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Research Paper

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KEYWORDS : Stabilization; Nanomaterials; Atterberg's limits;compaction characteristics; unconfined compressive strength;consolidation settlement; load carrying capacity

Improvement of Bearing Capacity of Soft Clay Using Nanomaterials

R.Priyadharshini — PG Student- Department of Civil Engineering (S), Govt. College of Technology, Coimbatore

Dr .P.D.Arumairaj — Associate Professor- Department of Civil Engineering (S), Govt. College of Technology, Coimbatore

ABSTRACT

Soft clay is characterized by low bearing capacity and high settlement. Structures constructed on soft clay can encounter many engineering problems such as bearing capacity and settlement. Stabilization technique is adopted to enhance the soft soil behavior and performance of foundation overlying weak soil. Stabilization using various chemical additives such as cement, lime, bitumen and flyash has been in practice to improve soil properties for many years. Nanomaterial is one of the newest additives. Nanotechnology is a rapidly emerging technology with vast potential to create new materials with unique properties for numerous applications. At scales of nanometer range, materials can exhibit unique properties different from their bulk state. This study aims to investigate the effect of three types of nanomaterials (nano clay, nano MgO and nano Al2O3) on Atterberg's limits, compaction characteristics, unconfined compressive strength and consolidation parameters. The nanomaterials are prepared by grinding in ball mill about 10,000 revolutions upto nanosize of 100-300nm.The size of the particle is determined from Particle Size Analyzer. The nanomaterial is mixed with soft clay at various percentages to study the geotechnical properties. The optimum percentage of nanomaterial is obtained. The consolidation settlement behavior is studied at the optimum dosage of nanomaterial. Model study is conducted in a steel tank of (30x30x30)cm with (6x6)cm square footing to determine the load carrying capacity of the footing for soft clay with nanomaterials. The results are compared.

INTRODUCTION

Soft soils possess high moisture, low shear strength, low bearing capacity and high settlement. These soils contain minerals such as montmorillonite that are capable of absorbing water. When they absorb water their volume increases. This causes major damage to buildings constructed on it. Thus structure on soft clay has always been associated with problems of stability and settlements. In order to overcome these problems, soil improvement methods are being practiced. It includes compacting grouting, permeation grouting, hydraulic fracture grouting, jet grouting, and deep mixing.

Soil stabilization is one of the oldest ground improvement techniques. The main aim of soil stabilization is to render the soils capable of meeting

the requirements of specific engineering projects. When the soil at a site is poor or when they have an undesirable property making them unsuitable for geotechnical projects, they have to be stabilized. This technique has been successfully used to increase bearing capacity and reduce the settlement of foundations for important structures. Inorder to improve the properties of soil various chemical additives such as cement, lime, flyash and bitumen has been in practice for many years. In addition to that, byproducts of agricultural and industrial wastes such as rice husk ash, bagasse ash, fly ash and cement kiln dust are used as additives.

As a recent advancement, nanoparticles are used as an additive to the soil and researches are going on to find its effects in soil. Nanotechnology can be applied in geotechnical engineering by studying the soil structure in nanometer scale to gain better understanding of soil nature.

In this study nanomaterials such as nano clay, nano magnesium oxide (MgO) and nano alumina (Al_2O_3) are added at various percentages to the soft clay. Properties such as Atterberg's limits, compaction characteristics, unconfined compressive strength are studied and the optimum dosage of nanomaterials is determined. The consolidation settlement behavior is studied at the optimum dosage. Model study is conducted to determine the load carrying capacity of stabilized soft clay.

MATERIAL

SOIL

The clay sample collected from Government College of Technology, Coimbatore, is analyzed for its various physical,engineering and strength properties. The properties of soil are shown in the following table.

TABLE 1
PROPERTIES OF SOIL

Sl.No	Properties	Results
1	Specific Gravity	2.7
2	Percentage of Gravel	2.5%
	Percentage of Sand	24.41%
	Percentage of Silt	26.23%
	Percentage of Clay	46.86%
3	Differential free swell	40%
4	Liquid limit	51.5%
5	Plastic limit	16.67%
6	Shrinkage limit	11.21%
7	Plasticity Index	34.83%
8	Consistency Index	1.178
9	Soil Classification	CH
10	Optimum Moisture Content	20.5%
11	Maximum Dry Density	1.67 g/cc
12	Unconfined Compressive Strength	139kN/m^2

SOFT CLAY

In this project, the soft clay consistency IClies between 0.25-0.5 and UCS lies between25 to 50 kN/m^2). This is achieved by increasing the water content from optimum moisture content. At 34% of water content the unconfined compressive strength is 37 kN/m^2 which falls between 25 to 50 kN/m^2 and I_C value obtained is 0.47 satisfying the range 0.25-0.5. Thus at 34% of water content

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the soft clay is obtained.

NANOMATERIALS

The stabilizing materials such as clay, magnesium oxide and alumina should be oven dried. The sample is ground in ball mill for 10,000 revolutions or it should be ground for 4-5 days.

Grinding the clay sample continuously is a difficult process as the clay particles sticks to the wall of the cylinder. Thus the cylinder should be cleaned for every four hours for uniform grinding. The fine ground sample is analyzed in Particle Size Analyzer to determine the size of the particle.

The Particle Size Analyzer works on the principle of Dynamic Light Scattering (DLS). Particle size measurements can be made from 0.3nm-8μm.The sample should be dispersed in dispersing agents such as ethanol, sodium hexametaphosphate or sodium carbonate. Thus 1mg of the sample is dispersed in ethanol taken in a test tube for half an hour such that the clay particle disperses well. Then the test tube is kept inside the instrument for analysis. The particle sizes obtained for nanoclay is 161nm, nano MgO is 124nm and nano Al_2O_3 is 157nm.

Nanometer is defined in various prospects based on their application. Generally 1nm-100nm sized particles named as ultrafine particles, 100nm-250nm particles as finer particles and 250nm-1000nm as coarser particles in nano range. Thus from the particle size analysis result the materials are in the finer particle range of nanometer.

EXPERIMENTAL PROGRAM

GENERAL

The experimental study involves Atterberg's limits, standard proctor's compaction test and unconfined compression tests on soil samples with different percentages of nanoclay (0.5, 1, 1.5, and 2%), nano MgO (0.1,0.2,0.3 and 0.4%) and nano Al_2O_3 (0.25,0.5,0.75 and 1%). Consolidation test for optimum percentage of nanomaterials.Steel tank of 30x30x30cm and 6x6cm square footing is used to determine the load carrying capacity for optimum dosage of nano materials.

ATTERBERG'S LIMITS

Determination of Liquid Limit

The liquid limit was determined in the laboratory with the aid of the standard mechanical liquid limit device, designed by Arthur Casagrande and adopted by the ISI, as given in IS:2720 (Part V)-1985.The tests results are shown in figure1.

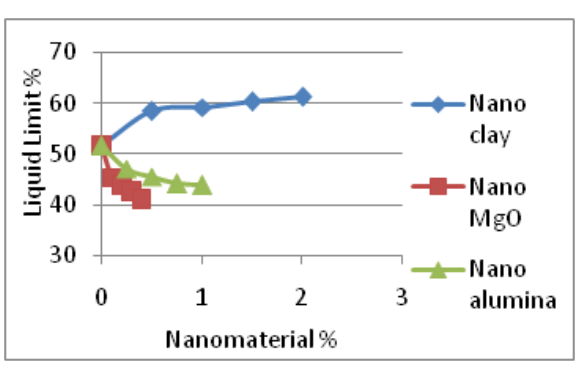

Fig. 1:Liquid limit for different nanomaterials

Determination of Plastic Limit

The test was conducted according to IS: 2720 (Part VI)-1972. The tests results are shown in figure 2 for different percentages of nanomaterials.

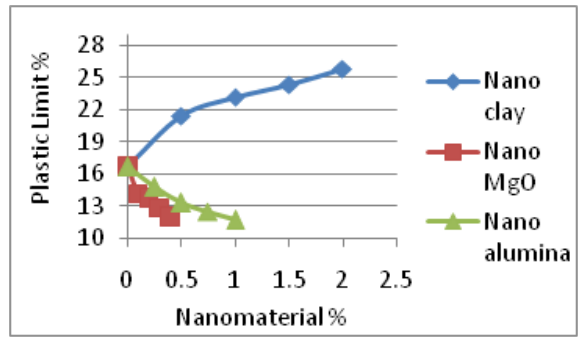

Fig. 2:Plastic limit for different nanomaterials

Determination of Shrinkage Limit

The test was conducted according to IS: 2720 (Part V)-1985. The tests results are shown in figure 3 for different percentages of nanomaterials.

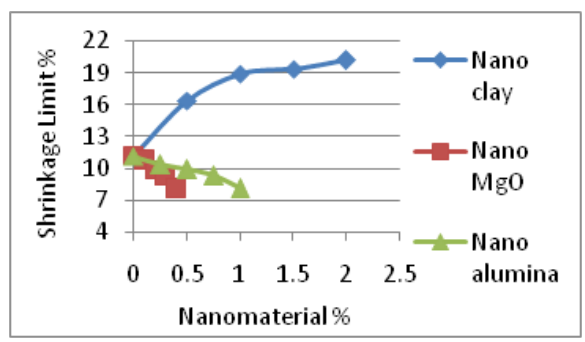

Fig. 3:Shrinkage limit for different nanomaterials

STANDARD PROCTOR COMPACTION TEST

Standard Proctor compaction test was done to assess the amount of compaction and water content required for the sample. The test was conducted as per IS 2720 (Part 7). The Optimum moisture content for different percentages of nanomaterials are shown in figure 4.

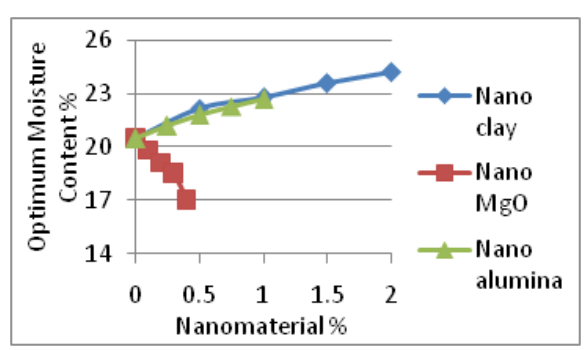

Fig. 4: Optimum moisture content for different nanomaterials

The maximum dry density for different percentages of nanomaterials are shown in figure 5.

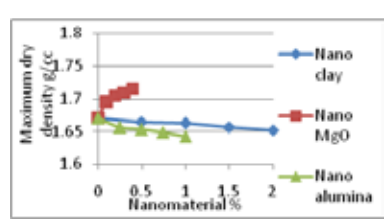

Fig. 5:Maximum dry density for different nanomaterials

UNCONFINED COMPRESSIVE STRENGTH TEST

The test was conducted according to IS: IS 2720(Part 10): 1991. The tests results are shown in figure 6 for different percentages of nanomaerials.

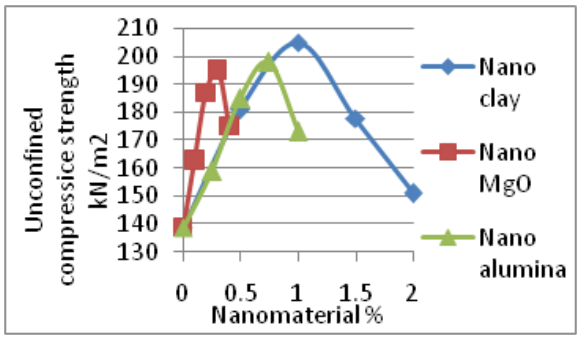

Fig. 6:Unconfined compressive strength for different nanomaterials

It is observed from the above test results the optimum dosage of nano clay is 1%, nano MgO is 0.3% and nano alumina is 0.75%.

CONSOLIDATION TEST

The consolidation characteristics is determined as per IS:2720 (part 15) – 1986. The test is conducted for soft clay (34% water content) and soft clay with optimum percentages of nano material.

Settlement is determined using calculated CC and e values for each applied pressures (0.1, 0.2, 0.4, 0.8, 1.6, 3.2 kg/cm2). The clay depth is considered to be 4m. Thus the settlement is calculated using the relation,

$$\text{Settlement} = \frac{C_c H}{1+e} \log \frac{\sigma_0 + \Delta\sigma}{\sigma_0}$$

where,

C_c = Compression Index
H = Depth of clay layer
e = Initial void ratio
σ_0 = Applied pressure (kg/cm²)
$\Delta\sigma$ = Increase in pressure (kg/cm²)

TABLE 2. Consolidation settlement values

Sl.No	Material	Settlement mm	Settlement reduction%
1	Soft clay	0.2257	--
2	Soft clay + Nanoclay	0.10553	53.24
3	Soft clay + nano MgO	0.09533	57.76
4	Soft clay + nano Al_2O_3	0.10284	54.43

MODEL TEST

In order to simulate the behavior of shallow footing on weak soil,a steel box having the dimensions (30×30×30) cm is used. This box was filled with soft clay at 34% water content. Also, a steel plate of (6×6×0.5)cm is used to simulate the shallow footing. As per IS 1888-1982, Settlements should be observed for each increment of load after an interval of 1, 2.25, 4, 6.25, 9, 16 and 25 min and thereafter at hourly intervals to the nearest 0.02 mm. The 'time settlement' curve shall be plotted at each load stage and load shall be increased to the next stage at the end of 24 hour. The test shall be continued upto 25 mm settlement.The load carrying capacity of the footing is resting on soft clay with nanomaterials are obtained from the load-settlement graph.

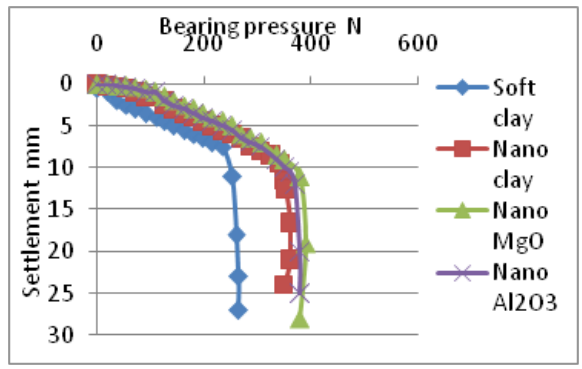

Fig.7:Load-settlement graph for different nanomaterials

The load carrying capacity of the footing obtained from the above graph are, soft clay: 235N, soft clay +nanoclay: 342N and soft clay + nano MgO: 380N and soft clay + nano Al_2O_3: 365N.

RESULTS AND DISCUSSION

Based on the laboratory tests, experimental studies and pavement design carried out in the above study the following conclusions are drawn.

1. It has been observed that increase in nanoclay content increases the Atterberg's limits. Increase in nano MgO and nano Al_2O_3 results in decrease in atterberg's limits.The increase in Atterberg's limits is due to the higher specific surface area of nanoparticles encompassing large amount ofwater to the outer surface.

2. With the increase in the percentage of nanoclay and nano Al_2O_3, the optimum moisture content increases. With increase in nano MgO, optimum moisture content decreases.

The presence of nanopores causes water accumulation in these pores, resulting in increase of optimum moisture content. Soft clay attains the OMC at lower energy as the nano MgO content increases

3. With the increase in the percentage of nanoclay and nano Al_2O_3, the maximum dry density decreases.With the increase in nano MgO content, the maximum dry density increases.Increase in moisture content decreases cementing property of soil and decreases dry density.

4. The unconfined compressive strength increases upto 48% for 1% nanoclay,41% for 0.3% nanoMgO and 43% for 0.75% of nano Al_2O_3.The strength increase is due to thixotropic behavior of the nano particles.

5. The consolidation settlement behaviour is reduced upto53% for optimum dosage of nano clay,57% for optimum dosage of nanoMgO and 54% for optimum dosage of nano Al_2O_3.Thus nanoMgO reduces the consolidation settlement when compared to the other two materials.

6. The load carrying capacity of the footing for soft clay with optimum dosage of nanomaterials is increases upto 45.53% for nano clay, 61.70% for nano MgO and 55.32% for nanoAl_2O_3.Thus nano MgO shows an improved result in reducing the settlement and improving the load carrying capacity compared to the other two materials.

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