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Comparison of Liquid Limit of Soils Resulted from Casagrande Test and Modified Cone Penetrometer Methodology

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Abstract

In this paper the experimental work in the field of evaluation the liquid limit is described. Two different types of soil were analyzed – loam (intermediate plasticity) and sodium bentonite (high plasticity). Two basic methods were used for the evaluation of the liquid limit – Casagrande percussion (cup) method and cone penetrometer method. Two approaches were applied to the evaluation of liquid limit based on cone penetrometer test (30°/80 g cone) – standard method assuming 20 mm penetration at liquid limit and new calibration line for cone penetrometer liquid limit - NCCLL (Mohajerani). Experimentally obtained calibration line assumes the influence of depth of cone penetration at liquid limit on undrained shear strength, which is not unique for all types of soils. The paper presents the comparison of results of liquid limit based on the previously mentioned methods. Presented results of laboratory tests show, that bentonite liquid limit based on the standard cone penetration test (using 20 mm penetration) is significantly lower in comparison with Casagrande liquid limit. On the other hand was verified very significant consistency of Casagrande liquid limit and liquid limit based on NCCLL (evaluated depth of penetration 29 mm). Obtained results indicate the need for further research in this area.

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Keywords: Consistency of cohesive soil; liquid limit determination; Casagrande (cup) method; cone penetrometer method; depth of cone penetration; new calibration line for cone penetrometer test (Mohajerani);

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1. Introduction

The behavior of cohesive soil depends on many factors, to the most important belong its mineral composition, structure and the water content. Depending on water content the cohesive soil can be in various physical states – in different consistency. Consistency of cohesive soil is characterized by its water content at critical stages (solid, plastic, liquid) – Atterberg’s limits. The water content, corresponding to the boundary between the plastic and liquid physical state of soil, is called liquid limit. The liquid limit, together with the plastic limit, are the most important Atterberg’s limits, which are essential in the classification of cohesive soils and their behavior. For the evaluation of the liquid limit two basic methods can be used. Casagrande [1] developed the percussion (cup) method, the alternative method is the cone penetrometer method. The cone penetrometer method is easier, faster and less sensitive to the subjective factors (better repeatability of test) and from this point of view this method was accepted as standard method for the liquid limit determination in European Standard EC7. But, as it was presented by many researchers ([2], [3], [4], [5], [6], [7]), the consistency of results of two previously mentioned methods is not satisfactory for all types of soils, especially for high plasticity soil, which could obtain significant differences. Mohajerani [8] suggested a new approach for the evaluation of penetration cone test to achieve better correspondence between the liquid limit obtained by Casagrande and cone penetrometer tests. Our paper presents some results of the experimental work in this research field for two different types of soils (intermediately plastic loam, bentonite). Results of cone penetrometer test (cone characteristics: apex angle 30 °, total weight 80 g) contribute to verification of new calibration lines for cone penetrometer liquid limit (NCCLL) created by Mohajerani [8].

2. Experimental methods for liquid limit determination

The study was realized by using of the previously mentioned laboratory methods for liquid limit determination. Standard Casagrande method uses a standard metal cup, in which a soil paste is placed, then the soil is divided by cutting a groove of standard dimension and the cup is dropped on a base made of a standard material. The liquid limit is defined as the water content of the soil corresponding to the closing of groove along a length of 12.5 mm resulted from the impact of 25 blows of Casagrande cup.

The cone penetrometer method is based on the relation between shear strength and penetration resistant and uses the free falling cone (standard cone has weight 80 grams with apex angle of 30°). According this standard the liquid limit of the soil is defined as the water content corresponding to cone penetration of 20 mm.

But the above mentioned methods for the determination of the liquid limit have some limitations. Casagrande test is a dynamic shear test and its results may be affected by many objective and subjective factors, among others, by the differences in behavior in response to shaking. This test is also very sensitive to the operator technique.

The cone penetrrometer test is less time-consuming and easier in comparison with the cup test and it allows to eliminate the subjectivity associated with the Casagrande cup test. But the methodology of this test, based on the Hansbo [10] and Houlsby [9] theory, assumed a constant undrained shear strength of 1.7 kPa corresponding to the liquid limit for all type of soils. According Hansbo theory the undrained shear strength \( c_u \) is inversely proportional to the square of the cone penetration \( d \) and can be expressed in the form (1):

\[
c_u = k \cdot \frac{g \cdot W}{d^2}
\]

(1)

where \( W \) is the weight of the cone, \( g \) is the gravity acceleration (9.81 m/s\(^2\)), \( d \) is the depth of penetration and \( k \) is the coefficient depending on cone geometry (for the standard cone 30°/80 g this coefficient \( k=0.867 \) ([13])).

From the research works of many authors (for example, [11] [12]) the undrained shear strength of remoulded soil at liquid limit is not unique, but varies in a range from 2.7 kPa (for low plasticity soil) to 0.7 kPa (for high plasticity soil). Based on the Hansbo´s equation, assuming the mean value of undrained shear strength of various types of soil \( c_u = 1.7 \) kPa at liquid limit for standard cone penetrometer (\( W = 80 \) g, apex angle 30°, \( k = 0.867 \)), we obtain widely used standard value of penetration 20 mm at liquid limit of soil. Because of the real variation of undrained shear
strength of soil at liquid limit, the evaluation of liquid limit at a constant penetration of cone 20 mm, can lead to the variations between the liquid limit obtained from the Casagrande \(w_L(cup)\) and from penetration test \(w_L(cone)\), thus this standard evaluation is not generally acceptable. These variations were presented in the studies of many authors (for example [4], [8]), and they are known to be very significant for the high plasticity soils. Mohajerani [8] suggested new calibration lines between the cone penetration \(p\) at Casagrande liquid limit and the Casagrande liquid limit \(w_L(cup)\) expressed by the following two lines (new calibration lines for cone penetrometer liquid limit - NCCLL) (Figure. 1):

\[
p = 2.48+11.5 \log w_L(cup) \tag{2}
\]

\[
p = 20.98 + 3.03 \log w_L(cup) \tag{3}
\]

The intersection of these two lines corresponds to a penetration of 27.5 mm and to a moisture of 150%. These two lines can replace the standard constant penetration value of 20 mm corresponding to the liquid limit. In order to evaluate the liquid limit, it is necessary to determine the intersection of the NCCLL line and the penetration test results. Fig.1 [8] shows the relation between the cone penetration and the moisture content (19 correlation lines for different types of soil) and position of the new correlation line NCCLL.

![Fig. 1 Relations between the cone penetration and moisture content, including drawing NCCLL ([8]).](image)

The graphs shown in the Fig. 1 indicate, that the standard evaluation of liquid limit for the bentonite (soil No. 12), is \(w_L(cone, \text{standard}) = 498\%\), and the modified methodology indicates \(w_L(cone, \text{NCCLL}) = 825\%\). Mohajerani shows, that the corresponding \(w_L(cup)\) of this soil No. 12 reaches a value of 875%. So the ratio between the \(w_L(cup)\) and \(w_L(cone, \text{standard})\) reaches a value of 1.76, whereas according to the modified methodology using NCCLL \(w_L(cup)\) and \(w_L(cone, \text{NCCLL})\) are very similar with their ratio of 1.1.

3. Experimental works

Our experimental works in the field of evaluation the liquid limit were performed using two different types of soil with significantly different plasticity.

The first analysed soil was loam of intermediate plasticity (Figure. 2) taken from the overburden of the brown coal layer of the open mine Bílina, situated in the north part of Czech Republic. The investigated type of loam has gray color, dry soil has high strength as claystone, but the weathering process causes degradation of the soil. In order to classify the soil particle analysis was investigated, using the utilization of Particle Sizer Analysette 22 NanoTec and RTG CT tomograph Nikon.
The second tested material was a very high plasticity material - sodium bentonite (commercially named Volclay). In order to evaluate the liquid limit of these analysed soils, following laboratory methods were used:
- Casagrande cup method
- cone penetrometer (30°/80 g) under assumption of penetration of 20 mm (standard cone penetrometer)
- cone penetrometer (30°/80 g) under assumption of new evaluation approach based on NCCLL

![Fig. 2 Loam of intermediate plasticity (dump Bilina- North Bohemia).](image)

### 4. Results of experimental works

The obtained results from the Casagrande cup method for the two tested soils are illustrated in the Fig. 3 [14] and Fig. 4. The bentonite liquid limit based on the standard cone penetration test using 20 mm penetration is lower in comparison with value obtained using the Casagrande cup method. The ratio between liquid limit of bentonite corresponding to Casagrande and standard cone test reaches value 1.32 (Fig. 6).

Using NCCLL methodology (Fig. 5) we obtain the liquid limits, which are presented in the fourth column of the Table 1, the fifth column of this table shows corresponding penetration. As we can see in the Fig. 5 and Table 1, in case of intermediately plastic loam the value of penetration is approximately the same as in the case of standard cone method (penetration 20 mm), but for the bentonite the corresponding depth of penetration at liquid limit is significantly greater (29 mm).

![Casagrande test (cup)- intermediate plastic loam](image)

Fig. 3 Result of liquid limit of loam based on the Casagrande cup method (wL_(cup)=45%) [14].
Fig. 4 Result of liquid limit for bentonite based on the Casagrande cup method ($w_{L(cup)}=492\%$).

Fig. 5 Evaluation of liquid limit of tested soils using Mohajerani modified methodology (NCCLL).
Table 1. Comparison of evaluation of liquid limit of soil based on variant determination methods

<table>
<thead>
<tr>
<th></th>
<th>Casagrande test w_	ext{L(cup)} [%]</th>
<th>Cone penetrometer w_	ext{L(cone)} [%] (penetration 20 mm)</th>
<th>Cone penetrometer w_	ext{L(cone)} [%] (Mohajerani NCCLL methodology)</th>
<th>Penetration (NCCLL) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam</td>
<td>45.4</td>
<td>39.4</td>
<td>39.4</td>
<td>21</td>
</tr>
<tr>
<td>Bentonite</td>
<td>492</td>
<td>374</td>
<td>493</td>
<td>29</td>
</tr>
</tbody>
</table>

5. Conclusions

Based on performed experimental laboratory testing to the determination of liquid limit can be formulated following conclusions:

- Standard penetration of 20 mm (standard cone method) may not be correct assumption for the determination of liquid limit for all types of soils
- Obtained results contribute to the verification of new calibration lines for cone penetrometer liquid limit (NCCLL) (Mohajerani [8])
- Casagrande liquid limit of intermediate plasticity soil is very similar to the liquid limit obtained from standard cone penetrometer method assuming penetration of 20 mm
- Standard cone penetrometer test (20 mm penetration) gives significantly lower value of liquid limit in comparison to Casagrande cup method for high plasticity soils
- Application of NCCLL method for cone penetrometer test gives the results, which are comparable with Casagrande liquid limit for high plasticity soil (bentonite)
- NCCLL method indicates the requirement for penetration of 29 mm at liquid limit for high plasticity soil (bentonite) and of 21 mm for intermediate plasticity soil
- Application of NCCLL method for cone penetrometer test gives the results, which are comparable with Casagrande liquid limit for high plasticity soil (bentonite)
- NCCLL method indicates the requirement for penetration of 29 mm at liquid limit for high plasticity soil (bentonite) and of 21 mm for intermediate plasticity soil
- Additional experiments for different types of soils are required for further confirmation of Mohajerani’s calibration function for the determination of a penetration depth at liquid limit of soil.

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