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**Research paper**

# The effect of methodology on determining the liquid limits values of selected organic soils

**Grzegorz Straż**[1]

**Abstract:** This paper discusses the use of the Casagrande Cup and Cone Penetrometer Methods for determining the liquid limit of selected organic soils in in the south-eastern region of Poland in laboratory conditions in accordance with the latest standard guidelines. 10 methods established on the basis of literature materials were used to interpret the test results: 4 for test in the Casagrande Cup and 6 for the Cone Penetrometer. The results were compared and used to determine the parameters necessary to assessment of consistency of all type of soils, e.g.: plasticity index $I_P$ (%), consistency index $I_C$ (–) or liquidity index $I_L$ (–). The knowledge of these parameters makes it possible to determine the degree of plasticity of the tested soils using the Cassagrande chart. The conducted research and analyses have shown that the results of determining the liquid limit using the selected methods are not always comparable. The application of calculation methods based on the results of laboratory tests organic soils carried out in accordance with the procedures of the one standard (PN-B-04481: 1988), in the case of interpretation with Method No. 5 and Method No. 7, generated results with the widest range and the highest values in relation to the reference values (Method No. 1). In terms of the suitability of a given method, the type of tested soil, extremely complicated, diverse and heterogeneous structure turned out to be important, and most importantly, the content of organic parts, as evidenced by the results of consistency determination.

**Keywords:** casagrande cup, cone penetrometer, laser diffractometer, liquid limit, organic soils, plasticity chart

[1]PhD., Eng., Rzeszow University of Technology, Faculty of Civil and Environmental Engineering and Architecture Civil Engineering, Powstańców Warszawy 12 Av., 35-959 Rzeszow, Poland, e-mail: gstraz@prz.edu.pl, ORCID: 0000-0001-5847-0441

# 1. Introduction

Classification and determination of geotechnical parameters of organic soils that can be used for design purposes is complicated, time-consuming and to a large extent requires an approach different from that used in the case of typical mineral soils, which the author has repeatedly shown in publications, verifying classic and prototype research methods [1–5] and artificial intelligence (Artificial Neural Networks) [6, 7].

The basis for estimating the suitability of plastic (cohesive, fine-grained) mineral soils for foundation purposes is the knowledge of the condition or consistency of the soil. The leading parameters are: plasticity index $I_P$ (%), plasticity degree $I_L$ (–) or consistency index $I_C$ (–) and the basis for their determination is the determination of the Atterberg limits. In the case of organic soils, there are no guidelines for their determination other than for mineral soil, but due to a completely different nature than mineral soil, these methods require special verification. The determination of the liquid limit $w_L$ (%), which can be determined using the Casagrande Apparatus or the Cone Penetrometer, raises particular doubts. Therefore, the study attempts to verify the suitability of known methods of determining the liquid limit in the tests of organic soils. First of all, the methods of interpreting research results, the method of which are described in detail later in the study, require verification. Therefore, the study attempts to verify the usefulness of known methods of determining the liquid limit $w_L$ in the research of organic soils, the knowledge of which may be useful when designing deep – indirect foundations.

The researches works aimed at verifying the usefulness of these methods have been undertaken by many researchers in the World [8–26] and in Poland [27–32], but very few refer to organic soils. Nowadays, the basic source of information in the field of laboratory and field tests of soils is the second part of the Eurocode 7 [33] standard, which, apart from the characteristics and description of test methods, also includes appendices explaining how to interpret the obtained results. This information is supplemented by the Technical Specifications package published in 2009, introducing detailed testing procedures for specific laboratory methods, and the document relating to the determination of consistency limits is PKN-EN ISO/TS 17892-12: 2009: *Geotechnical investigation and testing. Laboratory testing of soil. Part 12: Determination of Atterberg limits* [34]. In 2018 another thematic standard was introduced, PN-EN ISO 17892-12: 2018-08. *Geotechnical investigation and testing. Laboratory testing of soil. Part 12: Determination of liquid and plastic limits* [35]. For the purposes of this work, the latest guidelines contained in the 2018 standard were used.

# 2. Methods and materials

## 2.1. Characteristics of study area

The all testing sites were established in the Podkarpackie Voivodeship, located in the south-eastern part of Poland. The region covers three separate physiographic lands, very varied significantly in terms of geological structure and topography. In the northern part of the Sandomierz Basin is located in the middle of the Carpathian Foothills, Beskidy Mountains in the south, dividing the Bieszczady and Beskid Niski, and part of Roztocze in the north-eastern part [36]. The locations of the testing sites were selected on the basis of own archived exploratory research, where existence of relatively shallow located different organic soils. The samples with disturbed structures of selected organic soils for laboratory researches were collected from three locations of testing sites: Czarna (soil No. 1), Mielec (soil No. 2) and Rzeszów (soil No. 3) of subsoils. The locations illustrated in Figure 1.

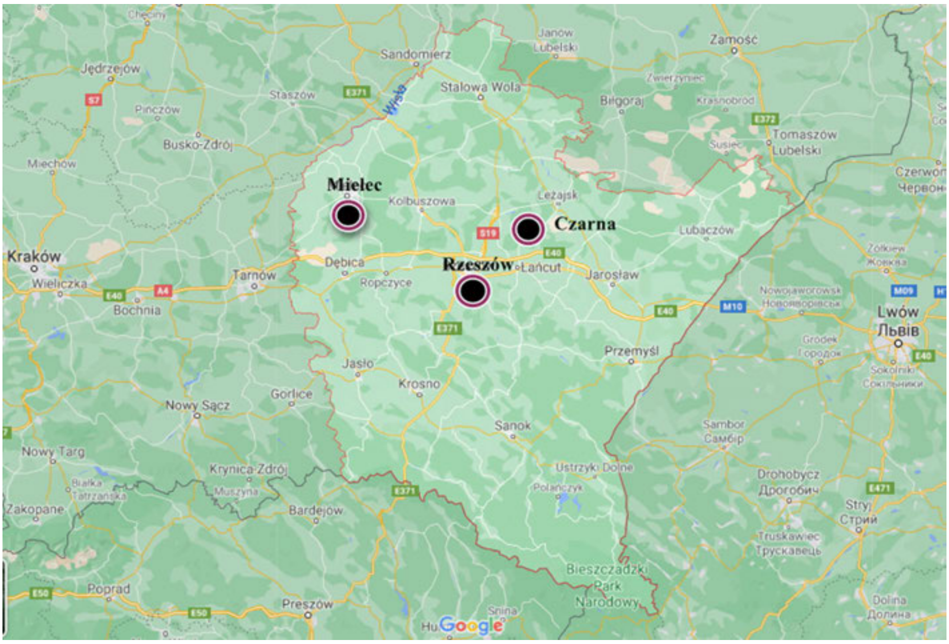


Fig. 1. The locations of selected testing sites in the Podkarpackie voivodeship by Google Maps

The origin of the samples organic soils:

– The samples soil No. 1 were collected from testing site at the Czarna area from the geotechnical layer separated on the basis of test drillings, which a variable thickness was from 0.9 to 2.3 m.
– The samples No. 2 came from testing site on the outskirts of the city of Mielec in the north-western part of the Podkarpackie Voivodeship, where during the ground investigation, it was found that in the near-surface zone of the site there is a layer of organic soils with a thickness of about 2 m.
– The samples soil No. 3 obtained for research from testing site on the in the area of single-family houses in the eastern part of Rzeszów on the floodplain the Wisłok river, where located layer organic soil which thickness was from 1.7 to 7.5 m.

The detailed data on the tested organic soils are provided in the research part of this work.

## 2.2. The determination of leading parameters of organic soils with a lab test

### 2.2.1. Determination of particle size distribution

The HELOS Laser Diffractometer manufactured by Sympatec GmbH is a particle size measuring device, which uses light diffraction at the interface of the particle as measurement principle. Particle size distribution of the sample is derived from the diffracted light beam recorded at the detector using Fraunhofer theory. Importantly, for particle size analysis with this method, knowledge of the optical parameters of the test substance is not required.

The measuring range of HELOS is very wide, from 0.1 μm to 8750 μm, because it utilizes seven different optical modules, each covering different range of particle sizes. The modules are selected following Sympatec approach: the chosen technology must meet the demands of the tested product. Each optical module is made of a single Fourier lens or a group of lenses. Module's focal length allows the light rays bent due to diffraction to be focused on the detector, not outside it. For the measurement to be reliable, the particles must enter the measuring zone dispersed to their original form. HELOS diffractometer can work with dry dispersion (RODOS, dispersion in compressed air), wet dispersion (QUIXEL, dispersion in liquid), and if necessary, it is also possible to combine both methods of dispersion (OASIS system). An example of a set for dry measurements was presented Figure2.

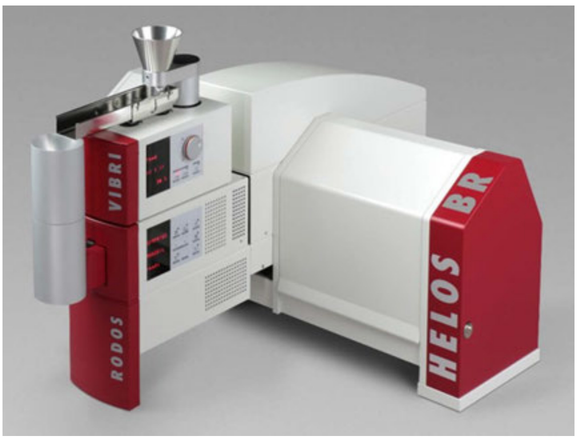


Fig. 2. The set for dry measurements: HELOS diffractometer, RODOS dispersant, VIBRI feeder [37]

Soil samples were tested in the wet dispersion system. The QUIXEL device is equipped with a basin for dispersing liquid, a centrifugal pump, a system that emits ultrasounds in order to break up agglomerates and a cuvette placed in the measuring zone in which the tested sample flows. The sample was placed in a beaker with a magnetic stirrer. While stirring, about 5 ml of sample was collected with a pipette and placed in the basin containing 1000 ml of dispersing liquid (demineralized water). The amount of sample is chosen so that the optical concentration (percentage of the light beam obscured by the particles) is in the range of 15–25%. Too high optical concentration "blinds" the detector, disturbing the measurement. In the next stage, the sample is exposed to ultrasounds for 60 seconds, which breaks up the agglomerates, dispersing the particles into their original form. The centrifugal pump runs all the time, mixing the liquid at a speed of 1000 rpm. Once the operation of ultrasound has ended, the dispersing liquid with particles flows through the cuvette placed in the measuring zone, where the measurement takes place. For these particular measurements two optical modules were utilized: R3 (focal length 100 mm) and R5 (focal length 500 mm). The laser beam passes successively through the measuring zone where diffraction occurs, gets focused at the optical module and finally hits the detector. The reference signal (recorded prior to sample introduction) is subtracted from the measurement signal recorded after diffraction, and the obtained values of the light intensity at the individual detector elements are converted by the computer into the particle size distribution [37].

### 2.2.2. Determination of leading parameters

The determination of:

– Water content $w$ (%) was carried out in accordance with the guidelines of the Polish standard PN-EN ISO 17892-1: 2015 [38].
– Bulk density $\rho$ (t/m$^3$) was carried out in accordance with the guidelines of the Polish standard PN-EN ISO 17892-2: 2015 [39].
– Plasticity limit $w_P$ (%) was carried out in accordance with the guidelines of the Polish standard PN-EN ISO 17892-12: 2018 [35].
– Liquidity limit $w_L$ (%) was carried out in accordance with the guidelines of the Polish standard PN-EN ISO 17892-12: 2018 [35].
– Organic matter content LOI$_T$ (%) was based on standard [40] and the results of the research presented in the paper [3, 4].

The calculations of the plasticity index $I_P$ (%) was carried out in accordance with the guidelines of the standard PN-EN ISO 14688-2: 2018-05 [41] based on the Formula (2.1):

$$I_p = w_L - w_P \tag{2.1}$$

where: $w_L$ – liquidity limit (%), $w_P$ – plasticity limit (%).

The calculations and term used for the designation of the plasticity index $I_C$ (–) was carried out in accordance with the guidelines of the standard PN-EN ISO 14688-2: 2018-08 [41] based on the Formula (2.2):

$$I_C = \frac{w_L - w}{I_P} \tag{2.2}$$

where: $w_L$ – liquidity limit (%), $w$ – water content (%), $I_P$ – plasticity index (%).

The classification of the tested soils was carried out according to their plasticity (degree of plasticity) with the use of plasticity Cassagrande'a chart in accordance with the guidelines of the standard PN-EN ISO 14688-2: 2018-08 [41].

## 2.3. The evaluation of liquidity limit based on laboratory test

The value of the liquidity limit $w_L$ (%) in laboratory tests is most often determined by the Casagrande Cup and Cone Penetrometer, two independent methods specified by standards of a properly prepared ground paste with changing water content. The usefulness of both methods for mineral soils is commonly known and confirmed, while in the case of organic soils it is not finally confirmed, so for the purposes of this study, i.e. for comparative purposes, laboratory tests were carried out simultaneously using both methods and the same ground paste. For both methods of liquid limit different methods of interpreting the results described in methodology in later in the work can be used.

### 2.3.1. The Casagrande cup test

The liquidity limits of organic soils by the Cassagande Cup Test was carried out in accordance with the guidelines of the standard PN-EN ISO 17892-12: 2018 [35], CEN ISO/TS 17892-12: 2004 [34] and PN-B-04481:1988 [40]. Until recently, in Poland, this method (5-points) was the basic and most frequently used method. In the Casagrande method, the basis for the interpretation of results is dependence between water content and number of rotations cup of apparatus. An example plot is shown in Figure 3a, where: X is number of rotations $N$ and Y is water content (%).

### 2.3.2. The cone penetrometer test

The liquidity limits the penetrometer method was carried out in accordance with the guidelines of the standard PN-EN ISO 17892-12: 2018 [35]. The fall cone method provides results with higher repeatability, and is the preferred method. The basis for the interpretation of results is dependence between water content and cone penetration, what is shown on example plot in Figure 3b, where: X is cone penetration (mm) and Y is water content (%).

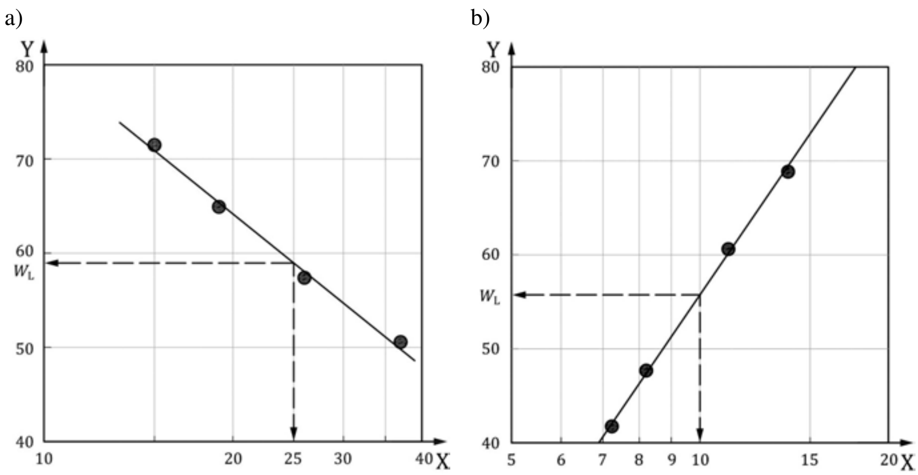


Fig. 3. The example of a the liquid limit test result based to the rules of the standard [35] from: a) the Casagrande cup test and b) the fall cone test

The information contained in the standard [35] suggests that for typical construction (mineral) soils that experience has shown that the liquid limit determined by the fall cone and the Casagrande apparatus are in general agreement from 30% to 40%, because the choice of test method to be used shall be agreed and reported.

In each test, the same Cassagrande apparatus and cone penetrometer were used, the parameters of which are described in detail in the relevant standards, while the calculation procedures (appropriate only for these devices and methods) were taken direct from the standards and literature.

## 2.4. The methods used to interpret the results of the liquid limit tests

After analyzing the literature resources, 10 interpretation methods were selected to determine the liquid limit: 4 for tests in the Casagrande apparatus and 6 for the cone penetrometer. They were both traditional, multi-point and single point methods, as well as new ones, based on two points of the series. The adopted research methodology illustrated in Figure 4.

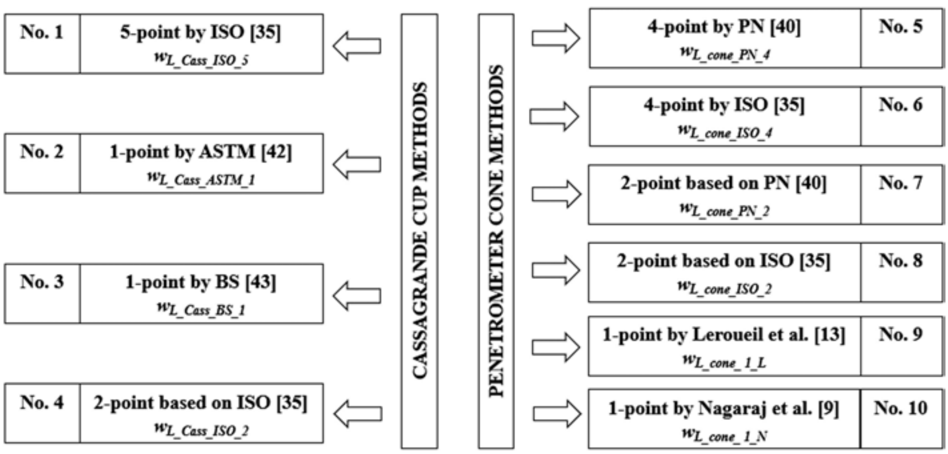


Fig. 4. The adopted researches method of determination of liquid limit of selected organic soils

The value of the liquidity limit of the tested organic soils was determined using the Casagrande cup method using the methods of interpretation of test results: 5-points (No. 1), 2-points (No. 4) and 1-point (No. 2 and No. 3):

- Method No. 1: it is 5-points method based on the diagram (Figure 1a), where X is number of rotations $N$ and Y is the water content $w$ (%) according to the rules of the standard PN-EN ISO 17892-12 [35] described as ***wL_Cass_ISO_5***;
- Method No. 2: it is 1-point method based on the Formula (2.3) according to the rules of the standard ASTM D 4318-05:2000 described as ***wL_Cass_ASTM_1*** [42] and based on the results the average value was calculated [31]:

$$w_{L\_\text{Cass\_ASTM\_1}} = w_{\text{cup}} \left( \frac{N_{\text{cup}}}{25} \right)^{0.121} \tag{2.3}$$

where: $w_{\text{cup}}$ – water content of the ground paste (%), $N_{\text{cup}}$ – number of rotations of the Casagrande cup (–).

- Method No. 3: it is 1-point method based on the Formula (2.4) according to the rules of the standard BS 1377:1990 described as ***wL_Cass_BS_1*** [43] and based on the results of each series the average value was calculated [31]:

$$w_{L\_\text{Cass\_BS\_1}} = w_{\text{cup}} \left( \frac{N_{\text{cup}}}{25} \right)^{0.092} \tag{2.4}$$

where: $w_{\text{cup}}$ – water content of the ground paste (%), $N_{\text{cup}}$ – number of rotations of the Casagrande cup (–).

- Method No. 4: it is 2-points method based on the diagram according to the rules of the standard PN-EN ISO 17892-12 [35] described as ***wL_Cass_ISO_2***, the principle has been adopted that these two points must be at least 15 number of rotations cup of the cup of apart from each other and based on the selected combinations the average value was calculated [31].

The value of the liquidity limit of the tested organic soils was determined using the penetrometer cone method using the methods of interpretation of test results: 4-points (Methods No. 5 and 6), 2-points (Methods No. 7 and 8) and 1-point (Methods No. 9 and 10):

- Method No. 5: it is 4-points method based on the diagram and Formula (2.5) according to the rules of the standard PN-B-04481: 1988 [40] described as ***wL_cone_PN_4***:

$$w_{L\_\text{cone\_PN\_4}} = 0.0043 w_{18}^2 + 0.88733 w_{18} + 3.62 \tag{2.5}$$

where: $w_{18}$ – water content of the ground paste (%) when cone penetration is 18 mm.

- Method No. 6: it is 4-points method based on the diagram (Figure 1b) where X is cone penetration (mm) and Y is the water content $w$ (%) according to the rules of the standard PN-EN ISO 17892-12 [35] described as ***wL_cone_ISO_4***;
- Method No. 7: it is 2-points method based on the diagram and formula (2.3) according to the rules of the standard PN-B-04481: 1988 [40] described as ***wL_cone_PN_2***, the principle has been adopted that these two points must be at least 5 mm apart on the scale of the cone and based on the selected combinations the average value was calculated [31];
- Method No. 8: it is 2-points method based on the diagram according to the rules of the standard PN-EN ISO 17892-12 [35] described as ***wL_cone_ISO_2***, the principle has been adopted that these two points must be at least 5 mm apart on the scale of the cone and based on the selected combinations the average value was calculated [31];
- Method No. 9: it is 1-point method based on the Leroueil and Bihan (1996) [13] Formula (2.6) described as ***wL_Cass_BS_1*** and based on the results of each series the average value was calculated: (30°/80 g):

$$w_{L\_cone\_1\_L} = \frac{40(w - 15)}{P_{80} + 20} + 15 \tag{2.6}$$

where: $w$ – water content of the ground paste (%) when cone penetration is 18 mm and $P_{80}$ is cone (30°/80 g) penetration (mm).

– Method No. 10: it is 1-point method based on the Nagaraj and Jayadeva (1981) [9] Formula (2.7) described as wL_Cass_BS_1 and based on the results of each series the average value was calculated (30°/80 g):

$$w_{L\_cone\_1\_N} = \frac{w}{0.65 + 0.0175P_{80}} \tag{2.7}$$

where: $w$ – water content of the ground paste (%) when cone penetration is 18 mm and $P_{80}$ is cone (30°/80 g) penetration (mm).

# 3. Results

## 3.1. The basic markings

The laboratory tests began with the preparation of research material, identification type and determination of the basic parameters of the selected organic soils [44]. The information and values of parameters for tested organic soils at the study were summarized in Table 1.

Table 1. The basic properties of selected organic soils at the study areas

| Soil No. | Location | Organic content $LOI_T$ (%) | Type of soil | Name of soil | Degree of decomposition | Water content $w$ (%) | Bulk density $\rho$ (t/m$^3$) |
|---|---|---|---|---|---|---|---|
| 1 | Czarna | $\frac{7.71}{7.68–7.73}$ | low-organic | warp, mud | – | $\frac{24.49}{23.26–25.72}$ | $\frac{2.00}{1.98–2.03}$ |
| 2 | Mielec | $\frac{48.71}{48.33–49.09}$ | high-organic | peat | amorphus | $\frac{70.12}{66.07–74.16}$ | $\frac{1.59}{1.61–1.57}$ |
| 3 | Rzeszów | $\frac{70.84}{70.29–71.39}$ | high organic | peat | pseudo-fibrous | $\frac{325.84}{321.43–330.25}$ | $\frac{1.13}{1.14–1.15}$ |

The particle size distribution organic soils made with the use of Laser Diffractometer. The soil samples were tested in the wet dispersion system. The sample was placed in a beaker with a magnetic stirrer. While stirring, about 5 ml of sample was collected with a pipette and placed in the basin containing 1000 ml of dispersing liquid (demineralized water). In the next stage, the sample is exposed to ultrasounds for 60 seconds, which breaks up the agglomerates, dispersing the particles into their original form. Each of the soil samples was analyzed three times and the presented curves are appointed on the basis of average values from 3 measurements. The results of the grain size analyses are illustrated in the graphs. The average particle size distribution: Cumulative Distribution (red line) and Standard Deviation (green line) for organic soil No. 1 ($LOI_T$ = 7.71%), No. 2 ($LOI_T$ = 48.71%) and soil No. 3 ($LOI_T$ = 70.84%) by Laser Diffractometer presented in Figures 5, 6 and 7.

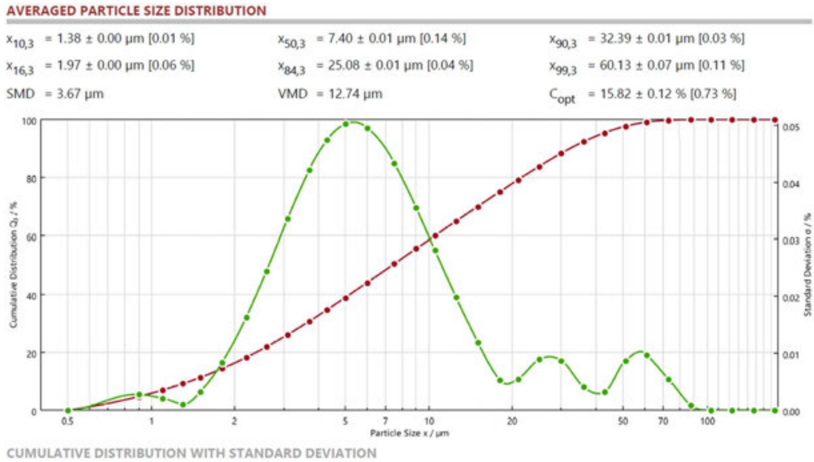


Fig. 5. The average particle size distribution by Laser Diffractometer for soil No. 1 ($LOI_T$ = 7.71%)

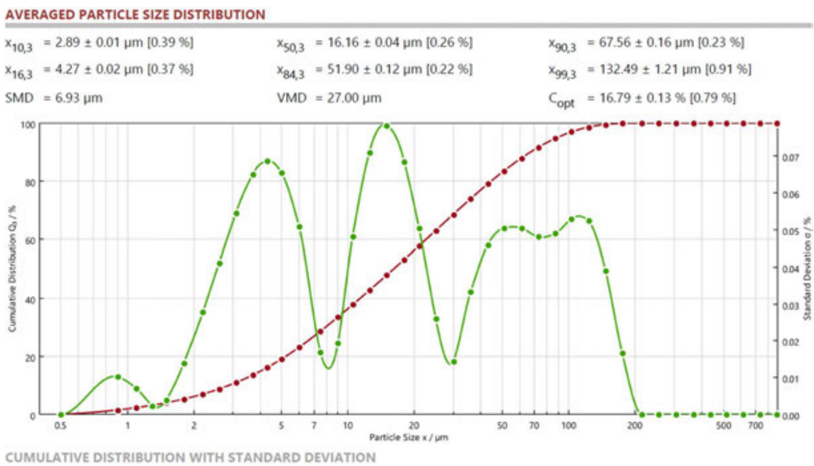


Fig. 6. The average particle size distribution by Laser Diffractometer for soil No. 2 ($LOI_T$ = 48.71%)

It was observed that each of the studied organic soils is characterized by an individual grain distribution diagram that differs from the others, which is the result of the structure and composition of the soil skeleton, and above all the amount, particle size and form of organic matter.

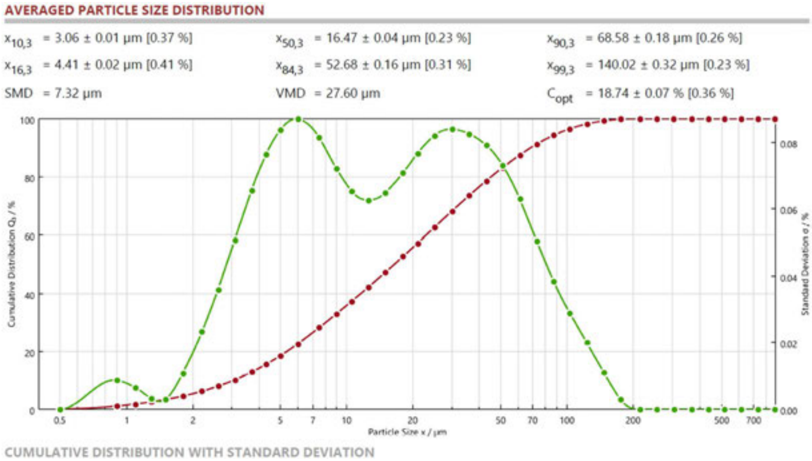


Fig. 7. The average particle size distribution by Laser Diffractometer for soil No. 3 ($LOI_T$ = 70.84%)

## 3.2. The results of determination of liquidity limit

The mean values of liquidity limits into account Standard Error (SE) and Standard Deviation (SD) of selected organic soils depending on the determination method were calculated in Statistica 13.3 [45]. Depending on the method of interpreting the test results, the number of valid data ranged from 10 to 40. The comparisons of the results of the liquidity limit from type of soil and the all used methods are presented in Figures 8, 9 and 10.

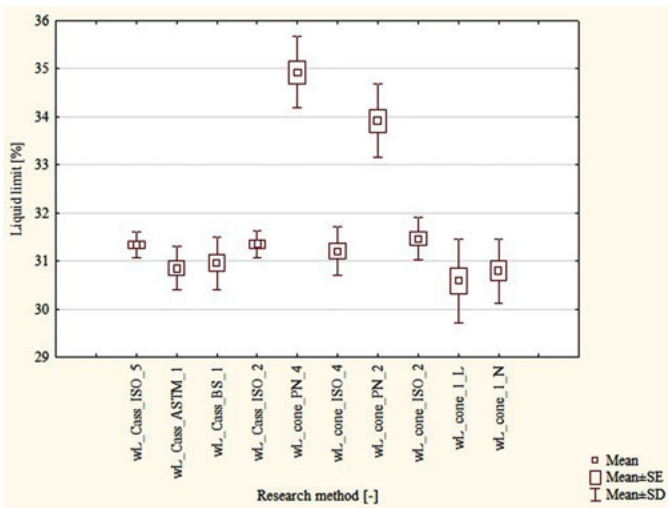


Fig. 8. The mean values of liquidity limits into account Standard Error (SE) and Standard Deviation (SD) of soils No. 1 ($LOI_T$ = 7.71%), depending on the determination method

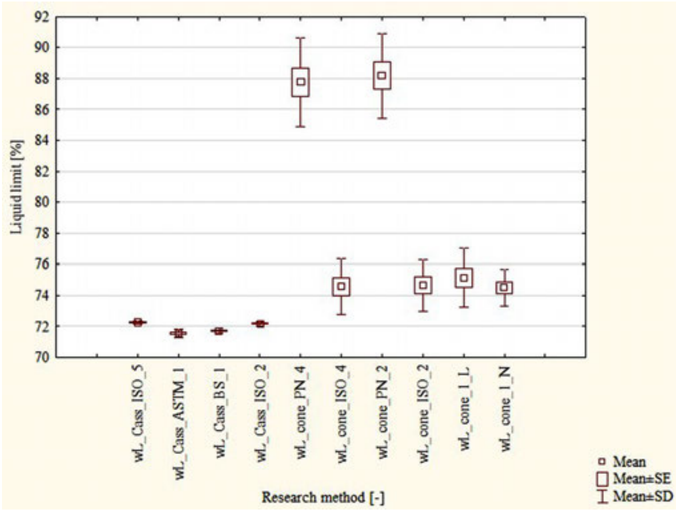


Fig. 9. The mean values of liquidity limits into account Standard Error (SE) and Standard Deviation (SD) of soils No. 2 ($LOI_T$ = 48.71%) depending on the determination method

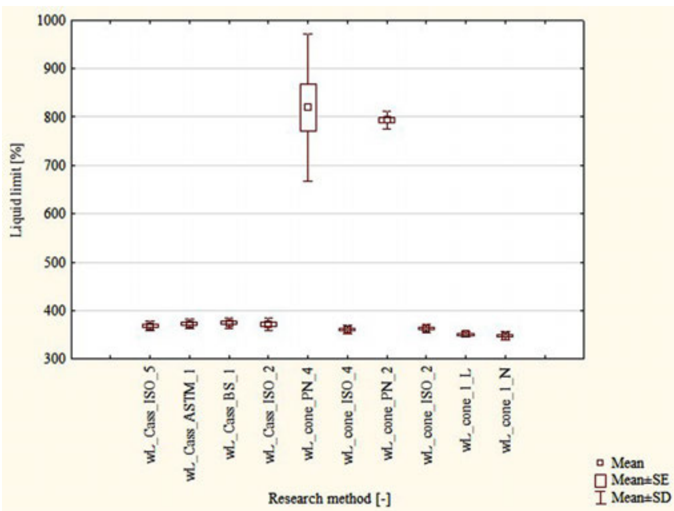


Fig. 10. The mean values of liquidity limits into account Standard Error (SE) and Standard Deviation (SD) of soils No. 3 ($LOI_T$ = 70.84%) depending on the determination method

When analyzing the values of the liquidity limits of selected organic soils calculated in accordance with the method used and presented in the above charts, it is clearly visible that the values calculated on the basis of the guidelines for the cone penetrometer using the 4-point Method No. 5 (*wL_cone_PN_4*) and the 2-point Method No. 7 (*wL_cone_PN_2*) in accordance with standard [40] are overestimated in relation to not only in relation to not only in relation to the reference values from Method No. 1 (*wL_Cass_ISO_5*) but also other methods used. Method No. 1 was considered the reference method due to many years of use in Polish laboratory practice and proven effectiveness in the case of researches mineral soils to the foundation of building structures. It was also noted that in general in these cases the range of the values obtained is the largest of all and additionally increases with the content of organic parts. The factor that could have had a decisive influence on the overestimation of the test results is the design of the test device, the usefulness of which (as research has shown) for the testing of organic soils is questionable, especially in relation to highly organic soils – peats with a pseudo-fibrous structure.

### 3.3. The plasticity index

Knowing the values of initial soil moisture $w$ (%) and liquidity limits $w_L$ (%), the plasticity index $I_P$ (%) was calculated for each method, using the results of 10 tests. The results in the form of mean, minimum and maximum values are shown in the Table 2. The reference values and method are marked in gray.

Table 2. The mean value of plasticity index $I_P$ [%] calculated for researched soils

| Method symbol | | wL_Cass_ISO_5 | wL_Cass_ASTM_1 | wL_Cass_BS_1 | wL_Cass_ISO_2 | wL_cone_PN_4 | wL_cone_ISO_4 | wL_cone_PN_2 | wL_cone_ISO_2 | wL_cone_1_L | wL_cone_1_N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil No. 1 | Min. | 9.55 | 8.79 | 8.65 | 9.95 | 12.23 | 9.37 | 11.29 | 9.39 | 8.14 | 8.56 |
| | Max. | 10.72 | 10.35 | 10.67 | 10.74 | 14.78 | 11.03 | 14.33 | 11.07 | 11.16 | 10.98 |
| | Mean | **10.23** | **9.75** | **9.85** | **10.25** | **13.82** | **10.10** | **12.81** | **10.35** | **9.48** | **9.69** |
| Soil No. 2 | Min. | 16.21 | 15.26 | 15.55 | 16.08 | 28.98 | 15.87 | 28.92 | 16.08 | 15.35 | 16.90 |
| | Max. | 16.48 | 16.14 | 16.16 | 16.52 | 36.51 | 21.22 | 36.32 | 21.01 | 20.99 | 20.47 |
| | Mean | **16.34** | **15.65** | **15.82** | **16.27** | **31.84** | **18.67** | **32.25** | **18.74** | **19.25** | **18.58** |
| Soil No. 3 | Min. | 50.43 | 58.77 | 59.22 | 51.70 | 310.66 | 54.50 | 467.75 | 54.80 | 48.62 | 42.21 |
| | Max. | 84.68 | 89,15 | 91.80 | 95.48 | 755.15 | 74.44 | 517.69 | 84.08 | 65.80 | 64.65 |
| | Mean | **71.12** | **75.77** | **77.83** | **74.86** | **522.83** | **64.47** | **496.90** | **66.12** | **54.29** | **51.17** |

The comparing the values of the plasticity index, it was observed that in the case of the organic soil with the lowest content of organic parts (soil No. 1) the results to some extent are comparable. In the case of organic soil No. 2, Methods No. 5 and 7 (*wL_cone_PN_2* and *wL_cone_PN_4*) stand out negatively and generate values almost two times higher than the others. The same methods generate extremely overstated results in the case of soil No. 3, where they max. differ from the rest by several hundred percent, e.g.: 921.8 % for Method No. 5 and 871.1 % for Method No. 7.

### 3.4. The degree of plasticity

Due to the fact that there are no separate, specific guidelines for organic soils, the tested soil samples classified in terms of the degree of plasticity (plasticity) according to the Casagrande plasticity chart [41] with the use of values of the liquidity limit $w_L$ and the plasticity index $I_P$ from own research and presented in Figures 11, 12 and 13.

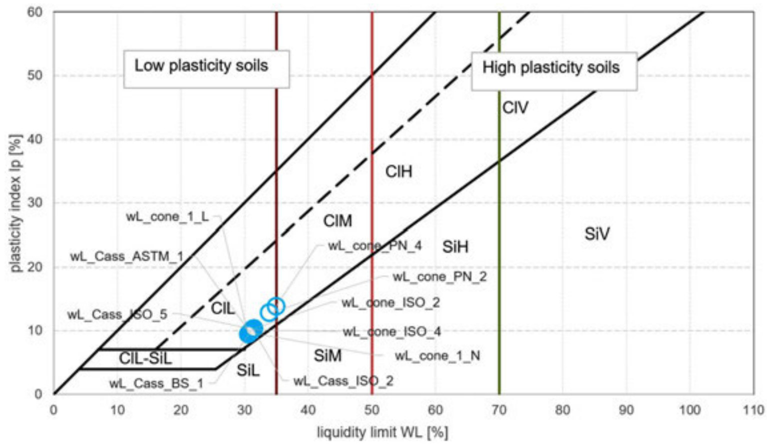


Fig. 11. The result of plasticity on the Cassagrande plasticity chart [41]
for soil No. 1 ($LOI_T$ = 7.71%)

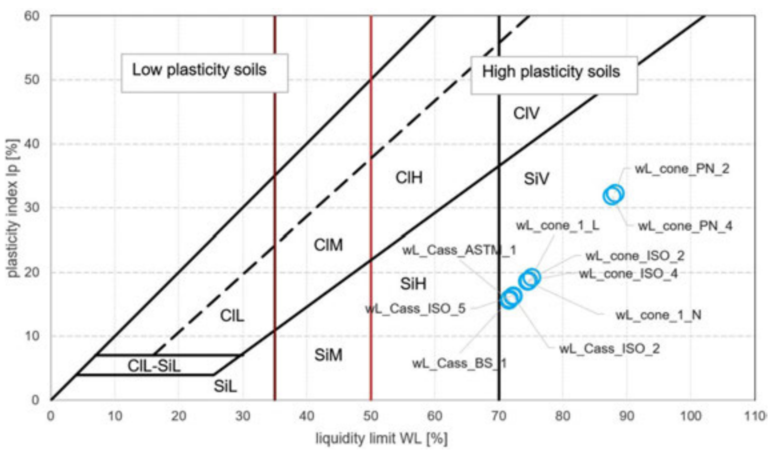


Fig. 12. The result of plasticity on the Cassagrande plasticity chart [41]
for soil No. 2 ($LOI_T$ = 48.71%)

When analyzing the position of the points on the graphs, it was observed that the values of the plasticity index calculated for soil No. 1 and 2 based on the results of the Cassagrande method are lower than with the cone penetrometer. In the case of soil No. 3 the situation is

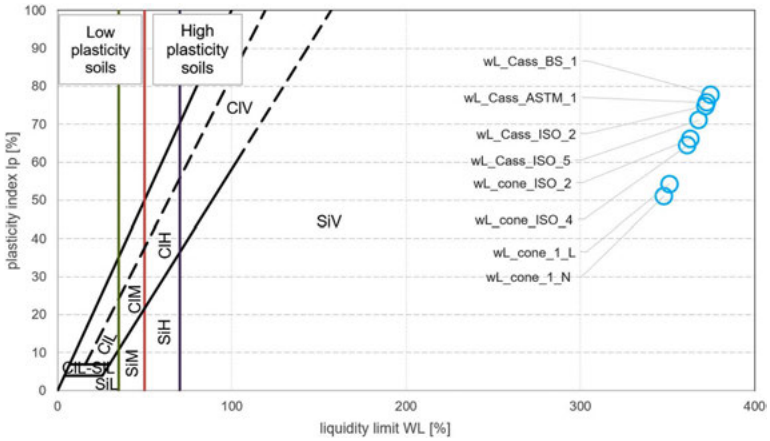


Fig. 13. The result of plasticity on the Cassagrande plasticity chart [41]
for soil No. 3 ($LOI_T$ = 70.84%)

reversed, which may suggest that the result is also influenced by a pseudo-fibrous structure of peat other than soil No. 1 or 2 and highest content of organic matter. However, this did not affect the peat classification result, because both soil (2 and 3) were located in the area of soils with very high plasticity, corresponding to the append to classification for organic material SiVO (very high plasticity organic silt). The soil No. 1 with the lowest content of organic matter was classified as a soil with low plasticity ClLO (low plasticity organic clay).

### 3.5. The consistency index

The consistency index $I_C$ according current standard [41] is the basis parameter to describe the consistency of clays and silts. Due to the lack of other guidelines, it was also applied to the analysed organic soils. The values were calculated using the results of 10 researches. The results in the form of mean, minimum and maximum values are shown in the Table 3. The reference values and method are marked in gray.

The analysis showed that the determination method had no effect on the result of the determination of the consistency of soil No. 1, as all cases were classified as "firm". The consistency of soil No. 2 was generally defined as "very soft", in the one case "soft" and in the case of two methods (Method No. 5 and 7) as "firm", significantly overstating and protruding from most of the results. In the case of soil No. 3, the situation is different because in most cases the consistency was defined as "firm", but there were also two cases of "stiff" and "soft".

In terms of the methods used, it was shown that the repeatability of determining the consistency for all types of soil was ensured by methods based on the results of the Cassagrande method. In the case of the cone penetrometer, the results turned out to be ambiguous, depending on the type of soil and the research method.

Table 3. The Consistency Index $I_c$ [–] calculated and consistency for researched soils

| Method symbol | | wL_Cass_ISO_5 | wL_Cass_ASTM_1 | wL_Cass_BS_1 | wL_Cass_ISO_2 | wL_cone_PN_4 | wL_cone_ISO_4 | wL_cone_PN_2 | wL_cone_ISO_2 | wL_cone_1_L | wL_cone_1_N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil No. 1 | Min. | 0.66 | 0.61 | 0.61 | 0.66 | 0.72 | 0.64 | 0.70 | 0.64 | 0.58 | 0.60 |
| | Max. | 0.68 | 0.67 | 0.68 | 0.68 | 0.77 | 0.69 | 0.76 | 0.69 | 0.70 | 0.69 |
| | Mean | **0.67** | **0.65** | **0.65** | **0.67** | **0.75** | **0.66** | **0.73** | **0.67** | **0.64** | **0.65** |
| Consistency | | Firm | Firm | Firm | Firm | Firm | Firm | Firm | Firm | Firm | Firm |
| Soil No. 2 | Min. | 0.12 | 0.07 | 0.09 | 0.12 | 0.51 | 0.10 | 0.51 | 0.12 | 0.07 | 0.16 |
| | Max. | 0.14 | 0.12 | 0.12 | 0.14 | 0.61 | 0.33 | 0.61 | 0.32 | 0.32 | 0.31 |
| | Mean | **0.13** | **0.09** | **0.10** | **0.13** | **0.55** | **0.23** | **0.56** | **0.24** | **0.25** | **0.23** |
| Consistency | | Very soft | Very soft | Very soft | Very soft | Firm | Very soft | Firm | Very soft | Soft | Very soft |
| Soil No. 3 | Min. | 0.42 | 0.51 | 0.51 | 0.44 | 0.91 | 0.47 | 0.94 | 0.47 | 0.40 | 0.31 |
| | Max. | 0.66 | 0.67 | 0.68 | 0.70 | 0.96 | 0.61 | 0.94 | 0.65 | 0.56 | 0.55 |
| | Mean | **0.58** | **0.61** | **0.62** | **0.60** | **0.94** | **0.54** | **0.94** | **0.55** | **0.46** | **0.42** |
| Consistency | | Firm | Firm | Firm | Firm | Stiff | Firm | Stiff | Firm | Soft | Soft |

## 4. Conclusions

The results of determining the liquidity limit of selected organic soils from Podkarpackie Voivodeship using commonly used research methods: Casagrande Cup and the Cone Penetrometer, taking into account 10 different methods of results interpretation, showed that one should be careful when choosing the method of interpreting the test results. This is evidenced by the fact that for each of the tested soils, containing a different amount of organic substances, two methods of interpreting the results of the cone penetrometer (Method No. 5 and 7) according to standard [40] significantly differ from the others and thus are of little use for geotechnical engineering purposes. They are distinguished by overstated mean values and a much wider range of results than in the case of alternative methods, which results in discrepancies in the values of the derived parameters ($I_P$, $Ic$, consistency). In the case of other interpretation methods, it was found that their results are comparable with the reference method (Method No. 1). In general, it has been observed that the results of determining the liquidity limit of selected organic soils, based on the Cassagrande method, are more concentrated and closest to the reference values, although due to the specificity of organic soils they significantly exceed the spread ranges for typical mineral soils.

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## References

[1] G. Straż, "Identification, marking and classification methods of organic soils according to Eurocode 7 and related standards", *Scientific Review Engineering and Environmental Sciences,* 2018, vol. 27, no. 2, pp. 227–235, DOI: 10.22630/PNIKS.2018.27.2.22.

[2] G. Straż, "Preliminary investigations of organics soil in a new calibration chamber with the use of the FVT and DPL probe", in *E3S Web of Conferences (SOLINA 2018),* 218, vol. 49, DOI: 10.1051/e3sconf/20184900109.

[3] M. Marut, G. Straż, "Verification of standard guidelines for organic matter content determination in organic soils by the loss on ignition method", *Geological Survey*, 2016, vol. 64, pp. 918–924.

[4] G. Straż, "The analysis of the impact temperature when it comes to the rate of ignition loss of selected kind of peat", *Scientific Review. Engineering and Environmental Sciences*, 2016, vol. 25, no. 73, pp. 264–276.

[5] G. Straż, "Estimating soil unit weight from CPT for selected organic soils", in: *Selected technical, economic and ecological aspects of contemporary construction*, K. Pujer, Ed. Exante, 2016, pp. 63–77.

[6] G. Straż, A. Borowiec, "Estimating the Unit Weight of Local Organic Soils from Laboratory Tests Using Artificial Neural Networks", *Applied Sciences*, 2020, vol. 10, no. 7, DOI: 10.3390/app10072261.

[7] G. Straż, A. Borowiec, "Evaluation of the unit weight of organic soils from a CPTM using an Artificial Neural Networks", *Archives of Civil Engineering*, 2021, vol. 67, no. 3, pp. 259–281, DOI: 10.24425/ace.2021.138055.

[8] R.F. Allbrook, "The drop-cone penetrometer method for determining Atterberg limits", *New Zealand Journal of Science*, 1980, vol. 23(1), pp. 93–97.

[9] T.S. Nagaraj, M.S. Jayadeva, "Re-examination of one-point methods of liquid limit determination", *Geotechnique*, 1981, vol. 31, no. 3, pp. 413–425.

[10] K. Wires, "The Casagrande method versus the drop-cone penetrometer method for the determination of liquid limit", *Canadian Journal of Soil Science*, 1984, vol. 64, no. 2, pp. 297–300.

[11] Y. Wasti, M. Bezirci, "Determination of the consistency limits of soils by the fall cone test", *Canadian Geotechnical Journal*, 1986, vol. 23, pp. 241–246.

[12] B. Christaras, "A comparison of the Casagrande and fall cone penetrometer methods for liquid limit determination in marls from Crete, Greece", *Engineering Geology*, 1991, vol. 31, no. 2, pp. 131–142, DOI: 10.1016/0013-7952(91)90002-3.

[13] S. Leroueil, J.P. Le Bihan, "Liquid limits and fall cones", *Canadian Geotechnical Journal*, 1996, vol. 33, pp. 793–798.

[14] T.W. Feng, "Fall-cone penetration and water content relationship of clays", *Geotechnique*, 2000, vol. 50, no. 2, pp. pp. 181–187.

[15] M. Orhan, M.Özer, N.S. Isik, "Comparison of Casagrande and cone penetration tests for the determination of liquid limit of natural soils", *Journal of the Faculty of Engineering and Architecture of Gazi University*, 2006, vol. 21, no. 4, pp. 711–720.

[16] M. Özer, "Comparison of liquid limit values determined using the hard and soft base Casagrande apparatus and the cone penetrometer", *Bulletin of Engineering Geology and the Environment*, 2009, vol. 68. no. 3, pp. 289–296, DOI: 10.1007/s10064-009-0191-4.

[17] G.L. Grønbech, B.N. Nielsen, L.B. Ibsen, "Comparison of liquid limit of highly plastic clay by means of Casagrande and fall cone apparatus", in *Symposium Proceedings: 14th Pan-American Conference on Soil Mechanics and Geotechnical Engineering, 2–6 Oct. 2011, Toronto, Canada*. Pan-AM CGS Geotechnical Conference, 2011, pp. 7.

[18] G. Spagnoli, "Comparison between Casagrande and drop-cone methods to calculate liquid limit for pure clay", *Canadian Journal of Soil Science*, 2012, vol. 92, no. 6, pp. 859–864.

[19] L. Di Matteo, "Liquid limit of low-to medium-plasticity soils: comparison between Casagrande cup and cone penetrometer test", *Bulletin of Engineering Geology and the Environment*, 2012, vol. 71, no. 11, pp. 79–85.

[20] K. Bicalho, J. Gramelich, S. Cunha, "Comparison between Casagrande cup and cone penetrometer test for determining liquid limit of different Brazilian clays", *Comunicações Geológicas*, 2014, vol. 101, pp. 1097–1099.

[21] G. Kollaros, "Liquid limit values obtained by different testing methods", *Bulletin of the Geological Society of Greece*, 2016, vol. 50, no. 2, pp. 778–787, DOI: 10.12681/bgsg.11784.

[22] A. El-Shinawi, "A comparison of liquid limit values for fine soils: A case study at the north Cairo-Suez district, Egypt", *Journal of the Geological Society of India*, 2017, vol. 89, no. 3, pp. 339–343, DOI: 10.1007/s12594-017-0608-9.

[23] E. Hrubesova, B. Lunackova, O. Brodzki, "Comparison of Liquid Limit of Soils Resulted from Casagrande Test and Modificated Cone Penetrometer Methodology", *Procedia Engineering*, 2016, vol. 142, pp. 364–370, DOI: 10.1016/j.proeng.2016.02.063.

[24] K. Eyyüb, D. Süleyman, "Liquid limit determination of various sand clay mixtures by Casagrande and fall cone test methods", *Journal of Balıkesir University Institute of Science and Technology*, 2018, vol. 20, no. 2, pp. 361-371; DOI: 10.25092/baunfbed.486389.

[25] H.I. Hawkar, N. Krikar, "Determining Casagrande Liquid Limit Values from Cone Penetration Test Data", *ZANCO Journal of Pure and Applied Sciences*, 2019, vol. 31, no. 3, DOI: 10.21271/ZJPAS.31.s3.16.

[26] H.U. Rehman, N. Pouladi, M. Pulido-Moncada, E. Arthur, "Repeatability and agreement between methods for determining the Atterberg limits of fine-grained soils", *Soil Science Society of America Journal*, 2020, vol. 84, pp. 21–30, DOI: 10.1002/saj2.20001.

[27] R. Szmoniewski, S. Szmoniewska, "Metoda jednopunktowego wyznaczania granicy płynności", *Geological Quarterly*, 1964, vol. 8, no. 1.

[28] K. Jaśkiewicz, M. Wszędyrówny-Nast, "Effect of methodology on determining the Atterberg limits for liquidity index*", Civil and Environmental Engineering*, 2013, vol. 4, pp. 113–118.

[29] W. Matusiewicz, Z. Lechowicz, G. Wrzesiński, "Determination of liquid limit by Cassagrande method and cone penetrometer", *Scientific Review Engineering and Environmental Sciences*, 2016, vol. 25, no. 3, pp.290–300.

[30] D. Krawczyk, M. Flieger-Szymańska, "The value of plasticity index ($I_P$) and liquidity index ($I_L$) of North Polish ablation boulder clays and varved clays depending of the method of its determination", *Scientific Review Engineering and Environmental Sciences*, 2018, vol. 27, no. 2 (80), pp. 167–174, DOI: 10.22630/PNIKS.2018.27.2.16.

[31] D. Krawczyk, "The possibility of objectivization of liquidity index determination based on glacial clays occurring in Poznan and its surrounding area", Doctoral dissertation, Poznan University of Technology, 2019.

[32] K. Goławska, Z. Lechowicz, W. Matusiewicz, M.J. Sulewska, "Determination of The Atterberg Limits of Eemian Gyttja on Samples With Different Composition", *Studia Geotechnica et Mechanica*, 2020, vol. 42, no. 2, pp. 168–178, DOI: 10.2478/sgem-2019-0041.

[33] EN 1997-2: 2009. Eurocode 7: Geotechnical Design – Part 2: Ground Investigation and Testing.

[34] PKN-EN ISO/TS 17892-12: 2009: Geotechnical investigation and testing. Laboratory testing of soil. Part 12: Determination of Atterberg limits.

[35] PN-EN ISO 17892-12: 2018-08. Geotechnical investigation and testing. Laboratory testing of soil. Part 12: Determination of liquid and plastic limits.

[36] Voivodship Inspectorate for Environmental Protection in Rzeszow, "Report on the state of the environment of the Podkarpackie Voivodeship in 2013–2015", Environmental Monitoring Library, Rzeszow, 2016.

[37] Atest Ltd, "Particle Size and Shape Analysis in Pharmaceutical R&D and Quality Control", PM Tour 2019/2020, Lublin, 2020. Available: https://www.atest.pl/.

[38] PN-EN ISO 17892-1: 2015. Geotechnical investigation and testing – Laboratory testing of soil – Part 1: Determination of water content.

[39] PN-EN ISO 17892-2: 2015. Geotechnical investigation and testing – Laboratory testing of soil – Part 2: Determination of bulk density.

[40] PN-B-04481: 1988. Building soils. Laboratory tests.

[41] PN-EN ISO 14688-2: 2018-05. Geotechnical investigation and testing. Identification and classification of soil. Part 2: Principles for a classification.

[42] ASTM D 4318-05: 2000. Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils. Annual Book of American Society for Testing and Material Standards.

[43] BS 1377:1990. Methods of test for soils for civil engineering purposes. General requirements and sample preparation.

[44] PN-EN ISO 14688-1: 2018-05. Geotechnical investigation and testing – Identification and classification of soil – Part 1: Identification and description.

[45] Statistica 13.3. TIBCO Software Inc. Available: https://www.statsoft.pl/Czytelnia.

## Wpływ metodyki oznaczania na wartości granicy płynności wybranych gruntów organicznych

**Słowa kluczowe:** dyfraktometr laserowy, granica płynności, grunty organiczne, metoda Cassagrande, penetrometr stożkowy, wykres plastyczności

### Streszczenie:

W artykule zaprezentowano zastosowanie aparatu casagrande i metody penetrometru stożkowego do wyznaczania granicy płynności w warunkach laboratoryjnych zgodnie z najnowszymi wytycznymi normatywnymi wybranych gruntów organicznych pochodzących z południowo-wschodniej Polski. Do interpretacji wyników badań wykorzystano 10 metod wyselekcjonowanych na podstawie materiałów literaturowych: 4 do badań w aparacie casagrande i 6 dla penetrometru stożkowego. Wyniki zestawiono, porównano i wykorzystano do wyznaczenia parametrów niezbędnych do oceny konsystencji, np.: wskaźnika plastyczności $i_p$ (%), wskaźnika konsystencji $i_c$ (–) czy stopnia plastyczności $i_l$ (–). Znajomość tych parametrów umożliwia określenie plastyczności badanych gruntów organicznych, bazując na normowym wykresie cassagrande. Przeprowadzone badania i analizy wykazały, że wyniki wyznaczania granicy płynności wybranymi metodami nie zawsze są porównywalne. Wykazano, że zastosowanie metod obliczeniowych opartych na wynikach badań laboratoryjnych wybranych gruntów organicznych przeprowadzonych zgodnie z procedurami normy PN-B-04481: 1988, w przypadku interpretacji metodami nr 5 i 7, generowało wyniki o najszerszym zakresie i najwyższych wartościach w stosunku do wartości referencyjnych (metoda nr 1). Z perspektywy przydatności danej metody ważnym okazał się również rodzaj badanego gruntu organicznego, z uwagi na niezwykle skomplikowaną, różnorodną i niejednorodną strukturę, a przede wszystkim ilość i rodzaj substancji organicznej, o czym świadczą wyniki oznaczeń konsystencji.

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