soil	τ_p = 0.3206 σ + 19.46	0.971
	τ_r = 0.2638 σ	0.995

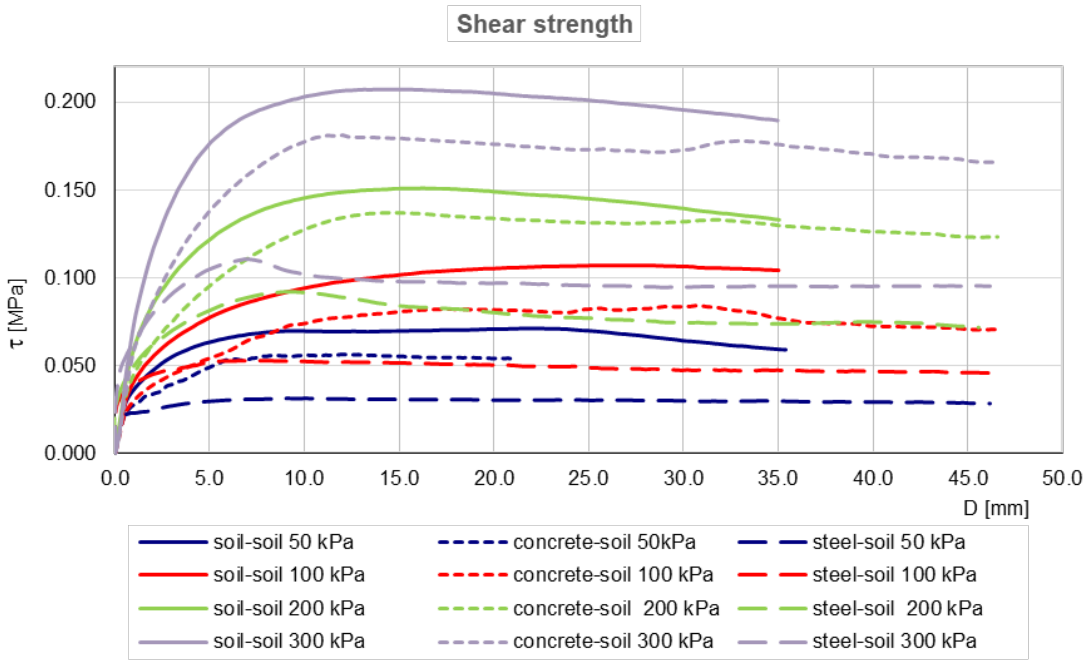


Fig. 6: Course of shear stresses during testing.

4 Conclusion

Test results showed that in the case of contact between soil and concrete, the angle δ can be larger than recommended in various studies, where the authors state that the angle δ ranges from δ ≤ 1/3φ to δ = 2/3φ. Our work found that it can be up to 90% of the peak friction angle φ. Reliability of this statement should be proven by a large series of tests with statistical evaluation of measured data. This will be the subject of further research.

Understanding the behaviour of both of construction material and soil is essential for safe and economical design. Engineers carefully consider these interactions during the design and construction phases to ensure the safety, durability, and stability of structures [23].

When determining the value of the angle δ, it is also necessary to respect other circumstances, for example the sum condition of equilibrium in the vertical direction. It is also necessary to consider whether the structure is able to transfer the vertical load from the soil acting on its backside without major vertical deformation. Otherwise, it is necessary to reduce the angle δ so that there is only a partial mobilization of friction on the back of the structure. In case of uncertainty, we do not recommend using the angle δ, which will make the design safer [24].

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References

[1] STAFFORD, J. V. - TANNER, D. W.: The frictional characteristics of steel sliding on soil. Journal of soil science, Vol. 28, Iss. 4, pp 541-553, 1977.

[2] CHEN, Y. J. - LIN, S. S. - CHANG, H. W. - MARCOS, M. C.: Evaluation of side resistance capacity for drilled shafts. Journal of marine science and technology, Vol. 19, Iss. 2, 2011.

[3] STACHO, J. - SULOVSKA, M.: Shear Strength Properties of Coarse-Grained Soils Determined Using Large-Size Direct Shear Test. Civil and Environmental Engineering, Vol. 12, Iss. 1, 2022, pp. 244-257.

[4] STACHO, J. - SULOVSKA, M. - SLAVIK, I.: Analysis of the Shear Strength of a Soil-Geosynthetic Interface. Civil and Environmental Engineering, Vol. 19, Iss. 1, 2023, pp. 452-463.
[5] KOZEL, M. - REMEK, Ľ. - ĎURÍNOVÁ, M. ŠEDIVÝ, Š. - ŠRÁMEK, J. - DANIŠOVIČ, P. - HOSTAČNÁ, V.: Economic Impact Analysis of the Application of Different Pavement Performance Models on First-Class Roads with Selected Repair Technology. Applied Sciences, 2021, Vol. 11, Iss. 21.
[6] NIEMIEC D. - BULKO, R. - MUŽÍK, J.: The Meshfree Localized Petrov-Galerkin Approach in Slope Stability Analysis. Civil and Environmental Engineering. Vol. 15, Iss. 1, pp 79-84.
[7] KANTY, P. - RYBAK, J. - STEFANIUK, D.: Some remarks on practical aspects of laboratory testing of deep soil mixing composites achieved in organic soils. IOP Conference Series-Materials Science and Engineering, Vol. 245 Iss. 2, 2017.
[8] HOSSAIN, M. A. - YIN, J. H.: Dilatancy and strength of an unsaturated soil-cement interface in direct shear tests. International journal of Geomechanics, Vol. 15, Iss. 5, 2015.
[9] KOVÁČ, M. - BRNA, M. - PISCA, P. - JANDAČKA, D. - DECKÝ M.: The Influence of Road Pavement Materials on Surface Texture and Friction. Sustainability. Vol. 15, Iss. 16, 2023.
[10] KOTEŠ, P. - VAVRUŠ, M. - JOŠT, J. - PROKOP, J.: Strengthening of Concrete Column by Using the Wrapper Layer of Fibre Reinforced Concrete. Materials, Vol. 13, Iss. 23, 2020, pp. 2-21.
[11] ZAHURANEC, M. - KOTEŠ, P. - KRAĽOVANEC, J.: The Influence of the Prestressing Level of the Fully Threaded Anchor Bar on the Corrosion Rate. Buildings, 2023, Vol. 13, Iss. 7.
[12] IZVOLT, L. - DOBES, P. - DRUSA, M. - KADELA, M. - HOLESOVA M.: Experimental and Numerical Verification of the Railway Track Substructure with Innovative Thermal Insulation Materials. Materials, 2022, Vol. 15 Iss. 1.
[13] BAČOVÁ, D. - IŽVOLTOVÁ, J. - ŠEDIVÝ, Š. - CHROMČÁK, J.: Different Approach for the Structure Inclination Determination. Buildings, 2023, Vol. 13 Iss. 3.
[14] FARBÁK, M. - CHROMČÁK, J. - BAČOVÁ, D. - ODROBIŇÁK, J.: Investigation of Actual In-Plane Geometric Imperfections of Steel Tied-Arch Bridges. Applied Sciences. 2023, Vol. 13 Iss. 11.
[15] VALAŠKOVÁ, V. - KUCHÁROVÁ, D. - MELCER, J.: Two-span bridge under moving load – numerical and experimental approach. Journal of Vibroengineering, Vol. 22, No. 3, pp. 672–684, 2020.
[16] RYBAK, J.: Some remarks on foundation pile testing procedures. IOP Conference Series-Materials Science and Engineering, Vol. 245. Iss. 2, 2017.
[17] VLACHAKIS, G. - COLOMBO, C. - GIOUVANIDIS, A. I. - SAVALLE, N. - LOURENÇO, P. B.: Experimental characterisation of dry-joint masonry structures: Interface stiffness and interface damping. Construction and Building Materials, Vol. 392, 2023.
[18] Mei, Z. - Xiao, A. - Mei, J. - Hu, J. - Zhang, P.: Experimental Study on Interface Frictional Characteristics between Sand and Steel Pipe Jacking. Applied Sciences, Vol. 13, Iss. 3, 2016.
[19] SLADEN, J. A.: The adhesion factor: applications and limitations. Canadian Geotechnical Journal. Vol. 29, Iss. 2, pp 322-326, 1992.
[20] BORANA, L. - YIN, J. H. - SINGH, D. N. - SHUKLA, S. K.: A Modified Suction-Controlled Direct Shear Device for Testing Unsaturated Soil and Steel Plate Interface, Marine Georesources & Geotechnology, Vol. 33 Iss. 4, pp 294-303, 2015.
[21] CHEN, X. - VAN DEN BROECKE, J. W. - LIU, G. - HONG, G. - MIEDEMA, S. A.: A study on the clay adhesion factor. Dredging Summit & Expo'19 Proceedings, 2019.
[22] GOSHTASB, A. K. - FIELKE, J. - DESBIOLLES, J.: A review of soil/tool adhesion principles and approaches to reducing limitations of disc seeders, 2009.
[23] COMBE, T. - MIEDEMA, S. A.: The influence of adhesion on cutting processes in dredging. In WEDA Dredging Summit and Expo 2015, Houston, TX, USA, pp. 41-56, 2015.
[24] ILORI, A. O. - UDOH, N. E. - UMENGE, J. I.: Determination of soil shear properties on a soil to concrete interface using a direct shear box apparatus. International Journal of geo-engineering, Vol. 8, pp. 1-14, 2017.