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Experimental Study of Physio-Mechanical and Engineering Properties of Clayey Soil Incorporating Hydraulic Lime and Nano-Silica

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ABSTRACT. *Soil is one of the most abundant and frequently used materials in geotechnical engineering and construction. Soil is heterogenous material with different minerals some of which are classified as problematic minerals. The soil is classified as unacceptable for construction purpose if some of these minerals are present in the soil. Soil improvement utilizing nano materials is a novel technique to upgrade engineering and shear strength parameters of problematic soils. The effects of varying amounts of nano-silica and lime in clayey soil are investigated in this study. For this purpose, soil samples were molded by incorporating 0, 3, 6, 9% nano silica and 0, 5, and 10% lime. The samples were tested for Atterberg limits, Plasticity index, optimum moisture content OMC, maximum dry density MDD, swelling, and unconfined compressive strength (UCS) at 7 and 28 days. The results revealed that addition of nano-silica in lime treated high plastic clay improved the plasticity index as well as UCS and swelling behavior by a significant margin. Results highlighted that incorporation of nano silica reduced the plasticity index. UCS values of the soil increased by adding nano silica 28 days UCS increased by 10 times as compared to 7 days strength. The swelling in soil samples with 10% lime and 9% nano silica is reduced by almost 32% as compared to controlled samples. OMC is also increased by 17% meanwhile MDD is reduced by 9% when nano silica was added. The findings of this study can be used in any project that requires improved engineering and geotechnical properties of high plastic clayey soil for shallow foundations.*

Keywords: Hydraulic lime, Nano-silica, soil improvement, UCS, swelling, curing time

1. INTRODUCTION

Soil is one of the most abundant and used materials in the construction and ground exploration. Almost all construction is done on ground or underground bringing soil into the equation [1]. The earth crest is made of different rocks and soils having extremely variable size, chemical and mineral composition. These varying soil particle size and mineral composition are classified into different groups and classes according to two main classification systems. American Association of State Highway and Transportation Officials AASHTO and Unified Soil Classification System USCS [2]. Naturally, soil is a heterogeneous material consisting of clay minerals and disintegrated rock particles of varying mean size. These clay minerals have different chemical composition, physio-mechanical properties and engineering properties [3, 4].

There are some soil types which are not suitable for construction such as expansive soils, high plastic clays, organic soils, and peat soils etc. When these types of soils are encountered during geotechnical site investigation and ground exploration, these soils must be treated, removed, replaced with soil having desired parameters or improved by using soil improvement techniques [5]. Soil improvement and stabilization is the exercise of upgrading the engineering characteristics i.e. compressive strength and compaction, physio-mechanical properties i.e. shrink swell potential, density and moisture content, and index properties i.e. Atterberg limits and plasticity index of in situ soil [6].

High plastic clays are one of the most abundant soils among the group of problematic soils. High plastic clay is a type of soil which consists of dominant fraction of fines and has very high liquid limit (L.L) low plastic limit (P.L) and high plasticity index (P.I) which make this type of soil unacceptable for construction purposes [7]. One of the most successful strategies for improving engineering and physical parameters of soil such as compressive strength, consolidation, and swelling is the addition of chemicals known as additives [8].

There are various soil stabilization and improvement techniques such as deep mixing, grouting, dynamic compaction, lime and cement treatment, geopolymers, waste products, chemical stabilization, and use of nano materials [9]. In the past decades, deep mixing and grouting has been used for the soil improvement but in modern world these techniques have become obsolete. Nanotechnology can be used in geotechnical engineering to upgrade physio-mechanical behavior of soils and make them more appropriate for construction projects. Incorporation of nanomaterials is an advanced technique in which nanomaterials are utilized as an addition in problematic soils [10-12]. The addition of nano-silica to fine-grained soils improves the mechanical behavior and engineering properties of the high plastic clays [13, 14].

Nano-silica gives the best results when used along an alkali activator. Lime, cement, and sodium hydroxide have been used as activators in the past [15]. Nanomaterials have been used in soil, either directly or as a supplement to a stabilizing component like lime. Lime is a significant resource that is often used for stabilization in a wide range of construction applications [16]. Jahangeri et al in 2015 studied the impact of nano silica. Their results revealed that adding nano-silica in lime treated clay significantly improved the Plasticity index of the clay, UCS, and swelling of soil samples. Adding nano-silica to high plastic clayey soil coupled with calcium and silica rich chemicals allowed the strength of the soil to increase [17]. Seyed Ali Reza et al 2018 published their work, they used nanomaterials to evaluate the upgradation of a medium plastic clay. In their research they used cement treated high plastic soil as base sample and mixed the soil with a combination of two compounds slaked lime and nano silica.

They concluded that the slaked lime acts as an activator for nano silica particles to react with the clay particles and cement to produce calcium silicate hydrate C-S-H gel. In another study, a total of eighty UCS tests were conducted. The findings revealed that lime had a minor impact on soil improvement without the addition of any additive. The outcomes indicated that adding nano-silica to the soil-lime mixture had a relevant and substantial effect. Both the UCS and the shear strength of soil are upgraded by adding nano-silica but the research lacks data regarding the improvement in swelling and shrinkage [18, 19].

Abhay Malik et al 2019, gave detailed insights on the effects of adding nano-silica to clayey soil. A series of experiments on soil having nano-silica concentration of 5%–20% by weight of dry soil was carried out. Thorough study of this research revealed the dispersion of nano-silica is extremely difficult because of its extraordinary small sized particles [20]. Nezhad et al 2021, published a research paper on treatment of gas oil-contaminated clay. They utilized lime as a typical addition and nano-silica as stabilizing material. The pollutant raised the liquid limit (LL) and plastic limit (PL)of soil samples while lowering its MDD and OMC [21]. Khelifa et al 2011 analyzed how lime and pozzolana, affect the physio-mechanical properties of two cohesive soils. These soils were treated with 0-8 percent lime and 0-20 percent natural pozzolana.

The findings of their study showed that mixture of lime and natural pozzolana improved the cohesion and internal friction angle [22]. Kulanthaivel et al 2022, investigated results of a laboratory inquiry into the application of nano-silica (0.2 to 1.0% at an interval of 0.2) and polypropylene fiber (0.25-1.0% at an interval of 0.25) in clayey soil to upgrade compaction and shear strength [23, 24]. It is evident from the literature that swelling behavior UCS Atterberg limits optimum moisture content and maximum dry density can be improved by adding appropriate additives. The goal of this research is to analyze how nano-silica used as a pozzolanic addition affects the engineering and physio mechanical behavior of clayey soil when used with hydraulic lime. For this purpose, UCS, swelling, Atterberg limits, compaction, plasticity index, MDD and OMC are studied.

2. METHODOLOGY

To investigate the effects of nano-silica on lime-stabilized high plastic clayey soil, extensive lab testing was performed. The problematic soil was collected from Gujranwala Pakistan. Soil samples were made by adding 0, 3, 6, and 9 percent nano-silica as well as 0, 5, and 10 percent hydraulic lime by weight of soil. Index properties and Physio mechanical behavior of the collected soil was observed. For index properties, Atterberg Limits, and standard proctor test was performed. The UCS and swelling test was done to analyze the engineering properties and physio mechanical behavior of soil samples. Effect of curing time on soil samples was also studied by testing the molded samples at 7 and 28 days. The results of the study are outcome of average of three remolded soil samples for each test.

2.1. Experimental Program

The ASTM D4318 technique was used to determine the plastic (PL), liquid (LL), and plasticity index (PI) limits. Casagrande apparatus was used to find out liquid limit while threading method was adopted to calculate plastic limit of samples. The ASTM D698 testing method was selected to determine MDD and OMC by the help of standard proctor test. ASTM D 2166-87 method was adopted to determine UCS of remolded soil samples. The size of the UCS mold was adjusted at 150mm diameter and 300mm height according to ASTM D2166-87. All soil samples made for UCS test were compacted by kneading up to 90% and 95% compaction. Test was performed on soil samples after 7 days and 28 days of curing. Soil samples were placed in airtight polythene bags for curing to avoid the loss of moisture Swelling tests on samples were also performed in accordance with ASTM D4546 to complete testing protocols and investigate the effects of nano-silica and lime on soil swelling properties.

3. RESULTS AND DISCUSSIONS

Soil samples incorporating 0, 3, 6, 9% nano silica and 0, 5, 10% hydraulic lime were tested for L.L, P.L, P.I, OMC, MDD, UCS at 90 and 95% relative compaction after 7 as well as 28 days of curing and swelling. Relative compaction of the soil samples for UCS test was determined by dividing the dry density of soil samples from site of collection to the dry density obtained from moisture density relationship. The results of all these tests are given and discussed below.

3.1. Atterberg Limits with and Without Lime and Nano-Silica

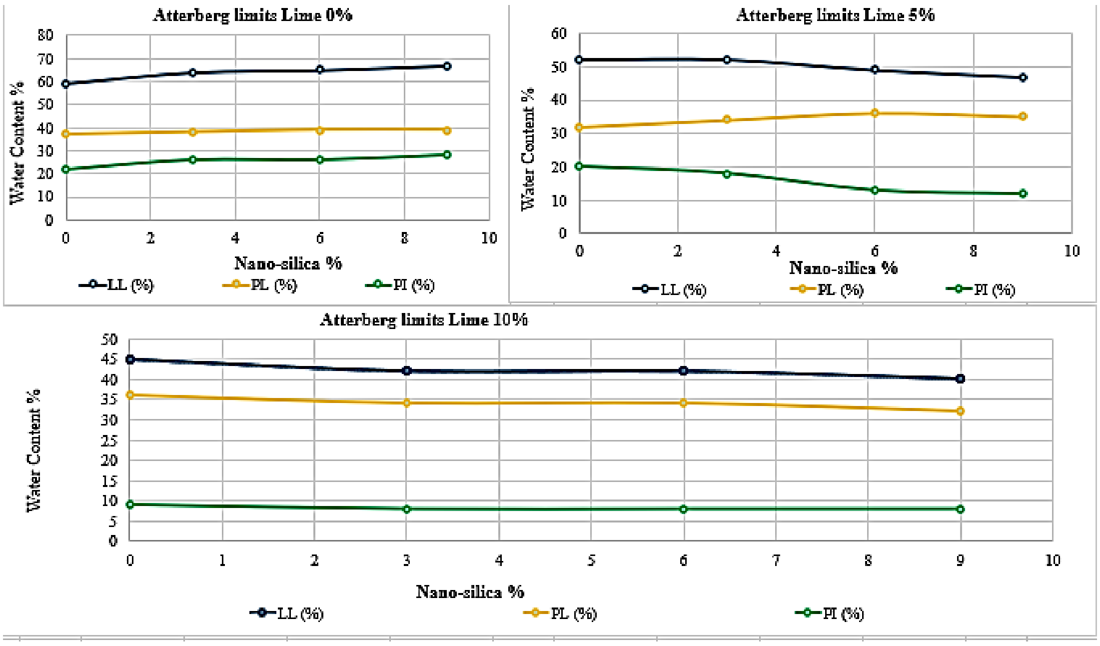

Fig-1: Graphical representation of Atterberg Limits at 0,5,10% Lime and 0, 3, 6, 9% Nano silica Content.

Above given figure indicates the L.L, P.L, P.I of the soil samples containing nano silica from 0-9% and hydraulic lime from 0-10%. The first graph highlights the results of soil specimen without lime treatment second and third graph represents results of soil samples with lime treatment. It can be seen from the graphs that the liquid limit is very high in soil without lime treatment and shows a downward trend from low to high percentage of lime and nano silica. At 10% lime the liquid limit of soil samples is lowest as compared to other two graphs. At this point the plastic limit and plasticity index are also lowest compared to the liquid limits and P.I of other two graphs. C-S-H gel, which is a byproduct of the reaction between silica from nano silica and calcium from lime, is said to be the cause of the drop in plasticity index liquid limit and plastic limit [2, 25-27]. These two minerals react with each other in the presence of water and form a chemical bond to produce a dense microstructure. This tight packing of soil particles with lime and nano silica caused the reduction in plastic limit and plasticity index [28].

3.2. Standard Proctor Test Results

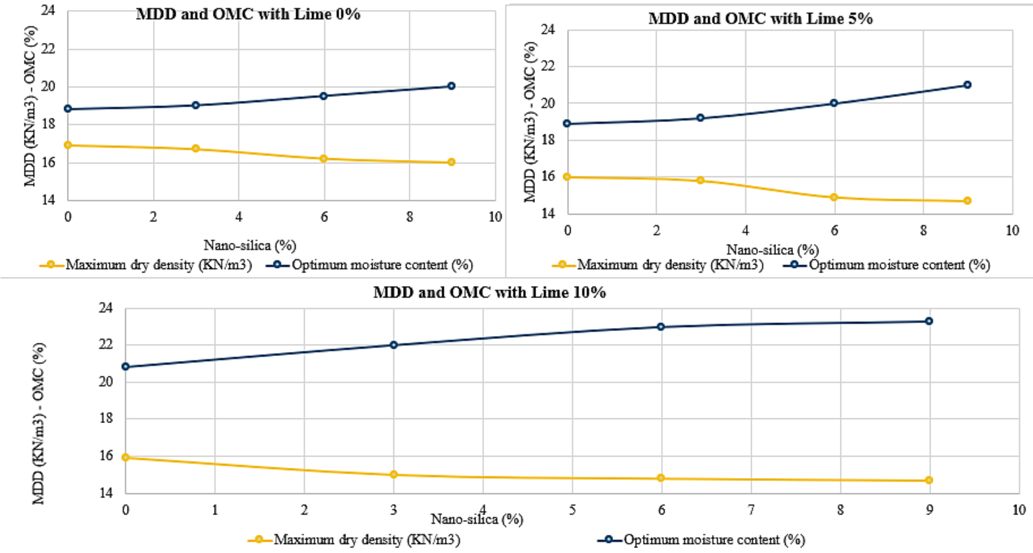

Fig-2: Graphical representation of Optimum Moisture Content and Maximum Dry Density at 0,5,10% Lime and 0, 3, 6, 9% Nano silica Content.

Above shown graphs in figure 2 highlight the results of MDD and OMC calculated by the help of standard proctor test SPT. Graphs show that there is gradual change in unit weight and OMC at zero percent addition of lime but rapid change in MDD and OMC when lime is added. This change is because of the fact that nano silica needs a calcium rich activator to stat the reaction which is lime in this case [16, 29]. The MDD is reduced with the addition of nano silica and lime while the OMC is increased [30, 31].

3.3. Unconfined Compressive Strength Results

Figure 3 represents the results of UCS test performed on soil samples with 90% and 95% relative compaction. The addition of nano-silica to untreated soil has a slight effect on 7 and 28-days compressive strength just because of the curing time. This implies that nano-silica requires the presence of an activator to start the reaction with soil particles. Compressive strength in samples containing lime and nano-silica increased by almost 10 times after 28 days [32-34].

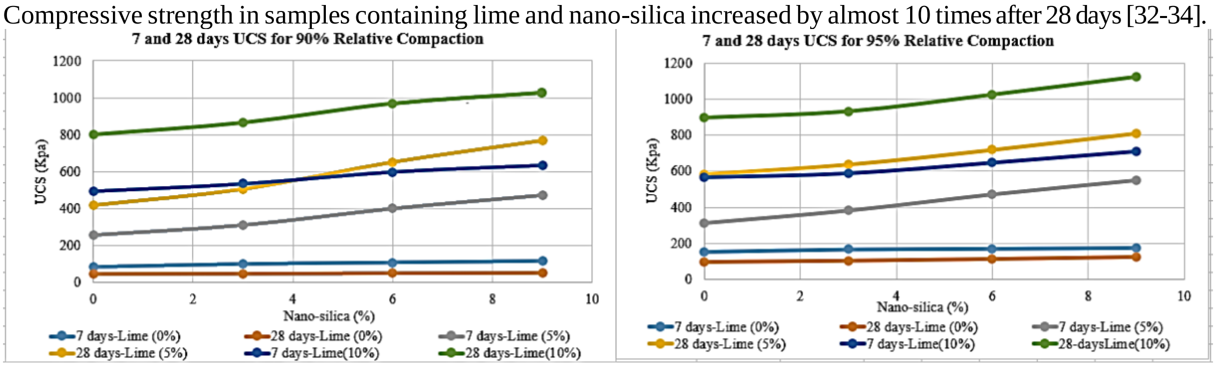

Fig-3: Represents unconfined compressive strength at 0, 5, 10% lime and 0, 3, 6, 9% Nano-silica at 90% and 95% Relative Compaction

3.4. Swelling Test Results

Below given figure 4 shows the results of swelling test. X-axis represents the number of days and Y-axis represents the percentage of swelling. It is evident from the graphs that untreated soil sample have a very high percentage of swelling even with the addition of nano silica as compared to the soil samples with lime treatment. The maximum swelling (38%) is obtained at 0% lime and 0% nano silica at 28 days. The minimum swelling (6%) is achieved by specimen with 10% lime and 9% nano silica at 28 days. The C-S-H gel formed by the hydration reaction of nano silica and lime forms a very dense and closely packed microstructure reducing the permeability of the samples. This reduced permeability of the soil samples resists the swelling [16, 35, 36].

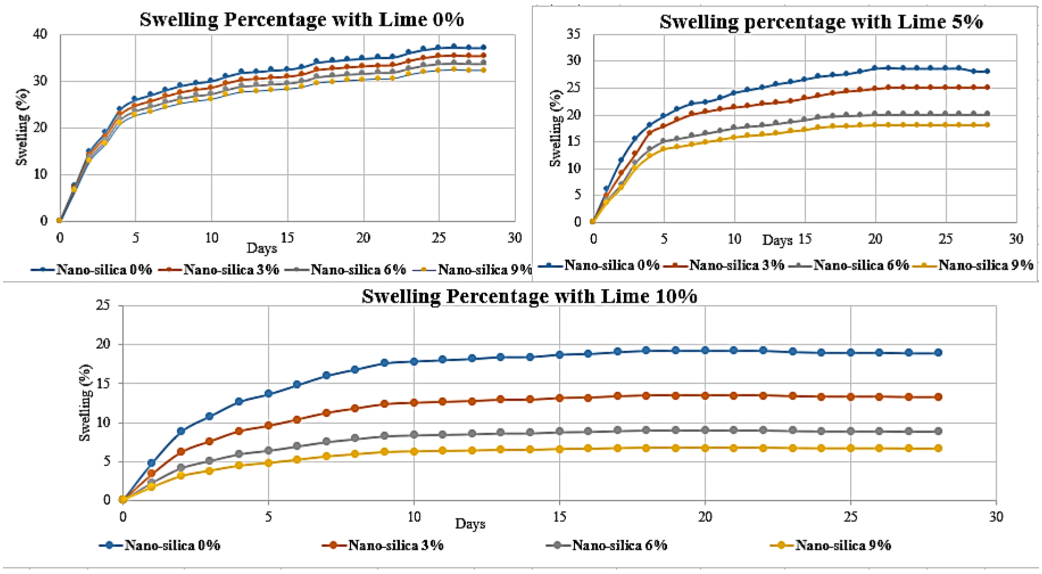

Fig-4: Represents the Swelling Percentage of Soil Samples at 0, 5, 10% Lime and 0, 3, 6, 9% Nano-silica.

4. CONCLUSIONS

- Nano silica particles without lime activator had negligible impact on physico-mechanical behavior and engineering properties of the soil samples.
- Nano silica combined with lime reduced the liquid limit, plasticity index, swelling and MDD meanwhile increased the OMC and UCS.
- Adding 10% lime and 9% nano-silica increased the OMC by 17.3% and reduced the MDD by 9.3% respectively.
- The addition of nano-silica without any activator slightly affected the UCS mainly because of curing time.
- Incorporation of 10% lime and 9% nano-silica to soil increased its 28 days strength by almost 10 times as compared to 7 days strength.
- The addition of nano-silica in the presence of lime reduced the percentage of swelling by a significant margin.
- Swelling after the addition of 9% nano-silica and 10% lime decreased from 36% to almost 6% percent in 28 days.

5. RECOMMENDATIONS

- Nano silica has an extremely small particles size as compared to any type of granular soil or clayey soil. The extremely small size makes the dispersion difficult. The results can significantly be improved by using a dispersion agent.
- Hardening of the clay occurs during the curing process but loss of moisture remains a significant problem. Authors tried their best utilising their resources to avoid the loss of moisture, but more efficient methods can be adopted.
- The availability of nano silica and difficulty in deep mixing makes it limited for shallow depths hence it is limited to shallow foundations.

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