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ENGINEERING APPROACH ON STABILITY ASSESSMENT OF LOESS SOIL STRUCTURES CONSIDERING BASIC GEOTECHNICAL CHARACTERISTICS

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Abstract: *The category of collapsible soils, including loess, is considered one of the most widely distributed geological hazards, often resulted in severe damages of engineering structures. These unsaturated deposits with a loose structure are subjected to large volumetric strains upon wetting, resulting in significant settlements. The present paper is dedicated to stability assessment of loess soils by taking into account the contribution of several geotechnical properties such as moisture content, porosity, shear strength and deformation to collapsibility behavior. According to the experimental criteria achieved from laboratory testing, an integrative analysis on collapsing particularities of investigated soils have been performed, in order to contribute to further applications in building design on unstable soils, urban planning and soil zoning maps to be used in risk management practice.*

Key words: *collapsibility, index correlation, intrinsic criteria*

1. Introduction

Loess deposits are recent geologic formations [1], covering more than 10% of global surface, especially located in Eastern Europe, Asia, North and South America, North Africa, Australia. These sediments, formed by the accumulation of wind-blown dust, are commonly present in arid and semi-arid areas, widespread in geographical regions as plateau (Chinese Loess Plateau), slopes and in main alluvial basins (Yellow, Mississippi, Rhine and Danube rivers). In Romania, loess and loess-like soils covers 17% of the territory, distributed in Romanian Plain, Moldova Plateau, Dobrogea, in the basins of Siret, Prut and Danube rivers, where the thickness can reach 40-50 m.

Also known as metastable deposits, collapsible soils are broadly classified as problematic soils [2], [3] from geotechnical point of view. Loess soils are susceptible to a large and sudden reduction of volume upon saturation with or without applying additional loading, which can

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affect the structure stability [4], [5]. Records experience of collapse character in response to differential settlements lead to structural damage of residential buildings, dams, roads and pipelines, leading to significant economic losses and life threatening [6], [7]. The most important characteristic of loess is very high sensitivity at water action, which can conduct to strong erosion and large settlement [8]. Geotechnical evaluations carried out on these distinct soils have demonstrated that collapse potential is controlled by a combination of factors [9], [10], [11] linked to geological conditions, soil composition, physical and mechanical parameters. Soil types with collapse potential are characterized by peculiar index properties that include low water content and initial bulk density, slight plasticity, low porosity (<60%), high porosity (40-60%), high strength and stiffness in natural dry state. Likewise, detailed studies have reported that loess soils contain a high percentage of fine grained particles (more than 50-60%, sometimes 80-90% silt fraction). It is mentioned that loess deposits have the ability to stand and support loads on nearly vertical slopes in dry condition.

Reviewing the existing literature, various criteria and correlations have been proposed to predict soil collapsibility considering the data gathered from field and laboratory testing. In order to differentiate collapsible and non-collapsible soils, [12] proposed a simple correlation between liquid limit and dry density of soils, while considered that collapse potential depends on void ratio, in natural state and at liquid limit. The connection of natural water content, saturation degree and plasticity characteristics with collapsibility was noted by [13], whereas [14] proposed the evaluation of collapse degree by taking into account in situ density and moisture content.

2. Material and Methods Used for Assessing Loess Properties and Their Correlation

In order to identify and predict the soil susceptibility to collapse, extensive experimental testing have been proposed for several loess samples collected from southeastern part of Romania, where the thickness of deposits is considerable. The study have been carried out to highlight and quantify the influence of basic soil properties as moisture content, dry density, porosity and saturation degree to mechanical characteristics. To achieve the research tasks, there were selected two sets of loess sample for determining shear strength and deformation parameters. In this regard, first stage of experimental studies consists in several tests conducted in direct shear apparatus on loess samples in natural and soaked state, considering different porosities (n,%) and moisture content (w, %) values. The obtained results allow establishing the variation of shear strength with moisture content (w) or saturation degree for different vertical stresses. It was observed that increase of moisture content can determine a decrease of shear strength, in case of w=25% reaching a value approximately equal to the one corresponding to inundation state, resulting from the fact that, around this moisture content, the two curves corresponding to the same pressures tend to overlap. Shear strength is more pronounced for the samples with low moisture content values, tending to be reduced for high values ones. Similar aspect is also remarked for the tests carried out on samples with porosity values ranging from 42% up 44%, as confirmed by curves shape corresponding to the same pressures, tending to cross w=25% for samples with different moisture contents exposed to soaked conditions (Fig. 1a). It can be noted that shear strength decrease is more pronounced for natural samples with low porosity that influence the reduction of soil bearing capacity. Upon saturation, the decrease of soil strength still remains pronounced for low porosity samples. This aspect can be revealed from the differences between corresponding ordinates of the same pressure, for natural and soaked conditions, that are much higher in 42-44% porosity interval comparing to 49-50% interval (Fig. 1b).

For a better evidence of soil resistance decrease under wetting conditions, several correlations have been built to emphasize the influence of initial moisture content on shear strength ratio in natural and soaked conditions (τ/τ_i) for different porosity values (Fig. 2).

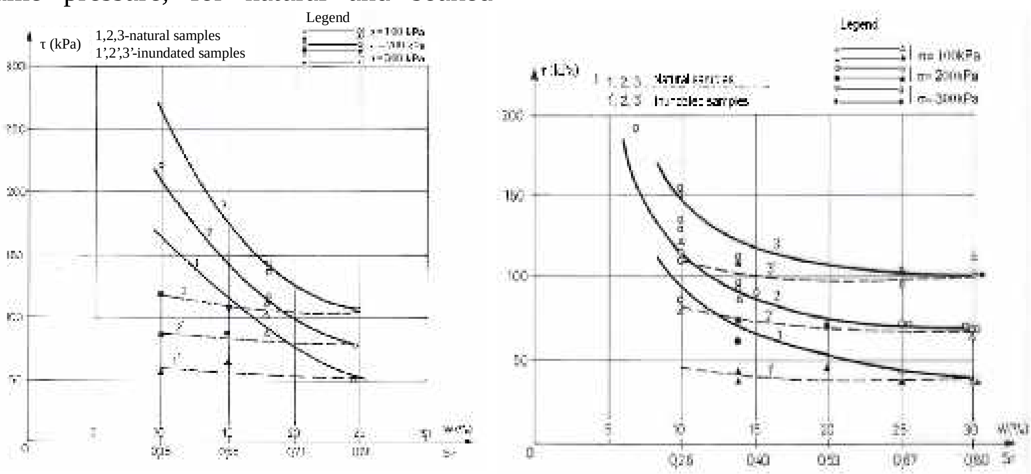

Fig. 1. *Variation of shear strength with moisture content / saturation degree at different vertical stresses: a) porosity n= 42-44%, b) porosity n=49-50%*

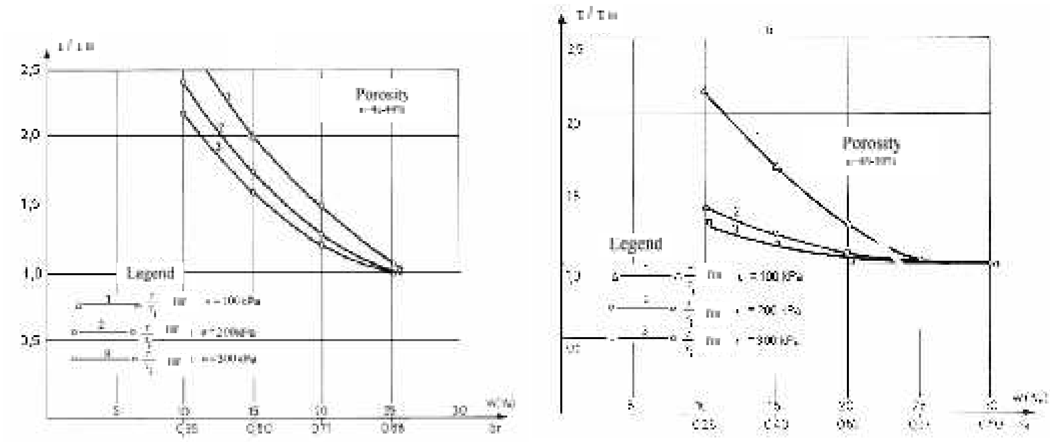

Fig. 2. *Variation of shear strength ratio with moisture content / saturation degree at different vertical stresses: a) porosity n= 42-44%, b) porosity n=49-50%*

High values of shear strength ratios reflect the important decrease of soil bearing capacity in a saturated test environment. This ratio decreases while moisture content increases and becomes almost equal to 1 for 25% moisture content and high saturation degree (>80%). The structural links are mostly damaged at moisture content higher than 20%. Depending on the size of vertical loads below which the shear tests are performed. At relatively small loads of 100 kPa, the soil structure is less damaged and due to the fact that the strength is ranging in restricted limits for high porosity values, because the porosity and less than 48-50% resistance varies very restricted, the curves will be presented without variations. After applying 200 kPa and 300 kPa loads, the change is reflected only in increasing of the curves general slope for higher stress.

Usually, loess strength and their bearing capacity are estimated only by considering soil saturation degree by neglecting the influence of porosity. It is considered that the degree of saturation can not represents a basic soil characteristic for strength assessment and it is necessary to take into account both moisture content and porosity. By analyzing the state diagrams dedicated to ratio τ/τin variation, it can be concluded a simultaneous influence of moisture content and porosity on structural strength. Moreover, by analyzing the parameters resulted from shear tests, it can be remarked the decrease of friction angle with moisture content increasing. The decrease of friction angle is much faster for low moisture content values (Fig. 3).

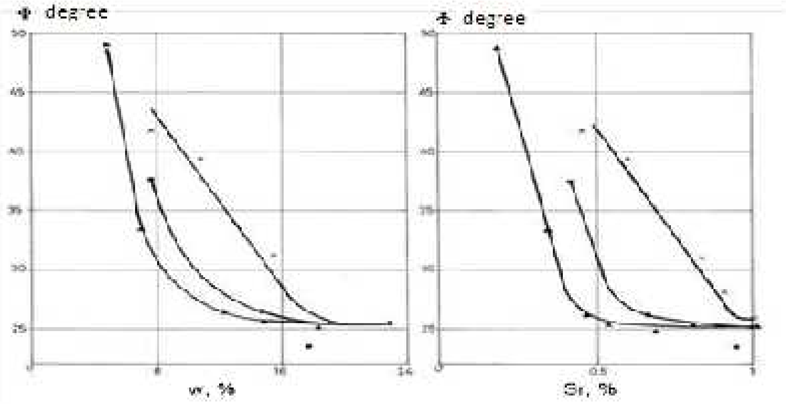

Fig. 3. *Variation of friction angle values with moisture content and saturation degree*

The second stage of experimental testing consists in basic determination of soil properties (moisture content, dry density, plasticity index, porosity) and collapse potential of loess samples according to American Standard. The assessment of physical characteristics has revealed that investigated loess deposits are characterized by the following specific properties: low natural density ranging from 1,45 g/cm^3 to 1,75 g/cm^3, slightly plasticity with average value of index plasticity (PI) around 10-12%, low moisture content ranging from 8% up to 15%, high porosity varying from 41% to 55%, low values of saturation degree (<60%). Based physical parameters, loess samples are within the variation limits of collapsible soils according to [15].

In order to analyze the collapse potential, Gibbs criterion [12] that considered collapsible degree when soil moisture content reaches saturation levels greater than liquid limit has been used and most of the samples are included in collapsible soil category, as illustrated in Fig. 4.

Measurements of soil collapse potential have been conducted according to [16] for determining the magnitude of one-dimensional collapse that occurs when unsaturated samples are soaked.

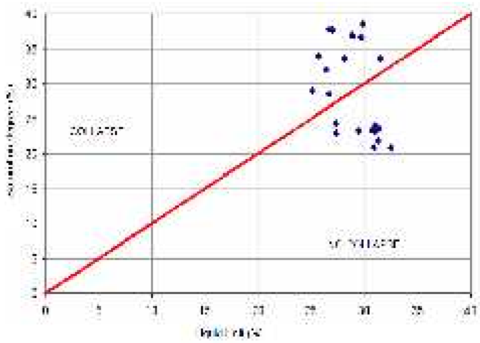

Fig. 4. *Collapse estimation using Gibbs criteria based on soil properties*

Laboratory testing consists in applying an initial loading of 5 kPa, followed by load increments 12, 25, 50, 100, 200 kPa, until appropriate vertical stress. Specimen saturation has been performed after applying 200 kPa loads. The deformations before each applied load increment versus time were recorded and several types of curves were represented (Fig. 5). Taking into consideration the results of compression-consolidation tests, it can be observed that 50% of the total deformation occurs in the first 10 seconds and the remaining is produced in 24 hours.

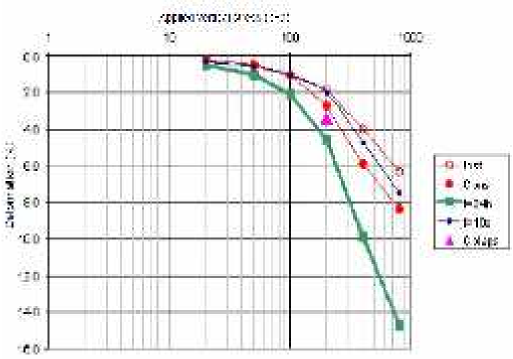

Fig. 5. *Deformation curves obtained for loess samples during compressibility tests*

3. Results and Discussions

Based on experimental results, shear strength decrease is more pronounced for natural and saturated samples with low porosity. In case of high loads and high porosity values, the trend of shear strength increases simultaneously with porosity decreasing, revealed by a pronounced slope, while the increase of soil density under vertical loads is necessary to be compensated by an increase of moisture content. In order to assess the structural strength the danger presented at inundation, the ratio (τ/τ_i) was used. It should be remarked that shear strength ratios in natural and soaked conditions are generally higher for low porosity. Likewise, the influence of shear strength parameters corresponding to investigated loess samples have to consider saturation degree, as well as density and moisture content. According to collapse potential classification, the values obtained for tested loess samples are varying between no degrees of collapse to slight (0,315-1,376%), moderate (2,11-4,46%) to moderate severe degree of collapse (6,43-10,99). Based on collapse potential measurements, it can be noticed that the majority of samples are considered collapsible, an issue confirmed by instantaneous consolidation produced by a high porosity.

4. Conclusions

Moisture content and porosity are considered the main factors that determine the structural strength of soils susceptible to wetting. Their influences are manifested simultaneously and are interdependent. It can be considered that structural strength is as more influenced by moisture content in the low porosity interval, for soils with low compressibility. By performing special shear testing on samples with different moisture content, geotechnical parameters for bearing capacity or stability calculations can be achieved.

Systematization of intrinsic soil parameters linked to collapse potential [17] may allow the direct establishment of necessary elements for foundation design, according to real soil conditions during building execution and exploitation.

Acknowledgements

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