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Selecting characteristic values of geotechnical parameters for collapsible loess

La sélection des valeurs caractéristiques des paramètres géotechniques des sols effondrables

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ABSTRACT: Loess deposits represent a difficult ground condition in civil engineering and it can often cause large differential settlements that reduce the serviceability of structures. Loess and loess-like sediments represent collapsible soils in Slovakia and cover almost 10% of the area of Slovakia. Structural collapses caused by loading and water content changes are a major problem in geotechnical practice encountered in loess deposits. Conditions and criteria for soil collapse such as genesis, silt content, clay content, degree of saturation, liquid limit and bulk density are analyzed in the paper. Experimental results obtained in laboratory and field testing performed in loess sediments in Slovakia are discused. Selection of characteristic values of geotechnical parameters of collapsible soils is analyzed using the recommended statistical approach according to Eurocode 7.

RÉSUMÉ: Les dépôts de loess représentent une condition du sol problématique en génie civil et peuvent souvent causer les tassements du sol différentiels excessifs qui réduisent la fonctionnalité des structures. Le loess et les sédiments ressemblant à loess représentent des sols effondrables en Slovaquie et couvrent près de 10% de la superficie du pays. Les effondrements structurels causés par la charge et les changements de la teneur en eau constituent un problème majeur dans la pratique géotechnique dans les dépôts de loess. Le document analyse les conditions et les critères d'effondrement du sol, tels que la genèse, la teneur en limon, la teneur en argile, le degré de saturation, la limite de liquidité et la masse volumique. Cet article analyse les résultats expérimentaux obtenus dans les essais en laboratoire ainsi que sur le terrain dans les dépôts de loess. La sélection des valeurs caractéristiques des paramètres géotechniques des sols effondrables est analysée à l'aide de l'approche statistique recommandée selon l'Eurocode 7.

Keywords: collapsible soils; laboratory tests; field testing; loess, characterisctic value

1 INTRODUCTION

Northern and western parts of Slovakia are characterised by the presence of loess deposits, which are from a geological point of view divided into several types presented in the Table 1. Based on the Digital Geological map of Slovakia 1: 50 000 (Káčer et al, 2005) loess and loess-like sediments cover 4610.23 km^2 (9.4%) of the territory of Slovakia (Figure 1). They are largely located in the uplands of Slovak lowlands, with thicknesses ranging from 10 to 30 m. However, they also occur separately in form of terrace gravels cover. They transit into loess loams towards the intramountainous depressions.

Table 1. Loess and loess-like sediments in Slovakia (Frankovska et al., 2010)

Type of loess sediments	Area (km^2)
Aeolian loess	2399,56
Loess-like (polygenetic) sediments	648,89
Loess-like sediments on alluvial terraces	1559,74

Loess and loess-like sediments represent collapsible soils in Slovakia, which have metastable structure. Loess sediments are susceptible to significant volumetric changes when they become saturated under loading, well-known as collapse. It can cause large differential settlements of the foundations that reduce the serviceability of buildings. Large number of failures and break-downs in buildings caused by soil collapse and extensive investigations of the properties of collapsible soils in the last 20 years are assessed in the project Monitoring of loess sediments which is the part of the project Monitoring of Environmental Geological Factors in Slovakia (Klukanová and Liščák, 2004).

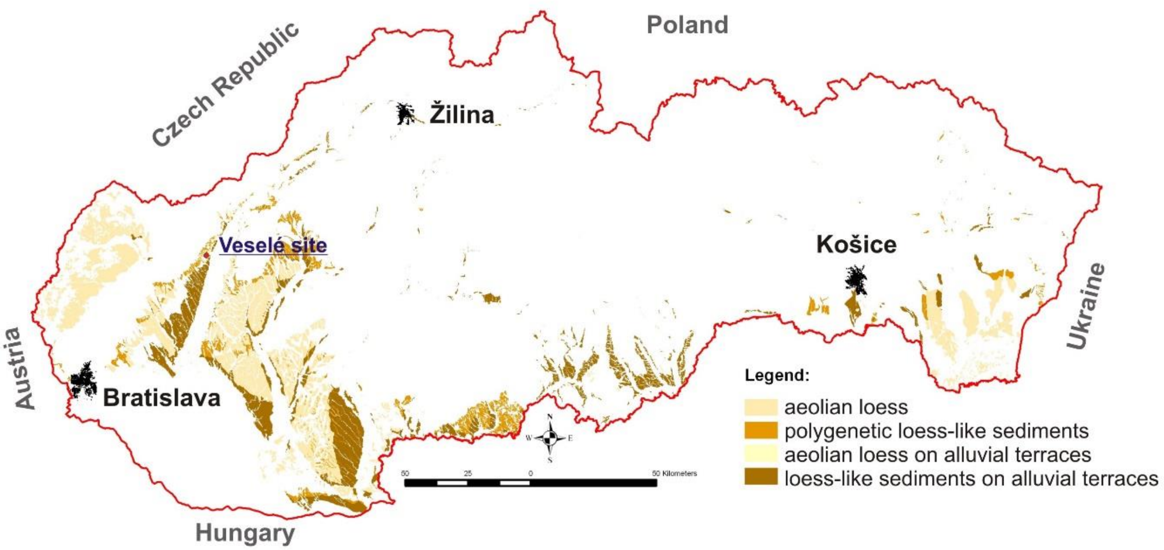

Figure 1 Occurrence of loess and loess-like sediments in Slovakia (Frankovská et al., 2010)

2 IDENTIFICATION AND BEHAVIOR OF COLLAPSIBLE SOILS

Generally, the collapsible soil is composed of silt and sand grains covered by clay/carbonate films, connected by clay/carbonate bridges and clay buttresses. Collapsible unsaturated loess deposits have a low plasticity index, density and a high porosity. Soils are susceptible to collapse according to Slovak standard STN 72 1001 (2010), if the following conditions are met:

- The soil is aeolian genesis;
- Silt content is more than 60 %;
- Clay content is less than 15 %;
- The degree of saturation is less than 70 %;
- Liquid limit is less than 35 %;
- Porosity is more than 40 %.

Delage (Delage et al., 2005) compared various existing collapse criteria and confirmed that Gibbs and Bara's criterion (Gibbs and Bara, 1962) provided the best answer, in a compliance with the oedometer tests. They proposed a criterion based on the values of the dry unit mass and the water content of the soil. The pore structure and degree of saturation has significant influence on loess mechanical behaviour.

The simple and double oedometer test has been found to be an effective method for measuring the collapse potential of loess sediments (Jennings and Knight, 1957). Soils are classified as collapsible according to Slovak standard STN 72 1001 (2010) when the collapse coefficient I_{mp} is more than 1 %. New criteria were published for the assessment of the metastable structure of typical loesses, determined on the basis of pressuremeter and radiometric measurements by Frankowski (Frankowski, 1994). Meier and Boley published empirically derived method for the qualitative estimation of collapse-type deformations, which can be expected as a consequence of hydroconsolidation based on density and empirical factors evaluated from diagrams (Meier and Boley, 2012).

The developments carried out in the past decades in the mechanics of unsaturated soils allow for a better understanding of collapse thanks to a relevant theoretical framework and advanced techniques of either controlling or measuring suction in collapsible samples (Delage et al., 2005).

3 FIELD AND LABORATORY TESTS

Results from ground investigations near the town Trnava in Slovakia are presented in the paper. Laboratory tests to determine the collapse potential of loess samples and dynamic penetration tests have been performed to determine geotechnical parameters of different soil layers. Dynamic penetration tests (DP) are very often used in ground investigation in Slovakia. The heavy dynamic probing (DPH) tests were performed to determine the in-situ resistance of soil to the dynamic penetration of a cone. The results from DP tests may be used for determining the strength and deformation properties of soil, generally of the coarse type but also possibly in fine soil, through appropriate correlations.

Laboratory tests were performed on good quality unsaturated samples with the degree of saturation from 0,40 to 0,55. Index of Collapsibility of soil was investigated for collapsible soils with different water content. Simple and double oedometer methods were used for laboratory testing. The soil was saturated at different vertical pressure using simple oedometer test. The collapse coefficients I_{mp} for soils with different water content are presented in Figure 2.

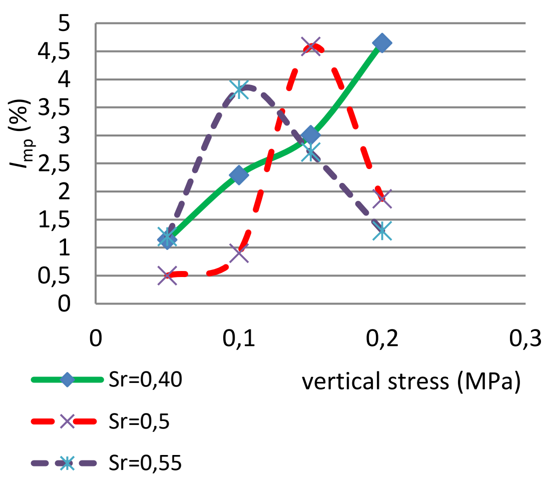

Figure 2. The collapse coefficients of soil with different degree of saturation, identified by simple and double oedometer methods.

The results of laboratory tests confirmed the collapse susceptibility of loess samples up to the depth 4.8 m bellow the surface. Geological conditions in this ground layer consist of silty fine grained soils with eolic geneses. There are also significant correlations between porosity, density and degree of the collapse coefficient I_{mp}. The value of the collapse coefficients depends on water content and on stress level. Comparison of degree of saturation and the collapse coefficient is presented in the Figure 3. Comparison of porosity and the collapse coefficient is presented in the Figure 4.

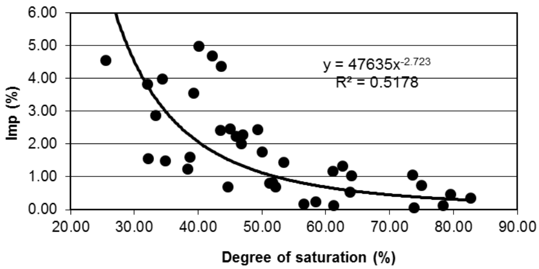

Figure 3. Relationship between the coefficient of collapsibility and degree of saturation of the soils

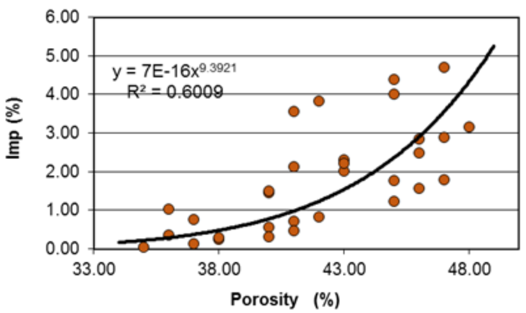

Figure 4. Relationship between the coefficient of collapsibility and porosity of the soils

The relationship between the collapse coefficients and density was confirmed (Figure 5).

The assessment of reliable strength and stiffness parameters of soils from in-situ tests is a necessary and fundamental step in every geotechnical design process. In calculation models, the degree of sophistication by which a loess is characterized varies considerably according to the selected testing method.

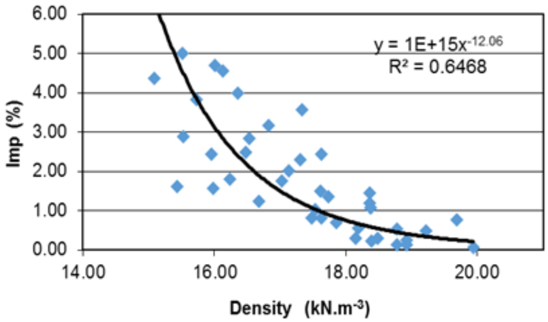

Figure 5. Relationship between the coefficient of collapsibility and density of the soils

For fine soil, the quantitative use of the results of dynamic probing should be employed only under well-known local conditions and supported by specific correlations (Schnaid, 2009). The skin friction during the test is a factor of special concern with this type of soil and should be duly taken into account.

Correlations of deformation modulus based on the results of DPH for fine grained soils generally can be expressed using equation:

$$E_{\mathrm{def}} = n \cdot q_{\mathrm{d}} \quad /\mathrm{MPa}/ \qquad (1)$$

The range of values of penetration resistance (q_d) in collapsible soils located in investigated area near Trnava was from 1.84 to 3.24 MPa. The minimum value of derived value of deformation modulus was 3.6 MPa and the maximum value was evaluated as 6.5 MPa. The value of the coefficient n in the equation (1) is based on comparable expierence 2. The relationship between penetration resistance q_{dyn} and modulus E_{def} obtained from laboratory testing was analysed and there is no significant correlation.

Francisca (Francisca, 2007) analyzed the data from in-situ and laboratory tests to establish possible correlations between the high strain elastic properties of loess and results from Standard penetration tests (SPT). He discovered that oedometric modulus of loess measured at natural water content cannot be correlated with the blow count. The same outcomes were observed for dynamic penetration tests analysed in this paper. The number of blows measured during the DPH test was very low. This can be an indirect method to determine the border between collapsible and non collapsible soils in engineering geological profile. Collapsibility decreases as the blow count *N* increases.

4 DETERMINATION OF CHARACTERISTIC VALUES

The selection of the characteristic values for geotechnical parameters takes into account the following:

- Geological and background information
- The variability of the measured property values and other relevant information, e.g. existing knowledge or comparable experience, research studies;
- The extent of the laboratory and field investigation;
- The type and number of samples;
- The soil volume affected by the geotechnical design;
- Quality of tests results.

If statistical methods are used, they should differentiate between local and regional sampling, and should allow the use of a priori knowledge of comparable ground properties.

As Eurocode 7 is not giving enough information about selection of the characteristic values for geotechnical parameters, new revised version of Eurocode 7 shall include the guidance on determinig characteristic values of ground parameters. The guidance shall be based on statistical framework combined with use of a priori knowledge, well-established experience or comparable experience. The model should be simple in order to avoid mistakes in understanding probabilistic concepts in its application. The guidance must be flexible so that it can be used in any situation, e.g. collapsible soils, the insufficient number of representative data, or the poor quality of some types of soil test, leading to extremely high scatter, not representative of the intrinsic scatter of the soil behaviour.

4.1 Statistical assessment of characteristic values

Basic statistical parameters used in determination of characteristic values of geotechnical parameters are the mean value and the variance (standard deviation or coefficient of variation). The characteristic value x_k can be calculated in general statistical terms using the following equation:

$$x_k = x_m\left(1 \pm k_n\, COV_{tot}\right) \qquad (2)$$

where:
x_m is the average (mean) value of the ground property;
COV_{tot} coefficient of variation expressing the uncertainty affecting the ground property;
k_n is a statistical coefficient for a given probability distribution and number of values.

For the purpose of statistical evaluation of characteristic values, several procedures common in geotechnical practice were used in this paper.

The equation proposed by Schneider (Schneider 1993):

$$x_k = x_m\,(1 - COV/2) \qquad (3)$$

Equation to calculate characteristic value for large amount of samples using in geotechnical practice in different countries (including Slovakia):

$$x_k = x_m - t_{95.\vartheta} \times s/\sqrt{n} \qquad (4)$$

where:

$t_{95.\vartheta}$ is the Student t factors for 95 % confidence level for ϑ degrees of freedom,

s – Standard deviation

The equation proposed by Schneider (Schneider 2010):

$$x_k = x_m \left(1 - 1.65 \times COV \times \sqrt{\frac{\delta}{L}}\right) \qquad (5)$$

where:

L_v is the vertical dimension of the zone of influence for the limit state under consideration (length of the governing failure mechanism);

δ is the scale fluctuation of the property.

European Standardisation Committee for Eurocode 7 TC250/SC7 established an Evolution Group, EG11 *Characterization* to provide quidance on determing the characteristic value of geotechnical parameters. Several equations were proposed in EG 11 and discussed in Working group 1 *EN 1997-1 and coordination*, e. g. equations (6) and (7):

$$x_k = x_m \left(1 - 1.65 \times COV \times \sqrt{\frac{1}{L} + \frac{1}{n}}\right) \quad (6)$$

Assessment Procedure 1 proposed in new infomative annex of EN 1997-1:

$$x_k = x_m \left(1 \pm {t_{95,\vartheta}}/{\sqrt{n}} \times \Delta x_{def} \sqrt{\frac{1}{L_v}}\right) \quad (7)$$

where:

Δx_{def} is the indicative value of parameter uncertainity e.g. according to Phoon and Kulhawy (1999) or Duncan (2000).

4.2 *Results*

Characteristic values of deformation modulus were determined separately from laboratory (n = 21, x_m = 5,12MPa) and field tests results (n = 21, x_m = 11,35MPa).

Results of calculations of characteristic values of deformation modulus of loess according to the equation (3), (4), (5) and (6) are presented in the Figure 6. Characteristics values of deformation modulus based on laboratory testing are in the range from 8.37 MPa to 10.45 MPa. Characteristics values of deformation modulus based on field testing are in the range from 4.11 MPa to 4.81 MPa.

The results of field testing measured values of geotechnical parameters, i. e. number of blows or cone penetration resistance, are small and not representing mechanical behaviour of collapsible soils.

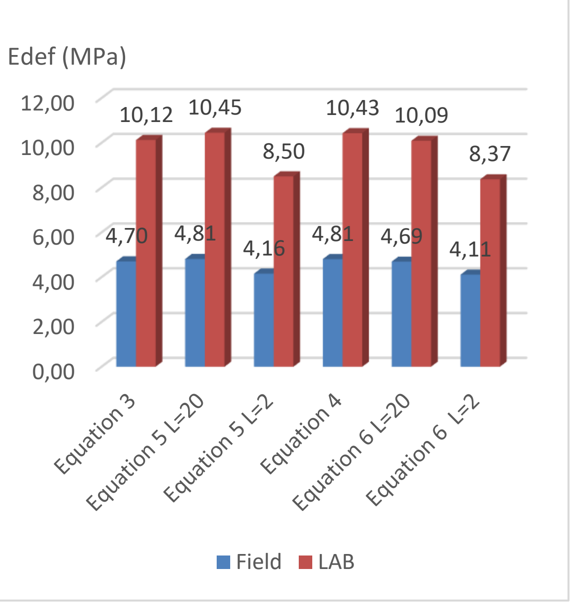

Figure 6. Characteristic values of deformation modulus calculated using different statistical equations and different type of testing

5 CONCLUSIONS

The present paper concerns with loess deposits susceptible to collapse. The ground water level has significant influence on the collapse susceptibility of loess samples. The value of the collapse coefficients depends on water content and on the stress level (Figure 2).

During the field tests, the soil collapses due to dynamic loading, which leads to low values q_{dyn} of the soil manifested by the test. In case of collapsible soils or other volume unstable soils, the characteristic values are expected to vary based on the laboratory or field test used. The laboratory test sample is often of varying quality.

The assesment of characteristic values of geotechnical parameters that would take into account the quality and type of testing is very important for geotechnical design. The paper has used the example of collapsible soils in order to show that the application of statistical methods without engineering judgement can be misleading. The testing method of obtaining derived values of geotechnical parameters, as well as the reliability of ground investigation, is essential. The concept of Bayesian statistical method can be used to combine a priori knowledge (comparable experience, judgment) with measured test values of geotechnical parameters.

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