Improvement of Soft Ground Using Nano-Chemical Stabilization

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Abstract. Soft clay soils spread over larger areas of Kerala are very weak to support the overlying structures. The need to stabilize these weak soils arises for the desired strength improvement. A series of unconfined compressive strength (UCS) tests have been performed on untreated and Nano-chemical treated clay soil samples to assess the effectiveness of a nano-chemical as a soil stabilizer. Herein, a nanotechnology-based organosilane compound (Terrasil) is introduced into the clay in various amounts of 0.03%, 0.04%, 0.045% and 0.05% of the dry weight of soil taken for stabilization. The study aims to determine the optimum dosage of nano-chemical corresponding to the maximum UCS after 7 & 14 days of curing. The results indicated that the UCS of stabilized soil increased with the increase in nano chemical dosage. But the increase in strength was high up to a specific dosage, and further, the growth rate decreased. The images obtained from scanning electron microscopy (SEM) support the mechanism behind the strength improvement of nano-chemical-treated clay soils. The chemical interactions between nano-chemical and clay soil make strong bonding and fill the pore spaces. Soft ground with nano chemical treatment has the advantages of lower cost and better environmental protection. The findings will help improve the strength of weak foundation soils, embankment dykes and road pavements.

Keywords: Clay Soil Stabilization, Unconfined Compressive Strength, Nano Material.

1 Introduction

1.1 Background

Low-strength, highly compressible soils with clay or silt on-site make the soil unsuitable for construction activities and pose a problem to civil engineers. It is uneconomical to get the entire soil deposits replaced. The engineering properties of these problematic soils need to be altered to achieve desired values. Ground improvement techniques, including compaction, dewatering, treatment with admixtures, reinforcement techniques, etc., are available to treat the soft clay grounds.

An economical solution to stabilize soils with low strength and high deformation is chemical soil stabilization, in which admixtures are used to improve the properties of soils. Most traditional additives, like lime, fly ash, rice husk ash, etc., require high energy demand for their production, which contributes to global warming [4, 15].

Besides, these have a high cost of excessive maintenance, poor soil structure, leaching away during Indian monsoons, secondary chemical pollution, and detrimental env i-ronmental impacts associated with construction [2]. All the above factors have tended to reduce the application of stabilization with traditional chemicals over the past decade.

At present days, science has advanced far better from the olden days. From an economic point of view, many alternative admixtures are being used nowadays to quicken the process of soil improvement and to avoid delays in construction activities. Thus, many more non-traditional additives are developed from the advanced search for new materials. Research is being carried out in this area using alternative stabilizing agents such as bio-enzymes, nano-chemicals, nanomaterials, ionic polymers, etc., to understand their behaviour in soil [3, 17, 14].

1.2 Stabilization using Nano Materials

Many studies are being conducted on different nano-materials, nano-chemical compounds, etc., to find their effectiveness as soil stabilizers. Unlike traditional materials such as lime and cement, the nano-materials are permanent, non-toxic, biologically and chemically inert, and have excellent durability. The studies conducted by [9, 16] indicated that adding nano-materials to soil leads to an improvement in the strength, Atterberg's limits and a decrease in the permeability properties of soil. Due to its high specific surface area, even a tiny amount of nano-material addition could cause a significant change in the physical and chemical properties of soil [17]. A study on the effect of different nano-materials (nano-clay, nano MgO, and nano alumina) on engineering characteristics showed that an increase in nano -clay content increases Atterberg's limits due to the higher specific surface area of nanoparticles. However, the increase in nano MgO and nano alumina decreased Atterberg's limits [12]. California Bearing Ratio (CBR) strength values increased considerably with nano-chemical addition, and the design of pavement resulted in a reduced thickness of about 25% lower than that with untreated soil due to reactions of clay soil with nano-chemical [10, 11, 8, 13]. Thus, nano-material stabilization will be of great significance in sustainable ground improvement. From all these studies, it is observed that nanotechnology-based stabilization makes the soil slightly less plastic and improves the strength characteristics of the clay soil to a higher degree. Thus, the main focus of this study is to minimize the use of environmentally detrimental traditional stabilizers like cement, lime, etc.

The Objective of the Study

This paper discusses the influence of an organosilane-based nano-chemical addition on the geotechnical engineering properties of a low-strength soil for different curing periods and varying dosages of nano-chemicals. The scope of this paper is limited to studying the variation in the unconfined compressive strength characteristics of a weak soil stabilized with nano-chemical and 1% cement after 7 and 14 days of curing period.

2 Materials and Methods

2.1 Materials

The natural untreated clay soil used in the study has been procured locally from Pantheerakavu, Kozhikode, Kerala, India, at a depth of 1.5- 2.0m from the ground level. The native soil used in the present study is termed virgin soil (VS). Characterisation tests were conducted in the laboratory according to Indian Standard specifications and Table 1 summarizes the characteristics of virgin soil used in the study.

Table 1. Geotechnical characteristics of the virgin soil

Property	Value
Silt size fractions (%)	60.0
Clay size fractions (%)	22.0
Liquid limit (%)	78.8
Plastic limit (%)	44.1
Plasticity Index (%)	34.7
Shrinkage limit (%)	27.5
IS soil classification	MH
Maximum dry density (kN/m^3)	12.6
Optimum Moisture Content (%)	39.1
Unconfined compressive strength (kPa)	50.0

The nanotechnology-based organosilane nano-chemical used in the present study is Terrasil, manufactured by Zydex industries in Vadodara, Gujarat, India. It is a concentrated liquid in golden brown colour and is water-soluble and designated as a Nano Chemical (NC) in the present study. The chemical composition of the nano-chemical used in the study, as provided by the manufacturer, is listed in Table 2.

Table 2. Chemical composition of nanochemical as provided by the manufacturer [18]

Chemical Compound	Value (%)
Hydroxyalkyl- alkoxy- alkylsil	65-70
Benzyl Alcohol	25-27
Ethylene Glycol	3-5

Based on economic considerations and to minimize environmental pollution, cement usage in the present study is restricted to 1% by weight of soil to act as a binder. Several published papers proved that the strength of nano-material stabilized clay soils is significantly more enhanced in the presence of even a tiny amount of cement content instead the shear strength of clay soils stabilized by nano chemicals/materials alone. Nano-chemical can act as an accelerator in the hydration of cement, which imparts strength development due to accelerated pozzolanic reactions in nano-chemical treated soil in the presence of cement binder.

2.2 Sample Preparation and Testing

The treated soil samples were prepared as follows: Initially, the binder cement at 1% by weight of soil is introduced into the airdried pure clay and mixed in a dry state to distribute uniformly. Later the specific dosage of nano-chemical is injected into the OMC of the soil to obtain the nano chemical solution. Nano-chemical solution has been sprayed directly on the dry soil-cement mixture and mixed thoroughly to spread uniformly. The present study chooses the trial dosages of nano-chemicals in the range of 0.03% to 0.05% by the weight of clay soil. Table 3 tabulates the composition of different soil mixes with designations used in the present study.

Table 3. Composition of soil mixes used in the study

Mix	Designation
VS	Virgin Soil
VS + C1	Virgin Soil + 1% Binder
VS + C1+ NC1	Virgin Soil + 1% Binder + 0.03% NC
VS + C1+ NC2	Virgin Soil + 1% Binder + 0.04% NC
VS + C1+ NC3	Virgin Soil + 1% Binder + 0.045% NC
VS + C1+ NC4	Virgin Soil + 1% Binder+ 0.05% NC

Unconfined Compressive Strength Test. The present study has also conducted the standard proctor compaction (SPCT) tests according to the Indian Standard light compaction test [5], to examine the influence of nano-chemicals on the variation of compacting density and optimum moisture content of clay soil. The samples were cured for three days before conducting the SPCT tests [15], and it has found that there were slight changes in the maximum dry density (MDD) and OMC since the replacement of soil is very minimal with 1% cement and up to 0.05% nano-chemical by the weight of soil. Hence the treated soil specimens for the UCS testing have been prepared at a maximum dry density of virgin soil for comparison with the parent clay soil and to maintain uniformity.

Unconfined compression tests were carried out on the nano-chemical treated soil specimens with 1% cement binder after being cured at 7 and 14 days to examine the influence of nano chemical on UCS strength variation of clay soil. The curing period allows the chemical reactions to take place and examine the effect of curing on strength improvement. UCS test specimens were stored under humid conditions with a covered curing technique to prevent moisture loss and cure the samples. Three treated soil specimens at particular nano-chemical dosage have been cast in test moulds of constant volume (38 mm diameter and 76 mm height) at compaction density of virgin soil and cured for the specified curing period. UCS testing has been conducted at a strain rate of 1.5 mm/min according to Indian Standards [6]. The average unconfined compression strength for each nano-chemical soil mixture had reported after conducting three UCS tests. The optimum dosage of nano-chemical is determined that gives the maximum unconfined compression strength of treated clay soil.

Scanning Electron Microscopy: The sample surface morphology had investigated using Field Emission Scanning Electron Microscopy (FESEM). FESEM image analysis was carried out to peer into the morphological details of untreated and nano-chemical treated samples at optimum dosage after seven days of curing. The image analysis had conducted on Hitachi SU 6600, Japan, at the SEM centre of the Nano Science Department, National Institute of Technology Calicut, Kerala, India.

3 Results and Discussion

A series of UCS tests had performed on various nano-chemical soil mixtures to determine the effect of nano-chemical on UCS of clay soil at a curing period of 7 and 14 days.

3.1 Strength Characterisation

Unconfined Compressive Strength. The effect of nano-chemical on UCS of clay soil at 7 and 14 days of curing is tabulated in Table 4. It presents the percentage increase in strength with nano-chemical dosage and curing times. It shows the soil mixture contains 0.045% nano-chemical along with 1% cement binder, providing maximum strength improvement of about 184-253% increase over the strength of clay soil. The UC strength has improved significantly with the increased curing period. The UC strength of treated soil mixtures has been found to increase by about 72 - 253% to the strength of clay with an increase in the curing period from 7 to 14 days. Hence the nano-chemical with 0.045% is the optimum dosage that gives the maximum UC strength of clay soil.

Table 4. Effect of nano-chemical addition on UC strength

Soil Mix	7 day UC strength (kPa)	% increase in strength	14 day UC strength (kPa)	% increase in strength
VS	50.0	-	50.0	-
VS+C1+ NC1	86.3	72.6	115.4	130.8
VS+C1+ NC2	123.9	147.8	166.6	233.2
VS+C1+ NC3	142.2	184.4	176.6	253.2
VS+C1+ NC4	106.2	112.4	141.9	183.8

The stress-strain relations of various soil mixtures obtained under UCS testing at 7 and 14 days of curing are shown in Figs. 1 and 2, respectively. The results show that the nature of the stress -strain response is similar for all the soil mixtures. Initially, the relation is linear, and then the stresses increase with strain in non-linear until it reaches a failure point, i.e. maximum compression strength (UCS), and decreases. It can see that the failure stress (UCS) depends on the dosage of the nano-chemical dosage, and it increases with an increase in nano-chemical up to a particular value and then decreases. It also finds that the flexibility, i.e. increase of strain at failure of soil mi x-tures, increases by adding nano chemicals up to the optimal dosage into the clay soil.

The strength improvement of nano chemical treated clay in the presence of 1% cement binder is more significant than the strength of clay soil treated with 1% cement. The results comply with published papers that investigated the effect of nano-chemicals on the strength of clay soils [7, 8].

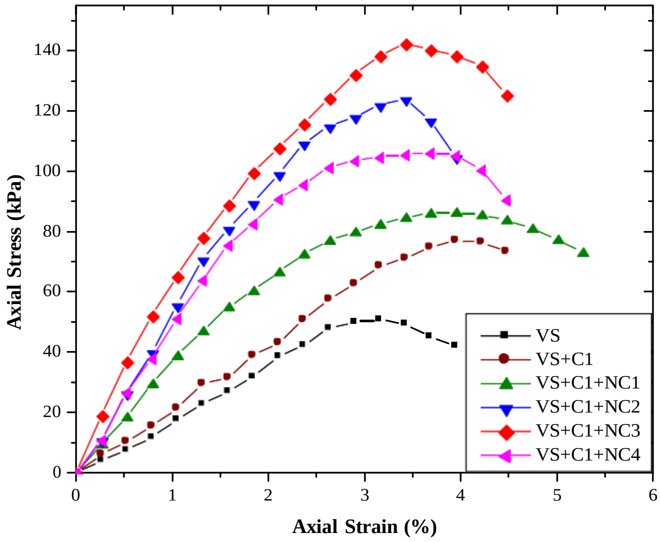

Fig. 1. Stress-strain relations of soil-cement-nano-chemical combinations at 7 days of curing.

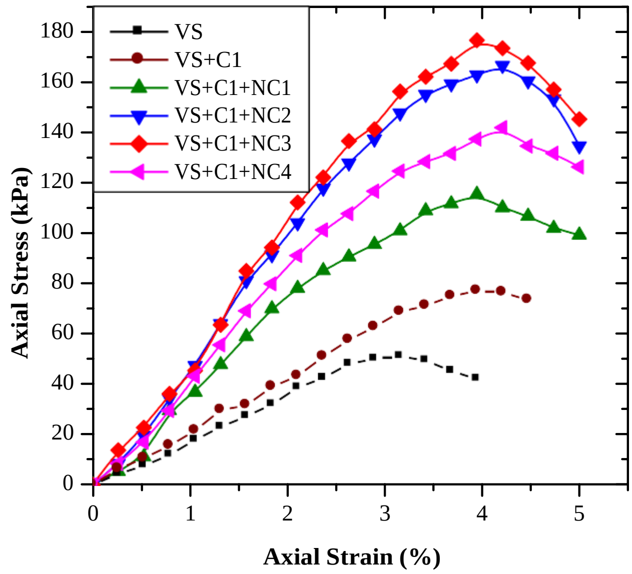

Fig. 2. Stress-strain relations of soil-cement-nano-chemical combinations at 14 days of curing.

3.2 Microstructural characterization

Scanning Electron Microscopy: Fig. 3 shows the FESEM images of virgin clay soil, and Fig. 4 shows the FESEM image of the nano-chemical treated soil mixture (VS+C1+NC3) containing the optimum dosage of nano-chemical (0.045%) after seven days of curing.

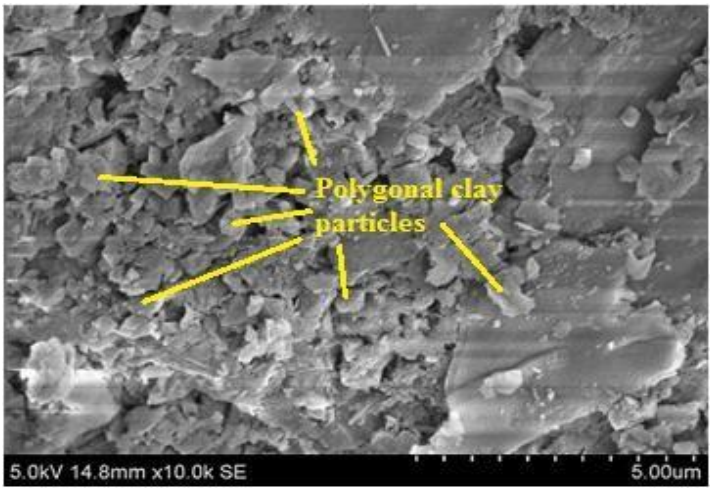

Fig. 3. FESEM image of untreated soil after 7 days of curing.

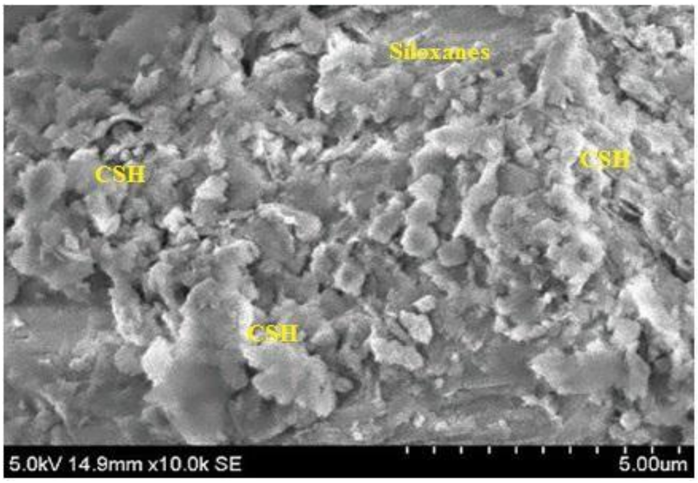

Fig. 4. FESEM image of the treated soil mixture (VS+C1+NC3) after 7 days of curing.

It can be seen from the figures that there is a significant change in the soil fabric of the treated soil mixture prepared at the optimum dosage of nano -chemical compared to virgin soil. In nano-chemical treated soil, the particles are bound together and are more closely packed or agglomerated, with a noticeable reduction in void spaces. It occurs because van der Waals forces develop strongly between the nanoparticles. Thus, addition of nano-chemical considerably reduced the porosity as it fills the microand nano-pores between soil particles.

4 Mechanism of Stabilization

The main ingredient of nano-chemical used in the present study is hydroxyalkyl-alkoxy-alkylsilanes. The considerable improvement in unconfined compression strength is due to the strong reaction of nano-chemical with silanol groups of soil and the resulting siloxane bondage [1], which forms a breathable in-situ membrane. The nano-chemical reacts with the soil particles and makes the surfaces waterproof, stiffening the soil and thus increasing the bond between soil particles [18]. Beyond optimum dosage, the strength decreases due to the loosening of the interaction between soil and nano-chemical in the presence of excess non-active nano-chemical.

5 Conclusions

A novel technique that can be applied as an alternative to environmentally harmful traditional soil stabilization additives is explained in this paper. A comprehensive experimental study was conducted on the soil before and after stabilizing with 1% cement and a nanotechnology-based organosilane compound to determine the effect of nano-chemical addition on the UC strength characteristics of the clay soil. The mechanism and microstructural characterization of nano-chemical treated soil has presented to support the strength improvement of clay soil with the addition of opt i-mum dosage of nano-chemical and 1% cement binder.

The salient conclusions drawn from the study are as follows:

- The UC strength of clay soil, along with 1% cement as a binder, increased with an increase in the nano-chemical dosage up to 0.045% of the weight of clay soil and is about 253% higher than the UC strength of untreated virgin soil at a 14-day curing period.
- The UC strength of nano-chemical stabilized soil after a 14-day curing period reveals a higher strength improvement than at seven days curing period. It is due to the improved chemical interactions of nano-chemical to flocculate and agglomerate the soil particles, thereby stiffening the soil with curing time.
- The FESEM images of nano-chemical treated soil showed that interparticle voids had reduced considerably, and the structure had changed to flocculated with the addition of nano-chemical.

In summary, treating weak subgrade soil with an organo-silane-based nano-chemical at a dosage of 0.045% of the weight of clay soil along with 1% cement content is the best combination to achieve higher UC strength. The shear strength achieved by this stabilization method is perfectly sufficient in a way that locally available field soil deposits could enhance the shear strength and can be used in pavement construction works. Thus, typical weak soils unsuitable for construction activities could be stabilized.

References

1. Arkles, B., Steinmetz, J.R., Zazyczny, J. and Mehta, P.: Factors contributing to the stabi l-ity of alkoxysilanes in an aqueous solution. Journal of Adhesion Science and Technology 6(1), 91-104 (1992). https://doi.org/10.1163/156856192X00133.
2. Buazar, F.: Impact of biocompatible nano silica on green stabilization of subgrade soil. Scientific Reports 9(1), 1-9 (2019). https://doi.org/10.1038/s41598-019-51663-2.
3. Carroll, D., Starkey, H.C.: Reactivity of clay minerals with acids and alkalies. Clays and Clay Mineralogy 19 (5), 321-333 (1971). https://doi.org/10.1346/CCMN.1971.0190508
4. Ewa, D. E., Egbe, E. A., Akeke, G. A.: Effects of nano-chemical on geotechnical proper-ties of ogoja subgrade. Jo urnal of Research Information in Civil Engineering 13 (1), 820 – 831 (2016).
5. IS 2720 -Part 7: Methods of test for soils- laboratory determination of water content- dry density relation using light compaction , Bureau of Indian Standards, New Delhi (1980).
6. IS 2720 -Part 10: Methods of test for soils- laboratory determination of unconfined com-pressive strength, Bureau of Indian Standards, New Delhi (1991).
7. Lekha, B. M., Goutham, S., and Ravi Shankar, A.U.: Laboratory investigation of soil stabi-lized with nano-chemical. In: Proceedings of Indian Geotechnical Conference, pp 1 -7. Roorkee (2013).
8. Mrudul, U. V., and Damodariya, S. M.: Laboratory investigatio n of soil stabilized using terrasil. International Journal for Scientific Research & Development 3(12), 537 -539 (2016).
9. Noll, M. R., Bartlett, C., Dochat, T. M.: In situ permeability reduction and chemical fix a-tion using colloidal silica, NATIONAL OUTDOOR ACTION CONFERENCE 1992, pp. 443–457. Las Vegas (1992).
10. Patel, A. N., Mishra, C. B., Pancholi, V. V.: Scientifically surveying the usage of terrasil chemical for soil stabilization. International Journal of Research in Advent Technology 3(6), 77 -84 (2015).
11. Prakash, M. M., and Shravan, K.: Effect of nanochemicals on properties of the black cot-ton soil. NATIONAL CONFERENCE ON SUSTAINABLE INFRASTRUCTURE DEVELOPMENT 2015, Chandigarh (2015).
12. Priyadharshini, R. and Arumairaj, P. D.: Improvement of bearing capacit y of soft clay us-ing nanomaterials. International Journal of Scientific Research 4(6), 218-221(2015).
13. Roshni, S. and Jeyapriya, S. P.: Experimental study on the use of nanochemical and ce-ment in the modification of subgrade. International Journal of Scient ific and Engineering Research 8(3), 1868 -72 (2017).
14. Sol-Sanchez, M., Castro, J., Urena, C. G., Azanon, J. M.: Stabilization of clayey and marly soils using industrial wastes: ph and laser granulometry indicators. Engineering Geology 200, 10-17 (2016). https://doi.org/10.1016/j.enggeo.2015.11.008
15. Taha, M. R., Khan, T.A., Jawad, I. T., Firoozi, A. A.: Recent experimental studies in soil stabilization with bio enzymes-a review. Electronic Journal of Geotechnical Engineering 18, 3881–3894 (2013).
16. Yonekura, R. and Miwa, M.: Fundamental properties of sodium silicate based grout. GEOTECHNICAL CONFERENCE 1993, pp. 439–444. Singapore (1993).
17. Zhang, G.: Soil nanoparticles, and their influence on engineering properties of soils. Ge-otechnical Special Publication (ASCE), 1 -13 (2007). https://doi.org/10.1061/40917(236)37
18. ZYDEX industries Home page, https://zydexindustries.com/soil-stabilization/, last ac-cessed 2022/10/7.