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The role of nano-materials and nanotechnology as a high-tech technology in geotechnical engineering

Le rôle des nano-matériaux et de la nanotéchnologie comme une téchnologie avancée en géotechnique

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ABSTRACT: In the field of soil mechanics, various initiatives have been launched recently to use Nano- Materials (NM) to enhance the characteristics of soils. Numerous studies have been done using various methods to determine how micro- and nano- particles affect the geotechnical characteristics of soils. Most of the research done over the last ten years is reviewed in this research paper. According to the new classification, clay particles vary between 0.1 and 2 mm, while NM specimens contain particles in the range from 1 to 100nm. All findings suggested that adding Nano-Particles (NP) as a Nano Soil-Improvement (NSI) technique to soil improved its mechanical and physical characteristics, the type, quality, and quantity of NM applied, as well as the properties of the native soil, all influence this enhancement natural soil properties. In this paper, a new categorization was introduced to investigate the important effects of NP and NM on soil properties as a Nano Ground-Improvement (NGI) method.

RÉSUMÉ: Des initiatives nouvelles dans le domaine de la mécanique des sols sont récemment introduites en ce qui concerne l'usage des nanomatériaux (NM) pour l'amélioration des sols. De nombreuses études sont effectuées pour déterminer l'influence des micro et nano-particules sur les caractéristiques des matériaux géotechniques. La majorité des études réalisées dans la décennie écoulée est analysée dans cette publication. Selon une classification nouvelle,la dimension des particules d'argile varie entre 0.1 et 2µm, tandis que NM contiennent éléments entre 1 et 100nm. Toutes les trouvailles suggérent que l'addition des nano-particules (NP) comme nano-technique d'amélioration des sols (NSI) revise leurs caractéristiques mécaniques et physiques. Une sorte, qualité et quantité de NM appliqués ainsi que les propriétés du sol naturel influencent l'état d'amélioration du sol concerné. Dans cet article, une classification nouvelle est introduite pour étudier les effets majeures de NP et NM sur les paramètres géotechniques par la méthode de nano-amélioration des sols (NGI).

Keywords: Nano-materials (NM), nano-particles (NP), nano soil-improvement (NSI), nano ground-improvement (NGI).

1 NANOTECHNOLOGY AND GEOTECHNICAL ENGINEERING

Nanotechnology is related to the nano-scale of materials. Most of the materials and minerals are in the micro-scale, although various materials have nano-scale components in their natural conditions. Existing knowledge is based on micro-scale analysis in geotechnical engineering. A few researchers and scientists have started various tests on the nano-scale of minerals and soils in geotechnical engineering. The performance of the nano-scale of soils and minerals in soil mechanics and rock mechanics is very important because nanotechnology in geotechnical engineering is a cutting-edge knowledge and high-tech technology. According to existing soil classifications, gravel, sand, clay and silt are included in soil mechanics, but a new term of nanosoil is needed. Nanosoil has a size range between 1-100 nm. According to new results, the nano-scale of soils improved various properties of different types of soils (Niroumand et al., 2023). Geotechnical engineering focuses on the behavior and performance of different soils, while nanotechnology focuses on the nano-scale of materials and their behaviors and feedbacks. Using nanotechnology in geotechnical engineering has two objectives:

First, nanotechnology can explore new knowledge about the structure of soils at the nano-scale rather than the existing knowledge at the micro-scale. A complete introduction and knowledge of the nano-scale of soils can develop new theories for advanced soil mechanics and foundation engineering.

Secondly, using the nano-scale of soils and additives can investigate soil behaviors and improve existing soils. The role of the nano-scale of additives in soil mechanics is related to soil stabilization as a technique of soil improvement.

A lot of soils have various problems worldwide. The role of the nano-scale of additives as soil stabilizers can change the role of micro-scale additives in current and ongoing projects. Existing knowledge for micro-scale additives in soil improvement has learned various lessons in geotechnical engineering, such as additive properties, soil type, additive percentages, water amount, improvement methods, etc., that are related to ground improvement methods in different projects. The nano-scale of materials is similar to the micro-scale of additives because existing factors are applicable for ground improvement in geotechnical engineering.

2 EXISTING KNOWLEDGE OF NANOTECHNOLOGY IN GEOTECHNICAL ENGINEERING

In this part, a few existing achievements on two objectives of nanotechnology in geotechnology are described, although various researchers have evaluated the performance of nano additives in various soils. Only selected experiences of authors are presented for this manuscript.

a) Niroumand et al. (2013) investigated the performance of nano-scale clay as an additive and soil stabilizer in bricks. Earth is a basic material in heritage, historic buildings and earth buildings in earth architecture style. Traditional bricks have been used in many countries, especially in the Middle East and Arabic countries. According to traditional methods, various additives such as Sarooj, straw, lime, cement, egg, and etc. were used as additives and stabilizers in bricks.

In this study, the authors used different percentages of nano-scale additives in earth bricks in a soil laboratory. Nano kaolinite was selected as a type of nano clay in this study. According to their results, the compressive strength of treated bricks with nano-scale additives was 4.8 times higher than untreated bricks at 14 days curing time. The best percentage of nano additives was 5% compared to untreated bricks. They mentioned that Nano-Bricks (NB) can be used as modern bricks rather than existing bricks as Micro-Bricks (MB) in various applications and projects as shown in Fig. 1. They used powder technique for brick improvement. (Niroumand et al., 2013)

Figure 1. Micro- and Nano- Earth Bricks (Niroumand et al., 2013).

b) Khaksar et al. (2023) produced a new spray for protecting and restoring historic adobe walls and buildings. They used nano-scale montmorillonite in their research. According to the results of various tests, such as scanning electron microscopy, atomic force microscopy, porosity tests, water capillary absorption, and compressive strength, they showed that the use of a 1% nanomontmorillonite clay solution exhibited the best results, filling cavities and reducing pores on the adobe surface, increasing compressive strength, and reducing water absorption and hydraulic conductivity. The study concludes that this innovative method using nanomontmorillonite clay can help address the challenges of historic adobe walls, such as erosion, cracking, and surface damage.

This research contributes to the growing field of nanotechnology applications in architecture and civil engineering, particularly in soil stabilization and improving the properties of building materials. It introduced new concepts of "Nano-Heritage", "Nano-Spray for Historic Buildings and Earth Houses", and "Nano Spray-Improvement" as shown in Fig. 2. (Khaksar et al., 2023)

Figure 2. Nano-Spray for Historic Buildings and Earth Houses (Khaksar et al., 2023).

c) Zyenali et al. (2023) investigated the role of micro- and nano-scale fly ash as a green material in geotechnical engineering. They used fly ash because it was an eco-friendly material and a waste additive that

can be used as a recycled material in the building industry. They evaluated the role of these additives at micro- and nano-scale in various soil mechanics tests. They used scanning electron microscopy (SEM), X-ray fluorescence (XRF), and X-ray powder diffraction (XRD) to evaluate the soil and additive structures at micro- and nano-scale. They also investigated various percentages of micro- and nano-fly ash in cohesive soils to explore the soil mechanic behavior of micro- and nano-scale additives in soil stabilization.

Nano Soil-Stabilization (NSS) is a new theory for improving soil in Nano Soil-Improvement (NSI) or Nano Ground-Improvement (NGI). The results showed that adding 7% of nano-fly ash to the soil improved its unconfined compression strength by 8.2 times and its triaxial strength by 8 times. The researchers concluded that nano-fly ash significantly improved the strength and stiffness of the soil-fly ash mixture by filling the pores and bonding the soil particles. They reported a cutting-edge knowledge for the performance of Nano-Additives (NA) in earth building technology that can be used to build new houses with high performance in the future. They used suspension technique for soil improvement as shown in Fig. 3. (Zyenali et al., 2023)

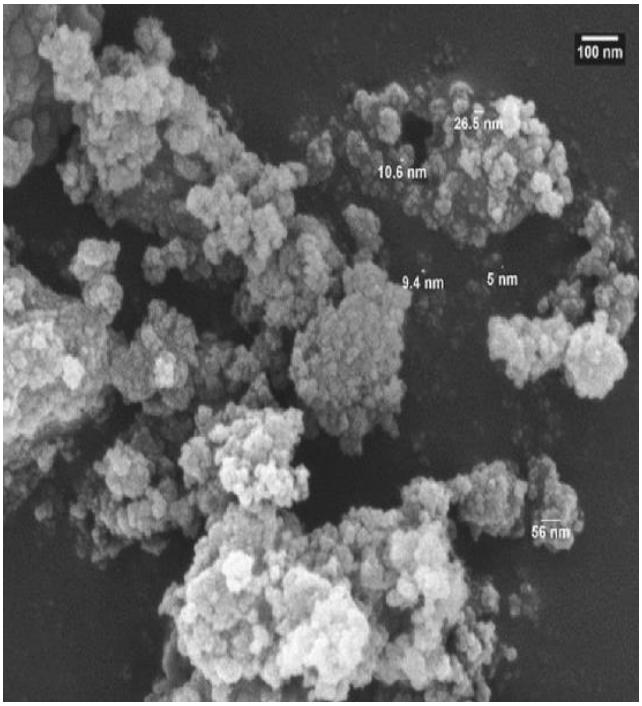

Figure 3. Nano – Fly ash (Zeynali et al., 2023).

d) Niroumand et al. (2023) described the role of micro- and nano-scale cement in geotechnical engineering. They selected a natural field soil site as untreated soil for soil stabilization objectives. They tried various percentages of micro- and nano-scale cement in soil stabilization as a soil improvement technique as shown in Fig. 4. They found that an optimum percentage of nano-cement was 7%, which increased the unconfined compressive strength by up to 29 times and reduced the strain at rupture by 74% compared to untreated soil. According to their results, they found a significant improvement of nano-scale cement on the strength and stiffness of the untreated soil-cement mixture. They used suspension method for soil improvement.

Figure 4. Micro- and Nano- Cement and NSI (Niroumand et al., 2023).

e) Cheraghalikhani et al. (2023) investigated the performance of micro- and nano-scale bentonite in geotechnical engineering. They used suspension technique for improving the cohesive soil properties. By using different percentages of micro- and nano-scale bentonite, they achieved good performance on the physical and mechanical properties in soil mechanics as shown in Fig. 5. They used SEM, XRD and XRF to control the properties, shape and size of soil and additive at micro- and nano-scale analysis. According to this investigation on clayed sand soil, at one day of curing time, the addition of 1% micro-bentonite increased the secant modulus to 2500 kg/cm^2, while 1% nano-bentonite increased it to 3000 kg/cm^2. The researchers emphasized the performance of suspension method rather than powder technique in micro- and nano-scale additives because suspension had a good performance in uniformity and soil mixing for various specimens and samples in soil mechanics laboratory.

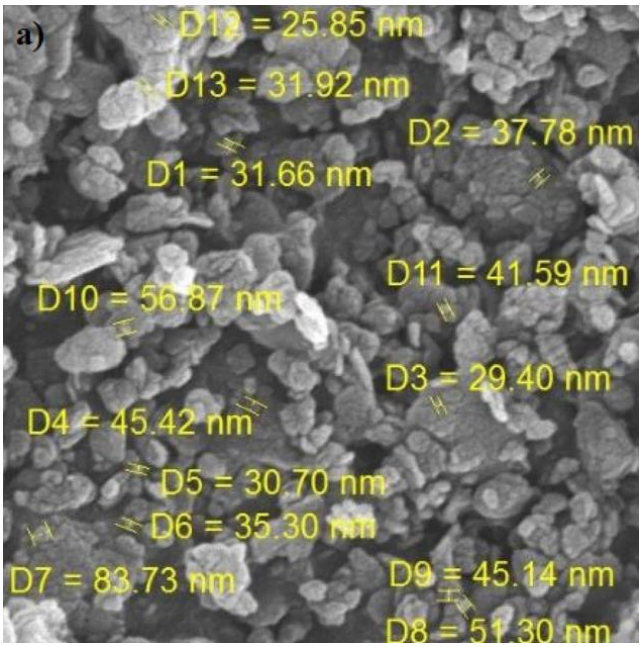

Figure 5. Nano-Bentonite and NSI (Cheraghalikhani et al., 2023).

3 THE FUTURE OF NANOTECHNOLOGY IN GEOTECHNICAL ENGINEERING

According to existing knowledge and results, the future of nanotechnology in geotechnical engineering, soil mechanics and rock mechanics looks promising. Existing knowledge proves the role of nano-scale soils as a good achievement for developing new techniques in the future of geotechnical engineering projects worldwide. The performance of nanotechnology started in soil stabilization and soil improvement, but it can be developed to various types of Nano-Foundations (NF), Nano-Additives (NA), Nano- Piles (NP), Nano Sheet-Piles (NSP), Nano-Geosynthetics (NG), NSI and subsidence as Nano-Subsidence, NSI and sinkhole as Nano-Sinkhole, and etc. The use of nano-scale materials has proven a good performance of the durability and soil properties in existing research. A new classification needs to be developed in soil classification; in other words, Nano-Soil (NS) needs to be added to existing soil classifications. These new terms emphasize new theories and techniques in soil mechanics and rock mechanics. It means a new way has opened in geotechnical engineering that requires various research and collaboration for modern types of materials in geotechnical engineering to improve the existing level of geotechnical engineering.

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