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THE INFLUENCE OF DISPERSING AGENTS ON SOIL PARTICLE SIZE ANALYSIS

BY

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Abstract. This article explores soil classification methods and the influence of using dispersing agents in various amounts for the soil particle size analysis. Laboratory testing with different dispersing agents was conducted to analyze the effects of sodium hexametaphosphate and lithium carbonate for two different soils with plasticity indices indicating one to be with low plasticity (PI = 8.23 %) and the other one with high plasticity (PI = 39 %). The article highlights differences in the granulometric fractions reported for each soil and usage of the same dispersing agent but in various amount. Thus, the classification of soils is influenced by the amount of the used dispersing agents, recommendations of standards being different in time and countries. These findings contribute to a better understanding of the anticipated behavior of fine soils and provide useful insights for various geotechnical applications.

Keywords: Soil classification, Dispersing agents, Particle size distribution, Plasticity index, Hydrometer analysis.

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1. Introduction

The foundation soils on which a building is built have a significant influence on the structural integrity of the building. The soil serves two main roles in relation to buildings: it acts as a construction material and as a support structure. As a construction material, the soil can be used to make bricks, concrete, mortar, and other components of buildings. As a support structure, the soil provides the base for the foundations of buildings and transfers the loads from the structures to the deeper soil layers. Different types of foundation soils have different properties and behaviour that affect the stability and performance of the structures built on them.

Depending on their degree of consolidation, foundation soils can be classified into two main types: compact rocks and disaggregated rocks, which are also known as soils (Verheye, 2009). Compact rocks are hard and dense rocks that have high strength and stiffness. Disaggregated rocks are loose and soft rocks that have low strength and stiffness. These two types of foundation soils have different characteristics and behaviour under various loading conditions. The classification of foundation soils into compact rocks and disaggregated rocks is important for understanding their behaviour and designing appropriate foundations for different structures. For example, compact rocks can provide a stable and rigid base for heavy structures, while disaggregated rocks may require special treatment or reinforcement to prevent excessive settlement or failure.

The inappropriate classification of foundation soils and a lack of understanding of their anticipated behavior can result in the failure of structures, leading to property damage, financial loss, and loss of human life. Soil classification can be determined using various methods both in the laboratory and in the field. Particle size distribution using the hydrometer analysis can be used to classify the fine soils. But in conducting this test for soil classification, fine soil types have the tendency to agglomerate or form flakes, which can lead to inaccurate results in the analysis. Dispersing agents help to break apart these agglomerates and flakes, allowing for a more accurate determination of the individual particle sizes and the overall mas percentage for the size distribution of soil particles.

This article aims to provide a comprehensive understanding of the methods used for the classification of the soil and the effects of using dispersing agents to break down finer soil particles for the accuracy of the testing methodology. The article will provide an overview of the classification of soils standards, methods for determining the particle size distribution, dispersing agents and a comparative analysis between hydrometer and the pipette methods. The hydrometer analysis for the soil classification is conducted in this study using different dispersing agents and the results are discussed.

1.1. Classification of Soils

The classification of the soils and the description of the rocks must be carried out according to EN ISO 14688-2 and EN ISO 14689-1 respectively. EN ISO 14688-2 is a standard that specifies the basic principles for the soils and rocks characteristics used for the classification of the soils used for engineering purposes. It is intended to be read in conjunction with EN ISO 14688-1, which gives rules for the identification and description of soils. EN ISO 14688-2 is applicable to natural soil in situ, natural soil reworked artificially and synthetic materials. EN ISO 14689-1 is a standard that specifies the principles for the identification and description of rocks based on their mineralogical and petrographic composition and on their structure. It is applicable to natural rock in situ, natural rock reworked artificially and synthetic materials.

Soils can be natural or anthropogenic. Natural soils can be mineral or organic. Mineral soils include carbonate, volcanic, loess and glacial soils. The identification of mineral soils follows these steps: a) classify soils into very coarse, coarse or fine subcategories; b) identify primary, secondary and tertiary fractions based on particle size; c) name the soil according to procedures presented in this article; d) identify the origin of deposits, the depositional environment and of the geological age.

The identification of very coarse and coarse mineral soils must be made on the basis of particle size fractions. The identification of fine soils must be done on the basis of plasticity, even if the particle size distribution has been defined for these soils as well. The elementary soils contain a single particle size fraction. Most soils are mixtures of particles of different sizes consisting of primary fractions, one or more secondary fractions and tertiary fractions.

To accurately identify the composition of a soil, a noun is attributed to the primary fraction (usually written in capital letters) and one or more adjectives (written in lower case), which describe the proportions of secondary and tertiary fractions (e.g., sandy gravel, clay with gravel). The order of the words assigned to the fractions is recommended to be determined by each country, so that the name clearly expresses the primary, secondary and tertiary fractions (ASTM D2487 2000).

1.2. Particle Size Composition

Soil is a complex system that consists of three phases: solid, liquid and gas. The solid phase is made up of different types and sizes of particles, such as clay, silt and sand. The liquid phase is mostly water that fills the spaces between the particles. The gas phase is mostly air that occupies the remaining spaces in the soil above underground water level. The soil as a foundation layer plays a

vital role in supporting various engineering structures, such as buildings, bridges, dams, roads and more. To design and construct these structures safely and efficiently, engineers need to study the soil in detail and prepare geotechnical documentation that describes its properties and behaviour. One of the key properties of soil is its granulometric composition, or how the particles are distributed by size. This can be determined by granulometric analysis, which separates the soil into different fractions based on their size limits.

Even though it is considered approachable, determining the size of soil particles is one of the most uncertain geotechnical procedures. Particle size analysis is the method of breaking down the mineral part of the soil into different fractions and determining their proportions, with a strong influence of the dispersing agents to establish the clay fraction of the investigated soil (Kaur and Fanourakis, 2016).

1.3. Methods for Determining the Size of Soil Particles

The experimental operations differ from one another, with each process or method having a specific field of use that is related to the dimensions of the particles in the composition of the soil. Currently, the following methods are used: (1) sieving method on sieves for soils with particles larger than 2.0 mm and on site for soils with particles larger than 0.063 mm; (2) sedimentation method for soils with particles smaller than 0.063 mm; and (3) combined method (sieving and sedimentation) for polydisperse soils with a wide range of granulation (clayey sand, sandy silt, etc.). Sedimentation analysis is performed either by pipette method or by hydrometer analysis (Arora, 2003).

From an immediate practical perspective, knowledge of the dimensions of the solid fragments that make up soil is useful for identifying and classifying the soil. At the same time, many geotechnical properties of soils such as plasticity, permeability, and strength are closely related to the shape and size of the particles that make it up. Therefore, their knowledge provides a first qualitative indicator of the behaviour of soils. For example, in the case of a soil composed predominantly of coarse particles (gravel, sand), it is expected to be able to take high static loads and have a high permeability (Stanciu, et al. 2016).

1.4. Comparison between the Hydrometer and the Pipette Method

The pipette analysis has several advantages over the hydrometer analysis. It takes less time because the sampling depth is adjustable, while the hydrometer analysis is fixed. At the same time, the calculations are simpler and it is not necessary to take into account the meniscus correction or dilation of the hydrometer. However, compared to the hydrometer, the pipette analysis is less

adapted to the conditions encountered in a field laboratory and requires accurate weight measurement.

Both analyses provide a similar particle size distribution on the curves. This similarity is not surprising since both analyses are based on sedimentation and sample preparation is almost identical. Using similar pre-treatment techniques, pipette and hydrometer methods give comparable results (Liu, et al. 1996). Both pipette and hydrometer methods are used for the calibration of the results using a new technology, the laser diffraction to provide reliability of the clay content of the investigated soil (Lopez et al. 2021).

1.5. Dispersing Agents

The hydrometer method for determining granularity of fine soils is based on the application of Stokes' law, which states that the rate of free fall of particles is directly proportional to the square of the particle diameter. The expression used to determine the particle diameter is based on the determination of the velocity. Therefore, particles must be dispersed to determine the exact size distribution of the particles. However, finer particles carry charges on their surface and thus tend to form flakes. If flake formation is not prevented, the particle diameter would be the diameter of the flakes and not the individual particle (Ranjan and Rao 1991). Therefore, deflocculating agents must be added to the sedimentation analysis.

Dispersing agents can act as a protective colloid on the solid particle or can modify the electrical charge of the particle to prevent flake formation (Sridharan, Jose and Abraham, 1991). Sodium hexametaphosphate, sodium oxalate, and sodium silicate are among the most common dispersing agents. The British standard recommends using 35 g of sodium hexametaphosphate with 7 g of sodium carbonate together with distilled water to make a litre of standard solution, reported also in the research of Emeka A.E. (2015) The Indian Standard Code of Practice (IS 2720-Part IVa) recommends using 33 g of sodium hexametaphosphate with 7 g of sodium carbonate in distilled water to make one litre of standard solution. Both codes recommend using 10 ml of this standard solution for each experiment. The ASTM standard method for particle size analysis (D422-ASTM 1965) suggests using 125 ml of sodium hexametaphosphate solution in distilled water. The influences of the amount of the solid phase, solution using sodium hexametaphosphate and the testing temperature on the soil classification is discussed by Keller and Gee (2006), Gangwar and Baskar (2019), and Abdulkarim et al. (2021).

In the study conducted by Sridharan et al. (1991), the clay fraction obtained from hydrometer analysis ranged from 4% to 45%, depending on the type of dispersing agent added. The study also found that adding a mixture of sodium hexametaphosphate and sodium carbonate resulted in a higher percentage of clay. Sachan, et al. (2008) observed that the largest clay fraction was obtained

due to the added dispersing agent, namely sodium hexametaphosphate. Nettleship, et al. (1997) performed hydrometer analysis using two sodium hexametaphosphate dispersants and a mixture of sodium triphosphate and sodium carbonate (Bindu and Ramabhadran, 2010).

Many substances have been tried as dispersing agents, most of which are useful for most soils. For instance, sodium polyphosphate, sodium hydroxide, sodium sixate, sodium tripolyphosphate, sodium hexametaphosphate, sodium tetraphosphate, sodium oxalate, tannic sodium, starch, sodium carbonate, sodium bicarbonate, trisodium phosphate, tetrasodium etc. For most purposes, sodium hexametaphosphate has been found to be the most suitable and convenient dispersing agent. However, the standard dispersant may not be fully effective for some types of soil. Other dispersing agents used were trisodium phosphate or tetrasodium phosphate but in a solution with a higher concentration (2 or 3 times stronger) (Head, 1980).

Several researchers, including Means & Parcher (1963), Head (1980), Sridharan, et al. (1991), and Bindu & Ramabhadran (2010), have investigated the impact of different dispersing agents on particle size analysis. At present, EN ISO 17892-4/2017 recommends using 100 cm^3 of a solution sodium hexametaphosphate - 40g dissolved in 1000 cm^3 of distilled water, without being limited to this option. When analysing materials with a low plasticity index (PI $\leqslant$ 10%), such as sand, silty sand, clayey sand, and sandy silt, anhydrous lithium carbonate was recommended to be used as the dispersant, while dilute sodium silicate solution serves as the anti-flocculent (according to former Romanian standard - STAS 1913-5/1985, 0.5 g of anhydrous lithium carbonate is added to the sample). In contrast, the same former standard, when analysing materials with a plasticity index (PI > 10%), such as clay, silty clay, and sandy clay, recommended a sodium hexametaphosphate solution as in the present EN ISO 17892-4/2017. This research program considered both dispersing agents, with variable quantities.

1.6. Correction

Meniscus (C_m), temperature (C_T), and dispersant (C_d) corrections are required to properly evaluate hydrometer measurements. The analysis performed by the hydrometer procedure includes not only the corrections listed above, but also corrections due to the geometry and volume of the bulb and the cross-sectional area of the cylinder.

The correction read from the R^Y hydrometer is:

$$R^Y = R + C_m + C_T - C_d \tag{1}$$

where: R is the reading obtained from the scale of the hydrometer above the meniscus.

The immersion of the hydrometer in clear water and the reading made by the meniscus, respectively below it, determine the meniscus correction C_m (Fratta, Aguettant and Roussel-Smith 2007).

2. Materials and Testing Methodology

According to former Romanian standard, STAS 1913-5/1985, an attempt was made to differentiate between two categories of soils based on their plasticity index (PI), specifically soils with PI $\leqslant$ 10% and PI > 10%. The purpose of this classification was to study the influence of the dispersing agent on the percentages of granular fractions of the soils. Laboratory investigations were carried out in accordance with the methodology specified in EN ISO 17892-12/2018 for determining the plasticity limits.

Two distinct soil samples were taken from different locations and tested. The Sample A was taken from an open excavation at a depth of 2 m in Iasi. The Sample B was taken from an excavation in the village of Coada Stâncii from a depth of 1.2 m. The plasticity index was determined for both samples according to EN ISO 17892-12/2018 and is presented in Table 1 below.

Table 1
Plasticity Index for the investigated soils

Sample identification	Plasticity index %
Sample A (Iasi)	39.00
Sample B (Coada Stâncii)	8.23

2.1. Preparation of Dispersing Agents

Sodium hexametaphosphate ($Na_6[(PO_3)_6]$) is delivered in powder form when in its pure state and is used to prepare soil samples according to EN ISO 17892-4/2017. To prepare the solution, 40g of powder is dissolved in 1000 cm^3 of distilled water.

Lithium carbonate (Li_2CO_3) is also in powder form and does not require dissolution in liquid. A dilute sodium silicate solution of 4.4%, density 1.04 g/ cm^3 is added at the time of determination as a stabilizing agent of the dispersed system in addition to the lithium carbonate.

2.2. Samples Preparation

The investigations were conducted on two soil samples using sodium hexametaphosphate and lithium carbonate as dispersing agents and dilute sodium silicate solution as an anti-flocculent. Each soil sample was initially dried in an oven for 24 hours at 105°C. After drying, 15 samples from each type of soil were taken.

The material that was subjected to the analysis was placed in a capsule, and the dispersing agents in different amounts of the solution ($Na_6[(PO_3)_6]$ or mass (Li_2CO_3), were used. Water was added, after which it was left for 24 hours until the material was completely softened. After 24 hours, the material together with the dispersing agent was poured into a graduated cylinder, and the suspension was completed with distilled water up to the division of 1000 cm^3. In addition, for the soil Sample B, the one with PI $\leqslant$ 10%, 5 cm^3 of dilute sodium silicate solution was added to the suspension. When using $Na_6[(PO_3)_6]$, it is not necessary to add a stabilizing agent. The suspension was stirred, and after completion of the homogenization, the hydrometer was introduced and readings were made at time intervals of 30 sec., 1 min., 2 min., 4 min., 8 min., 15 min., 30 min., 60 min., 120 min., 240 min., with the last reading being made at 24 hours.

The number of samples for each test and the amount of dispersing agent used are given in Table 2 for Li_2CO_3 and Table 3 for $Na_6[(PO_3)_6]$.

Table 2

Mass of Li_2CO_3 used in the analysis

No. test	1	2	3	4	5
Li_2CO_3 (g)	2	3	5	6.5	8
No. samples	3	3	3	3	3

Table 3

Amount of solution of $Na_6[(PO_3)_6]$ used in the analysis

No. test	1	2	3	4	5
$Na_6[(PO_3)_6]$ (ml)	40	60	100	130	160
No. samples	3	3	3	3	3

3. Interpretation of Results

3.1. Results obtained using Li_2CO_3 as Dispersant

The purpose of the analysis was to investigate the effect of varying the amounts of Li_2CO_3 on the main granular fractions. The amount of dispersing agent was increased from 2g to 8 g. The granulometric curves obtained from the

first sample (soil Sample A with PI > 10%) for the five different quantities of dispersing agent are presented in Fig. 1.

The percentages of granular fractions are presented graphically in Fig. 2. The predominant fraction for the amount of 2 g of Li_2CO_3 is silt (52.44%). As the amount of dispersing agent increases, the clay fraction begins to become predominant. The maximum point of the clay fraction (53.89%) is obtained at the amount of 5 g Li_2CO_3 (quantity recommended in the former Romanian standard STAS 1913). After this point, with the increase of the amount of dispersing agent, there is a slight decrease to 51.13% of the clay fraction and an increase in silt fraction. Above this amount, the clay fraction begins to grow significantly.

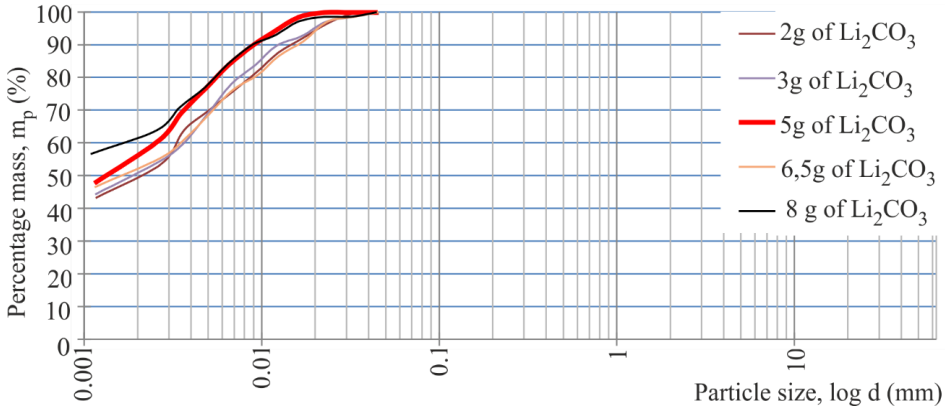


Fig. 1 – Granulometric curves for soil Sample A, with PI > 10%.

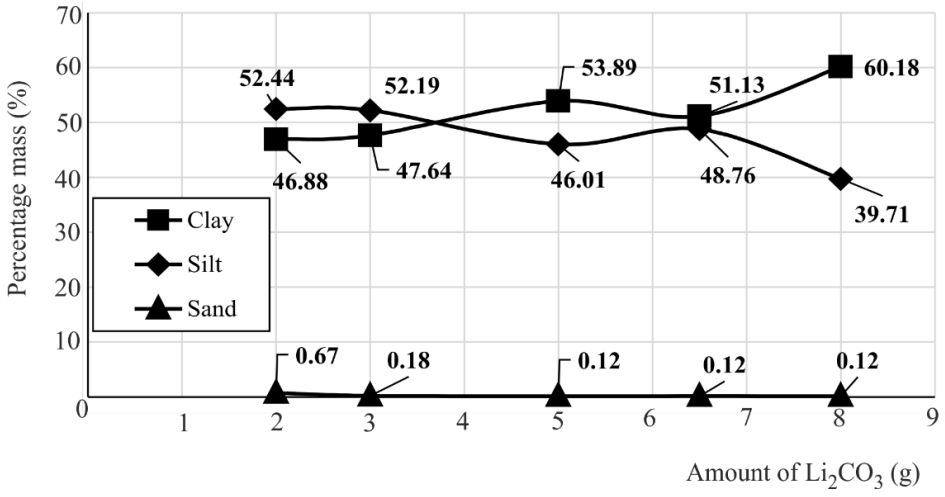


Fig. 2 – The influence of the mass variation of Li_2CO_3 dispersant for soil Sample A, with PI > 10%.

The granulometric curves obtained on the second sample, soil Sample B (soil with PI ⩽ 10%) for the 5 quantities of dispersing agent are presented in Fig. 3.

For the soil Sample B, the predominant fraction for 2 g of Li_2CO_3 is silt, followed by clay (29.82%), as seen in the graph in Fig. 4. For the quantity of 5 g, the minimum value of the silt and clay fractions for a quantity of 6.5 g is not obtained. Instead, the minimum value for the silt fraction and a maximum value for clay are obtained. Increasing the amount of dispersant above this limit leads to an increase in the silt fraction and a decrease in the clay fraction. The sand fraction is not influenced.

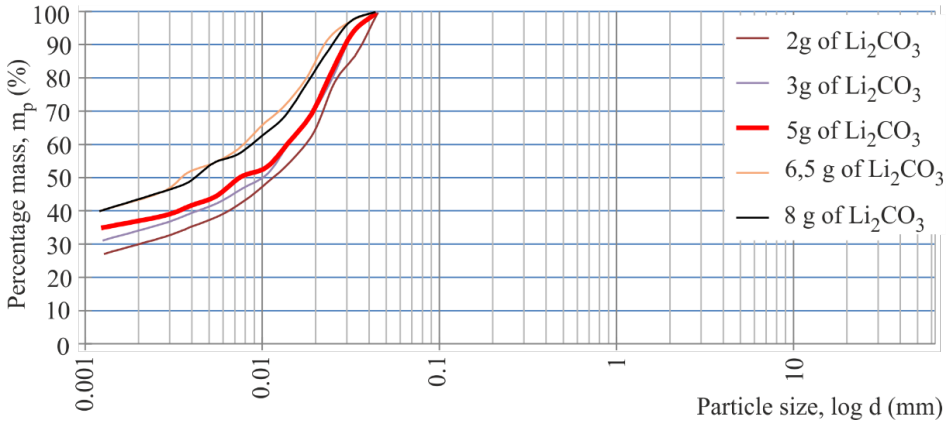


Fig. 3 – Granulometric curves for soil Sample B, with PI ≤ 10%.

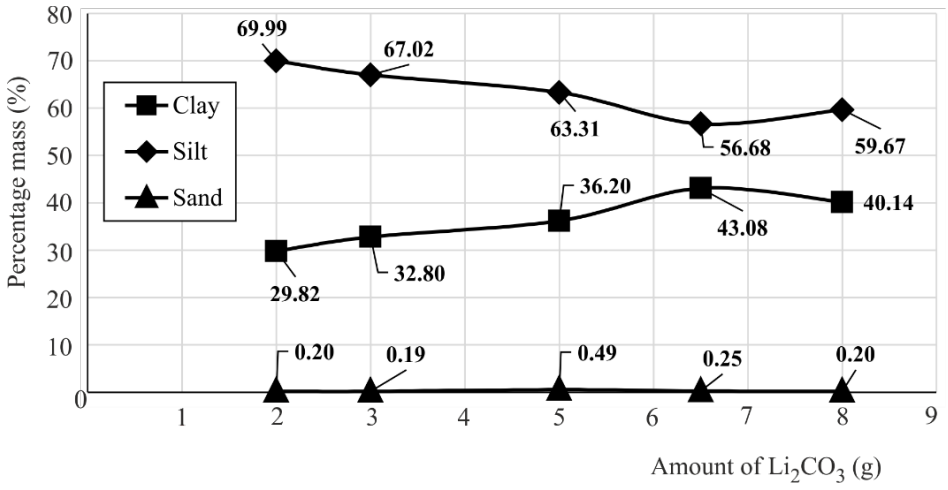


Fig. 4 – The influence of the mass variation of Li_2CO_3 dispersant for soil Sample B, with PI ≤ 10 %.

3.2. Results obtained using $Na_6[(PO_3)_6]$ as Dispersant

The granulometric curves are presented in Fig. 5 for soil Sample A (PI > 10%). The percentages of granulometric fractions are presented graphically in Fig. 6. According to the former Romanian standard, STAS 1913, when using 100 ml of dispersant solution, the clay fraction reaches the maximum point (55.10%). When adding the smallest amount of dispersing solution, it is observed that the fraction of silt (52.49%) is much higher than that of clay (43.42%). It is found that the clay fraction increases with increasing amount of dispersant.

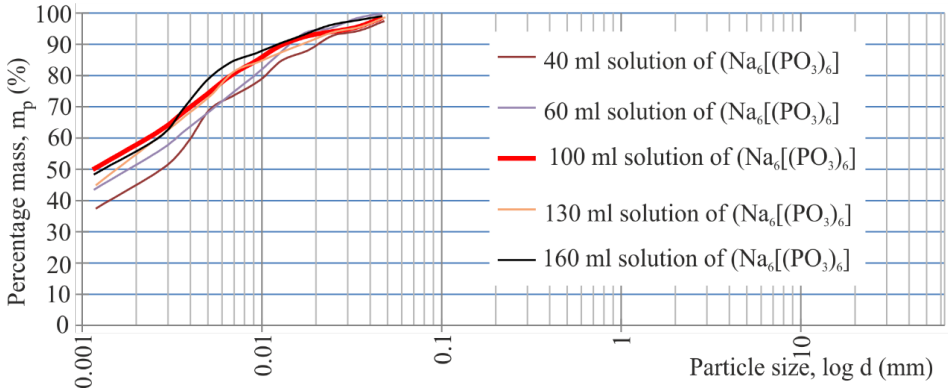


Fig. 5 – Granulometric curves for soil Sample A, with PI > 10%.

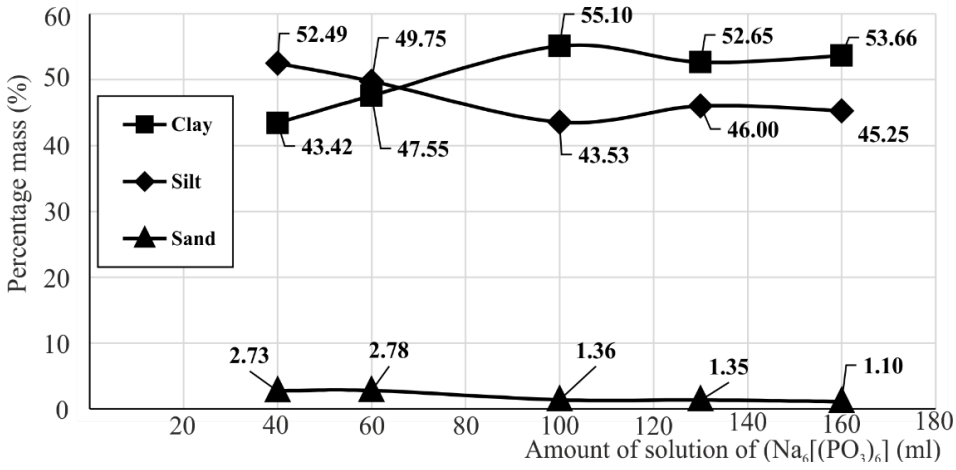


Fig. 6 – The influence of the amount of solution with dispersant $Na_6[(PO_3)_6]$ for soil sample A, with PI > 10%.

For soil Sample B, with PI $\leqslant$ 10%, the granulometric curves are presented in Fig. 7 and the mass percentage of the granulometric fractions are presented in Fig. 8. The silt fraction is predominant regardless of the amount of solution of the dispersing agent.

Increasing the amount of solution of dispersant above the limit (100 ml) leads to a slight increase in the clay fraction and a decrease in the silt fraction, but this change is insignificant.

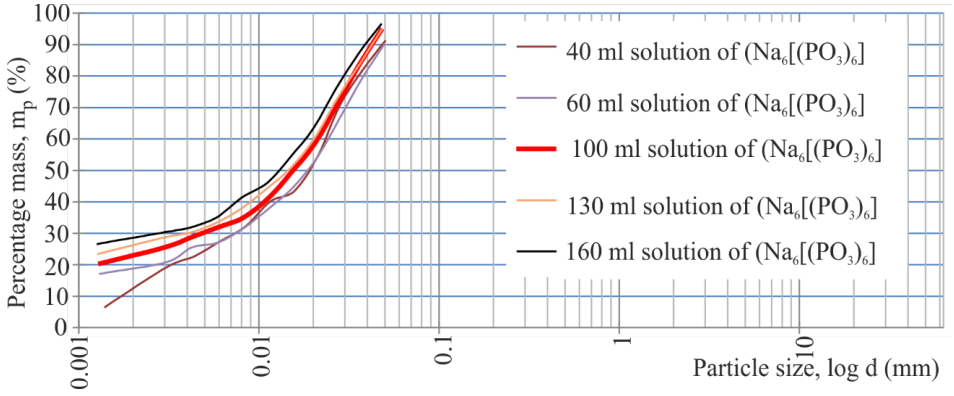


Fig. 7 – Granulometric curves for soil Sample B, with PI ≤ 10 %.

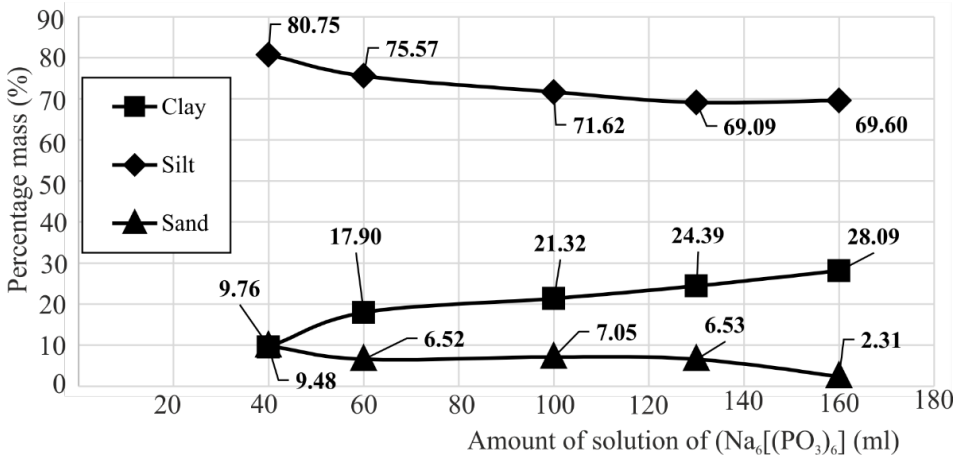


Fig. 8 – The influence of the amount of solution with dispersant $\boldsymbol{Na_6[(PO_3)_6]}$ for soil Sample B, with PI ≤ 10 %.

4. Conclusions

Soil classification is a critical process that requires accurate analysis to ensure the safety and stability of structures built on foundation soils. The laboratory analysis showed that adding different amounts of dispersing agent in the soil suspension resulted in differences for classifying the soil samples with different plasticity index. As the present EN ISO 17892-4/2017 is not limiting the use of specific dispersing agents, the research investigation used some recommendations of the former Romanian standard STAS 1913. Thus, it recommends using lithium carbonate for soils with plasticity index less than 10%. In this case, the silt fraction is predominant with percentages between 59-69%, and the clay fraction being between 29-40%. If the sodium hexametaphosphate solution is used as a dispersing agent, it is observed that the silt fraction is much higher than the clay fraction (the silt fraction being between 69-80% and the clay fraction being between 9-28%). Unlike the former Romanian standard STAS 1913, neither ASTM D 422 nor EN ISO 17892 do not recommend a dispersing agent based on plasticity index. The dispersing agent specified in ASTM D422 is sodium hexametaphosphate. The analysis shows that the use of the dispersing agent in the recommended amount of ASTM D 422 (125 ml of sodium hexametaphosphate) leads to a lower value of the clay fraction compared to the amount obtained according to the former Romanian standard STAS 1913. SR EN ISO 17892 only specifies sodium hexametaphosphate as the required dispersant.

The findings highlight the differences between the various standards for soil classification in terms of the recommended dispersing agents and their amounts. The significance of this investigation is leading to the necessity of further investigation for an optimum dosage of the dispersing agents that could clarify the accuracy need in soil classification. The soil classification leads to the estimation of the pore-size distribution that in turns leads to different design approach to various water removal works. The soil classification can also induce the soil activity that in turns lead to anticipated swell-shrinking potential with specific design measures for transportation infrastructure works.

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INFLUENȚA AGENȚILOR DE DISPERSIE ASUPRA ANALIZEI DIMENSIUNILOR PARTICULELOR DIN PĂMÂNT

(Rezumat)

Acest articol explorează metodele de clasificare a pământului și influența utilizării agenților de dispersie în diferite cantități pentru analiza dimensiunii particulelor din pământ. Au fost efectuate teste de laborator cu diferiți agenți de dispersie pentru a analiza efectele hexametafosfatului de sodiu și carbonatului de litiu pentru două pământuri diferite cu indici de plasticitate care indică unul cu plasticitate scăzută (PI = 8,23 %) și celălalt cu plasticitate ridicată (PI = 39 %).). Articolul evidențiază diferențele în fracțiunile granulometrice raportate pentru fiecare pământ și utilizarea aceluiași agent de dispersie, dar în cantități diferite. Astfel, clasificarea pământurilor este influențată de cantitatea de agenți de dispersie utilizați, recomandările de standarde fiind diferite în timp și țări. Aceste constatări contribuie la o mai bună înțelegere a comportamentului anticipat al pământurilor fine și oferă informații utile pentru diverse aplicații geotehnice.