Influence of Nano silica on geotechnical properties of soft- clay soil

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Abstract: **Expansive clay soils include increased voids that provide challenges for structural foundations during loading and unloading; however, these issues may be mitigated by stabilising the soil with appropriate additives in suitable proportions. The additives consist of cement, lime, and chemicals that fill cavities at a micro level. Subsequently, the stabilised soil exhibited increased issues related to weather conditions, particularly with durability qualities such as freezing and thawing, resulting from significant temperature fluctuations that adversely impacted the soil. In these scenarios, soils are improved by stabilisation using novel methods that use nanoparticles, which plug holes at the nanoscale and increase all geotechnical qualities during freeze-thaw cycles. This research addresses the stabilisation of soft soils using nanosilica. The ideal dose of nanosilica is determined by compaction properties. The engineering characteristics were assessed using the appropriate dose of nanosilica. The extracted nanosilica is used in many applications within building pathology and repair. The test findings indicate that the geotechnical qualities are significantly enhanced using nanosilica. The soil stabilisation approach reduced building pathology and restoration methods, resulting in enhanced building quality and longevity.**

Keywords: **nanosilica, Stabilization · Clay soil · Geotechnical properties**

1. INTRODUCTION

Soil comprises an aggregation of mineral particles ranging from 75 microns to 1 nanometre; this extensive range of particle sizes complicates the application, modelling, and utilisation of soil, making it one of the most challenging materials. Soil is categorised into four categories based on particle size: Gravel, Sand, Silt, and Clay. The dimensions of the clay particles are smaller than 2 mm, indicating a range from 1 to 2 nm [1]. Increased empty gaps and particular places resulted in more alterations in size concerning durability qualities. In these scenarios, the issues are resolved by stabilisation using novel nanomaterials, since the pores are filled at the nanoscale, hence enhancing all geotechnical qualities [2]. Nanomaterials include nanoalumina, nanomagnesium, nanoclay, terrasil, nanotubes, and nanosilica. Nanosilica demonstrated significant pozzolanic activity, robust bonding, nano-level void filling, increased production of C-S-H gel with soil, and a high specific surface area [3–5]. Nanosilica is naturally generated from rocks and the processing of agricultural waste materials. The processed agricultural residues include bioactive chemicals used in the production of composite materials [10–11], fillers [12–13], adsorbents [14–16], supplementary cement components [17–18], and silica-based products [19–23]. The items diminish manufacturing expenses and environmental contamination [24–26]. The primary waste in agriculture is rice husk, utilised for nanosilica extraction through various methodologies, including acid precipitation [27], calcination [28], surface modification [29], precipitation and reflux [30–31], worm digestive processes [32], sol-gel processes [33], fluidised bed processes [34], microwave heating [35], and high-temperature leaching with solutions [36–37]. The geotechnical properties (GTP) exhibited more variation in clays compared to other soils owing to the reduced particle size distribution. The durability features influencing the geotechnical qualities of clayey soils must be taken into account when evaluating soil performance for stability, settlement, slope analysis, embankments, pile foundations, retaining walls, and earth dams in cold locations. The performance of clayey soils was contingent upon freeze-thaw cycles of the soil [38].

The geotechnical qualities of the soil were assessed by soil gradation tests, compaction testing,

unconfined compressive strength tests, triaxial tests, California Bearing Ratio tests, and vane shear tests.
This research aims to investigate the stabilisation of fragile soils using nanosilica. The optimal dose of nanosilica is determined by compaction properties, specifically the proportion that achieves maximum dry density (MDD). Identify the engineering parameters associated with the optimal dose of extracted nanosilica and ascertain the geotechnical properties.

2 MATERIALS AND METHODS

The process involves the acquisition of the soil sample and nanosilica. Stabilising clay soil using nanosilica for evaluating geotechnical qualities.

2.1 Acquired soil specimen

The black cotton soil (BCS) was obtained from the Kanigiri area in Andhra Pradesh at a depth of 2 meters below the ground surface, next to the river. The BCS is located along the banks of the Kanigiri River and is formed from the weathering of coastal alluvial material. Consequently, the soil has an enhanced dispersed double layer, pronounced swelling and shrinking, higher seepage force, more settlements, and alterations in volume [39]. The geotechnical qualities of the soil were assessed in accordance with IS 2720 parts I to XV.
The soil sample was collected, air-dried, pulverised, sieved, and analysed for all geotechnical parameters (index and engineering) in accordance with IS 2720 parts I to XV, as shown in Table 1.

Table 1 All geotechnical parameters (index and engineering)

S. No	Property	Values
1	Specific Gravity	2.37
2	Consistency limits	(w_L-w_P) 67–31
	Plasticity Index (%)	36
4	IS Soil classification	CH
5	Compaction	
	(a) MDD (kN/m^3)	17.2
	(b) OMC (%)	19
6	UC Strength (kN/m^2)	63
7	Permeability(cm/s)	2.4×10^{-6}
8	Final settlement (mm) ΔH	4.5

2.2 Nanosilica

The Nanosilica used in this study was purchased from the local market of Saveer Martixnano Pvt Ltd. Bangalore. It is creamish in color and amorphous in nature. The particle size of this N-MgO is less than 100 Silicon Dioxide Nanopowder (SiO2, Purity: 99%, APS: <100 nm) Stock No: SMN/54/117, CAS: 7631-86-9. The oxide chemical composition of the Nanosilica is shown in Table 2.

Table 2. Chemical Composition of nanosilica

S.No.	Element	Concentration
1	SiO_2	99%
2	TiO_2	0.198%
3	P_2O_5	0.183%
4	CuO	0.021%
5	Nb_2O_5	0.194%
6	ZnO	0.269%
7	Al_2O_3	511.7 ppm
8	Fe_2O_3	428.1 ppm
9	Others	<1200 ppm

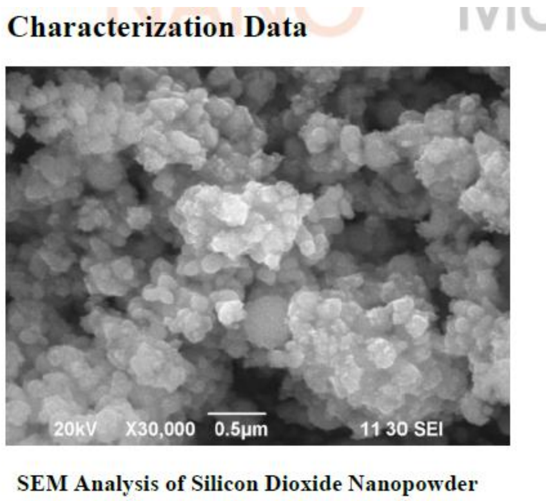

Fig 1. SEM image of Nanosilica

RESULTS AND DISCUSSION

Optimal dosage of nanosilica:

preparation of the soil

The percentages of nanosilica incorporated ranged from 1% to 5% of the sample's dry mass. Identify the ideal nanosilica percentage that yields the highest dry density (MDD) at the optimum moisture content among all percentages. Upon determining the correct dose of nanosilica, assess the responses of compressibility, permeability, and shear strength properties. In experimental investigations, the dry-mix procedure incorporated nanosilica at concentrations of 1%, 2%, 3%, 4%, and 5% into clay soil. The dirt and nanosilica are in powdered form and desiccated. This research seeks to assess the influence of the nanosilica stabiliser on the geotechnical characteristics of soft clay, which should exhibit low compressibility to reduce settlements or differential settlements. It also aimed to determine the optimal proportion of additional nanosilica.

Soil Compaction Test

Soil preparation included pulverised dry soil passing through a 2.36 mm IS sieve, which was combined with different ratios of nanosilica for a lightweight compaction test. The percentage achieved maximum dry density (kN/m3) in relation to the optimal moisture content (%) of the soil. The specified proportion is the ideal dose of nanosilica for the soil. Nanosilica was incorporated into the soil at concentrations of 1%, 2%, 3%, 4%, and 5% of the dry weight of the soil.

The impact of nanosilica doses ranging from 1% to 5% on the compaction properties of clay soil was assessed. The maximum dry density achieved with 4% nanosilica proportions is the greatest among all percentages, with MDD increasing from 17.2 to 20.5 kN/m³. The optimal dose of extracted nanosilica to be incorporated into the soil is 4%, resulting in maximum dry density, while the optimal moisture level is 12%. In this phenomena, untreated soil has more voids filled with soil grains, but treated soil with a stabilising agent (NS) exhibits higher bulk density and greater stability compared to untreated soil.

Stabilization of geotechnical properties of the soil with optimal percentage of nanosilica

Soil samples were created with 4% of the ideal nanosilica percentage, a maximum dry density of 20.5 kN/m³, and an optimum moisture content of 12% to assess the geotechnical parameters of the soil, including the coefficient of permeability, unconfined compressive strength, and compressibility characteristics. The reaction of geotechnical parameters of soil with appropriate nanosilica 4% compared to untreated soil. The permeability test indicated that the soil became completely impermeable following the addition of the ideal proportion of nanosilica. Nano-sized voids were filled using nanosilica. The flowing water obstructed the upper surface of the sample, preventing water from permeating it. The unconfined compressive strength of soil rose from 63 kN/m² (untreated soil) to 265 kN/m² at the optimum nanosilica content, surpassing the strength of clay soil by 4.2%. The ultimate settlements decreased from 4.5 mm (untreated soil) to 1 mm after the application of nanosilica. The soil settling combined with the correct proportion of nanosilica enhanced strength by about 4.2% compared to untreated clay soil. Under saturated circumstances, nanosilica demonstrated greater stability even under prolonged loading. Table 3 The response of geotechnical properties of the soil with the optimal percentage of nanosilica

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Properties	Without add NS	With add 4% of NS
Co-efficient of permeability (cm/s)	2.4×10^{-6}	Nil
UC Strength (kN/m^2)	63	265
Final Settlement (mm)	4.5	1

CONCLUSIONS

The dirt is gathered and categorised as CH (highly compressible clay) according to its index and engineering characteristics. The nanosilica exhibits an ideal proportion concerning compaction properties. The stabilised soil exhibits impermeability, enhanced unconfined compressive strength, and reduced compressibility properties at the optimum nanosilica percentage of 4%. The ultimate settlements decreased from 4.5 mm (untreated soil) to 1 mm after the application of nanosilica. The soil settling combined with the correct proportion of nanosilica enhanced strength by about 4.2% compared to untreated clay soil. Under saturated circumstances, nanosilica demonstrated greater stability even under prolonged loading. In the future, extracted nanosilica may be used for enhancing durability, slope stability, and soil stabilisation procedures.

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