Investigation On Application Of Nano-Clay Additives For Development Of Soft Soil Stabilisation

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This research investigates the impact of incorporating nanoclay on the geotechnical qualities of soil. The graphical trend analysis indicates that a rise in nanoclay content results in a decrease in soil density, attributed to the lightweight and porous nature of nanoclay particles. Furthermore, the addition of nanoclay increases both the Liquid Limit (LL) and Plastic Limit (PL), whereas the Plasticity Index (PI) diminishes with elevated nanoclay concentrations, resulting in a reclassification of the soil from "Clay of Intermediate Plasticity" to "Silt of High Plasticity." Moreover, elevated nanoclay content results in increased dry density, indicating improved soil compaction. Mechanical studies demonstrate fluctuations in compressive strength concerning axial strain and nanoclay content, highlighting their influence on soil strength. Scanning Electron Microscopy (SEM) corroborates these findings, demonstrating effectiveness of nano-clay addition in soft soil for its stabilization.

Keywords: Soil, Clay, Strength, Compression, Strain, Stress.

1. Introduction

This paper examines the essential significance of soil stability in civil engineering and construction, as it constitutes the foundation for constructed environments [1]. Soft soils, marked by poor shear strength and excessive compressibility, provide considerable obstacles for infrastructure building. These soils are susceptible to settlement, erosion, and inadequate load-bearing capability, requiring costly and labour-intensive rehabilitation measures [2], [3]. Researchers are utilising nanotechnology, specifically nano-silica and nano-clay, to overcome the intrinsic limits of soft soils in the pursuit of sustainable geotechnical solutions. Conventional stabilisation techniques, such cement and lime, possess environmental disadvantages and may not consistently be the most effective. Nano-silica and nano-clay offer a viable alternative for improving the geotechnical qualities of soft soils while minimising environmental effect. Nano-silica, consisting of nanoscale silicon dioxide particles, has demonstrated a substantial enhancement of soil mechanical characteristics owing to its elevated surface area and reactivity. Nano-clay, composed of nanometer-sized mineral particles, possesses distinctive properties including elevated cation exchange capacity and swelling potential, which can be utilised to alter the behaviour of soft soils. Researchers have investigated the efficacy of utilising high calcium fly ash and cement to stabilise fine-grained clayey soils (CL, CH) [4], [5]. A series of experiments, encompassing uniaxial compression, tensile strength, flexural strength, modulus of elasticity, and 90-day soaking California Bearing Ratio (CBR) values, were performed on soil samples with differing proportions of fly ash and cement. The research contrasted pavement structures utilising subgrades enhanced by in situ stabilisation with fly ash and cement to traditional flexible pavements lacking stabilised subgrades. Utilising high calcium fly ash and cement to stabilise clayey soils provides technical benefits in pavement construction, particularly concerning construction and traffic loads. The development of hydraulic compounds during curing, especially tobermorite, enhances soil density and stability. The incorporation of cement augments setting and hardening, hence enhancing both initial and ultimate strength. The stabilisation with fly ash and cement greatly enhanced mechanical qualities. Implementing appropriate methods to mitigate cracking in the stabilised layer might also result in decreased pavement thickness, especially in the asphalt layer. The study recognises that laboratory results necessitate confirmation via in situ experiments to get more accurate estimates for the mechanical properties of the stabilised layer under real-world settings [4].

In a separate study, researchers examined nucleation seeding with nano-silica, which enhances cement hydration by offering nucleation sites for C–S–H seeds. The acceleration is intricately linked to the surface area of nano-silica particles, as evidenced by research involving various particle sizes and surface areas. In-situ XRD tests demonstrated that nano-silica enhances the consumption of C3S and the synthesis of portlandite during cement hydration, with both processes affected by the surface area of the nano-silica. The incorporation of nano-silica into standard Portland cement markedly elevates hydration heat, accelerating the synthesis of portlandite and the consumption of C3S in the initial hours. This verifies that the hydration of C3S is expedited by nano-silica, with the process predominantly influenced by the overall surface area of the particles. Moreover, the incorporation of nano-silica facilitates the premature development of sulphate-type AFm phases, indicating that nano-silica is significant in interactions involving sulphate-containing phases during cement hydration. A hypothesised mechanism is the capacity of nano-silica to adsorb ions from the solution, hence modifying the specific sulphate equilibrium and influencing the kinetics of sulfate-type AFM production.

Researchers have investigated the use of nanotechnology in geotechnical engineering, concentrating on nanomaterials (NM) and their potential for soil stabilisation and enhancement. Nanomaterials, encompassing nanoparticles and nano objects, are characterised as materials with dimensions less than 100 nm, with nano objects being even smaller. This study emphasises the promise of nanotechnology in geotechnical engineering in two principal domains: comprehending soil structures at the nanoscale and altering soil at the atomic or molecular level via the incorporation of nanoparticles. The document examines the application of sophisticated instruments, including SEM, TEM, and AFM, for the analysis of soil nanostructures [15]-[18]. Nanoparticles possess a substantial specific surface area, rendering them highly reactive with other soil particles. Even minimal quantities of nanoparticles can significantly influence soil characteristics, such as strength, permeability, and resistance to deformation.

This research investigates the novel application of nano-silica and nano-clay as soil stabilisers. The article explores the fundamental mechanisms and advanced approaches for integrating these nanomaterials into soft soils. The research assesses the geotechnical enhancements attained, including augmented shear strength, diminished compressibility, and improved durability. The research underscores the environmental and economic benefits of employing nanomaterials in soil stabilisation, presenting a more sustainable strategy for infrastructure development by diminishing dependence on energy-intensive and ecologically detrimental technologies.

2. Methodology

2.1 Sample preparation

Five samples, as specified in Table 1, were prepared for examination. The initial sample, consisting of soft soil, functioned as the base sample, whilst the subsequent sample was formulated by incorporating 1% nanoclay into the soft soil. The third, fourth, and fifth samples were formulated by integrating 3%, 4%, and 5% nanoclay, respectively, into the soft soil.

At the optimal moisture content linked to the soil's maximum dry density, the samples were mixed with the malleable soil. After being prepared, the samples were analysed using X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) to determine the shape of the soil particles.

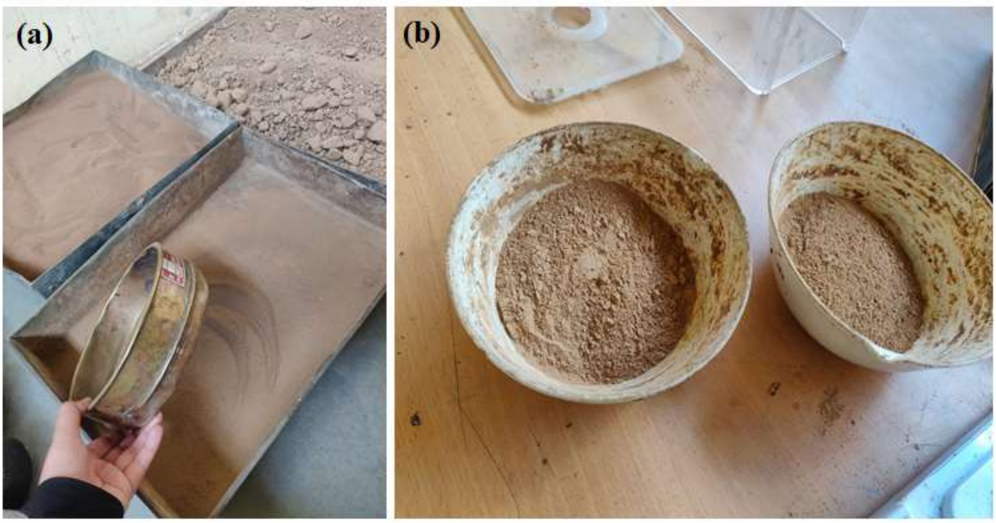

Figure 1 Sample preparation

The fundamental tests performed on the samples comprised the Unconfined Compressive Strength (UCT) test, compaction test, and Atterberg limits test, all adhering to the BS 1377:1990 requirements. The compression and consolidated draining tests were conducted by compacting the materials into moulds. To maintain moisture content, the samples designated for UCT and compaction tests were enveloped and stored at ambient temperature until testing, permitting adequate time for the interaction between the soil and various nanoclay percentages (1%, 3%, 4%, and 5%) to occur.

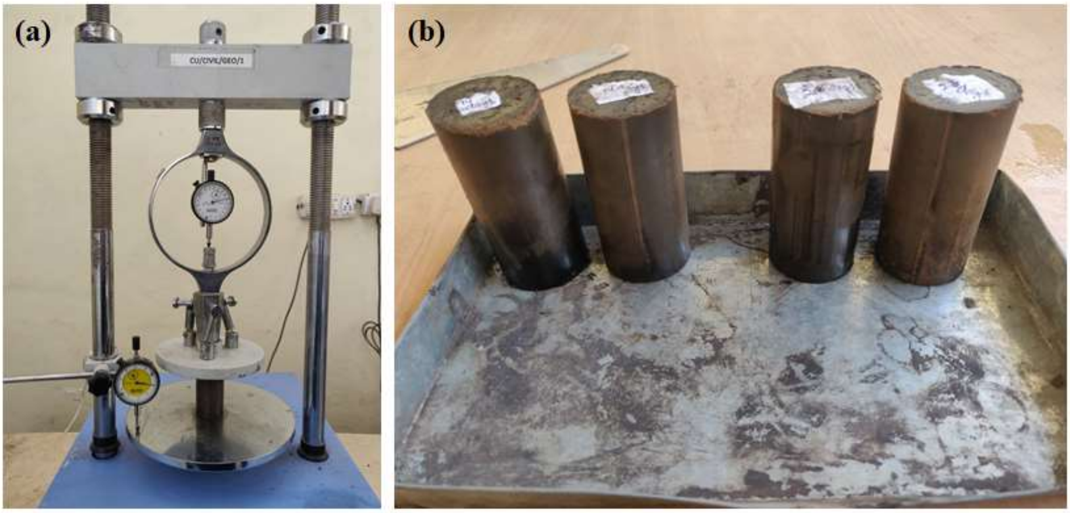

Figure 2 Sample preparation by compaction

Table 1 Sample nomenclature

Sample ID	**Constituents**
SS	Soft soil
1% NC	Soft soil + 1% nanoclay
3% NC	Soft soil + 3% nanoclay
4% NC	Soft soil + 4% nanoclay
5% NC	Soft soil + 5% nanoclay

The amalgamation of these components, specifically Nano-Clay and soft soil, is needed for exploration. Nanoclay should initially be blended separately with the soft soil, followed by tests utilising various combinations in compliance with ASTM and pertinent Indian Standard norms.

3. Results and Discussion

3.1 Result analysis of specific gravity

The specific gravity results show (figure 3) a decrease in specific gravity as the percentage of nanoclay increases:

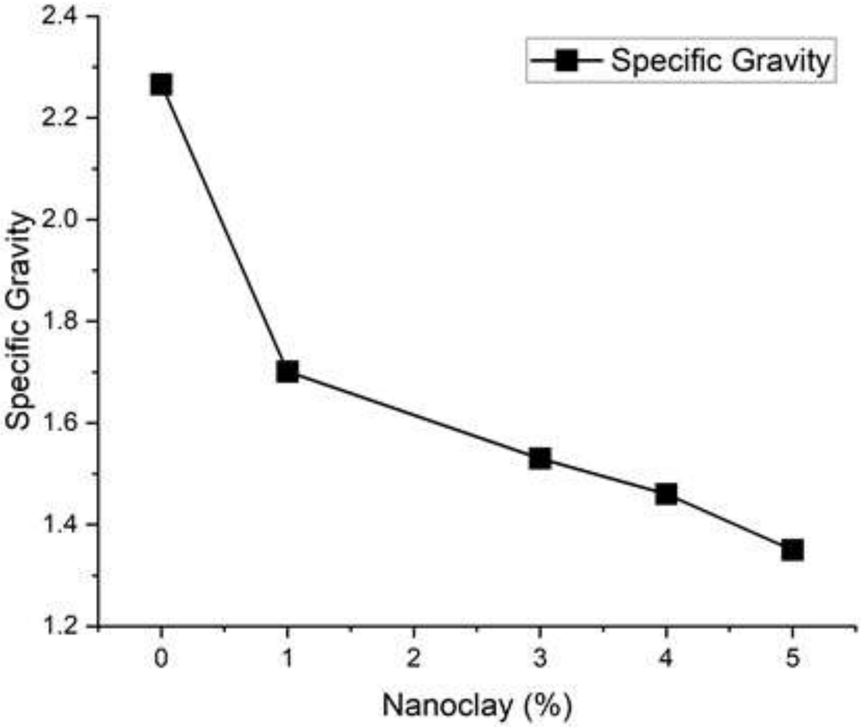

Figure 3 Nanoclay% v/s Specific gravity of soft soil and stabilized soft soil

The present graphical trend (figure 3) indicates that an increase in nanoclay content within the soil correlates with a decrease in soil density. This may result from the lightweight and porous characteristics of nanoclay particles, which diminish the overall density of the soil when integrated in substantial amounts.

3.2 Result analysis of Atterberg limits

The findings of this study indicate that the liquid limit and plastic limit exhibit a little increase with the rising nano-soil concentration. Conversely, the plasticity index exhibited a decline as the nano-soil concentration increased. According to the categorisation from the plasticity chart, the soft soil stabilised with nano-clay is categorised as silt of high plasticity, whilst the unstabilized soft soil is categorised as clay of intermediate plasticity, reflecting the increased percentage of nano-clay. Taha (2009) noted that markers of soil stabilisation and improvement of soil qualities include a reduction in the plasticity index. The incorporation of nano-clay elevates both the Liquid Limit (LL) and Plastic Limit (PL) values. As the proportion of nano-soil rises, the Plastic Index (PI) often diminishes. This indicates that the incorporation of nano-soil modifies the soil's plasticity properties, transforming it from a clay type to a higher plasticity silt type with increased nano-soil content.

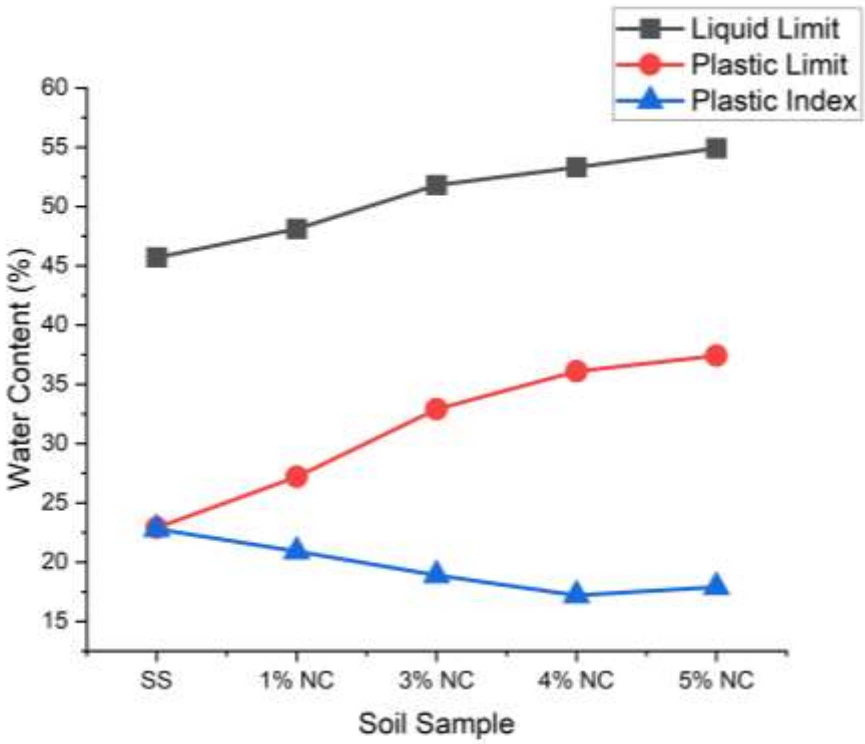

Figure 4 Liquid limit, Plastic limit and Plastic index of samples used w.r.t. water content

3.3 Result analysis of compaction test

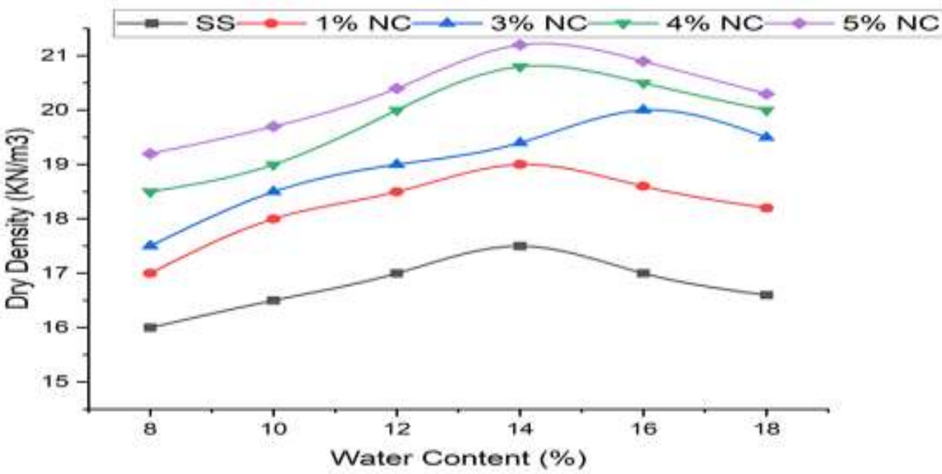

Figure 5 Compaction response with different percentage of nanoclay

Figure 5 illustrates the relationship between water content (%) and dry density (in kilonewtons per cubic meter, kN/m^3) across several soil compositions, encompassing soft soil and soft soil blended with differing proportions of nanoclay (1%, 3%, 4%, and 5%). As the moisture content rises from 8% to 18% (figure 4.3), a trend of rising dry density is observed across all compositions. Comparison of the dry densities of soft soil and soft soil augmented with nanoclay additions:

- The addition of nanoclay enhances the dry density of soft soil at equivalent water content.
- An increase in nanoclay percentage correlates with a rise in dry density, suggesting that nanoclay incorporation enhances soil compaction and density.
- The fluctuations in dry density across varying water contents and nanoclay percentages underscore the impact of these variables on the overall density and compaction properties of the soil mixtures.

3.4 Result analysis of UCS test

The table gives data on axial strain (%), indicating the deformation of the soil sample during axial compression, and compressive strength (in kilonewtons per square meter, kN/m²) for various soil compositions.

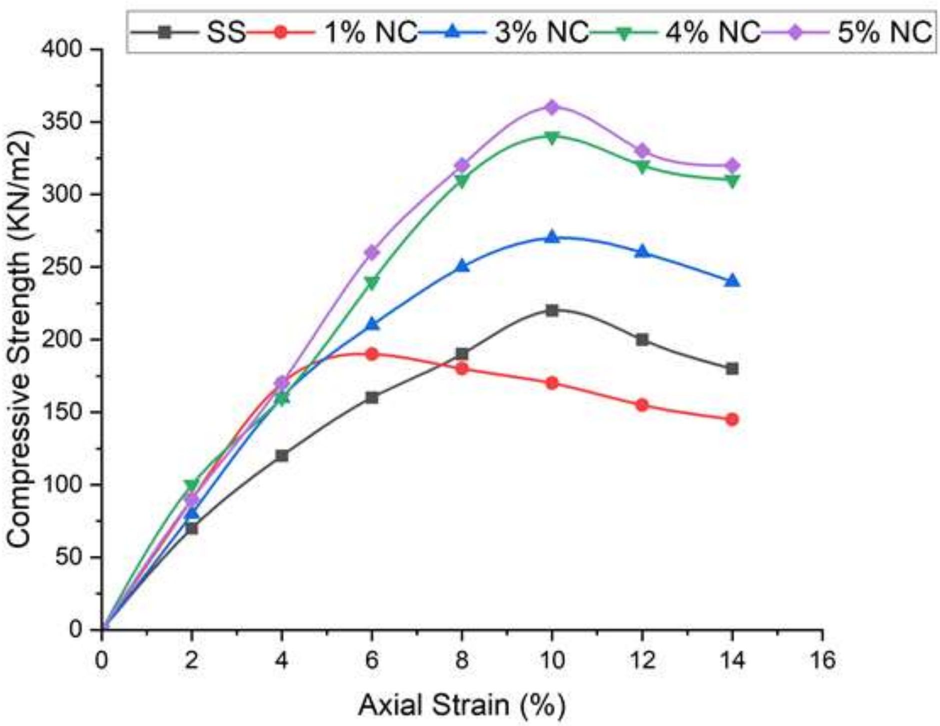

Figure 6 Axial strength versus Compressive strength (UCS test) for varying percentages of nanoclay

As the axial strain escalates from 0% to 14%, indicating heightened compression on the soil sample, the compressive strength typically rises across all compositions. Analyzing the compressive strengths of soft soil versus soft soil augmented by nanoclay additives:

- The incorporation of nanoclay often enhances the compressive strength at equivalent levels of axial strain when compared to soft soil alone.

- The compressive strength generally increases with higher nanoclay percentages, suggesting that the inclusion of nanoclay enhances the compressive strength properties of the soil mixtures.
- The fluctuations in compressive strength at varying axial strain levels and nanoclay percentages illustrate the impact of these variables on the mechanical behaviour and strength of the soil samples during compression.

3.5 SEM and XRD Characterization of Samples

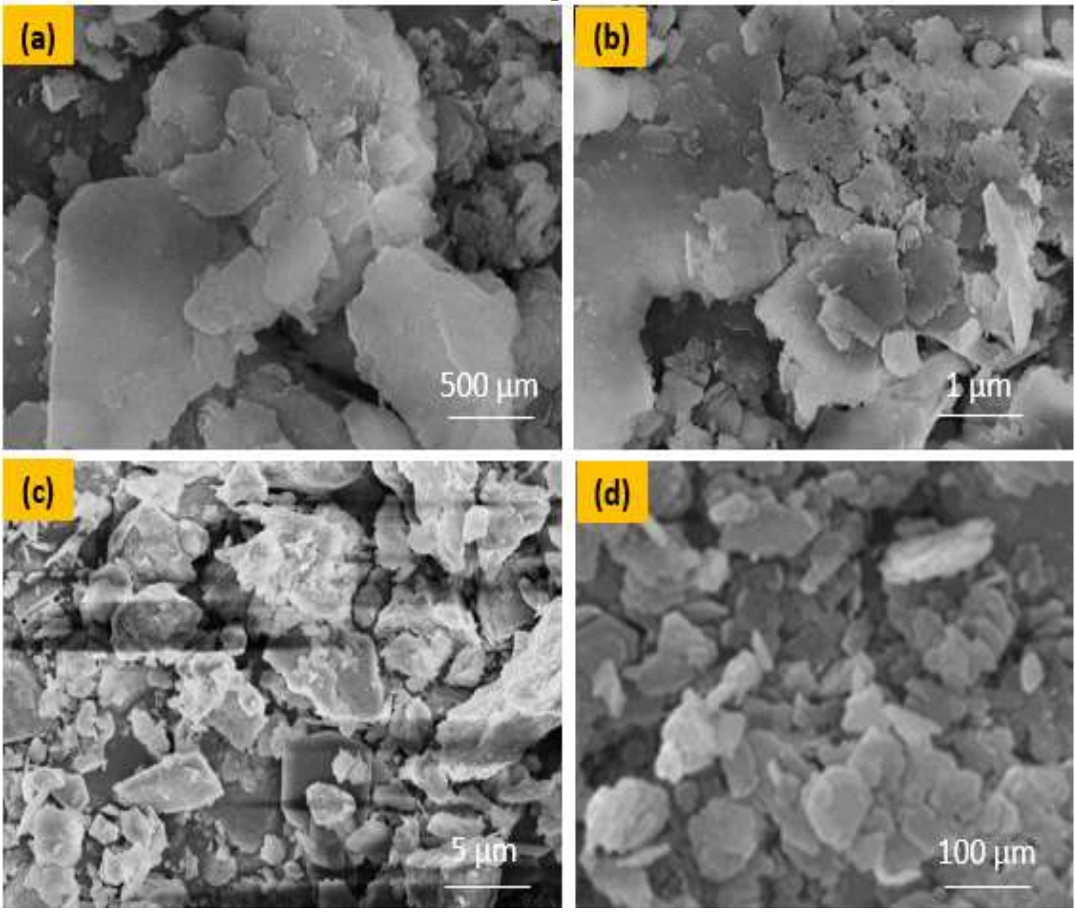

Figure 7 SEM images at 500x (a) Soft soil (b) Soft soil+1% Nanoclay
(c) Soft soil+3% Nanoclay (d) Soft soil+4% Nanoclay (e) Soft soil+5% Nanoclay

It is challenging to draw meaningful inferences from scanning electron microscopy pictures since the images only provide a visual depiction of the sample surface. During a 28-day curing period, samples of 1%,3%,4%, and 5% were administered to the treated soil in order to provide evolution images using scanning electron microscopy. SEM was used and the results were displayed. Sample preparation and operator-captured images are only two of many factors that impact the soil hydration system. As an example, operators may inadvertently change measurements when using extremely tiny particles to take pictures after magnification, often without realising it or understanding the consequences of the images. From the same sample, we can see that some soil is suitably hydrated and some is not. Therefore, it is reasonable to assume that the SEM images are sample-based, and any conclusions drawn from them should be evaluated in the context of that specific image rather than applied to other domains. By revealing the microstructures of the clay, SEM analysis confirmed the earlier claim. Figure 7 shows scanning electron microscopy (SEM) images of soil that has been combined with different percentages of clay and then cured for 28 days to show how the clay has dispersed. This diagram shows how particles can be randomly absorbed into a matrix of clay and hydration products. As the pozzolanic reaction takes place between fine clay minerals and hydrated products, the images show that these processes can happen without clay particles being involved in hydration. They also show how the stabilised clay structure is connected to the clay particles. Stabilised clay contains sand and silt particles inside its matrix due to the binding of sand particles to a stabilising paste by cement hydration products, including CSH, which sticks to the surface of the clay. As mentioned before, a small amount of clay and silt particles can be used as a strong and stable mixture.

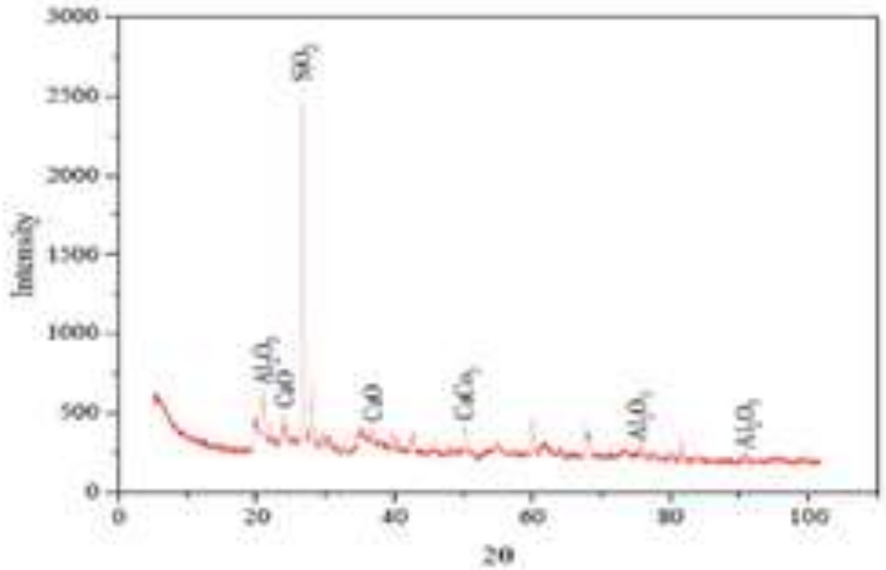

Figure 8 XRD pattern of soft soil

After 28 days of curing, samples with different percentages of 1%, 3%, 4%, and 5% were subjected to X-ray diffraction (XRD) analyses. This allowed us to determine the materials' phase composition and identify the main reactive chemicals, which included CH, CASH, CaCO3, C-S-H, and SiO2. After 28 days of curing, Figure 4.5 shows the aggregated X-ray diffraction patterns of the Admixture, Virgin, and soil samples that had different amounts of calcined clay added to them. Based on XRD analysis, the main components include CSH, CASH, CaCO3, CSHH, SiO2, and CH. The strength of the CSH peaks is increasing, while the intensity of the other peaks is decreasing. An analysis of the treated soil at4%,6%,8%, and 10% using XRD data confirmed the results obtained using SEM. The inclusion of CSH compounds significantly amplifies the reduction of CaCO3-(CH) in all four combinations, which improves soil strength by showing that the treated soil's hydration reactions are unimpeded. A change in the mineralogical structure and quantitative crystalline compounds is shown by the XRD spectra pattern. The spectrum shows that there are fewer crystalline phases because more material is used to improve particle bonding.

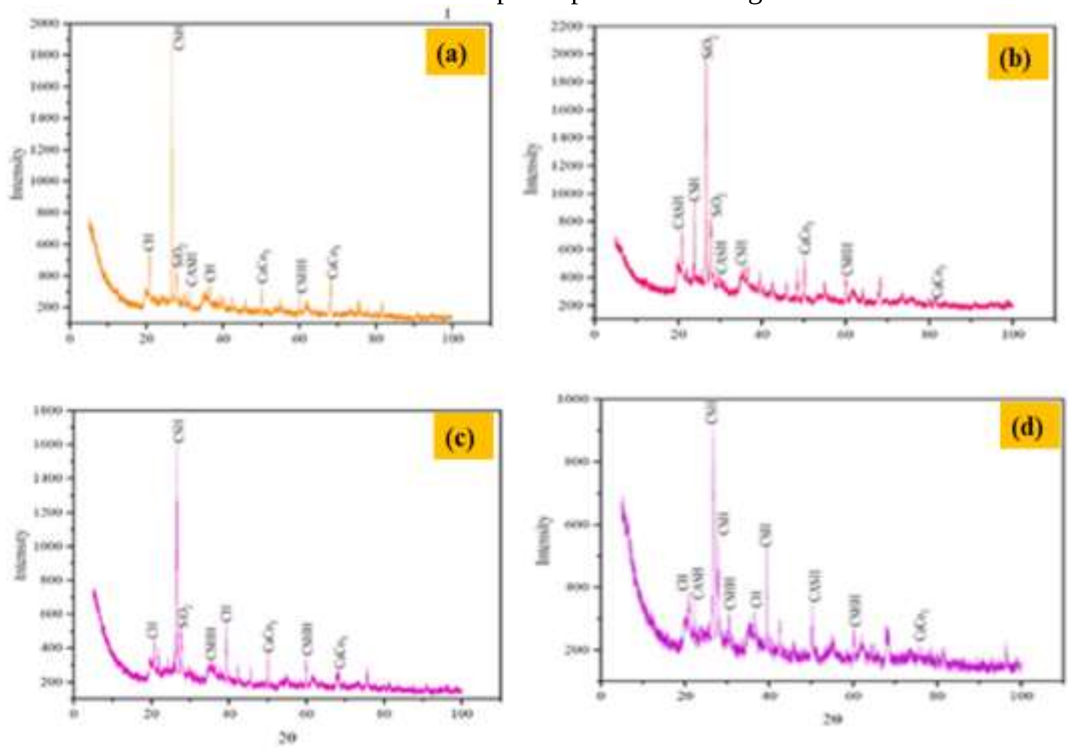

Figure 9 XRD pattern (a) Soft soil+1% Nanoclay
(b) Soft soil+3% Nanoclay (c) Soft soil+4% Nanoclay (d) Soft soil+5% Nanoclay

5. Conclusion

- The prevailing graphical trend indicates that an increase in nanoclay content in the soil correlates with a decrease in soil density. This may result from the lightweight and porous characteristics of nanoclay particles, which diminish the overall density of the soil when integrated in substantial amounts.
- The incorporation of nano-soil enhances both the Liquid Limit (LL) and Plastic Limit (PL) values. As the proportion of nano-soil rises, the Plastic Index (PI) often diminishes. The control soft soil is categorised as "Clay of Intermediate Plasticity," whereas the soil with added nano-soil (3%, 4%, and 5%) is categorised as "Silt of High Plasticity." This indicates that the incorporation of nano-soil modifies the soil's plasticity properties, transitioning it from a clay type to a higher plasticity silt type with increased nano-soil content.
- The dry density increases with larger percentages of nanoclay, suggesting that the introduction of nanoclay enhances soil compaction and density.
- The differences in compressive strength at various levels of axial strain and nanoclay percentages illustrate the impact of these parameters on the mechanical behaviour and strength of soil samples under compression.

- SEM examination substantiated the previous assertion by elucidating the clay's microstructures.

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