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INFLUENCE OF WATER CONTENT ON THE SHEAR STRENGTH PARAMETERS OF CLAYEY SOIL IN RELATION TO STABILITY ANALYSIS OF A HILLSIDE IN BRNO REGION

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Abstract

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Shear strength of soils is highly affected by moisture conditions (i.e. water content), especially if the soil contains clay materials. Usually the laboratory specimen, which are used to determine shear strength of soil are prepared at water content and dry density same as in the field conditions, without respect to the fact, that the conditions in the future might not remain the same. For the purpose of this study soil specimen were compacted and the optimum moisture content was identified. After compaction soil was tested at the dry side of optimum water content at w = 9 %, 10 % and 11 %. Parameters of shear strength were obtained and used for stability analysis with software GEOSLOPE/W 2012. According to referenced literature, it was expected for the shear strength of the soil to decrease with increasing water content. This hypothesis was not proven for clayey soil from Brno region. Development of values of friction angle and cohesion exhibited anomalous behaviour and such development was found also for values of Factor of safety (FOS) obtained from stability analyses. Results proved the necessity of taking moisture conditions into account, when processing stability analyses, in order to achieve reliable and safe constructions.

shear strength, water content, clay, factor of safety, cohesion, friction angle

1 INTRODUCTION

Water exerts controlling influence on most of the physical, chemical and biological processes, that occur in soil. Water in soil acts both as a lubricant and as a binding agent among the soil particulate materials, thereby influencing the structural stability and strength of soil and geologic materials (TOPP, G. C., FERRÉ, P. A., 2002).

Shear strength of soils is highly affected by moisture conditions, especially if the soil contains clay materials. Usually the laboratory specimen, which are used to determine shear strength of the soil are prepared at water content and dry density same as in the field conditions, without respect to the fact, that the conditions in the future might not remain the same.

Several landslides were caused by a sudden drop in the mechanical properties of the material associated with an increase in the water content. This was the case, for example, in the catastrophic events of the Vaiont Dam failure, where a landslide caused sudden emptying of the reservoir (HENDRON Jr., A. J., PATTON, F. D., 1987).

2 MATERIALS AND METHODS

2.1 Introduction

The soil samples used in this study were taken from surroundings of a forest road, located in a research area of the Mendel university near Brno, Czech Republic. Soil was classified according to

CSN CEN ISO/TS 17892–1 to 12. Tests performed on the soil included Sieve analysis, Densimeter analysis and Atterberg limits. The Proctor standard test according to CSN EN 13286-2 was used to determine the dry density and optimum moisture content. Soil specimen were compacted using the Proctor hammer and the optimum moisture content was identified at w = 12%. Preparation of the specimen with direct shear mould below 9% and above 12% was not possible, without creating extra cracks and cavities in the specimen, therefore the tested water contents had to be established dry of the optimum at w = 9%, 10% and 11%. Shear strength was determined by using direct shear machine Sheartronic num. S277-10/ZG/0004. Factor of safety (FOS) and the location of the shear plane were calculated with use of software GEOslope W/2012.

2.2 Shear strength of soil

Shear strength of soil is characterized by cohesion (c), friction angle (φ) and dilatation. The two parameters mentioned primarily, define the soil maximum ability to resist shear stress under defined load. Cohesion mobilises at the beginning of stress conditions and reaches maximum values around the plastic limit, i.e. at the beginning of structural collapse (MENCL, V., 1997). Cohesion decreases at water content heading towards the liquid limit (w_L) and increases towards the shrinkage limit (w_s). Cohesion usually does not increase with increasing stress, except for clayey soils, where the increase in stress causes increase in molecular binds. Internal friction is generally defined as resistance of two planes moving against each other, determined by their grading. Friction increases with increase in normal load, provided that the soil specimen are allowed to consolidate (MENCL, V., 1997). It is expected for the shear strength to grow with the decrease in water content. This assumption is in accordance with Toll (2000), who says that clayey materials compacted drier than optimum moisture content behave in a coarser fashion, due to aggregation, than would be justified by the grading. Therefore reduction of water content in clayey soils results in higher friction angle, due to the fact, that clay particles group into aggregates which have larger effective particle size, as proposed in Brackley (1973, 1975). Materials with higher friction, hence shear strength, are expected to exert higher Factor of Safety (FOS), when these parameters are used for evaluation of the stability of a hillside.

2.3 Factor of safety (FOS)

Stability of a hillside is evaluated through the values of FOS, which can be defined as ratio between „passive“ forces, which prevent the slippage of the mass of soil (cohesion, friction angle) and „active“ forces, which cause the slippage of the mass of soil (tangencial forces). Hulla, Šimek and Turček (1991) define FOS as ratio of limit load and deformation to proposed load and deformations, or also as coefficient, which has to be used to reduce the parameters of shear strength of soil to achieve equilibrium on the shear plane. Bishop´s method was used for calculation of FOS. The formula for the calculation is as follows (Krahn, J., 2004):

$$FOS = 1/(\Sigma W \times \sin\alpha) \times [\Sigma(c \times \beta + W\tan\varphi - (c \times \beta)/ /FOS \times \sin\alpha\tan\varphi)/m_{\alpha}\alpha] \quad [1]$$

$$m_{\alpha} = \cos\alpha \frac{\sin\alpha \tan\varphi}{FOS} \quad [2]$$

FOS ....factor of safety
α..........slice base inclination
φ’......... friction angle
c’..........cohesion
W........unit weight of soil
β..........slice base length.

2.4 Direct shear test procedure

For the purpose of this study 9 specimen were sheared. Soil was oven dried at 105 °C and then mixed with appropriate amount of distilled water to reach desired water contents. The mixture was left 24 hours in plastic box with controlled humidity in order to provide homogenous specimen. The soil was compacted with the Proctor standard compaction mould. Each specimen was cut out from the mould using direct shear mould. Specimen were weighed. In the next step, the specimen were inserted in the direct shear box and left 24 hours for consolidation, vertical deformation was measured during consolidation. In order to avoid changes in water content, the direct shear box was covered with moisturized cloth and specially designed plastic cover. The consolidation was held at σn = 25 kPa, 50 kPa and 100 kPa. The displacement rate was determined at 0.05 mm/min. Water content was checked by weighing each specimen before and after completion of the test.

2.5 Stability analysis procedure

Parameters of shear strength and unit weight of the soil were used as input parameters for the software GEOslope W/2012. Mentioned software divides the shear plane into 30 slices with minimum shear surface depth of 0.1 m and FOS tolerance 0,001. Number of points on the slip surface starting at 8 and ending at 16 with maximum number of iterations of 2000. Bishop´s method was used for calculation of FOS (Krahn, J., 2004). The software GEOslope W/2012 was used under Student license, which is available at http://www.geo-slope.com. The height of tested hillside was established at 10 metres and its inclination was set on 1:1.

3 TEST RESULTS

3.1 Soil classification results

Tab. I shows results of Sieve analysis, Densimeter analysis and Atterberg limits tests according to

I: *Physical, Index and Compaction properties*

Property	Value
Unit weight [kg/cm³]	1863.00
Liquid limit [%]	22.10
Plastic limit [%]	14.30
Plasticity index	7.80
Consistency index	0.90
Clay fraction [%]	37.00
Sand fraction [%]	41.00
Gravel fraction [%]	22.00
Optimum moisture content [%]	12.01
Maximum dry density [kg/cm³]	1912.00
Classification USCS EN ISO 14688-1	CS grClSa

CSN CEN ISO/TS 17892-1 to 12 and the Proctor standard test according to CSN EN 13286-2. Soil was classified according to Unified Soil Classification system. All the tests were performed in accordance with Eurocode 7.

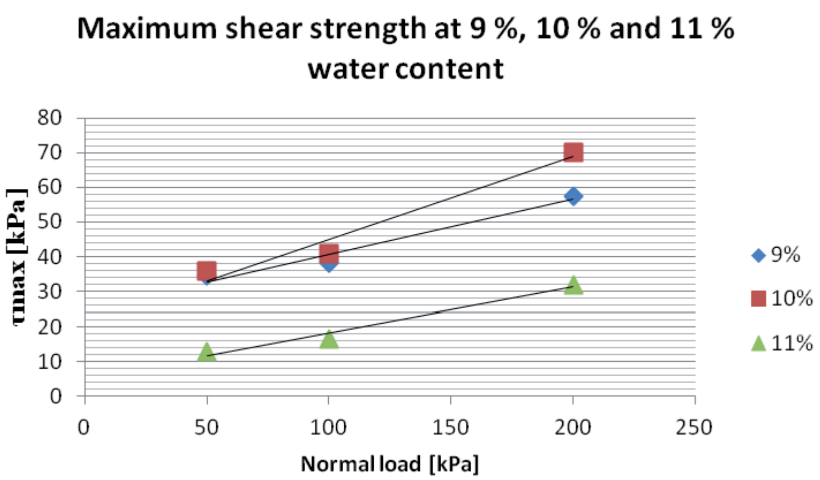
3.2 Shear test results

Tab. II shows results of maximum shear strength (τmax), cohesion (c) and friction angle (ϕ) for each water content. Values of maximum shear strength at 10% water content were slightly higher than those at 9%, but notably higher than those at 11% water content. Friction angle was the lowest (7.47°) at 11% water content and the highest (13.4°) at 10% water content. At 9% the friction angle reached 9°. Cohesion was descending with raise of water content. Between 9% and 10% cohesion diminished from 24,84 kPa to 21 kPa, between specimen with 10% and 11% water content, the values of cohesion exhibited considerable drop from 21 kPa to 5,09 kPa. Fig. 1 displays development of maximum shear strength for each of the water contents. It is clearly visible, that the most realistic results were obtained at 10% water content, with highest values of maximum shear strength, while at 11% the values were the lowest. Values of maximum shear strength for specimen at 9% water content exhibited uncommon behaviour and were lower than those at 10% water content. All three trend lines show similar development of values of τmax. Significant differences were noted at normal load of 200 kPa.

3.3 Stability analyses results

The results from the stability analyses with the software GEOslope/W 2012 are presented in Fig. 2–4. Tab. III shows values of FOS for tested hillside with forest road crossing the location. The tested hillside is 10 m high and declines in a ratio 1:1. FOS for specimen at 9% and 10% yielded approximately the same values, reaching 0,90 and 1,00 respectively. Marked drop was observed at 11% water content, where FOS reached only 0.39 which indicates critical condition of the tested hillside.

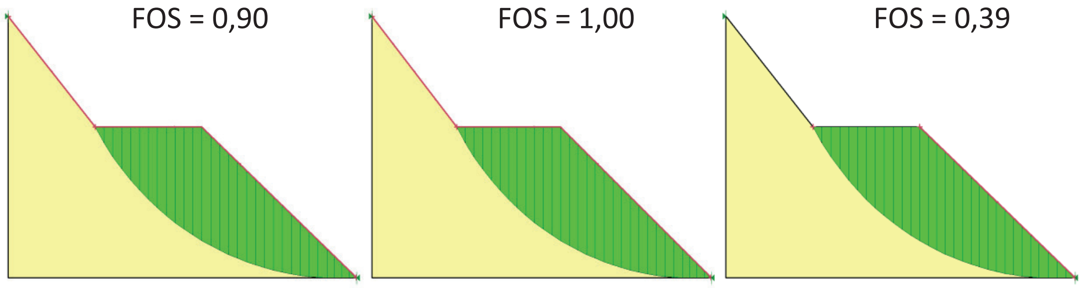
Fig. 5 displays stability analysis of the hillside with parameters, which are stated in the norm CSN EN 73 1001. The norm suggests for soil used in presented study c = 20 kPa and ϕ = 27°. Tested hillside is 10 m high and its declination is 1:1. Although greater mass of soil is influenced by potential landslide, the value of FOS obtained is significantly higher, than those obtained from tested



1: *Maximum shear strength for each of the water contents*

II: *Shear tests results*

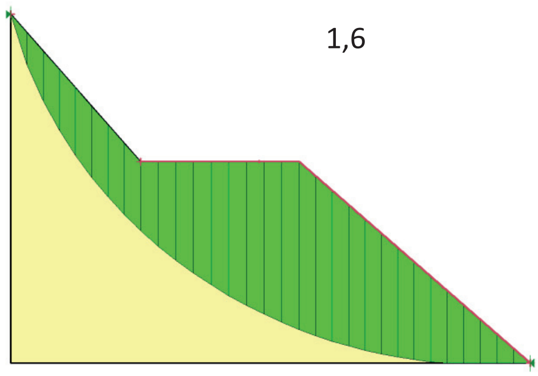
Water content	c[kPa]	ϕ[°]	τmax 50 kN	τmax 100 kN	τmax 200 kN
9%	24,84	9,00	34,39	38,22	57,32
10%	21,00	13,40	35,70	40,80	70,10
11%	5,09	7,47	12,74	16,56	31,85



2–4: *Shear plane location for each of the water content of the soil*

III: *Factor of safety (FOS) for each of the water contents*

Water content	FOS
9%	0.90
10%	1.00
11%	0.39



5: *Shear plane location with parameters from the norm 73 1001*

specimen. FOS in this case reached 1.6 and the hillside is considered secure.

4 DISCUSSION

Due to increasing water content the shear strength is expected to decrease. According to PELLET, F. L., KESHAVARZ, M., BOULON, M. (2013), the friction angle and the cohesion decrease when saturated. Overall, the shear strength is considerably reduced to approximately 50% of its original value. This reduction has to be accounted for when conducting stability analyses of rock slopes, dam foundations or underground openings. The results presented in Fig. 1 are in contradiction with expected development of the values of τmax. Also the values of φ differ from expected development, as can be seen in Tab. II. MENCL, V. (1997) states, that cohesion yields the highest resistance around the plastic limit. Cohesion decreases at water content heading towards the liquid limit and increases towards the shrinkage limit. Values of cohesion in presented study were in accordance with statement mentioned above, though the drop from 21 kPa to 5,09 kPa was found anomalous. Apart from moisture conditions, the cause of results, which indicate instability might be attributed to high percentage of sand fraction in the specimen, which causes lower values of cohesion, hence lower values of shear strength. Reason of such drop can also be due to changes in unit weight, which needs to be kept constant during all the tests. Another factor might be the presence of concretion or little gristles on the shear plane, which influences the values obtained from the direct shear tests.

CONCLUSIONS

Shear strength parameters are significantly influenced by moisture conditions. In referenced literature it can be found, that overall shear strength decreases with increasing water content, results of presented study showed, that there is considerable variability in the values obtained from shear tests of clayey soil, especially when limited number of specimen of the soil are available. Due to problems connected with cutting the specimen with direct shear mould, the tested water content needed to be established within the range of 9–11% (dry of optimum). Tested specimen showed variance in values of cohesion and friction angle, hence the values of FOS obtained from stability analyses differed. Such variability can be explained by many factors and it is necessary to provide sufficient number of specimen in order to secure realistic conclusions when dealing with water content and its relation to shear strentgh of soil. Presented results are planned to be extended with further shear tests, providing credibility of accomplished findings.

SUMMARY

It is generally recognised, that the shear strength of clayey soils is highly dependent on the water content of soil. Presented study aims to upgrade the knowledge of relationship between moisture conditions (i.e. water content) and parameters of shear strength of soil used in stability analyses. For the purpose of this research samples from Brno region were taken and tested in direct shear box machine Sheartronic No. S277-10/ZG/0004 and parameters obtained from these tests were used for stability analyses with the software GEOSLOPE/W 2012. Optimum water content was identified at w = 12%. The specimen were tested at the dry side of the optimum at 9%, 10% and 11%, respecting the fact, that the preparation of the specimen below 9% and above 12% with the direct shear mould was not possible without destroying the structure of the specimen. Dry of the optimum, the material tends to be more flocculated, therefore the shear strength increases, while on the wet side of the optimum the material is more dispersive. In general, the element of flocculated soil has a higher strength than the same element of soil at the same void ratio, but in a dispersed state (LAMBE, T. W., WHITMAN, R. V., 1979). It was expected for the shear strength of the soil to decrease with increasing water content. Obtained results embodied considerable variability, which can be explained by many factors. Among others, presence of concretion on the shear plane, condensed water content interim, changes in volume weight during test and limited number of specimen. The values of maximum shear strength (τmax) for samples with 9% water content were smaller than those at 10%. Marked difference was between values of τmax under normal load of 200 kPa, which reached 57,32 kPa, 70,10 kPa and 31,85 kPa, respectively. Cohesion diminished with increasing water content, significant drop was identified between 10% and 11% water content, where the cohesion dropped from 21 kPa to 5.09 kPa. Development of values of friction angle exhibited anomalous behaviour, as the values at 10% water content (13.40 °) were higher, than those at 9% (9 °) and dropped with 11% water content to 7.47 °. Factor of Safety (FOS) indicated critical condition of the tested hillside at 11% water content, reaching 0.39. FOS for water content at 9% and 10% yielded values 0,90 and 1,00 respectively. When parameters from the norm CSN ISO 73 1001 were used for stability analysis, the value of FOS was significantly higher and reached 1.60. Results obtained in presented research show the necessity of taking moisture conditions into account. Above all, sufficient number of specimen of the tested soil was found essential, when processing stability analyses, in order to achieve reliable and safe constructions, therefore presented results are planned to be extended with further shear tests.

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REFERENCES

BRACKLEY, I. J. A., 1973: Swell pressure and free swell in a compacted clay. In: COKCA, E., TILGEN, H.P., 2010: Shear strength-suction relationship of compacted Ankara clay. *Applied clay science* 49: 400–404. ISSN 1872-9053.

BRACKLEY, I. J. A., 1975: A model of unsaturated clay structure and its application to swell behavior. In: COKCA, E., TILGEN, H. P., 2010: Shear strength-suction relationship of compacted Ankara clay. *Applied clay science* 49: 400–404. ISSN 1872-9053.

FERRÉ, G. C., TOPP, P. A., 2002: The Soil Solution Phase. In: DANE, J. H., TOPP, G. C. (Co-editors): *Methods of Soil Analysis, Part 4 Physical Mehods*, Madison, Wisconsin, USA: Soil Science Society of America, Inc., 1663 p. ISBN 0-89118-841-X.

HENDRON, A. J., PATTON, F. D., 1987: The Vaiont slide – a geotechnical analysis based on new geologic observations of the failure surface. *Engineering Geology*, 24, 1: 475–491. ISSN 0013-7952.

HULLA, J., ŠIMEK, J., TURČEK, P., 1991: *Mechanika zemín a zakladanie stavieb*. Bratislava: ALFA, 336p. ISBN 80-05-00728-0.

KRAHN, J., 2004: *Stability Modeling with SLOPE/W. An engineering methodology*. Calgary, Alberta, Canada: GEO-SLOPE International, Ltd., 246.

LAMBE, T. W., WHITMAN, R. V., 1979: *Soil Mechanics*. New York: Wiley & Sons, Inc. 553 p. ISBN 0471511927, 9780471511922.

MENCL, V., 1997: *Súbor vybraných prednášok prof. Ing. Dr. V. Mencla, DrSc.* Žilina: INGEO a. s., 286.

PELLET, F. L., KESHAVARZ, M., BOULON, M., 2013: Influence of humidity conditions on shear strength of clay rock discontinuities. *Engineering Geology*, 157: 33–38. ISSN 0013-7952.

TOLL, D. G., 2000: *The influence of fabric on the shear behavior of unsaturated compacted soils.* Advances in Unsaturated Geotechnics. Denver: American Society of Civil Engineers, pp. 222–234. ISBN 9780784405109.

VANAPALLI, S. K., FREDLUND, D. G., PUFAHI, D. E., 1996: The relationship between the soil-water characteristic curve and the unsaturated shear strength of a compacted glacial till. *Geotechnical Testing Journal ASTM* 19, 3: 19–28. ISSN 0149-6115.

ZHAN, T. L. T., CHARLES, W. W. Ng., 2006: Shear strength characteristics of an unsaturated expansive clay. *Canadian Geotechnical Journal*, 43, 7: 751–763. ISSN 1208-6010.

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