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A Review Study on the Effect of Nanomaterials and Local Materials on Soil Geotechnical Properties

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Abstract. Considerable strides have been made in nanotechnology in recent years, with many nanotechnology-based achievements in the geotechnical-engineering. It seems certain that nanoparticles would be widely utilized to develop the geotechnical qualities for soils in modern applications. This study covers prior research on using nanomaterials in soil, their characteristics, and their influence on soil engineering. It seems certain that nanoparticles will be widely utilized to develop soil geotechnical properties in the near future. The application of current technologies to improve soil resistance requirements has resulted in the stability of many soil types with formation issues. This study analyzes the use of some nanomaterials and lime as additives or stabilization materials to improve soil resistance properties by geotechnical researchers. Researchers have demonstrated that adding local materials such as lime enhances the properties of soil. Still, a remarkable and interesting percentage of improvement was observed when adding nanoparticles to the soil by improving its engineering qualities as well as those of some other components, such as lowering stability and compressibility, raising density, and raising shear resistance.

Keywords: Soil Stabilization, Clayey Soil, Nano Silica, Nano Technology, Geotechnical, Resistance Metrics.

1. INTRODUCTION

The high compressibility and low shear strength of structures constructed on soft clay soils are just two of the issues they encounter. The price of raw materials and the cost of the machinery needed to complete the job make conventional installation methods pricey [1]. Of all the building resources, the soil is one of the most plentiful ;when building embankments, highways, railways, and other engineering projects that call for a significant volume of soil, where soils are the most frequently employed material. In most countries, clay soils cover a sizable portion of the world's surface [2-4]. To enhance the undesired geotechnical qualities of soils gypseous, soil stabilization is required [5]. The layers of soil used as a foundation for buildings, structures, and substrates to be utilized as a substrate, the soil must be able to resist loading conditions within the range of permitted deformations and transfer them to the ground. Strong and deformable characteristics are important. The nanoscale is a feasible size for soil stability when additives are used. It is a technique used in engineering to increase the strength and properties of soil. Nanotechnology has recently spread widely in many scientific disciplines [6].

Because nanomaterials actively interact with other particles, even very small amounts can significantly change the soil's physicochemical behavior and technical qualities [7,8]. By increasing the particular surface area and favoring quantum effects [9]. In order to stabilize problematic soils with complex and erratic behavior, like gypsum soils, which are mostly found in semi-dry and dry parts of the world and are prone to collapse when wet, a variety of additions can be utilized. Nanomaterials were employed to examine their impact on the geotechnical qualities of the soil to lessen the likelihood of soil collapse [10,11]. It was discovered that soil behavior was altered at the nanoscale. With particle sizes from 1 to 100 nm, they offered a new kind of soil particles, dubbed nano-cells. This study presents the discussion and evaluation of the effect of using conventional materials (lime) and nanomaterials on the physical properties of soft soil by making an analysis based on the results of geotechnical researchers' investigations.

2. STUDY METHOD

2.1 Statistical Frameworks

The method for choosing search terms and databases was followed to systematically identify sources for review. A comprehensive analysis differs from a standard assessment in that it follows a sufficiently clear method to allow other investigators to duplicate it, notably by giving an audit record of pertinent actions and choices. To choose and assess the works, we employed the search window evaluation procedure and recommended premium quality analysis techniques.

2.2 Criteria for Inclusion

Understanding at least one of our studies is required for a source to be regarded as credible and pertinent to our review. A research project with a peer review standard training file for systematic and works reviews must also be accessible in English. Peer-reviewed sources have been the only ones used in the literature because they are highly relevant. The ultimate query phrases were Geotechnical engineering, soft clay, resistance soil, and nanomaterial.

a) EBSCO: Education Research Complete
b) Google Scholar
c) ACM Digital Library
d) Research gate

3. RESULTS AND DISCUSSION

The marine mud was taken from the Cochin District's Vipin District for the study. To contrast the effect of silica nanoparticles on the mechanical properties of mud, investigations were conducted into how lime affected the characteristics of marine mud. The geometric features investigated were Atterberg's limit, Maximum dry unit weight, appropriate moisture level, and unrestricted compressive resistance. Increasing proportions decreased the indicator of plasticity [12], as shown in Figure 1.

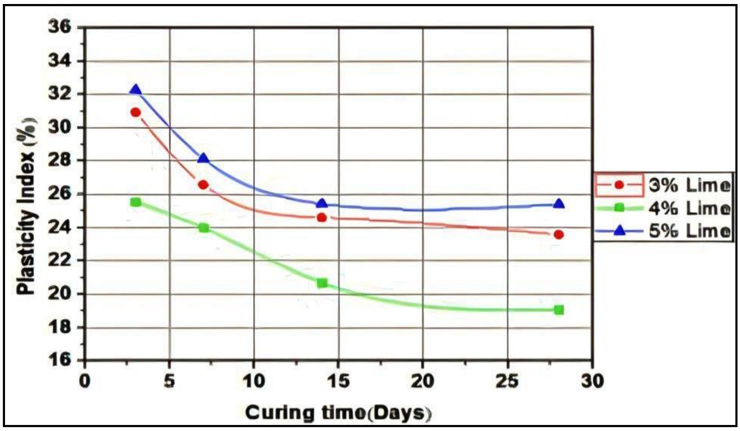

Figure 1: Changes in plastic limit with time of curing in lime-added clay[12].

A 3%, 4%, and 5% soil lime ratio has been applied. In the study, nanosilica comprised 0.5%, 0.8%, and 1% of the total material. For the periods of treatment 3, 7, 14, and 28 days, Atterberg boundary variability and unconfined compressive strength variations were assessed. In lime-treated soils, a higher lime content decreases the dry density. The soil treated with lime has a lower maximum dry density to boost the lime concentration. The electrolyte concentration rises, and the diffuse double layer falls at greater lime concentrations. The pressure curve is depicted in Figure 2.

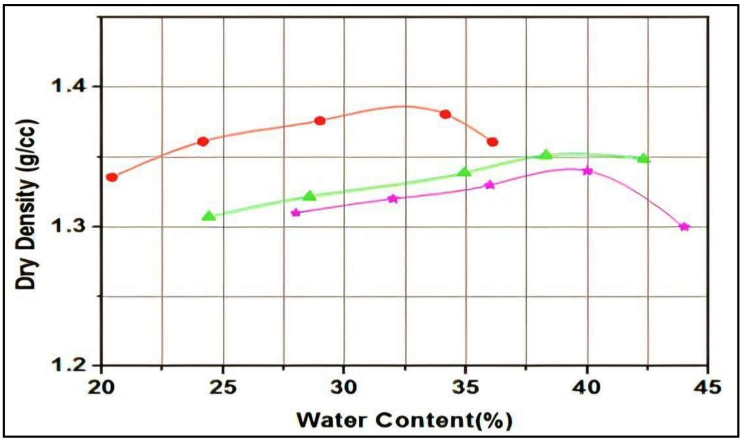

Figure 2: Compaction curve of lime-modified clay [9].

For the nano silica-modified mud, the forte has increased three times. Lime-stabilized clay's ideal lime and nano-silica contents were 4% and 0.8%, respectively. The plasticity properties were considerably altered by comparing lime-modified clay to nano-silica additions (Figure 3) .

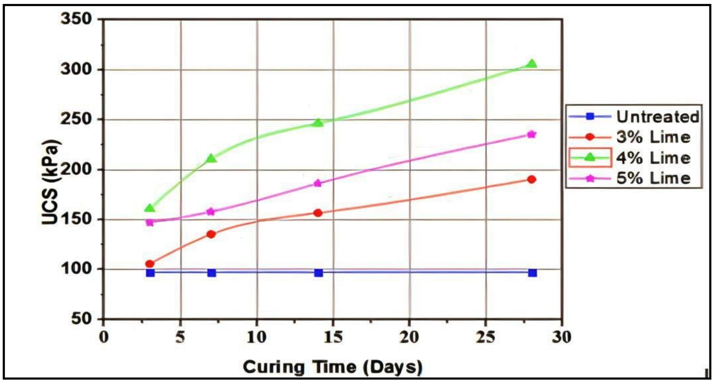

Figure 3: Changes in unconfined compressive strength UCS of clay with lime and curing time [9].

Figure 4 illustrates how the unconfined compressive strength has improved. The plasticity index decreases by 34, 38, and 41% compared to natural clay with 0.5, 0.8, and 1% of nanosilica, respectively.

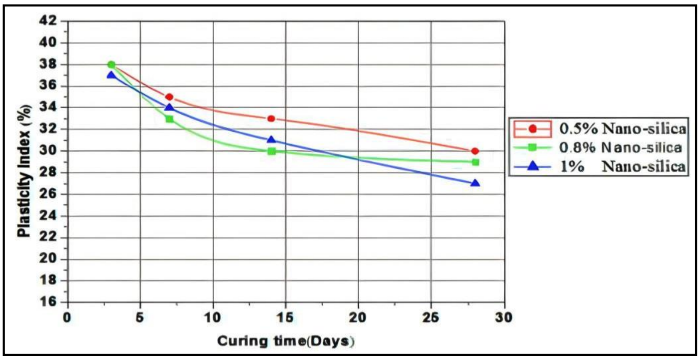

Figure 4: Changes in plasticity index with drying time in clay treated with nano-silica [12].

One may conclude that for all nanoscale silica concentrations, an immediate drop in the plasticity index can be seen because of the declining liquid limit and rising plastic limit, Figure 5.

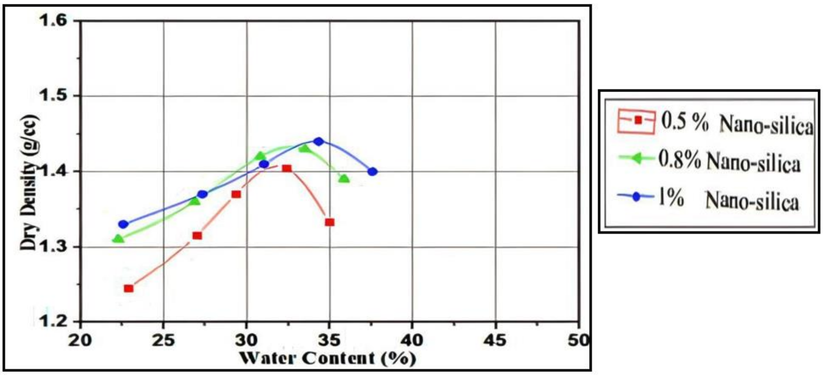

Figure 5: Dry density and Water Content with Various Nano-Silica Content [12].

Figure 5 depicts how clay's water content and dry density are connected to the various nano-silica content ratios. It becomes denser when soil treated with nano-silica includes more microscopic silica particles. As a result, the unconfined compressive strength of soil is modified with nano-silica. The UCS increases as the amount of nano-silica in the soil increases. The graph indicates that increasing the amount of silica nanoparticles by 0.5, 0.8, and 1% increases the strength. The UCS values of 0.8% and 1% are comparable. According to the slope of the UCS curves, more silica nanoparticles may result in higher resistance levels [12].

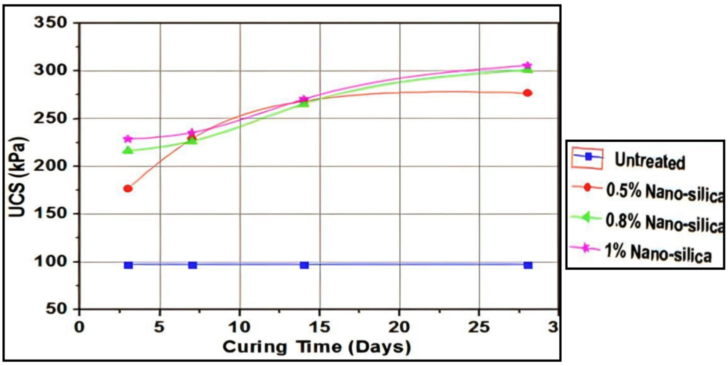

Figure 6: Changes in UCC of clay amended with nano-silica with curing time [12].

Extensive soil was dosed with up to 12% LSD in 3% increments. The test results demonstrated that the maximum dry density, hydraulic conductivity, swelling pressure, and liquid limit dropped consistently. In contrast, the plastic limit, shrinkage limit, and ideal moisture content increased to 12% LSD addition. However, when LSD was added at 9%, the UCS, wet CBR, cohesiveness, and internal friction angle increased to their greatest values. The optimum dose of LSD for stabilizing expanding soils was discovered to be 9% [13]. Various amounts of limestone were applied to high-expansion clay. The findings suggested that adding limestone powder could improve the geotechnical qualities of the soil. It is also recommended to include as much limestone as possible in the expanded soil [14].

Limestone was added to the clay soil to improve it. The chosen soil, a fine clay from southeast Spain, had its dry weight increased by 5, 10, 15, 20, and 25% by dry limestone dust. X-ray fluorescence and diffraction are two typical geotechnical tests. Enhancing the geotechnical properties of the mixture Soils were assessed using the one-dimensional uniformity test, free bulging index, unconfined compressive strength, and change in Atterberg limits. Scanning electron microscopy was used to investigate the microstructure of mixed soils. Overall, the results demonstrated decreased soil deformation and improved soil toughness in limestone [15]. The role of lime and nano-silica particles in soil enhancement was examined. According to the data, the UCC force produced by the nano-mixed soil was 589 kN/m^2, 1.2 times larger than that produced by non-nano particles in soil compared to soil without nanoparticles [16]. Kalhor et al. [17] studied the evaluation of the performance of clay soil that has been treated with nano-silica as an addition. The goal Tests on the Atterberg boundary, typical pressure and permeability, and ungrouped (UU) were carried out in order to achieve this. Using 1, 2, 3, and 4 wt% of NS mixed with fine-grained soil. Also utilized to view was scanning electron microscopy (SEM). Specimens treated with NS and those not treated have different textures. X-ray diffraction (XRF) fluorescence test was performed on a soil sample to assess the proportion of components present. When NS is introduced to soil, the results show that it decreases. The variation of the plasticity index, plastic limit, and liquid limit are shown in Figure 7.

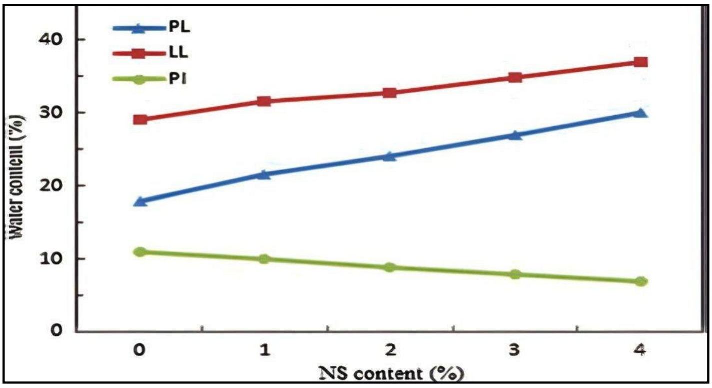

Figure 7: Impact of nano silica content on plastic+ liquid limit and plasticity index [17].

The permeability coefficient of the NS-treated samples was discovered to be lower than that of the control sample. Additionally, by performing 3-axis UU Tests on a material treated with 2% NS under confined pressure, an additional 60–68% maximum strength was attained. Additionally, internal friction and cohesion angle In comparison to the sample that wasn't treated with NS, the sample treated had an increase [17], as shown in Figure 8(a,b,c).

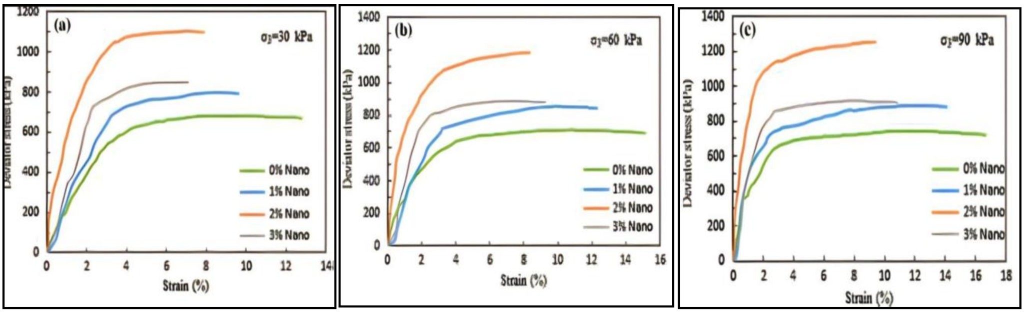

Figure 8: Stress-strain relation with different pressures of a) 30, b) 60, and c) 90 kPa [17].

Clay was tested for reaction to five to a hundred nanometer-sized silica nanoparticles, consolidation tests, three-axis, and compressive strength. The results demonstrated that nanomaterials found in the soil were configurable in the early phases of formation and that it later became elastoplastic [18]. Ren used electron microscopy to examine the impact of nanoscale silica on the mechanical and physical properties of alluvial clay, as well as a variety of tests to gauge its liquid and plastic limits, uniaxial pressure, specific gravity, and frost lift. The concentration of nano silica rising Uniaxial compressive strength and the plastic and liquid boundaries of the slurry both decreased the amount of frost produced. The clay sample's specific gravity did not alter, though. The composition of the clay sample was unaffected by nanosilica, but it did reduce Its structure is more uniform because of its average pore size [19]. Changizi and Haddad [20] examined how adding nano silica particles to soft clay might affect its resistance and mechanical qualities. The Atterberg limit, optimal moisture level, maximum dry weight, and compressive power were all measured using nanosilica. Nano silica ratios were 0.5, 0.7, and 0.1% in contrast to soil. The limitation has improved in response to an increase in nano silica content.

The plasticity index decreased, and contraction limitation increased as ratios increased. According to the findings, viscose gel got thicker during the first stress before hardening from 70 kN/m^2 for soft clay to 300 kN/m^2 for stabilized soil with NS 0.7%. Up to 56% more compressive force is now available. The soil's elastic modulus increased even though the tensile stress decreased as the nanosilica content increased. Based on the findings, it can be said that the addition of nanosilica enhanced clay's mechanical and resistivity properties [20]. Nano silica's impact on clay particle size is depicted in Figures 9 to 11, illustrating Nano silica's effect on compressive and shear strength, respectively.

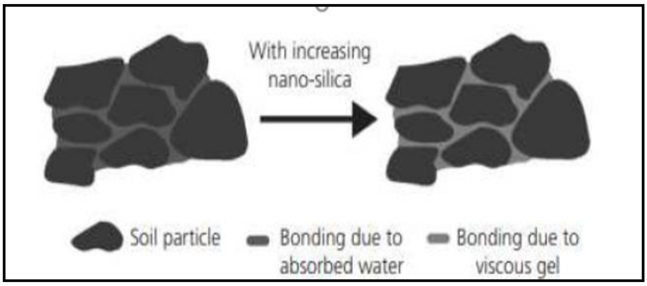

Figure 9: Nano silica Impact on clay soil particles [20].

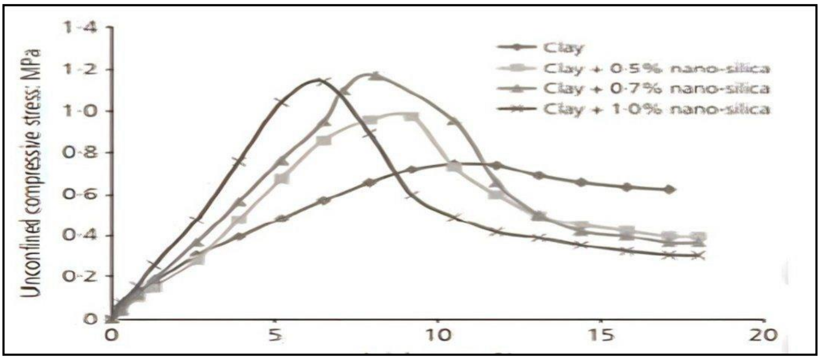

Figure 10: Nano silica impact on compressive strength [20].

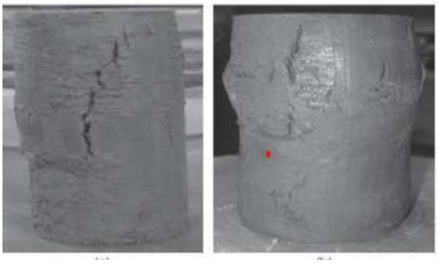

Figure 11: Nano silica impact on compressive strength (UCS) [20].

Ghavami et al. [21] studied the effects of an industrial byproduct, silica fume, and nanosilica on kaolin clay's geotechnical and microstructural characteristics and soft soil with poor resistance capabilities. Adding silica fume increased Kaolin clay's strength by 5, 10, and 15%. Additionally, nano silica was used to create stabilized soils at concentrations of 1, 2, and 3% by weight of soil dry matter. Then, tests for the Atterberg limit, standard control, unconfined compressive strength, and California bearing ratio were run. Additionally, a scanning electron microscope SEM was used to detect the tiny structural modifications of soil samples caused by fixation. According to the findings, silica dust and nanosilica increase the optimum water content while decreasing the maximum dry density of the stabilized soil. When 15% silica fume and 3% nano-silica were added to kaolin clay, the unconfined compressive strength rose by up to 70% and 55%, respectively, after 28 days of curing life, as shown in Figure 12.

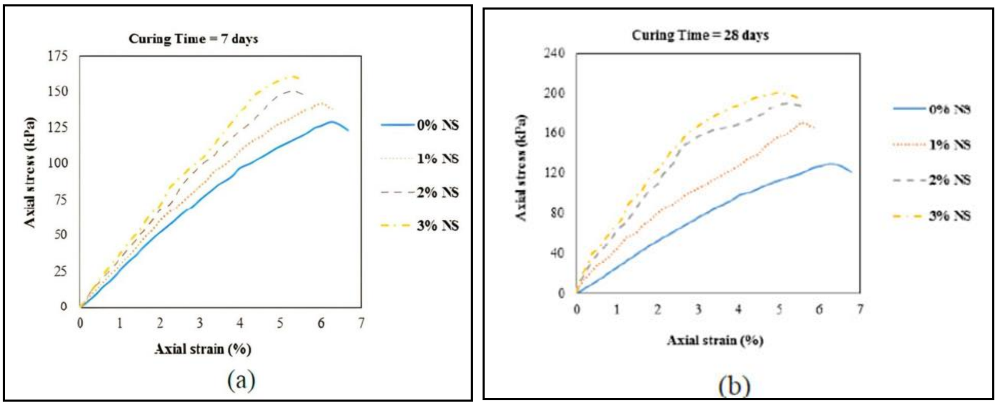

Figure 12: Effect of the addition of nanosilica on UCS after (a) 7 days (b) 28 days [21].

Clay soils, direct shear testing, Atterberg boundary tests, normal pressure tests, and unconfined compression strength (UCS) tests have all used nanosilica. Energy-dispersive X-ray spectroscopy, scanning electron microscopy, and X-ray diffraction have also been used to investigate the mineralogy and microstructure of core soils and treated samples EDS. The results showed that adding the appropriate amount of 1% nanosilica to the dispersed clay changed the properties of the non-dispersed soil. Despite silica nanoparticle treatment, the treated soil samples had a higher liquid limit, plastic limit, and moisture content, resulting in a lower plasticity index and maximum dry density. After 7 and 28 days of treatment, samples treated with 1% nanosilica content showed appreciable gains in absorbed energy, secant modulus of elasticity, and direct shear strength [22].

The effects on the clay of adding lime and nano-silica in various ratios are examined in this study. According to the findings, a little amount of nanoscale silica was added to the blended clay. When soil is supplemented with lime, the qualities of plastics, including their strength, swelling, and compression, are significantly improved. This study also examined the effects of treatment duration; the outcomes indicated that nano-silica was an effective addition. In a shorter amount of time, it causes the lime-mixed soil to become stronger more quickly. According to the study's findings, soil engineering properties should be improved for all projects [6].

Only 4% lime is used to prepare the samples for the first group, made from natural soft soil. Additionally, the second group is created by combining a mixture of soil and 4% lime with $CaCO_3$ Nanomaterial in varying amounts (0.25, 0.5, and 10%) as a final step. Using lime and nano $CaCO_3$, the additive created in this work is designed to treat the qualities of soft clay soil. Soft dirt has been delivered from the Iraqi city of Najaf [23]. Nano-SiO_2 was added to the loess soil. The mechanical, structural, and mineralogical properties of loess soil treated with nano-SiO_2 and subjected to different contents and curing times. The mechanical behavior was investigated using untreated and treated loess's unconfined compressive strength (UCS). The results reveal that the UCS increases with increasing SiO_2 content and curing time, resulting in coarser particles, denser packing, and smaller holes in treated loess. The outcomes of mineralogical component analysis further increase inter-particle interaction [24].

Kalhor et al. [25] added Nano-SiO_2 to the fine-grained soils and tested the freezing-defrosting cycles on the geotechnical properties of the samples treated with Nano-SiO_2. Unconfined compressive quality (UCS) was improved by approximately 63% by adding 2% of nano-SiO_2 and a relieving period of 42 days. Additionally, the samples' conductivity becomes brittle due to the growth in nano-SiO_2. Furthermore, the freeze-defrost cycles reduce the UCS of the sample cycles. On clayey soil blended with nano-SiO_2, laboratory tests such as typical Proctor, Atterberg limits, and unconfined compression tests (UCTs) were performed. Furthermore, the samples were cured for six weeks. As shown in Figures 13 to 15, when clay soils are stabilized and stabilized using nano-silica, the maximum dry unit weight and PI decrease while the optimum moisture level, liquid limit (LL), and plastic limit (PL) increase [25].

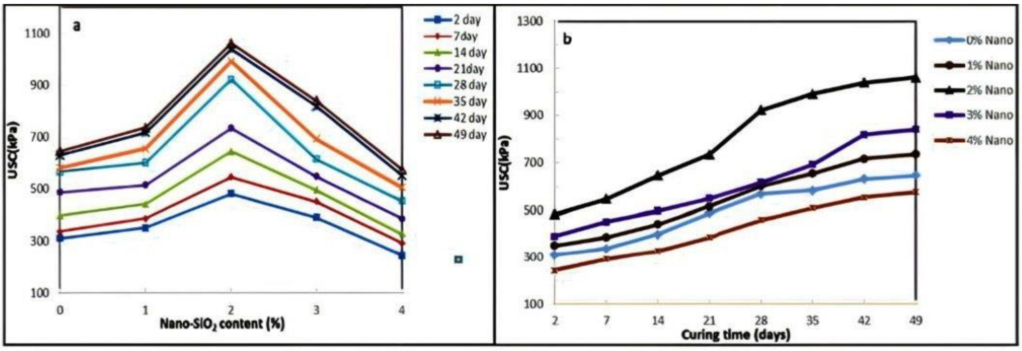

Figure 13: Strength variations of clay with nano silica combination (a) content of nanoparticles and (b) curing period [25].

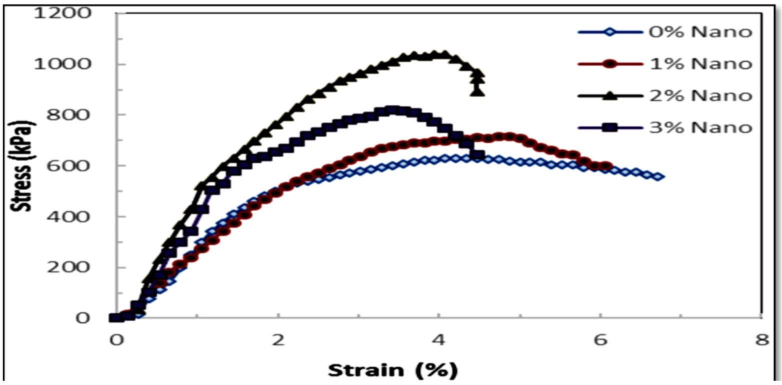

Figure 14: Impact of nanosilica on the stress-strain behavior [25].

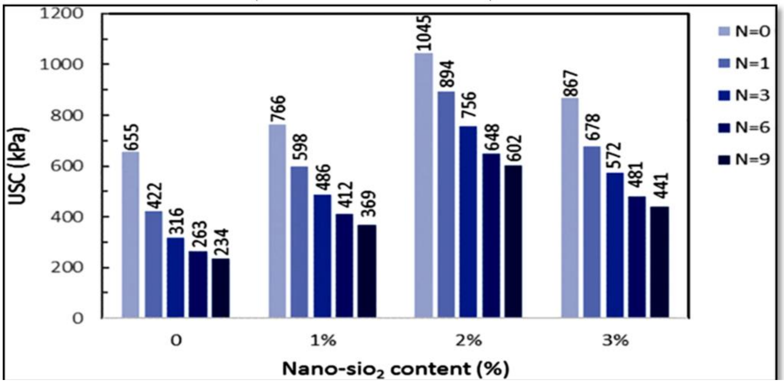

Figure 15: Effect of Nano-SiO_2-stabilized specimens on UCS [25].

Gelsefifi added nanosilica to the soil to test the effectiveness of employing nanomaterials to stabilize weak soil. Road in North Iran acquired the brittle soil and rated it as low-quality pliability clay. The study involved the administration of 50 CBR tests. In the initial step, lime's impact on the weak soil's stability was investigated. The findings demonstrated a negligible impact of lime on soil improvement. The impact of Nano-silica on the second step. The study looked at soil-lime combination stability. The results showed that nano-silica substantially impacted the soil-lime mixture, with the CBR strength of the soil and soil-lime being increased by up to 21 and 7.5 times the combination, respectively. The results of this investigation, which also considered the impacts of curing time, demonstrated that adding nanomaterial has a quicker effect on the soil-lime mixture's CBR strength increase. A combination of 5% lime and 3% Nano-silica was the best mixture design for stabilizing the Boodian poor soil [26].

In order to improve the Earth, scientists introduced two types of additions with the same elemental structure but differing particle sizes: nano silica and micro silica. Both additions' effects on the mud's geotechnical properties were compared through experimental studies. After 28 days of processing, samples were analyzed, and the maximum percentage added for both additives was 6%. Differences in consistency limits, sample pressure conditions, and the soil's undamaged shear strength were measured for each blend. The findings of the unconfined compression test revealed that the influence of nano-SiO on the soil's unconfined compressive strength and modulus of elasticity was more pronounced at dosages less than 2%. The strength of the samples is brought near to that obtained for stable samples employing microsilica by increasing the amount of nanomaterials. While microsilica followed a largely steady pattern, samples containing nanosilica showed a greater rate of strong growth in concentrations of less than 1% nanosilica. The maximum dry density dropped to 5% with adding additives, revealing a higher ideal moisture content. For both additions, there were some subtle differences in the plasticity alterations.

In contrast to micro silica, which marginally decreased these parameters, adding more nano-SiO$_2$ increased the liquid limit and soil plasticity index. The soil additions had no discernible impact on the soil's chemical composition, according to X-ray diffraction (XRD). Furthermore, field emission scanning electron microscopy (FESEM) analysis revealed that both materials were critical in lowering porosity and establishing particle integrity [27].

Mohammadi investigated the effects of calcium carbonate nanoparticles on the geotechnical properties of sand-clay soils. 0.3, 0.7, 1.1, and 1.5% of nano-calcium carbonate were added to SC soil that had been treated for 7, 14, or 28 days. The soil also contained 10%, 20%, and 30% clay. The neural network Synthetic and Group technique for data processing was used to quantitatively examine the experimental results. The microstructure of soil samples supplemented with calcium carbonate nanoparticles was examined using X-ray diffraction (XRD) examination of the crystalline phases. Nano-calcium carbonate was added to SC samples, especially those with low clay concentrations, and both the uniaxial and overall compressive strengths increased. It was shown that the optimal calcium carbonate level for soil with 10% clay content and 20% clay content was 0.7%, followed by 1.1% for soil with 30% clay content, as in Figures 16 to 18.

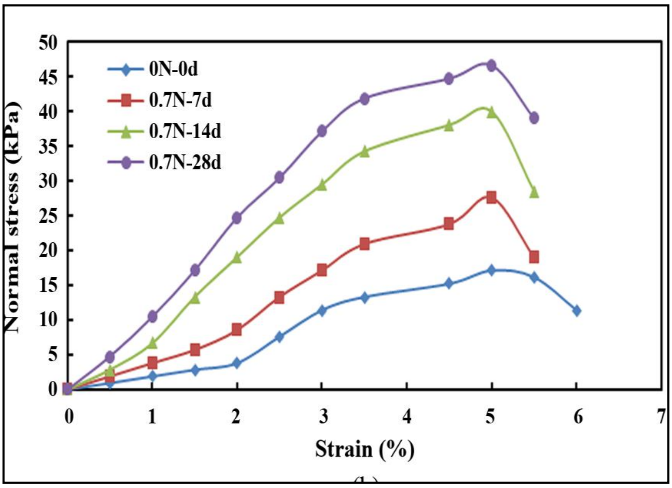

Figure 16: Effect of curing time on UCS for stabilized soil with nano silica [28].

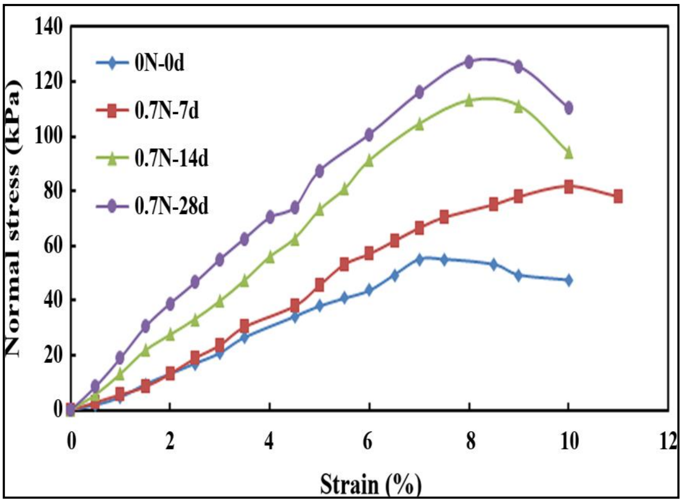

Figure 17: Unconfined compressive strength of soil after 7, 14, and 28 days of curing at Nano-$CaCO_3$ content 0.7% [28].

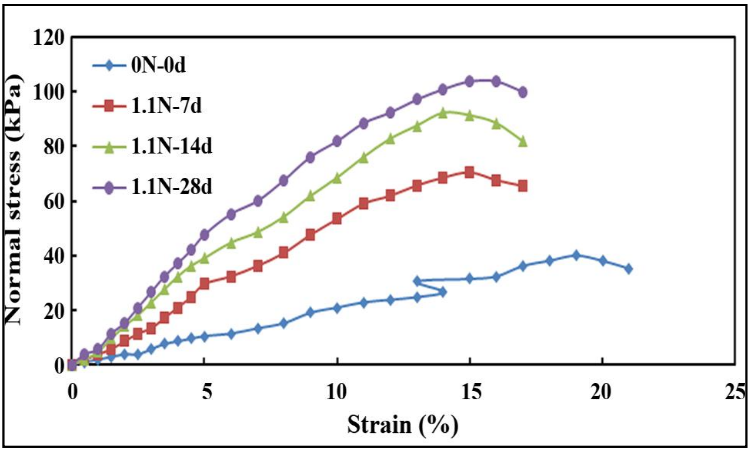

Figure 18: Unconfined compressive strength of soil after 7, 14, and 28 Days of Curing with Nano-$CaCO_3$ contents 1.1% [28].

The calcium carbonate nanoparticles improved the compressive strength of the soil and intermolecular recrystallization, according to the XRD patterns. The correlation between experimental results and the upgraded SC soil's uniaxial compressive strength was found to have an average error of 4% [28]. Yong investigated whether soil stabilizers made from calcium or magnesium hydroxide nanoparticles created using the rapid deposition approach may enhance the engineering qualities of the residual tropical soils. Compaction, Atterberg boundary, falling head permeability, and unconfined compressive strength were among the geotechnical tests utilized to investigate untreated and nanoparticle-treated soils (UCS) engineering properties. Researchers explored the fixation mechanisms connected to soil chemical reactions (EDX) utilizing microscopic technologies such as variable pressure scanning electron microscopy X-ray diffraction (XRD) (VP-SEM) and energy-dispersive X-ray spectroscopy. The researchers discovered that calcium hydroxide and magnesium hydroxide nanoparticles improved the geotechnical properties of the remaining soil by lowering hydraulic conductivity and increasing UCS. The percentages of soil treated with magnesium hydroxide and calcium hydroxide particles that showed hydraulic conductivity after seven weeks of permeability were 84.14% and 98.70%, respectively, compared to untreated soil. Magnesium hydroxide-treated soils experienced a 14-day rise in UCS of 148.05%, whereas calcium hydroxide-treated soils experienced an increase of 180.17% [29], as shown in Figures 19 to 21.

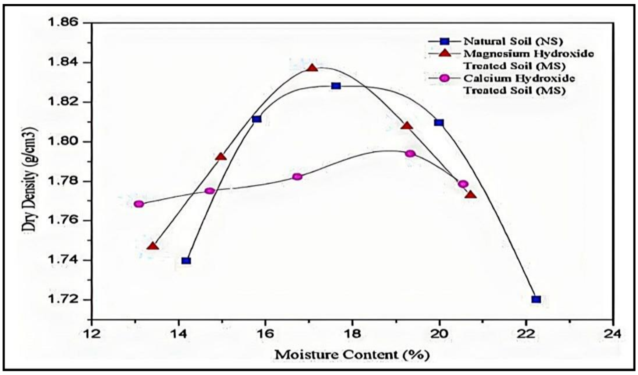

Figure 19**:** Compaction curves of untreated [29].

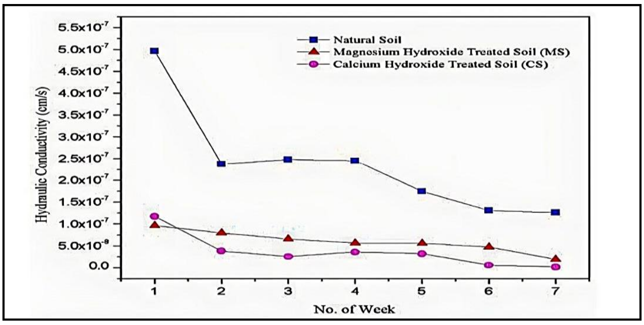

Figure 20**:** Variations of hydraulic conductivity of soil samples treated with nanomaterials and curing time [29].

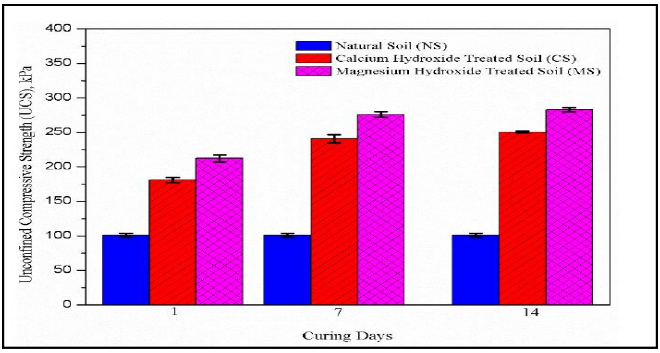

Figure 21**:** Effect of curing time on unconfined compressive strength for treated and untreated samples [29].

Taipodia and Dutta [30] examined how clay's characteristics were affected by nano-calcium dichloride, nano-calcium oxide, and nano-potassium nitrate particles and concluded that the use of nanoparticles increased shear strength, decreased permeability, and decreased compressibility.

4. CONCLUSIONS

The stability and resistance of soil to clay were investigated in this study about the additions of NS, Nano-$CaCO_3$, and limestone. Since they have a unique surface and vigorously interact with other soil matrix particles, these nanoparticles can significantly alter the soil engineering properties even after a brief exposure. This research demonstrated how nanoparticles impact various attributes, including resistance, density, permeability, and pressure. For this study, 30 studies looked at the effect of nanomaterials on soil resistivity. The influence of each type of material can be summarized as follows:

- Lime: Decrease in soil deformation and increase in soil hardness, compressive strength, friction angle, and cohesion.
- Nanosilica: Lower plasticity index and maximum dry density promote ideal water content and increase compressive strength.

- Nano $CaCO_3$: Improving the properties of plastic, including its strength, swelling, and compaction.
- Nanoclay: Improving the strength, swelling, and compaction and promoting ideal water content.

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