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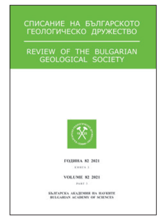

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Comparison of the liquid limit of loess defined by the Vasiliev and Casagrande test methods

Сравнение на границата на протичане на льос, определена по методите на Василев и Казагранде

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Abstract. The paper compares liquid limit values obtained by the Vasiliev and Casagrande apparatus in line with BDS 648:1984 and BDS EN ISO/ TS 17892–12:2018, on the basis of testing 25 silty loess samples. The results indicated that compared with the Vasiliev apparatus, the Casagrande apparatus gives a higher liquid limit. An equation allowing conversion of the liquid limit obtained by the Vasiliev cone penetrometer to the liquid limit by the Casagrande apparatus has been developed.

Keywords: liquid limit, loess soil, Casagrande apparatus, Vasiliev apparatus.

Introduction

The liquid limit is one of the most commonly used classification parameters of soils. A number of geotechnical properties of soils, like deformability, shear strength, swelling potential, permeability, liquefaction, cation exchange capacity, specific surface, etc., are correlated with the liquid limit (e.g Santamarina et al., 2002; Sharma, Bora, 2003; Yilmaz, 2004; Spagnoli, Shimobe, 2020).

The liquid limit of soils was first suggested by Atterberg (1911) and later standardized by Terzaghi (1926) and Casagrande (1958) for implementation in geotechnical and civil engineering research and practice. The method of liquid limit determination, using the Casagrande apparatus, has been adopted in geotechnical standards in the United States of America (ASTM, AASHTO), the United Kingdom (BSI), European Union (EN), Japan (JIS) and many other countries.

In Bulgaria, the geotechnical design according to the European norms (EN) has been in force since 2010. Until then the liquid limit in Bulgaria as well as most of the Eastern European countries was identified by Vasiliev's cone penetrometer (Vasiliev, 1942, 1949; GOST 5184:49; BDS 649:1971). The liquid limit obtained by Vasilev's test (w_L^v) differs from the liquid limit determined by Casagrande cup (w_L^c) apparatus.

Loess soil forms an almost continuous cover in North Bulgaria and amounts to approximately 13% of the territory of the country. Because of its specific engineering properties, many geotechnical classification tests were performed and plenty of archive test results are available. There is a necessity for these results to be used in new studies and projects. For that reason, a correlation between the liquid limit values determined by both methods would have a valuable application. The paper aims to present a comparison of results for liquid limit values of loess soil determined by the Vasiliev cone and Casagrande cup apparatuses.

Materials and methods

In the study, 25 loess soil samples from Kozloduy town area (North Bulgaria) were analyzed. The samples were taken from typical silty loess at depths between 1.5 and 9.0 m below the ground level. The samples average particle size distribution is as fol-

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lows: gravel >2 mm – 0%; sand 2–0.063 mm – 4%; silt 0.063–0.002 mm – 96% and clay < 0.002 mm – 0%. All samples are classified according to BDS EN ISO 14688 – 2:2018 as CIL (low plasticity clay) and according to USCS (ASTM D 2487–17e1) as CL (lean clay).

The liquid limit was obtained according to BDS 649:1971 and BDS EN ISO/ TS 17892–12:2018. For the determination of w_L^v a standard Vasiliev cone penetrometer with an apex angle of 30°, mass of 76 g, and penetration value of 10 mm was used in line with BDS 648:1984. As recommended in 5.4 of BDS EN ISO/ TS 17892-12:2018, the Casagrande apparatus with a hard base percussion cup and 25 blows was used to obtain the w_L^c values.

The tests were conducted on air-dry loess soil samples passing 425 µm. The samples were mixed thoroughly with a small amount of distilled water to adjust the water content of the remoulade soil paste to the desired consistency and they were left in an airtight container for approximately 4 h. The samples were then tested on both devices to obtain first data points. To obtain second points, soil specimens were remixed adding distilled water to increase the water content. Drying of the specimens between tests was prevented by putting them in an airtight container. This process was continued to obtain at least four water contents values for each sample and method. The results were plotted on semilogarithmic graphs: cone penetration depth against water content and number of blows against water content. The water contents matching to a cone penetration of 10 mm from the first graph were defined as w_L^v. From the Casagrande cup graph the water contents corresponding soil to 25 numbers of blows were defined as w_L^c.

Table 1. Statistical analysis of the liquid limit test results

Parameter	w_L^V	w_L^c
Mean	27.5	33.3
Standard error	0.30	0.43
Median	27.3	32.6
Mode	26.7	32.1
Standard deviation	1.49	2.13
Range	6.5	8.7
Minimum	25.1	30.2
Maximum	31.6	38.9
Count	25	25

Least square linear regression was used to establish empirical models between w_L^v and w_L^c. The w_L^v was used as a predictor variable to explain the response variable w_L^c. A graph of w_L^v was plotted against w_L^c and the coefficient of determination R^2 was used to determine the quality of the relationship; the higher the value of R^2, the stronger relationship between the variables. A strong relationship between the predictor variable and the response variable leads to a reliable empirical equation.

Results and discussion

Comparison of the liquid limits of the loess soil, determined by the Vasiliev cone penetrometer w_L^v and Casagrande method w_L^c is presented in Table 1 and Fig. 1a. It was observed that the liquid limits

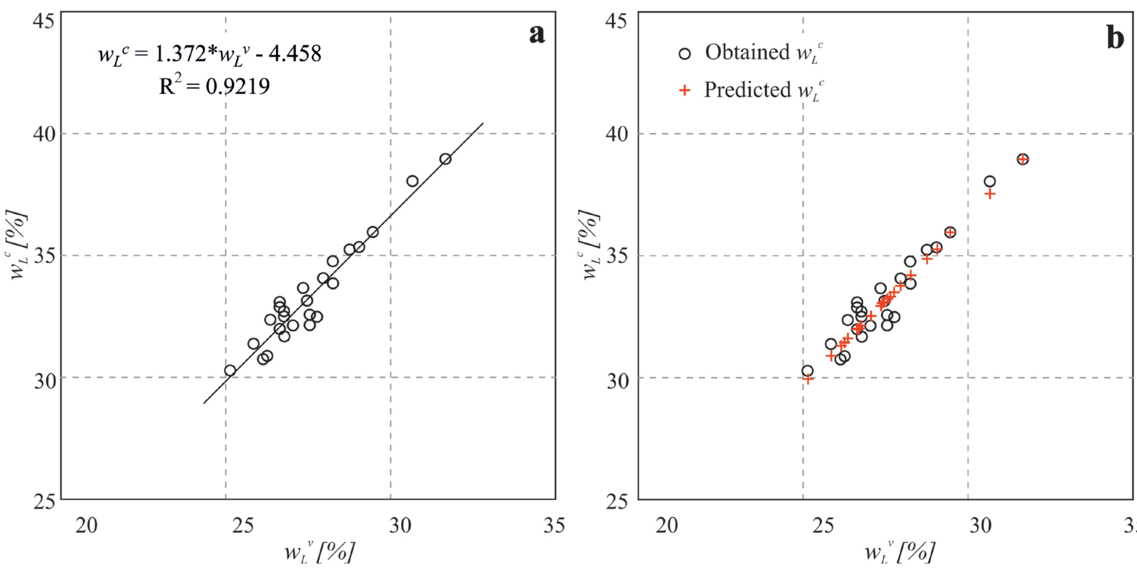

Fig. 1. *a*, Vasiliev cone penetrometer (w_L^v) vs Casagrande apparatus (w_L^c) liquid limit with the regression line; *b*, comparison of the calculated w_L^c values obtained by the correlation [1] and the Stefanoff's (1957) equation

determined by the Vasiliev cone penetrometer were rather lower than those obtained by the Casagrande apparatus. This is consistent with the results of other studies (e.g. Stefanoff, 1957; Škopek, Ter-Stepanian, 1975; Gruchot et al., 2017).

The coefficient of determination is $R^2 = 0.92$ (Fig. 1a), which means that there is high correlation between liquid limits obtained by both methods. The following equation was derived from least square linear regression analysis:

$$w_L^c = 1.37 * w_L^v - 4.46 \qquad [1]$$

where, $w_L{}^c$ is the Casagrande apparatus liquid limit, and $w_L{}^v$ is the Vasiliev cone penetrometer liquid limit. The derived empirical equation is applicable for low plasticity silty soils .The high value of the coefficient of determination demonstrates the validity the proposed relationship. The calculated $w_L{}^c$ values differ up to ±1% from the $w_L{}^c$ values obtained by tests. The limitation of this empirical equation is that it is only applicable for silty loess soil with values of $w_L{}^v$ in the range 25–35%.

A comparison of the calculated $w_L{}^c$ values obtained by the current empirical correlation [1] and Stefanoff's (1957) one is shown on the Fig.1b. The results of $w_L{}^c$ from both correlations are very similar – the difference is less than 1%. However it has to bear in mind that the Stefanoff's correlation is not derived especially for silty loess soils.

Conclusions

In order to compare liquid limit values of silty loess soil determined by the Casagrande cup and the Vasiliev apparatus, 25 silty loess samples were tested. Based on the statistical analysis of test results the following conclusions can be drawn:

- The liquid limits determined by the Vasiliev cone penetrometer were rather lower than those obtained by the Casagrande apparatus;
- There is a strong correlation between liquid limits obtained by both methods;
- An equation, allowing conversion of the liquid limit obtained by the Vasiliev cone penetrometer to the liquid limit by the Casagrande apparatus has been derived.

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