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Investigation on the Geotechnical Properties of Nanoclay Treated Clayey Soil

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***Abstract*: The recent introduction of nanoclays as fillers or additives in polymers for various desired effects is a subject of an increased interest for research and development to establish various applications. It plays a major role in the development of new products with improved qualities like less consumption of energy, less harmful to the environment, less consumption of resources (i.e., men, materials, money and machinery), increased safety and serviceability in construction and improvement in the geotechnical properties of soil etc. This paper investigates on locally available weak clayey soil stabilization using Montmorillonite nanoclay, an engineered nanomaterial. Test results indicate that nanoclay improves the shear strength of the soil even at its low percentages. To evaluate the effects of nanoclay on the geotechnical properties of clayey soil, varying fractions of nanoclay ranging from 0.2% to 3.5% by mass are added. Consistency limits, optimum moisture content, maximum dry density are found by varying percentages of nanoclay from 0.2% to 3.5%. The incorporation of nanoclay causes a reduction in pores between clay particles, which results in an increase in the total dry density.**

***Keywords*: Clay, Nanoclay, Stabilization, Optimum moisture content.**

1. Introduction

Nanoparticles are used as fillers or additives for various desired effects in various research fields like subgrade pavements, nanopolymer composites, cosmetics, health sectors etc. Various types of nanoparticles include nanocarbon, carbon nanotubes, nanoclays, and metal oxides

The concept of using nanoparticles fillers came with nanotechnology traced in a talk by Richard Feyman on December, 29, 1959, at the annual meeting of American Physical Society (California Institute of Technology, Pasadena, CA). Nanotechnology was then perceived as the design, characterization, production, and application of structures, devices, and systems by controlling the shape and size of material particles on a nanometer scale [11] lifestyle. As a result, solid wastes become more harmful to surroundings, and needs cautious disposal practices. It has been evaluated that about 30% of daily manufacturing in the ceramic industry goes as waste. The ejection of that creates soil, water and air pollution. Ceramic dust is a cohesion less element, which can improve the characteristics of soil. In general, nanomaterials are referred as miniaturized materials with at least one dimension that falls between the range of 1 to 100 nm in length. These particles have complex geometries such as globular, plate-like, rod-like, and near spherical called cluster with symmetrical, irregular and amorphous structures [9]. The physical and chemical characteristics of nanoparticles are different from conventional materials, largely due to the increase in ratio between surface area and volume of nanoparticles as well as the quantum effects caused by spatial confinement. The use of nanoparticles especially nanoclay has gained importance in various fields of interests due to ease of availability and less toxic nature. Nanoclay enhances the properties of nanocomposite materials and usually can be modified to make the clay compatible with organic monomers and polymers.

A. Nanoclays

Nanoclays are ubiquitous nanofiller and belong to a wider group of clay minerals. Ceramists have used nanoparticles since antiquity however, nanotechnology is the knowingly scientific utilization of nanoparticles. The use of kaoline is dated to the 3rd century BC in China. China clay, a traditional name of kaoline, is a mixture of minerals generally containing kaolinite, quartz, mica, feldspar, illite, and montmorillonite [11]. Clay minerals are the basic constituents of clay raw materials and platy structure is the dominant morphology. Depending on the clay type, the individual layers could be composed of two, three or four sheets of either $[SiO4]^{4-}$ tetrahedra or $[AlO_3(OH)_3]^6$ octahedra. The aluminosilicate layers organize themselves over one another like pages of a book, with a regular van der Waals gap between them, called an ‘interlayer’. Interlayers possess net negative charge which is due to the ionic substitutions in the sheets of clay minerals. The layer charge is neutralized by cations which occupy the inter-lamellar. These inter-lamellae cations can be easily replaced by other cations or molecules as per required surface chemistry and hence called exchangeable cations. Na^+, K^+, Mg^{2+}, and Ca^{2+}, are among common exchangeable cations present in the interlayer which are exchanged with other with other required cations [6].

The essential nanoclay raw material is montmorillonite, a two to one layered smectite clay mineral with a platy structure. The thickness of each layer is about 1 nm, diameter from 10 nm to several microns, and the interlayer space around 1 nm depending on the modification methods. Due to its high aspect ratio and good physical and thermal properties, nanoclay has the potential for exceptional improvements in barrier, flammability resistance, thermal and mechanical properties.

In this study, an attempt was made to perform laboratory testing programme on kaolinite clay. To evaluate the effects of nanoclay on the geotechnical properties of kaolinite clayey soil, varying fractions of nanoclay ranging from 0.2% to 3.5% by mass are added. Consistency limits, optimum moisture content, maximum dry density are found by varying percentages of nanoclay from 0.2% to 3.5%.

2. Materials

A. *Soil*

The soil considered in the study is clayey soil (Kaolinite) collected from Thonnakkal, Trivandrum. The soil was taken from a height of 10m from ground level. The obtained soil is in white powdered form. All the initial properties of the soil were done. Atterberg limits were found and classified the soil under clay of low compressibility (CL). Evaluated properties of the soil are shown in the table 1.

Table 1
Initial Properties of Kaolinite clay

Soil properties	Values
Colour	White
Liquid Limit (%)	32
Plastic Limit (%)	20
Plasticity Index (%)	12
Shrinkage Limit (%)	17.5
IS Classification	CL
Natural Moisture Content (%)	24.5
Optimum Moisture Content (%)	23
Maximum Dry density (g/cm^3)	1.5
Percentage of clay (%)	68.07
Percentage of silt (%)	21.93
Percentage of sand (%)	10
Specific gravity	2.62
UCC (kN/m^2) at OMC	50.32

B. *Montmorillonite Nanoclay*

The nanoclay considered for the study was Nanoclay Montmorillonite 20 A collected from Intelligent Materials Pvt Ltd., Punjab. Nanoclay is processed clay at least one of its dimension is in nanoscale. It has an aspect ratio of less than 80nm. It has light cream/off-white colour. The specification sheet of the montmorillonite nanoclay is shown in Table 2.

Table 2
Specification sheet of Nanoclay Montmorillonite 20 A

Product	Nanoclay Montmorillonite 20 A
Aspect Ratio	<80 nm
Purity	>99.9%
Form	Powder
Colour	Light Cream / Off White
pH	6-9
Surface Modifier	Quaternary Ammonium

3. Methodology

The index properties of soil were determined as per the respective IS Codes. Different tests were done such as Atterberg Limits, Standard proctor test after varying the percentage of nanoclay added to the soil. The nanoclay percentage varies from 0.2% to 3%.

4. Results and Discussions

The application of modified montmorillonite nanoclay to clays lowered the liquid limit and plasticity index. Unlikely plastic limit increased and a significant enhancement in soil's unconfined compressive strength. Liquid limit has decreased by about 7% for 2% of nanoclay.

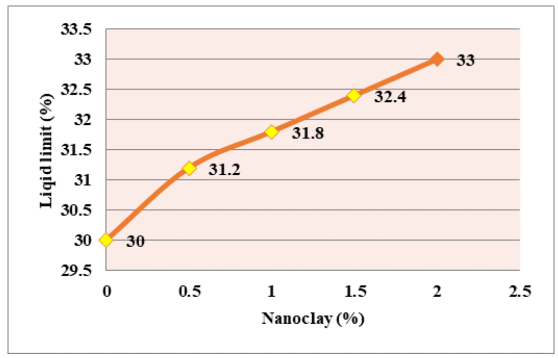

Fig. 1. Variation of liquid limit with different nanoclay percentage

Plastic limit has increased by about 4% for 2% of nanoclay. Figure 2 shows the variation of plastic limit with different percentages of nanoclay.

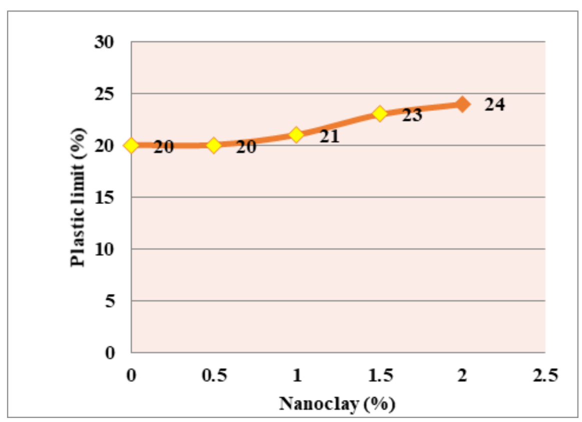

Fig. 2. Variation of liquid limit with different nanoclay percentage

Plasticity index has decreased about 11 for 2% of nanoclay. The behaviour is mainly due to the large specific surface area of the montmorillonite nanoclay particles relative to the natural clayey soil particles. Figure 3 shows the variation of plasticity index with different percentages of nanoclay.

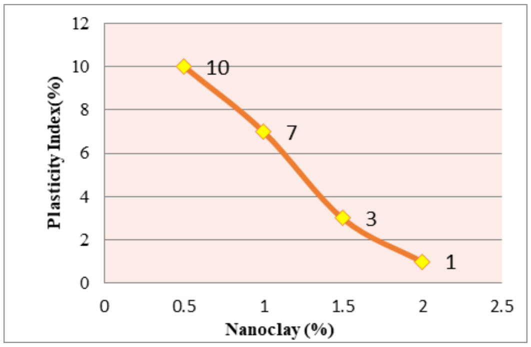

Fig. 3. Variation of plasticity index with different percentages of nanoclay

The optimum percentage of nanoclay for maximum dry density (1.6g/cm3) is 2.5% after that there is a decrease in MDD. Optimum moisture content has decreased from 23% to 22% with an increase in maximum dry density from 1.5g/cm3 to 1.66g/cm3. There may be agglomeration in nanoparticles for nanoclay content more than the optimum limit, which in turn causes an increase in void ratio and consequently a decrease in density [2]. Figure 4 shows the variation of dry density with varying percentages of nanoclay.

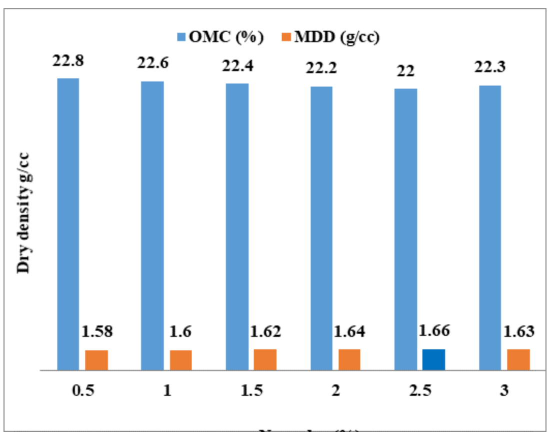

Fig. 4. Variation in compaction characteristics of kaolinite clay

Addition of montmorillonite nanoclay caused notable changes in the unconfined compressive strength (UCC) of kaolinite clay. The compressive strength of kaolinite clayey soil has increased from 50.32 to 71.72 kN/m^2 when nanoclay percentage increased up to 2.5 %. But after 2.5% the strength reduced to 65.48 kN/m^2. This is mainly due to the agglomeration of nanoclay particles after optimum concentration.

5. Conclusion

The introduction of nanoclays as fillers or additives in polymers for various desired effects has been of enormous interest for research and development studies. Due to nanoscale dimensions, nanoparticles hold a very high specific surface and react more actively with other particles in the soil matrix. With the addition of smaller % of nanomaterials, the soil exhibits extraordinary effects on the engineering properties. The incorporation of nanoclay results an increase in water absorption and a reduction in pores between clay particles, which results in an increase in both the total dry density and decrease in optimum moisture content of clay. The results showed that nanoclay has a positive influence on the dry density of the samples being handled.

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