Subgrade Stabilization with Nanomaterial: Nanoclay

Dr K Meeravali[1], Yaramapu Madhu[2], and Shaik Fayaz Basha[3], Pedalanka Sreemannarayana[4], Shaik Sajid[5], SD. Hussain Basha[6]

[1,] Assistant Professor, ABR College of engineering and Technology, China irlapadu, Kanigiri, Prakasam, A. P-523254.

[2, 3, 4, 5,6] B. Tech Students, Civil department, ABR College of engineering and Technology, China irlapadu, Kanigiri, Prakasam, A. P-523254.

Abstract: Expansive soil contains more voids that impact geotechnical properties, which effects wet-dry cycles must consider when choosing soil for strong foundations of any civil engineering structures. Wet-dry cycles happens due to drastic changes in groundwater levels, heavy rains, and these effected on beneath the foundations to make soil weak against geotechnical properties of the soil. This failure resisted with innovative technology is nanotechnology: nanomaterials added to weak soil. This paper deals with determining geotechnical properties of soil effected on subgrade with and without mixed Nanoclay. Tests for engineering properties are Lightweight Compaction, Permeability, Unconfined compressive strength (UCS), and CBR tests. These result in the permeability, settlements of soil controlled with Nanoclay, and increases the shear strength of soft-soil even CBR effected on the soil.

Index Terms: Expansive soil, geotechnical properties, Nanoclay, Nanotechnology, and Engineering properties.

I. INTRODUCTION

[Font: Recently, building development has grown globally, particularly in metropolitan areas. Land shortage is increasing, forcing engineers to develop on unfavourable soils. Improving soil conditions is crucial for building buildings in such settings. The particle size of silty and clay soil samples ranged from 2 to 75 µm and 1 nm to 2 µm, respectively [1]. The existence of nano-level empty spaces impacts soil shear strength, compaction, and consolidation [2]. The main geotechnical concerns in these soils are limited water-holding capacity, soft minerals, and high bulk density [3]. Traditional materials like cement, lime, and fly ash were employed to fill gaps in the building industry for decades. However, micro-level void filling has little impact on the given features [4]. Novel methods and nanomaterials were used to stabilise these soils. started recently to fill nano-voids [5]. This method improves geotechnical qualities by filling and strengthening materials with nanoparticles. Using nanomaterials at low levels improves geotechnical qualities of problematic soil, resulting in cost savings [6]. Researchers are increasingly adopting nano additives such nanocarbon, nano-clay, graphene oxide, and other nanoparticles for soil improvement due to nanotechnology [4, 6-11]. Many researches have used nanomaterials like Terrasil, nano-silica, and nano-clay to improve the geotechnical qualities of local poor soil. Civil, geotechnical, and geo environmental engineers are focusing on using nanotechnology and nanomaterials for soil stabilisation [12]. They recommend nano-clay, a sustainable natural resource, for soil stabilisation to address environmental issues.

Research indicates that adding nano-clay to clayey soil at a modest level (0.5%) improves index characteristics and shear strength compared to untreated soil [13]. Increased soil shear strength decreases plasticity index in clayey soil samples. Several authors researched how nano-clay improves geotechnical features such as permeability, swelling, and UCS in compacted clay liners. The scientists found that adding 4% nano-clay to clay soil decreased permeability from 10-9 to 10-11 cm/s and enhanced compressive strength by 36.28% by forming clusters in vacant areas, reducing interlayer spacing [14].

Little study has examined the effectiveness of nano-clay combined with low and high plasticity silty soils in nature. Researchers found that adding nanoclay to silty soil raised its liquid limit (LL) and plastic limit (PL), as well as changed its shear characteristics [2]. Researchers observed similar findings using nano-clay treated with field clay soil from Rasht City, Iran [15]. A study indicated that the optimal nano-clay level for treating field clay soil is 1.5%. Increasing the nano-clay content from 1.5 to 2.5% lowered the final compressive strength. Researchers found that increasing the weight percentage (0.5%, 1%, 1.5%, and 2%) of nano-clay enhanced the liquid and plastic limit of soil in UCS and California bearing ratio

(CBR) tests [16]. Additionally, adding 1.5% nano-clay boosted soil resilience. Similarly, nano-clay and cement were utilised to stabilise sand. Adding 2% nano-clay and 7% cement to the soil's dry weight raised its elastic modulus by 47% in tension after 28 days of curing [1]. Researchers examined the impact of adding nano-clay (0.5-3% dry weight) on the collapsibility and dispersity of loess soil. Nano-clay addition reduces cohesion and increases internal friction, enhancing loess soil shear strength and other geotechnical parameters [12]. While prior research has used nano-clay to improve the geotechnical qualities of silty and clayey soil samples, the impact under wet-dry circumstances is limited.

Kanigiri City, a fast-growing Indian city, is well-connected to national roads. The soil from this city were studied because to their low load-bearing capacity, which may lead to settlement concerns and structural instability in structures. We determined the optimal nano-clay dose for soil stabilisation and examined the impact of CBR.

2. METHODOLOGY

This paper deals with determining geotechnical properties of soil effected on subgrade with and without mixed Nanoclay. Tests for engineering properties are Lightweight Compaction, Permeability, Unconfined compressive strength (UCS), and CBR tests. These result in the permeability, settlements of soil controlled with Nanoclay, and increases the shear strength of soft-soil even CBR effected on the soil.

3. MATERIALS

3.1 Soil sample

Expansive soil collected from Kanigiri at a depth of 1m below the natural ground level. Geotechnical properties of the soil determined by separate the collected soil with sizes of the particles. Table 1 contains the geotechnical properties of the soil as per IS: 2720-1965

Table 1 Geotechnical properties of soil

S. No	Properties	Values
1	Specific Gravity	2.5
2	Consistency limits W_L (%) W_P (%) (I_P) (%) Shrinkage limit (%)	 40 25 15 15
3	Sedimentation Analysis Clay (%) Silt (%) Organic (%)	 59 36 5
4	Compaction Test (a) Density (kN/m^3) (b) Water content (%)	 16.4 19
5	UCS- (kN/m^2)	75
6	Permeability (cm/s)	1.9×10^{-7}
7	Consolidation Test Settlement (mm) Cv (cm^2/min)	 5 0.004
8	CBR (%)	3.8

Depend on geotechnical properties: Soil classified as CI (A-line: Intermediate Compressible Clay) exhibited problematic against an external load. It contains more pores to reach permeability, less UCS, and more settlements.

3.2 Nanoclay

This investigation used nano-clay from the Bangalore market (refer to Fig. 1) for its creamish colour and amorphous character. These nano-clay particles are fewer than 100 nm in size [17]. It has a unit weight of 2.49 kN/m3 and a molecular weight of 550 g/mol. The oxide chemical composition of nano-clay is reported in Table 2

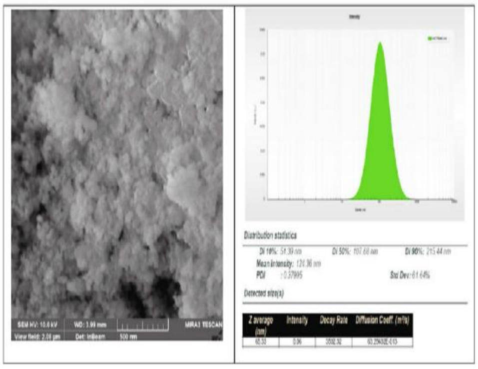

Fig. 1 Additive image: nano-clay and SEM image of nano-clay [33]

Table 2 Chemical composition of nano-clay [33]

Oxides	SiO_2	Al_2O_3	Na_2O	CaO	H_2O	Others
Percentages	44	17.9	2	1.2	34.9	0.08

4. THE OPTIMAL PERCENTAGE OF NANOCLAY

For the optimal percentage of Nanoclay depend on compaction characteristics, in which percentage got high maximum dry density (MDD) with respect to optimum moisture content (OMC) that percentage fixed as an optimal percentage of the soil. Trail percentages of Nanoclay varied from 0.05 to 0.25% of the soil. Samples prepared to estimate the optimal percentages: Expansive soil mixed with OMC, MDD, and dosages of Nanoclay as 0.05, 0.10, 0.15, 0.20, and 0.25% of the soil. The samples kept in final packing because of avoiding water evaporation.

4.1 Compaction Characteristics with Nanoclay

The prepared samples conducted a compaction test as per IS: 2720-1965. Table 3 explains the test results from the compaction test in terms of MDD and OMC. In which percentage got high maximum dry density (MDD) with respect to optimum moisture content (OMC) that percentage fixed as the optimal percentage of the soil. From the results, high MDD (18.5 kN/m3) got at the percentage of 0.15% of Nanoclay, so the percentage is optimal and showed more compacted. Figure 2 represents the response of the compaction Characteristics with percentages of Nanoclay.

Table 3 the compaction Characteristics with Nanoclay

% of Nanoclay	0.05	0.1	0.15	0.20	0.25
MDD (kN/m^3)	16.9	17.7	18.5	18	17.3
OMC (%)	17	16.5	14	16	18

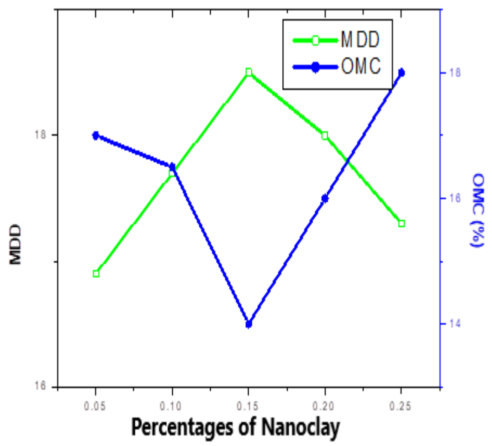

Fig. 2 Results from Compaction test with percentages of Nanoclay

4.2 The stabilization of soil with Nanoclay

The geotechnical properties determined with the optimal percentage, the soil samples prepared with MDD, OMC, optimal dosage kept 28 days for curing, tested as per IS: 2720-1965, and test results showed in table 4.

Table 4 Geotechnical properties of soil with Nanoclay

S. No	Properties	Values (% of Nanoclay)	
		0 (without added Nanoclay)	0.15 (Optimum)
1	Permeability	1.9×10^{-7}	Nil
2	UCS (kN/m^2)	75	220
3	ΔH or S_f (mm)	5	1
4	C_V (cm^2/min)	0.004	0.009

4.1 The subgrade stabilization of soil with Nanoclay

The geotechnical properties determined with the optimal percentage, the soil samples prepared with MDD, OMC, optimal dosage kept 28 days for curing, tested as per IS: 2720-1965, and test results showed in table 5. Figure 3 represents CBR properties of soil with Nanoclay.

Table 5 CBR properties of soil with Nanoclay

S. No	Properties	Values (% of Nanoclay)	
		0 (without added Nanoclay)	0.15 (Optimum)
1	CBR (%)	3.8	12.1

CBR value increased from 3.8 to 12.1 (%), these values suitable for any type pavement as subgrade.

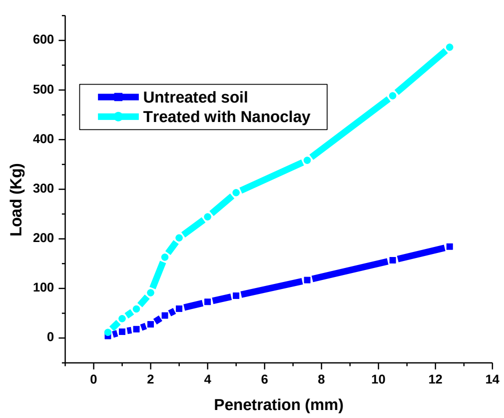

Fig.3 CBR properties of soil with Nanoclay

5. CONCLUSIONS

Collected soil classified as CI (Intermediate compressible Clay) based on index and engineering properties. The soil contains expensive soil improved with Nanoclay with an optimal percentage based on compaction characteristics, which percentage got more density. Permeability, UCS, and compressibility characteristics increased with the optimal percentage of Nanoclay. The soil exhibits more weakly and lost strength when exposed to wet-dry cycles. But Nanoclay controlled all characteristics mixed with soil while affected on CBR value increased from 3.8 to 12.1 (%), these values suitable for any type pavement as subgrade.

REFERENCES

[1] Aravindkumar, B. Hawalkar, S.S. Awanti, Laboratory Behavior of High-Volume Fly Ash Concrete Sections Under Flexural Fatigue Loading, Int. J. Eng. Technol. 3 (12) (2013).

[2] H. Abdulrahman, R. Muhamad, P. Visintin, A. Azim Shukri, Mechanical properties and bond stress-slip behaviour of fly ash geopolymer concrete, Constr. Build. Mater. 327 (2022) 126909, https://doi.org/10.1016/j.conbuildmat.2022.126909.

[3] V. Divya Prasad et al., Study on concrete containing Waste Foundry Sand, Fly Ash and Polypropylene fibre using Taguchi Method, Mater. Today:. Proc. 5 (2018) 23964–23973.

[4] B. Bhardwaj et al., Waste foundry sand in concrete: A review, Constr. Build. Mater. 156 (2017) 661–674.

[5] G. Sua-iam et al., Workability and compressive strength development of self consolidating concrete incorporating rice husk ash and foundry sand waste – A preliminary experimental study, Constr. Build. Mater. 228 (2018) 116813.

[6] B. Bhardwaj, P. Kumar, et al., Comparative study of geopolymer and alkali activated slag concrete comprising waste foundry sand, Constr. Build. Mater. 209 (2019) 555–565.

[7] F. Muhammad et al., Prediction of mechanical properties of green concrete incorporating waste foundry sand based on gene expression programming, J. Hazard. Mater. 384 (2020) 121322.

[8] R. Siddique, Performance Characteristics of High-Volume Class F Fly Ash Concrete, Cem. Concr. Res. 34 (2004) 487–493.

[9] N. Pathak, R. Siddique, Effects of elevated temperatures on properties of selfcompacting-concrete containing fly ash and spent foundry sand, Constr. Build. Mater. 34 (2012) 512–521.

[10] D.K. Ashish, S.K. Verma, Robustness of self-compacting concrete containing waste foundry sand and metakaolin: A sustainable approach, J. Hazard. Mater. 401 (2021) 123329, https://doi.org/10.1016/j.jhazmat.2020.123329.

[11] D.K. Ashish, S.K. Verma, Effect on permeability of concrete made with successive recycled aggregate and silica fume, in: Urbanization challenges in emerging economies: Resilience and sustainability of infrastructure, American Society of Civil Engineers, Reston, VA, 2018, pp. 196–205.

[12] D.K. Ashish, S.K. Verma, J. Singh, N. Sharma, Strength and durability characteristics of bricks made using coal bottom and coal fly ash, Adv. Concr. Construct. 6 (4) (2018) 407, https://doi.org/10.12989/acc.2018.6.4.407.

[13] D.K. Ashish, Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth, J. Build. Eng. 15 (2018) 236–242, https://doi.org/10.1016/j.jobe.2017.11.024.

[14] M. Karumanchi, R. Nerella, Shear strength parameters from digital tri-axial test and soils stabilization with extracted nanosilica, Nanotechnol. Environ. Eng. 7 (1) (2022) 307–318, https://doi.org/10.1007/s41204-022-00238-0.

[15] K. Meeravali, N. Ruben, K. Rangaswamy, Stabilization of soft-clay using nanomaterial: Terrasil, Mater. Today: Proc. 27 (2020) 1030–1037.

[16] M. Karumanchi, G. Avula, R. Pangi, S. Sirigiri, Improvement of consistency limits, specific gravities, and permeability characteristics of soft soil with nanomaterial: Nanoclay, Mater. Today: Proc. 33 (2020) 232–238.

[17] Meeravali Karumanchi, Ramamohana Reddy Bellum, Mahesh Chennupati, Veerabrahmam Kunchala, Madhu Regulagunta, Influence on mechanical properties of concrete of cement replacement with fly ash and river sand replacement with foundry sand, Materials

Today: Proceedings, Volume 65, Part 8, 2022, Pages 3547-3551, https://doi.org/10.1016/j.matpr.2022.06.146.

[18] Al Khazaleh, M., Karumanchi, M., Bellum, R.R. et al. Experimental Assessment of Geotechnical Properties of Nano-Clay-Stabilized Soils: Advanced Sustainable Geotechnical Solution. Int. J. of Geosynth. and Ground Eng. 10, 8 (2024). https://doi.org/10.1007/s40891-023-00517-z.