WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.146095
ARCHIVES OF CIVIL ENGINEERING
Vol. LXIX ISSUE 3 2023

pp. 521 –539

Research paper

The use of a laser diffractometer to analyse the particle size distribution of selected organic soils

Grzegorz Straż[1]

Abstract: This paper deals with the problem of determining the particle size distribution of selected organic soils from the vicinity of Rzeszów (Poland), using a laser diffractometer method, the knowledge of which will allow to determine the degree of differentiation or similarity of the tested organic soils in this aspect. The HELOS Laser Diffractometer manufactured by Sympatec GmbH was used for the tests. For proper analysis, the researches results in the form of graphs were grouped according to the content of organic substances in accordance with the standard classification. The conducted research was primarily aimed at presenting the grain differentiation and particle size distribution in terms of the applied method and comparing the test results of samples of selected, different organic soils, prepared using the same dispersion procedure and carried out in exactly the same test conditions, generated using capabilities of a diffractometer. Summing up, the laser diffractometer method presented in the article, although not fully verified in the case of organic soils, seems to be a the perspective method with capabilities allowing it to be nominated as an exceptionally useful method for the investigations of soft soils, including organic soils.

Keywords: laser diffraction, particle size distribution, organic soils, soft soils

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

1. Introduction

In the case of mineral soils, the suitability for geotechnical engineering purposes is determined by the leading parameters, which are most often considered i.e. natural water content and bulk density, as the vast majority of other geotechnical parameters are derived from them. In the case of organic soils [1–3], the dominant parameter is the organic matter content, a substance which may constitute a significant part of the soil skeleton and thus decisively change the properties of a given soil. Therefore, when examining soils classified as organic, they should be considered and analyzed as a monolithic organic-mineral aggregates. In the case of particle size analysis, it is of particular importance, because nowadays most of the analyzes used in this method are performed on samples containing only a mineral skeleton, laboratory devoid of organic parts, soluble salts, carbonates or iron oxides which, however, is not always obligatory depending on the recommended procedures [4]. The obvious and natural consequence of this type of interference is that, the obtained results are far from correct, because the tested soil is completely different from the source soil, both in terms of grain and mineral composition. Especially for soils that are considered organic, this is not the right approach as the organic content has a great influence on both physical and strength properties, which has been repeatedly shown by researchers in their research works [5–12].

The same applies to the determination of the particle size distribution, therefore, new alternative research methods are being sought that would allow the soil sample to be examined in its natural form, without eliminating organic matter [13]. The same applies to analyzing the results of investigations and comparing particle size distribution curves [14]. A proposed in this article method that can be used for this purpose is a laser diffractometer, where the sample can be prepared as a slurry, i.e. a representative sample of organic soil dissolved in distilled water. In the sample prepared in this way, all the components of the soil skeleton are preserved, so it is a reliable research material. The problem is the method of verification this method, because at the moment there are other methods that would fully confirm its usefulness or not. An alternative are standardized tests, which in principle concern mineral soil or soil devoid of humus or organic substances, therefore their reliability is very limited. Unfortunately, the comparison of the results of the research on the grain size composition of mineral soils using the method of laser diffractometry with the classical (sieving and hydrometer) methods [15–17] brings results that are not fully satisfactory [18–21]. Determining the grain size composition of soils containing organic substances is problematic not only in the field of geotechnics, but also in agriculture, where an extensive collection of works has been published on this topic, e.g. [4, 17, 22, 23].

This paper deals with the problem of determining the particle size distribution of selected organic soils from the vicinity of Rzeszów, using a laser diffractometer method, the knowledge of which will allow to determine the degree of differentiation or similarity of the tested organic soils in this aspect,within standard classification groups [1, 2]. The work isn't aimed at comparing the results of the particle size distribution tests with the use of a laser diffractometer with the classical standard methods intended for the testing of mineral soils, because the source materials didn't identify methods with a sufficient degree of suitability, i.e. taking into account both the mineral and the organic part of the skeleton as a result of the research. The conducted research was primarily aimed at presenting the grain differentiation and particle size distribution in terms of the applied method and comparing the test results of samples of selected, different organic soils, prepared using the same dispersion procedure and carried out in exactly the same test conditions, generated using capabilities of a laser diffractometer.

2. Materials and methods

2.1. The characteristic of organic soils

The organic soils are called soft soils, are characterized by extremely unfavourable physical properties and geotechnical parameters (e.g. extremely high water content and compressibility, relatively low strength and low stiffness compared to mineral soils), the determination of which, for the purposes of geotechnical engineering, most often requires the use of non-standard research methods. Due to changing soil and water conditions, biodegradation also takes place of organic matter in soils and mineralization and humification processes of varying intensity over time [5, 24]. However, due to the fact that areas with organic land are very often located in urban agglomerations, where land prices for construction investments are very high, they have become the object of interest of developers and investors, forcing the need for reliable geotechnical investigation necessary for designing and foundations of various types building and engineering structures.

Principles of marking and classifying land for purposes in the standard simplify the distinction between organic soils, dividing them into [1, 2]:

- low-organic – containing from 2% to 6% of organic parts,
- medium-organic – containing from 6% to 20% of organic parts,
- highly-organic – containing more than 20% of organic parts,
- peat, gyttja, dy, humus.

In Poland, there is also a more detailed classification presented in the national standard, theoretically withdrawn but still used, according to which we distinguish [3]:

- humus soil – non-rocky soil in which the presence of organic parts resulting from plant vegetation and the presence of microflora and microfauna exceeds 2% of organic parts,
- mud, warp – soils formed as a result of sedimentation mineral and organic substances in the aquatic environment, include from 2% to 30% of parts organic. Depending on the properties, two types of mud are distinguished: sandy with properties of non-cohesive soil and clayey corresponding cohesive soils,
- gyttja – mud with calcium carbonate content exceeding 5%, which can be bound by the soil skeleton, giving it features of rocky ground with a low compressive strength,
- peat – soil formed from dead and undergoing gradual carbonization plant parts, usually containing more than 30% of organic parts,
- brown and stone coal – rocky soils formed as a result of strong carbonization of phytogenic substances.

Unfortunately, standardized methods of soil research in the case of weak soils, including organic ones, are of relatively low usefulness, even for the determination of elementary geotechnical parameters. Therefore, more and more often non-standard methods are used for this purpose, e.g. artificial neural networks, which based on the available and still expanded, local land databases make it possible to predict the value of the searched parameters, and the preliminary results of these analyses carried out by the author are promising for the future, e.g. [25, 26].

2.2. The leading parameters

In the case of the researched organic soils, the leading parameters were adopted and determined:

- investigations the water content w (%) was determined in accordance with the guidelines of the standard PN-EN ISO 17892-1: 2015 [27];
- investigations the bulk density ρ (t/m^3) was determined in accordance with the guidelines of the standard PN-EN ISO 17892-2: 2015 [28];
- investigations the organic matter content LOI_T (%) was based on standard [3] and the results of the research were presented in the paper [29, 30].

2.3. The parameters of classification of the particle size distribution

The main classification parameters in terms of particle size distribution in accordance with the guidelines of the standard [2] are:

– The uniformity coefficient C_U (–) which is defined by the following formula:

$$C_U = \frac{D_{60}}{D_{10}} \tag{2.1}$$

where: D_{60} and D_{10} – the particle sizes such that 60% and 10% of the particles by weight are smaller than those sizes,

– The coefficient of curvature C_C (–) which is defined by the following formula:

$$C_C = \frac{D_{30}^2}{D_{10} D_{60}} \tag{2.2}$$

where: D_{30} and D_{10} and D_{60} – the particle sizes such that 30% and 10% and 60% of the particles by weight are smaller than those sizes.

The values of coefficients (C_U and C_C) provide means for defining the shape of the grading curve and the division can be made according to the term *gap-graded* [2] as presented in Table 1.

These guidelines are mainly used in the case of coarse-grained mineral soil, but it was decided to use them due to the lack of other dedicated organic soil.

Table 1. The shape of grading curve according to standards [2]

Term	Uniformity coefficient (C_U)	Coefficient of curvature (C_C)
Uniformly graded	< 3	< 1
Poorly graded	3 to 6	< 1
Medium graded	6 to 15	< 1
Well graded	> 15	1 to 3
Gap graded	> 15	< 0.5

2.4. The determination of particle size distribution using the laser diffractometer method

In the presented research, the laser diffractometer method, recognized as a standardized method, was used to determine the particle size distribution of organic soils [31–34]. The HELOS Laser Diffractometer manufactured by Sympatec GmbH was used for the tests, which uses light diffraction at the interface of the particle as measurement principle. Its greatest advantage is the possibility of testing the grain size distribution on samples prepared with minimal interference in the form of a soil-water suspension with full mineral-organic composition and the use of various dispersion methods, including the use of ultrasound. The optical system used in this diffractometer is schematically shown in Figure 1.

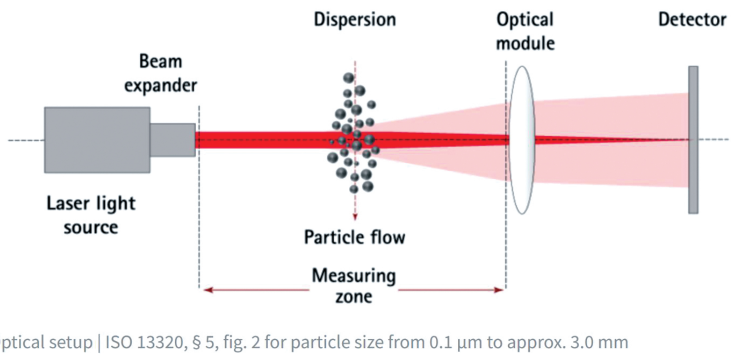

Fig. 1. The optical system used in the HELOS Laser Diffractometer [31]

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, how the diffractometer used for the research stand out from other devices has been operating on the market (Figure 2).

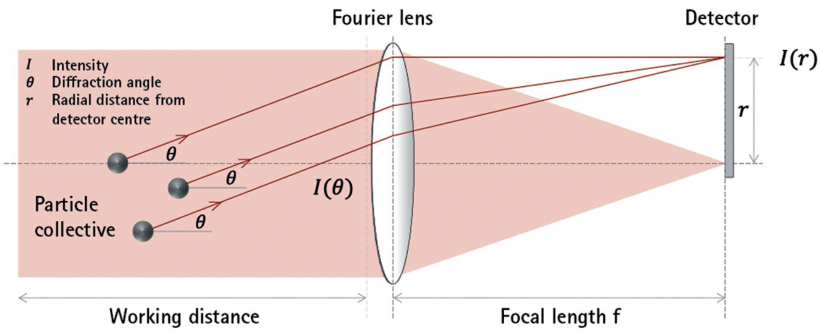

Fig. 2. The Laser Diffraction witch parallel laser beam and large working zone [33]

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) [32, 33].

2.5. The samples and their preparation

The organic soils are located at various depths, from subsurface zones to deeply located layers. They are very often accompanied by a high level of the groundwater table, which, combined with high compressibility, makes obtaining representative samples for laboratory tests very difficult and sometimes even impossible. It was so in the case of the presented research, for which 7 different locations and 12 layers in Rzeszów and its vicinity were selected. The priority was to obtain samples with an intact structure. Unfortunately, due to the immediate vicinity of groundwater, it was not always possible, therefore samples with natural moisture and grain size were also used. Ultimately, samples of 12 different of organic soils were qualified for the research; their characteristics is presented in Table 2.

The determination of the grain composition of organic soils is not covered by the standard test procedure due to their specific structure, because in fact they are not soil grains in the sense of mineral soils, but mineral-organic conglomerates, therefore the granulometric analyses were performed using laser diffraction analysis.

The priority was to investigate the grain size of organic soil samples as a monolithic, without removing organic matter, which was possible only with a laser diffractometer. In this case, the pre-preparation of samples in lab was relatively simple, because a representative part was separated from the soil material, which was dried to air-dry condition. Next, 20 g of dry organic soils from each location was collected from the dried material. The dried samples (without grinding) were poured over with distilled water and the suspension was

Table 2. The basic properties of selected organic soils from different study areas

Sample No.	Location	Soil	Organic content (%)	Water content (%)	Bulk density (t/m^3)
1	Rzeszow 1	medium-organic	6.95	25.11	1.70
2	Rzeszow 1	high-organic	65.89	250.07	1.08
3	Iskrzynia	low-organic	4.35	25.51	1.96
4	Rzeszow 2	low-organic	5.73	22.37	1.98
5	Rzeszow 2	high-organic	84.14	322.58	1.22
6	Rzeszow 2	high-organic	33.79	87.66	1.21
7	Rzeszow 2	medium-organic	19.64	69.59	1.67
8	Rzeszow 3	medium-organic	13.1	58.24	1.61
9	Rzeszow 3	medium-organic	8.92	81.90	1.45
10	Czarna	medium-organic	7.71	24.49	2.00
11	Mielec	high-organic	48.71	70.12	1.59
12	Rzeszów 4	high-organic	70.84	325.84	1.13

boiled until the sample disintegrated. After cooling, the suspension was poured into 100ml samplers and optionally topped up with distilled water.

The samples prepared in this way were tested in HELOS Laser Diffractometer with QUIXEL dispersant in the wet dispersion system. Immediately prior to the measurement procedure, each sample was thoroughly mixed before taking a representative sample. After pouring water into the dispersion attachment, a reference measurement was carried out on several lenses (the so-called reference measurement), because most of the measurements were combined, i.e. they consisted of 2 ranges, that is two optical modules were utilized: R3 (focal length 100 mm), R5 (focal length 500 mm) or R7 (focal length 2 mm) depend on situation [34]. Detailed measurement conditions are presented in Table 3.

The samples of organic soils for laser analysis were taken with a pipette (about 8–15 ml depending on the sample). Then, this sample was sent to the pool in the QUIXEL dispersion attachment (high water level in the pool – i.e. 1000 ml). The sample volume added to the pool depended on the optical concentration, which was read on an ongoing basis in the program. The optical concentration before the start of the measurement was about 17–20%. Then, after clicking the start button in the program, the measurement was triggered and the ultrasounds preceding it (30 s) to separate the particles from each other, then a 30 s pause and a 30 s measurement. If, after measuring with one lens, it was noticed that the test was outside the measuring range, the lens was changed and the measurement was repeated under identical test conditions, i.e. with the same pool content and without repeating the ultrasound.

Table 3. The detailed measurement conditions using a laser diffractometer

System	
Instrument Software	HELOS (H3324) & QUIXEL, R3+R7 PAQXOS 5.1.1
Dispersing method	
Dispersant	water
Cuvette size	2 mm
Fill level	High
Temperature	20°C
Sonication	60 s at 100% power, 30 s pause
Pump speed	1000 rpm

3. Results and discussion

The results of investigations grain size by the HELOS Laser Diffractometer are illustrated in the graphs as Figure 3–14, as particle size distribution: Cumulative Distribution (red line) and Standard Deviation (green line). Their main goal was to present the differentiation of “grain” size (aggregates) depending on the content of organic parts in the soil.

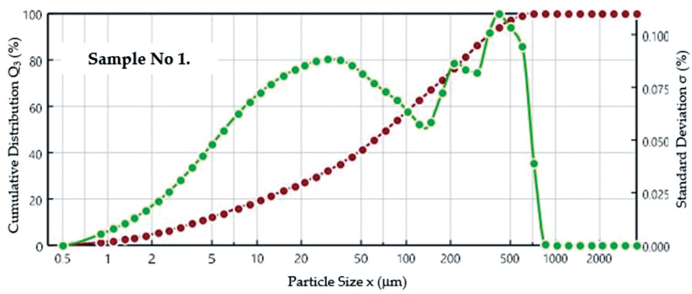

Fig. 3. The cumulative particle size distribution with standard deviation for sample No. 1

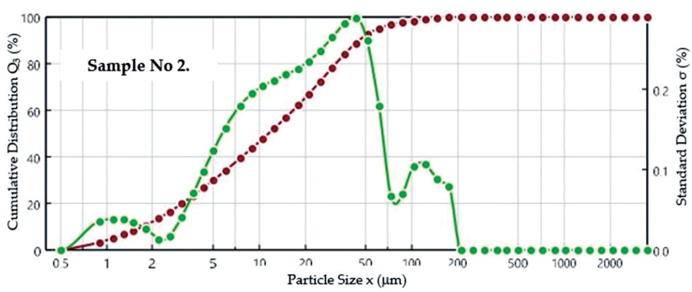

Fig. 4. The cumulative particle size distribution with standard deviation for sample No. 2

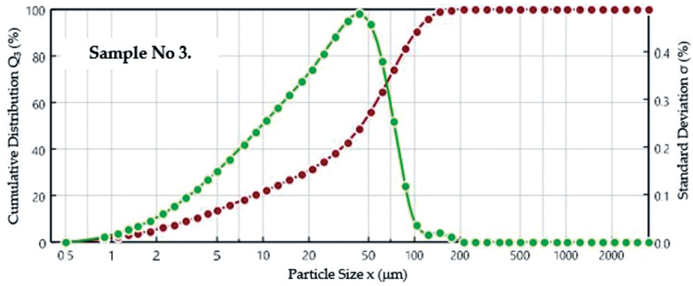

Fig. 5. The cumulative particle size distribution with standard deviation for sample No. 3

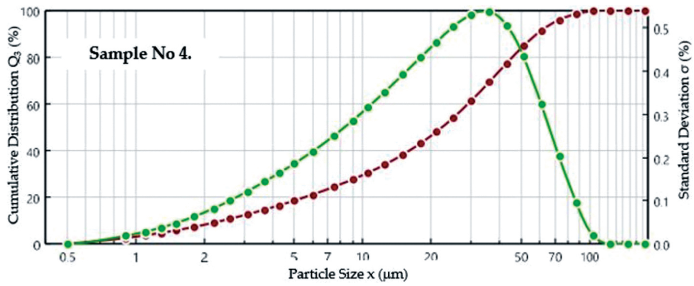

Fig. 6. The cumulative particle size distribution with standard deviation for sample No. 4

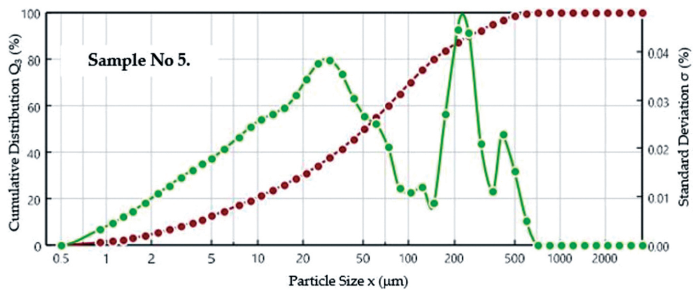

Fig. 7. The cumulative particle size distribution with standard deviation for sample No. 5

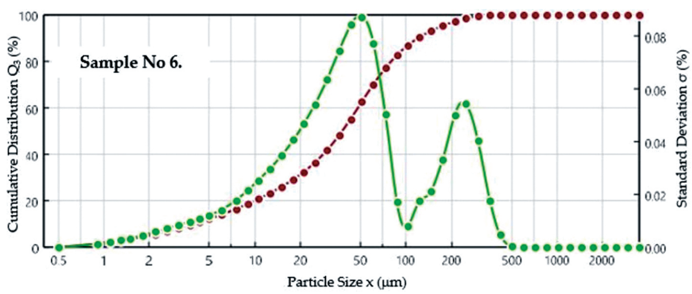

Fig. 8. The cumulative particle size distribution with standard deviation for sample No. 6

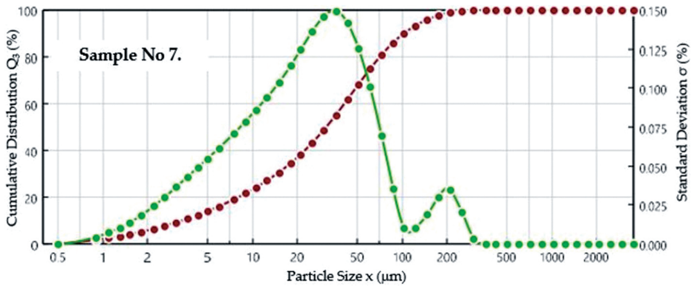

Fig. 9. The cumulative particle size distribution with standard deviation for sample No. 7

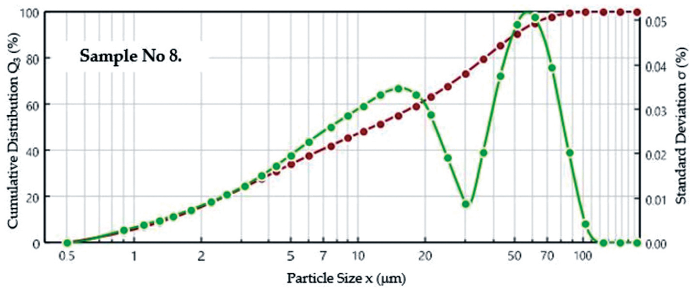

Fig. 10. The cumulative particle size distribution with standard deviation for sample No. 8

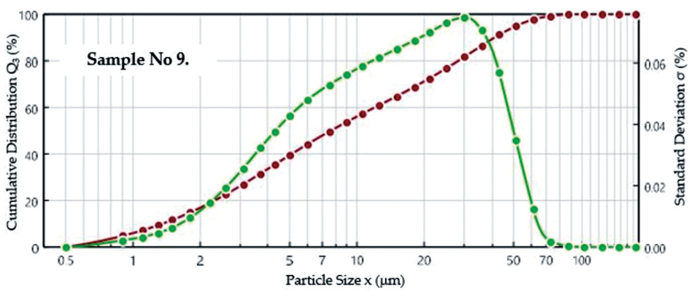

Fig. 11. The cumulative particle size distribution with standard deviation for sample No. 9

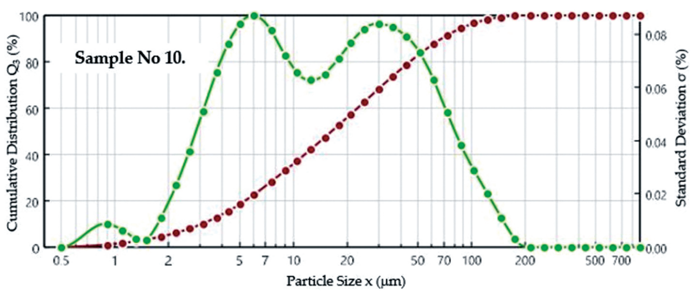

Fig. 12. The cumulative particle size distribution with standard deviation for sample No. 10

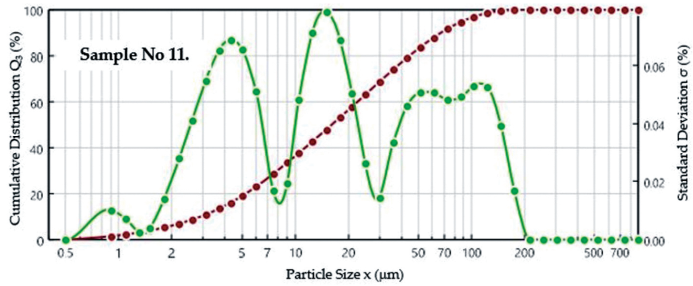

Fig. 13. The cumulative particle size distribution with standard deviation for sample No. 11

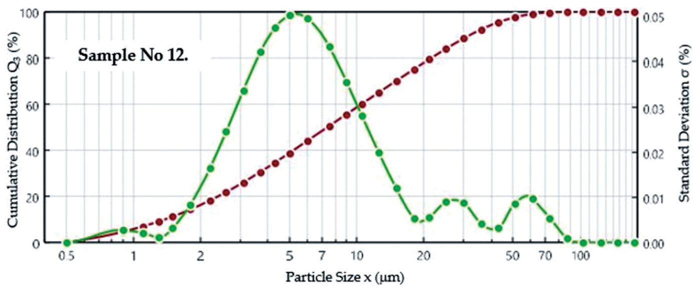

Fig. 14. The cumulative particle size distribution with standard deviation for sample No. 12

The data of interest to us was in the form of Particle Size (µm) marked on the abscissa (horizontal) axis, while the Cumulative Distribution (%) and Standard Deviation (%) are located on the ordinate axis.

When interpreting the diagrams, it should be remembered that the greater is the value of the Standard Deviation, the more the observed values are away from the mean value and, similarly, the smaller the standard deviation value, the more they are concentrated around the mean value. The largest deviations from the average value in the case of low-organic soils (sample No. 3, 4) were observed only for the grain diameter of approx. 40 µm. In the case of medium-organic soils, the situation was more complicated because the only one diameter with the highest standard deviation observed in each of the graphs (sample No. 1,7–10) was 30 µm. The other values were very differentiated in the range from 1 µm to 400 µm. In the standard deviation graphs prepared for highly organic soils (sample No. 2, 5, 6, 11, 12), it was not possible to distinguish the values common to all the graphs. Large variations from the average value occurred in principle in the entire range of grain diameters, and most often in the range of 1–60 µm, although they also occurred for diameters of about 100 µm, 200 µm or 400 µm.

For proper analysis, the researches results in the form of graphs were grouped according to the content of organic substances in accordance with the standard classification [2]. Figure 15 shows the particle size distribution curves of the tested low-organic soils (sample No. 3, 4), Figure 16 – medium-organic (sample No. 1, 7–10) and Figure 17 high-organic (sample No. 2, 5, 6, 11, 12).

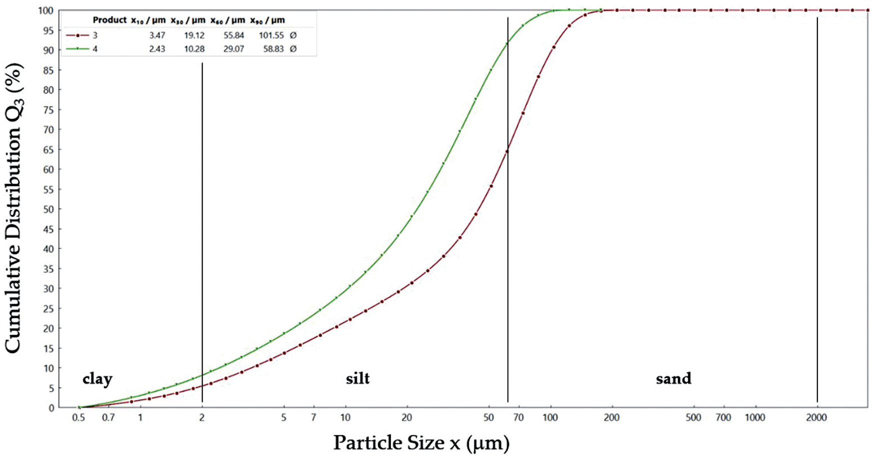

Fig. 15. The particle size cumulative distribution density for low-organic soils (sample No. 3, 4)

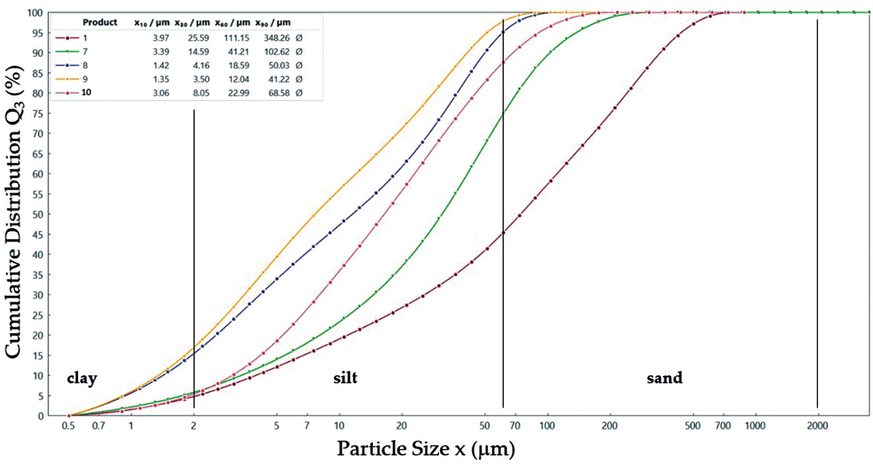

Fig. 16. The particle size cumulative distribution density for medium-organic soils (sample No. 1, 7–10)

In the case of the tested two low-organic soils containing from 4.35% to 7.73% of organic substances, the content of particles corresponding to the size of clays particles is in the range of 2% to 6%, silts from 59% to 84% and sands from 8% to 18%. The medium-organic soils, representing five locations, with the content of organic parts from 7.71% to 19.64%, were characterized by the content of particles corresponding to the size of clays from 5% to 18%, silts from 41% to 80% and sands from 2% to 54%. The last group consisted of five high-organic soils (peats) containing from 33.79% to 84.14% of organic parts. Due to the size of grains, particles classified as clays accounted for 5%

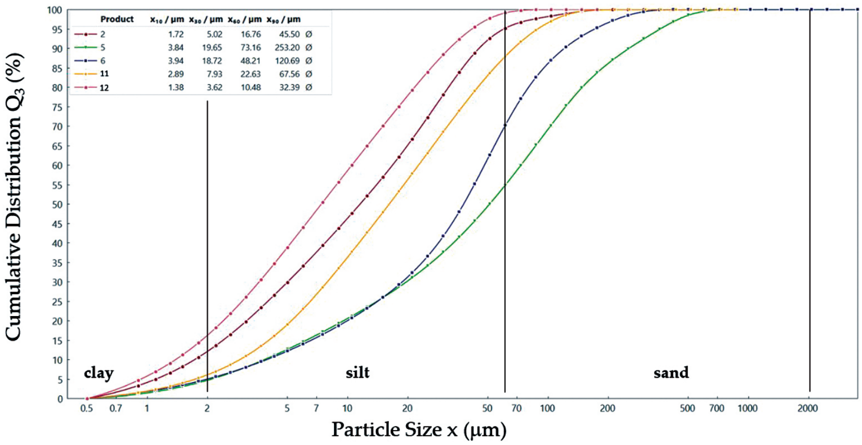

Fig. 17. The particle size cumulative distribution density for high-organic soils (sample No. 2, 5, 6, 11, 12)

to 17%, silts from 50% to 82% and sands from 1% to 45%. The analysis of the graphs (Figure 15–17) showed that the grain size composition, in the case of all the investigated soils, was definitely dominated by particles with a size corresponding to the silty fraction. The content of the clay fraction was almost identical in medium- and high-organic soils, while particles corresponding to the size of the sand fraction were dispersed almost in the entire range of the dedicated grain size range, depending on the case.

In determining the fraction from the cumulative distribution, uniformly, poorly, medium, well and gap graded particle size distributions can be distinguished. According to the standard [2], this division should be used for mineral coarse-grained soils, but due to the lack of other guidelines dedicated to organic soils, it was used for the purposes of this research. The results of examining the grain composition of selected organic soils using a laser diffractometer, the result in the form of graphs (cumulative curves) were grouped according to the content of organic substances: low-organic (Figure 15), medium-organic (Figure 16) and high-organic (Figure 17).

Based on the coefficient of curvature (C_C) and the uniformity coefficient (C_U) also specified the shape of the grading curve. The results are presented in Table 4.

Taking into account both factors (C_C, C_U), the tested low-organic soils (No. 3, 4) were classified as good and medium-grained; medium-organic soils (No. 1, 8, 9, 10) were classified mainly as medium-grained and medium-organic soils (No. 2, 5, 11, 12) were also classified mainly as medium-grained. One sample of medium-organic (No. 7) and one high-organic soil (No. 6) could not be classified using two coefficients simultaneously, which often happens, because standard classification guidelines are sometimes contradictory in this respect.

In the further part of the work, the graphically illustrated results of the research with a laser diffractometer in the form of graphs of the dependence of Distribution Density on the Particle Size were additionally analysed. The Figures 18–20 show the density distribution

Table 4. The shape of grading curve according to standard [2]

Sample No.	C_U (–)	C_C (–)	Shape
1	28.00	1.48	well
2	9.74	8.87	medium
3	16.09	1.34	well
4	11.96	1.50	medium
5	19.05	1.37	well
6	12.24	1.84	–*
7	12.16	1.52	–*
8	13.09	0.66	medium
9	8.92	0.75	medium
10	7.51	0.92	medium
11	7.83	0.96	medium
12	7.59	0.91	medium

*The sample could not be classified using two coefficients simultaneously

diagrams, on the basis of which it is possible to estimate the possibility of the occurrence of different values of the variable (Particle Size), i.e. which of the observed values are observed more often and which less frequently.

In the case of the tested low-organic soils (Figure 18), the observed graphs were unimodal with similar dominant grain sizes, i.e. 40 µm and 70 µm.

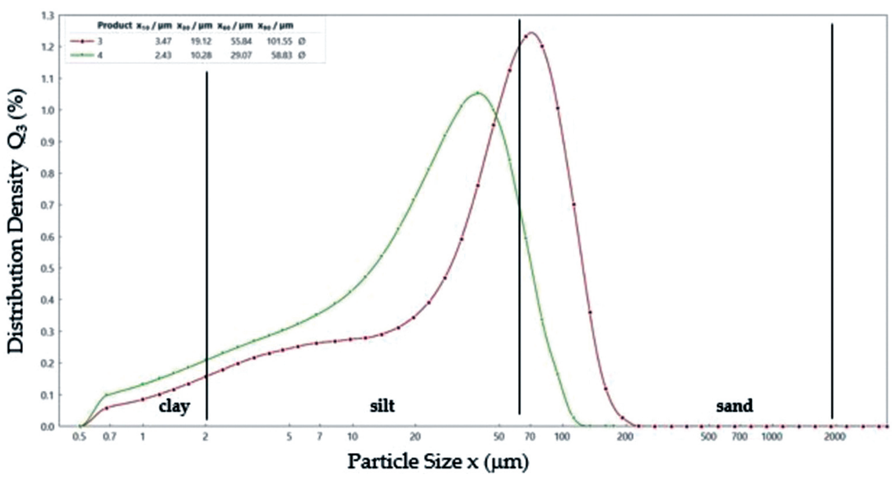

Fig. 18. The particle size Distribution Density for low-organic soils

Analyzing the results of the medium-organic soils (Figure 19), the presence of both unimodal and bimodal charts was found. The maximum values of the dominant particle size were mainly concentrated around the two values 4 µm and 45 µm.

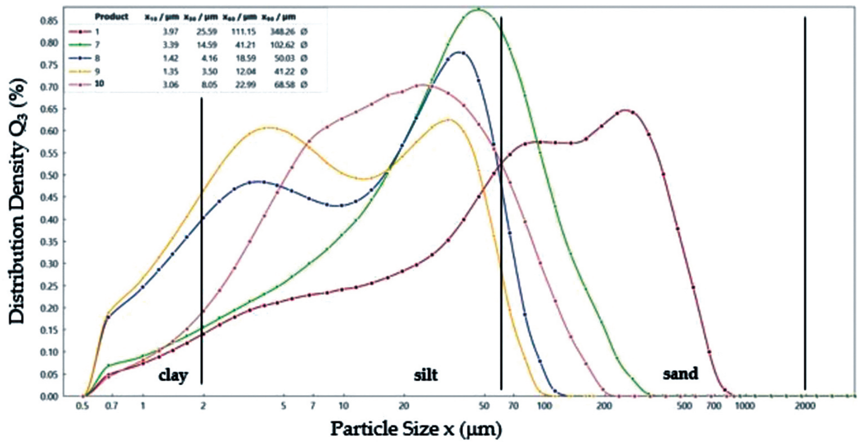

Fig. 19. The particle size Distribution Density for medium-organic soils

The density charts prepared for highly organic soils (Figure 20) were only unimodal, but with a wide range of dominant values: 7 µm, 30 µm, 50 µm and 100 µm, which would confirm the greatest diversity of the research material due to the presence of both mineral and organic particles with varying degrees of decomposition and mineral-organic hybrids.

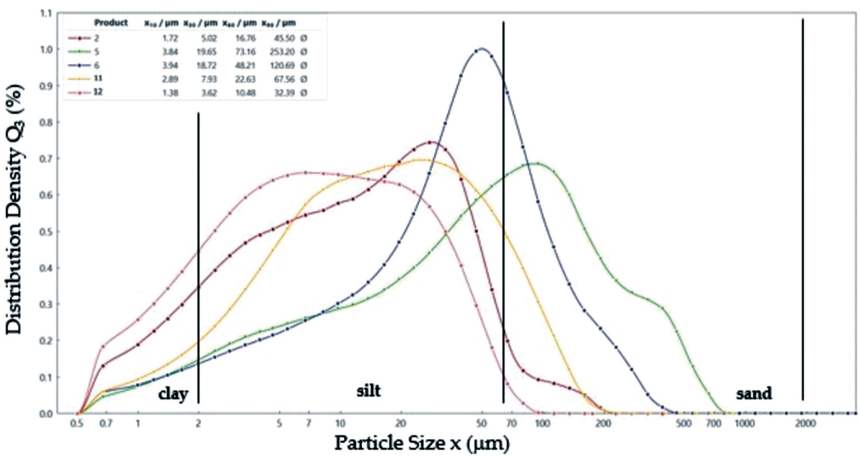

Fig. 20. The particle size Distribution Density for high-organic soils

As a complement with reference to the conducted research on the particle size composition, the separated fractions as well as the shape of the charts (Figure 19 and 20 it was found that the average content of particles corresponding to the size of the silt fraction for all tested types of organic soils was not less than 70%, and the value of the skewness index for this fraction proves the dominance of the value above the average. In the case of particles corresponding to the size of the clay fraction, estimated at about 12%, the skewness index value indicates that for the analysed samples, the content of the clay fraction was usually below the average. For medium and highly organic soils, the content of the clay fraction was at a similar level. In the case of low organic soils, the average content of the clay fraction is approx. 7%, while a wide range of particles of the dominant silt fraction was observed, from 58% to 81%. The particles are complemented with the standard size of the sands.

4. Conclusions

Although the publication resources concerning the determination of the grain size composition of both organic soils considered in the geotechnical aspect and the agricultural aspect are significant, at the moment no method has been defined that would be considered fully reliable. The difficulty of these studies is due to the fact that the skeleton of organic soil contains particles, conventionally called grains, which can be mineral, organic and mineral-organic complexes. Considerable diversification of grains, especially mineral-organic grains in terms of their mineral composition, type of organic substances or the degree of their decomposition, generates different strengths that bind the mineral with the organic parts. This is of particular importance in the process of preparing organic soil samples for testing, which is extremely susceptible to damage or even destruction. The laser diffractometer method presented in the work corresponds to the needs of contemporary research methods. Its greatest advantage is the ability to test samples without subjecting them to the processes of removing organic substances from the soil skeleton: testing the real soil material in the form of a source, i.e. actually present in the deposit. Significant advantages of the laser diffractometer method are also the uncomplicated process of preparing samples for testing, exceptionally short testing time, the possibility of repeating the test on the same sample by modifying the test parameters and to choose different dispersion methods, as well as a clear and flexible form for presenting the results.

Summing up, the laser diffractometer method presented in the article, although not fully verified in the case of organic soils, seems to be a the perspective method with capabilities allowing it to be nominated as an exceptionally useful method for the researches of soft soils, including organic soils. In order to meet these needs, the author, by continuing the presented research with the use of a diffractometer, will attempt to establish a reliable method of their verification for the most useful for geotechnical engineering applications.

Acknowledgements

Author is grateful to Atest Ltd. company representative of Sympatec GmbH for help in particle size researches with the use of a laser diffractometer.

References

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

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

[3] PN-B-04481: 1998 Building Soils. Laboratory Tests. Poland, 1998.

[4] M. Ryżak and A. Bieganowski, "Determination of particle size distribution of soil using laser diffraction – comparison with aerometric method", *International Agrophysics*, vol. 24, no. 2, pp. 177–181, 2010.

[5] E. Myślińska, *Organic soils and laboratory methods of their testing*. Warszawa: PWN, 2001.

[6] A. Puppala, S. Pokala, N. Intharasombat, and R. Williammee, "Effects of organic matter on physical, strength and volume change properties of compost amended expansive clay", *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 133, pp. 1449–1461, 2006.

[7] R. Varghese, S. Chandrakaran, and K. Rangaswamy, "Effect of organic content on geotechnical properties of bentonite clay", presented at Indian Geotechnical Conference IGC2016, 15-17 December 2016, IIT Madras, Chennai, India.

[8] H. Malkawi, A. Alawneh, and T. Osama, "Effects of organic matter on the physical and the physicochemical properties of an illitic soil", *Applied Clay Science*, vol. 14, no. 5-6, pp. 257–278, 1999, doi: 10.1016/S0169-1317(99)00003-4.

[9] M. Olgun and M. Yıldız, "Effect of organic fluids on the geotechnical behavior of a highly plastic clayey soil", *Applied Clay Science*, vol. 48, no. 4, pp. 615–621, 2010, doi: 10.1016/j.clay.2010.03.015.

[10] L. Zeng, Z. Hong, C. Wang, and Z. Yang, "Experimental study on physical properties of clays with organic matter soluble and insoluble in water", *Applied Clay Science*, vol. 132-133, pp. 660–667, 2016, doi: 10.1016/j.clay.2016.08.018.

[11] E. Ekwue, "Organic-matter effects on soil strength properties", *Soil and Tillage Research*, vol. 16, no. 3, pp. 289–297, 1990, doi: 10.1016/0167-1987(90)90102-J.

[12] G. Kacprzak, P. Pietrzykowski, and Ź. Veinović "Liquid consistency of organic soils under the bridge construction", *Archives of Civil Engineering*, vol. 67, no. 2, pp. 181–194, 2021, doi: 10.24425/ace.2021.137162.

[13] E. Shein, E. Milanovskii, and A. Molov, "The effect of organic matter on the difference between particle-size distribution data obtained by the sedimentometric and laser diffraction methods", *Eurasian Soil Science*, vol. 39, supll. 1, pp. 84–90, 2006, doi: 10.1134/S106422930613014X.

[14] L. Oprychał, R. Chmielewski, and A. Bąk "Liquid New method for comparing of particle-size distribution curves", *Archives of Civil Engineering*, vol. 68, no. 1, pp. 63–72, 2022, doi: 10.24425/ace.2022.140156.

[15] ISO 11277: 2009 Soil quality – Determination of particle size distribution in mineral soil material – Method by sieving and sedimentation. Switzerland, 2009.

[16] PN-EN ISO 17892-4: 2017 Geotechnical investigation and testing – Laboratory testing of soil – Part 4: Determination of particle size distribution. Poland, 2017.

[17] M. Ryżak, P. Bartmiński, and A. Bieganowski, "The methods for determining the grain size distribution of mineral soils", *Acta Agrophysica*, vol. 4, no. 175, pp. 1–84, 2009.

[18] G. Eshel, G. Levy, U. Mingelgrin, and M. Singer, "Critical evaluation of the use of laser diffraction for particle-size distribution analysis", *Soil Science Society of America*, vol. 68, pp. 736–743, 2004.

[19] M. Konert and J. Vandenberghe, "Comparison of laser grain size analysis with pipette and sieve analysis: A solution for the underestimation of clay fraction", *Sedimentology*, vol. 44, pp. 523–535, 1997.

[20] A. Gorączko and S. Topoliński, "Particle size distribution of natural clayey soils: a discussion on the use Laser Diffraction Analysis (LDA)", *Geosciences*, vol. 10, no. 2, 2020, doi: 10.3390/geosciences10020055.

[21] C. Keck and R. Muller, "Size analysis of submicron particles by laser diffractometry – 90% of the published measurements are false", *International Journal of Pharmaceutics*, vol. 355, pp. 150–163, 2008, doi: 10.1016/j.ijpharm.2007.12.004.

[22] D. Płoskonka, "Differences in results of grain-size analysis made by various methods", *Landform Analysis*, vol. 12, pp. 79–85, 2010.

[23] H. Traubner, B. Roth, and R. Tippkotter, "Determination of soil texture: Comparison of sedimentation method and laser-diffraction analysis", *Journal of Plant Nutrition and Soil Science*, vol. 172, pp. 161–171, 2009.

[24] A. Smagin, N. Sadovnikova, V. Vasenev, and M. Smgina, "Biodegradation of some organic materials in soils and soil constructions: experiments, modeling and prevention", *Materials*, vol. 11, no. 10, art. no. 1889, 2018, doi: 10.3390/ma11101889.

[25] G. Straż and A. Borowiec, "Estimating the unit weight of local organic soils from laboratory tests using Artificial Neural Networks", *Applied Sciences*, vol. 10, no. 7, art. no. 2261, 2020, doi: 10.3390/app10072261.

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

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

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

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

[30] 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*, vol. 25, no. 3, pp. 264–276, 2016.

[31] ISO 13320: 2020-01 Particle size analysis – Laser diffraction methods. Switzerland, 2020.

[32] Sympatec GmbH, "HELOS: HELOS/BR + HELOS/L + VIBRI/L". [Online]. Available: https://www.sympatec.com/en/particle-measurement/sensors/laser-diffraction/helos/. [Accessed: 09 June 2022].

[33] Atest Ltd., "Particle Size and Shape Analysis in Pharmaceutical R&D and Quality Control", PM Tour 2019/2020, Krakow, 2020. [Online]. Available: https://www.atest.pl/. [Accessed: 09 June 2022].

[34] G. Straż, "The effect of methodology on determining the liquid limits values of selected organic soils", *Archives of Civil Engineering*, vol. 68, no. 1, pp. 459–477, 2022, doi: 10.24425/ace.2022.140180.

Wykorzystanie dyfraktometru laserowego do analizy uziarnienia wybranych gruntów organicznych

Słowa kluczowe: słabonośne, analiza granulometryczna, dyfraktometr laserowy, grunty organiczne, grunty słabonośne

Streszczenie:

W niniejszej pracy zaprezentowano wyniki analizy granulometrycznej 12 próbek wybranych gruntów organicznych pochodzących z okolic Rzeszowa. Grunty te, ze względu na ich cechy charakterystyczne, zaliczane są do gruntów słabonośnych, charakteryzujących się w stosunku do gruntów mineralnych, głównie niewielką wytrzymałością oraz małą sztywnością. Pomimo tych niekorzystnych właściwości obecnie grunty te znajdują się w obszarze zainteresowań inżynierii geotechnicznej z powodu coraz częstszego ich lokalizowania na terenach będących obiektem zainteresowania inwestorów. Posadowienie obiektów budowlanych czy konstrukcji inżynierskich na terenach, gdzie zalegają grunty słabonośne, w tym organiczne, jest wyjątkowo skomplikowane, pracochłonne i kosztowne a kluczem do bezpiecznego posadowienia jest prawidłowe określenie ich właściwości i parametrów geotechnicznych, a określenie składu ziarnowego jest jednym z podstawowych badań geotechnicznych. Niestety, na chwilę obecną nie opracowano dedykowanej metody, która byłaby w pełni wiarygodna w przypadku badań granulometrycznych gruntów organicznych. Opracowania naukowe w tym zakresie, najczęściej obejmują badania mineralnej części szkieletu gruntowego, które w warunkach laboratoryjnych zostały pozbawione materii organicznej, a to przede wszystkim ona

decyduje o właściwościach gruntu organicznego. Skutkiem takiego modyfikowania próbek do badań jest fakt, że próbki te różnią się od naturalnego materiału pozyskanego ze złoża i oczywistym jest, że charakteryzują się zupełnie różnymi właściwościami. Wyników tych obydwu badań nie można bezpośrednio porównywać, mimo, że materiałem bazowym do badań granulometrycznych był ten sam grunt organiczny. Dlatego planując badania zaprezentowane w niniejszym opracowaniu, przyjęto że zostaną one przeprowadzone na próbkach gruntów organicznych o kompletnym szkielecie gruntowym, bez rozdzielania materiału badawczego na cześć mineralną i organiczną. Założono, że oznaczane i porównywane będą agregaty organiczno-mineralne, umownie nazywając je cząstkami lub ziarnami. Z uwagi na specyficzną budowę i skład szkieletu gruntów organicznych, metody uważane za typowe w zakresie analizy granulometrycznej (analiza areometryczna, sitowa), nie mogły być zastosowane w tym przypadku. Po przeanalizowaniu zasobów literaturowych założono, że ze współcześnie stosowanych metod najbardziej przydatną może okazać się metoda dyfraktometru laserowego, w przypadku którego ingerencja w zmiany materiału badawczego na etapie przygotowań do testów jest ograniczona i uproszczona do minimum. W literaturze tematycznej odnotowano liczne przypadki wykorzystania dyfraktometru laserowego do badań gruntów mineralnych. Podjęto próbę sprawdzenia czy wybrana metoda może być przydatna w przypadku badań gruntów organicznych. Prowadzone badania miały na celu przede wszystkim zaprezentowanie zróżnicowania i rozkładu uziarnienia w aspekcie zastosowanej metody (dyfrakcja laserowa) oraz porównanie wyników badań próbek wybranych, różnych gruntów organicznych, przygotowanych tą samą procedurą dyspergowania i przeprowadzonych w dokładnie takich samych warunkach badawczych, generowanych z wykorzystaniem możliwości dyfraktometru. Wyniki badań gruntów organicznych pogrupowano zgodnie z sugerowaną klasyfikacją normową w zależności od zawartości części organicznych i zobrazowano na odpowiednich wykresach oraz opisano w tekście. Na podstawie analizy uzyskanych wyników, stwierdzono, że zaproponowana metoda dyfraktometru laserowego, wydaje się być metodą przydatną i perspektywiczną w zakresie oznaczania składu ziarnowego gruntów organicznych, a jej niebagatelną zaletą jest łatwy i szybki sposób przygotowania materiału badawczego. Należy jednak zaznaczyć, że wg dostępnych materiałów źródłowych na chwilę obecną nie opracowano alternatywnej metody badania gruntów organicznych, która umożliwiłaby jej pełną weryfikację. Autor kontynuuje badania własne w tym zakresie.

Received: 2022-11-27, Revised: 2023-03-15