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Stabilization of soft-soils with Nano-Magnesium Oxide

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***Abstract*—To improve engineering characteristics, use local soil for building. Silty and siltey soils have nano-voids depending on particle size. Due to its high plasticity index, silt soil settles more, is less stable, and changes structure. Thus, soil additives are needed to improve characteristics. Recently, nanoparticles have been used in geotechnical engineering to improve soil stability and strength. This article examines how Nano Magnesium Oxide (N-MgO) affects soil geotechnical qualities. The effects of N-MgO on UCS and k were examined. The best soil N-MgO dose was 1, 2, 3, 4, and 5%. The creation of CSH gels connects soil particles and improves UCS, reducing 'k' and settling of soil samples regardless of N-MgO concentration or soil type. The treated and untreated experimental findings based on micro structural analysis. This amorphous N-MgO is indicated for stabilizing poor soils of any sort.**

***Index Terms*—N-MgO Soil stabilization Unconfined compressive strength**

I. INTRODUCTION

The application of nano-magnesium oxide (nano-MgO) has emerged as a promising technique for enhancing the geotechnical properties of soft silt soils, offering improvements in load-bearing capacity and settlement characteristics (BAĞRIAÇIK & Mahmutluoğlu, 2022). This advanced material, characterized by its surface effects, interface effects, and small size effects, exhibits superior chemical and physical properties compared to conventional magnesium oxide (Sadiq et al., 2023). Its high specific surface area enables a more reactive interaction with silt particles, facilitating more effective stabilization mechanisms (Siddiki, 2020). This enhanced reactivity contributes to improved compressibility behavior and increased unconfined compressive strength in treated silty silt, as evidenced by studies utilizing varying percentages of nano-MgO (Sadiq et al., 2023). Specifically, the shear strength of cement-admixed silty silt demonstrates a notable increase with escalating cement content, with an optimal nano-MgO content of 10‰ achieving peak cohesion for a 10% cement concentration (Yao et al., 2019). Further research indicates that the inclusion of nano-MgO can significantly reduce the compression index of soil by approximately 36.5% and substantially increase soil strength by up to 114% when applied at an optimal content of 0.6% (Sadiq et al., 2023). This improvement is attributed to the nanoparticles' ability to form stronger bonds within the soil matrix, thereby enhancing its overall structural integrity (Sadiq et al., 2023). This is further supported by observations that nano-MgO converts free water to bound water, significantly improving dynamic performance and freeze-thaw resistance in problematic soils (Sadiq et al., 2023). Furthermore, the incorporation of nano-MgO has been shown to notably increase both cohesive force and soil failure strength while having limited influence on the internal friction angle, according to triaxial shear tests (Sadiq et al., 2023). This enhanced mechanical performance results from nano-MgO's ability to reduce pore size and improve void arrangement, leading to increased density and a strengthened microstructure (Sadiq et al., 2023). The rapid bonding capabilities and fine particle size of nanomaterials, including nano-MgO, allow even small quantities to induce substantial changes in the physical and chemical properties of soil (Kulanthaivel et al., 2020). The smaller average diameter of nano-MgO particles, relative to soil particles, facilitates their ability to fill pore spaces and enhance resistance to compression (Sadiq et al., 2023). Beyond physical filling, the chemical reactions initiated by nano-MgO also contribute to enhanced soil properties, including reductions in plasticity and improved compaction (Harianja et al., 2025). Nanolime, a similar nano-material, demonstrates superior soil improvement over traditional lime even at 0.5% dosage, forming calcium silicate hydrate and promoting flocculation and agglomeration of silt particles through Ca+2 bridging (Taha et al., 2019). The efficacy of nano-MgO in soil stabilization is further corroborated by its capacity to improve Atterberg limits, decrease swelling potential, and elevate the maximum dry density of treated soils, mirroring the benefits observed with nano-lime and nano-alumina (Wong et al., 2020). Moreover, the formation of Mg2+ through the reaction between MgO and water leads to cementation, further decreasing the soil's compressibility (Sadiq et al., 2023). This cementation process, alongside the pore-filling effect, contributes to a more stable soil matrix with reduced void ratios and increased particle interconnections, ultimately enhancing the unconfined compressive strength and shear strength of the treated soil (Sadiq et al., 2023; Shwan, 2023). The alterations in silt microstructure, as investigated through field emission scanning electron microscopy, reveal the detailed mechanisms by which nano-MgO enhances soil properties (Sadiq et al., 2023). These microscopic changes, coupled with the interaction between nano-MgO groups and soil particles, elucidate the macroscopic improvements in soil behaviour, including the reduction in failure strain and the enhancement of strength (Gao et al., 2020; Sadiq et al., 2023). The experimental results in both treated and untreated conditions based on the experimental work.

II. MATERIALS AND CHARACTERIZATION

2.1 Soil Samples

The soil samples utilized in this investigation were collected from a site near ABR College, Kanigiri City, India. The siltey soil sample, designated as M1, was collected at a depth of 1 meter from the earth surface. These sediments are unsuitable for construction due to their excessively porous strata. The numerous geotechnical properties of the collected sample are provided in Table 1. The complete soil sample was oven-dried at 100°C and ground into a fine powder for the purpose of conducting various soil analyses. The proportions of silt, silt, and organic matter present in the collected soil samples, along with their soil classification, are detailed in Table 1 in accordance with IS standards.

Table 1 The geotechnical properties of the collected silty soil

Properties	Soil- M1	Properties	Soil- M1
Specific gravity G	2.45	Liquid limit (%)	51
clay (%)	43	Plasticity index (PI)	20
Silt (%)	49	MDD (kN/m^3)	19.02
Organic content (%)	8	UCS (kN/m$^{2)}$	67
FSI	14.2	CBR (%)	3
OMC (%)	12	k (cm/s)	5.9×10^{-2}
Final settlement (mm)	4	IS soil classification	MH

FSI Free swell index, OMC optimum moisture content, MDD maximum dry density

High Compressible Silt (MH) is the descriptor that has been assigned to the soil sample M1. The values of the Unconfined Compressive Strength (UCS) of the soil samples that were taken serve as the basis for this categorization. These values provide an indication of the consistency of the soil samples. Due to the fact that it contains 8% organic matter, M1 soil is considered to be soft. The CBR values of the soil samples that were collected suggest that the soil quality for subgrade performance is consistently unsatisfactory, regardless of the sample that was evaluated. In general, the soil samples that were collected had low permeability values, and the eventual settling of the soil samples is shown in Table 1. The settling, compressibility, and low compressive strength of the soil samples that were collected are all indications that the soil samples are rather weak and need stabilization.

2.2 N-MgO

The N-MgO used in this study was obtained from the local market of Saveer Martixnano Pvt Ltd. in Bangalore (see to Figure 1 for more details). It has an amorphous structure and exhibits a hue akin to cream. N-MgO, with a purity of 99% and an average particle size (APS) of less than 100 nm, has a particle size under 100 nm. The stock number is SMN/54/110, and the CAS number is 1309-48-4. Table 2 displays the oxide chemical composition of N-MgO.

Table 2. Chemical Composition of Magnesium Oxide Nanopowder

S. No.	Element	Concentration
1	MgO	99%
2	Ca	0.24%
3	Fe	0.15%
4	Si	0.087%
5	Al	0.0754%
6	Mn	0.324%
7	Others	<2200 ppm

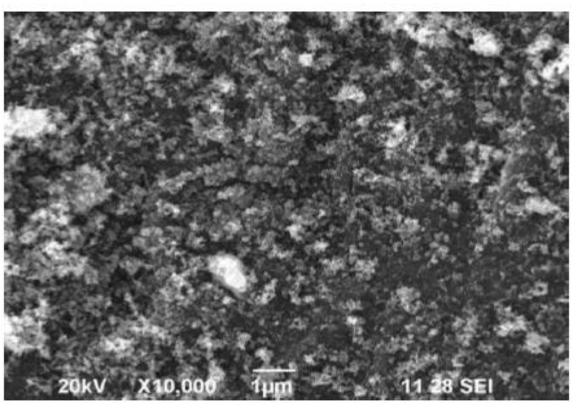

Fig SEM Analysis of Magnesium Oxide Nanopowder

III. METHODS

3.1 Sample Preparation

All collected soil samples were combined with dry powdered N-MgO in varied concentrations of 1%, 2%, 3%, 4%, and 5% based on the dry weight of the soil. Following comprehensive mixing under arid circumstances, the samples were introduced to distilled water and mixed once more to achieve a homogenous combination. The N-MgO mixed soil samples were used for further analyses, including compaction testing, permeability testing, unconfined compressive strength testing, and consolidation testing. The minimum and maximum dose range of N-MgO for each soil sample was determined by the trial-and-error approach in the laboratory, depending on its workability. Images depicting the processing of soil samples for the UCS test.

3.2 Experimental Investigation

The soil samples were prepared in accordance with IS 2720 (Part I)—1983. The classification of soil samples was conducted in accordance with IS 1498 (1970). The liquid limit and plastic limit were established in accordance with IS: 2720 (Part V)—1985. The light compaction test, unconfined compression strength test, and California Bearing Ratio test were conducted in accordance with IS: 2720 (Part VII)—1980, IS: 2720 (Part II)—1973, and IS: 2720 (Part XVI)—1987 standards. The coefficient of permeability for untreated and N-MgO-treated soil samples was determined using IS 2720 (Part XVII)—1986. The wetting and drying test of the soil, both with and without the inclusion of nanomaterial, was conducted in accordance with the guidelines specified in IS: 4332 (Part IV)—1968.

IV. RESULTS AND DISCUSSIONS

4.1 Determination of Optimum Dosage of N-MgO for the Stabilization of Collected Soil Samples

In order to ascertain the proper amount of N-MgO in soil, compaction parameters (MDD and OMC), as well as UCS and CBR values, are taken into consideration. In the laboratory, the geotechnical tests that were described above were carried out on the soil samples that had been produced without any treatment and those that had been treated with N-MgO. The results of these tests are presented in Table 3. In order to determine the appropriate dosage for each soil sample, the N-MgO-treated soil combination that had the highest UCS value was chosen. According to the findings of the tests, the number M1 represents the appropriate dosage of N-MgO for the soil samples. The quantity of nitrogen-magnesium oxide (N-MgO) that is required for soil stabilization is determined by the presence of a decreased void ratio in silt soil samples.

Table 3 Optimum dosages of N-MgO from compaction, UCS and CBR test results

soil	Nano MgO (%)	OMC (%)	MDD (kN/m^3)	UCS (kN/m^2)	CBR (%)
M1	0	12	19.02	67	3
	4	14.8	20.1	250	8

Almost 21.1 kN/m^3 of MDD was increased by adding 4% of N-MgO to the silty sample. It is seen that the percentage of increase in MDD is lower for silt samples when compared to increase by adding of N-MgO. Silt soil, due to its compact and dense nature, might exhibit a comparatively limited response to the introduction of N-MgO, resulting in a less pronounced increase in maximum dry density when compared to the more porous and loose structure. Further addition 4% of N-MgO seems to increase the O.M.C and MDD.

4.1 Unconfined Compression Strength Test and CBR Test

The soil specimens treated with N-MgO were prepared for the Unconfined Compressive Strength (UCS) test and the California Bearing Ratio (CBR) test at their respective Maximum Dry Density (MDD) and Optimum Moisture Content (O.M.C), along with the corresponding test results. The UCS test results indicate that the maximum UCS for M1 reached 250 kN/m2, compared to an untreated value of 67 kN/m2, following the addition of 4% N-MgO. The test results indicate that the incorporation of N-MgO into the collected soil sample at optimal levels enhanced the UCS strength. This enhancement is attributed to the formation of strong bonds and the creation of a CSH gel, which establishes a tight connection between soil particles while reducing the number of nanovoids. N-MgO enhances pozzolanic activity and increases the binding strength of soil particles. The application of N-MgO results in the optimal strength enhancement of the soils post-stabilization.

Researchers observed that incorporating 3% N-MgO into sandy silt of intermediate plasticity resulted in a 3.73-fold increase in unconfined compressive strength compared to its initial value. The presence of a large surface area in the N-MgO facilitated its reaction with the soil sample, resulting in an increase in the soil's strength.

4.2 Permeability and Consolidation Test

The falling head permeability test was conducted to assess the permeability of untreated and N-MgO-treated soil samples. Observation indicated a lack of water movement within the stand pipe of the permeability apparatus during the execution of the falling head permeability test. The formation of N-MgO gels in the void spaces is responsible for arresting the movement of water, thereby decreasing the permeability of soil. The investigation focused on the impact of N-MgO on the hydraulic properties of kaolinite. The findings indicated a reduction in the coefficient of permeability from the order of 10^{-2} to nil, achieving an almost impermeable state that aligns with the results of the current study.

A consolidation test was conducted on soil samples prior to and following treatment with N-MgO. The test results indicate that, consistent with previous tests, the final settlement value of samples decreased when compared to the untreated soil samples at their optimum dosage.

V. CONCLUSIONS

The study investigated the effect of N-MgO on various silt and silt samples and came to the following conclusion based on geotechnical factors and N-MgO stabilization. Silt is very compressible. The average particle size (APS) of 99% pure N-MgO is less than 100 nm.All samples received 1%, 2%, 3%, 4%, and 5% dry powdered N-MgO based on soil dry weight.4% N-MgO increased silty sample MDD by 21.1 kN/m3. Silt samples increased MDD less than N-MgO. Compact, thick silt soil may react less to N-MgO and increase its maximum dry density than porous, loose soil. 4% N-MgO raises O.M.C. and MDD.The falling head permeability test examined untreated and N-MgO-treated soil. Water did not flow in the permeability apparatus stand pipe during the falling head test. N-MgO gels in vacuum gaps reduce soil permeability by stopping water flow. The research investigated how N-MgO impacts kaolinite hydraulics. The coefficient of permeability dropped from 10–2 to zero, making the material impermeable for this investigation. Before and after N-MgO treatment, soil samples were consolidated. As in previous research, samples had a lower final settling value than untreated soil samples at their maximum dosage.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.
Conflict of Interest The authors have made a declaration that they have no competing interests in having this research published.

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