Proceedings of the 4th ACPMG 2024
4th Asia-Pacific Conference on Physical Modelling in Geotechnics
11-13 December 2024, Abu Dhabi, UAE

Innovative Approaches to Soil Improvement: Separating Macro, Micro, Nano, and Pico Additives for the Future of Physical Modelling in Geotechnical Engineering

Hamed Niroumand
Department of Civil Engineering, Faculty of Engineering, Buein Zahra Technical University, Qazvin, Iran
Department of Geotechnical and Hydraulic Engineering, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdańsk, Poland
Lech Balachowski
Department of Geotechnical and Hydraulic Engineering, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdańsk, Poland

ABSTRACT: In this paper, a new idea for the separation of additives in various sizes is prescribed. Until now, most researchers have used additives with existing sizes and scales in various soil stabilization techniques. However, we are developing new theories in physics and materials science, necessitating a renewal of our ideas and theories on the scale and size of additives and materials. In geotechnical engineering, a new theory for the description of macro, micro, nano, and pico -additives and the performance of various additives in soil mechanics laboratories is evaluated in this research. The evaluation of various additives in different scales and sizes, from macro to nano, can initiate a new step in various soil improvement projects and related techniques. According to this study, nano-additives demonstrated good performance in soil improvement, potentially paving the way for the future of physical modeling in geotechnical engineering. The role of these theories can help the geotechnical engineering community find new solutions for existing crises such as land subsidence, sinkholes, and other issues. These theories are also relevant to ongoing developments in geotechnical engineering in various countries worldwide.

1 INTRODUCTION

Most researchers have used a single category for additives in soil stabilization and ground improvement, despite the fact that additives come in different sizes, ranging from macro to micro and nano scales (Niroumand et al., 2023). Understanding the performance of these different sizes can help us, as geotechnical engineering experts, optimize materials, additives, diameters, and sizes, as well as reduce project costs in various applications. The main aim of this research is to develop a new approach for categorizing additives in soil stabilization and ground improvement into three sizes: macro, micro, nano, and pico. This study evaluates the performance of various additives across these sizes based on previous research by authors. By doing so, future researchers can better understand the role of different additive sizes in physical modeling, improve the performance of additives in various ground improvement techniques, and ultimately enhance practices in geotechnical engineering and the construction industry.

Based on this new idea, new words and sentences must replace existing theories such as Macro-Geotechnics (MaG), Micro-Geotechnics (MiG), Nano-Geotechnics (NaG), and Pico-Geotechnics (PiG) because the scale and size of additives are very important for investigations and analysis of soil properties in different objectives and applications. According to this revolution, physical modeling needs to start in various applications, and their results should renew existing theories and formulas. This is a new step towards a better and safer future in geotechnical engineering and the building industry. Although it is very difficult in the first steps, it can start a new way for our activities in soil mechanics. As pore spaces are a main issue in various research, these scales help us decrease the disadvantages of various additives in practical and research projects (Niroumand and Nikkhahnasab, 2019). This requires an important step in physical modeling and starting a new way for a safe future in the building industry. It is very important to note that various industries such as medicine, polymer, and others use different types of soils (Niroumand and Nikkhahnasab, 2019). Adding this new size classification to future soil classifications can help them in all their activities. It

seems these new sizes and scales are needed for future activities in soil mechanics and geotechnical engineering.

2 MACRO TO PICO ADDITIVES

This section highlights the importance of the size and scale of additives in soil improvement and soil stabilization. They developed new titles such as Micro Soil Improvement (MSI), Micro Ground Improvement (MGI), Nano Soil Improvement (NSI), and Nano Ground Improvement (NGI). However, new titles for Macro Soil/Ground Improvement and Pico Soil/Ground Improvement need to be developed for various applications of additives and their scales.

2.1 Macro to Nano Cement

Niroumand et al. (2023) evaluated various percentages of different sizes of cement as additives in various tests in a geotechnical laboratory. They assessed the role of additive size in Atterberg limits, unconfined compressive strength, direct shear tests, and various other soil mechanics tests. Additionally, they conducted image analysis to determine particle sizes under various conditions, ranging from macro to nano. They found that smaller sizes of additives improved soil conditions for ground improvement techniques. Their analysis focused on cohesive soils, which they enhanced using gel techniques. The role of nanotechnology in soil mechanics was proven in this research (Figure 1).

2.2 Macro to Nano Bentonite

Cheraghalikhani et al. (2023) produced various sizes of bentonites, ranging from macro to nano. Although it seems they had pico-sized particles, they did not mention pico sizes in their research. They evaluated the performance of different sizes of bentonites in clay-sand soils. They reported better performance in specimens with smaller additives, such as nano-sized particles, compared to those without small additives, in various aspects of soil mechanics and geotechnical engineering. According to their study, they conducted different tests on Atterberg limits, secant modulus, unconfined compressive strength, direct shear tests, etc., with various percentages of additives in different sizes and curing times. This proved the performance of new theories such as Nano Soil Stabilization (NSI) in geotechnical engineering (Figure 2).

2.3 Macro to Nano Illite

Cheraghalikhani et al. (2024) changed the additives in this research. They evaluated the performance of Illite in various sizes, from macro to pico. Although they did not mention pico sizes of particles, it seems they had this size of particles in their research. They developed nanotechnology in ground improvement and proved the role of NaG (Nano-Geotechnics) in their research. They showed better performance of clayey sand specimens with various sizes of particles, with smaller sizes performing better than larger sizes as additives. They demonstrated that with smaller percentages of smaller sizes of additives, such as nano-particles, the role of improved specimens changed. According to their study, they conducted different tests on Atterberg limits, secant modulus, unconfined compressive strength, direct shear tests, etc., with various percentages of additives in different sizes and curing times. For instance, in the study by Niroumand et al. (2023), the unconfined compressive strength increased from 150 kPa to 250 kPa with 5% nano cement after 28 days of curing. Similarly, Cheraghalikhani et al. (2023) found that the unconfined compressive strength increased from 200 kPa to 320 kPa with 4% nano bentonite after 14 days of curing. In another study by Cheraghalikhani et al. (2024), the unconfined compressive strength increased from 180 kPa to 290 kPa with 3% nano illite after 21 days of curing. This proved the performance of new theories such as Nano Soil Stabilization (NSS) in geotechnics (Figure 3). They tried to use clay as a natural and green material. Based on this idea, they were developing a new theory for Green Soil Improvement (GSI) or Green Soil Stabilization (GSS).

These examples demonstrate the significant role of macro to pico additives in addressing existing crises such as sinkholes and land subsidence. By enhancing soil properties, these additives can improve ground stability and prevent the formation of sinkholes. For instance, the increased unconfined compressive strength observed in our studies indicates a stronger, more resilient soil structure, which is crucial in areas prone to subsidence. Additionally, this research can pave the way for developing new ground improvement techniques tailored to combat these issues effectively. Furthermore, the findings can initiate new theories, such as Micro Subsidence or Nano-Subsidence, which provide a deeper understanding of subsidence phenomena at smaller scales. These theories are particularly relevant to the national crises faced by

various countries, offering innovative solutions to mitigate such challenges.

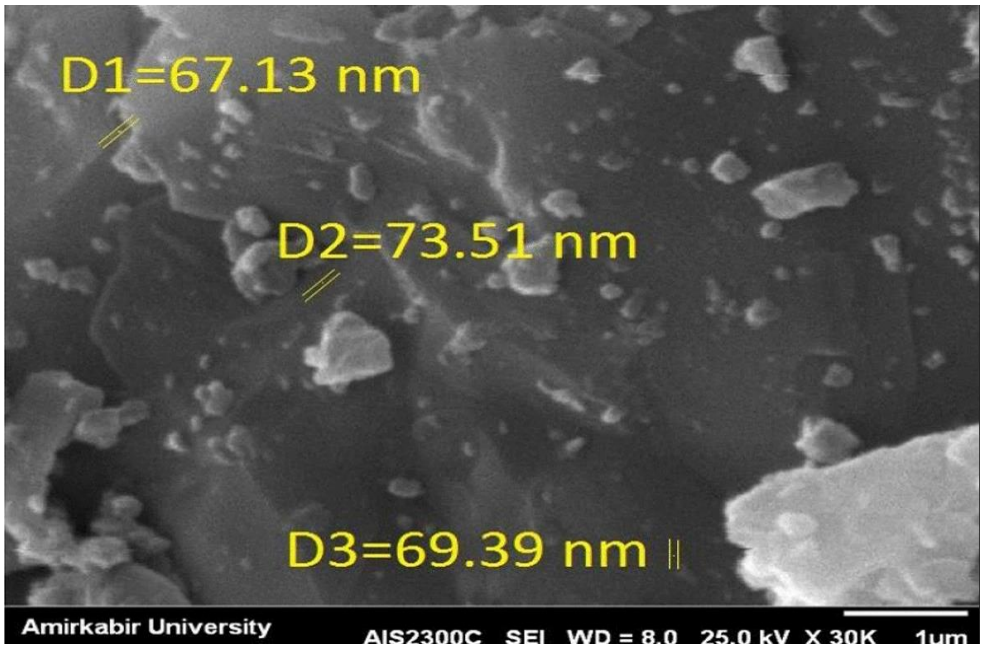

Figure 1. Macro to Nano cement in soil improvement (Niroumand et al., 2023)

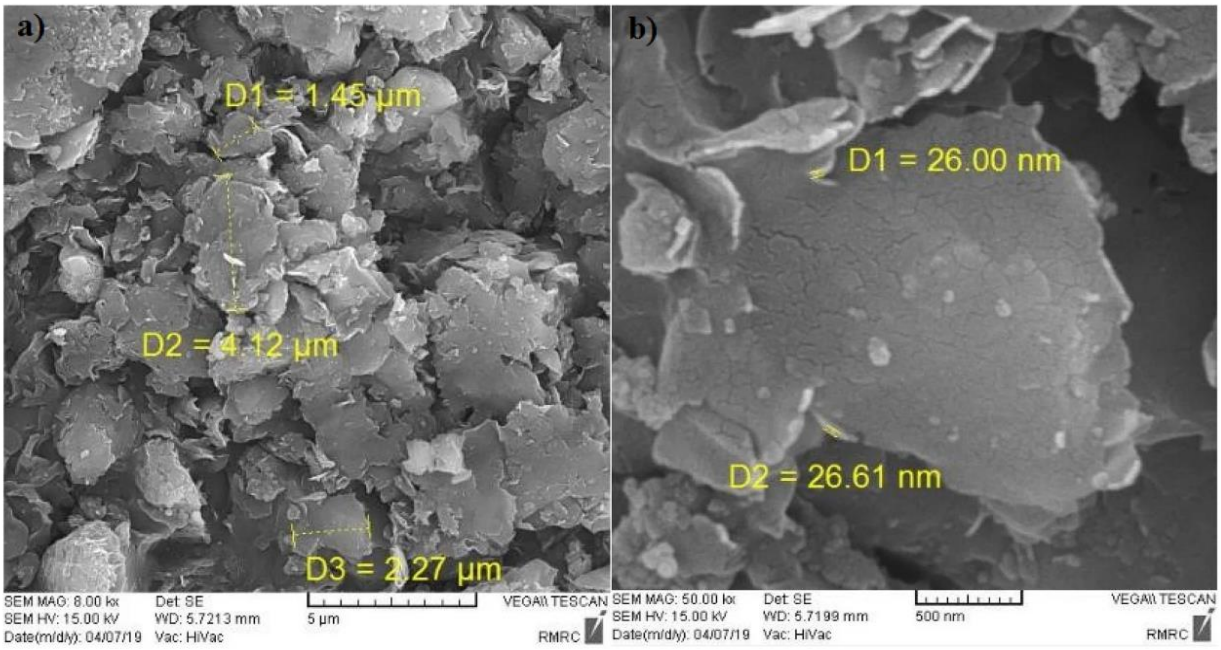

Figure 1. Macro to Nano bentonite in soil improvement (Cheraghalikhani et al., 2023)

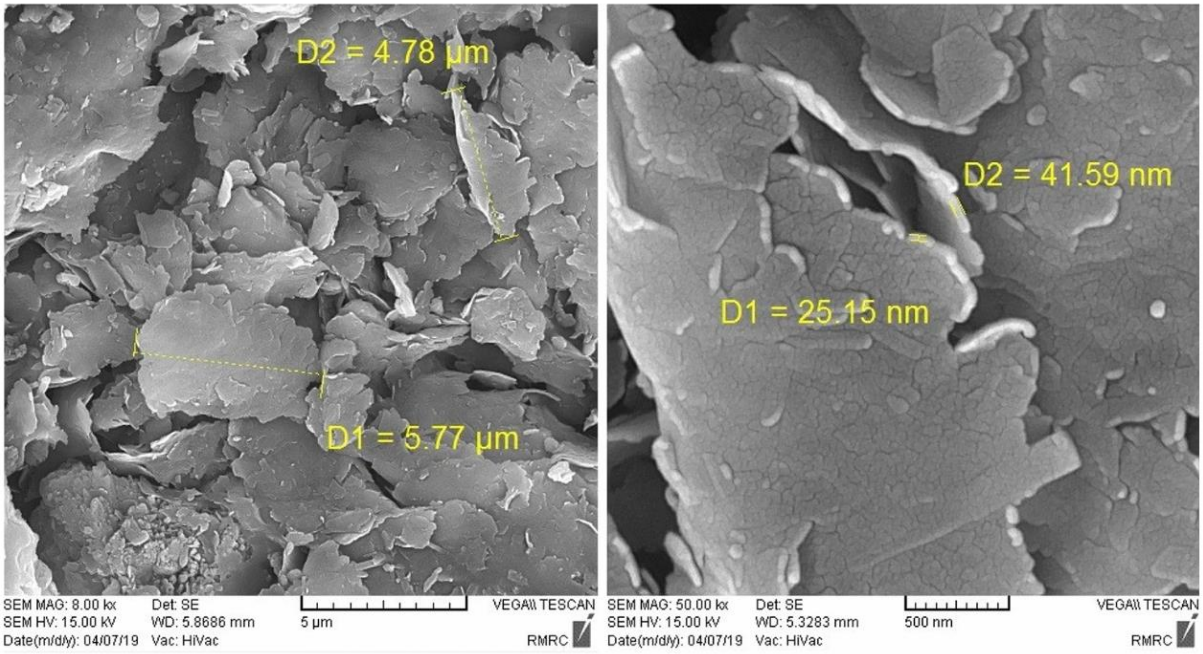

Figure 3. Macro to Nano illite in soil improvement (Cheraghalikhani et al., 2024)

3 CONCLUSIONS

According to this study, geotechnical engineering is facing a new direction. It involves the evaluation of various sizes of particles, from macro to pico, in different specimens. This requires development in physical modeling within geotechnical engineering across various applications. Although this idea is very interesting and innovative, it is still in its initial stages in the building industry and needs further development in various aspects, from geotechnical engineering to structural engineering. The importance of smaller particle sizes in pore spaces in soil mechanics is significant, as we face issues like land subsidence and sinkholes due to pore spaces. Addressing these issues with modern ground improvement techniques could help mitigate these crises in various countries.

REFERENCES

Niroumand, H., Balachowski, L. & Parviz, R. (2023). Nano soil improvement technique using cement. *Sci Rep*, *Nature,* 13, 10724, https://doi.org/10.1038/s41598-023-37918-z

Cheraghalikhani, M., Niroumand, H. & Balachowski, L. (2023). Micro- and nano- bentonite to improve the strength of clayey sand as a nano soil-improvement technique. *Sci Rep*, *Nature,* 13, 10913, https://doi.org/10.1038/s41598-023-37936-x

Cheraghalikhani, M., Niroumand, H. & Balachowski, L. (2024). Micro- and nano-Illite to improve strength of untreated-soil as a nano soil-improvement (NSI) technique. *Sci Rep*, *Nature,* 14, 10862¸ https://doi.org/10.1038/s41598-024-61812-x

Niroumand, H. and Nikkhahnasab, S. (2019). Soil Improvement. *ACECR*, Iran